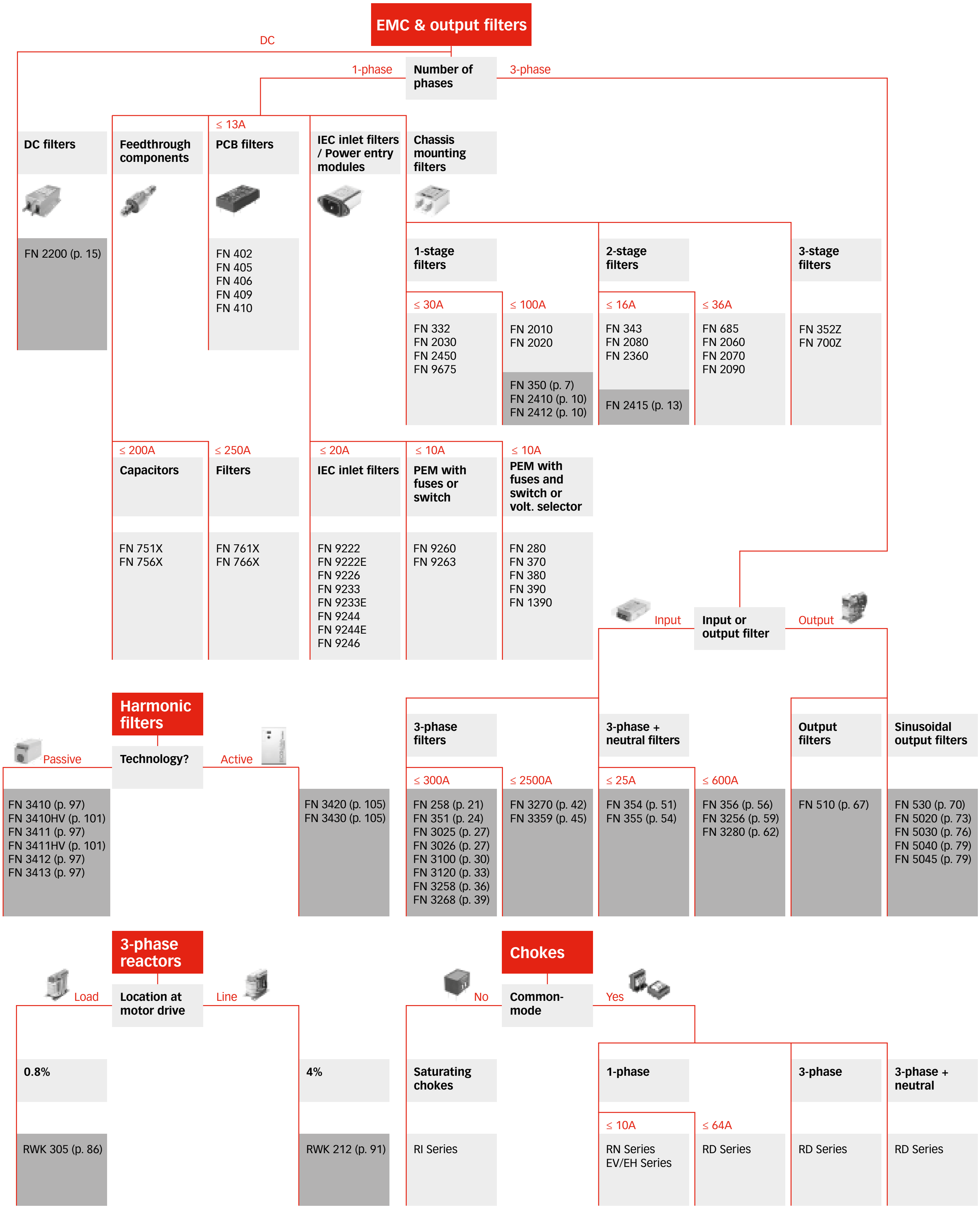
2011/12

EMC and Power Quality
Solutions for Industrial Power Systems

energy efficiency and reliability

Product Selection Chart



EMC & output filters

- DC
  - **DC filters**
    - FN 2200 (p. 15)
- **Number of phases**
  - 1-phase
    - **Feedthrough components**
      - ≤ 200A **Capacitors**
        - FN 751X
        - FN 756X
      - ≤ 250A **Filters**
        - FN 761X
        - FN 766X
    - ≤ 13A **PCB filters**
      - FN 402
      - FN 405
      - FN 406
      - FN 409
      - FN 410
    - **IEC inlet filters / Power entry modules**
      - ≤ 20A **IEC inlet filters**
        - FN 9222
        - FN 9222E
        - FN 9226
        - FN 9233
        - FN 9233E
        - FN 9244
        - FN 9244E
        - FN 9246
      - ≤ 10A **PEM with fuses or switch**
        - FN 9260
        - FN 9263
      - ≤ 10A **PEM with fuses and switch or volt. selector**
        - FN 280
        - FN 370
        - FN 380
        - FN 390
        - FN 1390
    - **Chassis mounting filters**
      - **1-stage filters**
        - ≤ 30A
          - FN 332
          - FN 2030
          - FN 2450
          - FN 9675
        - ≤ 100A
          - FN 2010
          - FN 2020
          - FN 350 (p. 7)
          - FN 2410 (p. 10)
          - FN 2412 (p. 10)
      - **2-stage filters**
        - ≤ 16A
          - FN 343
          - FN 2080
          - FN 2360
          - FN 2415 (p. 13)
        - ≤ 36A
          - FN 685
          - FN 2060
          - FN 2070
          - FN 2090
      - **3-stage filters**
        - FN 352Z
        - FN 700Z
  - 3-phase
    - **Input or output filter**
      - Input
        - **3-phase filters**
          - ≤ 300A
            - FN 258 (p. 21)
            - FN 351 (p. 24)
            - FN 3025 (p. 27)
            - FN 3026 (p. 27)
            - FN 3100 (p. 30)
            - FN 3120 (p. 33)
            - FN 3258 (p. 36)
            - FN 3268 (p. 39)
          - ≤ 2500A
            - FN 3270 (p. 42)
            - FN 3359 (p. 45)
        - **3-phase + neutral filters**
          - ≤ 25A
            - FN 354 (p. 51)
            - FN 355 (p. 54)
          - ≤ 600A
            - FN 356 (p. 56)
            - FN 3256 (p. 59)
            - FN 3280 (p. 62)
      - Output
        - **Output filters**
          - FN 510 (p. 67)
        - **Sinusoidal output filters**
          - FN 530 (p. 70)
          - FN 5020 (p. 73)
          - FN 5030 (p. 76)
          - FN 5040 (p. 79)
          - FN 5045 (p. 79)

Harmonic filters

- **Technology?**
  - Passive
    - FN 3410 (p. 97)
    - FN 3410HV (p. 101)
    - FN 3411 (p. 97)
    - FN 3411HV (p. 101)
    - FN 3412 (p. 97)
    - FN 3413 (p. 97)
  - Active
    - FN 3420 (p. 105)
    - FN 3430 (p. 105)

3-phase reactors

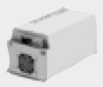
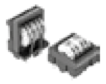
- **Location at motor drive**
  - Load
    - **0.8%**
      - RWK 305 (p. 86)
  - Line
    - **4%**
      - RWK 212 (p. 91)

Chokes

- **Common-mode**
  - No
    - **Saturating chokes**
      - RI Series
  - Yes
    - **1-phase**
      - ≤ 10A
        - RN Series
        - EV/EH Series
      - ≤ 64A
        - RD Series
    - **3-phase**
      - RD Series
    - **3-phase + neutral**
      - RD Series

▓ **EMC and Power Quality** – Solutions for Industrial Power Systems

░ **EMC/EMI Components** – Solutions for Commercial Power Systems (see separate catalog)

		Transportation	EDP & office	Drives & controls	Process automation	Elevators & cranes	Convenience	Medical	Military	Building automation	Power & energy	Telecom & datacom	Machinery
	Typical applications	– Rail vehicles – Locomotives – Electric car propulsion – Diesel-electric ship propulsion	– PCs – Printers – PC periphery – Fax machines – Copy machines – Monitors – Plotters – Mainframe computers	– AC & DC motor drives – SCR drives – Servo drives – Regenerative drives – Rectifiers (AC-DC) – Converters (AC-AC, DC-DC) – Inverters (DC-AC) – Battery chargers	– Robotics – Conveyors – Assembly lines – Control units – Mining industry – Chemical industry – Oil production – Metal processing	– Elevators for people and goods – Escalators – Cranes – Lifts – Hoists – Dumbwaiters	– Amplifiers, audio, video, TV, screens – Receivers, decoders – Laundry machines – Tumblers – Cooking equipment – Induction heaters – Exercise machines – Vending and gaming-machine	– X-ray equipment – CAT scanners – Defibrillators – Laboratory equipment – Analyzers – Measurement devices – MRI, MSI, EEG, ECG – Test equipment – Hospitals	– Security systems – Surveillance equipm. – Communication equipment – Aircraft, ships, tanks, submarines – Radar systems – Navigation systems	– HVAC – Security systems – Control units – Pumps – Self-ballasted lighting equipment – Autom. window shades – Water treatment – Office buildings	– SMPS, UPS – DC/DC converters – Gen-sets – Wind turbines – Fuel cells – Gas turbines – UPS – PV systems	– Base stations for GSM, UMTS, GPRS – Power line communications – Network technology – Servers – Telephone installations – Broadcast installations – Data centers	– Machine tools – Printing machines – Packaging machines – Extruders – Wood working mach. – Milling/drilling mach. – Laser cutting machines – Welding machines – Grinding machines
EMC and Power Quality – Solutions for Industrial Power Systems	**Single-phase filters and DC filters** 	Custom designs for hybrid and electric cars		FN 350 (page 7) FN 2410/12 (page 10) FN 2200 (page 15)	FN 350 (page 7) FN 2410/12 (page 10) FN 2415 (page 13)	FN 241X (page 10 ff)				FN 350 (page 7)	FN 2200 (page 15)		FN 350 (page 7) FN 2410/12 (page 10) FN 2415 (page 13)
	Three-phase filters 		FN 3025/26 (page 27) FN 3258 (page 36) FN 3268 (page 39)	FN 258 (page 21) FN 3025/26 (page 27) FN 3100 (page 30) FN 3258 (page 36) FN 3268 (page 39) FN 3270 (page 42) FN 3359 (page 45)	FN 258 (page 21) FN 3025/26 (page 27) FN 31xx (Page 30/33) FN 3258 (page 36) FN 3268 (page 39) FN 3270 (page 42) FN 3359 (page 45)	FN 258 (page 21) FN 3100 (page 30) FN 3258 (page 36) FN 3268 (page 39)	FN 3025/26 (page 27) FN 3258 (page 36) FN 3268 (page 39)	FN 258P (page 21) FN 258L (page 21) FN 3025/26 (page 27)	FN 258 (page 21) FN 3258 (page 36) FN 3268 (page 39) FN 3359 (page 45)	FN 258 (page 21) FN 351 (page 24) FN 3025/26 (page 27) FN 3258 (page 36) FN 3268 (page 39)	FN 258 (page 21) FN 3025/26 (page 27) FN 3100 (page 30) FN 3120 (page 33) FN 3258 (page 36) FN 3268 (page 39) FN 3359 (page 45)	Customized three-phase telecom filters	FN 258 (page 21) FN 3100 (page 30) FN 3120 (page 33) FN 3258 (page 36) FN 3268 (page 39) FN 3270 (page 42) FN 3359 (page 45)
	Three-phase and neutral line filters 		FN 354 (page 51) FN 355 (page 54) FN 3256 (page 59)	FN 356 (page 56) FN 3256 (page 59) FN 3280 (page 62)	FN 356 (page 56) FN 3256 (page 59) FN 3280 (page 62)		FN 354 (page 51) FN 355 (page 54)	FN 354 (page 51) FN 355 (page 54)	FN 354 (page 51)	FN 3256 (page 59)	FN 356 (page 56) FN 3256 (page 59) FN 3280 (page 62)	FN 354 (page 51)	FN 356 (page 56) FN 3256 (page 59) FN 3280 (page 62)
	Output filters and load reactors 	Customized magnetics for rail vehicles and ship propulsion		FN 510 (page 67) FN 50XX (page 73/76/79) FN 530 (page 70) RWK 305 (page 86)	FN 510 (page 67) FN 50XX (page 73/76/79) RWK 305 (page 86)	FN 510 (page 67) FN 50XX (page 73/76/79) RWK 305 (page 86)			FN 510 (page 67) FN 530 (page 70) FN 50XX (page 73/76/79) RWK 305 (page 86)	FN 510 (page 67) FN 50XX (page 73/76/79) RWK 305 (page 86)	Customized reactor and filter solutions for (renewable) energy production and feeding power into the network		FN 510 (page 67) FN 50XX (page 73/76/79) RWK 305 (page 86)
	Line reactors and harmonic filters 	Customized magnetics for rail vehicles and ship propulsion	FN 3430 (page 105)	FN 3410/11 (page 97) FN 3412/13 (page 97) FN 3420 (page 105) RWK 212 (page 91)	FN 3410/11 (page 97) FN 3412/13 (page 97) FN 3420 (page 105) RWK 212 (page 91)	FN 3410/11 (page 97) FN 3412/13 (page 97) FN 3420 (page 105) RWK 212 (page 91)		FN 3430 (page 105)		FN 3410/11 (page 97) FN 3412/13 (page 97) FN 3420 (page 105) FN 3430 (page 105)	FN 3420 (page 105) Customized reactor and filter solutions for (renewable) energy production and feeding power into the network	FN 3420 (page 105) FN 3430 (page 105)	FN 3410/11 (page 97) FN 3412/13 (page 97) FN 3420 (page 105) RWK 212 (page 91)
EMC/EMI Components – Solutions for Commercial Power Systems (see separate catalog)	**Feedthrough components** 	Customized feed-through solutions for automotive applications	FN 756X FN 766X		FN 751X FN 761X			FN 751X FN 756X FN 761X FN 766X	FN 751X FN 756X FN 761X FN 766X		FN 751X FN 756X FN 761X FN 766X	FN 751X FN 756X FN 761X FN 766X	FN 751X FN 761X
	PCB filters 	Customized PCB filters for automotive applications	FN 402 FN 405 FN 406 FN 410									FN 409	
	IEC inlet filters and Power entry modules 		FN 280 FN 390 FN 922X FN 9233(E) FN 9244(E) FN 9260 FN 9263				FN 280 FN 3X0 FN 9222(E) FN 9233(E) FN 9246 FN 9260 FN 9263	FN 280B FN 2450 FN 9222(E)B FN 9233(E)B FN 9244(E)B FN 9246B FN 9260B	Customized filter solutions with military connectors	FN 9246	FN 280 FN 3X0 FN 922X FN 9233(E) FN 9244(E) FN 9260 FN 9263	FN 9246	
	Single-phase filters 	Custom designs for hybrid and electric cars	FN 343 FN 20X0 FN 2360	FN 2070 FN 2080 FN 2090	FN 2070 FN 2080 FN 2090	FN 685 FN 2070 FN 2080	FN 332 FN 20X0 FN 2360	FN 332 FN 20X0B FN 2360 FN 2450 FN 700Z	FN 352Z FN 700Z	FN 2060 FN 2070 FN 2090	FN 2030 FN 2060 FN 2070 FN 2090	FN 700Z Customized single-phase telecom filters	FN 2070 FN 2080
	EMC/EMI chokes 		EV/EH Series RD Series RN Series	RD Series RN Series	RD Series	RD Series	EV/EH Series RD Series RN Series	EV/EH Series RD Series RN Series	RD Series RN Series	EV/EH Series RD Series RI Series RN Series	EV/EH Series RD Series RN Series	EV/EH Series RN Series	RD Series
	Pulse transformers 		IT Series	IT Series				IT Series	IT Series	IT Series	IT Series	IT Series	

This illustration only contains a few typical products and applications. Schaffner is also active in numerous other industry segments.
Most standard components can be customized to meet special requirements.

schaffner group

Schaffner is the international leader in the fields of electromagnetic compatibility and power quality, supplying components that support the efficient and reliable use of electric energy. Customers benefit from the technological know-how of the Schaffner Group in the development, manufacturing and marketing of high-performance products that offer optimized and fault-free operation and compliance with all major quality and performance standards. With its products and services, the Schaffner Group plays a key role in promoting technologies that support renewable energies, ensures the reliable functioning of electronic equipment and systems and meets the requirements for greater energy efficiency.

A global one-stop shop

EMC/EMI filters
- PCB filters
- IEC inlet filters / Power entry modules
- Single-phase filters
- Three-phase filters
- Three-phase + neutral line filters
- Open frame filters

EMC/EMI chokes

Feedthrough filters and capacitors

Automotive components

Customized solutions

Power Quality
- Line reactors
- dv/dt reactors and filters
- Sine wave filters
- Harmonic filters
- Regen reactors and filters
- Transformers

Customized solutions

With the EMC and power quality components it develops and its global services for OEM customers, equipment manufacturers and systems integrators, the Schaffner Group plays a key role in the promotion of technologies and the generation of renewable energies and enables the development of systems that meet the requirements of energy efficiency.

The Schaffner Group offers its expertise and services worldwide in the fields of development consultancy, EMC testing, application support and production. Through its worldwide network of sales, application and production centers, as well as research and development teams and efficient logistics management, Schaffner provides local support to regional and global customers.

Contents

Product overview

Important safety note

This publication contains statements about the suitability of Schaffner products for certain areas of application.

These are based upon typical known system requirements. However, such statements cannot be regarded as binding statements about the suitability of a Schaffner product for a particular customer application.

It is always incumbent on the customer to check and decide whether a Schaffner product is suitable for use in a particular customer application.

Overloading of EMC/EMI filters, such as with circuits able to cause resonances, impermissible voltages at high frequencies etc can lead to system reliability issues, material damage, or bodily injury.

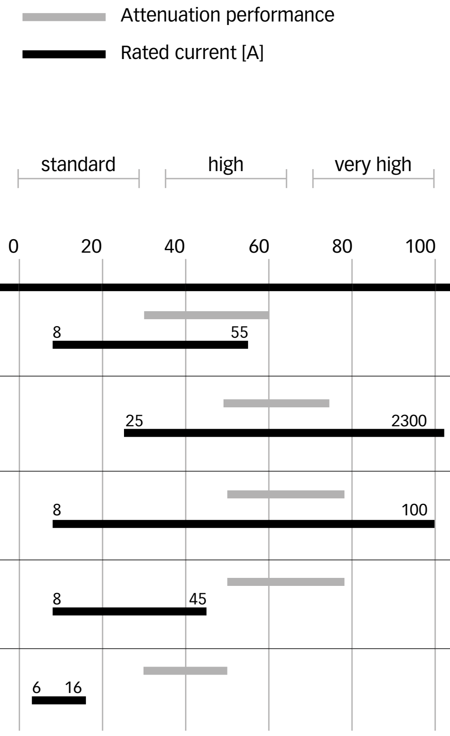
Such overloading can be avoided by proper power systems engineering. Schaffner application engineers are globally available to support customers with system engineering questions, proper Schaffner product selection and product design-in.

Single-phase Filters and DC Filters

Single-phase Filters and DC Filters.

Single-phase filters for chassis or DIN-rail mounting featured in this catalog are the key for EMC compliance of high power commercial equipment, electrical cabinets and low to medium power industrial applications. Their unique features allow a specific choice and deployment to overcome countless EMI challenges. A more extensive range of low power single-phase filters with a broad selection of electrical and mechanical features can be found in the separate catalog (EMC/EMI Products – Solutions for Commercial Power Systems). DC filters are specifically optimized for applications with DC supply like e.g. PV inverters.

Approvals *



Filter family	**Max. voltage**	Rated current [A]	1-stage filter circuit	2-stage filter circuit	Low frequency attenuation	High frequency attenuation	DIN-rail mounting	For DC applications			Power supplies, SMPS	1-phase motor drives	Control unit in machine tools	Office, test & measure. equip.	PV inverters	General purpose		
FN 350 p. 7	250VAC	8 55	■								■	■		■				
FN 2200 p. 15	1200VDC	25 2300	■			■		■			■				■	■		
FN 2410 p. 10	250VAC 520VAC (H)	8 100	■		■						■	■						
FN 2412 p. 10	250VAC 520VAC (H)	8 45	■		■		■				■	■	■					
FN 2415 p. 13	250VAC	6 16		■								■	■					

Features: columns 1-stage filter circuit to For DC applications. Typical applications: columns Power supplies, SMPS to General purpose.

* Products evaluated by one or more of the above certification agencies. For details please consult the detailed data sheet.

Single-phase EMC/RFI Filter for Motor Drives

energy efficiency and reliability

- **Compact filter solution for single-phase motor drive applications**
- **Industrial grade safety terminal blocks**
- **Designed to meet EN 55011/14/22**
- **Compliant with IEC 60950**

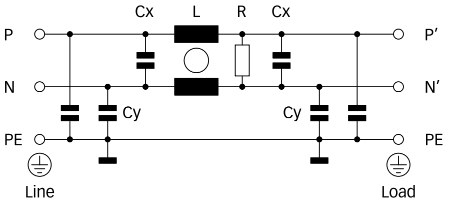
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	1x 250VAC
Operating frequency:	dc to 400Hz
Rated currents:	8 to 55A @ 40°C
High potential test voltage:	P –> E 2000VAC for 2 sec
	P –> N 1100VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 40°C/230V (Mil-HB-217F):	420,000 hours

Typical electrical schematic



Features and benefits

- High component values optimized for common and differential-mode attenuation in the lower frequency range makes this filter ideal for a large variety of single-phase motor drive applications.
- Supplied in a relatively small housing design with safety terminal blocks for fast and easy installation in primarily industrial environments.
- FN 350 also meets IEC 60950 requirements, thus providing additional application flexibility.

Typical applications

- Single-phase motor drives
- Automation equipment
- Power supplies, SMPS
- Office equipment
- Testing and measurements equipment

Filter selection table

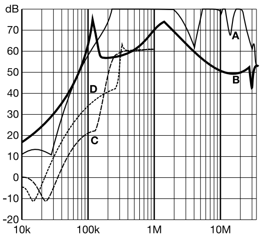
Filter	Rated current @ 40°C (25°C) [A]	Leakage current* @ 230VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections	Weight [kg]
FN 350-8-29	8 (9.0)	4.9	5.2	-29	0.7
FN 350-12-29	12 (13.5)	4.9	5.7	-29	0.7
FN 350-20-29	20 (22.4)	4.9	6.1	-29	0.7
FN 350-30-33	30 (33.6)	5.4	6.1	-33	0.7
FN 350-55-33	55 (61.5)	11.0	9.9	-33	1.2

* Maximum leakage under normal operating conditions. Note: if the neutral line is interrupted, worst case leakage could reach twice this level.

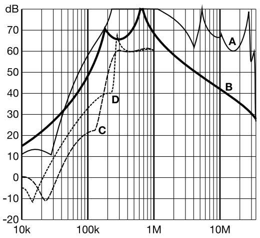
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

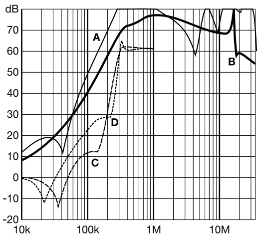
8A types



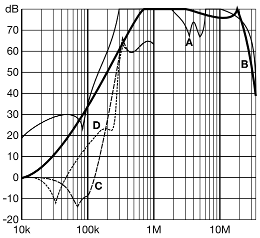
12A types



20 and 30A types

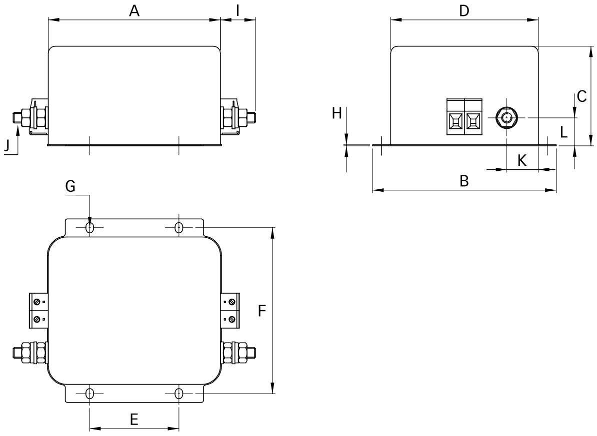


55A types

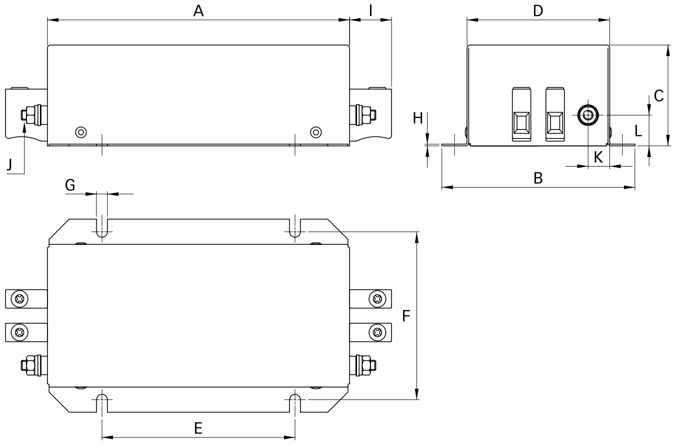


Mechanical data

8 to 30A types



55A types



Dimensions

	8A	12A	20A	30A	55A
A	99.5	99.5	99.5	99.5	180
B	105	105	105	105	115
C	57	57	57	57.6	60
D	84.4	84.4	84.4	84.4	85
E	51	51	51	51	115
F	95	95	95	95	100
G	6 x 4.4	6 x 4.4	6 x 4.4	6 x 4.4	6.5
H	0.6	0.6	0.6	1.2	1
I	19.5	19.5	19.5	25	25
J	M6	M6	M6	M6	M6
K	18	18	18	16	12.9
L	16	16	16	19	18.3

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-29	-33
Solid wire	6mm^2	16mm^2
Flex wire	4mm^2	10mm^2
AWG type wire	AWG 10	AWG 6
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm

Please visit www.schaffner.com to find more details on filter connectors.

1-phase Filters
FN 2410 / FN 2412

Single and Two-phase EMC/RFI Filters for Industrial Electronics

energy efficiency and reliability

- **Excellent filter performance for applications with high interference levels**
- **Filters for two-phase supply up to 2x 520VAC (P - P) available**
- **Fast and comfortable snap-in installation on popular TS 35 DIN-rails up to 45A**
- **Industrial grade terminal blocks for unsurpassed electrical safety**

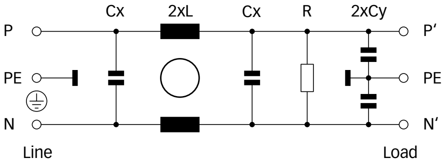
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	1x 250VAC (FN 2410 / FN 2412)
	2x 520/300VAC (FN 2410H / FN 2412H)
Operating frequency:	dc to 400Hz (except FN 2410H-60/-80/-100: 250Hz)
Rated currents:	8 to 100A @ 50°C (FN 2410)
	8 to 45A @ 50°C (FN 2412)
High potential test voltage:	P –> E 2000VAC for 2 sec
	P –> N 1100VDC for 2 sec
	P –> E 2700VDC for 2 sec (H types)
	P –> P 2250VDC for 2 sec (H types)
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/250V (Mil-HB-217F):	1,200,000 hours
MTBF @ 50°C/520V (Mil-HB-217F):	250,000 hours (H types)

Typical electrical schematic



Features and benefits

- FN 2410 filters up to 100A are designed for traditional chassis mounting.
- For extra fast installation, FN 2412 filters up to 45A can comfortably be snapped-in on popular TS 35 DIN-rails which are common in most electrical cabinets.
- Both FN 2410 and FN 2412 are also available as „H versions“. These are ideally suitable for an operation on two phases in a three-phase power network, handling voltages up to 520VAC.
- All filters provide an exceptional conducted attenuation performance, based on chokes with high saturation resistance and excellent thermal behavior. Thus, all filters retain the expected filter performance even in very noisy applications and under full load conditions.
- Touch-safe industrial grade terminal blocks provide maximum electrical safety and protect humans from undeliberate contact with life conductors. They help to fulfill the most demanding installation standards.

Typical applications

- Small to medium-sized machines and industrial equipment
- High-end single-phase power supplies
- Single-phase variable speed motor drives, inverters and converters
- DIN-rail filter versions are ideal for panel building and electrical cabinets
- Various noisy applications with higher power single-phase or two-phase supply

Filter selection table

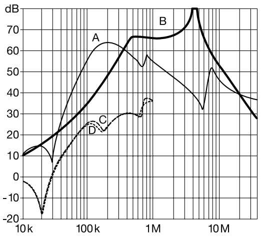
Filter	Rated current @ 50°C (40°C)	Leakage current* @ 230VAC/50Hz	Power loss @ 25°C/50Hz	Input/Output connections	Weight
	[A]	[mA]	[W]		[kg]
FN 2410-8-44	8 (8.8)	3.4	2.6	-44	0.4
FN 2410-16-44	16 (17.5)	3.4	3.5	-44	0.5
FN 2410-25-33	25 (27.4)	3.4	5.5	-33	0.6
FN 2410-32-33	32 (35.0)	3.4	5.6	-33	0.7
FN 2410-45-33	45 (49.3)	3.4	7.4	-33	0.7
FN 2410-60-34	60 (65.7)	3.4	5.5	-34	1.8
FN 2410-80-34	80 (87.6)	3.4	9.9	-34	1.8
FN 2410-100-34	100 (109.5)	3.4	15.4	-34	1.8
FN 2410H-8-44	8 (8.8)	3.4	2.6	-44	0.5
FN 2410H-16-44	16 (17.5)	3.4	3.5	-44	0.6
FN 2410H-25-33	25 (27.4)	3.4	5.5	-33	0.7
FN 2410H-32-33	32 (35.0)	3.4	5.6	-33	0.8
FN 2410H-45-33	45 (49.3)	3.4	7.4	-33	0.8
FN 2410H-60-34	60 (65.7)	3.4	5.5	-34	1.9
FN 2410H-80-34	80 (87.6)	3.4	9.9	-34	1.9
FN 2410H-100-34	100 (109.5)	3.4	15.4	-34	1.9
FN 2412-8-44	8 (8.8)	3.4	2.6	-44	0.4
FN 2412-16-44	16 (17.5)	3.4	3.5	-44	0.6
FN 2412-25-33	25 (27.4)	3.4	5.5	-33	0.7
FN 2412-32-33	32 (35.0)	3.4	5.6	-33	0.8
FN 2412-45-33	45 (49.3)	3.4	7.4	-33	0.8
FN 2412H-8-44	8 (8.8)	3.4	2.6	-44	0.5
FN 2412H-16-44	16 (17.5)	3.4	3.5	-44	0.7
FN 2412H-25-33	25 (27.4)	3.4	5.5	-33	0.8
FN 2412H-32-33	32 (35.0)	3.4	5.6	-33	0.9
FN 2412H-45-33	45 (49.3)	3.4	7.4	-33	0.9

* Maximum leakage under normal operating conditions. Note: if the neutral line is interrupted, worst case leakage could reach twice this level.

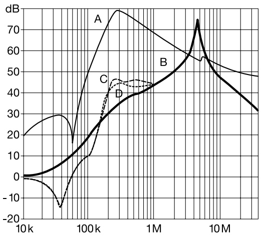
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

8 to 45A types

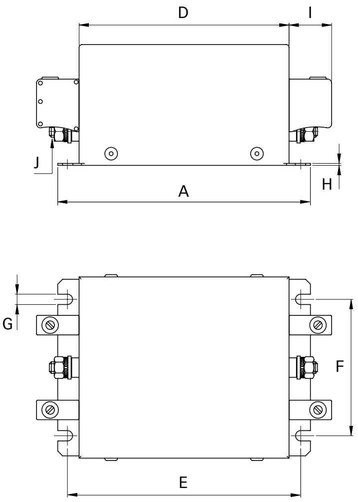


60 to 100A types

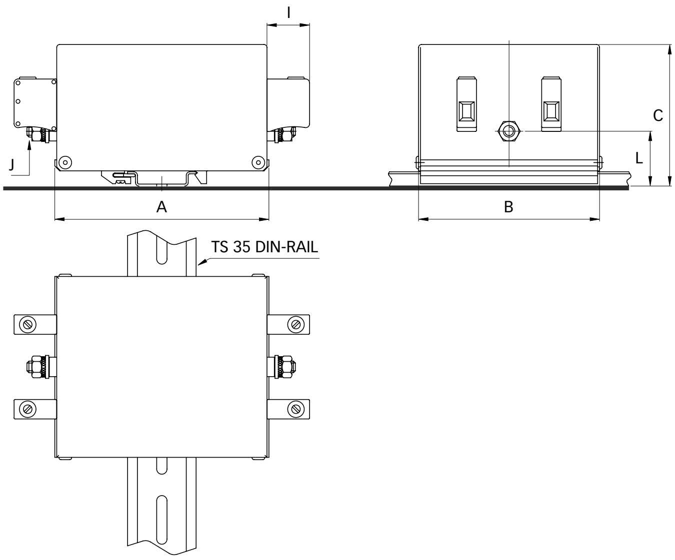


Mechanical data

FN 2410(H)



FN 2412(H)



Dimensions

	FN 2410								FN 2412				
	8A	**16A**	**25A**	**32A**	**45A**	**60A**	**80A**	**100A**	**8A**	**16A**	**25A**	**32A**	**45A**
A	130	130	130	130	130	165	165	165	110	110	110	110	110
B	93	93	93	93	93	115	115	115	93	93	93	93	93
C	62	62	76	76	76	100	100	100	73	73	87	87	87
D	108	108	108	108	108	140	140	140					
E	120	120	120	120	120	155	155	155					
F	70	70	70	70	70	90	90	90					
G	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3					
H	1.0	1.0	1.0	1.0	1.0	1.2	1.2	1.2					
I	22	22	25	25	25	39	39	39	22	22	25	25	25
J	M6	M6	M6	M6	M6	M8	M8	M8	M6	M6	M6	M6	M6
L	17.5	17.5	31.5	31.5	31.5	39.2	39.2	39.2	28.5	28.5	42.5	42.5	42.5

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-33	**-34**	**-44**
Solid wire	16mm^2	35mm^2	10mm^2
Flex wire	10mm^2	25mm^2	6mm^2
AWG type wire	AWG 6	AWG 2	AWG 8
Recommended torque	1.5 - 1.8Nm	4.0 - 4.5Nm	1.5 - 1.8Nm

Please visit www.schaffner.com to find more details on filter connectors.

1-phase Filters
FN 2415

Single-phase Filter for the Control Line of Equipment

schaffner
energy efficiency and reliability

- **Filter for the control line of complex equipment and machinery**
- **Ensures the interference-free operation of the control unit / PLC**
- **Improves the immunity and reliability of the entire system**
- **Compact EMC filter design with minimum space requirement**

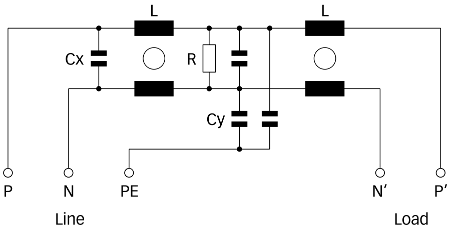
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	250VAC (230VAC +10% possible)
Operating frequency:	dc to 60Hz
Rated currents:	6 to 16A @ 50°C
High potential test voltage:	P/N –> E 2250VDC for 2 sec
	P –> N 1100VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/230V (Mil-HB-217F):	>1,300,000 hours

Typical electrical schematic



Features and benefits

- An additional filter for the supply cables of controls of rather large and complex systems, to ensure a fault free operation of the control unit (PLC, Motion Control etc.).
- Improves the immunity, reliability and service security of the entire system significant by reducing the risk of internal interference propagation and coupling.
- An extremely compact and light weight filter design requiring minimum mounting space in machinery and equipment.
- Simple and time-saving installation with good accessibility for automatic and hand tools.
- Solid, touch-safe terminal blocks offering sufficient contacting cross section according to the EN 60204-1 installation standard, which is very common for machine tools and industrial equipment.
- By providing a very decent attenuation performance, FN 2415 contributes siginificant to the achievement of electromagnetic compliance according to the last standards (like EN 50370-1 for machine tools).

Typical applications

Ideal for industrial equipment, machinery and diverse process automation systems, which involve any kind of control units (NC, CNC, PLC, Motion Controls). Rather large and complex machine tools, with 8 or even more driving axes and very long motor cables, can be subjected to major reliability problems, caused by internal coupling of interferences from the drive system to the control lines. Very often, this causes a drop out of the control unit and consequently downtimes of the entire machine. By operating an FN 2415 in addition to a mains input filter, these negative effects can be eliminated for most situations. FN 2415 can also be used for the most diverse single-phase applications with medium to high interference levels, such as single-phase motor drives or power supplies.

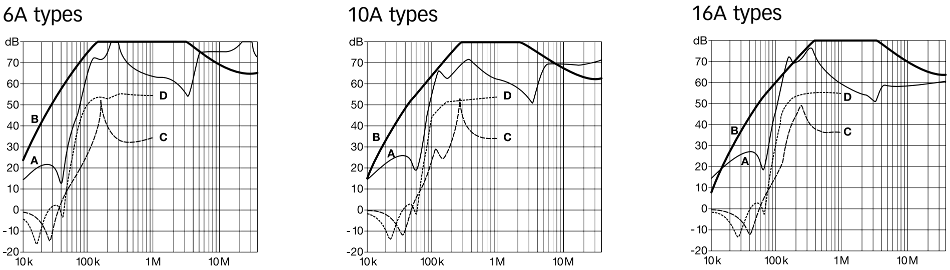
Filter selection table

Filter	Rated current @ 50°C (40°C) [A]	Leakage current* @ 250VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections	Weight [kg]
FN 2415-6-29	6 (6.6)	9.4	2.2	-29	0.4
FN 2415-10-29	10 (11)	9.4	2.4	-29	0.4
FN 2415-16-29	16 (17.5)	9.4	4.3	-29	0.4

* Maximum leakage under normal operating conditions. Note: if the neutral line is interrupted, worst case leakage could reach twice this level.

Typical filter attenuation

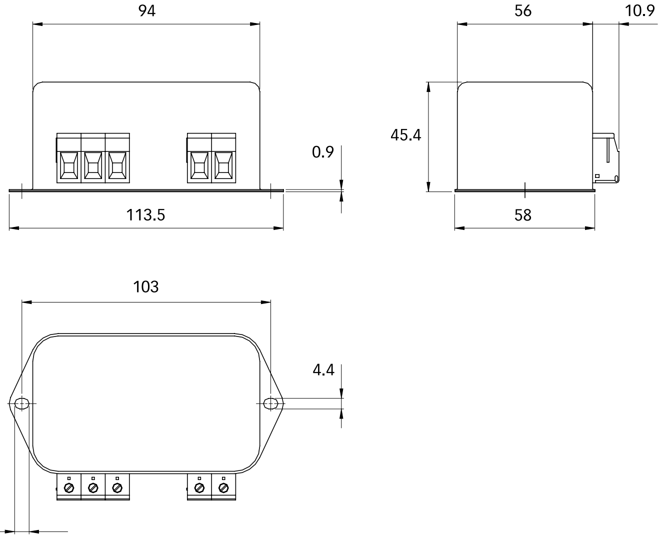
Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym


6A types

10A types

16A types

Mechanical data



All dimensions in mm, 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-29
Solid wire	6mm²
Flex wire	4mm²
AWG type wire	AWG 10
Recommended torque	0.6 - 0.8Nm

Please visit www.schaffner.com to find more details on filter connectors.

DC Filters
FN 2200

DC EMC/EMI Filter for PV Inverters

schaffner
energy efficiency and reliability

- **Reduces conducted emissions towards the solar panel**
- **Reduces the probability of EMI radiation off the solar panel**
- **Helps to prevent pre-mature panel aging because of HF leakage currents**
- **Helps to meet international EMC regulations for the entire PV system**
- **Most compact standard solution in the industry, optionally available without capacitors to ground (B types)**

Approvals

c UL us (600VDC)

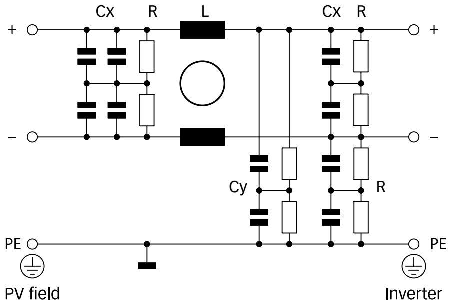
ENEC 14 850VDC

RoHS

Technical specifications

Maximum continuous operating voltage:	Max. 1200VDC
Operating frequency:	DC
Rated currents:	25 to 2300A @ 55°C
High potential test voltage:	P –> E 3600VDC for 5 sec
	P –> P 3000VDC for 5 sec
Protection category:	IP20 (25 to 150A types); IP00 (250 to 2300A types)
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-40°C to +100°C (40/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939

Typical electrical schematic



Features and benefits

FN 2200 range of standard EMC/EMI filters is based on Schaffner's years of experience in custom filter design for the global photovoltaic (PV) inverter industry. Installed between the PV inverter and the solar panel, FN 2200 DC filters help to control conducted emissions on the panel side of the system and therefore significantly reduce the potential for high-frequency (HF) interference radiation off the panel. The filter also protects the solar panel from HF stray and leakage currents which can cause pre-mature aging in the PV modules.

FN 2200 are the most compact dedicated DC filters for PV inverters in the industry and therefore support the integration in the ever shrinking frame sizes of today's power electronics. All FN 2200 come in unsymmetrical housings, which help to prevent inverse installation and wrong electrical connection. Along with grid-side installed Schaffner AC EMC/EMI filters, FN 2200 are key to meet the stringent international standards for electromagnetic compatibility (EMC) like EN 61000-6-3 and -6-4 and help to ensure a reliable and fault-free operation of the entire PV system.

FN 2200 are designed for very low power loss, to support overall PV system efficiency.

Typical applications

FN 2200 are primarily designed for PV inverters. However, they can potentially also be used in other DC applications within published specifications, like UPS, DC motor drives, or DC quick chargers.

Filter selection table

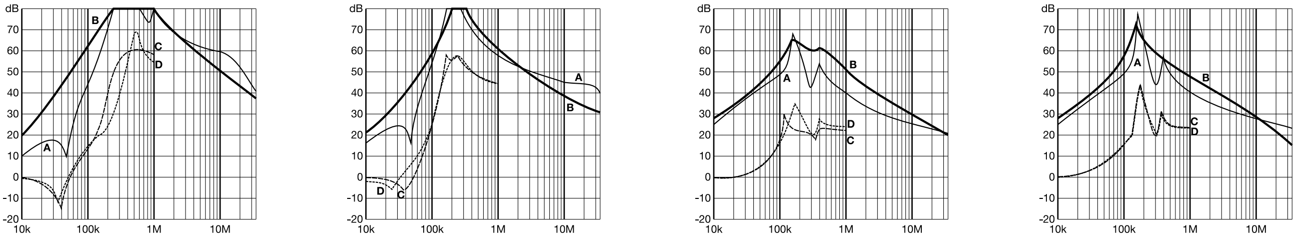
Filter	Rated current @ 55°C (40°C)	Typical inverter AC power rating*	Filter efficiency @ 25°C / DC	Power loss @ 25°C/DC	Input/Output connections		Weight
	[A]	[kW]	[%]	[W]			[kg]
FN 2200-25-33	25 (28)	10	> 99.9	8	-33		0.9
FN 2200-50-34	50 (57)	20	> 99.9	17	-34		1.6
FN 2200-75-34	75 (86)	30	> 99.9	18	-34		1.7
FN 2200-100-35	100 (115)	40	> 99.9	22	-35		2.7
FN 2200-150-40	150 (173)	60	> 99.9	31	-40		4.9
FN 2200-250-99	250 (288)	100	> 99.9	10		-99	5.0
FN 2200-400-99	400 (460)	150	> 99.9	16		-99	6.1
FN 2200-600-99	600 (690)	250	> 99.9	29		-99	6.5
FN 2200-800-99	800 (920)	350	> 99.9	26		-99	9.3
FN 2200-1000-99	1000 (1150)	400	> 99.9	40		-99	9.4
FN 2200-1500-99	1500 (1600)	500	> 99.9	45		-99	14.6
FN 2200-2300-99	2300 (2500)	800/1000	> 99.9	400		-99	25.0
FN 2200B-25-33	25 (28)	10	> 99.9	8	-33		0.9
FN 2200B-50-34	50 (57)	20	> 99.9	17	-34		1.6
FN 2200B-75-34	75 (86)	30	> 99.9	18	-34		1.7
FN 2200B-100-35	100 (115)	40	> 99.9	22	-35		2.7
FN 2200B-150-40	150 (173)	60	> 99.9	31	-40		4.9
FN 2200B-250-99	250 (288)	100	> 99.9	10		-99	5.0
FN 2200B-400-99	400 (460)	150	> 99.9	16		-99	6.1
FN 2200B-600-99	600 (690)	250	> 99.9	29		-99	6.5
FN 2200B-800-99	800 (920)	350	> 99.9	26		-99	9.3
FN 2200B-1000-99	1000 (1150)	400	> 99.9	40		-99	9.4
FN 2200B-1500-99	1500 (1600)	500	> 99.9	45		-99	14.6
FN 2200B-2300-99	2300 (2500)	800/1000	> 99.9	400		-99	25.0

* Based on rated DC current of typical 3-phase PV inverters with 900VDC input. Note: depending upon manufacturer and model, DC currents for a given PV inverter power can differ significantly.

Filters with higher current ratings for large central inverters up to the MW range are available upon request.

Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym



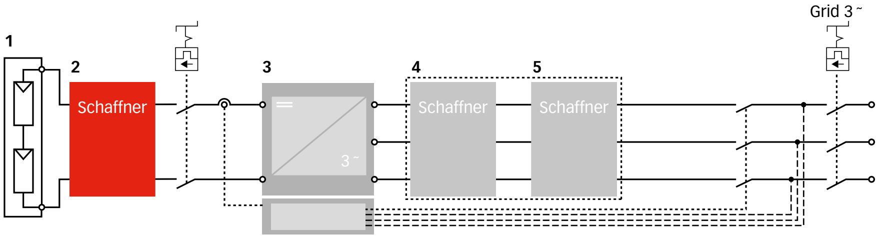
25 to 75A types

100 to 150A types

250A types

400 to 2300A types

Typical block schematic



1 PV modules

2 Schaffner FN 2200

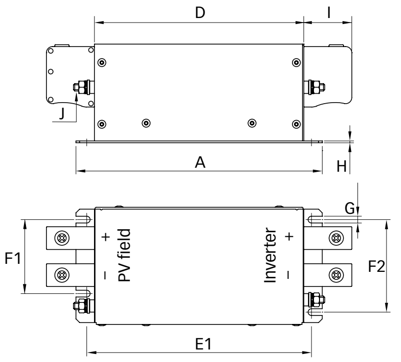
3 Central inverter

4 Schaffner magnetic components

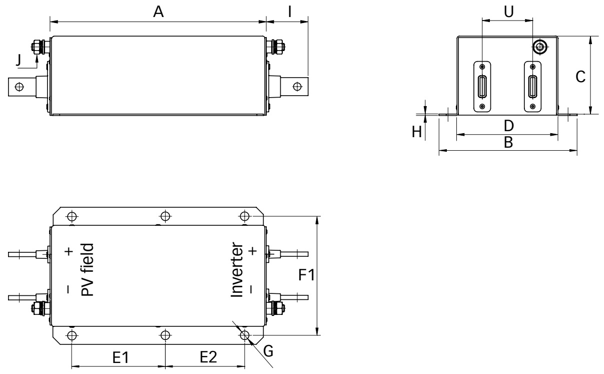
5 Schaffner AC EMC/EMI filter

Mechanical data

25 to 150A types

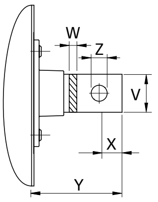


250 to 2300A types

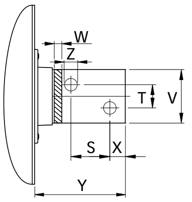


Busbar connections

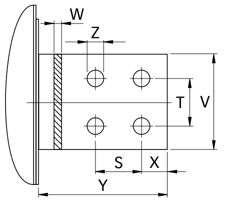
250 to 1000A types



1500A types



2300A types



Note: all FN 2200 provide unsymmetrical mounting hole patterns to prevent inverse filter installation in the field.

Dimensions

	25A	50A	75A	100A	150A	250A	400A	600A	800A	1000A	1500A	2300A
A	170	200	200	220	250	300	300	300	300	300	300	400
B	80	95	95	125	140	180	190	190	200	200	200	250
C	65	80	80	95	115	110	110	110	140	140	150	180
D	140	170	170	190	220	130	140	140	150	150	150	195
E1	152.5	182.5	182.5	202.5	232.5	130	130	130	130	130	130	190
E2						110	110	110	110	110	110	150
F1	45	60	60	80	100	155	165	165	175	175	175	225
F2	60	75	75	100	120							
G	5.5	5.5	5.5	5.5	5.5	Ø12	Ø12	Ø12	Ø12	Ø12	Ø12	Ø12
H	1	1.5	1.5	1.5	2	2	2	2	3	3	3	3
I	25	39	39	45	51	58	58	58	65	65	110	100
J	M5	M6	M6	M8	M10	M10	M10	M10	M12	M12	M12	M16
S											43	35
T											26	35
U						70	70	70	70	70	70	100
V						20	25	25	40	40	60	70
W						5	6	8	8	8	10	15
X						15	15	15	20	20	17	20
Y						58	58	58	65	65	110	100
Z						Ø9	Ø10.5	Ø10.5	Ø14	Ø14	Ø14	Ø14

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-33	-34	-35	-40
Solid wire	16mm^2	35mm^2	50mm^2	95mm^2
Flex wire	10mm^2	25mm^2	50mm^2	95mm^2
AWG type wire	AWG 6	AWG 2	AWG 1/0	AWG 4/0
Recommended torque	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm

Please visit www.schaffner.com to find more details on filter connectors.

Three-phase Filters

Three-phase Filters.

EMC/EMI filter solutions for industrial applications like motor drives and machine tools. Furthermore, these types of filters are also suitable for mainframe computer systems, large uninterruptible power supplies, medical equipment, wind turbine power stations and a vast array of other three-phase power electronics.

Approvals *

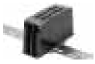
IEC/EN 60939

Attenuation performance

Rated current [A]

standard — high — very high

0 — 200 — 400 — 600 — 800 — >1000

Filter family	**Max. voltage**	Attenuation performance / Rated current [A]	Multi-stage filter circuit	Safety connector blocks	Busbar connection	Optional protective covers	Standard protective covers	Offering EMC compliance	Low leakage current	DIN-rail mounting	Inverters, servo drives	Energy regeneration drives	Renewable energy generation	Machinery, machine tools	Industrial automation	Medical equipment	High power office equipment	General purpose
FN 258  p. 21	480VAC 690VAC (HV)	7 250	■	■				■	■		■			■	■			■
FN 351  p. 24	440VAC 520VAC (H)	8 280		■				■			■				■			
FN 3025  p. 27	520VAC	10 - 50		■			■	■	■		■				■	■	■	■
FN 3026  p. 27	520VAC	10 - 50		■			■	■	■	■	■				■	■	■	■
FN 3100  p. 30	520VAC	35 300		■				■			■	■	■	■	■			
FN 3120  p. 33	520VAC (H)	25 230		■				■			■	■	■	■	■			
FN 3258  p. 36	480VAC 520VAC (H)	7 180		■				■			■				■		■	■
FN 3268  p. 39	520VAC	7 180		■				■	■		■			■	■			■
FN 3270  p. 42	520VAC (H)	10 1000		■	■	■		■			■			■	■			■
FN 3359  p. 45	520VAC 690VAC (HV)	150 2500	■		■	■		■			■	■	■	■	■			

* Products evaluated by one or more of the above certification agencies. For details please consult the detailed data sheet.

Book-style EMC/RFI Filter for Three-phase Inverters and Power Drive Systems

energy efficiency and reliability

- **Industry standard EMC solution for three-phase PDS filtering**
- **Slim space-saving book-style housing**
- **Solid safety connector blocks or optional wire output connections**
- **Excellent attenuation performance**
- **HV versions for up to 690VAC**
- **HVIT versions for IT distribution networks**
- **P/L versions with low leakage current**

Approvals

RoHS

UL / CSA: FN 258 up to 180A (ex. -180-07)

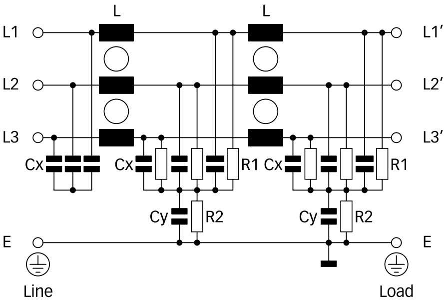
RoHS

UL / CSA: HV and HVIT up to 600VAC

Technical specifications

Maximum continuous operating voltage:	3x 480/277VAC (FN 258, FN 258L, FN 258P)
	3x 690/400VAC (FN 258HV, FN 258HVIT)
Operating frequency:	dc to 60Hz
Rated currents:	7 to 250A @ 50° (480V filters)
	7 to 130A @ 50° (690V filters)
High potential test voltage:	P –> E 2650VDC for 2 sec (480V filters)
	P –> P 2100VDC for 2 sec (480V filters)
	P –> E 3100VDC for 2 sec (690V filters)
	P –> P 3000VDC for 2 sec (690V filters)
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	220,000 hours

Typical electrical schematic



Note: HVIT versions without discharge resistor to ground.

Features and benefits

- FN 258 range of filters provides state-of-the-art EMI attenuation based on an innovative multi-stage filter topology. They help to ensure compliance with Class A or even Class B limits.
- The slim book-style shape allows a convenient and space-saving installation next to inverters and motor drives.
- With 480VAC rating and filter modules from 7 to 250A, FN 258 are ready for the most diverse applications worldwide.
- FN 258HV filters up to 130A are designed for 690VAC distribution networks.
- FN 258HVIT filters up to 130A meet the special requirements for the application in industrial 690VAC IT distribution networks.
- FN 258L and FN 258P filters help to fulfill tough requirements in respect of leakage current limitation and provide an excellent solution to overcome problems with nuisance tripping of sensitive earth leakage detectors.

Typical applications

- Three-phase variable speed drives and power drive systems (PDS)
- IT power distribution networks (FN 258HVIT)
- Applications comprising energy conversion devices (inverters, converters)
- Process automation equipment
- Three-phase power supplies and UPS
- Applications with low-leakage current requirements (FN 258L and FN 258P)

Filter selection table

Filter*	Rated current @ 50°C (40°C) [A]	Typical drive power rating** [kW]	Leakage current*** @ 440VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input connections	Output connections		Weight [kg]
FN 258-7-..	7 (7.7)	4	16.5	9	-29	-07	-29	1.0
FN 258-16-..	16 (17.5)	7.5	18.3	20	-29	-07	-29	1.4
FN 258-30-..	30 (33)	15	24.2	21	-33	-07	-33	1.7
FN 258-42-..	42 (46)	22	25.8	30	-33	-07	-33	2.5
FN 258-55-..	55 (60)	30	25.8	30	-34	-07	-34	2.9
FN 258-75-34	75 (82)	37	25.8	24	-34		-34	3.9
FN 258-100-35	100 (110)	55	25.8	51	-35		-35	5.5
FN 258-130-35	130 (143)	75	30.0	50	-35		-35	6.9
FN 258-180-..	180 (197)	90	30.0	73	-40	-07	-40	11.0
FN 258-250-..	250 (275)	132	30.0	79	-40	-07	-40	12.0
FN 258HV-7-29	7 (7.7)	5.5	13.0	9	-29		-29	1.0
FN 258HV-16-29	16 (17.5)	11	19.0	20	-29		-29	1.5
FN 258HV-30-33	30 (33)	22	19.0	21	-33		-33	1.8
FN 258HV-42-33	42 (46)	30	21.6	30	-33		-33	2.6
FN 258HV-55-34	55 (60)	45	21.6	30	-34		-34	3.0
FN 258HV-75-34	75 (82)	55	21.6	24	-34		-34	4.3
FN 258HV-100-35	100 (110)	90	21.6	51	-35		-35	5.6
FN 258HV-130-35	130 (143)	110	25.0	50	-35		-35	7.1
FN 258HVIT-7-29	7 (7.7)	5.5	13.0	9	-29		-29	1.0
FN 258HVIT-16-29	16 (17.5)	11	19.0	20	-29		-29	1.5
FN 258HVIT-30-33	30 (33)	22	19.0	21	-33		-33	1.8
FN 258HVIT-42-33	42 (46)	30	21.6	30	-33		-33	2.6
FN 258HVIT-55-34	55 (60)	45	21.6	30	-34		-34	3.0
FN 258HVIT-75-34	75 (82)	55	21.6	24	-34		-34	4.3
FN 258HVIT-100-35	100 (110)	90	21.6	51	-35		-35	5.6
FN 258HVIT-130-35	130 (143)	110	25.0	50	-35		-35	7.1
FN 258L-7-..	7 (7.7)	4	0.8	9	-29	-07	-29	1.0
FN 258L-16-..	16 (17.5)	7.5	0.8	20	-29	-07	-29	1.4
FN 258L-30-..	30 (33)	15	0.8	21	-33	-07	-33	1.7
FN 258L-42-..	42 (46)	22	0.7	30	-33	-07	-33	2.5
FN 258L-55-..	55 (60)	30	0.7	30	-34	-07	-34	2.9
FN 258L-75-34	75 (82)	37	0.7	24	-34		-34	3.9
FN 258L-100-35	100 (110)	55	0.7	51	-35		-35	5.5
FN 258L-130-35	130 (143)	75	0.7	50	-35		-35	6.9
FN 258L-180-..	180 (197)	90	0.7	73	-40	-07	-40	11.0
FN 258L-250-07	250 (275)	132	0.7	79	-40	-07		12.0
FN 258P-7-..	7 (7.7)	4	3.3	9	-29	-07	-29	1.0
FN 258P-16-..	16 (17.5)	7.5	3.3	20	-29	-07	-29	1.4
FN 258P-30-..	30 (33)	15	3.3	21	-33	-07	-33	1.7
FN 258P-42-..	42 (46)	22	3.5	30	-33	-07	-33	2.5
FN 258P-55-..	55 (60)	30	3.5	30	-34	-07	-34	2.9
FN 258P-75-34	75 (82)	37	3.5	24	-34		-34	3.9
FN 258P-100-35	100 (110)	55	3.5	51	-35		-35	5.5
FN 258P-130-35	130 (143)	75	3.5	50	-35		-35	6.9
FN 258P-180-..	180 (197)	90	3.5	73	-40	-07	-40	11.0
FN 258P-250-07	250 (275)	132	3.6	79	-40	-07		12.0

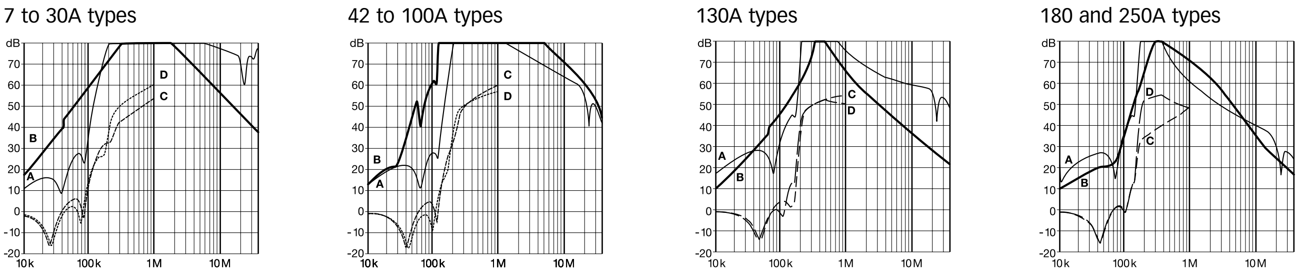
* To compile a complete part number, please replace the -.. with the required output connection style.

** Calculated at rated current, 440VAC (FN 258) / 690VAC (FN 258HV) and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

*** Maximum leakage under normal operating conditions (FN 258 at 440V, FN 258HV at 690V). Note: if two phases are interrupted, worst case leakage could reach 5.7 times higher levels.

Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym



7 to 30A types

42 to 100A types

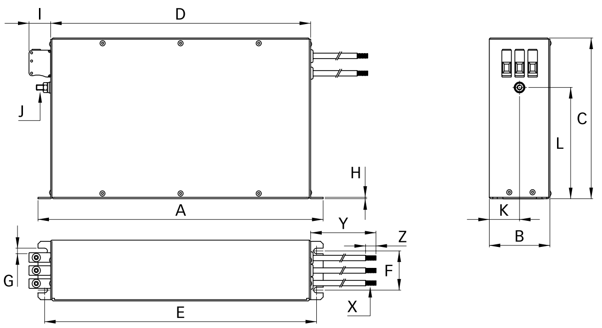
130A types

180 and 250A types

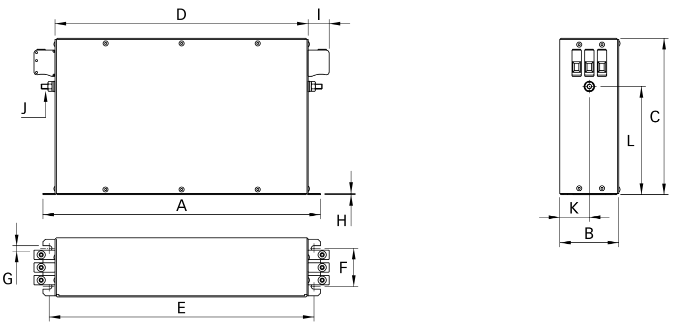
Note: typical attenuation performance of FN 258 standard filters. The behavior of FN 258HV, FN 258HVIT, FN 258P and FN 258L may be slightly different.

Mechanical data

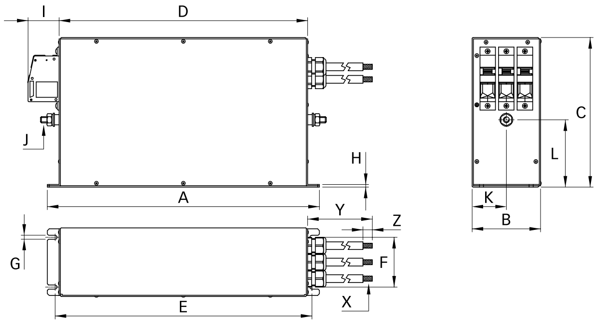
7 to 55A types (-07)



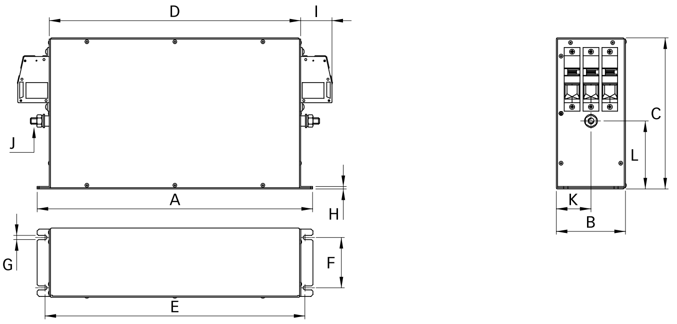
7 to 130A types (-29, -33, -34, -35)



180 and 250A types (-07)



180 and 250A types (-40)



Note: in favour of a better readability, connectors and earth studs are not shown in the horizontal projection.

Dimensions

	7A	16A	30A	42A	55A	75A	100A	130A	180A	250A
A	255	305	335	329	329	329	379	439	438	478
B	50	55	60	70	80	80	90	110	110	110
C	126	142	150	185	185	220	220	240	240	240
D	225	275	305	300	300	300	350	400	400	440
E	240	290	320	314	314	314	364	414	413	453
F	25	30	35	45	55	55	65	80	80	80
G	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
H	1	1	1	1.5	1.5	1.5	1.5	3	4	4
I	10.9	10.9	25	25	39	39	45	45	51	51
J	M5	M5	M5	M6	M6	M6	M10	M10	M10	M10
K	25	27.5	30	35	40	40	45	55	55	55
L	85	100	110	130	105	140	130	140	110	110
X*	AWG 16	AWG 14	AWG 10	AWG 8	AWG 6				50mm²	70mm²
Y*	300 ±10	300 ±10	400 ±10	500 ±10	500 ±10				500 ±10	500 ±10
Z*	9	9	9	12	12				15	15

* Filters with output wire connections (-07) only.

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-29	-33	-34	-35	-40
Solid wire	6mm²	16mm²	35mm²	50mm²	95mm²
Flex wire	4mm²	10mm²	25mm²	50mm²	95mm²
AWG type wire	AWG 10	AWG 6	AWG 2	AWG 1/0	AWG 4/0
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm

Please visit www.schaffner.com to find more details on filter connectors.

General Purpose EMC Filter for Three-phase Applications

schaffner
energy efficiency and reliability

- **EMC solution for industrial inverters and motor drives**
- **Rated currents from 8 to 280A**
- **Selectable voltage level of 440V and 520V**
- **High differential and common-mode attenuation**
- **Compliant with IEC 60950**

Approvals

FN 351 up to 110A

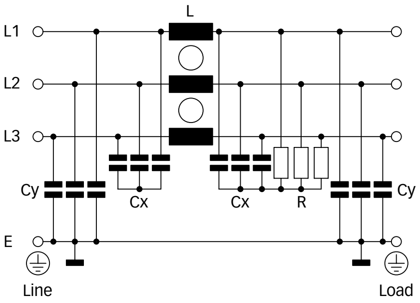
FN 351H up to 110A

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 440/250VAC (FN 351)
	3x 520/300VAC (FN 351H)
Operating frequency:	dc to 60Hz
Rated currents:	8 to 280A @ 40°C
High potential test voltage:	P –> E 2600VDC for 2 sec (FN 351)
	P –> P 1900VDC for 2 sec (FN 351)
	P –> E 2750VDC for 2 sec (FN 351H)
	P –> P 2250VDC for 2 sec (FN 351H)
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +85°C (25/085/21) (FN 351)
	-25°C to +100°C (25/100/21) (FN 351H)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 40°C/400V (Mil-HB-217F):	135,000 hours

Typical electrical schematic



Features and benefits

- Broad range of power ratings for fast and convenient filter selection.
- Available as 440VAC (FN 351) and 520VAC (FN 351H) versions for network-specific applications.
- FN 351 filters provide a broadband common and differential-mode attenuation performance, which remains available also when high interference levels are present.
- Solid, touch-safe filter terminals contribute to overall equipment safety and make the filters compliant with IEC 60950.
- Introduced as one of the very first motor drive EMC filters in the market, FN 351 has been widely imitated and has successfully proven its function over more than 10 years.

Typical applications

- Three-phase motor drives
- Inverters and converters
- Industrial automation equipment
- UPS
- SMPS
- General purpose three-phase filtering

Filter selection table

Filter*	Rated current @ 40°C (25°C) [A]	Typical drive power rating** [kW]	Leakage current*** @ 400VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections		Weight [kg]
FN 351-8-29	8 (9.2)	3	1.9	7	-29		0.8
FN 351-16-29	16 (18.5)	5.5	1.9	8	-29		1.3
FN 351-25-33	25 (28.9)	11	28.0	8	-33		1.4
FN 351-36-33	36 (41.6)	15	28.0	9	-33		1.5
FN 351-50-..	50 (57.7)	22	29.5	11	-33	-34	1.6
FN 351-64-..	64 (73.9)	30	29.5	15	-33	-34	1.7
FN 351-80-34	80 (92.3)	37	31.8	23	-34		5.6
FN 351-110-35	110 (127)	55	31.8	25	-35		5.8
FN 351-180-36	180 (208)	90	29.6	49	-36		13.0
FN 351-280-37	280 (323)	132	35.7	70	-37		28.0
FN 351H-8-29	8 (9.2)	4	2.3	7	-29		1.1
FN 351H-16-29	16 (18.5)	7.5	2.3	8	-29		1.3
FN 351H-25-33	25 (28.9)	15	32.7	8	-33		1.4
FN 351H-36-33	36 (41.6)	18.5	32.7	9	-33		1.5
FN 351H-50-..	50 (57.7)	30	32.7	11	-33	-34	1.6
FN 351H-64-33	64 (73.9)	37	32.7	15	-33		1.7
FN 351H-80-34	80 (92.3)	45	38.0	23	-34		5.6
FN 351H-110-35	110 (127)	75	38.0	25	-35		5.8
FN 351H-180-36	180 (208)	110	35.6	49	-36		13.0
FN 351H-280-37	280 (323)	160	42.9	70	-37		28.0

* To compile a complete part number, please replace the -.. with the required I/O connection style.

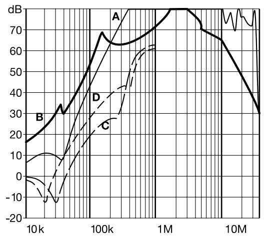
** Calculated at rated current, 400VAC (FN 351)/480VAC (FN 351H) and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

*** Maximum leakage under normal operating conditions (FN 351 at 400V, FN 351H at 480V). Note: if two phases are interrupted, worst case leakage could reach 6 times higher levels.

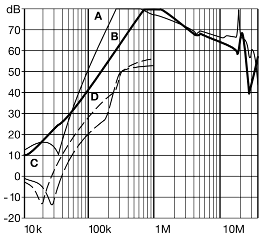
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

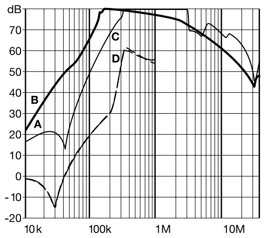
8A types



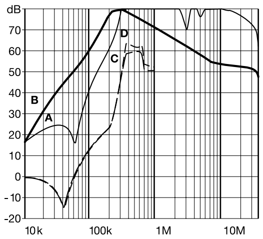
16A types



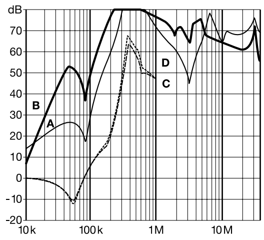
25A types



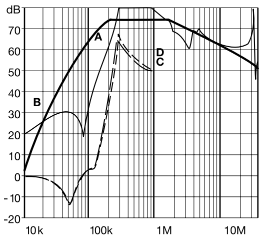
36 and 50A types



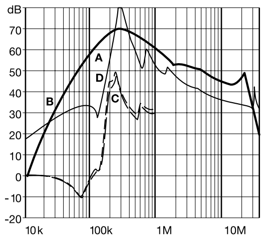
64A types



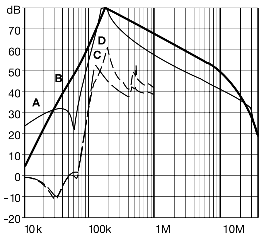
80 and 110A types



180A types

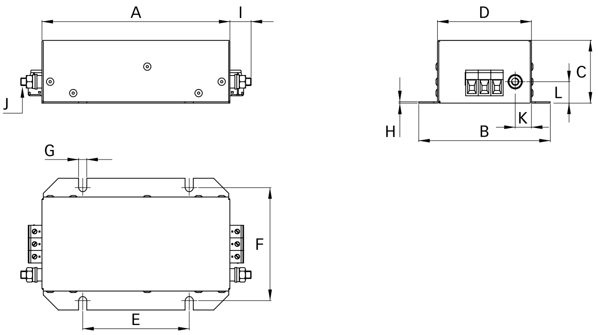


280A types

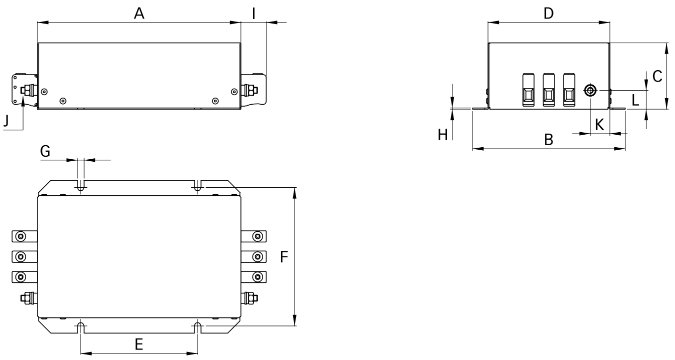


Mechanical data

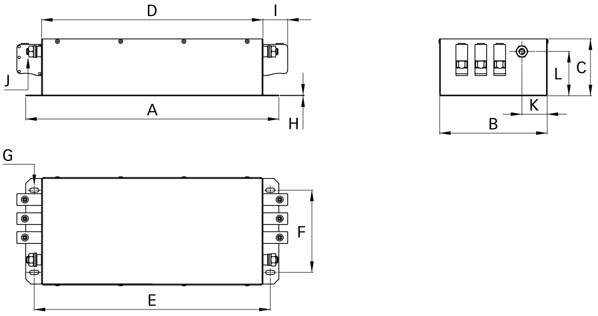
8 and 16A types



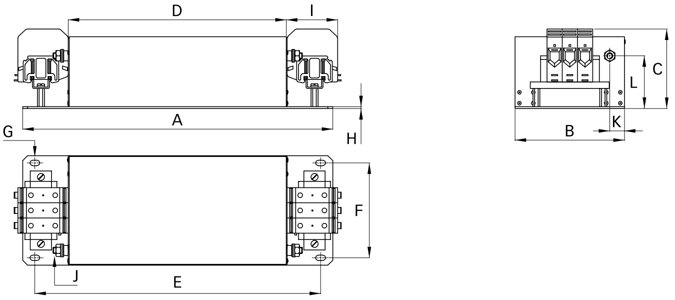
25 to 64A types



80 and 110A types



180 and 280A types

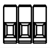
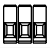
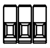
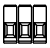


Dimensions

	8A	8A (-H)	16A	25A	36A	50A (-33)	50A (-34)	64A (-33)	64A (-34)	80A	110A	180A	280A
A	180	200	200	200	200	200	200	200	200	400	400	510	700
B	115	150	150	150	150	150	150	150	150	170	170	180	260
C	60	65	65	65	65	65	80	65	80	90	90	130	155
D	85	120	120	120	120	120	120	120	120	350	350	360	530
E	115	115	115	115	115	115	115	115	115	373	373	470	660
F	100	136	136	136	136	136	136	136	136	130	130	156	220
G	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	15 x 6.5	15 x 6.5	16 x 9	16 x 9
H	1	1	1	1	1	1	1	1	1	1	1	4	4
I	17	17	17	25	25	25	39	25	39	39	45	85	110
J	M6	M6	M6	M6	M6	M6	M6	M6	M6	M10	M10	M10	M10
K	13	19.25	19.25	19.25	19.25	19.25	18.75	19.25	18.75	40	40	25	30
L	17	17	17	18.4	18.4	18.4	17	18.4	17	70	70	85	100

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-29	-33	-34	-35	-36	-37
						
Solid wire	6mm^2	16mm^2	35mm^2	50mm^2	95mm^2	150mm^2
Flex wire	4mm^2	10mm^2	25mm^2	50mm^2	95mm^2	150mm^2
AWG type wire	AWG 10	AWG 6	AWG 2	AWG 1/0	AWG 4/0	AWG 6/0
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm	27 - 30Nm

Please visit www.schaffner.com to find more details on filter connectors.

3-phase Filters FN 3025 / FN 3026

Advanced EMC/RFI Filter Concept with Minimum Leakage Current

energy efficiency and reliability

- **Compact state-of-the-art filter concept**
- **Light weight plastic enclosure design**
- **Minimized filter leakage current**
- **Hinged safety covers**
- **Revolutionary embedded filter terminals**
- **Chassis or DIN-rail mounting option**
- **Selectable performance level**
- **Environmental friendly design without potting compound**

Approvals

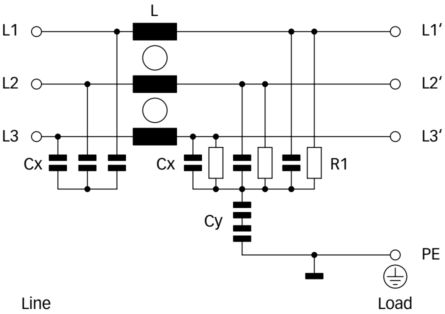
RoHS

Design protected by European patent (EP 1727280)

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC
Operating frequency:	dc to 60Hz
Rated currents:	10 to 50A @ 50°C
High potential test voltage:	P –> E 2000VAC for 2 sec (HL types)
	P –> E 3000VDC for 2 sec (HP types)
	P –> P 2250VDC for 2 sec
Protection category:	IP00 (protection according to VBG 4)
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>200,000 hours

Typical electrical schematic



Features and benefits

- FN 3025 filters are designed for traditional chassis mounting.
- For extra fast installation, FN 3026 filters can comfortably be snapped-in on TS 35 DIN-rails.
- Two different performance levels are offered (L types, P types). The suitable filter can be selected by choosing the required performance level, the admissible leakage current and the preferred installation style.
- A plastic housing and a metal ground plate are cleverly combined to get the lowest possible product weight without compromizing EMC behavior.
- The embedded jump-terminal system from Schaffner guarantees user-friendly handling as well as fast and reliable electrical connection.
- Captive hinged protective covers contribute to overall safety by offering protection against unintended contact with life conductors. They are included in the standard delivery package without causing extra cost.
- Very low leakage current values make these filter ranges ideally suitable for use in Japanese electricity networks as well as in applications which set value on safety and reliability.

Typical applications

- Applications with the requirement for extremely compact filter solutions
- Applications with tough leakage current requirements or sensitive earth leakage detectors
- Applications with insufficient internal filtering or moderate interference levels
- Automation equipment
- Motor drives and servo drives with short motor cables
- Applications including stepping motors
- Semiconductor manufacturing equipment
- Electrical cabinets
- Three-phase power supplies
- Medical equipment (not patient-coupled)

Filter selection table

Filter	Rated current @ 50°C (40°C) [A]	Typical drive power rating* [kW]	Leakage current** @ 480VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections	Weight [kg]
FN 3025HL-10-71	10 (10.7)	5.5	0.4	4.8	-71	0.52
FN 3025HL-20-71	20 (21.4)	11	0.4	6.2	-71	0.52
FN 3025HL-30-71	30 (32.1)	18.5	0.4	7.0	-71	0.54
FN 3025HL-50-72	50 (53.5)	30	0.4	10.5	-72	0.93
FN 3025HP-10-71	10 (10.7)	5.5	2.5	4.8	-71	0.52
FN 3025HP-20-71	20 (21.4)	11	2.5	6.2	-71	0.52
FN 3025HP-30-71	30 (32.1)	18.5	2.5	7.0	-71	0.54
FN 3025HP-50-72	50 (53.5)	30	2.5	10.5	-72	0.93
FN 3026HL-10-71	10 (10.7)	5.5	0.4	4.8	-71	0.56
FN 3026HL-20-71	20 (21.4)	11	0.4	6.2	-71	0.56
FN 3026HL-30-71	30 (32.1)	18.5	0.4	7.0	-71	0.58
FN 3026HL-50-72	50 (53.5)	30	0.4	10.5	-72	0.98
FN 3026HP-10-71	10 (10.7)	5.5	2.5	4.8	-71	0.56
FN 3026HP-20-71	20 (21.4)	11	2.5	6.2	-71	0.56
FN 3026HP-30-71	30 (32.1)	18.5	2.5	7.0	-71	0.58
FN 3026HP-50-72	50 (53.5)	30	2.5	10.5	-72	0.98

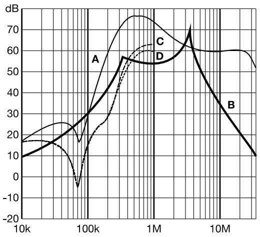
* Calculated at rated current, 480VAC and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

** Maximum leakage under normal operating conditions. Note: if two phases are interrupted, worst case leakage could reach up to 10 times higher levels (at 520VAC/60Hz).

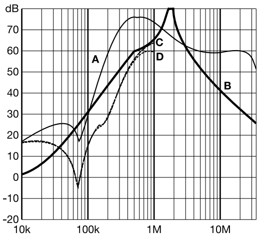
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

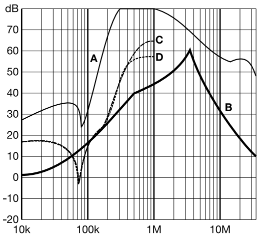
10 and 20A HL types



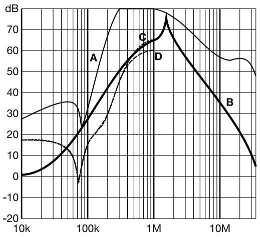
10 and 20A HP types



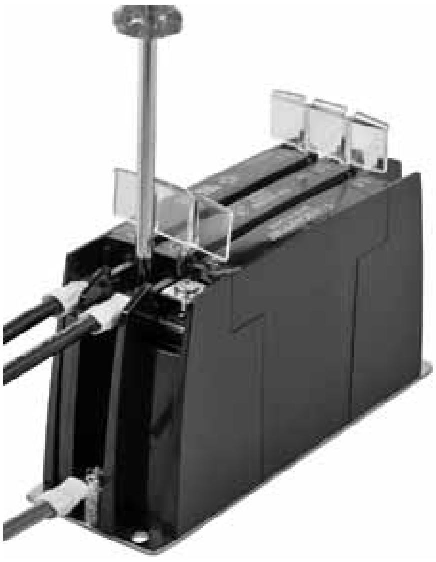
30 and 50A HL types

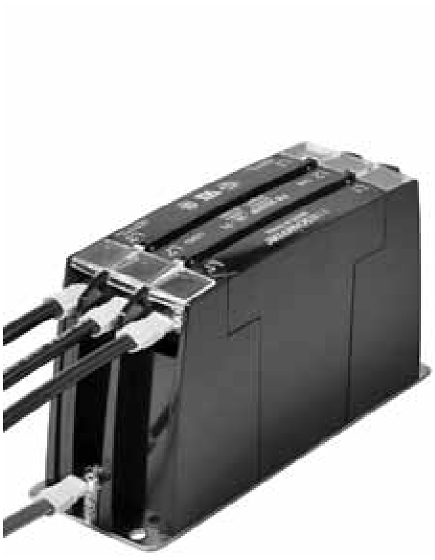


30 and 50A HP types



Installation



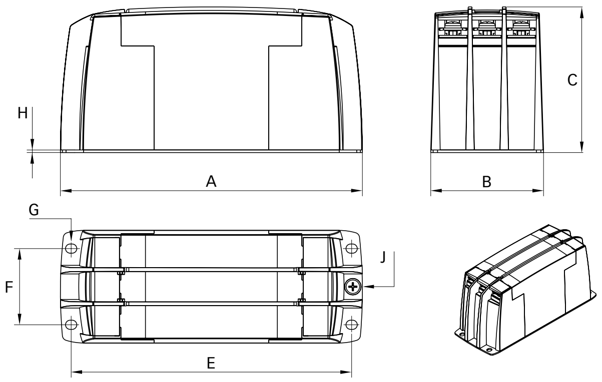


FN 3025/FN 3026 are delivered with closed plastic covers and unfastened terminals. To install the filter please proceed as follows:

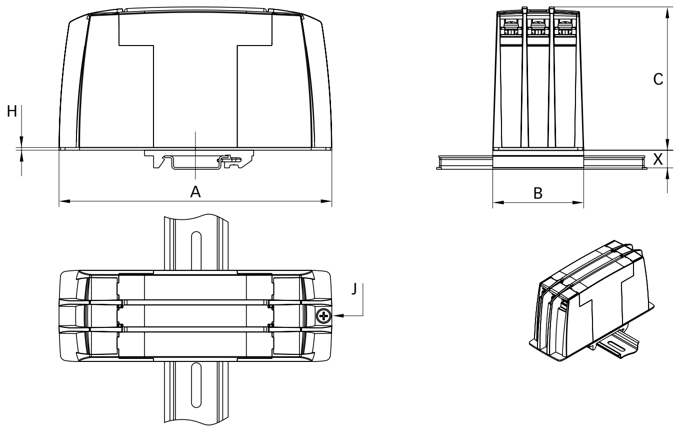
- Mount the filter on a metal surface with four screws or snap it onto a TS 35 DIN-rail.
- First connect the green/yellow wire to the earth stud of the filter.
- Gently lift the two hinged plastic covers.
- Connect phase wires with cable lugs by pushing down and tightening the screws.
- Please note the torque recommendation on top of the filter.
- Push the covers back into their locked position to finish the filter installation.

Mechanical data

FN 3025



FN 3026



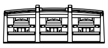
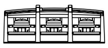
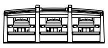
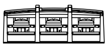
Dimensions

	FN 3025 10A	20A	30A	50A	FN 3026 10A	20A	30A	50A
A	150	150	150	177	150	150	150	177
B	50	50	50	65	50	50	50	65
C	78	78	78	84	78	78	78	84
E	140	140	140	162				
F	32	32	32	44				
G	4.3 x 5.5	4.3 x 5.5	4.3 x 5.5	5.3 x 6.5				
H	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
J	M4	M4	M4	M5	M4	M4	M4	M5
X					9.7	9.7	9.7	9.7

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

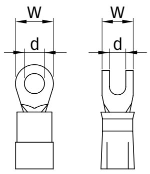
Filter input/output connector cross sections

	-71 (10A)	-71 (20A)	-71 (30A)	-72 (50A)
				
Flex wire	1.3 - 2.5mm^2	4 - 6mm^2	8 - 10mm^2	16 - 20mm^2
AWG type wire	AWG 16 - AWG 13	AWG 12 - AWG 10	AWG 8 - AWG 7	AWG 5 - AWG 4
Ring/fork lug (W/d)*	max. 11mm (9.5mm)/	max. 11mm (9.5mm)/	max. 11mm (9.5mm)/	max. 16.5mm (15mm)/
	min. Ø4.3mm**	min. Ø4.3mm**	min. Ø4.3mm**	min. Ø5.3mm**
Recommended torque	1.0 - 1.2Nm	1.0 - 1.2Nm	1.0 - 1.2Nm	1.9 - 2.2Nm

* Schaffner recommends the use of insulated and UL-recognized ring lugs or fork lugs of the appropriate size.

** Specification in () relates to earth connector.

Please visit www.schaffner.com to find more details on filter connectors.



3-phase Filters
FN 3100

EMC/RFI Filter for Regenerative Motor Drives

- **Exceptional broadband attenuation performance from 10kHz up to 30MHz**
- **Equally suitable for conventional and regenerative motor drives (latter with additional line reactor only)**
- **Slim and user-friendly book-style design with touch-safe terminal blocks for minimum space and maximum safety**
- **Enables compliance with Class B limits**

Approvals

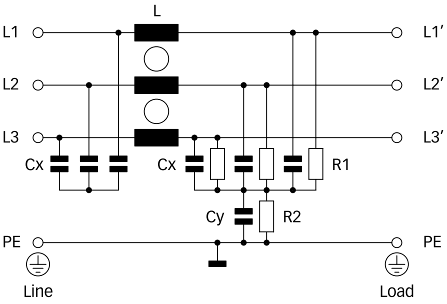
FN 3100 up to 150A

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC
Operating frequency:	dc to 60Hz
Rated currents:	35 to 300A @ 50°C
High potential test voltage:	P –> E 2750VDC for 2 sec
	P –> P 2250VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>400,000 hours

Typical electrical schematic



Features and benefits

- High performance filter for mainly industrial motor drive applications with significant interference levels.
- Attenuation performance for Class B compliance in applications comprising multiple motor drives (e.g. machine tool with up to 8 driving axes with ~10 to 20m motor cable each).
- Broadband filter performance with low frequency attenuation down to 10kHz for reliable suppression of conducted interference in applications with regenerative motor drives.
- Slim book-style shape requiring minimum cabinet space and allowing convenient installation right beside the motor drive.
- Touch-safe terminal blocks provide unsurpassed electrical safety and contacting cross section according to EN 60204-1 installation standard.
- For even better filter specifications, please consider FN 3120H series from Schaffner.

Typical applications

- Conventional motor drives with long motor cables and high interference levels
- Four quadrant motor drives and servo drives with energy regeneration mode (in combination with a suitable line reactor)
- Industrial applications comprising power conversion devices, such as machinery, machine tools and process automation equipment
- Uninterruptible power supplies (UPS)
- Converters for renewable energy generation
- Thyristor drives
- Elevators and cranes

Filter selection table

Filter	Rated current @ 50°C (40°C) [A]	Typical drive power rating* [kW]	Leakage current** @ 400VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections		Weight [kg]
FN 3100-35-33	35 (38.4)	22	48.9	11.8	-33		2.3
FN 3100-50-34	50 (54.8)	30	66.1	18.0	-34		3.4
FN 3100-80-35	80 (87.6)	45	71.5	25.9	-35		5.3
FN 3100-110-35	110 (120.5)	55	71.5	32.7	-35		5.4
FN 3100-150-40	150 (164.3)	75	71.5	50.6	-40		8.5
FN 3100-200-40	200 (219)	110	71.5	67.2	-40		9.1
FN 3100-230-40	230 (230)	132	71.5	36.5	-40		9.2
FN 3100-300-99	300 (329)	160	71.5	54.0		-99	11.8

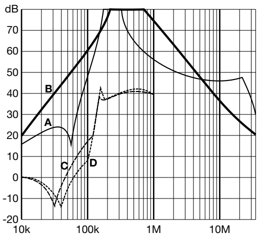
* Calculated at rated current, 480VAC and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

** Maximum leakage under normal operating conditions. Note: if two phases are interrupted, worst case leakage could reach 5.3 times higher levels.

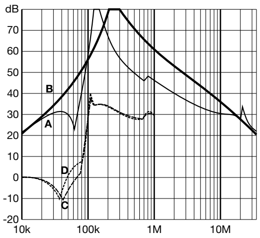
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

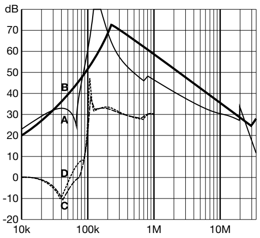
35 to 80A types



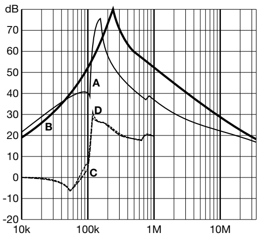
110 and 150A types



200A types

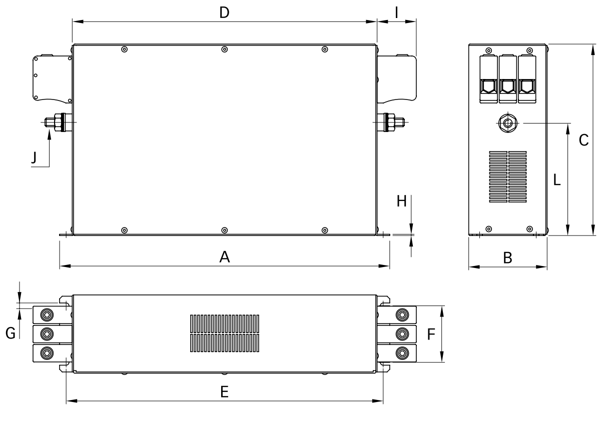


230 and 300A types

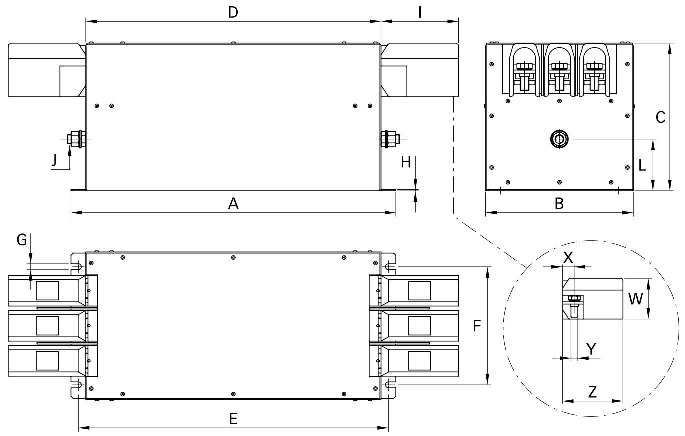


Mechanical data

35 to 230A types



300A types



Dimensions

	35A	50A	80A	110A	150A	200A	230A	300A
A	335	329	379	379	438	438	438	440
B	60	80	90	90	110	110	110	200
C	150	185	220	220	240	240	240	200
D	305	300	350	350	400	400	400	400
E	320	314	364	364	413	413	413	420
F	35	55	65	65	80	80	80	160
G	6.5	6.5	6.5	6.5	6.5	6.5	6.5	8
H	1	1.5	1.5	1.5	4	4	4	1.5
I	25	39	45	45	51	51	51	105
J	M5	M6	M10	M10	M10	M10	M10	M12
L	93.5	107	129	129	108	108	108	70
W								71.5
X								~22
Y								M12
Z								~105

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-33	-34	-35	-40	-99
Solid wire	16mm²	35mm²	50mm²	95mm²	–
Flex wire	10mm²	25mm²	50mm²	95mm²	150mm²
AWG type wire	AWG 6	AWG 2	AWG 1/0	AWG 4/0	AWG 6/0
Recommended torque	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm	27 - 30Nm

Please visit www.schaffner.com to find more details on filter connectors.

3-phase Filters
FN 3120

High-end EMC/RFI Filter for Conventional and Regenerative Drives

energy efficiency and reliability

- **High-performance filter for extremely noisy applications**
- **Ideal for the latest regenerative drives (with additional line impedance)**
- **Significantly improves the reliability and immunity of installations**
- **Enables compliance with Class B limits even with very long cables**

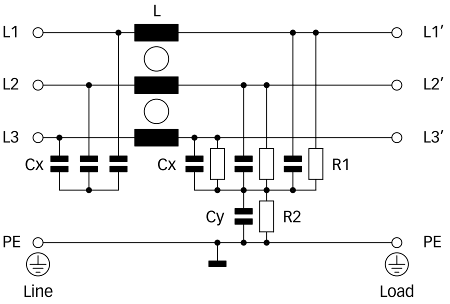
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC (480VAC +10% possible)
Operating frequency:	dc to 60Hz
Rated currents:	25 to 230A @ 50°C
High potential test voltage:	P –> E 2750VDC for 2 sec
	P –> P 2250VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>300,000 hours

Typical electrical schematic



Features and benefits

- High-performance filter for mainly industrial motor drive applications with extremely high noise levels, providing sufficient interference suppression to achieve Class B even with very long motor cables (e.g. machine tools with up to 12 axes with ~10 to 20m cables each).
- Broadband attenuation performance and exceptional saturating resistance ensure reliable interference suppression also in applications with regenerative drives (with an additional line impedance).
- FN 3120 operated on the mains input of machines or equipment contributes significantly to the reliability and immunity by offering protection against conducted interference phenomena coming from the environment.
- Solid, touch-safe terminal blocks offer sufficient contacting cross section according to the EN 60204-1 installation standard, which is very common for industrial equipment like machine tools.
- Compact dimensions and light weight design with good accessibility for automatic and hand tools guarantee a simple time and space-saving installation.

Typical applications

Mainly industrial equipment, machinery and machine tools such as printing machines, packaging machines, extruders, wood working machines, milling and drilling machines, laser cutting machines, welding machines, robotics, conveyors, assembly lines, pumps, oil production, chemical and mining industry, etc. The filters are ideal for most motor drive applications and particularly for regenerative drives.

Filter selection table

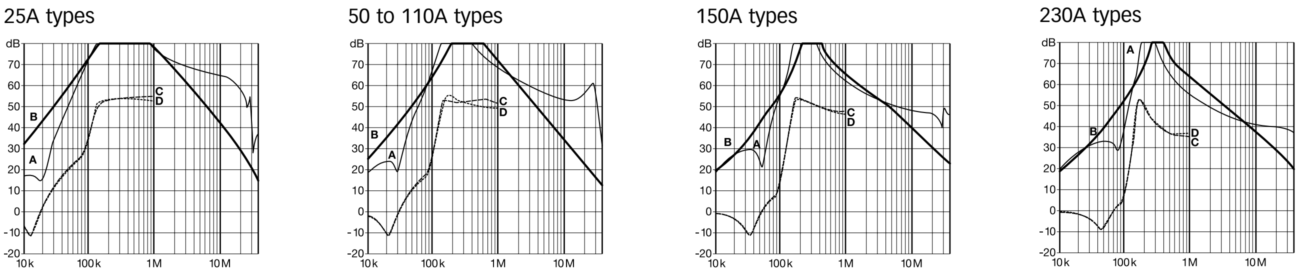
Filter	Rated current @ 50°C (40°C) [A]	Typical drive power rating* [kW]	Leakage current** @ 480VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections	Weight [kg]
FN 3120H-25-33	25 (27)	15	97.9	17.1	-33	2.4
FN 3120H-50-53	50 (54)	30	97.9	17.5	-53	2.7
FN 3120H-80-35	80 (87)	45	97.9	25.9	-35	5.0
FN 3120H-110-35	110 (120)	55	97.9	25.4	-35	6.1
FN 3120H-150-40	150 (164)	75	97.9	40.5	-40	6.3
FN 3120H-230-40	230 (230)	132	97.9	33.5	-40	13.3

* Calculated at rated current, 480VAC and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

** Maximum leakage under normal operating conditions. Note: if two phases are interrupted, worst case leakage could reach 5.4 times higher levels.

Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym



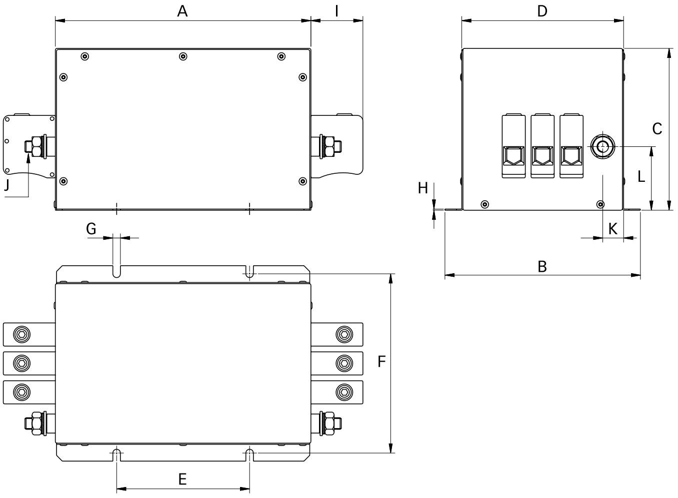
25A types

50 to 110A types

150A types

230A types

Mechanical data



Dimensions

	25A	50A	80A	110A	150A	230A
A	214	214	221	221	221	300
B	159	159	169	169	169	168
C	64	64	140	140	140	140
D	129	129	140	140	140	140
E	115	115	115	115	115	165 (82.5/82.5)*
F	145	145	155	155	155	155
G	6.5	6.5	6.5	6.5	6.5	6.5
H	1	1	1	1	1	1
I	25	29.45	45	45	51	51
J	M5	M6	M10	M10	M10	M10
K	21.5	24.5	18	18	13	13
L	26	35	55	55	62	62

* 230A filters provide 2 additional mounting slots, to do justice to the additional product weight. They are located right in the center of those mounting slots shown in the drawing above (82.5/82.5 –> 165mm).

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-33	-35	-40	-53
Solid wire	16mm²	50mm²	95mm²	25mm²
Flex wire	10mm²	50mm²	95mm²	16mm²
AWG type wire	AWG 6	AWG 1/0	AWG 4/0	AWG 4
Recommended torque	1.5 - 1.8Nm	7 - 8Nm	17 - 20Nm	2.0 - 2.3Nm

Please visit www.schaffner.com to find more details on filter connectors.

3-phase Filters
FN 3258

Ultra-compact EMC/RFI Filter for Three-phase Systems and Motor Drives

energy efficiency and reliability

- **New: solid safety connector blocks available for the whole range**
- **Exceptional attenuation performance from 150kHz to 30MHz**
- **Excellent saturation resistance up to 50m cable length**
- **Most compact and slim filter design in its class**

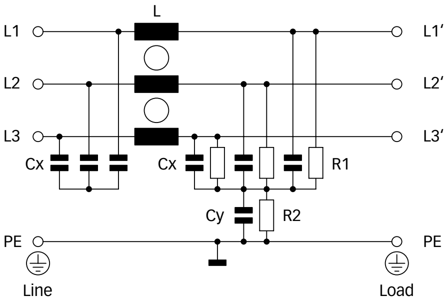
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 480/277VAC (FN 3258)
	3x 520/300VAC (FN 3258H)
Operating frequency:	dc to 60Hz
Rated currents:	7 to 180A @ 50°C
High potential test voltage:	P –> E 2650VDC for 2 sec
	P –> P 2100VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	300,000 hours

Typical electrical schematic



Features and benefits

- The extremely compact and slim filter design allows a trouble-free installation even where the available mounting space is minimal.
- With new additional filter types providing safety terminal blocks, the most preferred connection style can be chosen fast and easy. This helps to stay in line with the electrical connection concept of a given application.
- FN 3258 filters ensure compliance with Class A limits according to EN 55011 up to 50m cable length and beyond. Further they can contribute significantly to meet conducted emission limits according to Class B.
- Filter operation on the mains input side of consumers increases their reliability and conducted immunity significant.
- Chokes with exceptional saturation resistance and excellent thermal behavior are a vital part of FN 3258 design. Thus, all filters retain the expected filter performance even in very noisy applications and under full load conditions.

Typical applications

- Three-phase variable speed motor drives, servo drives, inverters and converters
- Applications comprising energy conversion devices like machines or process automation equipment
- HVAC equipment, elevators, power supplies, UPS and further three-phase applications

Filter selection table

Filter	Rated current @ 50°C (40°C) [A]	Typical drive power rating* [kW]	Leakage current** @ 400VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections	Weight [kg]
FN 3258-7-44	7 (7.7)	4	33.0	3.8	-44	0.5
FN 3258-16-44	16 (17.5)	7.5	33.0	6.1	-44	0.8
FN 3258-30-33	30 (32.9)	15	33.0	11.8	-33	1.2
FN 3258-42-33	42 (46.0)	22	33.0	15.7	-33	1.4
FN 3258-55-34	55 (60.2)	30	33.0	25.9	-34	2.0
FN 3258-75-34	75 (82.2)	37	33.0	32.2	-34	2.7
FN 3258-100-35	100 (109.5)	55	33.0	34.5	-35	4.3
FN 3258-130-35	130 (142.4)	75	33.0	43.1	-35	4.5
FN 3258-180-40	180 (197.1)	90	33.0	58.3	-40	6.0
FN 3258H-7-44	7 (7.7)	4	33.0	3.8	-44	0.5
FN 3258H-16-44	16 (17.5)	7.5	33.0	6.1	-44	0.8
FN 3258H-30-33	30 (32.9)	18.5	33.0	11.8	-33	1.2
FN 3258H-42-33	42 (46.0)	22	33.0	15.7	-33	1.4
FN 3258H-55-34	55 (60.2)	37	33.0	25.9	-34	2.0
FN 3258H-75-34	75 (82.2)	45	33.0	32.2	-34	2.7
FN 3258H-100-35	100 (109.5)	55	33.0	34.5	-35	4.3
FN 3258H-130-35	130 (142.4)	75	33.0	43.1	-35	4.5
FN 3258H-180-40	180 (197.1)	110	33.0	58.3	-40	6.0

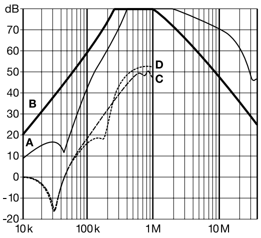
* Calculated at rated current, 440VAC (FN 3258)/480VAC (FN 3258H) and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

** Maximum leakage under normal operating conditions. Note: if two phases are interrupted, worst case leakage could reach 5.4 times higher levels.

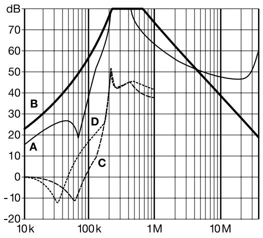
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

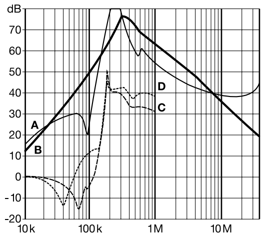
7 to 42A types



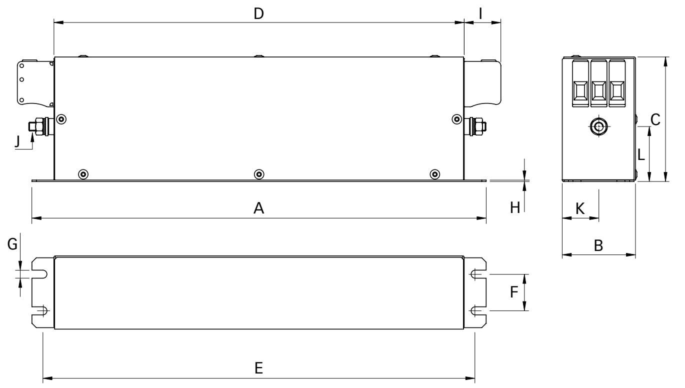
55 to 100A types



130 and 180A types



Mechanical data



Note: in favour of a better readability, connectors and earth studs are not shown in the horizontal projection.

Dimensions

	7A	16A	30A	42A	55A	75A	100A	130A	180A
A	190	250	270	310	250	270	270	270	380
B	40	45	50	50	85	80	90	90	120
C	70	70	85	85	90	135	150	150	170
D	160	220	240	280	220	240	240	240	350
E	180	235	255	295	235	255	255	255	365
F	20	25	30	30	60	60	65	65	102
G	4.5	5.4	5.4	5.4	5.4	6.5	6.5	6.5	6.5
H	1	1	1	1	1	1.5	1.5	1.5	1.5
I	22	22	25	25	39	39	45	45	51
J	M5	M5	M5	M6	M6	M6	M10	M10	M10
K	20	22.5	25	25	42.5	40	45	45	60
L2	29.5	29.5	39.5	37.5	26.5	70.5	64	64	47

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-33	-34	-35	-40	-44
Solid wire	16mm^2	35mm^2	50mm^2	95mm^2	10mm^2
Flex wire	10mm^2	25mm^2	50mm^2	95mm^2	6mm^2
AWG type wire	AWG 6	AWG 2	AWG 1/0	AWG 4/0	AWG 8
Recommended torque	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm	1.5 - 1.8Nm

Please visit www.schaffner.com to find more details on filter connectors.

Low-leakage Current EMC/EMI Filter for Installations with Residual Current Device (RCD)

schaffner
energy efficiency and reliability

- **Full functionality with RCDs according to IEC 61008 and new VDE 0664-110***
- **Compatible with 30mA RCDs up to 30m motor cable for electric shock protection according to IEC 61008**
- **Compatible with 300mA RCDs up to 100m motor cable for fire protection according to IEC 60364-4-42 (VDE 0100-482)**

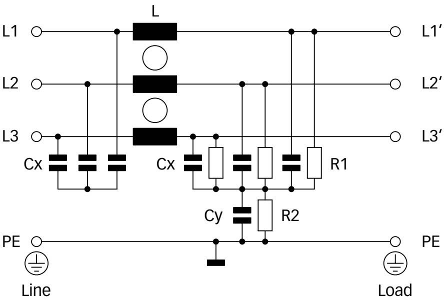
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC
Operating frequency:	dc to 60Hz
Rated currents:	7 to 180A @ 50°C
High potential test voltage:	P –> E 2650VDC for 2 sec
	P –> P 2100VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>300,000 hours

Typical electrical schematic



Features and benefits

- Innovative low-leakage current filter with same smallest dimensions as FN 3258.
- Significant reduction of leakage and ground currents caused by long motor cables.
- Prevents unwanted fault shut-downs from RCDs in machines and process automation equipment.
- Patented filter design avoiding early saturation and ringing effects.
- Excellent attenuation compliant with:
  C1 limits EN 61800-3 with 30 meter motor cable and 30mA RCD (electric shock protection)**.
  C2 limits EN 61800-3 with 100 meter motor cable and 300mA RCD (fire protection).

Typical applications

- Three-phase variable speed drives (VSD), servo drives, and inverters
- Machinery and process automation equipment
- Building automation, HVAC equipment, pumps, ventilation, and elevators
- Conveyors, handling and storage systems, and cranes
- Machine tools, wood working machines, and printing machines

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* If supply voltage is contaminated with harmonics according to IEC 61000-2-4, class 2, where odd-numbered multiples of three are limited to 30%.

** Filter types 7A up to 42A: C1, 30m, 30mA; 55A: C2, 30m, 30mA; 75A up to 180A: C2, 100m, 300mA

Filter selection table

Filter	Rated current @ 50°C (40°C) [A]	Typical drive power rating* [kW]	Leakage current** @ 400VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections	Weight [kg]
FN 3268-7-44	7 (7.7)	4	4.5	4.5	-44	0.5
FN 3268-16-44	16 (17.5)	7.5	4.7	6.1	-44	0.8
FN 3268-30-33	30 (32.9)	18.5	4.6	13.5	-33	1.2
FN 3268-42-33	42 (46.0)	22	4.6	17.4	-33	1.4
FN 3268-55-34	55 (60.2)	37	4.7	18.1	-34	2.2
FN 3268-75-34	75 (82.2)	45	7.8	25.3	-34	2.9
FN 3268-100-35	100 (109.5)	55	20.5	30.0	-35	4.1
FN 3268-130-35	130 (142.4)	75	30.4	38.0	-35	4.6
FN 3268-180-40	180 (197.1)	110	37.0	48.6	-40	6.0

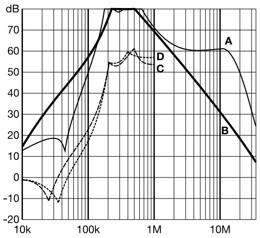
* Calculated at rated current, 440VAC and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

** Maximum leakage under normal operating conditions. Note: if two phases are interrupted, worst case leakage could reach 5.4 times higher levels.

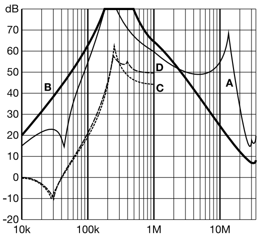
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

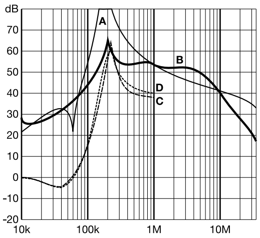
7 to 42A types



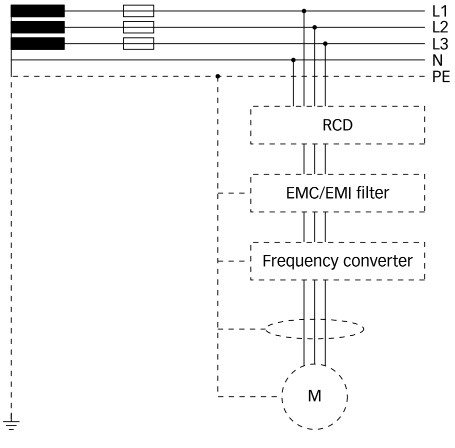
55 to 100A types



130 and 180A types



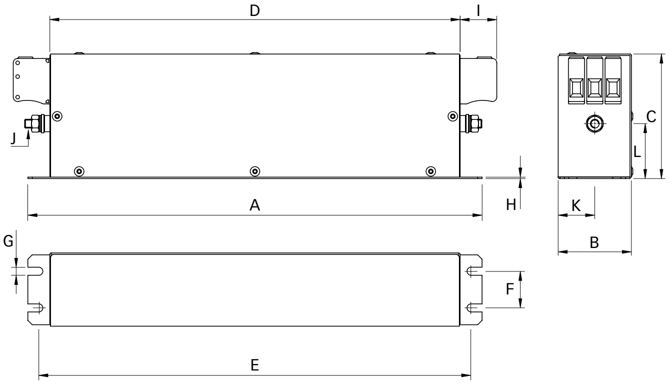
Installation



Typical installation with RCD, EMC/EMI filter and motor drive system

- RCD
  Please note that for electrical devices with 6-pulse rectifiers at line input, like three-phase motor drives, a RCD type B or B+ is required. RCD with time delay are needed to prevent unwanted fault trip at switch on or voltage spikes. These RCD types B with time delay have often an added letter "S" or "K", please ask the supplier for correct type. Caution: Please validate system with chosen RCD to guarantee functionality.
- EMC/EMI filter FN 3268
  Filter types from 7 to 55A are designed to be compatible with 30mA RCDs according to IEC 61008 and new VDE 0664-110 standards. Filters from 75 up to 180A are designed to be compatible with 300mA RCDs. Install the filter as close as possible at line side of the motor drive. Regarding correct EMC installation, please refer to the EMC installation guide in the manual from motor drive supplier.
- Motor drive
  Please set the PWM pulse pattern of the variable speed motor drive fixed to 4kHz. Other pulse patterns cause higher leakage currents. Filter designs with other pulse pattern than 4kHz are possible upon request.
- Motor cable length
  Motor cable length should not exceed 30 meters for 7 up to 55A filter types to fulfill class C1 of recommended standard EN 61800-3. For 75 up to 180A filters, cable length should not exceed 100 meters to fulfill class C2.
- Internal EMC/EMI components
  Please disconnect all internal Y-capacitors (internal EMC/EMI filters) in the motor drive, because these capacitors cause additional leakage currents.
- Harmonics on line voltage
  High voltage harmonics can create additional system leakage currents. FN 3268 filters are tested under following conditions: Supply voltage is contaminated with harmonics according to IEC 61000-2-4, class 2, where odd-numbered multiples of three are limited to 30%.

Mechanical data



Note: in favour of a better readability, connectors and earth studs are not shown in the horizontal projection.

Dimensions

	7A	16A	30A	42A	55A	75A	100A	130A	180A
A	190	250	270	310	250	270	270	270	380
B	40	45	50	50	85	80	90	90	120
C	70	70	85	85	90	135	150	150	170
D	160	220	240	280	220	240	240	240	350
E	180	235	255	295	235	255	255	255	365
F	20	25	30	30	60	60	65	65	102
G	4.5	5.4	5.4	5.4	5.4	6.5	6.5	6.5	6.5
H	1	1	1	1	1	1.5	1.5	1.5	1.5
I	22	22	25	25	39	39	45	45	51
J	M5	M5	M5	M6	M6	M6	M10	M10	M10
K	20	22.5	25	25	42.5	40	45	45	60
L	29.5	29.5	39.5	37.5	26.5	70.5	64	64	47

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-33	-34	-35	-40	-44
Solid wire	16mm^2	35mm^2	50mm^2	95mm^2	10mm^2
Flex wire	10mm^2	25mm^2	50mm^2	95mm^2	6mm^2
AWG type wire	AWG 6	AWG 2	AWG 1/0	AWG 4/0	AWG 8
Recommended torque	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm	1.5 - 1.8Nm

Please visit www.schaffner.com to find more details on filter connectors.

3-phase Filters
FN 3270

Compact Three-phase EMC/RFI Filter for Industrial Motor Drive Applications

schaffner
energy efficiency and reliability

- **Very compact and light weight design requiring minimum space**
- **Easy, time-saving installation and contacting**
- **Protective covers as optional accessory available**
- **Attenuation performance according to EN 61800-3/A11**

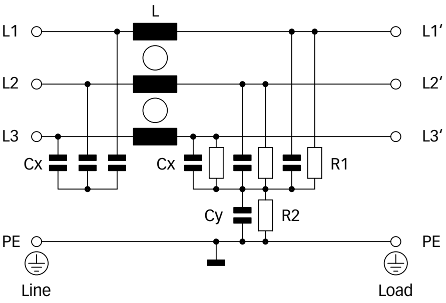
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC (480VAC +10% possible)
Operating frequency:	dc to 60Hz
Rated currents:	10 to 1000A @ 50°C
High potential test voltage:	P –> E 2750VDC for 2 sec
	P –> P 2250VDC for 2 sec
Protection category:	IP20 (10 to 100A)
	IP00 (150 to 1000A)
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>320,000 hours

Typical electrical schematic



Features and benefits

- An extremely compact and light weight filter design requiring minimum mounting space in installations and cabinets.
- Simple and time-saving installation with good accessibility for automatic and hand tools.
- Solid, touch-safe terminal blocks, for all filters from 10 to 100A, offering sufficient contacting cross section according to the EN 60204-1 installation standard.
- Optionally available transparent protective covers for all filters with busbars from 150 to 1000A, to protect the installer, operator or inspector from undeliberate touching of life conductors. They can easily be retro-fitted even if the filter is already installed and connected.
- These EMC filters provide the attenuation performance needed to fulfill EN 61800-3/A11.
- Guaranteed filter performance under full-load operating conditions.
- 15 different filter models allow the specific choice and deployment for most industrial applications.

Typical applications

- Variable speed electrical power drive systems/motor drives for mainly industrial purpose
- Various industrial applications comprising frequency inverters, motor drives and servo drives

Filter selection table

Filter	Rated current @ 50°C (40°C)	Typical drive power rating*	Leakage current** @ 480VAC/50Hz	Power loss @ 25°C/50Hz	Input/Output connections		Weight	Protective covers***
	[A]	[kW]	[mA]	[W]			[kg]	Order code
FN 3270H-10-44	10 (11)	5.5	26.4	2.4	-44		0.4	
FN 3270H-20-44	20 (22)	11	26.4	4.1	-44		0.5	
FN 3270H-35-33	35 (38)	22	29.4	6.8	-33		0.7	
FN 3270H-50-34	50 (55)	30	29.4	12.8	-34		1.2	
FN 3270H-65-34	65 (71)	37	29.4	13.5	-34		1.3	
FN 3270H-80-35	80 (88)	45	29.4	13.5	-35		2.2	
FN 3270H-100-35	100 (110)	55	29.4	17.1	-35		2.6	
FN 3270H-150-99	150 (164)	75	59.5	7.5		-99	6.1	1151-047
FN 3270H-200-99	200 (219)	110	59.5	13.2		-99	6.1	1151-047
FN 3270H-250-99	250 (274)	132	59.5	20.6		-99	6.1	1151-047
FN 3270H-320-99	320 (350)	160	59.5	12.2		-99	7.2	1151-047
FN 3270H-400-99	400 (438)	220	59.5	19.2		-99	7.2	1151-047
FN 3270H-600-99	600 (657)	315	59.5	35.6		-99	7.7	1151-047
FN 3270H-800-99	800 (876)	400	59.5	51.8		-99	15.8	1151-049
FN 3270H-1000-99	1000 (1095)	560	59.5	81.0		-99	15.8	1151-049

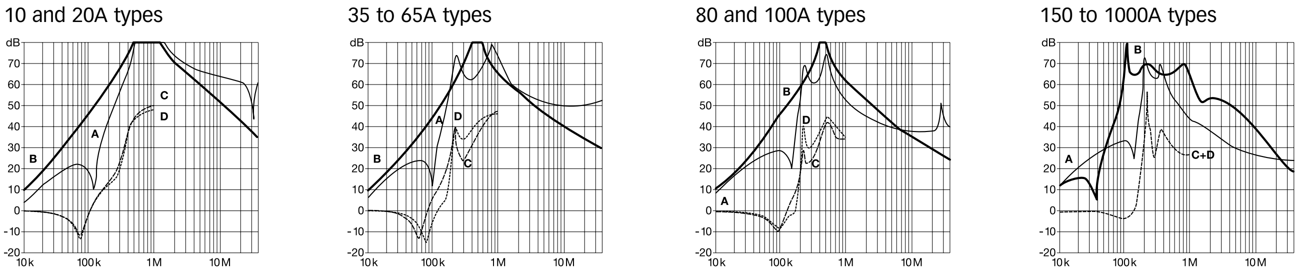
* Calculated at rated current, 480VAC and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

** Maximum leakage under normal operating conditions. Note: if two phases are interrupted, worst case leakage could reach 5.2 times higher levels.

*** Please contact your local Schaffner partner to order the optional protective covers with the order code in the table above.

Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym


10 and 20A types

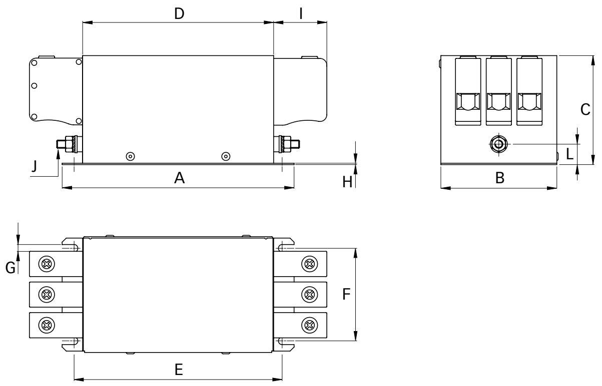
35 to 65A types

80 and 100A types

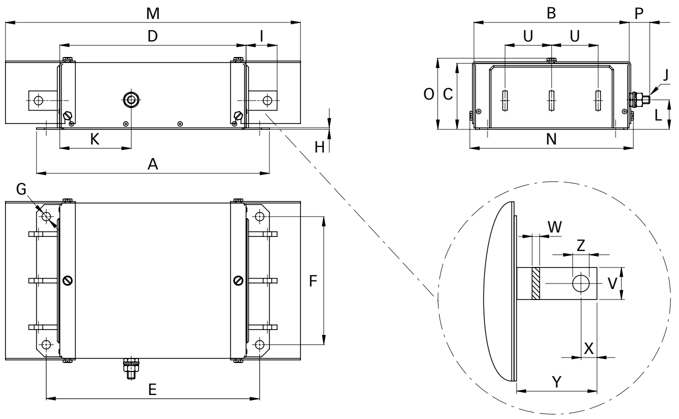
150 to 1000A types

Mechanical data

10 to 100A types



150 to 1000A types



Dimensions

	10A	20A	35A	50A	65A	80A	100A	150A	200A	250A	320A	400A	600A	800A	1000A
A	150	150	160	170	170	200	230	300	300	300	300	300	300	370	370
B	58	58	70	85	85	95	95	200	200	200	200	200	200	190	190
C	58	58	68	80	80	90	90	86	86	86	86	86	86	125	125
D	120	120	130	140	140	170	200	240	240	240	240	240	240	310	310
E	132.5	132.5	142.5	152.5	152.5	182.5	212.5	275	275	275	275	275	275	345	345
F	42	42	50	65	65	75	75	165	165	165	165	165	165	155	155
G	4.5	4.5	5.5	5.5	5.5	5.5	5.5	Ø11	Ø11	Ø11	Ø11	Ø11	Ø11	Ø11	Ø11
H	1	1	1	1	1	1.5	1.5	2	2	2	2	2	2	3	3
I	10.9	10.9	25	39	39	45	45	40	40	40	40	40	40	50	50
J	M4	M4	M5	M6	M6	M8	M8	M10	M10	M10	M10	M10	M10	M12	M12
K								92	92	92	92	92	92	138	138
L	20.5	20.5	20	15	15	16	16	37	37	37	37	37	37	67	67
M								380	380	380	380	380	380	610	610
N								211	211	211	211	211	211	201	201
O								93	93	93	93	93	93	132	132
P								26.5	26.5	26.5	26.5	26.5	26.5	29	29
U								60	60	60	60	60	60	60	60
V								20	20	20	25	25	25	40	40
W								3	3	3	6	6	8	8	8
X								10	10	10	12.5	12.5	12.5	20	20
Y								37	37	37	37	37	37	47	47
Z								Ø9	Ø9	Ø9	Ø11	Ø11	Ø11	Ø13.5	Ø13.5

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-33	-34	-35	-44
Solid wire	16mm^2	35mm^2	50mm^2	10mm^2
Flex wire	10mm^2	25mm^2	50mm^2	6mm^2
AWG type wire	AWG 6	AWG 2	AWG 1/0	AWG 8
Recommended torque	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	1.5 - 1.8Nm

Please visit www.schaffner.com to find more details on filter connectors.

FN 3359

High-current Three-phase EMC/RFI Filter

schaffner
energy efficiency and reliability

- **Off-the-shelf high-power filter for rated currents up to 2500A**
- **HV versions designed for 690VAC IT power networks**
- **Busbars for convenient and universal electrical connection**
- **Protective plastic covers optionally available for unsurpassed safety**

Approvals (filters up to 1000A)

c UR us
(600VAC)

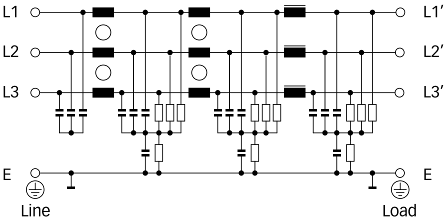
ENEC 14

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC (FN 3359)
	3x 690/400VAC (FN 3359HV)
Operating frequency:	dc to 60Hz
Rated currents:	150 to 2500A @ 50°C
High potential test voltage:	P –> E 2700VDC for 2 sec (FN 3359)
	P –> P 2150VDC for 2 sec (FN 3359)
	P –> E 3100VDC for 2 sec (FN 3359HV)
	P –> P 3000VDC for 2 sec (FN 3359HV)
Protection category:	IP00
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 45°C/480V (Mil-HB-217F):	130,000 hours

Typical electrical schematic



Note: HV versions without discharge resistor to ground.

Features and benefits

- High-power filter for Class A compliance. With approval measurement also Class B compliance possible for some applications.
- Extremely compact high-current filter solution with minimum space requirement.
- FN 3359HV versions for 690VAC are also designed for use in IT power networks.
- All filters 320A and above are suitable for regenerative motor drive system (with a suitable line reactor).
- Optionally available transparent protective covers for all filters up to 1000A, to protect the installer, operator or inspector from undeliberate touching of life conductors. They can easily be retrofitted even if the filter is already installed and connected.
- FN 3359 also improves conducted immunity of installations.

Typical applications

- High-power motor drives, inverters and converters
- Industrial three-phase systems
- Entire factories, plants and installations
- Large UPS
- Machinery
- Mining equipment
- Photovoltaic systems with galvanic isolation*
- Wind turbines

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* For EMI solutions for PV system without galvanic isolation, please contact your local Schaffner partner.

Filter selection table

Filter	Rated current @ 50°C (40°C)	Typical drive power rating*	Leakage current** @ 480VAC/50Hz	Power loss @ 25°C/50Hz	Input/Output connections		Weight	Protective covers***
	[A]	[kW]	[mA]	[W]			[kg]	Order code
FN 3359-150-28	150 (164)	75	<6	24	-28		6.5	1151-050
FN 3359-180-28	180 (197)	90	<6	34	-28		6.5	1151-050
FN 3359-250-28	250 (250)	132	<6	49	-28		7.0	1151-051
FN 3359-320-99	320 (350)	160	<6	19		-99	10.5	1151-052
FN 3359-400-99	400 (438)	220	<6	29		-99	10.5	1151-052
FN 3359-600-99	600 (657)	315	<6	44		-99	11.0	1151-053
FN 3359-800-99	800 (876)	400	<6	39		-99	18.0	1151-054
FN 3359-1000-99	1000 (1095)	560	<6	60		-99	18.0	1151-054
FN 3359-1600-99	1600 (1600)	900	<6	131		-99	27.0	
FN 3359-2500-99	2500 (2500)	1320	<6	300		-99	55.0	
FN 3359HV-150-28	150 (164)	110	<6	24	-28		6.5	1151-050
FN 3359HV-180-28	180 (197)	132	<6	34	-28		6.5	1151-050
FN 3359HV-250-28	250 (250)	200	<6	49	-28		7.0	1151-051
FN 3359HV-320-99	320 (350)	250	<6	19		-99	10.5	1151-052
FN 3359HV-400-99	400 (438)	315	<6	29		-99	10.5	1151-052
FN 3359HV-600-99	600 (657)	500	<6	44		-99	11.0	1151-053
FN 3359HV-800-99	800 (876)	630	<6	39		-99	18.0	1151-054
FN 3359HV-1000-99	1000 (1095)	710	<6	60		-99	18.0	1151-054
FN 3359HV-1600-99	1600 (1600)	1320	<6	131		-99	27.0	
FN 3359HV-2500-99	2500 (2500)	2000	<6	300		-99	55.0	

* Calculated at rated current, 480VAC (FN 3359) / 690VAC (FN 3359HV) and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

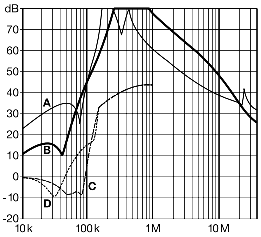
** Maximum leakage under normal operating conditions. Note: if two phases are interrupted, worst case leakage could be much higher than the value shown.

*** Please contact your local Schaffner partner to order the optional protective covers with the order code in the table above

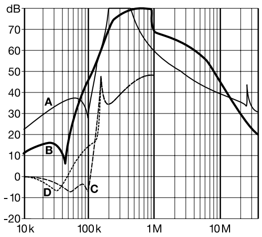
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

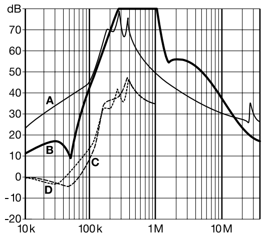
150 to 180A types



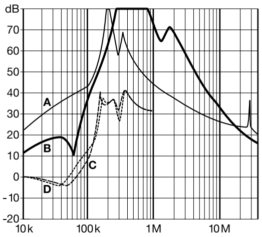
250 to 600A types



800 and 1000A types

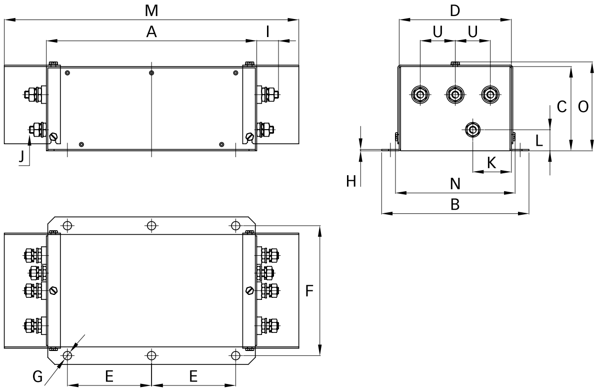


1600 and 2500A types

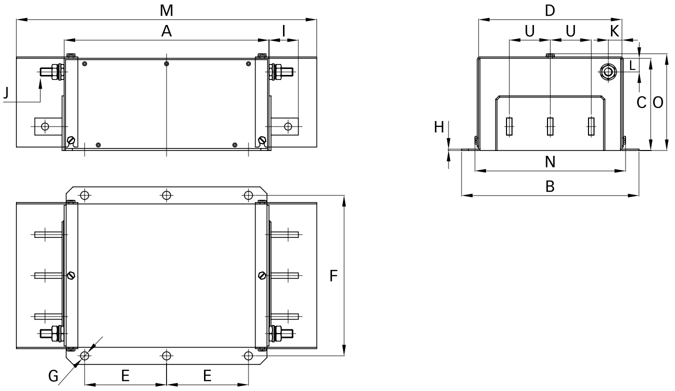


Mechanical data

150 to 250A types

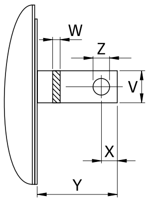


320 to 2500A types

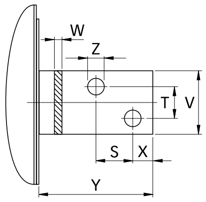


Busbar connections

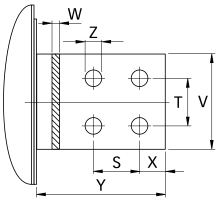
320 to 1000A types



1600A types



2500A types



Dimensions

	150A	180A	250A	320A	400A	600A	800A	1000A	1600A	2500A
A	300	300	300	300	300	300	350	350	400	600
B	210	210	230	260	260	260	280	280	300	370
C	120	120	125	115	115	135	170	170	160	200
D	160	160	180	210	210	210	230	230	250	300
E	120	120	120	120	120	120	145	145	170	250
F	185	185	205	235	235	235	255	255	275	330
G	Ø12	Ø12	Ø12	Ø12	Ø12	Ø12	Ø12	Ø12	Ø12	Ø14
H	2	2	2	2	2	2	3	3	3	3
I	33	33	33	43	43	43	53	53	93	98
J	M10	M10	M10	M12	M12	M12	M12	M12	M12	M16
K	55	55	62.5	20	20	20	25	25	25	25
L	30	30	35	20	20	20	25	25	25	25
M	420	420	420	440	440	440	510	510		
N	171	171	191	221	221	221	241	241		
O	127	127	132	122	122	142	177	177		
S									26	35
T									26	35
U	50	50	55	60	60	60	60	60	60	100
V				25	25	25	40	40	60	70
W				6	6	8	8	8	10	15
X				15	15	15	20	20	17	20
Y				40	40	40	50	50	90	95
Z				Ø10.5	Ø10.5	Ø10.5	Ø14	Ø14	Ø14	Ø14

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

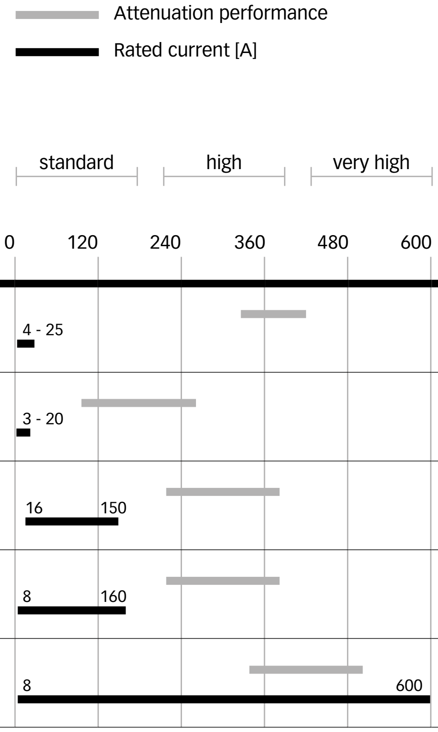
Three-phase and Neutral Line Filters

Three-phase and Neutral Line Filters.

Three-phase and neutral line filters are a compact solution for the interference suppression on the mains input of cabinets and control units of equipment, ranging from industrial applications like machine tools to sensitive medical installations. These typically involve separate and often insufficiently filtered frequency inverters and SMPS, causing current imbalance and significant interference problems. As individual elements they may be interference-suppressed already. The conjunction of several switching components in the same cabinet and a non-EMC conscious cabling will rise the demand for an additional EMC/EMI filter on the mains input of the whole installation. Many times this is the only way to get the CE mark for the cabinet in accordance with the EMC directive.

Approvals *

IEC/EN 60939



Filter family		Max. voltage	Rated current [A]	1-stage filter circuit	2-stage filter circuit	Safety connector blocks	Faston connectors	Offering EMC compliance	For asymmetrical loads	Broadband attenuation	Very low leakage current	For entire systems, install.	Machinery, machine tools	Industrial automation	Power supplies	Medical equipment	For high frequency appl.	High power office equipment	General purpose
				Features								**Typical applications**							
FN 354 p. 51		440VAC	4 - 25		■		■	■		■					■	■	■	■	■
FN 355 p. 54		440VAC	3 - 20	■			■	■			■					■		■	■
FN 356 p. 56		440VAC	16 150	■		■		■	■			■		■	■				
FN 3256 p. 59		520VAC (H)	8 160	■		■		■	■			■	■	■	■			■	■
FN 3280 p. 62		520VAC (H)	8 600		■	■		■	■	■		■	■	■	■				

* Products evaluated by one or more of the above certification agencies. For details please consult the detailed data sheet.

3-phase + Neutral Line Filters
FN 354

Compact Three-phase and Neutral Line Filter for High Frequency Attenuation

energy efficiency and reliability

- **Compact four-wire filter for applications with limited space**
- **High attenuation performance up to 300MHz**
- **Equally suitable for star and delta power networks**

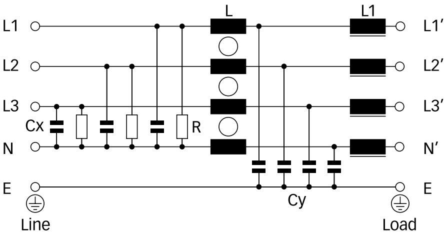
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 440/250VAC
Operating frequency:	dc to 60Hz
Rated currents:	4 to 25A @ 40°C
High potential test voltage:	P –> E 2000VAC for 2 sec
	P –> P 1900VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 40°C/400V (Mil-HB-217F):	500,000 hours

Typical electrical schematic



Features and benefits

- The FN 354 family of filters is intended primarily for applications that require extremely effective interference suppression across a broad frequency spectrum.
- Advanced two-stage filter circuits with highly saturating resistant toroidal inductors, in conjunction with feedthrough capacitors on each of the three phases and the neutral line, ensure that these filters provide very high attenuation in the upper frequency band.
- FN 354 are equally suitable for the operation on star and delta power networks.

Typical applications

- Applications requiring high-frequency attenuation
- Power supplies
- Medical equipment
- Office and data processing equipment

Filter selection table

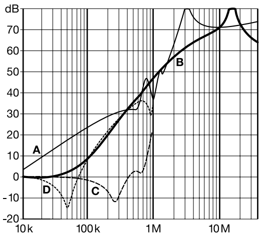
Filter	Rated current @ 40°C (25°C) [A]	Leakage current* @ 400VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections		Weight [kg]
FN 354-4-05	4 (4.5)	0.175	2.0	-05		0.23
FN 354-6-05	6 (6.7)	0.175	3.9	-05		0.38
FN 354-12-05	12 (13.4)	0.175	7.8	-05		1.1
FN 354-15-47	15 (16.8)	0.5	10.8		-47	4.7
FN 354-25-47	25 (28)	0.5	16.9		-47	4.7

* Maximum leakage under normal operating conditions, based on the assumption that all three phases and the neutral conductor are connected to the supply and the consumer. In this case, the current will mainly return through the neutral line, not as earth leakage.

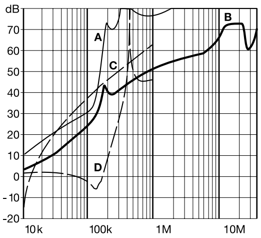
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

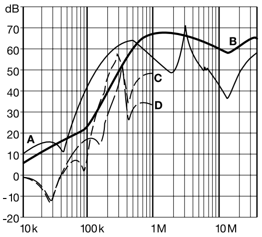
4 and 6A types



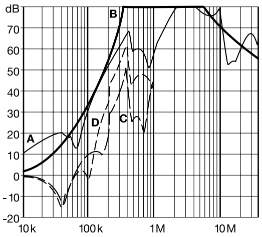
12A types



15A types

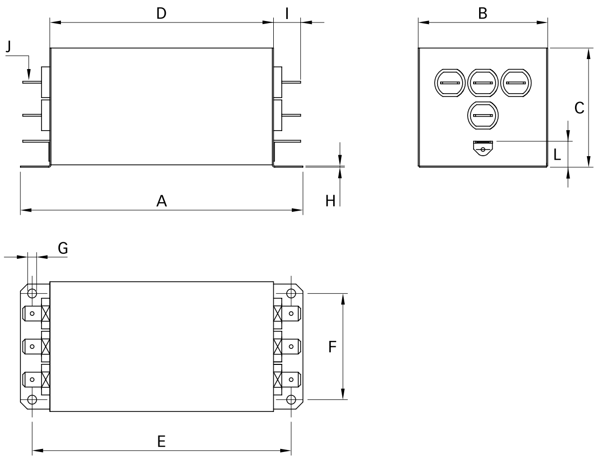


25A types

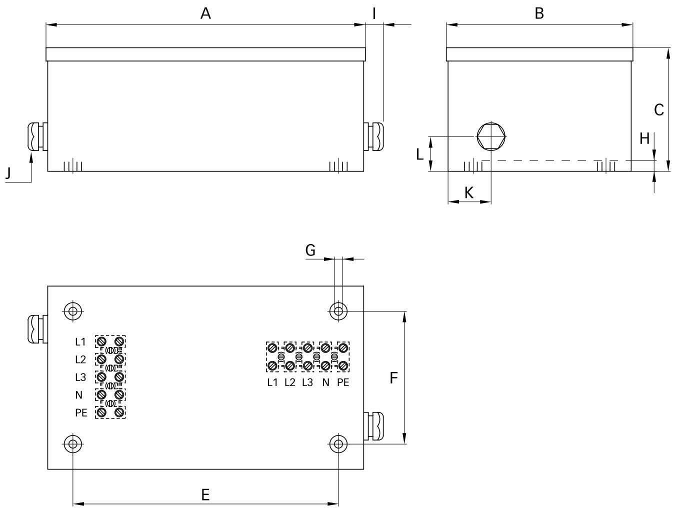


Mechanical data

4 to 12A types



15 and 25A types

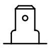
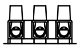


Dimensions

	4A	6A	12A	15A	25A
A	103	120	150	273.6	273.6
B	43	55	65	158.6	158.6
C	40.5	50.5	60	107	107
D	80	95	125		
E	95	110	140	230	230
F	35	45	55	115	115
G	Ø3.8	Ø3.8	7.5 x 4.4	M8	M8
H	0.5	0.5	0.75	9.5	9.5
I	11.1	11.1	11.1	~20	~20
J	Faston 6.3 x 0.8	Faston 6.3 x 0.8	Faston 6.3 x 0.8	PG13	PG13
K				35.5	35.5
L	7	11	11	30	30

All dimensionsin mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-05 	-47 
Solid wire	n/a	16mm²
Flex wire	n/a	10mm²
AWG type wire	n/a	AWG 8
Recommended torque	n/a	1.9 - 2.2Nm

Please visit www.schaffner.com to find more details on filter connectors.

Ultra-compact Three-phase and Neutral Line Filter with very Low Leakage Current

schaffner
energy efficiency and reliability

- **Ultra-compact four-wire filter for applications lacking space**
- **Exceptional low operating leakage current**
- **Equally suitable for star and delta power networks**

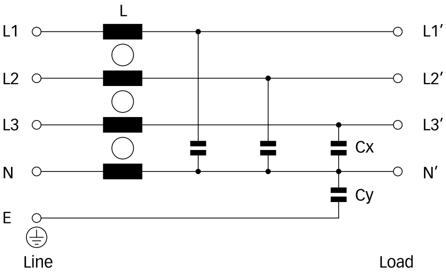
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 440/250VAC
Operating frequency:	dc to 400Hz
Rated currents:	3 to 20A @ 40°C
High potential test voltage:	P –> E 2000VAC for 2 sec
	P –> P 1900VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 40°C/400V (Mil-HB-217F):	850,000 hours

Typical electrical schematic



Features and benefits

- The FN 355 family of three-phase and neutral line filters provides a cost-effective interference suppression solution for a wide variety of applications.
- Available in four versions, with current ratings from 3 to 20A, the filters employ a single-stage four-wire LC circuit with saturating resistant chokes, and have a very low operational leakage current.
- FN 355 filters are contained within an extremely compact metal housing, making them ideal for use in situations where space is at a premium.

Typical applications

- Office equipment
- Medical equipment
- General purpose four-wire filtering
- Applications with tight space conditions

Filter selection table

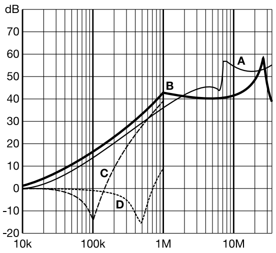
Filter	Rated current @ 40°C (25°C) [A]	Leakage current* @ 400VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections		Weight [kg]
FN 355-3-05	3 (3.4)	0.07	1.4		-05	0.25
FN 355-6-05	6 (6.9)	0.07	1.5		-05	0.25
FN 355-10-05	10 (11.5)	0.07	1.8		-05	0.25
FN 355-20-03	20 (23)	0.29	3.4	-03		0.29

* Maximum leakage under normal operating conditions, based on the assumption that all three phases and the neutral conductor are connected to the supply and the consumer. In this case, the current will mainly return through the neutral line, not as earth leakage.

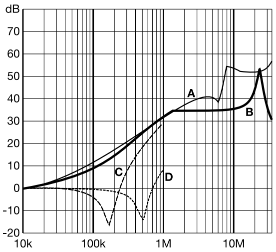
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

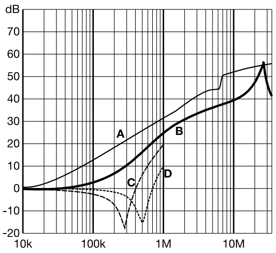
3A types



6A types

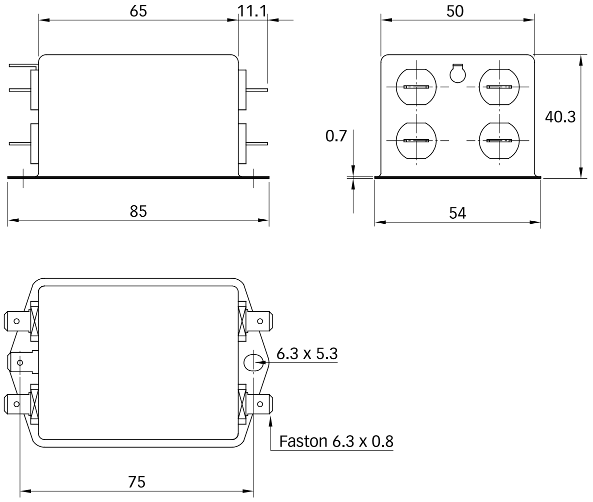


10 and 20A types

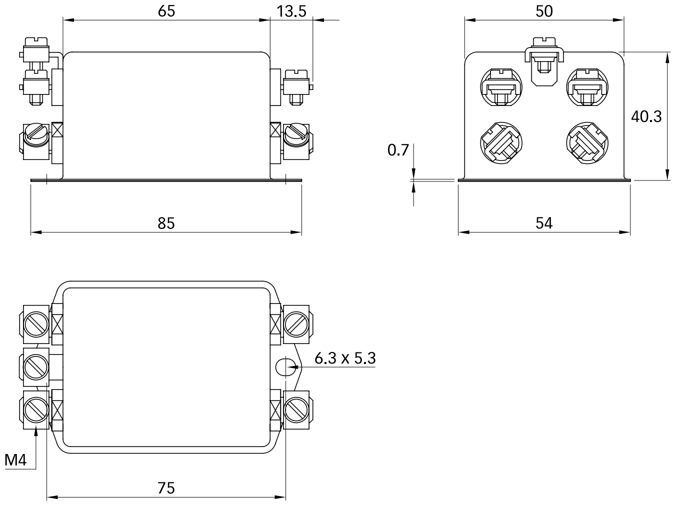


Mechanical data

Filters with faston terminals (3 to 10A types)



Filters with clamp terminals with M4 screw (20A types)



All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

3-phase + Neutral Line Filters
FN 356

General Purpose
Three-phase and Neutral Line Filter

energy efficiency and reliability

- **Three-phase and neutral line filter for general four-wire filtering tasks**
- **Choice of connection style**
- **Low operating leakage current**
- **Compliant with IEC 60950**
- **Suitable to meet EN 55011/14/22**

Approvals

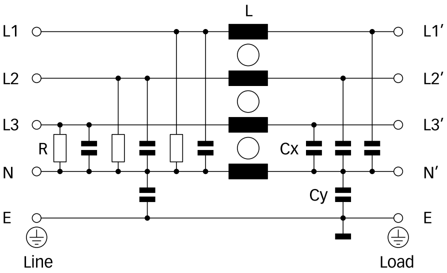
FN 356 up to 100A

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 440/250VAC
Operating frequency:	dc to 60Hz
Rated currents:	16 to 150A @ 40°C
High potential test voltage:	P –> E 2000VAC for 2 sec
	P –> P 1900VDC for 2 sec
Protection category:	IP20 (filters with connectors -29, -33, -34)
	IP00 (filters with connectors -06, -24, -28)
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 40°C/400V (Mil-HB-217F):	220,000 hours

Typical electrical schematic



Features and benefits

- FN 356 represents the industry standard filter solutions for EMC compliance on three-phases and the neutral conductor, providing high attenuation of both symmetrical and asymmetrical interference.
- Choice of connection style is offered for an application-specific filter selection.
- Solid touch-safe terminal blocks (-29, -33, -34 versions) offer a generous contacting cross section and contribute to overall safety (IP20).
- Used as a mains input filter, FN 356 filters increase the conducted immunity and thus contribute to system reliability.
- Design compliance with IEC 60950 provides additional application flexibility.

Typical applications

- General purpose four-wire filtering
- Mainframe computer systems
- High power office equipment
- UPS
- Installations comprising automation equipment

Filter selection table

Filter*	Rated current @ 40°C (25°C) [A]	Leakage current** @ 400VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections			Weight [kg]
FN 356-16-..	16 (18.4)	0.43	7.0	-06		-29	1.2
FN 356-25-..	25 (28.8)	0.43	10.1		-24	-33	1.5
FN 356-36-..	36 (41.5)	0.43	10.9		-24	-33	1.6
FN 356-50-..	50 (57.7)	0.43	15.8		-24	-33	2.3
FN 356-100-..	100 (115.0)	1.33	24.0		-28	-34	5.9
FN 356-150-28	150 (172.5)	8.00	45.9		-28		8.1

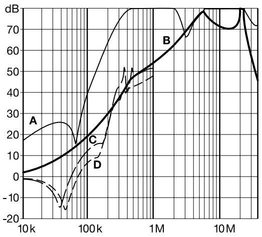
* To compile a complete part number, please replace the -.. with the required I/O connection style.

** Maximum leakage under normal operating conditions, based on the assumption that all three phases and the neutral conductor are connected to the supply and the consumer. In this case, the current will mainly return through the neutral line, not as earth leakage.

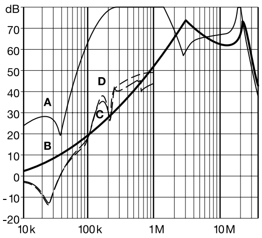
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

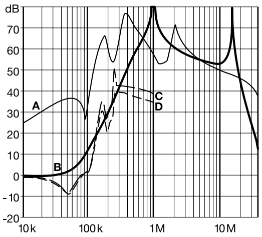
16A types



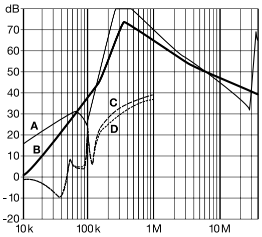
25 to 50A types



100A types

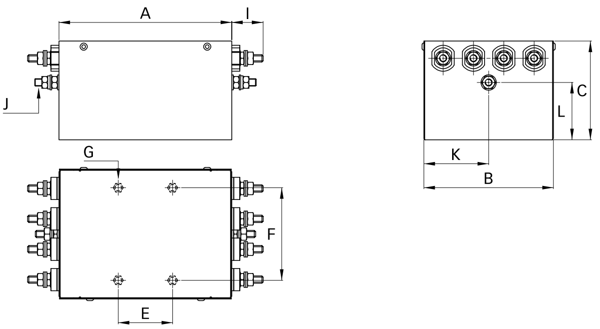


150A types

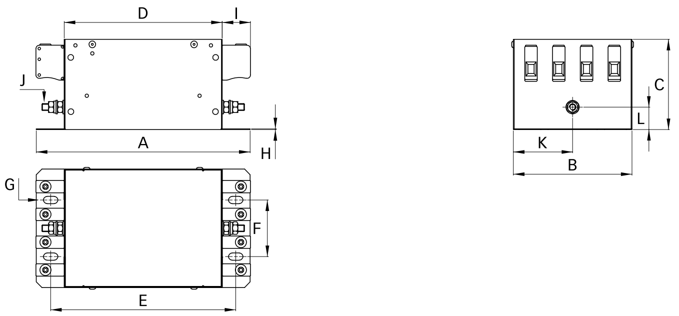


Mechanical data

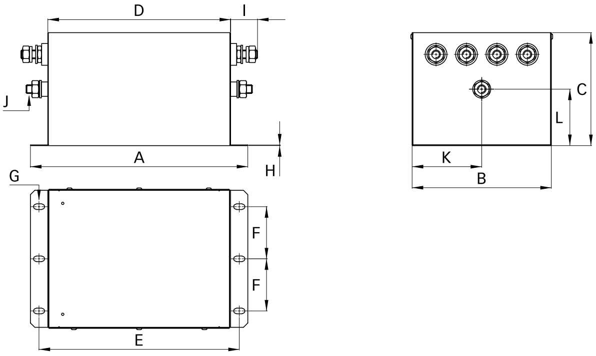
16 to 50A types (-06, -24)



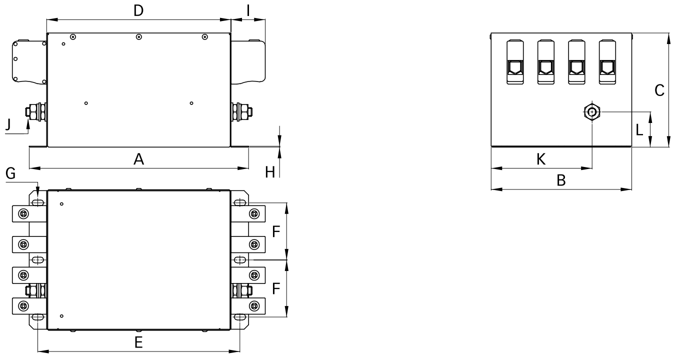
16 to 50A types (-29, -33)



100 and 150A types (-28)



100A type (-34)



Note: in favour of a better readability, connectors and earth studs are not shown in the horizontal projection.

Dimensions

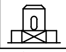
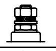
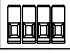
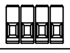
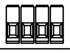
	16A (-06)	16A (-29)	25A (-24)	25A (-33)	36A (-24)	36A (-33)	50A (-24)	50A (-33)	100A (-28)	100A (-34)	150A
A	149	189.5	140	189.5	140	189.5	143.25	192	250	250	340
B*	104	105	105	105	105	105	122	122	160	160	160
C	50	80	80	80	80	80	102	102	130	130	130
D		140		140		140		142.5	210	210	300
E	44 ±0.3	165.5	44 ±0.3	165.5	44 ±0.3	165.5	44 ±0.3	168	230	230	320
F	75 ±0.3	80	75 ±0.3	50	75 ±0.3	50	75 ±0.3	98	60	65	60
G	M5 x 7	13 x 6.5	M5 x 7	13 x 6.5	M5 x 7	13 x 6.5	M5 x 7	13 x 6.5	13 x 6.5	13 x 6.5	13 x 6.5
H		0.7		0.7		0.7		0.7	1	1	1
I	11	10.9	25.4	25	25.4	25	25.4	25	34	39	34
J	6.3 x 0.8	M6	M6	M6	M6	M6	M6	M6	M10	M10	M10
K	52	82	52.5	52.5	52.5	52.5	61	61	80	116	80
L	22.5	25	46.5	20	46.5	20	68.5	35	65	40	65

* Rivets exceed this dimension by max. 1.3mm on each side.

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-06 (6.3 x 0.8mm) 	-24 (M6) 	-28 (M10) 	-29 	-33 	-34 
Solid wire	n/a	n/a	n/a	6mm²	16mm²	35mm²
Flex wire	n/a	n/a	n/a	4mm²	10mm²	25mm²
AWG type wire	n/a	n/a	n/a	AWG 10	AWG 6	AWG 2
Recommended torque	n/a	3.5 - 4.0Nm	15 - 17Nm	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm

Please visit www.schaffner.com to find more details on filter connectors.

3-phase + Neutral Line Filters
FN 3256

Compact Three-phase and Neutral Line Filter for Industrial Machinery/Equipment

schaffner
energy efficiency and reliability

- **Compact, space-saving design, optimized for industrial machinery**
- **Combines high attenuation performance with low leakage current**
- **Performance according to the machine tool standard EN 50370-1**
- **Increases also the immunity if operated directly on the mains input**

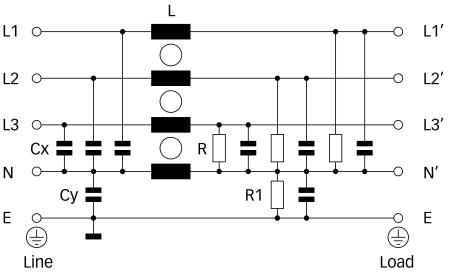
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC (480VAC +10% possible)
Operating frequency:	dc to 60Hz
Rated currents:	8 to 160A @ 50°C
High potential test voltage:	P –> E 3000VDC for 2 sec
	P –> P 2250VDC for 2 sec
Protection category:	IP20
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>410,000 hours

Typical electrical schematic



Features and benefits

- An extremely compact and light weight filter design with a „cubic“ shape, requiring minimum mounting space and thus taking the constructional conditions on the mains input of machinery into account.
- Simple and time-saving installation with good accessibility for automatic and hand tools.
- Solid, touch-safe terminal blocks offering sufficient contacting cross section according to the EN 60204-1 installation standard, which is very common in industrial applications.
- As a mains input filter for three phases and neutral line, FN 3256 ensures the compliance with the new product family standard for machine tools in mainly industrial environments EN 50370-1. Further, its use will also increase the conducted immunity of the entire installation significantly.
- FN 3256 provides the attenuation performance to meet the requirements of various machine tools with up to 8 driving axes with ~10m of motor cable each.
- For easy selection and application, the filter current ratings are aligned with common fuse values.

Typical applications

Mainly industrial equipment, machinery, machine tools and diverse process automation systems with three-phase and neutral electricity supply. Further, these filters are suitable for power supplies, high-power office equipment and further applications, where efficient interference suppression on three phases and the neutral line is required and where space is critical. Because of the very low leakage current, FN 3256 can even be used for some medical devices.

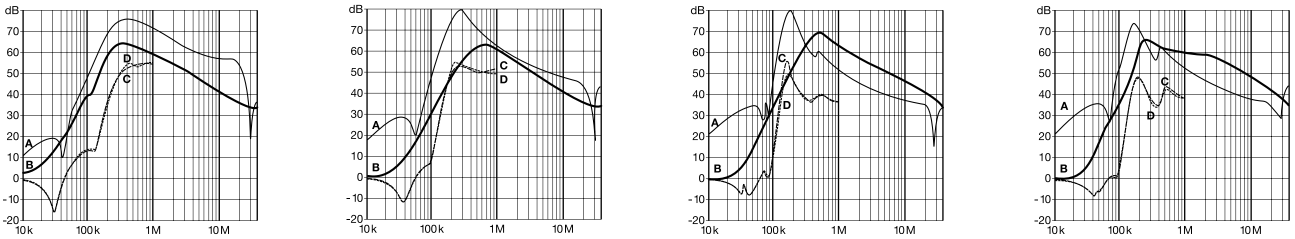
Filter selection table

Filter	Rated current @ 50°C (40°C) [A]	Leakage current* @ 480VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections	Weight [kg]
FN 3256H-8-29	8 (8.8)	<1	2.7	-29	0.6
FN 3256H-16-29	16 (17.5)	<1	5.0	-29	0.7
FN 3256H-25-33	25 (27)	<1	9.8	-33	1.1
FN 3256H-36-33	36 (39)	<1	11.3	-33	1.2
FN 3256H-64-34	64 (70)	<1	17.2	-34	2.3
FN 3256H-80-35	80 (88)	<1	14.5	-35	3.5
FN 3256H-120-35	120 (131)	<1	25.0	-35	4.7
FN 3256H-160-40	160 (175)	<1	26.9	-40	5.7

* Maximum leakage under normal operating conditions, based on the assumption that all three phases and the neutral conductor are connected to the supply and the consumer. In this case, the current will mainly return through the neutral line, not as earth leakage.

Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym



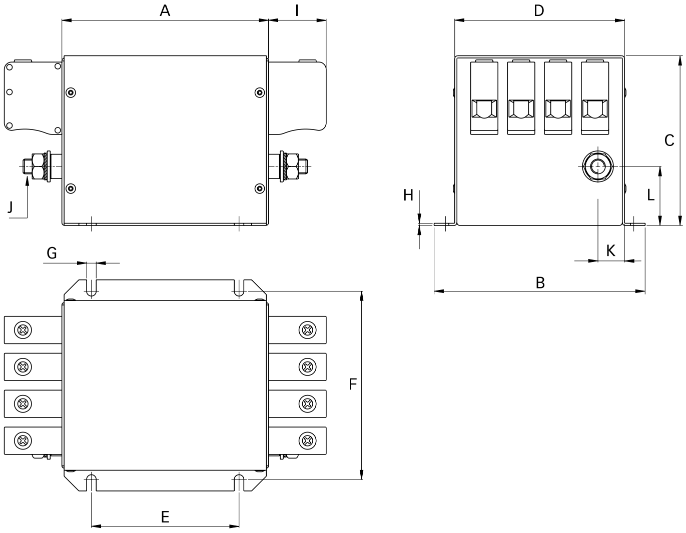
8 to 36A types

64 and 80A types

120A types

160A types

Mechanical data



Dimensions	8A	16A	25A	36A	64A	80A	120A	160A
A	110	110	130	130	140	170	210	200
B	110	110	118	118	143	163	170	190
C	70	70	85	85	115	125	125	130
D	82	82	90	90	115	135	140	160
E	70	70	90	90	100	120	160	150
F	94.5	94.5	102.5	102.5	127.5	147.5	153.5	173.5
G	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
H	1	1	1	1	1.5	1.5	1.5	1.5
I	10.9	10.9	25	25	39	45	45	51
J	M6	M6	M6	M6	M10	M10	M10	M10
K	12	12	12	12	18	18	17.5	16.5
L	33	33	40	40	40	35	44	55

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-29	-33	-34	-35	-40
Solid wire	6mm²	16mm²	35mm²	50mm²	95mm²
Flex wire	4mm²	10mm²	25mm²	50mm²	95mm²
AWG type wire	AWG 10	AWG 6	AWG 2	AWG 1/0	AWG 4/0
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm

Please visit www.schaffner.com to find more details on filter connectors.

3-phase + Neutral Line Filters
FN 3280

High-end Three-phase and Neutral Line Filter for Industrial Machinery/Equipment

energy efficiency and reliability

- **Now available up to 600A**
- **Compact, space-saving design, optimized for industrial equipment**
- **Combines exceptional attenuation with low leakage current**
- **Suitable for machines in mixed/domestic environments (Class A/B)**
- **Increases also the immunity if operated directly on the mains input**

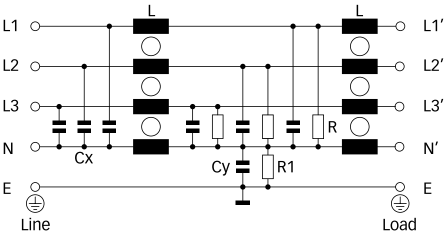
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 520/300VAC (480VAC + 10% possible)
Operating frequency:	dc to 60Hz
Rated currents:	8 to 600A @ 50°C
High potential test voltage:	P –> E 2750VDC for 2 sec
	P –> P 2250VDC for 2 sec
Protection category:	IP20 (8 to 200A types)
	IP00 (300 to 600A types)
Overload capability:	4x rated current at switch on,
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>360,000 hours

Typical electrical schematic



Features and benefits

- A compact and light weight filter design with a „cubic“ shape, requiring minimum mounting space and thus taking the constructional conditions on the mains input of machinery into account.
- Simple and time-saving installation with good accessibility for automatic and hand tools.
- Solid, touch-safe terminal blocks (8 to 200A types) offering sufficient contacting cross section according to the EN 60204-1 installation standard, which is very common in industrial applications.
- As a mains input filter for three phases and neutral line, FN 3280 provides enough performance to ensure EMC compliance of machinery in mixed (Class A) or even domestic (Class B) environments. Further, its use will also increase the immunity of the entire installation significantly.
- FN 3280 provides the attenuation performance needed to meet the requirements of various machine tools with up to 12 driving axes and ~10 to 20m of motor cable each.
- For easy selection and application, the filter current ratings are aligned with common fuse values.

Typical applications

Mainly industrial equipment, machinery, machine tools and diverse process automation systems with three-phase and neutral electricity supply. Due to the outstanding attenuation performance, FN 3280 is also the first choice for noisy power supplies, renewable energy applications, highpower office equipment and further three-phase and neutral devices. Because of the relatively low leakage current, FN 3280 may even be used for some medical devices.

Filter selection table

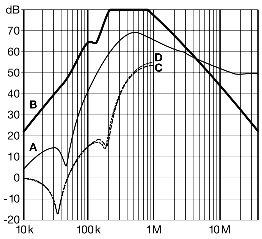
Filter	Rated current @ 50°C (40°C) [A]	Leakage current* @ 480VAC/50Hz [mA]	Power loss @ 25°C/50Hz [W]	Input/Output connections		Weight [kg]
FN 3280H-8-29	8 (8.8)	<1	2.7	-29		0.8
FN 3280H-16-29	16 (17.5)	<1	6.0	-29		0.8
FN 3280H-25-33	25 (27)	<1	11.6	-33		1.3
FN 3280H-36-33	36 (39)	<1	14.8	-33		1.6
FN 3280H-64-34	64 (70)	<1	18.4	-34		2.7
FN 3280H-80-35	80 (88)	<1	18.9	-35		4.1
FN 3280H-120-35	120 (131)	<1	28.5	-35		5.9
FN 3280H-160-40	160 (175)	<1	30.7	-40		7.9
FN 3280H-200-40	200 (219)	<1	46.8	-40		8.5
FN 3280H-300-99	300 (328)	<1	20.3		-99	10.0
FN 3280H-400-99	400 (438)	<1	36.0		-99	10.0
FN 3280H-600-99	600 (657)	<1	64.8		-99	11.0

* Maximum leakage under normal operating conditions, based on the assumption that all three phases and the neutral conductor are connected to the supply and the consumer. In this case, the current will mainly return through the neutral line, not as earth leakage.

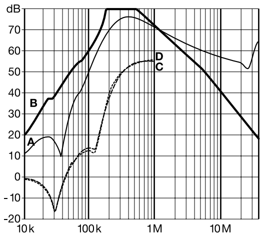
Typical filter attenuation

Per CISPR 17; A = 50Ω/50Ω sym; B = 50Ω/50Ω asym; C = 0.1Ω/100Ω sym; D = 100Ω/0.1Ω sym

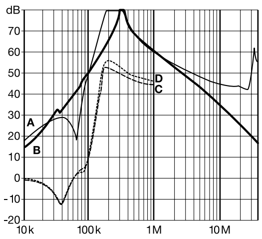
8 and 16A types



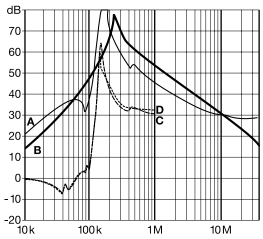
25 and 36A types



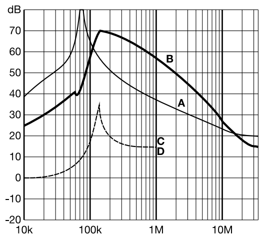
64 to 120A types



160 and 200A types

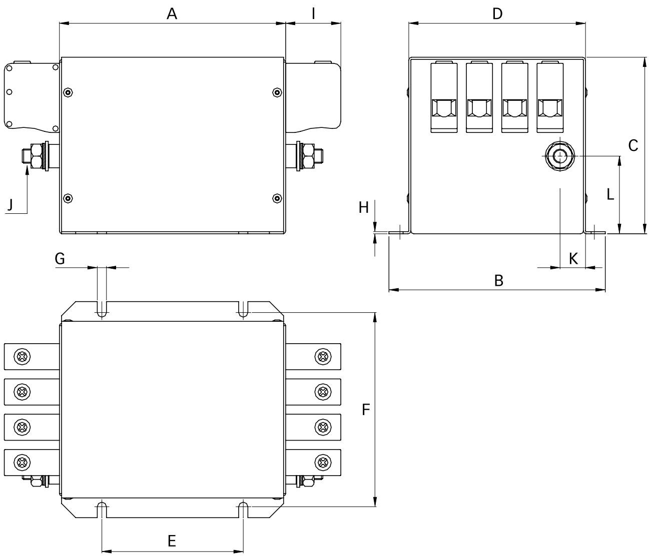


300 to 600A types

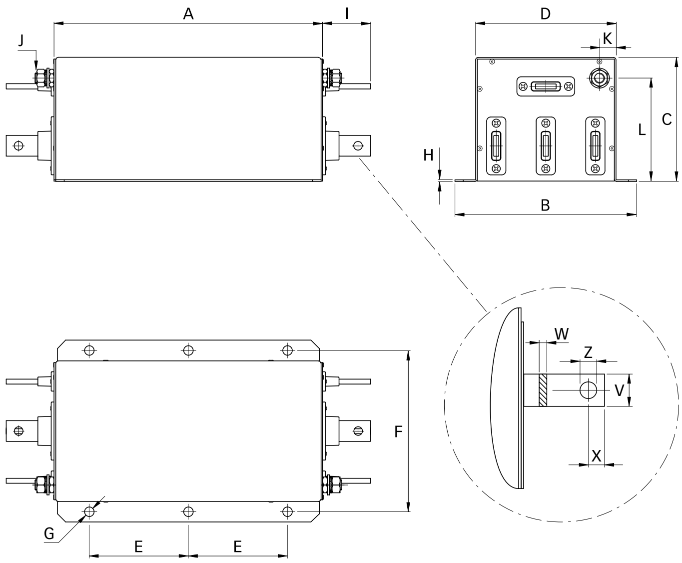


Mechanical data

8 to 200A types



300 to 600A types



Dimensions

	8A	16A	25A	36A	64A	80A	120A	160A	200A	300A	400A	600A
A	120	120	130	130	160	230	250	280	280	325	325	325
B	143	143	153	153	153	163	170	170	170	220	220	220
C	80	80	115	115	125	125	140	170	170	150	150	150
D	115	115	125	125	125	135	140	140	140	170	170	170
E	80	80	90	90	100	120	200	230	230	120	120	120
F	127.5	127.5	137.5	137.5	137.5	147.5	153.5	153.5	153.5	195	195	195
G	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	12	12	12
H	1	1	1	1	1.5	1.5	1.5	1.5	1.5	2	2	2
I	10.9	10.9	25	25	39	45	45	51	51	58	58	58
J	M6	M6	M6	M6	M10	M10	M10	M10	M10	M12	M12	M12
K	12	12	12	12	18	18	17.5	17.5	17.5	20	20	20
L	33	33	50	50	55	45	55	55	55	125	125	125
V										25	25	25
W										6	6	8
X										15	15	15
Z										Ø10.5	Ø10.5	Ø10.5

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

	-29	-33	-34	-35	-40
Solid wire	6mm²	16mm²	35mm²	50mm²	95mm²
Flex wire	4mm²	10mm²	25mm²	50mm²	95mm²
AWG type wire	AWG 10	AWG 6	AWG 2	AWG 1/0	AWG 4/0
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm	17 - 20Nm

Please visit www.schaffner.com to find more details on filter connectors.

Output Filters and Load Reactors

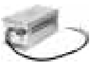
Output Filters and Load Reactors.

Output components for motor protection and the improvement of system reliability, availability and functionality. Deployed at the output side of frequency inverters, these filters ensure reliable operation by avoiding expensive downtimes of installations, manufacturing plants, machinery and a vast array of other industrial and domestic motor drive applications due to premature motor damage. An appropriate output solution will even allow the deployment of unshielded motor cables, the use of multiple motors in parallel on the same drive or the retrofit of modern drives in existing installations with old motors and unshielded cabling.

Approvals *

C UL US LISTED

C ® US

Filter family		**Max. voltage**	Typical motor power [kW] 0 60 120 180 240 300	Rated current [A] 0 200 400 600 800 >1000	**Features**											**Typ. applications**				
					dv/dt restriction	Overvoltage restriction	Motor temperature reduction	Red. acoustic motor noise	Sym. sinusoidal output signal	Asym. sinusoidal output signal	Eliminat. of bearing damage	Replaces cable shields	Connection to dc link required	Improves overall EMC	Reduces equipment downtime	Motor drives	Servo drives, torque motors	High-speed motor applications	Appl. with long unshield. cabl.	Retrofit of motor drives
FN 510 p. 67		520VAC	1.5 - 30	4 - 66	■	■	■							■	■	■	■			
FN 530 p. 70		520VAC	1.5 - 7.5	4 - 16	■	■	■	■	■	■	■	■	■	■	■	■			■	■
FN 5020 p. 73		500VAC	11 55	25 - 120	■	■	■	■	■					■	■	■		■		
FN 5030** p. 76		500VAC	11 55	25 - 120			■	■		■	■	■	■	■	■	■		■	■	■
FN 5040 p. 79		500VAC	1.1 630	4.5 1200	■	■	■	■	■					■	■	■				■
FN 5045 p. 79		500VAC	1.1 630	4.5 1200	■	■	■	■	■					■	■	■				■
RWK 305 p. 86		500VAC	1.5 630	4 1100	■		■							■	■	■	■			

* Products evaluated by one or more of the above certification agencies. For details please consult the detailed data sheet.

** Additional output filter module to be operated in conjunction with FN5020 or FN5040 / 45.

Output Filters
FN 510

Output Filter for Motor Drives

energy efficiency and reliability

- **Reduction of drive output voltage dv/dt**
- **Restriction of overvoltages on motor cables**
- **Reduction of motor temperature**
- **Increase of motor service life**
- **Improvement of system reliability**

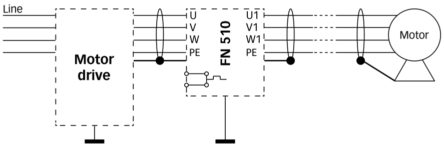
Design protected by international patent

RoHS

Technical specifications

Nominal operating voltage:	3x 500/288VAC
Motor frequency:	0 to 400Hz (4 to 24A)
	0 to 200Hz (33 to 66A)
Switching frequency:	2 to 16kHz
Rated currents:	4 to 66A @ 50°C
Motor cable length:	80m max. @ 16kHz
Voltage drop:	≤10V @ 50Hz
Typical dv/dt reduction:	Factor 8 to 12
Typical reduction of overvoltages:	≤1000V
High potential test voltage:	P –> E 2500VDC for 2 sec
	P –> P 1100VDC for 2 sec
Protection category:	IP20
Overload capability:	1.4x rated current for 1 minute, every 15 minutes
Temperature range (operation and storage):	-25°C to +70°C (25/070/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>100,000 hours

Typical block schematic



Features and benefits

- Efficient reduction of high output voltage dv/dt from IGBT motor drives (as per DIN VDE 0530).
- Restriction of overvoltages caused by line reflections on motor cables (as per DIN VDE 0530).
- Protection of motor coil insulation from premature aging and destruction.
- Significant increase of service life of electric motors.
- High reliability and production up time for mission critical applications.
- Less interference propagation towards neighboring equipment or lines.
- Output filter with low impedance, ideal for processes requiring exceptional precision and reproducibility of movements.
- IP20 housing and touch-safe terminal blocks contribute to overall equipment safety.
- Temperature monitoring and internal fan cooling protect the filter from thermal overload.

Typical applications

- Servo drives
- Close loop vector drives
- Motor drive applications with short to medium motor cable length
- Machinery comprising servo or torque motors
- Robots
- Pick and place machines
- Applications where sine wave filters are not applicable

Filter selection table

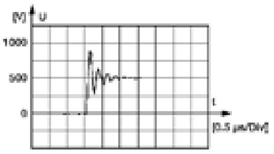
Filter	Rated current @ 50°C [A]	Typical motor power rating* [kW]	Typical power loss** [W]	Input/Output connections	Weight [kg]
FN 510-4-29	4	1.5	90	-29	2.1
FN 510-8-29	8	3.7	90	-29	2.1
FN 510-12-29	12	5.5	90	-29	4
FN 510-16-29	16	7.5	90	-29	4.8
FN 510-24-33	24	11	100	-33	7.7
FN 510-33-33	33	15	110	-33	10
FN 510-50-34	50	22	130	-34	21
FN 510-66-34	66	30	150	-34	22

* General purpose four-pole (1500r/min) AC induction motor rated 400V/50Hz.

** Power loss at 16kHz switching frequency/80m motor cable length. Exact value depends upon the motor cable type and length, switching frequency and further stray parameters within the system.

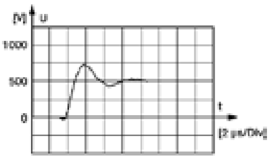
Typical measurement results

dv/dt without FN 510



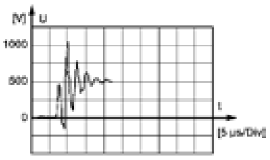
$(dv/dt)_{max}$ = 11kV/µs

dv/dt with FN 510



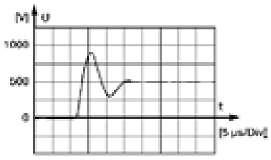
$(dv/dt)_{max}$ = 480V/µs

Overvoltages without FN 510



Over shoot 106%

Overvoltages with FN 510



Over shoot 72%

dv/dt reduction: maximum dv/dt at the motor terminals, measured with the motor drive operating at 14kHz switching frequency, 5m of shielded cable, motor with 100% load.

Overvoltage limitation: maximum overvoltages at the motor terminals, measured with the motor drive operating at 14kHz switching frequency, 80m of shielded cable, motor idling.

Typical application range at different operating conditions

The power loss in the filter depends mainly on the switching frequency (fs) of the motor drive and the length of the motor cable.
FN 510 have been designed for an ambient temperature of 50°C. Other conditions can, however, occur in practice. In such cases, care must be taken to limit the maximum cable length and/or the switching frequency of the motor drive, depending on the real ambient temperature conditions.

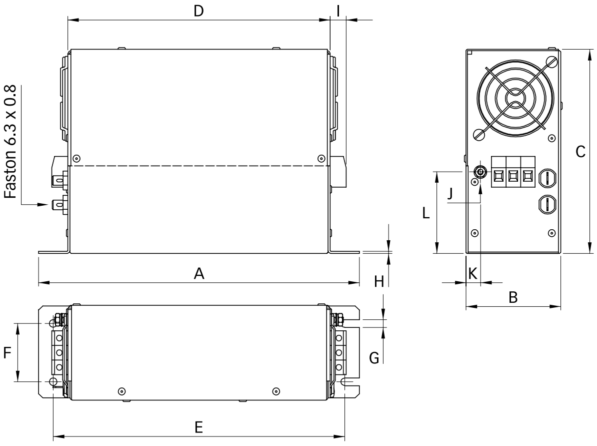
	Tamb.	Max. fs	Max. cable
FN 510 are designed for:	50°C	10kHz	80m
Possible application, e.g.:	50°C	16kHz	50m
	40°C	16kHz	80m

Temperature monitoring function

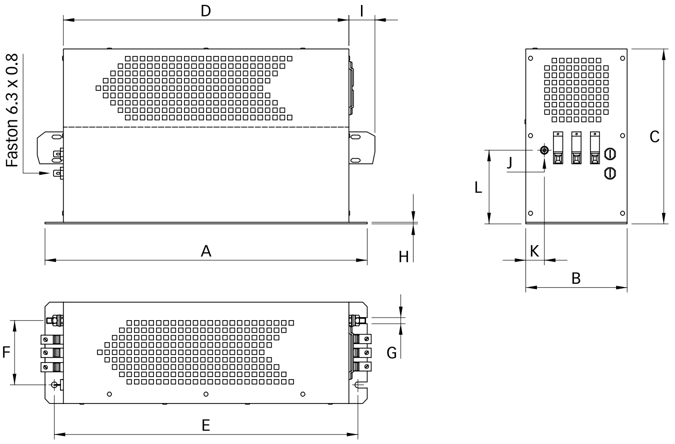
The temperature monitoring device opens a potential-free contact in the case of filter overtemperature (>120°C). The maximum switching capability is 5A/240V. The switch can be used, for example, in the input of a CNC controller or as the trip of a circuit breaker in order to interrupt the mains power supply.

Mechanical data

4 to 16A types



24 to 66A types



Dimensions

	4A	8A	12A	16A	24A	33A	50A	66A
A	220	220	260	260	350	350	470	470
B	65	65	85	85	110	110	140	140
C	140	140	160	160	190	190	235	235
D	180	180	220	220	310	310	420	420
E	200	200	240	240	330	330	440	440
F	40	40	60	60	70	70	100	100
G	5.3	5.3	6.5	6.5	6.5	6.5	8.3	8.3
H	1.5	1.5	1.5	1.5	2	2	5	5
I	10.9	10.9	10.9	10.9	25	25	39	39
J	M4	M4	M4	M4	M6	M6	M8	M8
K	10	10	12.5	12.5	20	20	20	20
L	56	56	65	65	80	80	125	125

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input/output connector cross sections

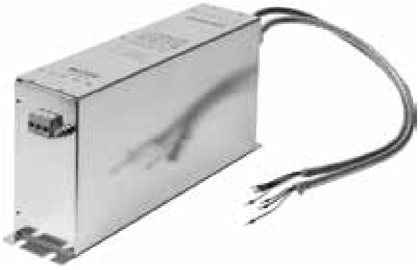
	-29	-33	-34
Solid wire	6mm²	16mm²	35mm²
Flex wire	4mm²	10mm²	25mm²
AWG type wire	AWG 10	AWG 6	AWG 2
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm

Please visit www.schaffner.com to find more details on filter connectors.

For additional information please ask for FN 510 installation instructions and the Schaffner application note „Output Filters for Use with Frequency Inverters in Motor Drive Applications“.

Sine Wave and EMC Output Filter for Motor Drives with a Voltage dc Link

energy efficiency and reliability



- **Smoothing of PWM drive output voltage**
- **Efficient motor protection**
- **Reduction of common-mode interferences on motor cables**
- **Improvement of EMC environment**
- **Elimination of motor bearing damages**
- **Possibility to use very long unshielded motor cables**
- **Improvement of system reliability**

Design protected by international patent

RoHS

Technical specifications

Nominal operating voltage:	3x 500/288VAC
dc link voltage:	850VDC max.
Motor frequency:	0 to 200Hz
Switching frequency:	6 to 20kHz
Rated currents:	4 to 16A @ 40°C
Motor cable length:	1000m max.
Voltage drop:	≤10V @ 50Hz
Current in +/- control loop:	1 to 2A approx.
Residual ripple voltage:	<5%
High potential test voltage:	P –> E 2500VDC for 2 sec
	P –> P 1100VDC for 2 sec
Protection category:	IP20
Overload capability:	1.4x rated current for 1 minute, every 15 minutes
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 40°C/400V (Mil-HB-217F):	>100,000 hours

Features and benefits

- Conversion of the PWM output signal (differential and common-mode voltage components) of motor drives into a smooth sine wave with low residual ripple.
- Elimination of premature motor damage caused by high dv/dt, overvoltages, motor overheating, eddy current losses or bearing damage.
- Elimination of interference propagation towards components or conductors in the vicinity.
- Provision of all benefits of traditional LC sine wave filters, plus:
- Allows the use of extremely long unshielded motor cables without causing radiation problems (EN 55014, MDS clamp).
- Restricts pulse currents to ground and hence limits leakage currents in the PE.
- Reduces the required EMI suppresssion efforts on the line side.
- Allows the use of lower rated drives with long motor cables due to lower losses in the IGBTs and in the motor cable.

Typical applications

- Motor drive applications with extremely long motor cables
- Motor drive applications with unshielded motor cables
- Chemical and petro-chemical applications
- Semi-conductor manufacturing
- Mission critical applications
- Applications with multiple motors in parallel
- Retrofit of motor drives into existing installations with old wiring and motors

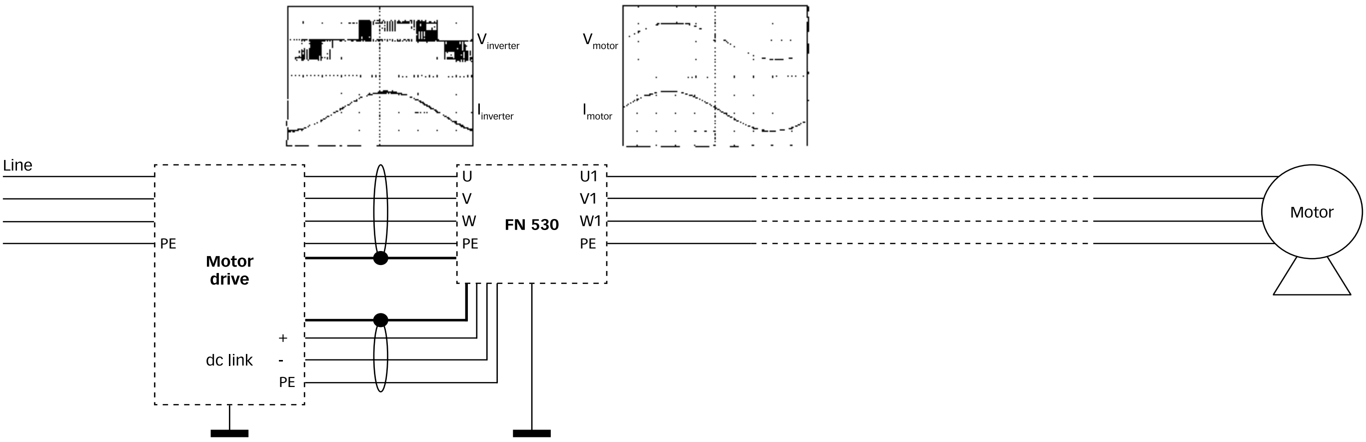
Filter selection table

Filter	Rated current @ 40°C [A]	Typical motor power rating* [kW]	Typical power loss** [W]	Input connections	Output connections	Weight [kg]
FN 530-4-99	4	1.5	15	-29	-99	11.5
FN 530-8-99	8	3.0	33	-29	-99	15
FN 530-12-99	12	5.5	50	-29	-99	18.5
FN 530-16-99	16	7.5	37	-33	-99	21

* General purpose four-pole (1500r/min) AC induction motor rated 400V/50Hz.

** Exact value depends upon the motor cable type and length, switching frequency, motor frequency and further stray parameters within the system.

Typical block schematic



Connection to the dc link

For best results, the connection to the dc link of the motor drive is required with this series of filters.

If only one connection to the dc link is brought out of the drive («+» or «-») then the dc link cable connections from the filter (identified by «DC+» and «DC-» must be connected together to the «+» or «-» motor drive connection.

The operation of the sine wave interference filter is not seriously affected as a result.

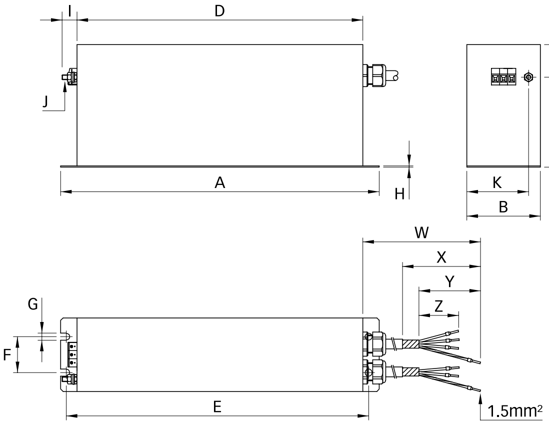
The «+» and «-» connections on the motor drive must never be connected together. Otherwise a short-circuit will result.

The PWM switching frequency must lie within the range from 6 to 20kHz in order to ensure satisfactory operation of the filter. A lower switching frequency or a pure square wave is unsuitable and will result in the motor drive switching off with the error message «overcurrent or short to earth.»

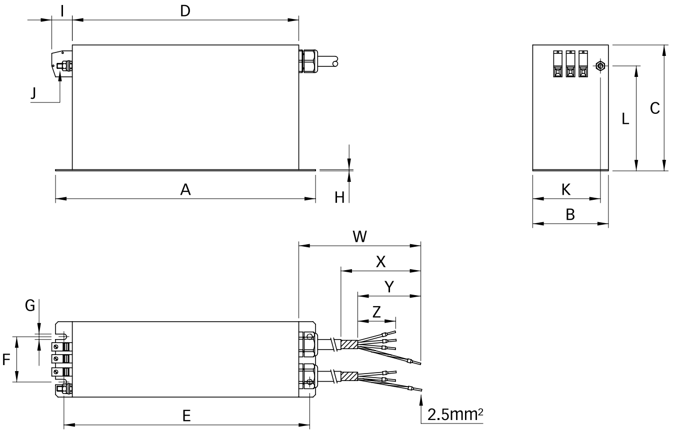
For additional information please ask for FN 530 installation instructions and the Schaffner application note „Output Filters for Use with Frequency Inverters in Motor Drive Applications“.

Mechanical data

4 to 12A types



16A types

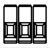
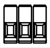


Dimensions

	4A	8A	12A	16A
A	390	390	390	350
B	90	90	90	140
C	150	180	215	230
D	350	350	350	310
E	373	370	370	330
F	44	44	44	95
G	6.5	8.7	8.7	8.7
H	1.5	1.5	1.5	2.3
I	19	19	19	25
J	M6	M6	M6	M6
K	75	75	75	107.5
L	107	137	172	181
W	720 +15/-0	720 +15/-0	720 +15/-0	720 +15/-0
X	120	120	120	120
Y	100	100	100	100
Z	70	70	70	70

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter input connector cross sections

	-29 	-33 
Solid wire	6mm²	16mm²
Flex wire	4mm²	10mm²
AWG type wire	AWG 10	AWG 6
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm

Please visit www.schaffner.com to find more details on filter connectors.

Output Filters
FN 5020

Sine Wave Output Filter for High-speed Motor Drives

schaffner
energy efficiency and reliability

- **Smoothing of PMW drive output voltage**
- **Suitable for motor frequencies up to 600Hz**
- **Increased service life of expensive high-speed motors**
- **Reduction of audible motor noise**
- **Improvement of system reliability**
- **Production up time for mission critical applications**

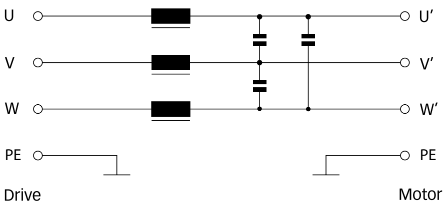
Approvals

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 500/288VAC
dc link voltage:	1000VDC max.
Motor frequency:	0 to 600Hz
Switching frequency:	6 to 15kHz
Rated currents:	25 to 120A @ 50°C
Motor cable length:	200m max.
Residual ripple voltage:	<5%
High potential test voltage:	P –> E 2000VAC for 2 sec
	P –> P 1000VDC for 2 sec
Protection category:	IP20
Overload capability:	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>100,000 hours
Lifetime (calculated):	> 10 years (25, 55A)
	~ 5 years (75, 120A)

Typical electrical schematic



Features and benefits

- Suitable for fast rotating fields up to 600Hz.
- Conversion of the PWM output signal (symmetrical voltage components) of motor drives into a smooth sine wave with low residual ripple.
- Elimination of premature motor damage caused by high dv/dt, overvoltages, motor overheating and eddy current losses.
- Significantly increased service life of expensive (high-speed) motors.
- Reduction of the pulse load of motor drive IGBTs and the parasitic losses on long shielded motor cables.
- Less interference propagation towards neighboring equipment or lines.
- Advanced choke design to minimize filter losses and voltage drop.
- IP20 protection, touch-safe terminals and temperature monitoring function to increase overall equipment safety.

Typical applications

Motor drives and motors in high-speed applications, like:

- High-speed spindles
- Textile machinery
- Lasers
- Military appliances (400Hz)

Motor drive applications with medium to long motor cables and/or with multiple motors in parallel, like:

- Pumps
- Conveyors

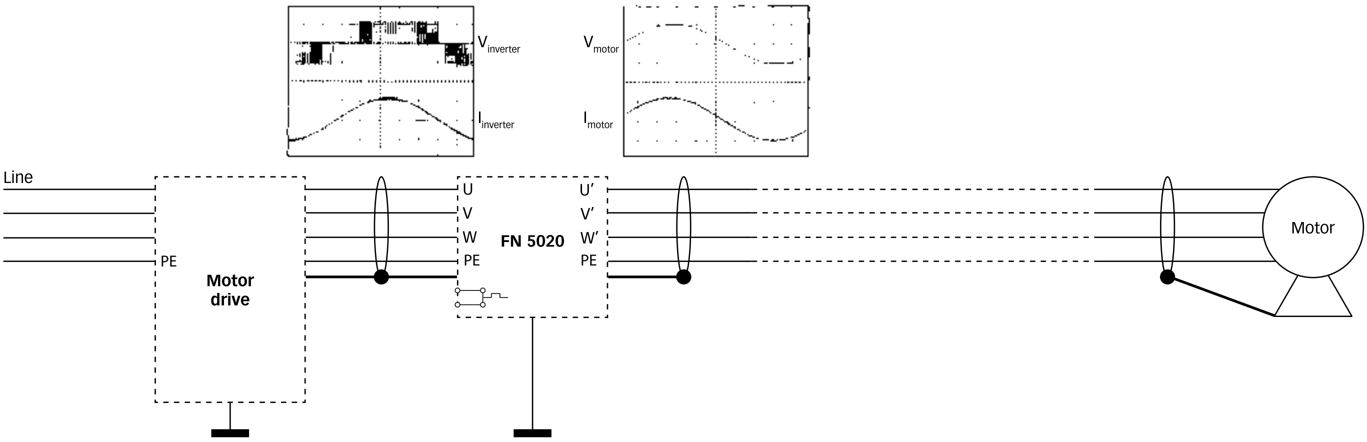
Filter selection table

Filter	Rated current @ 50°C [A]	Typical motor power rating* [kW]	Typical power loss** [W]	Output connections	Weight [kg]
FN 5020-25-33	25	15	n.a.	-33	13
FN 5020-55-34	55	30	n.a.	-34	29
FN 5020-75-35	75	45	n.a.	-35	49
FN 5020-120-35	120	75	n.a.	-35	57

* General purpose four-pole (1500r/min) AC induction motor rated 480V/50Hz.

** Exact value highly depends upon the motor cable type and length, switching frequency, motor frequency and further stray parameters within the system. Please contact your local Schaffner partner for individual application support.

Typical block schematic



Temperature monitoring function

All filters of this range are equipped with a temperature monitoring function. The built-in temperature sensor opens a potential-free contact in the case of filter overtemperature (>120°C). The maximum switching capability is 6A/250V. This function can be used, for example, in the input of a CNC controller or as the trip of a circuit breaker in order to interrupt the mains power supply. Connections are located next to the phase connectors (see mechanical data for details).

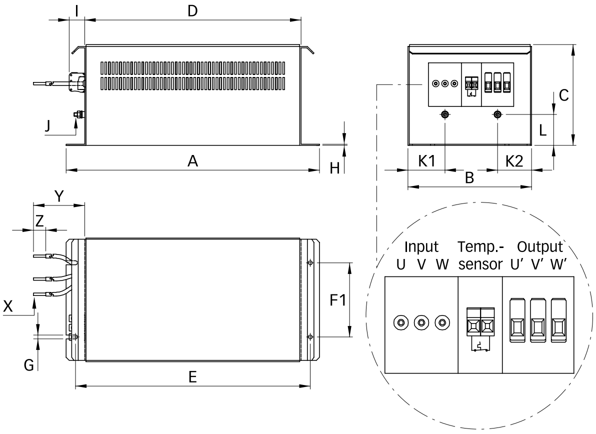
Forced cooling

The 75A and 120A filters provide internal cooling fans which require external power supply (24VDC/~4W). Connections are located next to the connectors of the temperature sensor (see mechanical data for details).

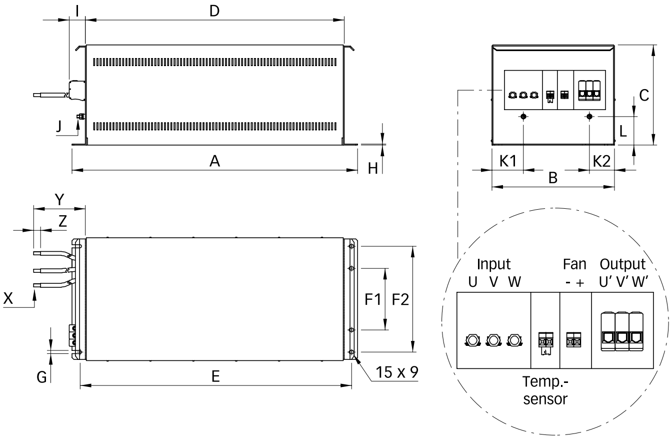
For additional information please consult the Schaffner application note „Sinus Plus – New Output Filter Concept for Power Drive Systems“.

Mechanical data

25 and 55A types



75 and 120A types



Dimensions

	25A	55A	75A	120A
A	410	554	799	799
B	200	250	343	343
C	163	203	280	280
D	350	500	725	725
E	380	524	760	760
F1	120	170	172	172
F2			296	296
G	6.5	9	9	9
H	2	3	3	3
I	25	39	45	45
J	M6	M6	M8	M8
K1	60	70	88	88
K2	55	55	70	70
L	50	69	80	80
X	AWG 10	AWG 6	25mm^2	35mm^2
Y	1000 +20/-0	1000 +20/-0	1000 +20/-0	1000 +20/-0
Z	20	20	20	20

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

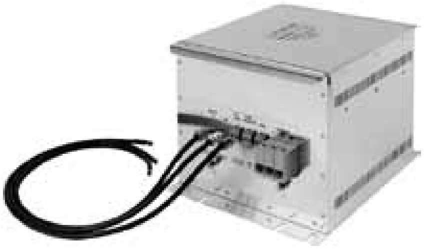
Filter output connector cross sections

	-29	-33	-34	-35
Solid wire	6mm^2	16mm^2	35mm^2	50mm^2
Flex wire	4mm^2	10mm^2	25mm^2	50mm^2
AWG type wire	AWG 10	AWG 6	AWG 2	AWG 1/0
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm

Please visit www.schaffner.com to find more details on filter connectors.

Add-on Sine Wave Output Filter Module for Common-mode Voltage Improvement

schaffner
energy efficiency and reliability



- **Additional module for use with FN5040 / 45 or FN 5020 sine wave filters only**
- **For motor frequencies up to 600Hz**
- **Reduction of common-mode interferences on motor cables**
- **Improvement of EMC environment**
- **Elimination of motor bearing damages**
- **Possibility to use very long unshielded motor cables**
- **Improvement of system reliability**

Design protected by international patent

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 500/288VAC
dc link voltage:	1000VDC max.
Motor frequency:	0 to 600Hz
Switching frequency:	6 to 15kHz
Rated currents:	25 to 120A @ 50°C
Motor cable length:	1000m max. (in combination with FN 5020 only)
High potential test voltage:	P –> E 2000VAC for 2 sec
	P –> P 1100VDC for 2 sec
Protection category:	IP20
Overload capability:	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 1283, CSA 22.2 No. 8 1986, IEC/EN 60939
MTBF @ 50°C/400V (Mil-HB-217F):	>100,000 hours
Lifetime (calculated):	> 10 years (25, 55A)
	~ 5 years (75, 120A)

Features and benefits

- Add-on output filter module for the use with FN5040 / 45 or FN 5020 sine wave output filters from Schaffner.
- Elimination of premature motor failure caused by bearing damage.
- Eliminates interference propagation towards components or conductors in the vicinity.
- Restricts pulse currents to ground and hence limits leakage currents in the PE.
- Allows the use of extremely long unshielded motor cables without causing radiation problems (EN 55014, MDS clamp).
- Reduces the required EMI suppression efforts on the line side.
- Allows the use of lower rated drives with long motor cables due to lower losses in the IGBTs and in the motor cable.
- Suitable for rotating fields up to 600Hz.

Typical applications

- Motor drive applications with extremely long motor cables
- Motor drive applications with unshielded motor cables
- Motor drives and motors in high-speed applications
- Mission critical applications
- Applications with multiple parallel motors
- Retrofit of motor drives into existing installations with old wiring and motors

Important note

FN 5030 are additional common-mode modules. They can NOT work alone! FN 5030 have to be operated downstream of a regular (symmetrical) sine wave output filter. Possible combinations are FN 5020/FN 5030 for motor frequencies up to 600Hz, or FN 5040/45/FN 5030 for max. 70Hz. For additional information please consult the Schaffner application note „Sinus Plus – New Output Filter Concept for Power Drive Systems“.

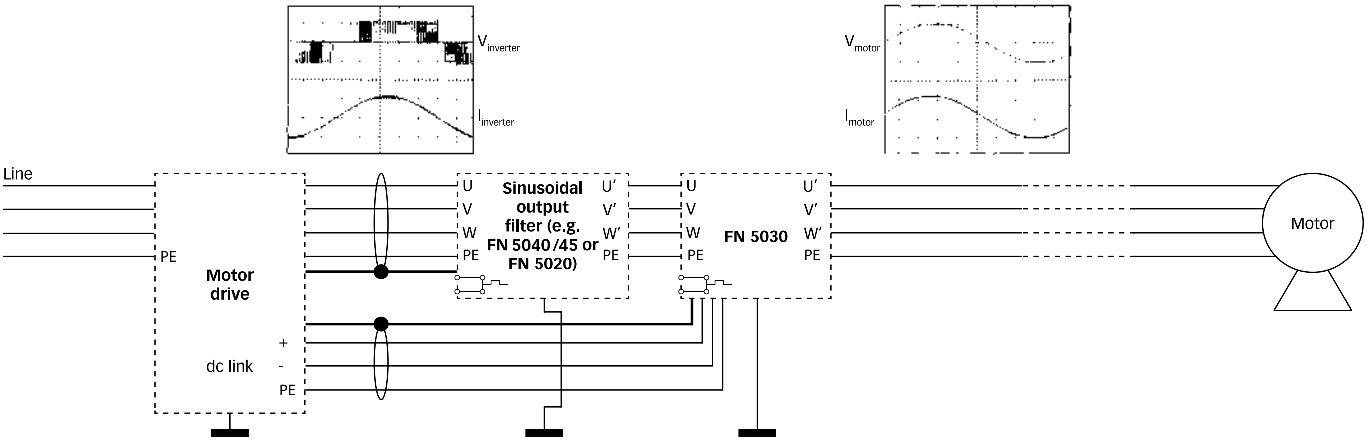
Filter selection table

Filter	Rated current @ 50°C [A]	Typical motor power rating* [kW]	Typical power loss** [W]	Output connections	Weight [kg]
FN 5030-25-33	25	15	n.a.	-33	13
FN 5030-55-34	55	30	n.a.	-34	14
FN 5030-75-35	75	45	n.a.	-35	27
FN 5030-120-35	120	75	n.a.	-35	40

* General purpose four-pole (1500r/min) AC induction motor rated 480V/50Hz.

** Exact value highly depends upon the motor cable type and length, switching frequency, motor frequency and further stray parameters within the system. Please contact your local Schaffner partner for individual application support.

Typical block schematic



Temperature monitoring function

All filters of this range are equipped with a temperature monitoring function. The built-in temperature sensor opens a potential-free contact in the case of filter overtemperature (>120°C). The maximum switching capability is 6A/250V. This function can be used, for example, in the input of a CNC controller or as the trip of a circuit breaker in order to interrupt the mains power supply. Connections are located next to the phase connectors (see mechanical data for details).

Forced cooling

The 75A and 120A filters provide internal cooling fans which require external power supply (24VDC/~4W). Connections are located next to the connectors of the temperature sensor (see mechanical data for details).

Connection to the dc link

For best results, the connection to the dc link of the motor drive is required with this series of filters.

If only one connection to the dc link is brought out of the drive («+» or «-») then the dc link cable connections from the filter (identified by «DC+» and «DC-» must be connected together to the «+» or «-» motor drive connection.

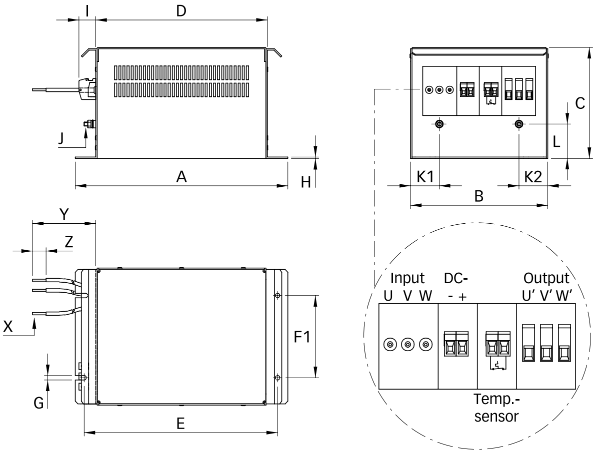
The operation of the add-on sine wave output filter is not seriously affected as a result.

The «+» and «-» connections on the motor drive must never be connected together. Otherwise a short-circuit will result.

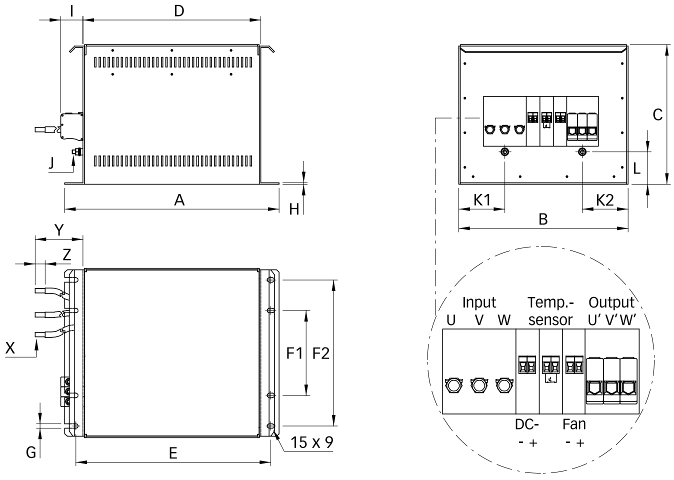
The PWM switching frequency must lie within the range from 6 to 15kHz in order to ensure satisfactory operation of the filter. A lower switching frequency or a pure square wave is unsuitable and will result in the motor drive switching off with the error message «overcurrent» or «short to earth».

Mechanical data

25 and 55A types



75 and 120A types



Dimensions

	25A	55A	75A	120A
A	310	354	434	434
B	200	250	343	343
C	162	200	283	283
D	246	300	360	360
E	280	324	395	395
F1	120	170	172	172
F2			296	296
G	6.5	9	9	9
H	2	3	3	3
I	25	39	45	45
J	M6	M6	M8	M8
K1	42	70	93	93
K2	42	55	93	93
L	50	66	66	66
X	AWG 10	AWG 6	25mm^2	35mm^2
Y	1000 +20/-0	1000 +20/-0	1000 +20/-0	1000 +20/-0
Z	20	20	20	20

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Filter output connector cross sections

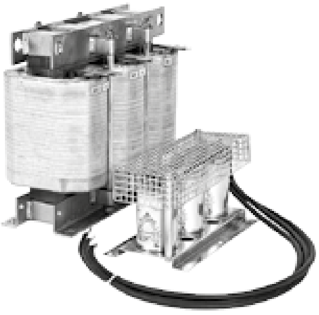
	-29	-33	-34	-35
Solid wire	6mm^2	16mm^2	35mm^2	50mm^2
Flex wire	4mm^2	10mm^2	25mm^2	50mm^2
AWG type wire	AWG 10	AWG 6	AWG 2	AWG 1/0
Recommended torque	0.6 - 0.8Nm	1.5 - 1.8Nm	4.0 - 4.5Nm	7 - 8Nm

Please visit www.schaffner.com to find more details on filter connectors.

Output Filters
FN 5040 / FN 5045

LC Sine Wave Filter for Motor Drives

energy efficiency and reliability



- **Smooth sine wave without voltage peaks**
- **Perfect motor protection**
- **Reduce bearing currents**
- **Motor frequency up to 200Hz**
- **Extended motor cable lenght capability**

Approvals

c UL US LISTED

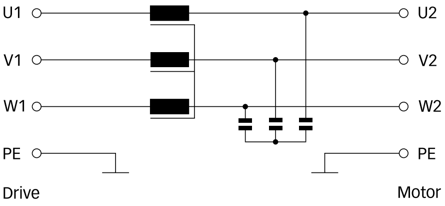
(in preparation)

RoHS

Technical specifications

Nominal operating voltage:	3x 500VAC ±10%
Motor frequency:	0 to 70Hz (up to 200Hz with derating (see graph))
Switching frequency:	See filter selection table
Rated currents:	4.5 to 1200A @ 45°C
Motor cable length:	Up to 2,000m (see graph)
Impedance (uk):	8 to 10% @ 400V, 50Hz and rated current
Residual ripple voltage:	<5%
High potential test voltage:	P –> E 3000VAC, 1 minute
	P –> P 2500VAC, 1 minute
Protection category:	IP00 (FN 5040)
	IP20 (FN 5045)
Overload capability:	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +70°C (25/070/21)
Acoustic noise level:	<70dB(A) @ 1m
Insulation class:	EIS 200
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	IEC 61558-2-20
Environmental reliability:	IEC 60068-2-1
MTBF:	>100,000 hours
Approvals:	UL 508 pending
Declaration of conformity:	CE / LVD

Typical electrical schematic



Features and benefits

- Converts the rectangular PWM output voltage of motor drives into a smooth sine wave with low residual ripple.
- Elimination of premature motor damage caused by high dv/dt, overvoltages, cable ringing, motor overheating, and eddy current losses.
- Improves bearing life time because of bearing currents caused by circulating currents.
- Complies with IEC 60034-17* and NEMA-MG1 requirements for general purpose motors.
- Optional with NEMA 1 protective cover.

Typical applications

- HVAC applications
- Pumps
- Ventilators
- Conveyors
- Compressors
- Elevators
- Cranes
- Medium voltage applications, deployed in front of the step-up transformer
- Retrofit installations with motor drives
- Motor drive with long motor cable
- Motor drive with multiple motors in parallel

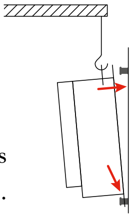
Filter selection table

Filter	Rated current @ 45ºC/50Hz [A]	Rated current @ 45°C/100Hz [A]	Typical motor drive rating [kW]	Nominal inductance [mH]	Nominal capacitance [µF]	Capacitance connection	Min. switching frequency [kHz]	Typical power loss [W]	Input/Output connections		Weight [kg]
FN 5040-4.5-82	4.5	4.05	1.1/1.5	13	2.2	Y	4	65	-82		3.3
FN 5040-8-82	8	7.2	2.2/3	6.9	4.7	Y	4	80	-82		4.6
FN 5040-10-83	10	9	4	5.2	6.8	Y	4	90	-83		6.1
FN 5040-17-83	17	15.3	5.5/7.5	3.1	10	Y	4	115	-83		7.8
FN 5040-24-84	24	21.6	11	2.4	10	Y	4	150	-84		14.4
FN 5040-38-84	38	34.2	15/18.5	1.6	10	Y	4	170	-84		25.0
FN 5040-48-85	48	43.2	22	1.1	14.7	Y	4	260	-85		33.0
FN 5040-62-85	62	55.8	30	0.85	30	Y	3	280	-85		36.0
FN 5040-75-87	75	67.5	37	0.75	30	Y	3	330	-87		42.0
FN 5040-115-87	115	103.5	45/55	0.5	20	Δ	3	500	-87		68.0
FN 5040-180-99	180	162	75/90	0.3	33	Δ	3	680		-99	86.0
FN 5040-260-99	260	234	110/132	0.2	47	Δ	3	880		-99	125.0
FN 5040-410-99	410	369	160/200	0.13	66	Δ	3	1100		-99	184.0
FN 5040-480-99	480	432	250	0.11	94	Δ	3	1350		-99	235.0
FN 5040-660-99	660	594	315/355	0.14	141	Δ	2	2000		-99	310.0
FN 5040-750-99	750	675	400	0.12	165	Δ	2	2800		-99	470.0
FN 5040-880-99	880	792	450/500	0.11	188	Δ	2	3400		-99	640.0
FN 5040-1200-99	1200	1080	560/630	0.075	282	Δ	2	3800		-99	680.0
FN 5045-4.5-44	4.5	4.05	1.1/1.5	13	2.2	Y	4	65	-44		4.1
FN 5045-8-44	8	7.2	2.2/3	6.9	4.7	Y	4	80	-44		5.4
FN 5045-10-44	10	9	4	5.2	6.8	Y	4	90	-44		6.9
FN 5045-17-33	17	15.3	5.5/7.5	3.1	10	Y	4	115	-33		9.0
FN 5045-24-33	24	21.6	11	2.4	10	Y	4	150	-33		15.6
FN 5045-38-33	38	34.2	15/18.5	1.6	10	Y	4	170	-33		18.9
FN 5045-48-34	48	43.2	22	1.1	14.7	Y	4	260	-34		35.8
FN 5045-62-34	62	55.8	30	0.85	30	Y	3	280	-34		37.8
FN 5045-75-35	75	67.5	37	0.75	30	Y	3	330	-35		60.0
FN 5045-115-35	115	103.5	45/55	0.5	20	Δ	3	500	-35		70.0
FN 5045-180-99	180	162	75/90	0.3	33	Δ	3	680		-99	92.0
FN 5045-260-99	260	234	110/132	0.2	47	Δ	3	880		-99	131.0
FN 5045-410-99	410	369	160/200	0.13	66	Δ	3	1100		-99	198.0
FN 5045-480-99	480	432	250	0.11	94	Δ	3	1350		-99	243.0
FN 5045-660-99	660	594	315/355	0.14	141	Δ	2	2000		-99	425.0
FN 5045-750-99	750	675	400	0.12	165	Δ	2	2800		-99	482.0
FN 5045-880-99	880	792	450/500	0.11	188	Δ	2	3400		-99	652.0
FN 5045-1200-99	1200	1080	560/630	0.075	282	Δ	2	3800		-99	692.0

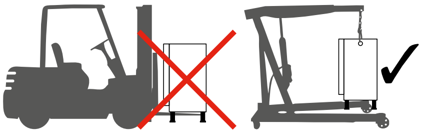
Installation

- Filter placement

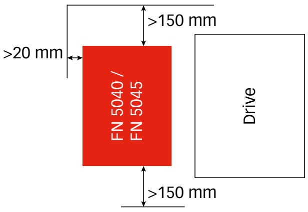
  Lift the filter with appropriate crane using lifting eye bolts – smaller types may be lifted manually by two persons (no lifting eye bolt applicable).



Never attempt to handle the filter with a forklift!

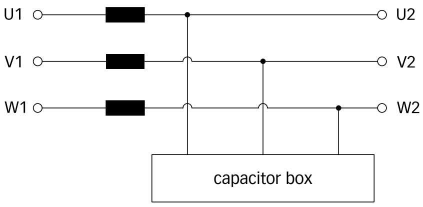


In order to ensure sufficient air flow, keep a distance of 150mm above and below the filter to walls or other components.
A 20mm distance on either side is recommended.



- Wiring and connections

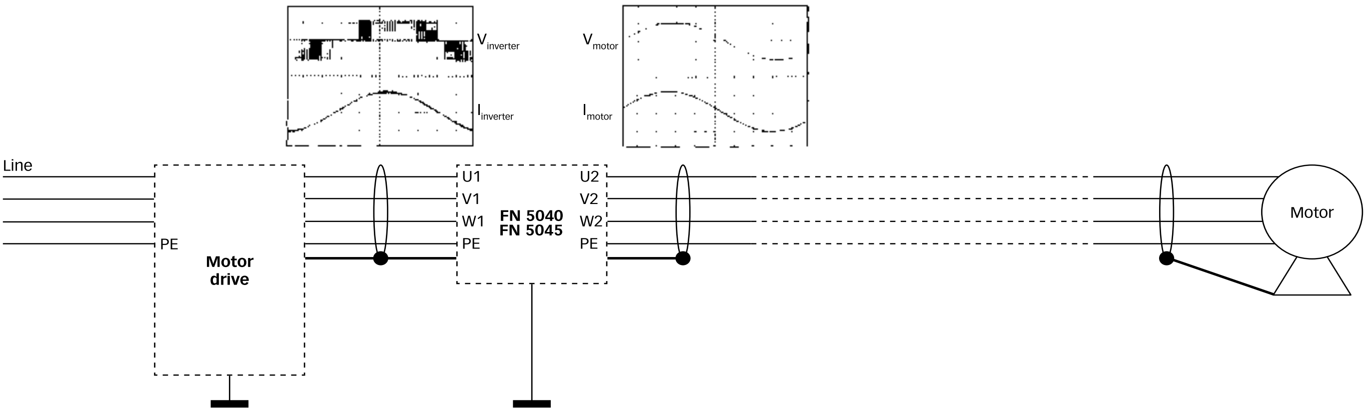
  The filter rating has to be compatible with the inverter to which it is to be connected. All inverter manufacturer installation and safety instructions must be fulfilled. The typical block schematic is shown for a motor load but the load can be also multiple motors or a transformer. Inverter and load cable selection/placement should be in accordance with all local electrical standards and regulations. Filters with separate capacitor bank must be connected as follows:



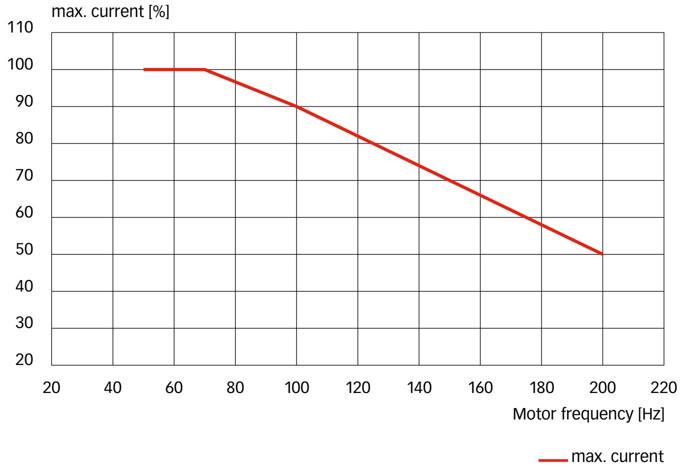
- Required settings

  Ensure the drive's switching frequency is set to the required minimum switching frequency (see filter selection table). Higher frequencies are allowed. The mode of operation must be "scalar" (V/Hz). Check the inverter manual whether special settings are necessary. In any doubt contact the inverter manufacturer.
  CAUTION: If the inverter settings are not in accordance the filter may be damaged.

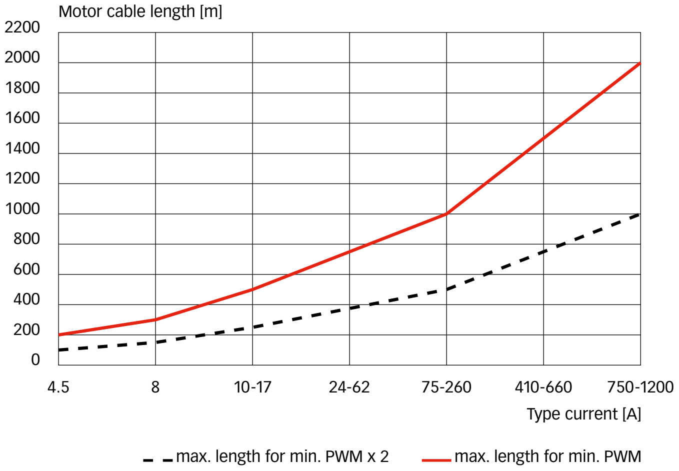
Typical block schematic



Motor frequency derating

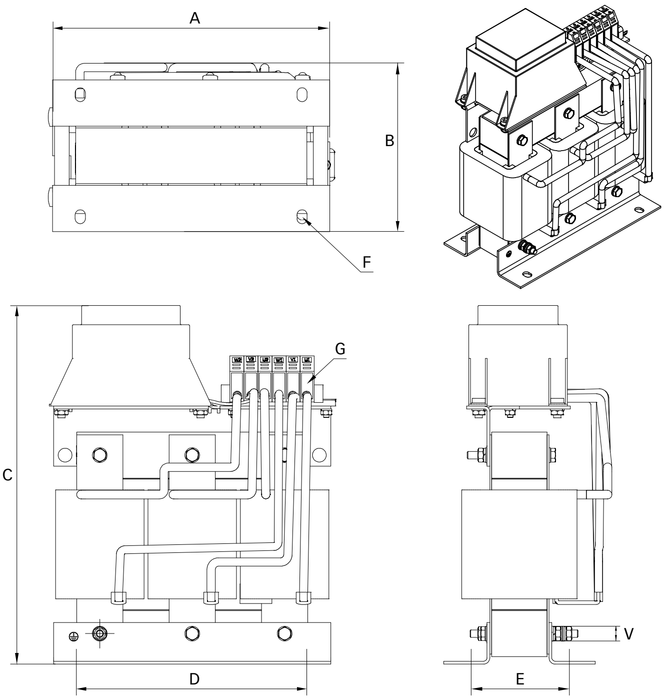


Max. motor cable length

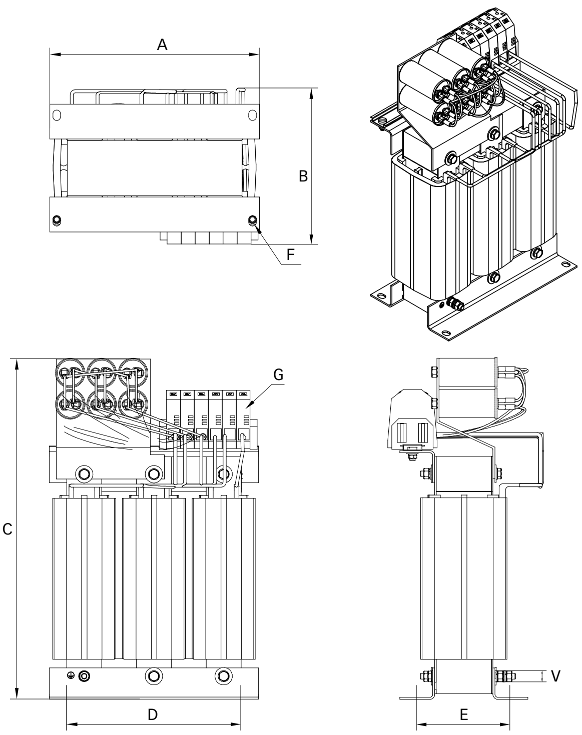


Mechanical data FN 5040

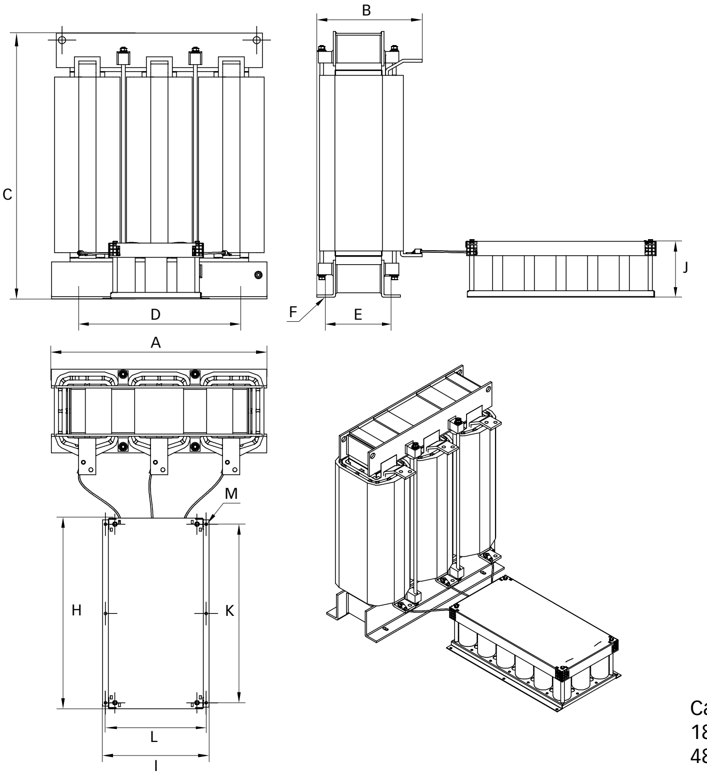
4.5 to 75A types



115A types



180 to 1200A types*



Cable length of capacitor box:
180 to 410A = 1000mm
480A to 1200A = 1500mm

Dimensions FN 5040

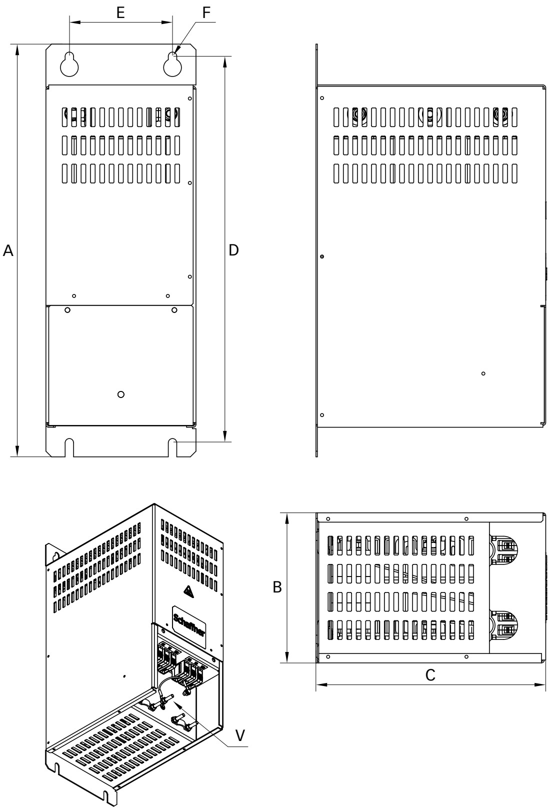
	4.5A	**8A**	**10A**	**17A**	**24A**	**38A**	**48A**	**62A**	**75A**	**115A**
A	125	155	155	190	190	230	300	320	305	305
B	77	84	94	115	116	151	171	190	240	236
C	171	212	208	224	224	275	355	395	395	495
D	100	130	130	170	170	180	240	240	240	280
E	55	56	71.5	57.5	77.5	122	137	132	162	151
F	5x8	8x12	8x12	8x12	8x12	8x12	11x15	11x15	11x15	11x15
G	2.5mm^2	2.5mm^2	4mm^2	4mm^2	10mm^2	10mm^2	16mm^2	35mm^2	50mm^2	50mm^2
V	M3	M4	M4	M6	M6	M8	M8	M8	M8	M8

	180A	**260A**	**410A**	**480A**	**660A**	**750A**	**880A**	**1200A**
A	450	453	490	510	632	665	660	750
B	260	245	292	321	360	415	385	372
C	385	485	600	618	730	670	885	925
D	400	370	430	430	570	570	570	570
E	130	150	194	195	210	220	220	220
F	9x13	11x15	10.5x18.5	13x27	13x27	13x26	13x26	13x26
H	328	328	328	328	436	555	436	665
I	170	170	170	270	370	375	370	375
J	200	220	240	220	220	200	220	220
K	300 (150)	300 (150)	300 (150)	300 (150)	400 (200)	510 (255)		620 (310)
L	150	150	150	250	350	350	350	350
M	9	9	9	9	9	9	9	9
V	M10	M10	M10	M10	M10	M10	M10	M10
W	25	25	40	40	40	40	50	60
X	13/15	13/15	13/16	13/20	20	20	14	17
Y	21	20	25	23	40	40	22	26
Z	10.3	10.3	10.3	10.3	14	14	14	14

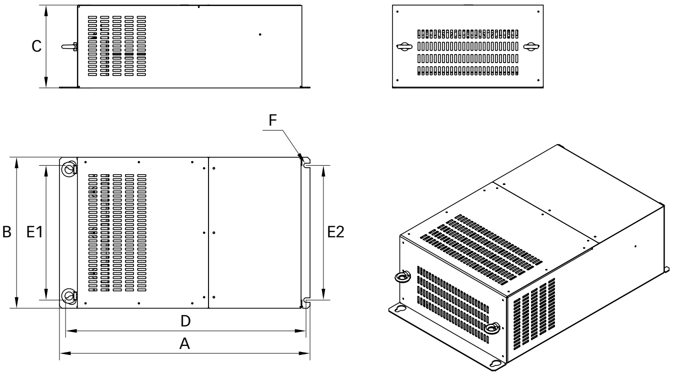
All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Mechanical data FN 5045

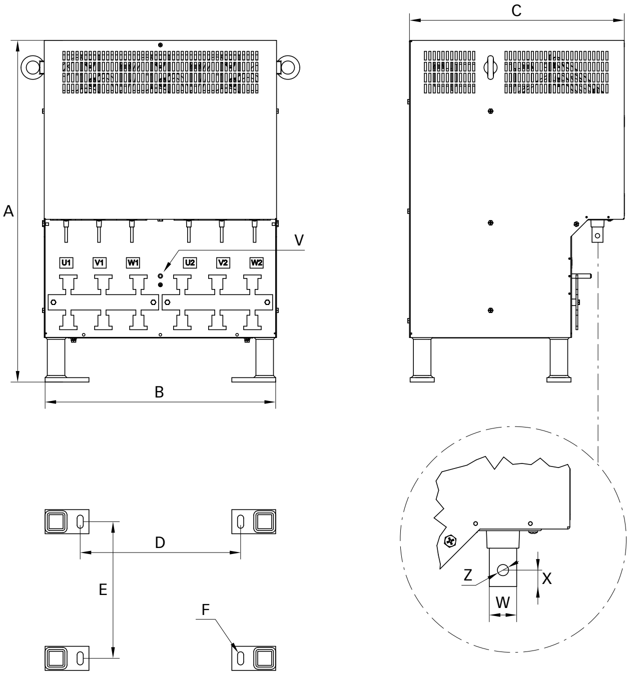
4.5 to 38A types



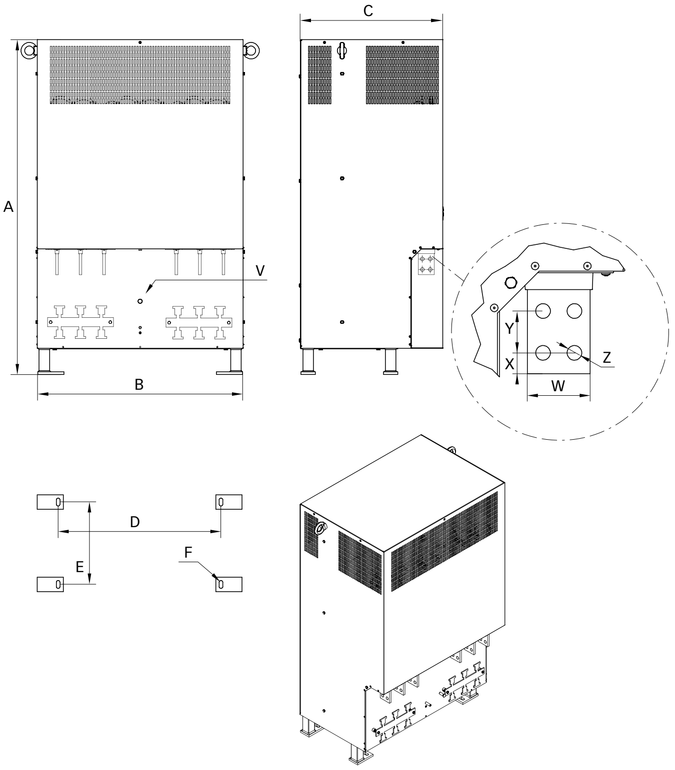
48 to 115A types



180 to 480A types



660 to 1200A types

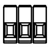
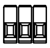
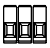
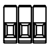
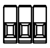


Dimensions FN 5045

	4.5A	8A	10A	17A	24A	38A	48A	62A	75A	115A	180A	260A	410A	480A	660A	750A	880A	1200A
A	330	330	330	440	440	440	515	515	615	615	650	650	780	780	1280	1280	1280	1280
B	100	100	100	160	160	160	320	320	370	370	508	508	538	538	794	794	794	794
C	165	165	165	245	245	156	156	153	203	203	400	400	494	494	498	498	550	550
D	310	310	310	412	412	412	488	488	590	590	336	336	336	336	622	622	622	622
E	60	60	60	110	110	110	280	280	330	330	243	243	312	312	315	315	315	315
F	7	7	7	9	9	9	9	9	11	11	14x30	14x30	14x30	14x30	14x30	14x30	14x30	14x30
J	M5	M5	M5	M5	M5	M5	M5	M5	M8	M8	M10	M10	M10	M10	M10	M10	M10	M10
W											20	20	25	25	40	40	40	60
X											15	15	15	15	20	20	20	20
Y															40	40	40	30/40
Z											9	9	10.2	10.2	14	14	14	14

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter output connector cross sections

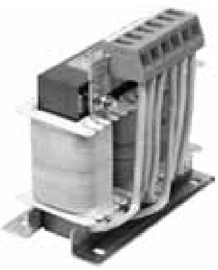
	-82 	-83 	-84 	-85 	-87 
Solid wire	0.75 - 2.5mm²	0.75 - 4.0mm²	2.5 - 10.0mm²	2.5 - 25.0mm²	16.0 - 50.0mm²
Flex wire	1.0 - 2.5mm²	1.0 - 4.0mm²	4.0 - 10.0mm²	4.0 - 16.0mm²	25.0 - 50.0mm²
AWG type wire	AWG 18 - 12	AWG 18 - 10	AWG 18 - 6	AWG 22 - 4	AWG 6 - 0
Recommended torque	1.0 - 1.2Nm	1.5 - 1.8Nm	4.0 - 4.5Nm	1.5 - 1.8Nm	6.0 - 8.0Nm

Please visit www.schaffner.com to find more details on filter connectors.

Load Reactors
RWK 305

Three-phase dv/dt Reactor for Efficient Motor Protection

schaffner
energy efficiency and reliability



- **Reduction of drive output voltage dv/dt**
- **Reduction of motor temperature**
- **Increase of motor service life**
- **Compact and economic open frame design**
- **Standard catalog reactors up to 1100A**
- **UL rated materials used**

Approvals

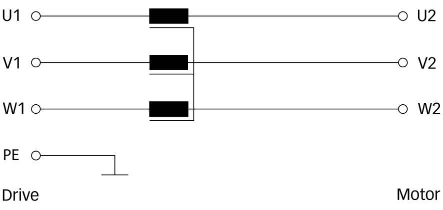
c UL us
(in preperation)

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 500/288VAC
Motor frequency:	60Hz max.
Switching frequency:	2 to 16kHz
Rated currents:	4 to 1100A @ 40°C
Motor cable length:	30m max. @ 16kHz (derating curve next page)
Impedance (uk):	0.8% @ 400VAC, 50Hz & rated current
Typical dv/dt reduction:	≥ factor 5
High potential test voltage:	P –> E 3000VAC for 3 sec
	P –> P 3000VAC for 3 sec
Protection category:	IP00 (KL types according to VBG 4)
Overload capability:	2x rated current at switch on for 30 seconds
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Insulation class:	T40/F (155°C)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	EN 61558-2-20 (VDE 0570-2-20), UL508C, CSA C22.2 NO.14
MTBF @ 40°C/400V (Mil-HB-217F):	>200,000 hours

Typical electrical schematic



Features and benefits

- Efficient reduction of high output voltage dv/dt from IGBT motor drives.
- Protection of motor coil insulation from premature aging and destruction.
- Significantly increased servie life of electric motors.
- High reliablility and secured production up time for mission critical applications.
- Reduced converter pulse load.
- Less interference propagation towards neighboring equipment of lines.
- „Output filter“ with low impedance, ideal for processes requiring exceptional precision and reproducibility of movements.
- Vacuum impregnation for reduced humming noise and high durability.

Typical applications

- Servo drives
- Close loop vector drives
- Motor drive applications with short motor cables
- Machinery comprising servo or torque motors
- Robots
- Pick and place machines

Reactor selection table

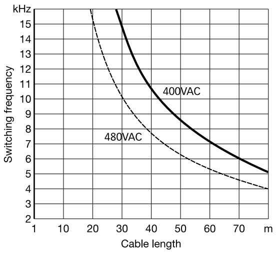
Reactor	Rated current @ 40°C	Typical motor power rating*	Nominal inductance	Typical power loss**	Input/Output connections					Weight
								Total	Cu.	Al.
	[A]	[kW]	[mH]	[W]				[kg]	[kg]	[kg]
RWK 305-4-KL	4	1.5	1.47	22	KL			1.2	0.14	
RWK 305-7.8-KL	7.8	3	0.754	25	KL			1.2	0.28	
RWK 305-10-KL	10	4	0.588	30	KL			1.8	0.22	
RWK 305-14-KL	14	5.5	0.42	34	KL			2.2	0.35	
RWK 305-17-KL	17	7.5	0.346	38	KL			2.5	0.5	
RWK 305-24-KL	24	11	0.245	45	KL			2.5	0.5	
RWK 305-32-KL	32	15	0.184	55	KL			3.9	0.56	
RWK 305-45-KL	45	22	0.131	60	KL			6.1	0.7	
RWK 305-60-KL	60	30	0.098	65	KL			6.1	1.3	
RWK 305-72-KL	72	37	0.082	70	KL			6.1	1.6	
RWK 305-90-KL	90	45	0.065	75	KL			7.4	2.4	
RWK 305-110-KL	110	55	0.053	90	KL			8.2	2.4	
RWK 305-124-KS	124	55	0.047	110		KS		8.2	2.4	
RWK 305-143-KS	143	75	0.041	115		KS		10.7	2.7	
RWK 305-156-KS	156	75	0.038	120		KS		10.7	2.85	
RWK 305-170-KS	170	90	0.035	130		KS		10.7	3.8	
RWK 305-182-KS	182	90	0.032	140		KS		16	2.8	
RWK 305-230-KS	230	132	0.026	180		KS		22	3.5	
RWK 305-280-KS	280	160	0.021	220		KS		29	2.8	
RWK 305-330-KS	330	160	0.018	240		KS		32	3.5	
RWK 305-400-S	400	200	0.015	330			S	34	3.8	2
RWK 305-500-S	500	250	0.012	340			S	35	5.4	3.3
RWK 305-600-S	600	355	0.01	380			S	37	5.4	3.3
RWK 305-680-S	680	400	0.009	410			S	38	7.2	3.5
RWK 305-790-S	790	450	0.007	590			S	43	10.5	3.5
RWK 305-910-S	910	500	0.006	740			S	49	12	3
RWK 305-1100-S	1100	630	0.005	760			S	66	12	3.5

* General purpose four-pole (1500r/min) AC induction motor rated 400V/50Hz.

** Exact value depends upon the motor cable type and length, switching frequency, motor frequency and further stray parameters within the system.

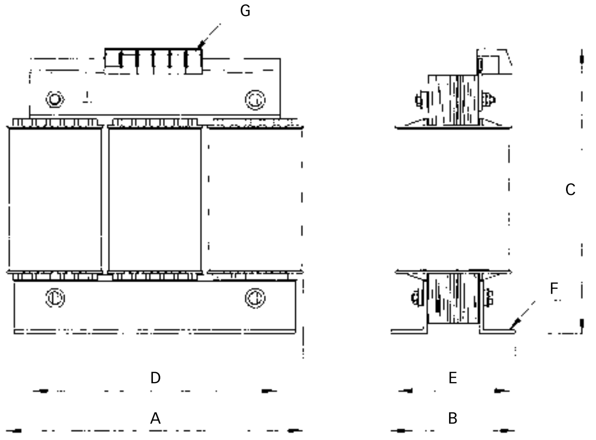
Reactor derating

The maximum admissible motor cable length depends mainly on the switching frequency and the drive output voltage. The applicable value for a given application can be found in the derating curve below.

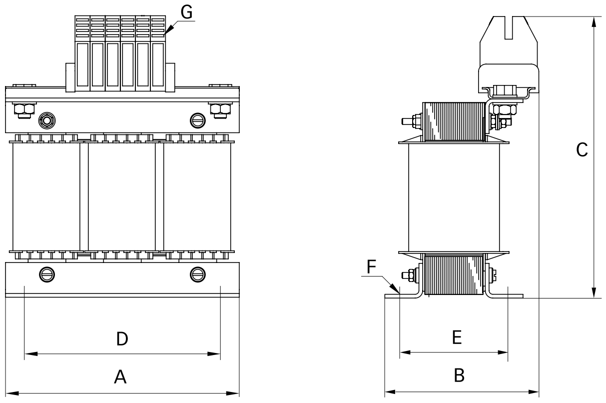


Mechanical data

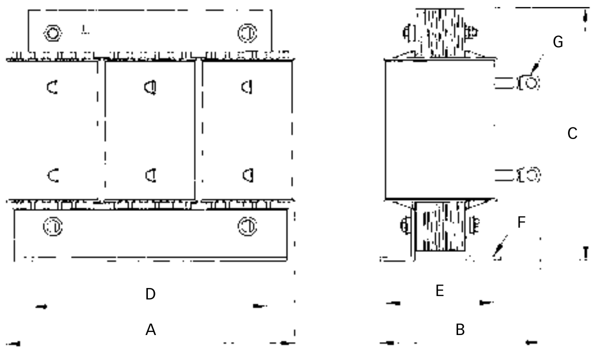
4 to 45A types



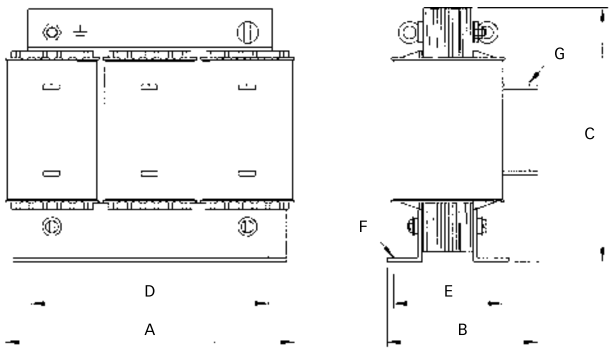
60 to 110A types



124 to 330A types



400 to 1100A types



Dimensions

	A	B	C	D	E	F	G
4 and 7.8A	100	max. 60	max. 115	56	34	4.8 x 9	2.5mm^2
10A	100	max. 70	max. 115	56	43	4.8 x 9	2.5mm^2
14A	125	max. 70	max. 135	100	45	5 x 8	2.5mm^2
17A	125	max. 75	max. 135	100	55	5 x 8	2.5mm^2
24A	125	max. 75	max. 135	100	55	5 x 8	4mm^2
32A	155	max. 95	max. 170	130	56	8 x 12	10mm^2
45A	155	max. 110	max. 190	130	72	8 x 12	10mm^2
60 and 72A	155	max. 125	max. 190	130	70	8 x 12	16mm^2
90A	190	max. 115	max. 225	170	57	8 x 12	35mm^2
110A	190	max. 130	max. 220	170	67	8 x 12	35mm^2
124A	190	max. 180	max. 160	170	67	8 x 12	Ø8
143A	190	max. 180	max. 160	170	77	8 x 12	Ø8
156 and 170A	190	max. 180	max. 160	170	77	8 x 12	Ø10
182A	210	max. 180	max. 185	175	97	8 x 12	Ø10
230A	240	220	220	190	119	11 x 15	Ø12
280A	240	235	220	190	133	11 x 15	Ø12
330A	240	240	220	190	135	11 x 15	Ø12
400 and 500A	240	220	325	190	119	11 x 15	Ø11
600 and 680A	240	230	325	190	128	11 x 15	Ø14
790A	300	218	355	240	136	11 x 15	2 x Ø11
910A	300	228	355	240	148	11 x 15	2 x Ø11
1100A	360	250	380	310	144	11 x 15	2 x Ø11

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Line Reactors

Line Reactors.

Line reactors operated on the line side of power drive systems, efficiently protect inverter electronics and dc link capacitors from inrush, peak and short-circuit currents. Additionally, low-frequency interference and harmonics are reduced significantly.

Approvals *

c UL US

▬ Attenuation performance

▬ Rated current [A]

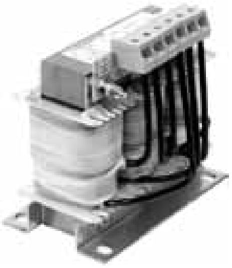
		standard / high / very high	Features								Typical applications						
Filter family	**Max. voltage**	0 200 400 600 800 >1000	Safety connector blocks	Busbar connection	Offering EMC compliance	Less commutation notches	Form factor (I) improvement	Inrush current limitation	Harmonics reduction	4% impedance	Inverters, servo drives	Machinery, machine tools	Industrial automation	General purpose			
RWK 212  p. 91	500VAC	4 – 1100	■	■		■	■	■	■	■	■	■	■	■			

* Products evaluated by one or more of the above certification agencies. For details please consult the detailed data sheet.

Line Reactors
RWK 212

Three-phase Line Reactor for Motor Drive Applications

schaffner
energy efficiency and reliability



- Provision of 4% impedance
- Reduction of mains harmonics
- Reduction of commutation notches
- Protection of motor drive electronics
- Limitation of inrush currents
- Improvement of true power factor

Approvals

c UL us

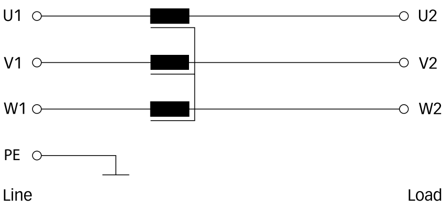
(in preperation)

RoHS

Technical specifications

Maximum continuous operating voltage:	3x 500/288VAC
Operating frequency:	50 to 60Hz
Rated currents:	4 to 1100A @ 40°C
Impedance (uk):	4% @ 400VAC, 50Hz & rated current
Typical harmonics reduction:	See table on next page
High potential test voltage:	P –> E 3000VAC for 3 sec
	P –> P 3000VAC for 3 sec
Protection category:	IP00 (KL types according to VBG 4)
Overload capability:	2x rated current at switch on for 30 seconds
	1.5x rated current for 1 minute, once per hour
Temperature range (operation and storage):	-25°C to +100°C (25/100/21)
Insulation class:	T40/F (155°C)
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	EN 61558-2-20 (VDE 0570-2-20), UL508C, CSA C22.2 NO.14
MTBF @ 40°C/400V (Mil-HB-217F):	>200,000 hours

Typical electrical schematic



Features and benefits

- Ensure reliability, performance and a long service life of electrical consumers.
- Reduction of mains harmonics and commutation notches.
- Help to meet international power quality standards such as IEEE 519 or EN 61000-3-2.
- Protection of motor drive electronics and dc link capacitors against mains transients.
- Reduction of inrush and peak currents.
- Reduction of conducted LF emission.
- Improvement of conducted LF immunity.
- Prevention from nuisance tripping caused by power line voltage spikes.
- Improvement of true power factor.

Typical applications

- Motor drives and various adjustable speed drive systems, such as:
- Elevators
- Robots
- Machinery
- Process automation equipment

Reactor selection table

Reactor	Rated current @ 40°C	Typical drive power rating*	Nominal inductance	Typical power loss**	Input/Output connections			Weight		
								Total	Cu.	Al.
	[A]	[kW]	[mH]	[W]				[kg]	[kg]	[kg]
RWK 212-4-KL	4	1.5	7.3	23	KL			2.1	0.21	
RWK 212-7-KL	7	3	4.2	36	KL			2.5	0.31	
RWK 212-11-KL	11	4	2.6	37	KL			2.5	0.7	
RWK 212-16-KL	16	7.5	1.8	59	KL			3.9	0.85	
RWK 212-21-KL	21	11	1.4	66	KL			5.4	0.95	
RWK 212-29-KL	29	15	1	69	KL			5.4	1.63	
RWK 212-35-KL	35	18.5	0.84	70	KL			5.9	2.25	
RWK 212-46-KL	46	22	0.64	99	KL			11	2.3	
RWK 212-60-KL	60	30	0.49	138	KL			15	2.35	
RWK 212-75-KL	75	37	0.39	133	KL			15	3.7	
RWK 212-95-KL	95	45	0.3	166	KL			22	3.4	
RWK 212-124-KS	124	55	0.23	172		KS		25	3.4	
RWK 212-156-KS	156	75	0.19	249		KS		25	5.1	
RWK 212-182-KS	182	90	0.16	245		KS		32	7.45	
RWK 212-230-KS	230	110/132	0.13	301		KS		35	9.55	
RWK 212-280-KS	280	160	0.1	335		KS		41	8.5	
RWK 212-330-KS	330	160	0.09	386		KS		56	9.25	
RWK 212-400-S	400	200	0.073	692			S	57	3.4	4.7
RWK 212-500-S	500	250	0.058	761			S	67	4.5	5.74
RWK 212-600-S	600	315	0.049	825			S	76	4.5	6.6
RWK 212-680-S	680	355	0.043	876			S	80	5.6	8
RWK 212-790-S	790	400	0.037	956			S	90	6.8	8.7
RWK 212-910-S	910	450	0.032	1022			S	107	6.8	8.7
RWK 212-1100-S	1100	630	0.026	1096			S	138	9.2	9.6

Customized line reactors with different electrical and mechanical specifications are available on request.

* Calculated at rated current, 400VAC and cos phi = 0.8. The exact value depends upon the efficiency of the drive, the motor and the entire application.

** Power loss at 25°C/50Hz, considering a typical harmonic spectrum of a motor drive with B6U rectifier bridge.

Harmonics reduction

Line reactors are a cost-effective way for the limitation of mains harmonics. The harmonics reduction capability is related to the reactor impedance. A higher impedance translates directly into lower harmonic currents, but of course also into a larger component with a higher voltage drop – and vice versa.

4% impedance reactors like RWK 212 provide an excellent cost/benefit ratio and are particularly beneficiary in the most diverse motor drive applications.

The table below shows various reactor impedance values and their calculated effect in terms of harmonics reduction.

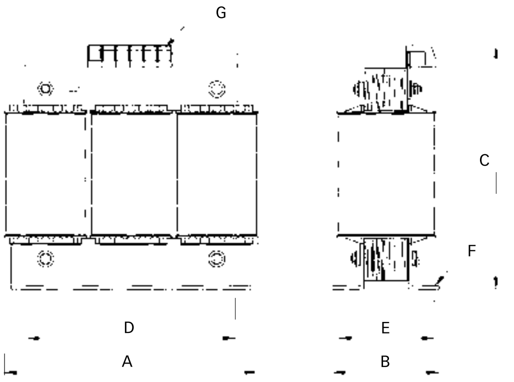
Harmonic number / Input impedance (uk) vs. remaining harmonics [%]

	0.5%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
5th	80	60	46	40	34	32	30	28	26	24	23
7th	60	37	22	16	13	12	11	10	9	8.3	7.5
11th	18	12	9	7.3	6.3	5.8	5.2	5	4.3	4.2	4
13th	10	7.5	5.8	4.9	4.2	3.9	3.6	3.3	3.15	3	2.8
17th	7.3	5.2	3.6	3	2.4	2.2	2.1	0.9	0.7	0.5	0.4
19th	6	4.2	2.8	2.2	2	0.8	0.7	0.4	0.3	0.25	0.2
%THID	102.5	72.2	52.3	44.13	37.31	34.96	32.65	30.35	28.04	25.92	24.68

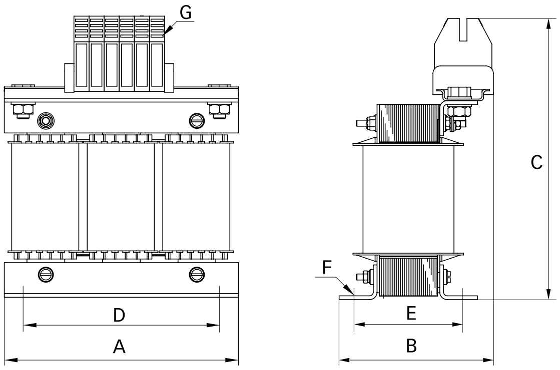
Reading example: a 4% impedance reactor typically reduces the THID to ~37% of the fundamental.

Mechanical data

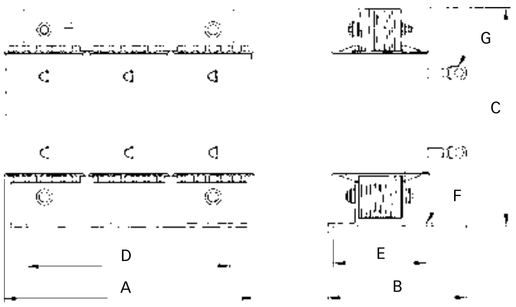
4 to 46A types



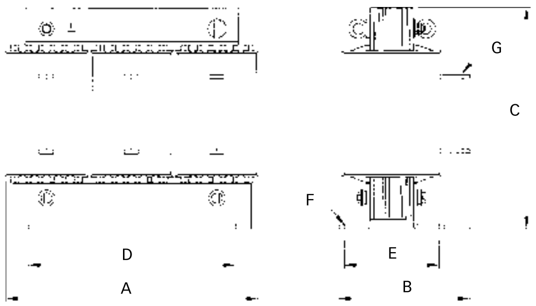
60 to 95A types



124 to 330A types



400 to 1100A types



Dimensions

	A	B	C	D	E	F	G
4A	100	max. 70	max. 115	56	43	4.8 x 9	2.5mm^2
7 and 11A	125	max. 80	max. 130	100	55	5 x 8	2.5mm^2
16A	155	max. 80	max. 155	130	56.5	8 x 12	4mm^2
21A	155	max. 95	max. 155	130	70.5	8 x 12	4mm^2
29A	155	max. 95	max. 155	130	71.5	8 x 12	4mm^2
35A	155	max. 105	max. 170	130	70	8 x 12	10mm^2
46A	190	max. 120	max. 195	170	77.5	8 x 12	10mm^2
60A	210	max. 155	max. 240	175	97	8 x 12	16mm^2
75A	210	max. 160	max. 249	175	97	8 x 12	35mm^2
95A	230	max. 185	max. 275	180	122	8 x 12	35mm^2
124 and 156A	240	max. 210	max. 210	190	130	11 x 15	Ø10
182A	265	max. 210	max. 230	215	114	11 x 15	Ø10
230A	300	210	270	240	134	11 x 15	Ø12
280A	300	218	270	240	142	11 x 15	Ø12
330A	300	255	270	240	165	11 x 15	Ø12
400A	420	205	390	370	134	11 x 15	Ø11
500A	420	215	390	370	140	11 x 15	Ø14
600A	420	225	390	370	149	11 x 15	Ø14
680A	420	225	390	370	150	11 x 15	Ø14
790A	420	240	390	370	162	11 x 15	Ø18
910A	420	255	390	370	177	11 x 15	2 x Ø11
1100A	420	290	390	370	200	11 x 15	2 x Ø11

All dimensions in mm; 1 inch = 25.4mm

Tolerances according: ISO 2768-m / EN 22768-m

Active and Passive Harmonic Filters

Active and Passive Harmonic Filters.

Harmonic filters help to obtain compliance with international standards like e.g. IEEE 519-1992 or EN 61000-3-12, and with local utility codes. They reduce the electrical and thermal stress upon the electrical infrastructure, eliminate the risk of harmonics-related reliability problems, and support long-term energy efficiency and cost savings. ECOsine™ advanced passive filters are the industry standard for 6-pulse rectifiers and non-regenerative motor drives to achieve the often specified level of <5% THID. ECOsine™ Active harmonic filters provide latest generation digital technology. With a response time of less than 300µs an efficient harmonics mitigation, power factor correction, and load balancing is achieved in real time.

Approvals *

c UL us LISTED CE

c RU us

Rated power [kW/HP]

Corrective current [A]

Filter family		**Nom. voltage**	0 100 200 300 400 500	Features: For 50Hz grids	Features: For 60Hz grids	Features: THID <5%	Features: Power factor correction	Features: Load balancing	Features: 3-phase / 3-wire	Features: 3-phase / 4-wire	Typical applications: For 6-pulse diode rectifiers	Typical applications: For 6-pulse SCR rectifiers	Typical applications: AC Motor drives	Typical applications: DC Motor drives	Typical applications: Welding machines	Typical applications: HVAC installations	Typical applications: Building power distribution	Typical applications: Semiconductor industry	Typical applications: Water / wastewater treatment
FN 3410 p. 97		380 - 500VAC	4 400kW	■		■			■		■		■			■			■
FN 3410 HV p. 101		690VAC	7.5 250kW	■		■			■		■		■			■			■
FN 3411 p. 97		380 - 500VAC	4 400kW	■					■			■	■	■					■
FN 3411 HV p. 101		690VAC	7.5 250kW	■					■			■	■	■					■
FN 3412 p. 97		380 - 480VAC	5 500HP		■	■			■		■		■			■			■
FN 3413 p. 97		380 - 480VAC	5 500HP		■				■			■	■	■					■
FN 3420 (active) p. 105		380 - 480VAC	30 300	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
FN 3430 (active) p. 105		380 - 415VAC	30 300	■	■	■	■	■		■	■	■					■	■	

Note: filters FNxx11xx and FNxx13xx are available on request.
Note: power ratings marked with hatchings are in preparation.

* Products evaluated by one or more of the above certification agencies. For details please consult the detailed data sheet.

Harmonic Filters
FN 3410/11 / FN3412/13

ECOsine™ Advanced Passive Harmonic Filters

schaffner
energy efficiency and reliability

- **Efficient mitigation of harmonic currents**
- **Compliance with IEEE 519 and other Power Quality standards**
- **Increased equipment service life and system reliability**
- **More efficient utilization of electric system capacity**
- **Long-term savings in system operation and maintenance cost**

Approvals

c UL US LISTED CE

RoHS

Technical specifications

Nominal operating voltage:	3x 380 to 500VAC ±10% (FN 3410/11)
	3x 380 to 480VAC ±10% (FN 3412/13)
Operating frequency:	50Hz ±1Hz (FN 3410/11)
	60Hz ±1Hz (FN 3412/13)
Nominal motor drive input power rating:	4 to 200kW (FN 3410/11)
	5 to 250HP (FN 3412/13)
Total harmonic current distortion THID**:	<5% @ rated power
Total demand distortion TDD:	According to IEEE-519, table 10-3
Efficiency:	98.5 to 99.5% @ nominal line voltage and power
High potential test voltage:	P –> E 2500VAC (1min)
Protection category:	IP20 / NEMA1
Cooling:	Internal fan cooling
Overload capability:	1.6x rated current for 1 minute, once per hour
Ambient temperature range:	–25°C to +50°C fully operational
	+50°C to +70°C derated operation***
	–25°C to +85°C transport and storage
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL 508, EN 61558-2-20, CE (LVD 2006/95/EC)
MTBF @ 50°C/460V (Mil-HB-217F):	200,000 hours
SCCR****:	100kA

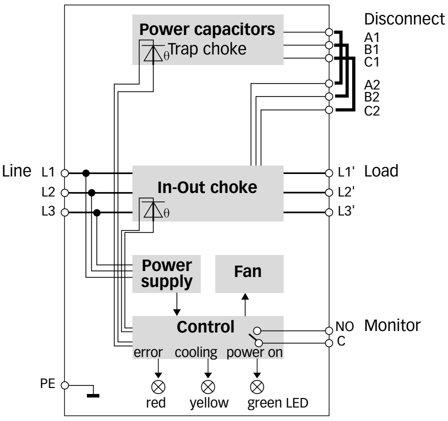
* ECOsine filters reduce RMS input and peak current by reducing harmonic currents and improving true power factor.

** System requirements: THVD <2%, line voltage unbalance <1%
Note: performance specifications in this brochure refer to six-pulse diode rectifiers. SCR rectifier front-ends will produce different results, dependent upon the firing angle of the thyristors.

*** $I_{derated} = I_{nominal}$ * √(85°C-T_{amb})/35°C

**** External UL-rated fuses required. Please consult the user manual.

Typical electrical schematic



Features and benefits

Schaffner ECOsine™ harmonic filters represent an economical solution to the challenge of load-applied harmonics mitigation in three-phase power systems. With a plug-and-play approach and more compact dimensions than comparable products, they can be quickly installed and easily commissioned. They increase the reliability and service life of electric installations, help utilize electric sytem capacity better, and are the key to meet Power Quality standards such as IEEE 519.

ECOsine™ filters calm your harmonic waves. Schaffner ECOsine™ filters can be applied to virtually any kind of power electronics with front-end six-pulse rectifiers, where harmonic current distortion needs to be reduced to defined limits. Typical applications, where the above-mentioned non-sinusoidal consumers of power can account for a significant portion of the load, include:

Typical applications

- Equipment with front-end six-pulse rectifier
- Motor drives
- Factory automation equipment
- Water/wastewater treatment facilities
- Fan and pump applications
- HVAC installations
- Mission-critical processes
- DC fast chargers

Filter selection table FN 3410/11

Filter*	Rated load power @ 400VAC/50Hz	Rated load power @ 500VAC/50Hz	Power loss** @ 400V/500V	Input/Output connections		Capacitor disconnections	Weight	NEMA1 covers***
	[kW]	[kW]	[W]				[kg]	Order code
FN 341x-10-44	4	5.5	60/83	-44		-44	13	1151-081
FN 341x-13-44	5.5	7.5	83/113	-44		-44	14	1151-081
FN 341x-16-44	7.5	11	113/165	-44		-44	21	1151-082
FN 341x-24-33	11	15	165/225	-33		-44	27	1151-083
FN 341x-32-33	15	18.5	225/278	-33		-44	31	1151-083
FN 341x-38-33	18.5	22	259/308	-33		-44	35	1151-083
FN 341x-45-34	22	30	286/390	-34		-33	45	1151-084
FN 341x-60-34	30	37	360/444	-34		-33	54	1151-084
FN 341x-75-35	37	45	407/495	-35		-34	65	1151-085
FN 341x-90-35	45	55	450/550	-35		-34	77	1151-085
FN 341x-110-35	55	75	495/675	-35		-34	86	1151-085
FN 341x-150-40	75	90	600/720	-40		-35	118	1151-086
FN 341x-180-40	90	110	630/770	-40		-35	136	1151-086
FN 341x-210-40	110	132	770/924	-40		-35	154	1151-086
FN 341x-260-99	132	160	792/960		-99	-35	201	1151-086
FN 341x-320-99	160	200	960/1200		-99	-35	201	1151-086

* To compile a complete part number, please replace the x with a 0 for diode or 1 for SCR rectifiers.
Filter to be selected by system voltage and load (motor drive) power. Note: the harmonic filter will reduce the RMS input current. Example: the rated RMS input current of an unfiltered 400V/15kW/32A drive will be reduced to approximately 23A. Therefore, filter selection by current rating, as it is common for EMC/EMI filters, is not suitable.

** Calculated power loss at rated load power.

*** Please contact your local Schaffner partner to order the optional NEMA1 covers with the order code in the table above.

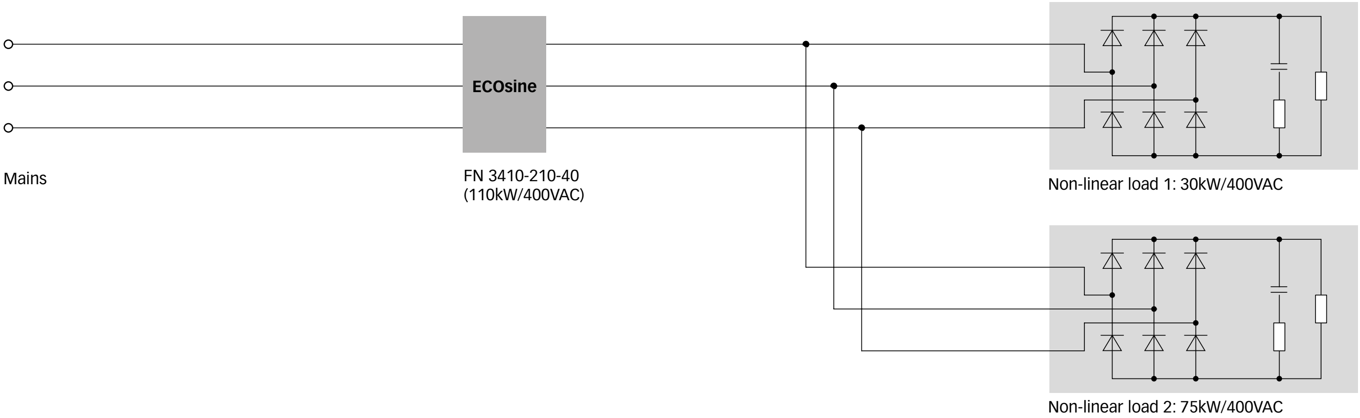
Filter selection table FN 3412/13

Filter*	Rated load power @ 460VAC/60Hz	Power loss** @ 460V	Input/Output connections		Capacitor disconnections	Weight	NEMA1 covers***
	[HP]	[W]	▥▥▥	▮	▥▥▥	[kg]	Order code
FN 341x-8-44	5	56	-44		-44	12	1151-081
FN 341x-11-44	7.5	84	-44		-44	13	1151-081
FN 341x-15-44	10	112	-44		-44	17	1151-082
FN 341x-21-44	15	168	-44		-44	21	1151-082
FN 341x-28-33	20	209	-33		-44	28	1151-083
FN 341x-35-33	25	261	-33		-44	32	1151-083
FN 341x-41-33	30	291	-33		-33	35	1151-083
FN 341x-53-34	40	328	-34		-33	48	1151-084
FN 341x-65-34	50	373	-34		-34	52	1151-084
FN 341x-80-35	60	403	-35		-34	69	1151-085
FN 341x-105-35	75	447	-35		-34	77	1151-085
FN 341x-130-35	100	522	-35		-35	87	1151-085
FN 341x-160-40	125	559	-40		-35	124	1151-086
FN 341x-190-40	150	671	-40		-35	132	1151-086
FN 341x-240-99	200	746		-99	-35	185	1151-086
FN 341x-310-99	250	932		-99	-35	202	1151-086

* To compile a complete part number, please replace the x with a 2 for diode or 3 for SCR rectifiers.
Filter to be selected by system voltage and load (motor drive) power. Note: the harmonic filter will reduce the RMS input current. Example: the rated RMS input current of an unfiltered 460V/20HP/28A drive will be reduced to approximately 20A. Therefore, filter selection by current rating, as it is common for EMC/EMI filters, is not suitable.

** Calculated power loss at rated load power.

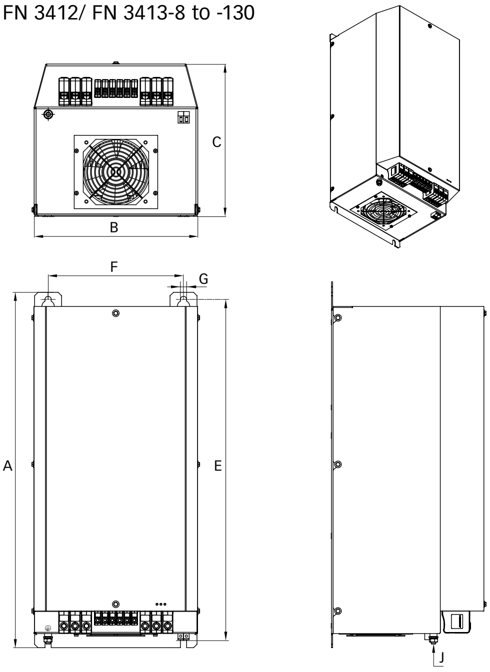
*** Please contact your local Schaffner partner to order the optional NEMA1 covers with the order code in the table above.



Mechanical data

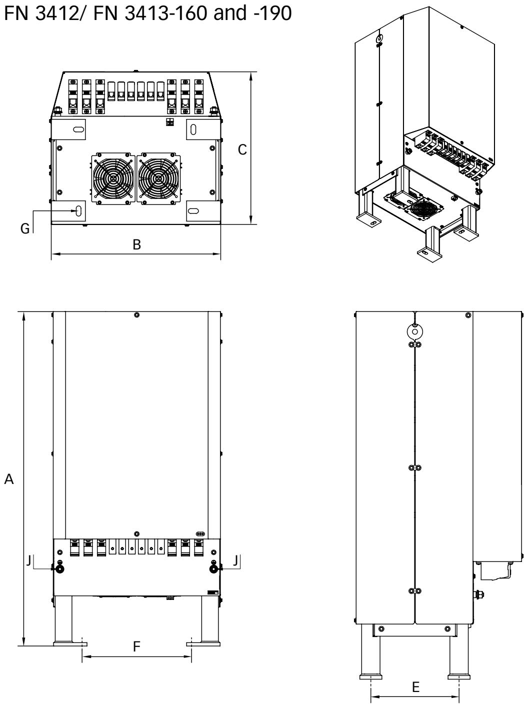
FN 3410/ FN 3411-10 to -110

FN 3412/ FN 3413-8 to -130



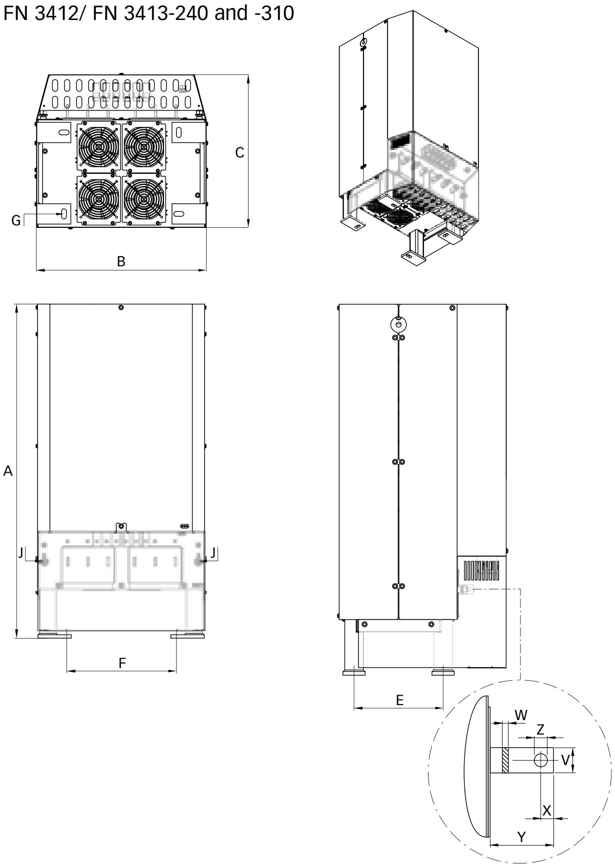
FN 3410/ FN 3411-150 to -210

FN 3412/ FN 3413-160 and -190



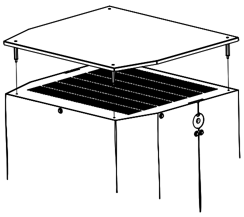
FN 3410/ FN 3411-260 and -320

FN 3412/ FN 3413-240 and -310



Installation. All filters from FN 341x-8 to -130 are wall mountable and have to be operated vertically. The filters FN 341x-150 and higher are designed for floor mounting. In order to allow for sufficient air flow all filters must be clear on top and bottom min. 150mm.

Optional NEMA1 cover. All filters can be optionally fitted with a NEMA1 cover. Please find order codes on previous pages.



Dimensions

FN 3410/ FN 3411-... FN 3412/ FN 3413-...	**10** **8**	**13** **11**	**16** **15**	 **21**	**24** **28**	**32** **35**	**38** **41**	**45** **53**	**60** **65**	**75** **80**	**90** **105**	**110** **130**	**150** **160**	**180** **190**	**210** 	**260** **240**	**320** **310**
A	400	400	430	430	520	520	520	590	590	750	750	750	1000	1000	1000	1000	1000
B	170	170	210	210	250	250	250	300	300	320	320	320	500	500	500	500	500
C	190	190	210	210	280	280	280	300	300	300	300	300	450	450	450	450	450
E	380	380	410	410	495	495	495	565	565	725	725	725	240	240	240	240	240
F	130	130	170	170	200	200	200	250	250	270	270	270	338	338	338	338	338
G	7	7	9	9	11	11	11	11	11	11	11	11	14x30	14x30	14x30	14x30	14x30
J	M6	M6	M6	M6	M8	M8	M8	M8	M8	M10	M10	M10	M10	M10	M10	M10	M10
V																25	25
W																6	6
X																12.5	12.5
Y																40	40
Z																11	11

All dimensions in mm; 1 inch = 25.4mm
Tolerances according: ISO 2768-m / EN 22768-m

Filter connector cross sections

	–33	**–34**	**–35**	**–40**	**–44**
Solid wire	16mm²	35mm²	50mm²	95mm²	10mm²
Flex wire	10mm²	25mm²	50mm²	95mm²	6mm²
AWG type wire	AWG 6	AWG 2	AWG 1/0	AWG 4/0	AWG 8
Recommended torque	1.5 – 1.8Nm	4.0 – 4.5Nm	7 – 8Nm	17 – 20Nm	1.0 – 1.2Nm

Please visit www.schaffner.com to find more details on filter connectors.

Harmonic Filters
FN 3410HV / FN 3411HV

ECOsine™ Passive Harmonic Filters for 690V Applications

energy efficiency and reliability

- **Dedicated range of harmonic filters for 690VAC systems**
- **Highly efficient harmonic current mitigation**
- **Help to comply with IEEE-519 and other PQ standards**
- **Increased equipment service life and system reliability**
- **More efficient utilization of electrical system capacity**
- **Ideal for motor drives**

Approvals

CE

RoHS

Typical specifications	
Nominal operating voltage:	3x 690VAC
Voltage tolerance range:	3x 586 to 760VAC
Operating frequency:	50Hz ±1Hz
Nominal motor drive input current rating*:	10 to 320A @ 50°C
Nominal motor drive input power rating:	7.5 to 250kW
Total harmonic current distortion THID**:	<5% @ rated power (filters up to 37kW)
	~5% @ rated power with Ldc (filters 45kW and up)
Total demand distortion TDD:	According to IEEE-519, table 10-3
Efficiency:	>98% @ nominal line voltage and power
High potential test voltage:	P → E 2500VAC (1min)
Protection category:	IP20
Cooling:	Internal fan cooling
Overload capability:	1.6x rated current for 1 minute, once per hour
Ambient temperature range:	-25°C to +50°C fully operational
	+50°C to +70°C derated operation***
	-25°C to +85°C transport and storage
Flammability corresponding to:	UL 94V-2 or better
Design corresponding to:	UL508, EN61558-2-20, CE (LVD2006/95/EC)
MTBF @ 50°C/690V (Mil-HB-217F):	tbd
SCCR****:	100kA

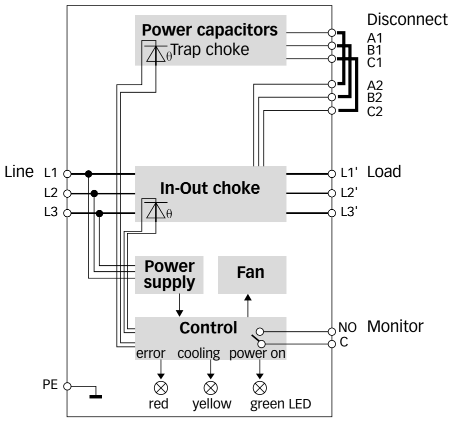
* ECOsine filters reduce RMS input and peak current by reducing harmonic currents and improving true power factor.

** System requirements: THVD <2%, line voltage unbalance <1%
Note: performance specifications in this brochure refer to six-pulse diode rectifiers. SCR rectifier front-end will produce different results, depending upon the firing angle of the thyristors.

*** Iderated = Inominal * √(85°C-Tamb)/35°C

**** External UL-rated fuses required.

Typical electrical schematic



Features and benefits

Schaffner ECOsine™ harmonic filters represent an economical solution to the challenge of load-applied harmonics mitigation in three-phase power systems. With a plug-and-play approach and more compact dimensions than comparable products, they can be quickly installed and easily commissioned. They increase the reliability and service life of electric installations, help utilize electric sytem capacity better, and are the key to meet Power Quality standards such as IEEE 519.

ECOsine™ filters calm your harmonic waves. Schaffner ECOsine™ filters can be applied to virtually any kind of power electronics with front-end six-pulse rectifiers, where harmonic current distortion needs to be reduced to defined limits. Typical 690V applications, where the above-mentioned non-sinusoidal consumers of power can account for a significant portion of the load, include:

Typical applications

- Equipment with front-end six-pulse rectifier
- Motor drives
- Factory automation equipment
- Water/wastewater treatment facilities
- Fan and pump applications
- Oil and gas exploration
- Chemical industry

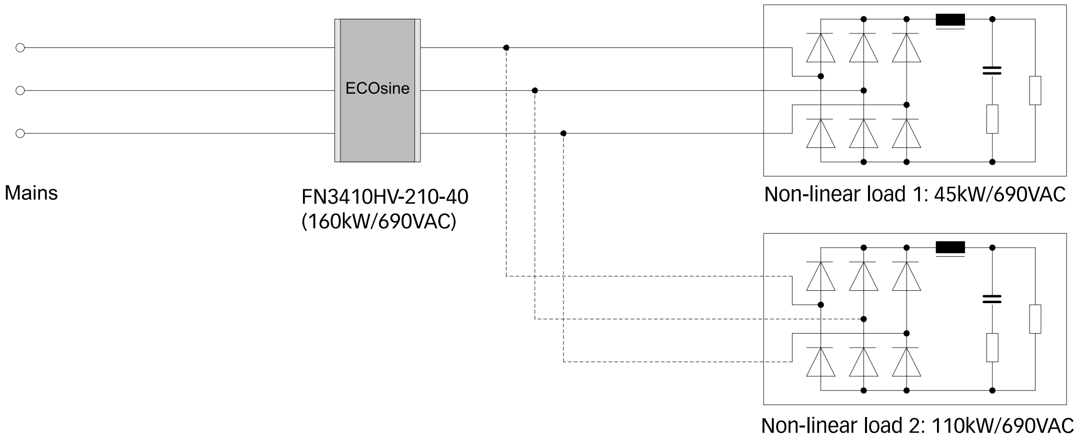
Filter selection table (50Hz)

Filter*	Rated load power @ 690VAC/50Hz [kW]	Power loss @ 25°C/50Hz [W]	Input/Output connections		Capacitor disconnections	Weight [kg]
FN341xHV-10-44	7.5	150	-44		-44	20
FN341xHV-13-44	11	209	-44		-44	21
FN341xHV-16-33	15	270	-33		-44	29
FN341xHV-24-33	18.5	333	-33		-44	33
FN341xHV-32-53	22	374	-53		-33	44
FN341xHV-38-53	30	480	-53		-33	48
FN341xHV-45-53	37	555	-53		-33	56
FN341xHV-60-35	45	610	-35		-34	58
FN341xHV-75-35	55	690	-35		-34	62
FN341xHV-90-35	75	860	-35		-34	77
FN341xHV-110-35	90	960	-35		-34	91
FN341xHV-150-40	110	1145	-40		-35	131
FN341xHV-180-40	132	1275	-40		-35	147
FN341xHV-210-40	160	1600	-40		-35	169
FN341xHV-260-99	200	1940		-99	-35	230
FN341xHV-320-99	250	2500		-99	-35	233

* To compile a complete part number, please replace the x with a 0 for diode or 1 for SCR rectifiers.
Filter to be selected by system voltage and load (motor drive) power. Note: the harmonic filter will reduce RMS input current. Therefore, filter selection by current rating, as it is common for EMC/EMI filters, is not suitable.

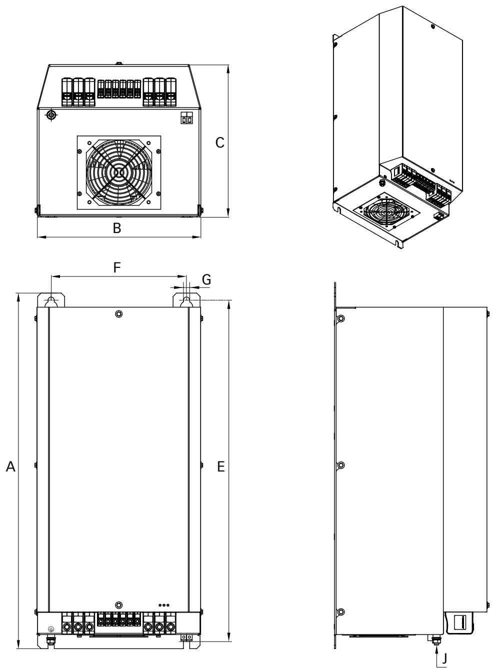
Filter application

ECOsine™ filters are best installed directly at the input of 6-pulse rectifiers. It is possible to connect several non-linear loads (e.g. motor drives) in parallel. In this case the rating of the filter must match the sum of the power ratings of drives connected to it. The use of a (built-in) DC-link choke is recommended for all motor drives 45kW and up for best harmonics mitigation performance and DC-link capacitor protection.

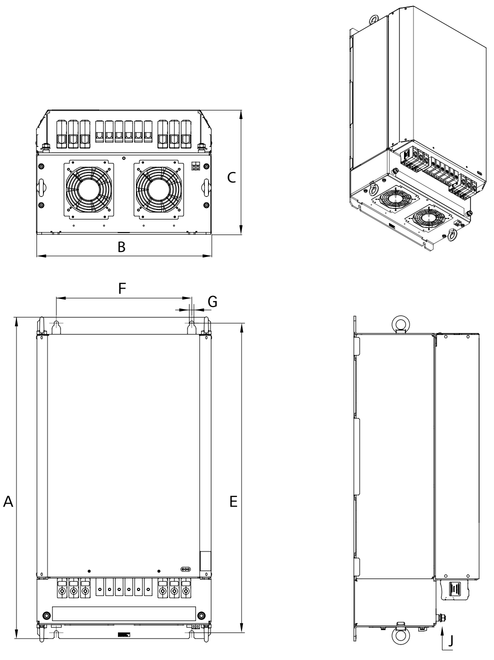


Mechanical data

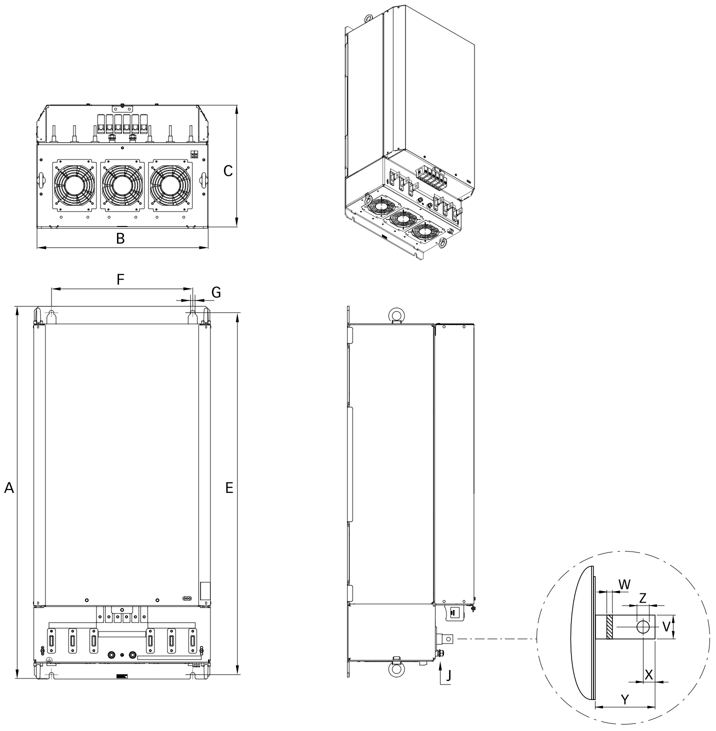
FN 3410HV / FN 3411HV-10 to -110



FN 3410HV / FN 3411HV-150 to -210



FN 3410HV / FN 3411HV-260 to -320



Filters with busbar terminals are shipped with a protective cover.

Installation

Detailed installation and wiring instructions as well as cooling requirements can be found in the Installation Manual available from every Schaffner sales point or from www.myecosine.com

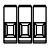
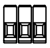
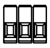
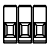
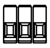
Dimensions

FN341xHV-...	10	13	16	24	32	38	45	60	75	90	110	150	180	210	260	320
A	430	430	520	520	590	590	590	750	750	750	750	830	830	830	1055	1055
B	210	210	250	250	300	300	300	320	320	320	320	450	450	450	500	500
C	210	210	280	280	300	300	300	300	300	300	300	320	320	320	360	360
E	410	410	495	495	565	565	565	725	725	725	725	800	800	800	1025	1025
F	170	170	200	200	250	250	250	270	270	270	270	350	350	350	400	400
G	9	9	11	11	11	11	11	11	11	11	11	11	11	11	13	13
J	M6	M6	M8	M8	M8	M8	M8	M10	M10	M10	M10	M10	M10	M10	M10	M10
V															25	25
W															6	6
X															12.5	12.5
Y															50	50
Z															11	11

All dimensions in mm; 1 inch = 25.4mm

Tolerances according to: ISO 2768-m / EN 22768-m

Filter connector cross sections

	–33 	–34 	–35 	–40 	–44 	-53 
Solid wire	16mm²	35mm²	50mm²	95mm²	10mm²	25mm²
Flex wire	10mm²	25mm²	50mm²	95mm²	6mm²	16mm²
AWG type wire	AWG 6	AWG 2	AWG 1/0	AWG 4/0	AWG 8	AWG 4
Recommended torque	1.5 – 1.8Nm	4.0 – 4.5Nm	7 – 8Nm	17 – 20Nm	1.0 – 1.2Nm	2.0 - 2.3Nm

Please visit www.schaffner.com to find more details on filter connectors.

Harmonic Filters

FN 3420 / FN 3430

ECOsine™ Active - the Compact, Fast, and Flexible Solution for Better Power Quality

energy efficiency and reliability

- Global or selective compensation of harmonic currents up to the 50th order
- Compensation of displacement power factor
- Load balancing capability
- Response time of less than 300 microseconds
- Compact solution for easy installation and intuitive operation

Approvals

FN 3420: 30A to 100A UL recognized
FN 3420: 200A to 300A UL listed

Technical specifications

Nominal operating voltage*:	380 to 480V ±10% (FN 3420: 3-wire)
	380 to 415V ±10% (FN 3430: 4-wire)
Operating frequency:	47 to 63Hz
Rated compensation current:	30 to 300A @ 40°C (FN 3420)
	30 to 300A @ 40°C (FN 3430)
Total harmonic current distortion THID**:	<5%
Total demand distortion TDD:	According to IEEE-519, table 10-3
Compensation capability:	Odd harmonics up to the 50th order
Response time:	<300µs
Protection category:	IP20 (30 to 100A)
	IP54 (200 to 300A)
Cooling:	Forced air cooling (30 to 100A)
	Forced air cooling, internal liquid cooling
	(200 to 300A)
Overload capability:	2.5x rated comp. current for 10ms (peak value)
Ambient temperature:	40°C, derating up to 55°C, 2%/K
Altitude:	1000m, derating up to 4000m, 1%/100m
Parallel operation:	Up to 5 filters
Interfaces:	Ethernet, RS485, ModBus
Controller topology:	Digital with FFT analysis
Current limitation:	Nominal current
Current transformers (not included):	100:5 to 50000:5
Design corresponding to:	UL 508, CE (LVD 2006/95/EC)
MTBF @ 40°C/400V:	Up to 100,000 hours

* different ratings upon request.

** depending upon the rated compensation current of the selected filter in relation to the compensation requirement.

Features and benefits

ECOsine™ Active is the new generation of active harmonic filters (AHF). It reliably mitigates harmonics and compensates voltage dips as well as reactive power.

ECOsine™ Active's functionality can be compared to waves in the ocean: If two waves of the same height and intensity meet, they cancel each other out. The same principle can be applied also to power networks. The AHF analyzes network disturbances and provides an opposing compensation current. In doing so, ECOsine™ Active actively adapts to fluctuations and responds in less than half a millisecond. Its compact dimensions, simple installation, and digital intelligence allow for a quick and straight forward integration in the most diverse applications.

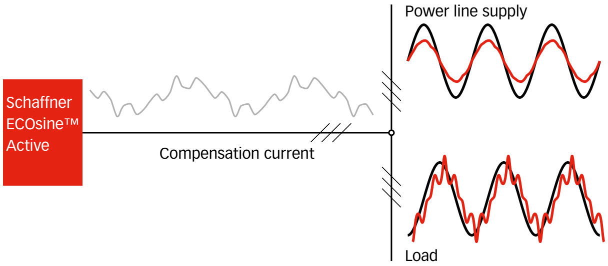
Typical applications

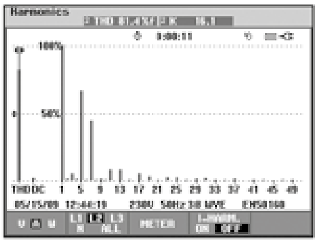
- Building automation
- Data and banking centers
- HVAC installations
- Machines and automation ship propulsion
- Tunnel ventilation
- UPS
- Motor drives
- Welding equipment
- Water/wastewater treatment
- Automotive manufacturing

Filter selection table

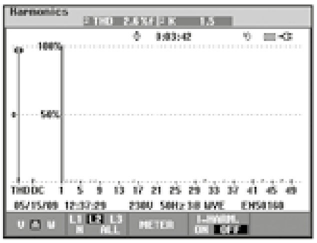
Filter*	Rated phase comp. current [A rms]	Rated neutral line comp. current [A rms]	Power loss [W]	Cooling air requirement [m^3/h]	Noise level [1m] [dB(A)]	Dimensions [WxHxD [mm]	Weight [kg]
FN 3420-30-480-3	30		<900	<350	65	360x590x290	47
FN 3420-50-480-3	50		<1300	<550	65	360x590x290	47
FN 3420-100-480-3	100		<2200	<1400	68	468x970x412	105
FN 3420-200-480-3	200		<5000	<2600	70	800x2000x760	415
FN 3420-250-480-3	250		<6000	<3100	70	800x2000x760	415
FN 3420-300-480-3	300		<7500	<3400	70	800x2000x760	415
FN 3430-30-400-4	30	90	<950	<400	63	415x840x300	70
FN 3430-60-400-4	60	180	<1800	<600	63	415x840x300	70
FN 3430-100-400-4	100	300	<3000	<1700	69	468x1460x412	145
FN 3430-200-400-4	200	600	<5500	<2800	70	800x2000x760	495
FN 3430-250-400-4	250	750	<6300	<3300	70	800x2000x760	495
FN 3430-300-400-4	300	750	<8500	<3600	70	800x2000x760	495

Block schematic



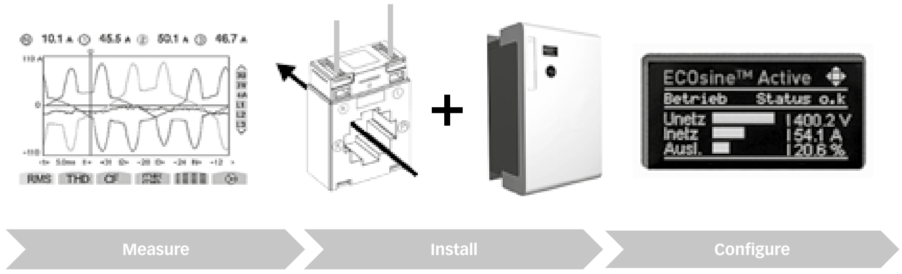


Without ECOsine™ Active:
Harmonics and reactive power stress the electrical installation and lead to problems



With ECOsine™ Active:
Reactive power and harmonics are actively compensated, thus ensuring better power quality

Plug-and-play: 3 simple steps to better power quality



For more details, please ask for the ECOsine™ Active brochure and the user manual.

2011/12

Basics in EMC and Power Quality

Introduction, Annotations, Applications

schaffner

energy efficiency and reliability

Basics in EMC and Power Quality

I Introduction 111

III Typical applications 152

IV Abbreviations **160**

V Index **161**

I Introduction

1 Sources of electromagnetic signals

Electromagnetic signals are the result of electrical currents and voltages. Whenever electricity is used to drive equipment, an electromagnetic signal ensues as well. These signals can be used to transmit information from one point to the next, or they can simply be a byproduct of the operation of equipment. Where the signals are unintended, we speak of electromagnetic noise. It is this noise that can cause equipment to malfunction, and manufacturers must therefore take steps to reduce the effects of noise.

In this chapter we will mainly look at the unwanted noise, but for the purpose of explanation we will sometimes also refer to intended signals. Most people are more aware of the intended signal transmission than of unintended signals.

1.1 Natural and technical sources of electromagnetic signals

To a certain extent, electromagnetic signals are natural phenomena. One of the best known phenomena is a lightning strike, which is nothing more than a huge current flowing from a cloud towards Earth. This current causes high electromagnetic fields. Other than that, we also have atmospheric radiation. These types of signals are comparably small and are generally not considered for EMC on an equipment level.

More important for our purposes are the technical sources of electromagnetic signals. Electrically powered equipment, as already mentioned, is one such source. In this category we can identify two main sources of electromagnetic noise: power supplies and motor drive systems. On the other hand, we also purposely generate signals in order to transmit them over a distance, as in a TV station. With the increase of communication and especially wireless services, this element is becoming more and more important.

1.2 Definition of noise

The intended generation of signals for information transmission is not considered noise, but it does have an impact on the overall EMC of equipment. This will come up again in a later chapter. In this chapter, our focus is on unwanted noise signals and their characteristics.

1.2.1 Frequency ranges

A key characteristic of electromagnetic noise is its frequency. The EMC standards generally cover the range from 0Hz to 400GHz. Currently, however, not all frequency ranges are completely regulated.

The first important frequency range is the range around the power network frequency, which in Europe is 50Hz. Most loads connected to the power network are non-linear loads, i.e., they draw a current that does not follow the sinusoidal voltage. Non-linear loads have the characteristic of generating additional currents at multiples of the network frequency. These currents are called harmonics and are generally considered up to the 40th or 50th order. In other words, our first frequency range starts at 50Hz and ends at 2kHz or 2.5kHz. For 60Hz networks, the range goes from 60Hz to 2.4kHz or 3kHz.

From the end of the harmonics range to 9kHz, we have a frequency range that is not currently regulated. We will come back to this in the “Power quality” chapter. Above 9kHz, the high-frequency range starts. This range is also called the radio-frequency or RF range.

Radio frequency is the collective term for all frequencies from a few kilohertz to several gigahertz. EMC standards limit the frequency range to 400GHz on the upper end, although test methods for such frequencies have not been defined yet. Current standards define testing methods from 9kHz to 1GHz, and some newer versions go up to 2GHz or higher. The technical progress today is faster than the development of standards. Computers and communication equipment use fundamental frequencies that are already above 2GHz. Looking at harmonic frequencies, even a 2GHz upper limit is no longer sufficient to cover RF problems.

The RF range is generally split into a conducted and a radiated range. For the lower part of the RF range, noise is expected to travel along lines rather than radiate from the equipment. The main reason for this is that the required antenna structures are bigger for lower frequencies. In other words, the physical size of most equipment is simply not sufficient to radiate low frequency noise. While an exact frequency cannot be defined, the standards generally set the conducted RF range from 150kHz to 30MHz. Some standards also start at the lower frequency of 9kHz. The radiated range then starts at 30MHz. The upper limit of this range depends on the standard, but it will generally be about 1GHz, for some products 2 or 3GHz. To summarize, we have the following ranges:

Harmonics	LF range	Conducted RF range	Conducted RF range	Radiated RF range	Radiated RF range
🟥	⬜	⬛	🟥	🟥	⬜
50Hz - 2/2.5kHz 60Hz - 2.4/3kHz	2/2.5Hz - 9kHz 2.4/3kHz - 9kHz	9kHz - 150kHz	150kHz - 30MHz	30MHz - 1/2/3GHz *	Above 3GHz

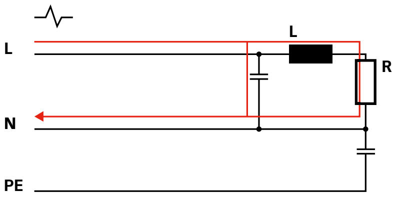
🟥 Regulated range
⬜ Unregulated range
⬛ Regulated range for some products
* Upper limit depends on product

Definition of frequency ranges

The defined testing methods for these frequency ranges are explained in a later chapter.

1.2.2 Differential-mode noise

Looking at conducted signals, noise can occur between any two lines of the system. In a single-phase system this could be between phase (P) and neutral (N) lines. In a three-phase system it could be phase 1 (R) and phase 2 (S). In DC systems, the noise can travel from plus to minus. Such noise is called differential-mode noise or symmetrical noise. The picture below shows differential-mode noise in a single-phase system.

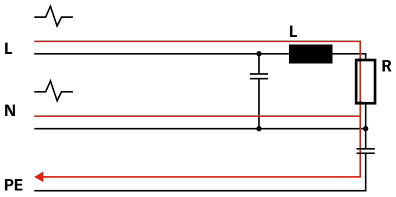


Differential-mode noise in single-phase systems

Differential-mode noise is a result of parasitic components in a circuit, such as equivalent series inductance (ESL) or equivalent series resistance (ESR) or components. In an electronic system, differential-mode noise usually occurs at lower frequencies and is commonly associated with the switching frequency of a switch-mode power supply or a motor drive.

1.2.3 Common-mode noise

Noise can also be conducted from any line in the system towards earth. In a single-phase system, signals could go from L and P towards earth. This type of noise is then called common-mode noise. The main difference is that common-mode noise travels in all lines in the same direction and then towards earth. The picture below shows common-mode signals in a single-phase system.



Common-mode noise in single-phase systems

Common-mode noise results from stray capacitances in a system, often occurring between semiconductors and heat sinks. It is more often found in the higher frequency range.

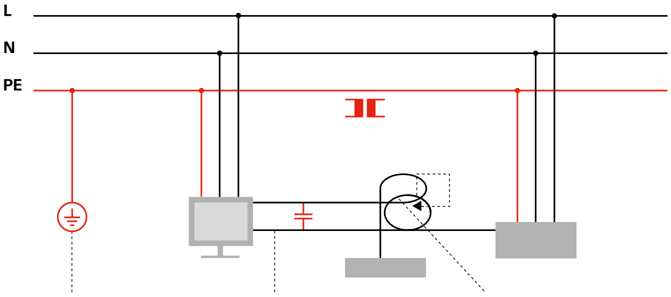
When we look at the measurements later, we will see that the result of the measurement does not make the differentiation between the two types of noise. For noise suppression, however, it is crucial to understand what kind of noise signal we are dealing with.

1.3 Noise propagation

Electromagnetic signals are generated in electrical and electronic systems and can then propagate inside the system or even outside. This propagation can work along lines or through radiation. These coupling paths are explained in the following paragraphs.

1.3.1 Coupling methods

Looking at the connections in an electrical or electronic system, we can identify three different coupling paths. One is galvanic coupling, which requires a direct connection between the single parts of the system. Second is capacitive coupling, which can happen when two cables of the system are routed close to each other, thus forming a parasitic capacitor. Where cable loops of different cables are laid out too close to each other, inductive coupling can occur.



Galvanic coupling e.g. through common earth

Capacitive coupling e.g. through parallel lines

Inductive coupling e.g. through cable loops

Coupling paths between systems

Galvanic coupling effects often ensue due to common ground connections. Capacitive coupling is typical for industrial applications, where power and signal lines are laid parallel over long distances.

1.3.2 Radiation

Noise can not only propagate along direct connections but also through the air via radiation. Once HF signals are generated inside a system, they are simply propagating along the path of least resistance. If the structure or layout of the system provides good antenna characteristics, the signals will use those parasitic antennas and radiate from the system into the air. There, the noise travels as electromagnetic waves and can be picked up by other equipment along its path.

2 Legal requirements

2.1 Global legislation

Electromagnetic phenomena and their effect on electric and electronic equipment have compelled many countries to implement measures that ensure the proper operation of equipment. Originally, most requirements came from military sectors and civil aviation, where the need for flawless operation of equipment is strongly related to the safety of people. Only later, when the use of electronic components expanded into almost every aspect of our lives and wireless transmission and communication systems became increasingly important, did requirements for electromagnetic compatibility expand into other civil sectors.

Legislation in various countries produced regulations and standards with which equipment has to comply. Since legislative systems vary from country to country, the compliance schemes used in each country are also very different. Where some schemes entail strong legislation and mandatory approval rules, others rely on voluntary registration and manufacturers' responsibility.

2.1.1 CE marking for the European Union

The concept of CE marking tries to reduce the huge number of national approvals by introducing harmonized rules. These rules are written in the EU directives. The directives as such are not legally binding to manufacturers, but all member countries are obliged to convert any approved directive into national law within a given period of time. Any failure to do so is a direct violation of European law, and the member state doing so will be punished.

The CE marking in this context is the mark of the manufacturer, indicating that the product is in compliance with all applicable directives. In addition to the CE marking, the manufacturer has to prepare a declaration of conformity stating that the described product is in compliance with the directives.

CE mark

This was meant to make trading easier for manufacturers, since they do not have to go through the ordeal of national approvals for each country. This requires, however, that manufacturers know which directives exist, are approved and apply to each of their products. The EU does not offer comprehensive information on this topic. For this reason, the European system is very often regarded as difficult and prohibitive.

As mentioned before, the rules are defined in the European directives, which are then converted into national laws. As one example, the EMC directive with the title 89/336/EU was converted into law in each member state, such as the German EMC Act from November 1992. Each directive also defines the conformity procedures that can be used to show compliance with the directive. The directives contain the technical contents to be harmonized. They do not contain any guidelines about implementation and fining systems. As a result, non-compliant equipment can lead to a fine in one country but imprisonment in another.

The EU has produced a number of basic directives, such as the CE marking directive, with the purpose of defining procedures applicable to many other directives. One directive defines all existing conformity procedures. However, not all of these procedures can be used for all directives.

Typical conformity routes are modules A (self-declaration), B (competent body) and H (notified body). Other conformity routes would be type approvals in connection with a certified quality system (medical directive).

The scope of the EMC directive is very general. All products likely to emit or be susceptible to electromagnetic energy are covered. To show compliance with the directive, products must not emit EM energy in an amount sufficient to affect other equipment. At the same time, each piece of equipment must be sufficiently immune against EM energy from other sources.

This leaves a lot of room for interpretation and speculation, and the EU soon released an unofficial document providing guidance on the EMC directive. A new version of the EMC directive is also forthcoming to further clarify the gray areas of the initial directive.

However complicated the EMC directive may seem, it still covers its main purpose. It removes the necessity to test to various national standards and guarantees acceptance in all EU member states.

The conformity routes permitted by the EMC directive are self-declaration, competent body route and EC-type approval by a notified body. This is due to change in the new directive, however, where the institution of a competent body is completely removed and only notified bodies remain. The self-declaration route is a way for manufacturers to take care of their approvals without involving any third parties. For the EMC directive, conformity can be assumed if the product is in compliance with existing harmonized EMC standards. We will explain the system of harmonizing standards in a later chapter. The manufacturer can therefore test its product against these standards and then declare the conformity.

Where harmonized standards do not exist or testing is uneconomical, the manufacturer has the option of involving a competent body. The manufacturer prepares a technical construction file (TCF), which should contain all EMC-relevant information, including testing data. The TCF is then checked by the competent body, and if the EMC concept is clear and acceptable, the competent body will issue a certificate.

For radio transmitting devices (for example, radio telephones), the involvement of a notified body is mandatory. The manufacturer has to submit documents and one sample to the notified body for testing and approval.

As mentioned before, the situation with competent and notified bodies will change in the future. The new directive no longer contains the competent body approval route. The notified body will assume the tasks of the competent body. However, the involvement of notified bodies is no longer mandatory, even if harmonized standards are not used. Approvals of radio transmitting devices are no longer in the scope of the EMC directive, having been handled for some time now by the telecom directive. The changes from this new EMC directive will come into effect on July 20, 2007, with an additional two-year transition period.

2.1.2 CCC and CQC approvals for China

CQC develops voluntary product certification services called CQC Mark Certification for products that fall outside the compulsory certification catalog. The aim is to protect consumers and property, safeguard consumer rights and interests, improve the product quality of domestic enterprises, increase product competitiveness in the international market and facilitate the access of foreign products to the domestic market. CQC, as the body that earlier conducted quality certification activities and a high authoritative body in China, is a brand well known in the world. This, in turn, can greatly enhance the brand image of the enterprises it certifies.

In December 2001, the State General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China issued the regulations for compulsory product certification. The Compulsory Product Certification System began to replace the original Quality License System for Commodity Inspection and Safety Certification System for Electrical Equipment. The abbreviation of the China Compulsory Product Certification is CCC or 3C. It is the statutory compulsory safety certification system and the basic approach to safeguarding consumer rights and interests and protecting personal and property safety adopted widely by international organizations.

China Compulsory Certification System came into force on May 1, 2002. In accordance with the joint announcement no. 38 [2003] by the State General Administration for Quality Supervision and Inspection and Quarantine of the People's Republic of China and the Certification and Accreditation Administration of the People's Republic of China, the date for implementing the supervision and management of the market for compulsory product certification was set as August 1, 2003.

The compulsory product certification requirements cover 135 products divided into 20 categories, including household appliances, motor vehicles, motorcycles, safety goggles, medical devices, lighting apparatuses, cables and wires. CQC has been appointed to undertake the work of compulsory product certification for 17 categories within the CCC catalog.

2.1.3 FCC registrations for the USA

Approvals for the American market are usually related to the Federal Communications Commission (FCC). The FCC is an independent United States government agency, directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and U.S. possessions. The most commonly referred to regulation is part 15, which covers all commercial products. Like the European standards, the FCC rules define environments for residential and industrial areas.

Equipment used in residential areas requires verification and certification. The equipment has to be tested in a test site and by testing personnel listed by FCC.

In recent amendments to the rules, FCC now enables manufacturers to use the same testing methods as laid out in CISPR 22, with only minor additional rules. Other commonly used rules of the FCC are the parts 18 for industrial equipment and 68 for telecommunication equipment.

Approvals according to FCC regulations are straightforward for manufacturers. However, the approval can only be used for the American market. Manufacturers who wish to sell the same product in Canada, Mexico or even the European market must go through completely different approval procedures.

2.1.4 EMC framework in Australia/New Zealand

One of the newer EMC schemes is the EMC Framework covering Australia and New Zealand. The Framework takes a very similar approach to Europe, giving manufacturers more responsibility in the marketing of their products. The EMC Framework came into effect on January 1, 1997. It covers all electric and electronic products to be sold on the Australian and New Zealand markets.

The authority for all related matters is the Australian Communication Authority (ACA). As in the U.S. model, the main goal of the EMC Framework is the protection of essential radio and broadcast services and the minimization of electromagnetic interference. For this reason, immunity testing is required only for radio and broadcast equipment. For all other equipment, only emission requirements apply. In addition, the Framework only applies to commercial, residential and light industrial environments.

As in Europe, the EMC Framework defines different compliance routes. The manufacturer can choose the self-declaration route or the involvement of a competent body. Accredited testing is required only when the competent body is involved. In all other cases, it is recommended but not mandatory. All standards for Australia are produced by Standards Australia, but as mentioned previously, they are based on international or European standards.

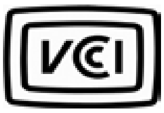
The ACA introduced the C-tick mark as its conformity mark. Like the CE marking, the C-tick mark shows compliance with regulations – in this case, the relevant EMC standards. However, there are two preconditions for a manufacturer to use this mark. First, the manufacturer must be represented in Australia. This can be through a branch office or an authorized representative. Second, the manufacturer has to register with the ACA, but only for the initial use of the C-tick mark.

C-tick mark

Like in Europe, market access can be very easy for well-informed manufacturers. Third-party approvals are not generally required and manufacturers can market their products on their own responsibility.

2.1.5 VCCI registrations for Japan

The Japanese scheme is quite different. In 1985 four organizations – the Japan Electronic Industry Development Association, the Japan Business Machine Makers Association, the Electronic Industries Association of Japan, and the Communications Industry Association of Japan – jointly established the Voluntary Control Council for Interference by Information Technology Equipment and Electronic Office Machines (VCCI) to cope with radio interference problems arising from personal computers, word processors, facsimile terminals and other similar electronic equipment. The system is completely voluntary, but strongly supported in Japan. Selling equipment without VCCI registration and the VCCI mark is legally possible, but the product will fail from a marketing point of view.



VCCI mark

As the name of the VCCI already says, the scheme currently applies only to ITE (information technology equipment). The implemented standard requires the same limits as CISPR 22. The classes A and B from the CISPR publication are transferred to classes 1 and 2, respectively.

One drawback of the scheme is that only members can register products and display the VCCI label. In other words, manufacturers who wish to register their products with VCCI must first become members.

2.1.6 Other international requirements

A worldwide movement is in progress to implement compliance schemes for product safety and EMC. Argentina and Taiwan are among the most recent countries to join this trend, and many others are following. In both fields, there is a clear tendency towards international standards. However, most countries still require approvals and certifications that can only be issued by governmental organization or accredited institutions.

2.2 EMC standards

In the past, most countries had their own regulations and standards governing electromagnetic interference (EMI) or radio frequency interference (RFI). Then, on January 1, 1992, the European Directive 89/336/EEC on electromagnetic compatibility (EMC) came into force. This directive brings a common approach to EMC to every member state

of the European Union. Common standards will be used throughout Europe to ensure that technical trade barriers are removed. As well as controlling EMI emissions from equipment, the directive also calls for equipment to be immune to external electromagnetic disturbances.
The task of elaborating the standards to be used has been assigned the European organization called CENELEC. Most of the European standards will be based upon international standards from CISPR and IEC. The numbering system used in the European standards is:

EN xxyyy. EN = European Norm. xx = 50 denotes that the standard is a standard of CENELEC origin. yyy is just a continuous number. The EMC product standard for machine tools, EN 50370, is one such example. If xx = 55, the standard is based on a CISPR standard yyy. CISPR 13 therefore becomes EN 55013. Standards based on an IEC standard yyy are indicated with xx = 60. The numbering for these standards is harmonized between IEC and CENELEC, and as a result, these standards are often described like IEC/EN 61800-3, which would be the EMC product family standard for power drive systems.
Once the European standard is complete, the individual members of the European Union will create national harmonized standards, usually assigning their harmonized standard a national number. For example, the British harmonized standard of EN 55011 is BS EN 55011.

2.2.1 Standard classification

The standards in the international system are divided into three different categories.

Basic standards describe the general and fundamental rules for meeting the requirements. Terminology, phenomena, compatibility levels, measurement, test techniques and classification of EM environments are so described within. The EN 61000-4-x series of standards are the best known examples for basic standards.

Generic standards refer to specific environments. They set minimal EMI levels that equipment in these environments must meet. Where no product-specific standards exist, the generic standards are to be used. Generic standards describe household and industrial EMI environments. Examples of generic standards are EN 61000-6-1/2/3/4.
Products standards are for specific products or product groups. These standards are coordinated with the generic standards.

Product standards always take precedence over generic standards. If a product or product family standard exists for a certain product, the manufacturer must use this standard. Only in the absence of a product standard can the manufacturer use generic standards.

Overview of common product-related standards (excerpt)

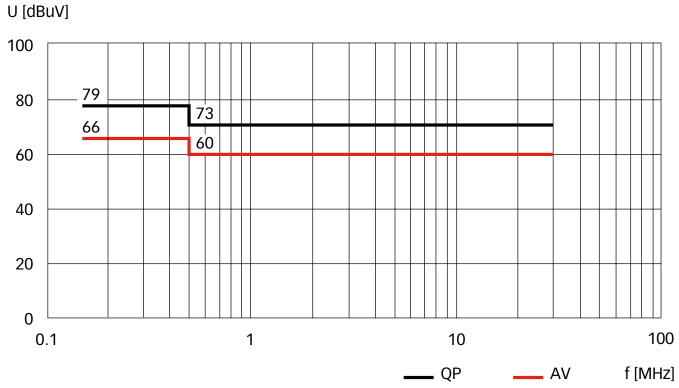
Product type	Emission	Immunity
Household appliances and portable tools	EN 55014-1	EN 55014-2
Vacuum cleaners	EN 61000-3-2	
Laundry machines	EN 61000-3-3	
Heating		
Cooking equipment		
Luminaries	EN 55015	EN 61547
Discharge lamps	EN 61000-3-2	
Fluorescent lamps	EN 61000-3-3	
Home electronics	EN 55013	EN 55020
Amplifiers	EN 61000-3-2	
Audio players	EN 61000-3-3	
Radio, TV receivers and decoders		
IT equipment	EN 55022	EN 55024
Computers	EN 61000-3-2	
PC periphery equipment	EN 61000-3-3	
Copy machines		
Equipment for data & voice transmission on low voltage networks (3 to 148.5kHz)	EN 50065-1	EN 61000-6-1/-2
Power line communication		
Power supplies with DC output	EN 61204-3	EN 61204-3
Switch mode power supplies	EN 61000-3-2	
DC/DC power converters	EN 61000-3-3	
Uninterruptible power supplies	EN 50091-2	EN 50091-2
	EN 61000-3-2	
	EN 61000-3-3	
Motor speed control equipment	EN 61800-3	EN 61800-3
Frequency inverters		
Current converters		
Servo drives		
Electrical medical devices	EN 60601-1-2	EN 60601-1-2
X-ray equipment		
CAT-scanners		
Machine tools	EN 61000-6-4	EN 50370-2
Lathing machines	(to be replaced by EN 50370-1)	
Grinding machines		
CNC centers		
Scientific equipment	EN 55011	EN 61000-6-1
Measurement equipment		EN 61000-6-2
Laboratory equipment		

Generic standards (if no product standards applicable)	Emission	Immunity
Residential, office and light industrial environment	EN 61000-6-3	EN 61000-6-1
Industrial environment	EN 61000-6-4	EN 61000-6-2

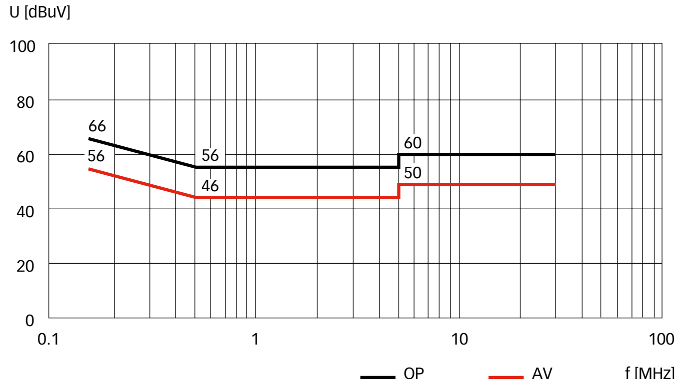
2.2.2 Common limit lines

The various standards set down limits for conducted and radiated EMI emission. These limits are defined in dBμV for the conducted voltage and dBμV/m for the radiated field strength. The reference values are 1μV for 0dBμV and 1μV/m for 0dBμV/m.

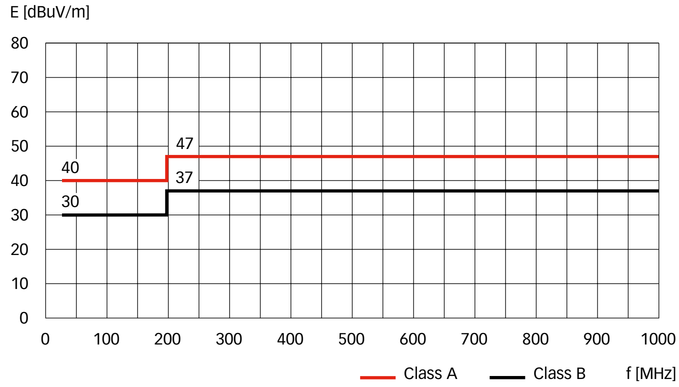
Typically, limit lines are defined separately for residential areas and industrial areas. These two areas are represented by two classes of limits: class A represents the industrial environment; class B defines the limits for residential areas. While a number of different limit lines exist for the various standards, the class A and B limits of EN 55011 and EN 55022 have become the reference limits for most standards.



Limits for line conducted voltage class A (EN 55011/22)



Limits for line conducted voltage class B (EN 55011/22)



Limits for radiated field strength classes A and B (EN 55011/22)

The respective measurement methods for conducted and radiated emission measurements are described in a later chapter.

2.3 Safety approvals

The UL mark stands for “listed” and identifies units whose use for the generally accepted applications in the relevant field is not restricted. Here at Schaffner, we feature the UL mark on medical and safety facility filters and power quality products.

The mirror image “RU” stands for “recognized” and identifies tested products or components that are subsequently used in UL-certified end products, machines or systems. A good share of our standard and customized components such as chokes and filters bear this label.

Recognized component mark for Canada and the United States. This UL Recognized Component mark, which became effective in April 1998, may be used on components certified by UL to both Canadian and U.S. requirements. Although UL had not originally planned to introduce a combined Recognized Component mark, the popularity of the Canada/ U.S. Listing and Classification marks among clients with UL certifications for both Canada and the United States led to this mark.

The ENEC mark for lighting components, IT equipment, transformers, equipment switches, control units, clamping devices and connector plugs, capacitors and RFI suppression components documents the uniform Europe-wide certification in the ENEC procedure according to EN standards.

A CSA mark on its own, without indicators, means that the product is certified primarily for the Canadian market for the applicable Canadian standards. If a product has features from more than one area (such as electrical equipment with fuel-burning features), the mark indicates compliance with all applicable standards.

China Quality Certification Center (CQC). CQC develops voluntary product certification services called CQC Mark Certification for products not subject to compulsory certification. The objective is to protect consumers, ensure the safety of persons and property, safeguard the rights and interests of users, improve the product quality and international competitiveness of Chinese enterprises, and facilitate the import of foreign products to China.

2.3.1 EMC testing as a service

The fully equipped Schaffner EMC testing laboratory with its trained personnel is dedicated primarily to testing and measuring our own products. However, we also provide EMC testing as a service. Schaffner is ISO 9001:2000-certified and the test center is ISO/IEC 17025-accredited. The scope of services even encompasses mobile testing vehicles.

These mobile EMC labs make it possible to conduct testing and interpret the results right at the customer's site.

2.3.2 The test

Prototypes are subject to the most stringent standards. In the EMC laboratory, for example, prototypes are checked for electromagnetic compatibility. In the test center, their surge and short-circuit protection is checked, while continuous load testing is used to gauge their reliability. Environmental compatibility begins with the selection and testing of materials, the use of environmentally friendly manufacturing processing and compliance with the latest standards worldwide.

3 EMC measurements

3.1 Emission

Emission is every electromagnetic disturbance that is produced by the equipment under test (EUT) and given off to the environment. If we look at a portable telephone with a base station, for example, the telephone emits the communication signal and the base station receives it. This kind of emission is intended and necessary for the correct operation of the equipment. Every government has the task of controlling these intended emissions by controlling the frequencies of operation and requiring special approvals.

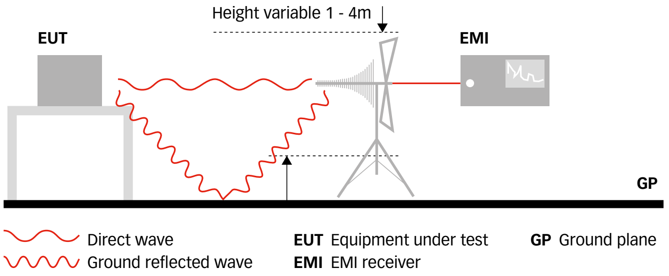
However, most electric and electronic equipment also produces a lot of unintended emission that is not necessary for the operation – that is, emission as a kind of waste product. To guarantee the proper operation of other equipment in the vicinity, this unintended emission must be limited. This unintended emission can be spread over a vast frequency range, starting from the power network frequency (50Hz for Europe) up to several GHz (gigahertz = 1 billion cycles per second).

Signals can generally be transmitted through air or along cables, resulting in radiated and conducted emission.

3.1.1 High-frequency (HF) radiated emission

While there is no fixed definition as to where high frequency starts, EMC authorities typically consider everything from a few kHz (kilohertz = 1000 cycles per second) upwards to be HF. In the EMC field, the term radio frequency (RF) is often used instead of HF.

Air-transmitted interference, called radiated emission, can be measured with a receiving antenna on a proper test site. The following picture shows a sample setup.



Radiated emission test on an open-area test site (OATS)

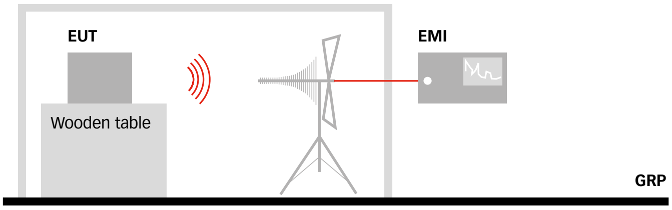
The classic radiated measurement according to common standards is performed on an open area test site (OATS). The minimum ground plane area as given in CISPR 22 should be regarded as indicative only; the true measure of an OATS is its calibrated normalized site attenuation (NSA), and meeting this will normally require a larger ground plane area. Maintaining a large area free of obstructions (including wooden buildings) is also important.

The ground plane is necessary to regularize reflections from the ground surface, and the antenna height scan deals with the nulls that inevitably result from the presence of the ground plane. The height scan is not intended to measure emission from the EUT in the vertical direction. Only the horizontal plane of emission as given by the azimuth rotation of the EUT is tested.

Any open area test site is likely to suffer from ambient signals, that is, signals that are generated in the neighborhood and received on the site but not emitted from the EUT. These signals can easily exceed both the emission of the EUT and the limit values at many frequencies. An emission plot which contains ambients is hard to interpret, and more importantly, ambients that mask EUT emission make it impossible to measure the EUT at these frequencies. There is no foolproof method whereby ambient signals can be subtracted from an emission measurement.

Other problems of OATS can be unwanted reflections from objects that are not within the defined borders but that nonetheless can reflect the EUT signal back to the antenna. It should also be noted that objects that do not appear to be reflecting normally can begin doing so under certain circumstances. A tree would surely not be suspected of reflecting electromagnetic waves, but if it is wet after a rain shower, it definitely would.

In order to avoid problems with the OATS, alternative testing methods are under investigation. The first one that was also approved by EMC standards was the anechoic chamber. The outer hull is an RF-tight shielded chamber that keeps out the ambient signals. Measurement in such a chamber would be impossible, however, since the reflections inside cannot be controlled and the measurement result could not be compared to OATS measurements.



EUT Equipment under test
GRP Ground reference plane
EMI EMI receiver

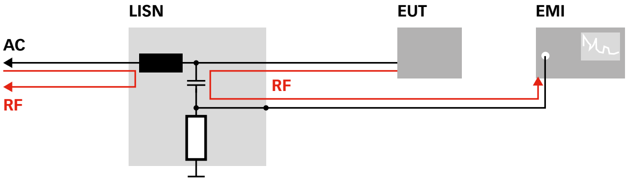
Radiated emission test in an anechoic chamber

In order to prevent reflections, the walls of the chamber are lined with absorbing material. Modern chambers achieve this through a combination of ferrite material, usually in the form of tiles glued directly to the wall, and cone-shaped foam absorbers on top of the tiles. The tiles work excellently in the lower frequency range, but their performance deteriorates with increasing frequencies. Foam cones work well in any frequency range, but their size is directly related to the wavelength, so at low frequencies, cones must be very long to be effective, meaning that the shielded chamber must also be much bigger. The combination of cones and tiles has proven practical and economical.

3.1.2 High-frequency conducted emission

Conducted emission is any emission transported from equipment to the environment along cables. The main emphasis in measuring line-conducted emission is placed on the AC mains input of the EUT, though other interface ports are becoming more and more important, like telecom and network ports on information technology equipment.

In order to measure conducted emission, a line impedance stabilization network (LISN) is inserted into the mains power supply of the EUT. Newer standards call this network artificial mains network (AMN). The LISN leads the RF signals from the EUT to the output for the measurement receiver, while at the same time blocking the AC input voltage from the receiver. According to the standard, the highest emission on each of the phases has to be recorded, but in common practice a peak measurement is performed on one phase, and only if the measured emission is within a defined margin from the limit will the testing be performed with average (AV) and quasi-peak (QP) detectors on all phases.



LISN Line impedance stabilization network
EUT Equipment under test
EMI EMI receiver

Measurement principle for line-conducted voltage measurements

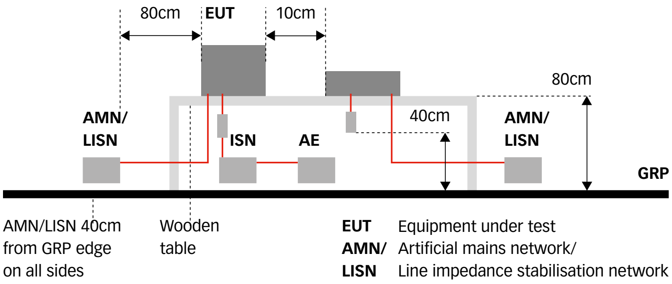
The CISPR quasi-peak and average detectors weigh the indicated value according to its pulse repetition frequency (PRF). Continuous interference is unaffected; the indicated level of pulsed interference is reduced by a defined degree based on the time constants and bandwidths defined in CISPR 16. A receiver is calibrated using pulses of a defined impulse area, spectral density and repetition rate.

It is normal practice to perform initial emissions testing with the peak detector. Provided that the receiver dwells on each frequency for long enough to capture the maximum emission – this depends on the EUT's emission cycle time – the peak detector will always give the maximum output level. A list of frequencies at which high emissions are detected is created, and these frequencies are revisited individually with the quasi-peak (and average, for conducted emissions) detectors, which will give the reading to be compared against the limit.

The ground reference plane (GRP) is an essential part of the conducted emission test. A proper measurement is impossible without a GRP. Even a Class II EUT without safety earth connection must be tested over a GRP, since it provides a return path for stray capacitance from the EUT. The GRP should be:

- at least 2m x 2m, and at least 0.5m larger than the boundary of the EUT;
- made of copper, aluminum or steel, though the thickness is not too important;
- bonded to the local supply safety earth (this is for safety only and not necessary for the measurement);
- bonded by a very short, low-inductive strap to the reference terminal of the AMN/LISN. A length of wire is not adequate for repeatability at the higher frequencies. The AMN/LISN should preferably be bolted directly to the GRP.

For table-top apparatuses, different standards allow the GRP to be either vertical or horizontal, but all require the closest face of the EUT to be maintained at a distance of 40cm from the GRP and at least 80cm from all other conductive surfaces. This is typically achieved with a wooden table either 40cm high off a conducting floor used as the GRP or 80cm high and 40cm away from a conducting wall used as the GRP. Floor-standing EUTs should be placed on a conducting floor used as the GRP but not in electrical contact with it. The distance between the boundary of the EUT and the closest surface of the AMN/LISN must be 80cm. The mains lead from the EUT to the AMN/LISN should preferably be 1m long and raised at least 10cm from the GRP for the whole of its length. Longer mains leads may be bundled non-inductively, but this introduces considerable variations into the results, and it is preferable to shorten them to the standard length. Alternatively, provide a standard wooden jig such that the bundling can be done in a repeatable manner. The following picture shows the setup as defined in the measurement standard.



EUT	Equipment under test
AMN/ LISN	Artificial mains network/ Line impedance stabilisation network
ISN	Impedance stabilization network
AE	Auxiliary equipment
GRP	Ground reference plane

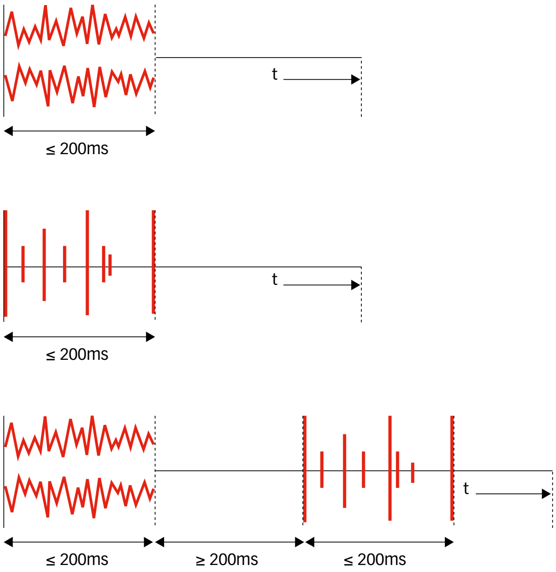
Standard compliant setup for conducted emission measurements

Mains-powered peripherals that are necessary for the operations of the EUT but not themselves under test should be powered from a separate artificial mains network (AMN) or LISN. Other connected leads should be terminated in their normal loads but not extend closer than 40cm from the GRP. The measurement should be well decoupled from any external disturbances. These can be coupled into the setup either via the mains supply or by direct coupling to the leads. Although the AMN/LISN will reduce both the noise on the mains supply and variations in the supply impedance, it does not do this perfectly, and a permanently installed RF filter at the mains supply to the test environment is advisable. Ambient radiated signals should also be attenuated, and it is usual to perform the measurements inside a screened room, with the walls and floor of the room forming the ground reference plane. However, a fully screened room is not essential if ambient signals are at a low enough level to be tolerated.

3.1.3 Discontinuous interference (clicks)

Domestic appliances, power tools and certain other products need to be measured for discontinuous interference in the frequency range of 150kHz to 30MHz. Because the interference generated by such products is not periodic, the limits are relaxed compared to continuous limits.

The relevant standard was designed to allow products' interference levels to be suppressed according to annoyance levels. Hence, emissions must be measured for their amplitude, duration and repetition rate, to determine whether the interference is discontinuous – a "click" – or continuous, as defined in the standard.

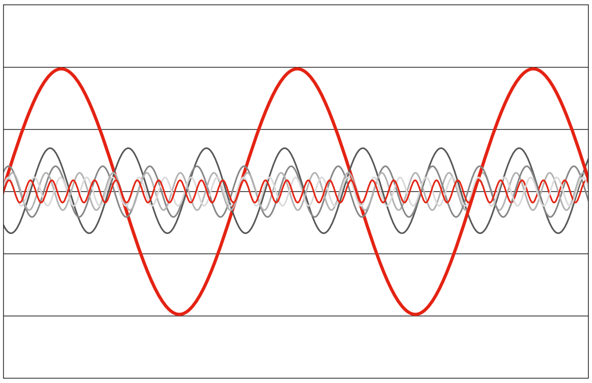


Definition of clicks

Once the discontinuous interference has been quantified, corrected limits can be applied. Such a process is complex, difficult and prone to errors if measurements are made manually. For accurate and repeatable results, automated analysis is necessary.

3.1.4 Mains harmonics

In general the public mains power supply voltage waveform is sinusoidal, which means that it includes only the fundamental frequency (50 or 60Hz) without any harmonic multiples of this frequency. Purely resistive circuits such as filament lamps or heaters, when powered from the mains, draw a current that is directly proportional to the applied voltage, and do not create any extra harmonic components. By contrast, non-linear circuits do draw a non-sinusoidal current, despite the applied voltage being sinusoidal. All non-linear currents, however, will cause harmonics currents, i.e., currents with frequencies that are integer multiples of the supply frequency.



Mains current with harmonics

Traditionally, harmonic pollution was only a concern for larger installations, particularly for power generation and distribution and heavy industry. But the modern proliferation of small electronic devices, each drawing perhaps only a few tens or hundreds of watts of mains power, and usually single-phase (such as personal computers), has brought the problem of mains harmonics to the fore even in domestic and commercial applications. Of all the above examples, it is the electronic DC power supplies that are causing the most concern due to the increasing numbers of electronic devices such as TV sets in domestic premises, information technology equipment in commercial buildings and adjustable-speed drives in industry.

The difficulties caused by harmonic pollution can be divided into two categories: those caused by the harmonic currents themselves and those caused by voltage waveform distortion resulting from the harmonic currents flowing in a finite supply source impedance.

The principal problem with the harmonic currents is that they can cause overheating in the local supply distribution transformer if it is inadequately rated, or if it is rated on the assumption of low harmonic levels. Power factor correction capacitors can overheat as well, due to the much higher harmonic currents they experience because of their lower impedance at higher frequencies, leading to failure.

Harmonic currents in the neutral conductors of three-phase supplies present reliability and safety risks, where neutral conductors have not been suitably dimensioned. Many modern installations use neutral conductors of the same cross-sectional area as their associated phase conductors, and some (usually older) buildings are known to use half-size or smaller neutral conductors. Unfortunately, emission of “triplen” harmonics (multiples of 3: 3, 6, 9, 12, etc.) add constructively in neutral conductors and can reach 1.7 times the phase current in some installations. Overheating of conductors is aggravated by the skin effect, which tends to concentrate higher frequency currents towards the outside of the conductor, so that they experience greater resistance and create more heating effect.

A further result of harmonic currents, especially when they leak into the earth network, is increased magnetic interference with sensitive systems operating in the audio band, such as induction loop installations.

The non-sinusoidal current drawn from the supply causes distortion of the supply voltage, since the inductance of the supply increases the source impedance as the harmonic order rises. This waveform distortion can cause serious effects in direct-on-line induction motors, ranging from a minor increase in internal temperature through excessive noise and vibration to actual damage. Electronic power supplies may fail to regulate adequately; increased earth leakage current through EMI filter capacitors due to their lower reactance at the harmonic frequencies can also be expected.

System resonance effects at the harmonic frequencies can create areas of the power distribution network where the voltage is more heavily distorted than elsewhere and/or has significant over-or under-voltage. Also, some areas of the network can suffer from much higher levels of current than elsewhere, at a few harmonic frequencies.

Common standards for harmonics are the IEC/EN 61000-3-2 and the U.S. standard IEEE 519. IEC/EN 61000-3-2 bases its requirements on an equipment level, i.e., the standard defines limit values for harmonic currents that must be fulfilled by each individual piece of equipment. The IEEE 519 looks at harmonics from an installation point of view. Rather than looking at equipment, this standard measures harmonics at the point of common coupling, i.e., where equipment of one installation starts to interact with equipment from a second installation.

3.1.5 Voltage fluctuations and flicker

When loads are being switched on and off constantly, the voltage supply will experience fluctuations and changes that cannot be compensated fast enough. Although not directly influencing other equipment, such fluctuations can become an annoyance if electric light connected to the same supply unit changes varies to the fluctuations. The subjective impression of such light changes are called flicker and represent varying brightness or intensity. Above a certain level, flicker can be disturbing or even harmful to one's health. To avoid such problems, the voltage changes resulting from any equipment need to be restricted, or equipment needs to be installed such that voltage changes from the equipment cannot lead to flicker.

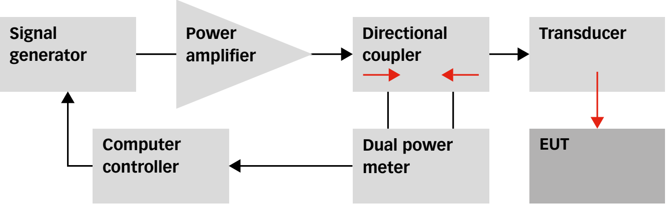
Flicker is a result of voltage fluctuations. It is therefore natural that all equipment with timers and thermostats, which cause frequent changes of the load, will also cause voltage changes and fluctuations. Examples of such equipment are copy machines, laser printers, heaters, air conditioners and similar appliances.

3.2 Immunity

A product manufacturer is unlikely to know or have control over the actual location of use of its products, and products should be expected to work correctly in any environment that they are reasonably likely to encounter. While it is a requirement of the EMC and R&TTE Directives that any product placed on the market or taken into service should have adequate immunity, any manufacturer who is concerned about the quality of its products will take steps to ensure this, irrespective of the legislation, since the issue is a straightforward one of fitness for purpose.

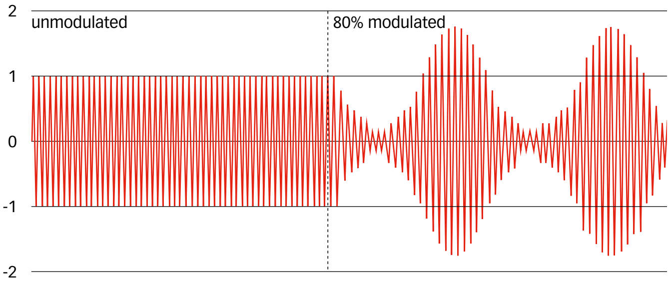
3.2.1 RF immunity

In order to test equipment for its immunity against RF signals, a defined signal needs to be generated and coupled into the EUT. Due to the nature of the signals and their means of transmission, various transducers are defined by the relevant standards for various testing methods.
The base signal for all RF immunity tests is a sine wave signal, which is then modulated in different ways and applied to the EUT. The range for testing spans from 0.15 to 1000MHz, with a rising trend for the upper limit. A signal generator must therefore be able to generate signals over that frequency range. Since the power output of generators is usually limited and the outgoing signal is not high enough to cover the requirements of the testing standards, additional amplifiers are used. The amplifiers must also cover the whole frequency range, but since the power requirements change with the frequency, most testing systems utilize two amplifiers, a higher power version for the lower frequency range and a lower power version for the upper one.



Testing principle for RF immunity

The EUT may be susceptible to modulated but not unmodulated RF. Signal circuits will detect the RF signal and respond to its amplitude; an unmodulated carrier may cause a non-critical DC shift in AC coupled circuits, whereas detected modulation can be within the signal bandwidth. The EUT can also be immune to a high level of RF but unexpectedly susceptible at a lower level. Most standards mandate the use of amplitude modulated (AM) signals. Using frequency modulated (FM) signals does not generally produce any additional susceptibilities except in special cases. For AM, a 1kHz sine wave is normally used, with some product-specific exceptions. These standards refer the specified level of the unmodulated signal, which is then modulated at 80% depth. This increases the peak applied signal by over 5dB. By contrast, some automotive RF immunity standards refer the test level to the peak value after modulation. An alternative modulation technique is pulse modulation, in which the signal is effectively switched on and off. This has been used for emulating GSM signals at 900MHz, where a 200Hz pulse modulation is specified. No increase in the overall peak level is caused by this technique.



80% modulation gives 1.8 times peak level of unmodulated signal

AM modulation of RF signals

The application of an interference signal to the EUT is an important part, but it covers only the first half of the test. As important as the signal generation is the evaluation of the behavior of the EUT. Only if the EUT functions within normal operation parameters during the whole test can it be considered as having fulfilled the requirements.

There are a number of ways to observe the behavior of the EUT during testing, and some product standards are actually very detailed about the monitoring method. For equipment involving audio functions, measurement methods are often used to monitor correct performance. Systems involving data transmission and digital signal processing can often be evaluated with network analyzers or similar analysis tools. Equipment with defined, tangible output is often evaluated after the test by investigating the output material. The most common method, though, is simple observation of the EUT and its functions with a video camera. This camera needs to be immune to the interference in the chamber and needs to be constructed in a way, that the field is not distorted. Usually, such cameras are built into boxes covered with ferrite tiles.

Where product standards do not clearly define the intended operation of the EUT during testing, the manufacturer can refer to the general performance criterion as laid out in many basic standards as well as the generic EN EMC standards, which states that:

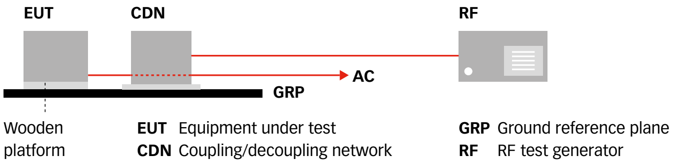
“The equipment shall continue to operate as intended without operator intervention. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer when the equipment is used as intended.

The performance level may be replaced by a permissible loss of performance. If the minimum performance level or the permissible performance loss is not specified by the manufacturer, then either of these may be derived from the product description and documentation, and by what the user may reasonably expect from the equipment if used as intended.”

Care should be taken that performance criteria are clearly defined before the testing is started. Once the testing starts and the equipment fails, performance criteria should not be softened to make the EUT pass, because this would only mean that the criteria were not well defined in the first place.

3.2.2 Conducted immunity

At frequencies up to the point at which the EUT dimensions approach a quarter wavelength, the major coupling route into the EUT is via interference injected in common mode on the connected cables. Cable testing is therefore an important method for checking RF susceptibility, and IEC/EN 61000-4-6 specifies the test methods. Any method of cable RF injection testing should require that the common-mode impedance at the end of the cable remote from the EUT be defined. Each type of cable should have a common-mode decoupling network at its far end to ensure this impedance with respect to the ground reference plane (GRP) and to isolate any ancillary equipment from the effects of the RF current on the cable. For equipment to be used and tested in a system where the cable lengths and terminations at either end are controlled, these terminations provide the appropriate common-mode impedance. Otherwise, where the far end termination is unspecified, a nominal impedance of 150 ohms will represent the average of most installation conditions, which can vary between a few ohms and a few hundred ohms over the test frequency range of 150kHz up to 80MHz. If ancillary equipment (AE) is not isolated from the signal by a decoupling network or filter, then it must be able to withstand the applied RF without affecting the system performance.



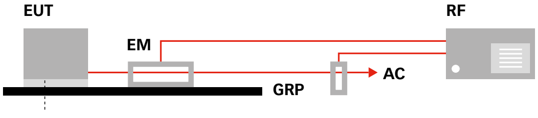
Testing principle for conducted immunity

The most straightforward method of coupling is by a capacitive connection to the cable under test. The disturbance signal is split via a coupling network to each of the conductors in the cable, so that the disturbance appears in common mode on all conductors together.

In addition to a coupling network, a decoupling network is required to prevent the signals applied to the EUT from affecting other devices or being fed into the mains power supply. The combination of a series resistance of 100 ohms and the amplifier output impedance of 50 ohms establishes a common-mode RF impedance at the EUT port of 150 ohms. The coupling and decoupling networks are normally combined into one box to form a so-called coupling/decoupling network (CDN).

A useful alternative to the CDN for RF injection is the EM clamp. This device consists of a tube of split ferrite rings of two different grades that can be clamped over the cable to be tested and is therefore non-invasive and applicable to any cable type.

The signal is fed in via a single-turn loop extending the entire length of the clamp and terminating at each end in an impedance. This creates both a voltage that gives capacitive coupling and a current that gives inductive coupling to the cable. The combination of graded ferrite and capacitive/inductive coupling gives the clamp significant directivity, particularly above 10MHz, so that substantially less signal is applied to the AE end of the cable, and the common-mode impedance seen by the EUT is quite close to 150 ohms across a large part of the spectrum of the test signal.



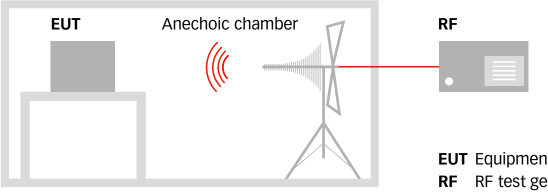
Conducted immunity testing with capacitive coupling clamp

As with the CDN, the EM clamp should be properly bonded to the ground plane to give a repeatable impedance. But also as with the CDN, variations due to cable layout on the AE side of the test setup and due to the AE itself should be minimized.

3.2.3 Radiated immunity

The standard test for radiated immunity is IEC/EN 61000-4-3. This requires a radiated RF field generated by an antenna in a shielded anechoic enclosure using a pre-calibrated field, swept from 80MHz to 1000MHz with a step size not exceeding 1% of fundamental and a dwell time sufficient to allow the EUT to respond. The antenna faces each of the four sides of the EUT in each polarization (and top and bottom, if these might be affected), hence there are 8 (or 12) tests in all. Amendment 1:1998 adds tests from 800 to 960MHz and 1.4 to 2GHz for protection against digital mobile phones.

The EUT is placed on the usual 0.8m high wooden table (for table-top devices) with its front face in the same plane as the uniform field area that was previously calibrated. Both the antenna position and the uniform area are fixed with respect to the chamber. The standard requires that at least 1m of connected cable length be exposed to the field, and recommends the use of ferrite chokes to decouple longer cables. The cable layout cannot be generally specified, but at least some of the length should be in the same plane as one of the polarizations of the antenna.



Testing principle for radiated immunity

The EUT is rotated on the table so that each of its four sides – and the top and bottom, if it may be used in any orientation – face the antenna in turn and are coplanar with the uniform area. For each orientation, two sweeps are performed across the frequency range, one in each antenna polarization. If the frequency is swept from 80 to 1000MHz in 1% steps with the conventional minimum dwell time of 3 seconds per step, each sweep should take about 15 minutes, and the whole test should take over two hours. This ignores the need for the software to control the frequency step, however, including settling and leveling at each new frequency. Depending on the software algorithm, this can increase the duration per step (and therefore the total test duration) 1.5- to 2-fold.

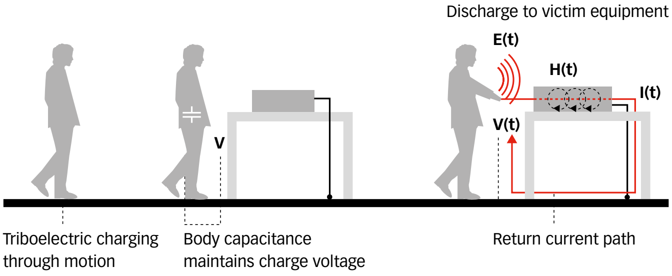
3.2.4 Transient immunity

In addition to covering continuous radio frequency phenomena, EMC means ensuring product immunity from several sources of transient phenomena that are present in the electromagnetic environment. These phenomena can be natural, such as electrostatic discharge (ESD) and lightning surge, or man-made, such as switching transients and fault surges. They involve short-duration (nanosecond or microsecond) events that have high enough amplitudes to disrupt the operation of electronic circuits and, in some cases, have enough energy to destroy or damage components. Except for ESD, the source of a transient is not normally near to the victim equipment, and its energy is almost entirely coupled into the circuits via cable connections. Therefore, immunity testing involves applying a repeatable pulse of a defined waveform and level into each relevant cable port in a specified and reproducible manner. Apart from the rarely used pulsed magnetic field and damped oscillatory wave tests of IEC 61000-4-9 and -10, there are no commercial tests that apply radiated transients. ESD is the special case that is the exception to this rule: it is applied from a simulator that attempts to mimic the real-world event and includes both radiated and conducted components. Application of a series of transients is accompanied by monitoring of the function of the EUT to determine whether it has been disrupted and, if so, whether the disruption is acceptable.

3.2.5 Electrostatic discharges (ESD)

All conductive objects have self-capacitance with respect to ground and mutual capacitance with respect to other bodies. This capacitance can maintain a DC charge with respect to ground. With perfectly insulating materials, this charge would remain on the object indefinitely, but in reality, there

is some surface and volume conductivity, and the free electrons drift, so that the charge differential is gradually neutralized. This is called electrostatic discharge.
In a moving person, all these factors come together to give a continuously varying voltage on that person. In the worst case – highly insulating materials, low relative humidity and vigorous movement – the voltage may reach as high as 25kV. Charge potentials higher than this tend to be limited by corona effects. In more typical situations, voltages vary between 2 to 8kV.



Typical human discharge scenario

When a charged object contacts another object at a different potential, the charge is equalized between the two objects, and there is both a voltage v(t) and current i(t) transient as this occurs. Digital circuits in particular may respond to these induced pulses as if they were intentional signals, and their operation is consequently corrupted.

IEC 61000-4-2 and its EN equivalent is the principal basic standard for testing electrostatic discharge immunity. It applies a defined current waveform at a specified voltage level from a handheld generator, which is essentially a capacitor supplied from a high-voltage supply whose charge voltage is discharged via a series impedance through the point of contact to ground. Two methods are given: contact discharge and air discharge.

In the **contact discharge** method, the stress may be applied directly to the EUT or to a coupling plane adjacent to the EUT. Before each test pulse, the capacitor is charged to the desired level, but its voltage is held off the generator's probe by a vacuum relay. The probe is applied to a suitably chosen point on the EUT or the coupling plane. The generator is then triggered. This action is repeated the desired number of times, at each location, with the appropriate polarities and levels.

The same generator is used for the **air discharge** method, but with a rounded rather than a pointed probe tip. The capacitor is charged to the desired level as before, but the voltage is now continuously applied to the probe, which is held away from the EUT. For each test pulse, the tip is brought up to the chosen point on the EUT, gradually, until it touches. Just before this, the air gap between the tip and the EUT will break down and a discharge current will flow, limited as before by the combined series impedance of the generator, the air gap, the EUT and the return path. Again, the action is repeated the desired number of times, at each location, with the appropriate polarities and levels.

The ESD pulse has a sub-nanosecond rise time, so radio frequency layout precautions are vital. The test must re-create the fast rise time found in reality, since this is an important parameter in deciding both the path the discharge takes through the EUT and the response of the EUT itself. The ground reference plane (GRP) is an integral part of the setup and the generator's return lead must be well bonded to it, since this connection forms part of the current return path.

The indirect discharge part of the test uses two other planes, different from the GRP, known as the horizontal coupling plane (HCP) and the vertical coupling plane (VCP). Discharges to these planes simulate the stress caused by the radiated field from real-life discharges to nearby objects. Each coupling plane is connected to the GRP by a resistor lead to ensure that any charge bleeds off within a few microseconds.

3.2.6 Electrical fast transients (bursts)

When a circuit is switched off, the current flowing through the switch is interrupted instantaneously. Put another way, at the moment of switching there is an infinite di/dt. As a result, a high instantaneous voltage, added to the circuit-operating voltage, appears across the opening switch contacts. This causes the tiny but increasing air gap across the contacts to break down, and a current flows again, which collapses the voltage spike, so that the briefly formed arc extinguishes. But this re-interrupts the current, so another voltage spike appears, creating a further arc. This process repeats itself until the air gap is large enough to sustain the applied voltage without breakdown, at which point the circuit can be said to be properly switched off. The visible effect is a brief spark between the contacts, which actually consists of a whole series of micro sparks – the so-called "showering arc" – whose repetition rate and amplitude depend on the circuit and switch parameters.
Poor filtering or inadequate screen termination on each interface then lets these transients pass into the electronic circuits, where they appear as interfering signals at sensitive nodes. As with other types of transient, digital circuits tend to be more susceptible, since each short pulse can

appear as a valid digital signal. Occurring in bursts, there is a higher probability that one or more pulses will coincide with a critical timing edge. However, analog circuits can also be affected, typically by saturation of sensitive amplifiers. Pulse-counting circuits are also susceptible if the burst masquerades as real input.

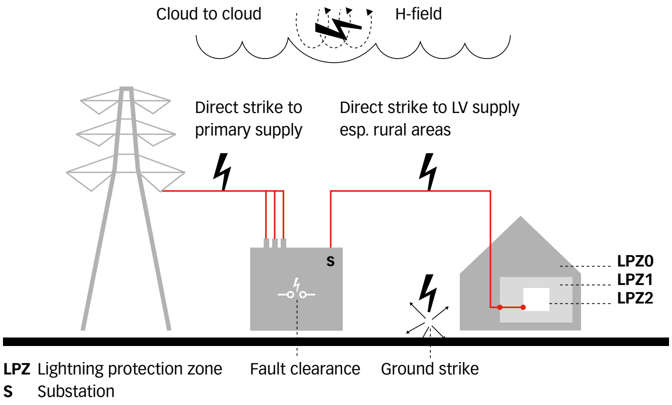
IEC 61000-4-4 and its EN equivalent are the principal basic standards for testing fast transient immunity. Testing involves applying a specified burst waveform via a defined coupling network to the mains connection and via a defined clamp device to any signal connection. Only conducted coupling is used; there is no specification for radiated transient immunity. The choice of ports for the application of the burst depends on the instructions in the product standard being used, but it is generally applied to AC and DC power ports and to signal and control ports that may be connected to cables longer than 3m.

The effects of burst transients relate mostly to high-frequency components of the pulses. Common EMI filters will thus have some positive effects on burst problems. On the other hand, it should be pointed out that EMI filters are not specifically designed for burst suppression. The HF components of the pulses reach such high frequencies that oscillation of the filter circuit is also possible.

3.2.7 Surge

High-energy transients appearing at the ports of electronic equipment are generally the result either of nearby lightning strikes or due to major power system disturbances such as fault clearance or capacitor bank switching. Lightning can produce surges with energies of several joules by the following mechanisms:

- Direct strike to primary or secondary circuits: the latter can be expected to destroy protective devices and connected equipment; the former will pass through the service transformers either by capacitive or transformer coupling.
- Indirect cloud-to-ground or cloud-to-cloud strikes create fields which induce voltages in all conductors.
- Ground current flow from nearby cloud-to-ground discharges couples into the grounding network via common impedance paths and causes substantial potential differences between different ground points.
- Primary surge arrestor operation or flashover in the internal building wiring causes voltage transients.



LPZ Lightning protection zone
S Substation

Surge generation

Surges impinging on electronic equipment may cause hardware damage and complete failure or, in lesser cases, operational upset. Below a certain level dependent on equipment design, no effect is observed. Above this level, a surge may cause the operation of the equipment to change state, without any long-term effect on the circuit components. But at a higher level, there may be enough energy to cause breakdown in critical components. The maximum voltage that is likely to occur is limited by flashover considerations. In a typical domestic mains supply, for instance, no more than about 6kV can be withstood by the wiring components. Typically, protection involves adding parallel surge suppression devices such as clamping diodes, varistors or spark gaps. The purpose of these devices is to break down in a controlled manner at a voltage lower than can be sustained by the circuit and dissipate the surge energy within themselves. They must therefore be sized to withstand the maximum surge energy to be expected in a particular application. The rate of change of applied voltage and current also has a bearing on both the susceptibility of a particular interface to upset and on the ability of protection devices to cope with the surge.
Schaffner filters will show little suppression effects for surge pulses unless they are equipped with additional surge suppressors (Z versions). Nonetheless, Schaffner filters are tested against destruction from overvoltages and can therefore be used without risk of damage by surge pulses.

3.2.8 Power magnetic fields

Power magnetic fields are magnetic fields caused by the AC mains power supply in conductors. The fields are continuous and related to the current flowing in the conductor. The frequency of the field corresponds to the net supply frequency, i.e., 50Hz in European systems.

Magnetic fields are always present around conductors carrying any amount of current. If the conductor forms a loop, the circular magnetic field waves add up and form a directional field. In both cases, the fields generated are directly proportional to the current that is flowing. In other words, the higher the current, the stronger the magnetic field.

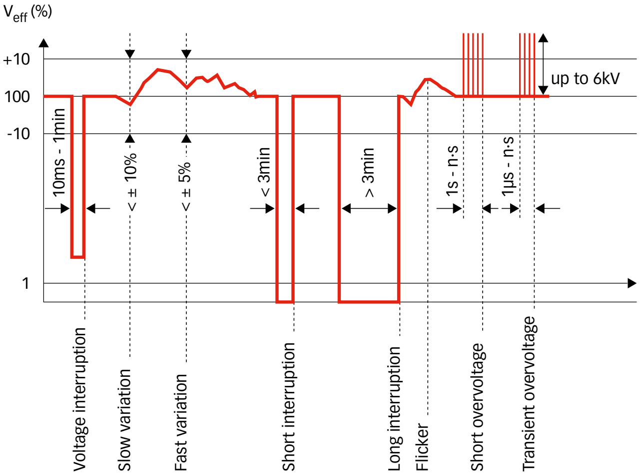
Power magnetic fields can reach field strengths of more than 100A/m, depending on the environmental conditions. Logic dictates that the higher the current, the more severe the effect of the magnetic fields. Industrial applications and high-voltage distribution systems thus present more stringent conditions than household appliances. High magnetic fields exist in the vicinity of motors, generators and all equipment with high power requirements.

Magnetic fields affect only a very limited range of electrical equipment, i.e., equipment that relies on magnetic fields for its function. The most commonly used equipment is a standard CRT (cathode-ray tube), but the ongoing replacement of this technology with LCD and plasma displays is steadily reducing this problem. Also, the effect of magnetic fields on displays is easy to recognize, and misinformation of the user is very unlikely. However, the display can become illegible, and in areas where the information on the screen is essential for the proper use of the equipment, such disturbances cannot be accepted. One example would be the use in medical environments, where screens often display the physical status of a patient.

More critical is the effect of magnetic fields on sensors and readers that use magnetic effects to produce measurement results. If the meter starts flickering or behaving strangely in any other way, the user will easily recognize an equipment malfunction. However, the influence of a magnetic field might lead merely to an inaccurate reading that is not recognizable to the user. Immunity of such equipment against magnetic fields is therefore essential.

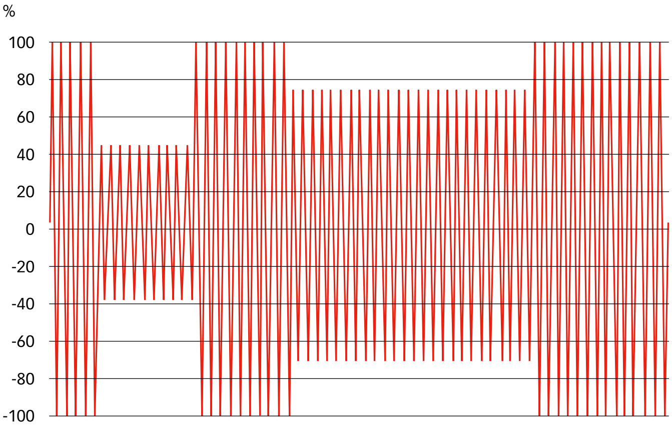
3.2.9 Supply network

When equipment is connected to the power network, its operation usually affects the supply voltage characteristics. We have already explained the occurrence of harmonics as a result of non-linear currents. Equipment is also affected by interference that already exists in the supply network. The following picture gives an overview of existing interference.



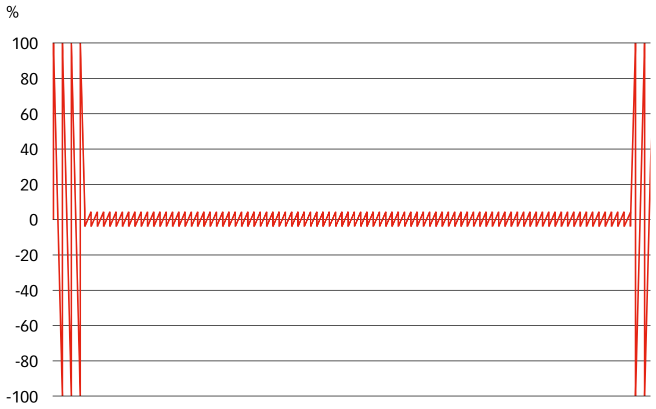
Supply changes in a typical supply network

The currently existing standards deal mainly with voltage dips and short interruptions. Voltage dips are interference in the mains power supply, ranging from constant repeating variations to sudden dips or a complete shut-off. Such power distortions can seriously affect other equipment. Whereas a short dip can influence processors in other equipment, a complete temporary shut-off can reset equipment and have it start up again in an unsafe condition. Voltage dips are short changes of the supply voltage to a certain level – for example, the voltage can drop to 50% of its original value. The duration of such a dip can be expected to be between half a period of the net frequency to a few seconds, but usually the duration is on the lower end of that scale.



Example of voltage dips

Short interruptions are voltage dips to 0%. The duration of such interruptions can be several seconds but does not usually exceed one minute.



Example for short interruptions

Voltage dips and variations not only affect industrial networks but are also very common in residential areas. Voltage dips occur very frequently but are not always a problem. In many cases, the internal circuitry of equipment or the power supply installation can compensate for such occurrences. Interruptions will usually lead to degradation of the performance of the equipment, but it has to be ensured that afterwards, the equipment is either safely shut down or does not restart in unsafe conditions.

In order to perform testing against voltage dips and interruptions, the EUT must be connected to a well-defined power supply, thus enabling exact switching parameters and synchronization of the dips with the phase angle of the power supply.
The key point for testing is the generator, and the standards set very high requirements for such generators. They must be capable of handling constant currents at voltage levels of 100%, 70% and 40% of the supply voltage.
More difficult than that are the requirements for rise time and inrush currents. At a supply voltage of 230V, the generator must be able to switch (dip) within 1 to 5µs while at the same time being able to handle up to 500A of inrush current. These two requirements make the development of appropriate generators difficult, and a lot of existing testing equipment still does not comply.

4 Noise suppression

With the explosive increase of the popularity of electronic devices, the demand for regulation has created innumerable standards and conformity procedures. Accompanying this is the need not only for testing but for improvements to equipment design as well. In this chapter, we wish to examine some common design features affecting EMC and noise suppression components.

4.1 Conceptual EMC

Before looking at the different methods of noise suppression, it is important to point out that proper handling of EMC always requires a concept. It starts with the first design idea and ends with the product launch.
Very often, EMC is the last step in a design. When all the product features have implemented and the functionality is established, any EMC problems are solved. At this point, EMC becomes expensive, time-consuming and difficult to handle. Manufacturers should therefore always start thinking about EMC in the early stages of product design.

4.2 Shielding

From the point of view of legislation and standards, EMC takes place only outside of the equipment. Internal EMC is considered a functional issue and therefore not part of the regulations. Shielding is therefore a good measure to reduce electromagnetic noise outside of the equipment by keeping the noise inside. Shielding can be applied to enclosures and cables.

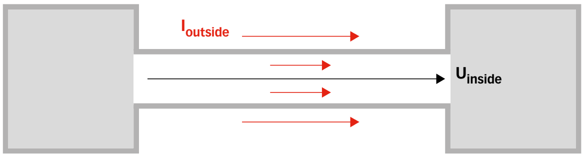
4.2.1 Shielded housings

For many kinds of equipment, shielded housings have become a default measure for noise reduction. Shielded enclosures should be made of metal or other conductive materials. The enclosure has to be grounded plainly, because ungrounded enclosures will provide only minimum shielding attenuation. The paint of enclosures often neutralizes the shielding effect of the enclosure. If the paint is non-conductive, the enclosure has long openings at doors and other openings. The same applies to gaskets, which in most cases are made of rubber to guarantee a certain IP class. Conductive paints and gaskets are available, but more expensive.

Every opening in an enclosure acts like an antenna. A horizontal opening acts like a vertical antenna and vice versa. Openings can be apertures for ventilation purposes but also contact points between non-conductive parts of the enclosure (paint). If EMC characteristics are critical, the relation between size of apertures and wavelength of the disturbance to be attenuated should be considered. If necessary, special EMC openings, conductive paints and gaskets can help.

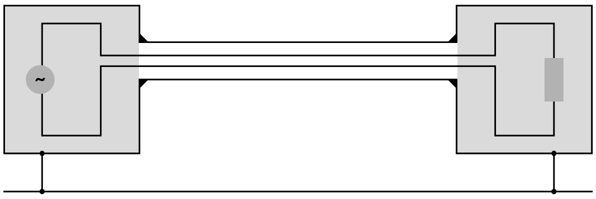
4.2.2 Shielded cables

Cable shielding is a very effective measure to improve susceptibility and reduce emission. However, incorrect installation can reduce the effectiveness or even completely destroy the effect of shielding. External voltages and currents do not directly affect the signal line, only the shield around the cable. The disturbances that reach the inside conductor are thus attenuated. The shielding effectiveness can therefore be described as the relation between the current on the shield and the induced voltage on the inner conductor.



Principle of shield effectiveness

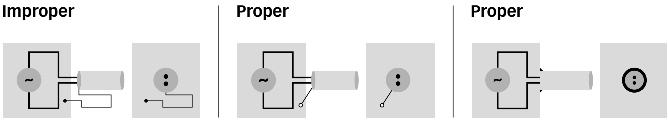
The attenuation of a shield depends on the material and installation. The best values are achieved with conduits, but this is necessary in only a few cases. Metal films or braided wires serve well enough for common applications. For more critical installations, double-braided wires or two separate shields can be used.
If shielded cables are used, the ends of the shield have to be connected to ground. If none of the ends is connected, the shield becomes ineffective. Induced fields cannot be diverted; ground currents cannot be reduced. If shields are connected on only one side, they become effective against electric fields. However, once the resonance frequency of the shield is reached, the shield becomes ineffective and even amplification can occur. If both ends of the shield are connected to ground, the shield has the best effect. Electrical and magnetic fields can be reduced. Differences of potential do not affect the signal line. However, since potential differences result in currents on the shields, other lines can be affected.



Proper connection of shielded cable ends

For the sake of completeness, it should be pointed out that shield connections as shown above can occasionally generate additional ground loops. If additional problems occur, compensation conductors between the two units or additional earthing along the shield should be applied.

Proper connection of the ground is also important for the performance of the shield.
The most common problem with the connection of shields is the use of “pigtails”, as shown on the left side of the picture. The shield is twisted to one tail and then connected to ground on only one point. This increases the coupling resistance of the shield and reduces its performance. The best connection of a shield is a 360° connection at both ends as shown on the right side.



Improper and proper shield connections

4.3 Grounding

Ground connections are essential for EMC concepts in many ways. Connection types and concepts have influence on the function and performance of a grounding system. Basically, grounding should fulfill the following requirements:

- Coupling between susceptible paths and paths with high emission should be reduced.
- Coupling from external radiated fields should be reduced, along with emission from the equipment itself.
- Differences in potential between several units are to be avoided.

4.3.1 Grounding concepts

As mentioned before, grounding is not the only effective measure. The optimum result can be achieved together with other design tools such as shielding and filtering. For all EMC countermeasures, the whole set of tools should be used and the most economical solution chosen. For grounding, a number of general rules apply:

- Each electrical circuit should have an independent ground connection in order to avoid different potentials.
- The method of grounding depends on the frequency of the signal.
  - For lower frequencies, the dimensions of the circuit are small compared to the wavelength and resonances are not likely to occur. Grounding on one side is sufficient and should be done on the transmitter side, with the receiver side floating. This method is called single-point grounding
  - For higher frequencies, the wavelength is small against the dimensions and resonances are hard to avoid. In order to have defined conditions, cables with well-known characteristic impedances are used and grounded on both ends. In some cases, cables are additionally grounded at several points along the signal path. This grounding concept is called multi-point grounding.

- For circuits with low- and high-frequency signals, triaxial cables would be the best solution. However, high price and weight rules them out in many cases. Mixed concepts are therefore used, combining grounding with twisted cables and other methods.
- Grounding is not only necessary for one piece of equipment but for the whole system. All single units should be connected to the same ground point to avoid potential differences. If more than one system grounding point is used, a low-resistance connection between those points is imperative.

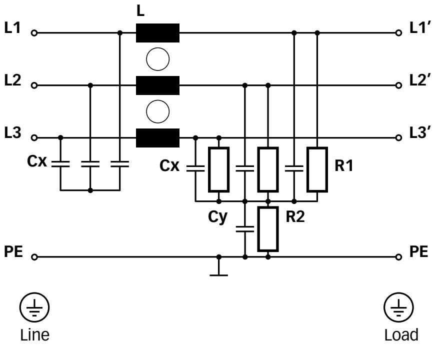
4.3.2 Earthing

Grounding and earthing have separate functions in equipment and different rules apply to them. Earthing is solely for safety reasons, so the resistance of the earth connection is important. Most safety standards required the earth connection to be tested. Grounding, however, is mostly used for EMC reasons. More important than the resistance is the impedance of the ground connection, especially at higher frequencies. Plain connections are therefore more effective than point connections. Flat, braided cables should also be preferred over round solid wires.
Grounding should never be confused with earthing. Earthing is the connection of the whole system to common ground for safety reasons. Grounding can be applied for functional reasons or to improve EMC characteristics.

4.4 Suppression components

Interference can be reflected towards its source by incorporating an LC network in the noise path. This prevents interference energy from leaving a suppressed device and entering the power supplyline. An efficient inductor-capacitor combination to protect against line-conducted interference consists of the following:

- Series inductances in the interference paths
- Cx capacitors between phase and neutral
- Cy capacitors between phases and earth



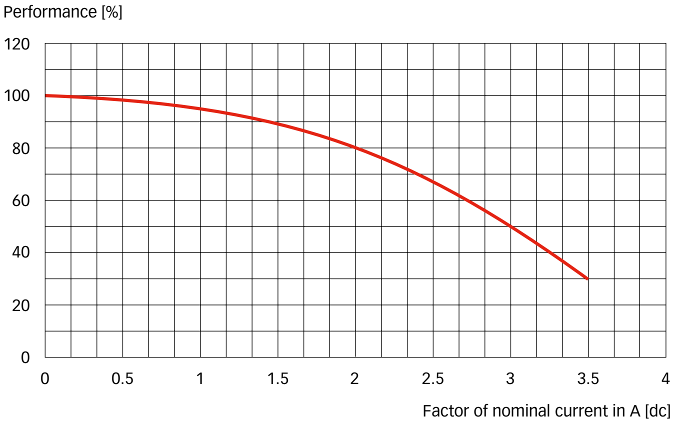
Typical circuit diagram of an EMI filter

4.4.1 Chokes

Chokes consist of an electrical conductor wound around a material with magnetic characteristics, the core. Various shapes exist for the core material: ring cores, D-cores, E-cores, I-cores, etc. Regardless of the shape, the choke always makes use of its magnetic characteristics to suppress RF noise.

Ring, D-, E- and I-cores

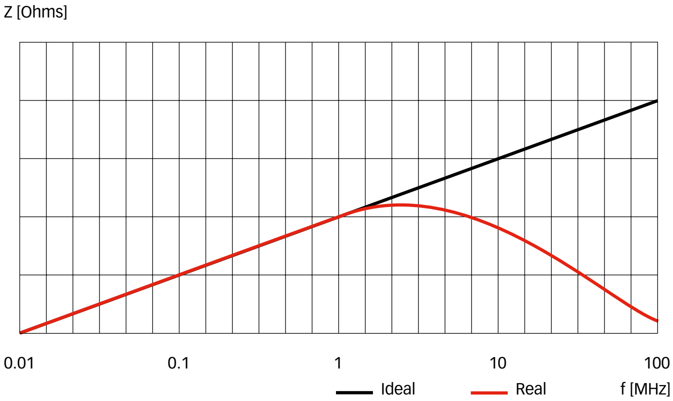
The core material pushes the performance of a choke to its maximum. It enhances the magnetic effects in the choke, improves the suppression characteristics and leads to more compact components. Core materials are also dependent on outside factors such as temperature or current, however. When used outside of its specifications, a choke can saturate, leaving it unable to supply its original impedance.



Saturation of chokes due to current

While the rated current is one of the main factors causing saturation, high asymmetric noise currents can be another reason for this effect. Saturation can be avoided by keeping the choke within its specifications or by a special winding technique called current compensation. This is explained later.

The impedance characteristic of a choke in relation to the frequency makes it an interesting component for noise suppression. The impedance increases at higher frequencies. Theoretically, the impedance would continue to increase with the frequency. A real choke, however, includes a certain winding capacitance. When the resonance point is reached, the impedance of the choke will reverse and decrease. This is shown in the following picture.

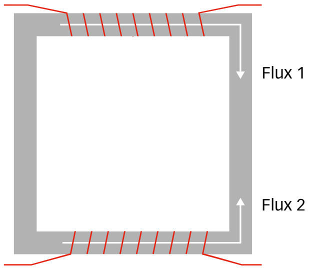


Typical impedance characteristic of chokes

Three main types of chokes may be used for the purpose of noise suppression:

- Common-mode chokes – with multiple windings to avoid saturation (loss of effective inductance) of the core material
- Saturating chokes – ideal for reducing fast current changes
- Rod-cored chokes – which present a constant inductance even at high currents

Common-mode chokes (RN, RD and EV/EH series) are used to attenuate common-mode or asymmetric (P/N –> E) interference signals by being connected in series with the phase and neutral lines of an AC power line input. The magnetic fields produced by this winding technique cancel each other out. Full inductance is only presented to interference signals that flow asymmetrically from phase/neutral to earth.

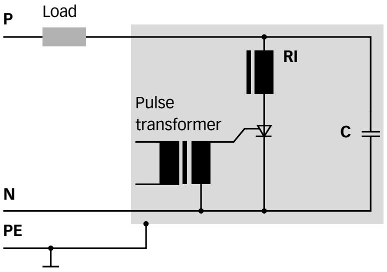


Principle of current compensation

Symmetrical components of the noise are also attenuated by the leakage inductance of the windings. The impedance of the choke at power line frequencies is therefore negligible, resulting in practically zero voltage drop. These chokes are typically used in conjunction with suppression capacitors as follows:

- In phase-angle control circuits where the desired degree of suppression cannot be achieved by saturating chokes alone
- For suppressing high interference levels from ultrasonic generators, fast rectifiers, switched mains equipment etc.
- For suppressing equipment with no earth connection
- For input filters to protect digital circuitry from mains-borne interference

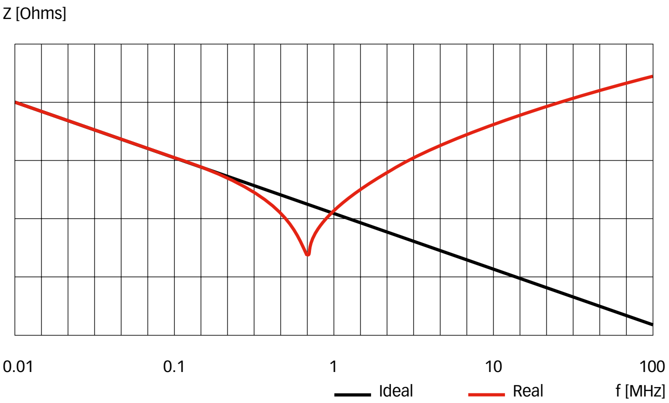
Saturating-type chokes (RI types) change impedance at the moment of switching and can be used to attenuate differential mode or symmetrical (P –> N) interference as generated by phase angle control devices such as thyristors and triacs. Interference levels can be brought within the limits of national and international regulations by using these chokes in conjunction with appropriate suppression capacitors. For optimum attenuation, chokes must be connected as close as possible to the semiconductor switching device. A simple single-stage suppression circuit is shown in the following illustration; this can be made into a dual-stage filter by the load itself and one additional capacitor.



Saturating chokes in series with thyristors

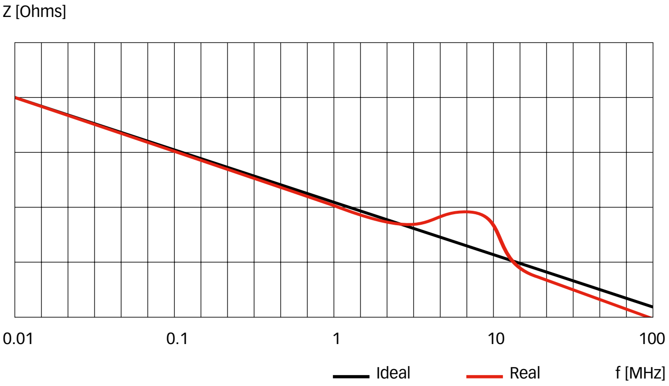
4.4.2 Capacitors

Capacitors are basically two metal plates separated by a distance filled with a non-conductive medium like air, but more often other sturdy materials are used to improve the capacity. Most solutions in this catalog employ a self-healing plastic film dielectric, which offers significant quality and reliability advantages. All capacitor dielectric materials contain pinholes and other imperfections; during manufacture, a high voltage is applied to the dielectric to burn away the metallization around the pinhole, creating a high-quality capacitor in which any weak areas are totally isolated. Similarly, if a voltage surge punctures the dielectric during normal operation, an arc occurs at the point of failure, melting the surrounding metal and isolating the area of the breakdown. This maintains the quality of the capacitor instead of causing a failure due to voltage breakdown. The impedance of a capacitor decreases at higher frequencies. Due to the inductive behavior of the connection leads, however, capacitors reach a point of resonance after which their impedance increases again.



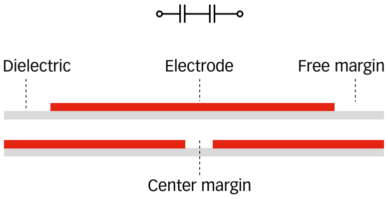
Typical impedance characteristic of RFI capacitors

Resonances can be almost completely avoided with feedthrough constructions. Instead of connection leads attached to the capacitor coil, the line is directed through the center of the coil. One side of the capacitor is then connected directly to the line; the other end is connected to the housing. The result is a common-mode capacitor without significant connection leads, thus avoiding resonance points.



Typical impedance characteristic of a feedthrough capacitor

Capacitors are connected between phases or between phase and earth and are therefore subject to safety considerations. All the capacitors used in Schaffner's feedthrough components are of a series construction, which reduces the voltage stress on each capacitor element. This provides an excellent safety margin for high-voltage transients, and – in the case of AC feedthrough components – minimizes ionization effects to ensure long and reliable component life.



Series construction of capacitors

4.4.3 Filters

The mains, or power line, filter is the key element in eliminating mains-borne interference. This filter has to meet not only the requirements of electromagnetic compatibility (EMC) but safety aspects as well. For some applications, the filter also has to prevent the radiation of classified information from the mains line (TEMPEST applications). Other applications require a filter to protect equipment from destructive voltages on the power line, like those caused by lightning or nuclear explosion (NEMP).

Filters are available with a variety of electrical and mechanical specifications. PCB filters are designed for compactness and ease of assembly, and avoid the need for extra mounting components and installation operations necessary with chassis styles, but at the expense of finite available space for filtering circuitry. Consequently, they typically offer just a single stage of attenuation, with limitations on the maximum power handling capability. This typically makes these filters ideal for companies that have planned for EMC protection throughout the equipment design process and are completing equipment protection with these low-cost components. When integrating these components, care must be taken to provide a low-impedance connection to earth and minimize the potential for any noise radiation from the mains inlet connection.

Schaffner PCB filter FN 409

IEC inlet filters are widely used for interference suppression purposes in computers and their monitors, business equipment such as printers or copiers, and in medical devices. The filters combine the commonly used IEC inlet with excellent filter performance at a very small size and are therefore an excellent choice for equipment with switch-mode power supplies (SMPS). In addition to the classic filter function, IEC inlet filters are also available in combination with switches, fuse holders and/or voltage selectors.

Schaffner IEC inlet filter FN 9222

Chassis mount filters provide a higher performance solution in metal cases for optimum connection to earth and good high-frequency performance. With the space available for up to three circuit stages for noise attenuation, users can usually find an option with the performance to provide an off-the-shelf solution for even the most difficult EMC problem (retrofitting an EMC solution to an existing design, for instance).

Schaffner chassis mount filter FN 2410

Power electronic devices such as industrial frequency converters, as well as machine tools, are typical application areas for three-phase power line filters. In addition to this industrial market sector, these types of filter are also suitable for mainframe computer systems, large uninterruptible power supplies, and medical equipment such as X-ray machines. All the filters are supplied in chassis mounting metal cases, facilitating good connection to earth and optimum high-frequency performance. Versions are also available with a neutral line or different operating voltages up to 690VAC, enabling designers to quickly locate the most economical and technically suitable EMC solutions for their projects.

Schaffner three-phase filter FN 3270

Feedthrough capacitors and filters offer a particularly cost-effective means of combating conducted interference. Offering a high insertion loss across a broad band of frequencies – from a few tens of kHz right through to the GHz region – these single-line components are exceptionally easy to fit and can provide a more economical RFI suppression solution than dedicated filters, especially for systems that have multiple input or multiple output power lines.

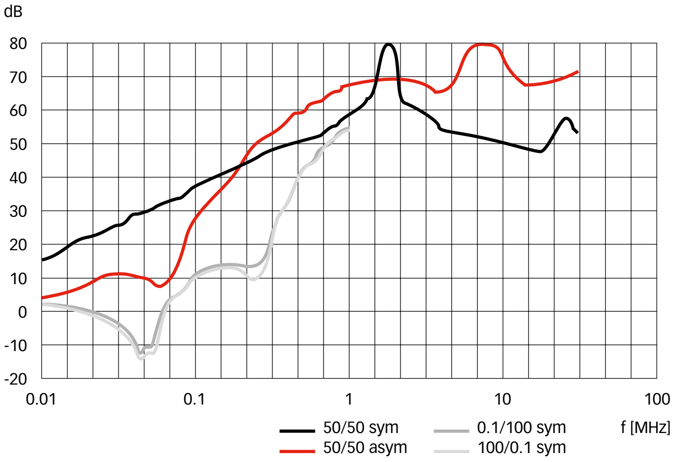
Schaffner feedthrough filter FN 7611

4.4.4 Filter attenuation

Filters are generally described by their attenuation, also called insertion loss. In order to determine the attenuation, a defined source and load are connected and the signal from the source is measured. The filter is then inserted and the measurement repeated. The attenuation is then calculated from the two results with

$$A[dB] = 20 \cdot \log \frac{V_2}{V_1}$$

where V2 and V1 are the results with and without the filter, respectively. The measurement is described in CISPR 17. The load and source impedance must be 50Ω each. Both asymmetrical (common-mode) and symmetrical (differential-mode) attenuations need to be measured. The results are then usually shown in an attenuation diagram.



Typical attenuation diagram

The attenuation diagram of Schaffner products always shows two additional lines: the symmetrical attenuations for 0.1/100Ω and 100/0.1Ω load and source impedances. The attenuation diagram of a filter never reflects the subsequent reality, just the laboratory measurement conditions. Measurements at different impedance values easily show that the attenuation shifts with changing impedances. The attenuation characteristic also does not tell the end user how well the filter is going to perform under load conditions. Schaffner filters are therefore always tested additionally at various load conditions in order to guarantee good attenuation performance without saturation in the final application.

5 Power quality

Power quality is an issue of increasing importance, and many electricity supply utilities are now mandated to provide a mains supply with controlled quality parameters such as harmonic distortion and voltage limits. To achieve this, they must in turn place restrictions on the pollution caused by various types of connected load, especially those which draw distorted current waveforms.

5.1 Definition

In previous chapters about EMC measurements, we have already seen the effects of harmonics and voltage fluctuations on equipment connected to the power grid. These effects can be supplemented by frequency variations and similar interference related to the power grid voltage and frequency.
The efficiency of a power network is generally described by the power factor PF. This power factor is calculated by the formula.

$$PF = \frac{I_{1,rms}}{I_{rms}} \cdot \cos\varphi$$

where $I_{1,rms}$ = rms value of the fundamental current
I_{rms} = rms value of the total current, including harmonics and distortions

The closer the power factor is to 1, the more efficient the power grid is being used.

When we move down to the equipment level and consider the quality of the power, we often come across frequency inverters. Frequency inverters are among the most widely used pieces of equipment for AC motor control. Nowadays, they are found in virtually every area of industry, in applications as diverse as pumps, air conditioning systems, elevators and cranes, conveyors, machine tools, alternative energy production and in a vast array of other industrial and domestic automation.
In the quest for ultra-compact, efficient power conversion, inverter manufacturers employ high-speed semiconductor (IGBT) switches and pulse width modulation (PWM) techniques to generate fast rise time voltage pulses of the appropriate duration and polarity. Unfortunately, this creates a considerable number of problems for OEMs and system integrators, from purely functional difficulties to very severe motor damage. There follows a brief summary of the most significant problems and phenomena:

Inverter input
- EMC problems
- Harmonics
- Commutation notches
- Inrush & peak currents
- Low-frequency interference

Inverter output
- Excessive dv/dt
- Peak & overvoltages
- Parasitic earth currents
- Eddy current losses in the motor
- Displacement currents in the coils
- Bearing currents
- Additional inverter pulse loads
- Acoustic motor noise
- EMC problems

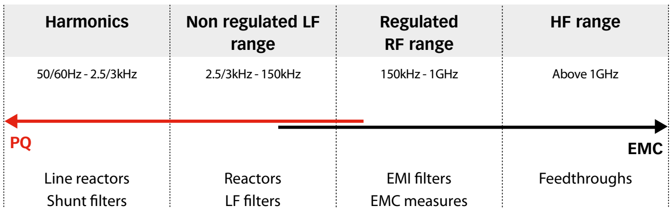
Inverter DC link
- DC link capacitor stress
- Harmonics
- Various other problems

Whole system
- Low efficiency/low power factor
- Uncertain system immunity
- Unacceptable interference emissions
- Uncertain service security & reliability

5.1.1 Frequency ranges

According to the definitions in the standards, EMC deals with a frequency range from DC to 400GHz. However, limits are currently only defined for a very limited area of that whole frequency range. The following ranges are currently defined:
- 50/60Hz to 2.5/3kHz for mains harmonics (depending on power frequency)
- 150kHz to 30MHz for line-conducted emission
- 30MHz to 1GHz for radiated emission
- 9 to 150kHz for certain equipment for conducted emission
- 1GHz to 18GHz for some industrial equipment for radiated emission
- 1GHz to 40GHz for some telecom equipment for radiated emission

This leaves an undefined area from 2.5/3kHz to 150kHz. However, this area is not noise-free; it is simply not regulated. While excessive noise in this frequency range will not lead to non-compliant equipment, it will most certainly lead to functional problems.



Regulated and non-regulated frequency ranges

The lower frequency range is typically seen as the power quality (PQ) range. However, the picture above illustrates that the PQ and EMC ranges overlap. As a matter of fact, EMC is only one part of the overall power quality. The same is true for the solutions. A filter for the conducted emission range from 150kHz to 30MHz will not simply cover this defined range; it will also attenuate at lower and at higher frequencies. Manufacturers can therefore profit from a single provider of PQ and EMC solutions like Schaffner.

5.2 Reactors in drive systems

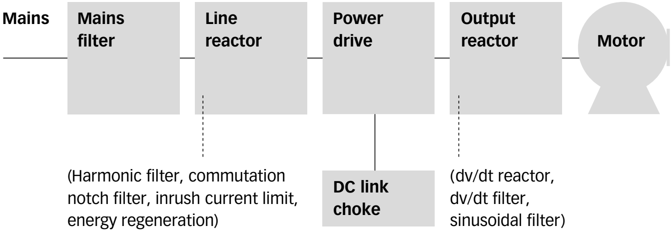
5.2.1 Need for protection

Manufacturers of variable speed drives (VSD) nowadays are operating in an extremely competitive marketplace, and the tendency is to offer drive products without input reactors unless the end user specifically requests it. Users, though, often are not familiar with the reasons why a reactor is beneficial both for the reliability of the drive's electronics and for the quality of the power supply. The introduction of an input reactor has the following effects:

- Buffers the electronics from input transients due to utility and load switching elsewhere in the supply
- Prevents high inrush currents and reduces the transient load on the input components
- Improves VSD crest factor, reducing power input line losses
- Controls emissions of line current harmonics due to the rectifier input circuit
- Controls the impact of commutation notches on the power supply
- Protects and increases the service life of DC link capacitors of VSDs
- Reduces differential-mode low-frequency phenomena up to a few hundred kHz

5.2.2 Overview of uses

Reactors and filters can be used in various locations in a power drive system: in line with the power input (line reactor), in the DC link between the rectifier and capacitor (DC link choke) and at the drive output to the motor (motor reactor). A reactor at each of these positions has specific effects that are by no means mutually exclusive. Generally, it would be unnecessary to have a reactor in both the power input and the DC link, but the functions of the input line reactor are quite different from a filter at the drive output, and it is entirely reasonable to include both of these.



Possible locations of reactors in drives

5.2.3 Line input

A reactor in the power supply input will do two things: protect the drive electronics from power disturbances and protect the power supply from disturbances created by the drive.

Harmonic attenuation. A three-phase input rectifier with a reservoir capacitor draws current discontinuously. When the input voltage across any pair of diodes is greater than the DC link voltage maintained across the capacitor, then current flows and charges the capacitor. When the input voltage is less, the diodes block the input current and the reservoir capacitor supplies the DC link current. This gives rise to a characteristic "double pulse" input current drawn from any of the three phases; these accumulate in the DC link to give a series of unipolar pulses of current at six times the frequency of the input (300Hz in EU applications).

The discontinuous phase current is rich in harmonics of 50Hz. The total harmonic distortion (THD) is typically 90% to 150% with a harmonic content predominantly made up of 5th, 7th, 11th and 17th harmonics.

The effects of these harmonics on the power supply and ultimately on other users are manifold:

- Transformer and neutral conductor overload due to excessive zero-phase currents
- Overheating of power factor correction capacitors due to high frequency currents
- Conductor losses due to skin effect at higher frequencies
- Voltage distortion, amplified at remote points in the network due to resonances
- Failure of direct-off-line induction motors trying to run at harmonic frequencies
- Acoustic and electrical interference at audio frequencies

- Increased earth leakage currents due to stray and EMI filter capacitances

The electricity supply industry is naturally keen to reduce these effects. Electricity suppliers are required in many countries today to offer a supply of guaranteed quality, and they can do this only if the users' pollution is controlled. Limits are placed on harmonics emissions either by the terms of connection offered by the utility or by a requirement to meet international standards, of which IEC 61000-3-2 for equipment <16A per phase and IEC 61000-3-12 (draft) for equipment current between 16 and 75A per phase are the most significant. In the USA, harmonics are in the scope of the IEEE 519 standard.
To meet these requirements for a standard three-phase rectifier-reservoir input circuit, some inductance in line is needed. This is the function of the line reactor. The reactor's inductance slows the rate of rise of each individually rectified pulse and continues supplying current for a millisecond or two after the input voltage has dropped below the DC link voltage. The six-pulse waveform is thus “stretched” and can become continuous rather than discontinuous if the inductance is high enough.

At the same time, the peak amplitude of the current is reduced. This means that the crest factor of the waveform is reduced so that the peak-to-rms ratio is lower. This has many benefits, including lower stress on the reservoir capacitors and hence greater reliability. The harmonic attenuation is directly related to the value of inductance in circuit. Since Schaffner reactors are specified as a percentage voltage drop, we can relate this percentage to the harmonic attenuation as shown in the table below. As can be seen, the 4% inductor gives considerably better harmonic attenuation than the 2% inductor but at the cost of greater voltage drop and a much larger component.
In addition to standard line reactors and harmonic filters, Schaffner can also offer a variety of customized solutions for harmonics reduction.

Relation between uk and harmonics reduction

Harmonic											Input impedance uk in % vs. remaining harmonics
Number	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
5	80	60	46	40	34	32	30	28	26	24	23
7	60	37	22	16	13	12	11	10	9	8.3	7.5
11	18	12	9	7.4	6.3	5.8	5.2	5	4.3	4.2	4
13	10	7.5	5.8	4.9	4.2	3.9	3.6	3.3	3.15	3	2.8
17	7.3	5.2	3.6	3	2.4	2.2	2.1	0.9	0.7	0.5	0.4
19	6	4.2	2.8	2.2	2	0.8	0.7	0.4	0.3	0.25	0.2
THID	102.5	72.2	52.3	44.13	37.31	34.96	32.65	30.35	28.04	25.92	24.68

5.3 Output solutions for motor drives

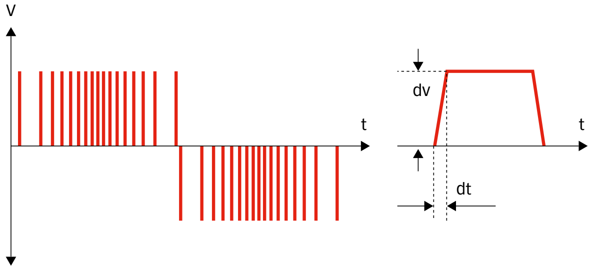
At present, there are trends observable in the motor drive market that could have tremendous effects on the reliability of entire drive systems and the measures taken to guarantee it:

- Miniaturization, both of motor drives and motors, often accompanied by cost savings in the insulation strength of motor windings
- Retrofitting of motor drives in existing systems with old motors and unshielded cables
- Trends towards high-rotational speed machines with low mass (such as HF spindles)
- Innovative low-speed motor technologies with a high number of poles (such as tool beds with torque motors in machine-tool engineering applications)

Motor drives are known sources of interference and are therefore usually equipped with an input filter. However, fewer people are aware of the problems on the output side where the converter supplies the motor with the modulated signal. Some of the typical output challenges are described below.

5.3.1 dv/dt – voltage potential jumps in relation to the time

To keep the losses in the frequency converter or servo low, the aim is to keep the switching times of the power semiconductors as short as possible. The result of this is that with the newest generation of IGBTs, rise times of sometimes more than 12kV/µs can be measured, whereas – depending on the motor – a dv/dt of <1000V/µs is considered permissible (VDE 0530: 500 to 1000V/µs).

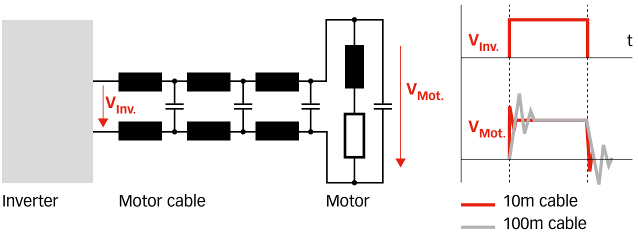


Definition of dv/dt

In the case of short motor cables up to about 20m, these rise times – owing to the small line impedance – act fully on the insulation of the motor windings. Depending on the structure of the motor coils, wires that carry the full voltage are situated immediately in parallel and next to each other. Since even very short parallel-laid wires have a capacitive action, the permanent potential jumps result in pole reversal losses across the winding insulation. Now, if the enamel insulation is impure even to a very minor extent, this results in the so-called hot-spots, and hence, sooner or later, to a destruction of the winding insulation. In any case, this dv/dt stress load leads to premature aging and thus to a reduction in the life of the motor.

5.3.2 Voltage overshoots and voltage peaks

Voltage overshoots and voltage peaks can come with high dv/dt values but are also a problem on their own. Due to the structure of the windings, a motor acts like a capacitor in the equivalent circuit diagram – owing to the fast voltage pulses of the switching frequency – and not as an inductance, as is the case in normal 50Hz applications. With every additional meter of motor cable, more wire inductance is added to this structure. This inductance acts like a choke according to the energy storage principle. If chokes are subject to voltage pulses, voltage peaks occur every time switching on or off takes place. The higher the energy content (inductance) of the choke, the higher these voltage peaks become. In other words, the longer the motor cable, the higher the maximum voltage amplitudes. These amplitudes can, in turn, reach values that cause a stress situation in the winding insulation of the connected motor. Owing to the cable impedance, the dv/dt stress – in the case of longer motor cables – is reduced to less problematical values. On the basis of the line theory, however, peak values of 1600V or more (depending on the DC link voltage) can occur due to cable reflections, which can have very steep dv/dt values. According to VDE 0530, peak values of <1000V are recommended. Despite the reduced dv/dt owing to the cable impedance, there is no significant stress relief for the motor, since now the increased voltage amplitudes represent the dominant stress factor.



Simplified equivalent circuit of shielded cables

Note that the picture above shows only the equivalent circuit of one phase.

5.3.3 Additional losses in the motor

Apart from the problem with the winding insulation, the steep switching edges create another phenomenon: harmonics of the output signal. By applying Fourier analysis, it can be mathematically proven that the harmonic spectrum of the motor currents becomes wider with the steepness of the pulses – that is, the harmonic content increases. The current ripple (PWM and harmonics) results in additional magnetic losses in the motor. The life of the motor is sensitively shortened owing to the permanently increased operating temperature.

5.3.4 Cable shields and parasitic earth currents

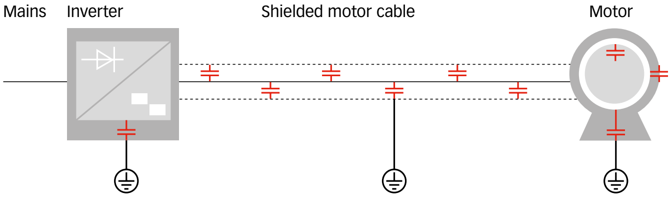
From the standpoint of EMI suppression, shielded motor cables are required to avoid back-coupling of radiated interference to the mains cable in the frequency range from about 1 to 30MHz. This measure of the EMC can, however, only be considered to be efficient if the ends of the cable shield of the motor cable are put in contact with the ground of the motor and the frequency converter – if possible, at HF low impedance and over as large an area as possible. This ensures that the interference currents can mostly flow back to the source by the shortest route.

Frequency converters normally work in grounded networks and do not have any potential separation. The geometric expansion of both the frequency converter motor and this shielded motor cable therefore form parasitic capacitances of the electrically conducting components with respect to the ground potential. If the available DC voltage is chopped in the frequency converter, then during the potential jumps of the voltage, considerable pulse currents flow across the parasitic capacitances to the earth. The level of the interference currents on the cable shield depends on the dv/dt as well as the value of the parasitic capacitances (I = C * dv/dt). With a motor cable length of about 100m, peak values of the pulse currents of 20 amperes and more are not unusual, regardless of the power rating class of the drive.

The harmonic spectrum of these currents can reach a range of several MHz. The shield of the motor cable, owing to the existing braiding, offers a very large surface area and a sufficient cross-section to carry these currents. As a result, the impedance of the shield across a broad frequency range is of a very low-impedance nature. Losses due to the skin effect are limited to a minimum because of the large surface area. Inadequate ground connections of the cable shield (the so-called “pigtails”), on the other hand, are highly resistive for the frequency range under consideration and often nullify the desired shielding effect.

If there are parallel-laid control cables or electronic components in the vicinity of the motor cables, pulsed HF currents flow across their geometric expansion and the resultant parasitic capacitances, which in turn could have an impermissible influence on neighboring equipment through capacitive coupling.

If neighboring components are located in the immediate vicinity of the motor cable, the conductor loops and the high di/dt values of the shield currents also result in a magnetic coupling that can also lead to impermissible influencing.



Parasitic capacitances in a drive system

The currents flowing across the shield must be supplied by the frequency converter as well. They are not dependent on the rating of the drive but only on the geometric expansion of the structure. With small power ratings, the result of this, especially in case of long motor cables, can be that a frequency converter of the next higher rating has to be used that is able to supply both the currents required by the load and the parasitic currents via the earthing.

The operation of several motors connected in parallel on one frequency converter is problematic. The parallel connection of several shielded cables results in a relatively high total capacitance and thus correspondingly high shield currents. The parallel connection of several drives, however, is accompanied by even more problems. Parasitic currents across the motor and the entire system can considerably affect the reliability of the whole system.

5.3.5 Bearing damage

A general distinction has to be made between two different physical occurrences:

- The shaft voltage (or rotor voltage) is an inductive voltage that is induced in the motor shaft owing to the differences in the flux densities of the stator and rotor. Above all, it is influenced by the length of the motor. As long as the lubricant film in the bearing is intact, the voltage builds up until, finally, a compensating current flows towards the earth. In this case, the path of least resistance is through the motor bearings. This bearing current (I_1), over a long period of time, usually results in drying of the bearings and thus failure of the motor. It is possible to counter this phenomenon to a certain degree through the use of ceramic bearings.

- The bearing voltage is an asymmetric (common-mode) voltage that occurs because of capacitive coupling between the motor housing, the stator and the rotor (C_1, C_2, C_3) and results in dv/dt and electrostatic discharge currents ($I_{dv/dt}$ and I_{EDM}) across the bearing ($C_{Bearing}$, $U_{Bearing}$). To be more accurate, this bearing voltage results in two different currents: in the first minutes of operation, as long as the lubricant in the bearing is cold, currents in the range of 5 to 200mA ($I_{dv/dt}$) flow through $C_{Bearing}$ because of the dv/dt. These rather negligible currents generally do not result in any bearing damage. After a little while, when the lubricant film has heated up, peak currents of 5 to 10A and more can be measured (I_{EDM}). These flashovers leave behind small pits on the surface of the bearing. The running of the bearing becomes increasingly rough because of the damaged surface and the life is thus considerably shortened. Typically, the bearing voltage is between 10 and 30V. But since it is directly dependent on the mains supply voltage, bearing damage increases overproportionally at higher supply voltages.

In the case of unshielded motor cables, the cable capacitance (C_{Cable}) and hence the current (I_{Cable}) is relatively small. The parasitic capacitances on the inside of the motor dominate. Ideally, the parasitic currents flow through the motor housing to the ground (I_{C1}). However, if the grounding of the motor is inadequate, an additional impedance results (Imp.), which limits the current (I_{C1}). As a result of the additional impedance, the potentials at C_2, C_3 and $C_{Bearing}$ increase sharply. The values of the bearing currents also increase massively and flow fully through the bearings to the earth ($I_{Bearing}$); in that case, the life expectancy of the ball bearings, and hence of the entire motor, is reduced to a few hours.

5.3.6 Acoustic noise levels

Compared to the previously described problem cases, the whistling noises of the motor – caused by the switching frequency – would appear to be negligible. However, in applications related to heating, ventilation and air-conditioning technology (HVAC), in which the noise is distributed more intensely in the entire building through air ducts or heating pipes, this point has to be taken into account.

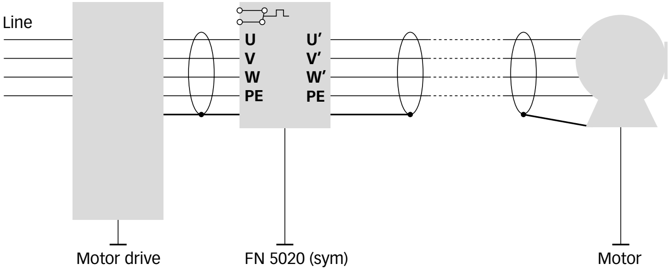
5.3.7 Solutions for output problems

For reasons of cost, time and space, an attempt is generally first made to manage without additional components. However, the subsequent costs that can result from motor or system failures are often entirely out of proportion to the far lower initial costs of preventive interference suppression measures.

If the decision is made in favor of components to increase the reliability and operational safety, the following types have established themselves in the market:

- dv/dt chokes and filters (low inductance, hardly any reduction in the control dynamic)
- Motor chokes (increased inductance, better signal smoothing, but not universally applicable to controlled drives)
- Sinusoidal output filters (high L and C for optimizing the output signal, but also not universally applicable)

Traditional symmetric sinusoidal output filters – FN 5020, FN 5040, FN 5045. Traditional symmetric sinusoidal output filters are LC-low passes filters that convert the PWM signal of the frequency converter between the phases into a smooth sinusoidal curve. The residual ripple of the signal can be adjusted by using the values of the L and C. An optimum cost-benefit ratio is often reached at a ripple voltage of 3% to 5%.



Drive with symmetrical sinusoidal filter

Symmetric sinusoidal output filters connected directly to the converter output have, above all, the following advantages:

- Complete protection of the motor from dv/dt and overvoltages
- Reduction of the additional magnetic losses and eddy current losses in the motor
- Reduction of the additional losses of the frequency converter owing to lower pulse currents to earth
- Reduction of the acoustic noise of the motor
- Reduction of the interference potential coming from shielded motor cables
- Increase in the reliability and operational safety of the overall system

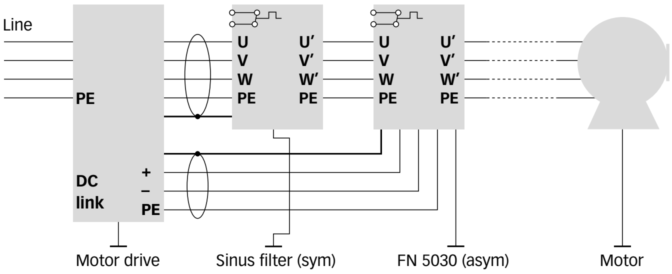
For a large number of applications, this can be considered the ideal solution. Most problems are solved efficiently and in a cost-effective manner with the symmetric sinusoidal signal.

In some cases, additional measures are necessary. Symmetric sinusoidal filters, despite all their advantages, are not able to improve certain problem cases, since despite the filter, there is still a pulsed signal to earth. These problems are:

- Bearing damage
- Parasitic earth currents
- Necessity of shielded motor cables
- Limited maximum possible motor cable length

Sinus Plus symmetrical and asymmetrical sinusoidal output filter – FN 530, FN 5020 with additional module FN 5030.

Sinus Plus is a highly developed modular sinusoidal filter concept from Schaffner that is unique in the market today. Consisting of a traditional symmetric and an additional asymmetric sinusoidal filter module, it can be customized exactly to any requirement. Through innovative circuits and an additional connection to the DC link, the additional module is capable of sending the asymmetric interferences directly to the very place they originated.



Drive with symmetrical and asymmetrical filter modules

This procedure is in keeping with the basic principle of interference suppression techniques: take the necessary measures at the source of the noise, not at the drain. Sinus Plus should always be considered to be a modular system in which the symmetrical filter part (FN 5020) can be connected autonomously but the asymmetric (FN 5030) may only be connected together with the symmetric module. FN 530 combines both solutions in one box. Operated in combination, this solution results in the following additional advantages:

- Complete elimination of bearing damage
- The possibility of using unshielded motor cables without any reductions in immunity
- Practically no more limitations with regard to the maximum cable length
- Almost complete elimination of the pulse currents to earth
- No interference influence of neighboring cables and equipment
- Elimination of the additional losses in the frequency converter
- Reduction in the suppression efforts on the input side. Since frequency converters are operated in ground-referred networks, every measure taken on the output side also influences the behavior on the input side (and vice versa). Since hardly any pulsed interference currents flow to the earth when Sinus Plus is used, the asymmetric part of the EMC mains input filter can be reduced, resulting in total cost savings.

II Annotations to filter specifications

1 Filter ratings

1.1 Electrical specifications

Where indicated, the component values in the datasheets are nominal values. The actual values can vary from the indicated ones based on the electrical tolerances given by the manufacturers. The test conditions for the components are listed below.

Tolerances and test conditions for passive components

Parameter	- Tolerance	+ Tolerance	Test
Inductance	30%	50%	1kHz
Capacitance	20%	20%	1kHz
Resistance	10%	10%	DC

1.1.1 Current

Current ratings of EMI filters are determined by the individual filter components. Since current flow leads to a temperature rise in passive components, the ambient temperature of the environment where the filter is to be used has a direct impact on the rated current.

The nominal currents stated for our components refer to an ambient temperature of $\theta_N = 40°C$ or $\theta_N = 50°C$ as indicated on the component and in this catalog. The maximum operating current at any other ambient temperature θ can be calculated by means of the following formula:

$$I = I_N \cdot \sqrt{\frac{\theta_{max} - \theta_{act}}{\theta_{max} - \theta_N}}$$

where

I_N	rated current at θ_N
θ_{act}	actual ambient temperature
θ_N	temperature at which the rated current is defined
θ_{max}	rated maximum temperature of the component

If a filter with $I_N = 7A$ at $\theta_N = 50°C$ and a rated maximum temperature of $\theta_{max} = 100°C$ is to be used at an ambient temperature of $\theta_{act} = 65°C$, the rated current of this filter must be reduced to $I_{N,65°C} = 5.9A$.

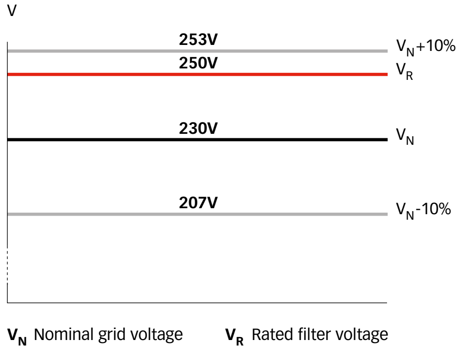
The actual current may also exceed the nominal current for a certain period of time. The exact specifications are given in the datasheet for each product.

1.1.2 Voltage

When looking at voltage ratings, care needs to be taken not to confuse the voltage rating of the filter with the nominal voltage of the power grid.

The most common nominal voltages are defined in IEC 60038. A European power grid, for example, has a defined nominal voltage of 230V ±10%. The maximum voltage at the terminals can therefore be 230V + 10% = 253V.

The rated voltage of the filter defines the maximum continuous operating voltage, i.e., the maximum voltage at which the filter should be used continuously. Short overvoltages are permitted in accordance with IEC 60939, but to avoid damage to the filter capacitors, the continuous voltage should not exceed the rated voltage for an extended period of time.



Relation between nominal and rated voltage

The nominal voltage +10% can exceed the rated voltage of the filter, as shown in the graph above. It is important to note that the nominal voltage of power grids is supposed to be at the defined value and within the boundaries of ±10% but not continuously at one of the limiting values. It is therefore safe to say that a power network in Europe will not run continuously at 253V.

The voltage rating is usually given for a supply frequency of 50/60Hz. If the filter is operated at higher frequencies (e.g., 400Hz), the voltage must be derated. This is also described in the following chapter.

The rated voltage of three-phase filters indicated on labels, in datasheets or catalogues sometimes lead to confusion when only one voltage value is stated, i.e. 480VAC. This value always has to be understood as phase-to-phase voltage. The respective phase-to-neutral voltage is $1/\sqrt{3}$ times

this value, i.e. 480VAC/$\sqrt{3}$ = 277VAC.
The rated voltage of newer products indicated for both, phase-to-phase voltage and phase-to-neutral voltage respectively, stating i.e. 480/277VAC.

1.1.3 Frequency

Depending on the type of filter, three different frequencies can be defined.
Supply frequency. The frequency of the AC mains supply network, typically 50 or 60Hz. The operating frequency of the filter is determined by the behavior of the capacitors. Depending on the voltage-frequency characteristic of the capacitor, it might be possible to operate a filter at a higher frequency but with a reduced input voltage.
Switching frequency. The frequency used to switch the IGBTs in the output stage of a frequency converter or SMPS. This frequency has a direct relation to the power loss in the converter and in the output components. Generally speaking, lower frequencies result in lower losses. For an output filter, it is also necessary to consider the relation between the switching frequency and the resonance frequency of the filter. Our filters are always designed in such a way that the resonance frequency is at least 2.5 times lower than the lowest switching frequency.
Motor frequency. The simulated supply frequency of the frequency converter. This frequency determines the rotational speed of the motor. Most applications operate at 50/60Hz motor fields, but applications with higher rotational speeds also exist (high-speed spindle drives up to 2000Hz).

1.1.4 DC resistance

The DC resistance of the filter is the resistance measured at the relevant power network frequency, i.e., 50Hz for European applications and at a defined temperature, such as 25°C.

1.1.5 Discharge resistors

Discharge resistors are connected across the filter capacitors to avoid electrical charges at the terminals of the filter after the filter has been disconnected. Failure to do so can be lethal, and discharge resistors are therefore a safety standards requirement. Generally, high-value resistors are used to slowly discharge the capacitor after disconnection.
If a filter is to be used in IT power networks (see “Power distribution networks” chapter), discharge resistors are not recommended. In IT networks the insulation of the power system is usually monitored in order to detect initial fault conditions. Discharge resistors can interfere with the monitoring equipment and indicate fault conditions where none exist.

1.1.6 MTBF

The MTBF (mean time between failures) is the reciprocal value of the failure rate. The failure rate indicates the statistical percentage of units failing over a certain amount of time. The MTBF will thus change over time, because the reliability of a product decreases as components age. The MTBF in our catalogs is calculated according to MIL-HB-217F.
The MTBF should not be confused with the lifetime of a product. It is instead an indication for the reliability – that is, for the probability of failure in the field. As an illustrative example, we could look at the airbag in a car. The MTBF has to be very high, because the airbag should deploy when needed, even if the car is more than 20 years old. The lifetime of the airbag, however, is short: the deployment takes seconds and then the lifetime is over.

1.2 Mechanical specifications

1.2.1 Mechanical tolerances

The mechanical tolerances in our drawings are given in accordance with EN 22768-2 (ISO 2768-2). All measures in a mechanical drawing should have defined tolerances. Instead of defining each individual tolerance, it is sufficient to give a reference to the tolerance classes of the above-mentioned standard. The general tolerances are defined in categories “fine,” “medium,” “coarse” and “very coarse.” The table below shows the actual tolerance measures according to these categories.

Mechanical tolerances

	Rated measure in mm							
	≥ 0.5 … 3	> 3 … 6	> 6 … 30	> 30 … 120	> 120 … 400	> 400 … 1000	> 1000 … 2000	> 2000 … 4000
Category	**Tolerance measure in mm**							
f (fine)	±0.05	±0.05	±0.1	±0.15	±0.2	±0.3	±0.5	–
m (medium)	±0.1	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2
c (coarse)	±0.2	±0.3	±0.5	±0.8	±1.2	±2	±3	±4
v (very coarse)	–	±0.5	±1	±1.5	±2.5	±4	±6	±8

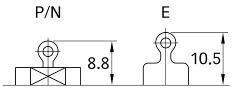
1.2.2 Filter terminals and cable cross-sections

Schaffner filters can be equipped with a number of different standard connectors. Below is an overview of all standard connection types available. Upon request, filters can also be built with other popular connection types. Please contact your nearest Schaffner office for more details.

Terminals and connection types

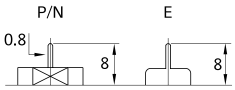
Type -01

Solder lug with a hole capable of accommodating several small wires



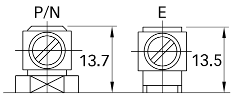
Type -02

Pin suitable for direct assembly onto through-hole printed circuit boards



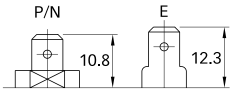
Type -03

Clamp terminal with M4 screw
Recommended torque: 1 - 1.3Nm



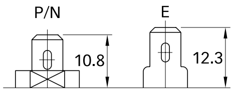
Type -05

Industry-standard size faston terminal
6.3 x 0.8mm



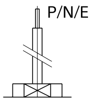
Type -06

Industry-standard size faston, which may also be used as a solder lug 6.3 x 0.8mm



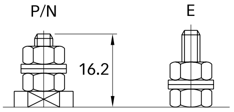
Type -07

Insulated wire, stripped ready for soldering.
Wire gauge varies according to filter



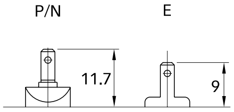
Type -08, -09, -10

08: M4 screw (1.3Nm)
09: M5 screw (2.2Nm)
10: UNC 8-32 screw (1.3Nm)



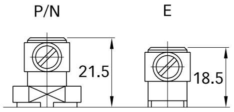
Type -13

Faston, 2.8 x 0.5mm



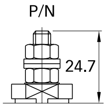
Type -23

Clamp terminal with M5 screw
Recommended torque: 1.8 - 2.2Nm



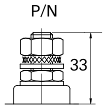
Type -24

M6 screw lead-through
Recommended torque: 3.5 - 4Nm



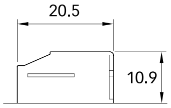
Type -28

M10 screw lead-through
Recommended torque: 15 - 17Nm



Type -29

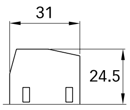
Safety terminal block for solid wire 6mm², flex wire 4mm² or AWG 10
Recommended torque: 0.6 - 0.8Nm



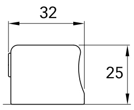
Type -33

Safety terminal block for solid wire 16mm², flex wire 10mm² or AWG 6
Recommended torque: 1.5 - 1.8Nm

HDFK 10



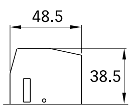
STB 10



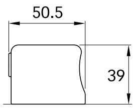
Type -34

Safety terminal block for solid wire 35mm², flex wire 25mm² or AWG 2
Recommended torque: 4 - 4.5Nm

HDFK 25



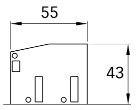
STB 25



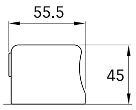
Type -35

Safety terminal block for solid and flex wire 50mm² or AWG 1/0
Recommended torque: 7 - 8Nm

HDFK 50

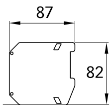


STB 50



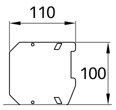
Type -36

Safety terminal block for 95mm² or AWG 4/0 cables
Recommended torque: 20Nm



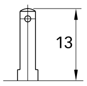
Type -37

Safety terminal block for 150mm² or AWG 6/0 cables
Recommended torque: 30Nm



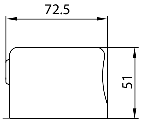
Type -16, -38

16: Solder/faston, 2.8 x 0.5mm
38: Faston, 2.8 x 0.8mm



Type -40

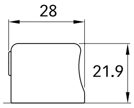
Safety terminal block for solid and flex wire
95mm^2 or AWG 4/0
Recommended torque: 17 - 20Nm



Type -44

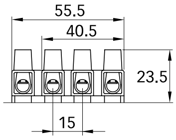
Safety terminal block for solid wire 10mm^2,
flex wire 6mm^2 or AWG 8
Recommended torque: 1.5 - 1.8Nm

STB 6



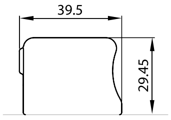
Type -47

Strip terminal block for solid wire 16mm^2,
flex wire 10mm^2 or AWG 8
Recommended torque: 1.9 - 2.2Nm



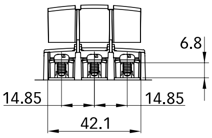
Type -53

Safety terminal block for solid and flex wire
16mm^2 or AWG 4
Recommended torque: 2 - 2.3Nm



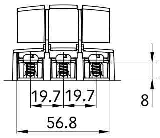
Type -71

M4 screw terminal for ring/fork lug
self-lifting
Recommended torque: 1 - 1.2Nm



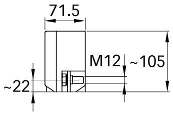
Type -72

M5 screw terminal for ring/fork lug
self-lifting
Recommended torque: 1.9 - 2.2Nm



Type -99*

High current terminal for flex wire 150mm^2
or AWG 6/0
Recommended torque: 27 - 30Nm



* Specification for FN 3100-300-99 only. Other -99 specifications (FN 2200, FN 3270, FN 3359, FN 3410, FN 3412) can be found on the individual product data sheets.

Below is a reference list showing the relation between the AWG number of connectors and the corresponding copper cross section of the wire.

AWG and metric cable specifications

AWG number	Cu mm^2
22	0.33
20	0.54
18	0.83
16	1.34
14	2.15
12	3.44
11	4.17
10	5.26
9	6.63
8	8.37
7	10.5
6	13.3

1.2.3 Torque specifications

The torque specifications in the table above are given to guarantee proper connections and avoid destruction of the terminals. They should be complied with at all times.

1.3 Environmental requirements

1.3.1 RoHS

With the adoption of EU Directive 2002/95/EC, the use of certain hazardous chemical substances is prohibited. Effective July 1, 2006, no new electric or electronic equipment may contain any of the following banned substances:

a) Lead (Pb)
b) Hexavalent chromium (Cr(VI))
c) Mercury (Hg)
d) PBB (polybrominated biphenyls) and PBDE (polybrominated diphenyl ethers)
e) Cadmium (Cd)

As complete elimination of the banned substances is impossible, an EU Commission Decision of August 18, 2005 (2005/618/EC) tolerates certain maximum concentrations. These tolerances, defined by weight in homogenous materials, are:

- ≤0.1 weight % for a, b, c, d
- ≤0.01 weight % for e

The following exceptions are applicable as listed in the Annex of Directive 2002/95/EC:

- Lead as an alloying element
  - in steel containing up to 0.35% lead by weight
  - in aluminum containing up to 0.4% lead by weight
  - in copper alloy containing up to 4% lead by weight
- Lead in glass of electronic components

As a global enterprise, the Schaffner Group designs and manufactures products in accordance with this legislation. We see the need for implementation and compliance as a key element of our business activity and, whenever possible, we strive to achieve concentration levels below the maximum tolerances.
Schaffner uses the following labels to identify RoHS-compliant or lead-free products in documents and on its website:

RoHS

Lead FREE

Labels for RoHS and lead-free compliance

1.3.2 Vibration and bump testing

Our filters are typically specified to maintain their characteristics when properly mounted after being subjected to a vibration test consisting of a sinusoidal sweep from 10Hz to 55Hz and back to 10Hz for a duration of 120 minutes. The test is applied in the main axes and a deviation of ±0.75mm or 10g is used. Vibration testing is performed in accordance with the standard IEC 60068-2-6.
The filters will also maintain their characteristics after being subjected to the following bump test: 1000 bumps of 10g, applied for 16ms in three axes appropriate to the mounting instructions. The relevant testing standard is the IEC 60068-2-29.

1.3.3 Climatic classification

All components have to work in defined climatic conditions. IEC 60068-1 defines climatic categories and the relevant testing methods. Typically, the climatic category is indicated by three numbers separated by slashes as shown below.

25/100/21

25	Test A: cold (lower category temperature) -25°C (in accordance with IEC 60068-2-1)
100	Test B: dry heat (upper category temperature) 100°C (in accordance with 60068-2-2)
21	Test C: damp heat (duration of test) 21 days (in accordance with IEC 60068-2-78)

For environments where the standard specifications are not sufficient (e.g., military) Schaffner can also offer custom-made solutions with extended environmental specifications.

2 Safety requirements

Most filters are connected in the mains supply line to the power supply system, making them the object of safety-related concerns. A number of items have to be considered during the design of a filter.

2.1 Type testing

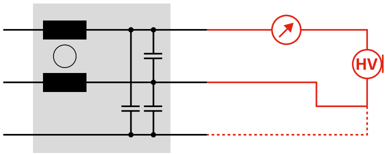
Type testing is performed with an initial sample in order to verify the safety-relevant specifications for the design. All type testing is performed in accordance with the relevant safety standards. For some tests, the discharge resistors have been removed for type testing. This is in accordance with the relevant testing specification.
When the filter is built into equipment and type testing is performed for the final equipment, the following points should be considered:

- Some tests might overstress the discharge resistors and lead to their destruction.
- In some cases, the equipment requires the measurement of the insulation resistance (e.g., EN 60204). This measurement cannot be performed with discharge resistors.

In special cases, samples without discharge resistors can be provided. Please contact your nearest Schaffner representative for details.

2.2 Hipot testing

In filters we use components that are connected between the phases of the supply network or between one phase and earth. It is therefore important to determine how well filters resist high voltages. A high-voltage test, often called hipot test, is performed for this reason by applying a voltage between enclosure and phase or between two connectors for a defined time. The current flowing between the same points is measured. Current flow means that the insulation is broken; the equipment fails the test.



Testing principle of high-voltage testing

During approval procedures, the test is usually performed over a longer period (typically one minute) with a defined voltage. Many safety standards require the testing to be performed on 100% of all units, but to save time, a test with higher voltage but reduced time is accepted. It should be noted that repeated high-voltage testing can lead to a damage of the insulation.

The testing voltages used for 100% testing are indicated in the individual datasheets. Please note that hipot tests are high-stress tests for the capacitors inside the filter. Each additional test stresses the capacitors again and leads to a reduction of lifetime. Schaffner recommends keeping the number of hipot tests to a minimum and never testing the filters at higher than the indicated voltages.

2.3 Leakage currents

During normal operation of electrical equipment, some current flows along the protective earth conductor towards earth. Such currents, called leakage currents, pose a potential safety risk to the user and are therefore limited by most current product safety standards. Examples for these standards are EN 60950-1 for information technology equipment or UL 1283 for passive EMI filters. The standards include limits for the maximum allowed leakage current.

In most installations today we find residual current breakers or leakage-current breakers to protect against high leakage currents. Typical tripping values for these breakers are 30mA where personal protection is the main goal and 300mA for protection against fire.

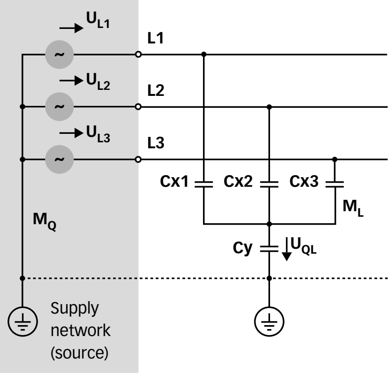
For equipment that can by definition not meet these limits, additional provisions are required-for example, attaching special warning labels.

Warning!
High touch current.
Connect to earth first.

Warning!
High leakage current.
Connect to earth first.

Warning labels for increased leakage currents

For passive EMI filters it is common to calculate the leakage currents based on the capacitor values against earth and other parasitic components. The following figure shows a typical capacitor configuration. In the case of a balanced capacitor network, the leakage currents will be negligible. On the other hand, the leakage currents will reach the maximum value at the highest imbalance between the phases. Causes for the imbalance are the tolerances of the capacitor values as well as the voltage imbalance in the supply network.



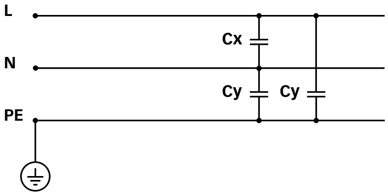
Typical capacitor configuration in three-phase filters

Most capacitors in passive filters are rated by the manufacturers with a tolerance of ±20%. The highest voltage drop at Cy occurs when two of the X-capacitors show the lowest tolerance values and one shows the highest. In addition, Cy is assumed at its highest tolerance value. To put a good picture to the theory, a sample calculation can be performed with a 480V three-phase filter. The capacitor values are given at Cx = 4.4µF and Cy = 1.8µF; the tolerances for all capacitors are ±20% according to the manufacturer. Not considering the supply voltage imbalance, the leakage current is calculated as approximately 23mA.

Practical experience shows that the tolerances of capacitors are never spread that widely. An assumed tolerance range from -20% to 0% seems more realistic. Using this assumption in the calculation above results in a leakage current of only about 10mA. It should be pointed out, though, that there is no agreement between filter manufacturers regarding the calculation method for leakage currents in filters. It is therefore perfectly possible to have differing leakage currents in two filters, even though the circuit diagrams and component values are identical.

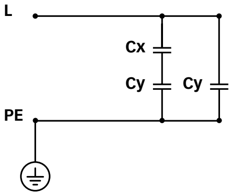
Up to this point, the voltage imbalance of the supply network was not figured into the calculation. In practical application, supply networks do have a certain imbalance. To include this in the calculation, we use the supply network standard EN 50160, which defines the conditions in public power supply networks. According to this standard, the voltage imbalance for regional networks can be up to 3%. Using this in the previous calculation, the leakage current now adds up to 26mA for a capacitor tolerance of ±20% and 13mA for +0/-20%.

Compared to three-phase networks, the calculation of leakage currents in single-phase networks is significantly easier. With a given supply voltage and frequency, the leakage current depends solely on the total capacitance. The following figure shows the typical capacitor circuit for single-phase filters.



Typical capacitor configuration for single-phase filters

For a filter with Cx = 100nF and Cy = 2.2nF and a given tolerance of ±20%, the leakage currents come to 190µA. The worst-case scenario is given if the neutral conductor is interrupted. The total capacitance then consists of two parallel capacitors: CyL on the one hand and the series connection of Cx and CyN on the other. The following figure shows the equivalent circuit.



Total capacitance with interruption of neutral

For fault conditions, the maximum leakage current can be as high as 377µA.

It was already mentioned that the leakage current is lowest when the supply network and the capacitor network are balanced. Every imbalance increases the leakage current. With this in mind, it is also obvious that the supply network topology must have a significant influence on the amount of leakage current from equipment. The network topologies are explained in the “Power distribution networks” chapter. Another potential source of imbalance problems is the moment when equipment is switched on.

2.4 Flammability classification

The American approval agency UL requires flammability tests for all plastic materials used in devices and appliances to ensure that the material cannot burn in case of malfunction of the equipment. The exact requirements are defined in the standard UL 94.

During the tests, a specimen of the plastic material is exposed twice to an open flame. The exact specifications are given in the above-mentioned standard. During the test the following items are observed:

- Afterflame time after first flame application, t1
- Afterflame time after second flame application, t2
- Afterglow time after second flame application, t3
- Whether or not specimens burn up to the holding clamp
- Whether or not specimens drip flaming particles that ignite the cotton indicator

Based on the results, the material is then classified as shown in the table below.

2.5 Fuses

All filters with fuse holders are delivered without fuses due to the variety of fuses in different local markets. Below you’ll find a brief recommendation regarding fuses.

The maximum rated current in the specification is not always the fuse value required by our customers. Users should also consider the current rating in relation to the ambient temperature. A fuse needs to be selected by the user depending on ambient temperature, tripping rating, acting behavior (fast, medium, slow) and other electrical specifications. Fuse holders are designed to hold cartridge fuses with 5 x 20mm for Europe and 6.3 x 32mm for the USA. Please refer to the product datasheet to see the kind of fuse supported by a particular model.

Custom filters can be equipped and delivered with fuses. If you wish to buy IEC filter modules with pre-mounted fuses, please contact your local Schaffner sales office.

Test criteria for UL flammability classes

Criteria conditions	V-0	V-1	V-2
Afterflame time for each individual specimen t_1 or t_2	10s	30s	30s
Total afterflame time for any condition set (t_1 plus t_2 for the five specimens)	50s	250s	250s
Afterflame plus afterglow time for each individual specimen after the second flame application ($t_2 + t_3$)	30s	60s	60s
Afterflame or afterglow of any specimen up to the holding clamp	No	No	No
Cotton indicator ignited by flaming particles or drops	No	No	Yes

3 Power distribution networks

3.1 Designation of networks

Throughout the world we find a variety of different power distribution networks. The most common ones are defined in IEC 60364-1. The constellation of the power network often has an impact on the filter performance, and some filters are even designed for specific networks to ensure maximum performance at the highest reliability level. The distribution networks are designated using the following codes:

AB (-C -D)

A	Grounding condition of the supply I: insulated T: grounded
B	Connection of the installation N: connected to PE T: grounded directly
C	Connection of N and PE C: connected S: separated
D	Indication that part of the system has separate N and PE lines

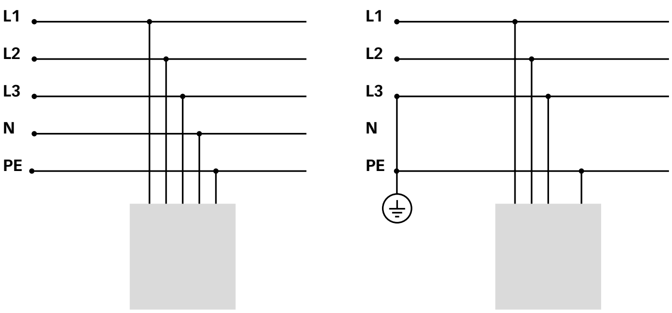
Example: TN-C-S: Grounded supply network where the installation is connected to PE. PE and N are combined to a PEN conductor, but in parts of the network there are also separate PE and N lines.

3.2 TN network

In TN networks one point of the distribution system is directly connected to ground. Each installation in the systems is connected to this common grounding point via the PE conductor. There are three different variations of TN networks

3.2.1 TN-S system

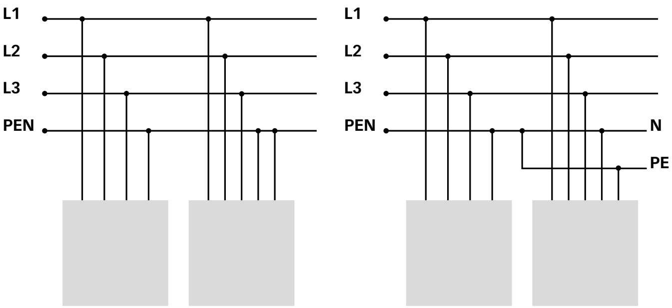
The S indicates that there must be a separate PE conductor throughout the whole system. The figures below show the possible configurations.



TN-S distribution networks

3.2.2 TN-C and TN-C-S systems

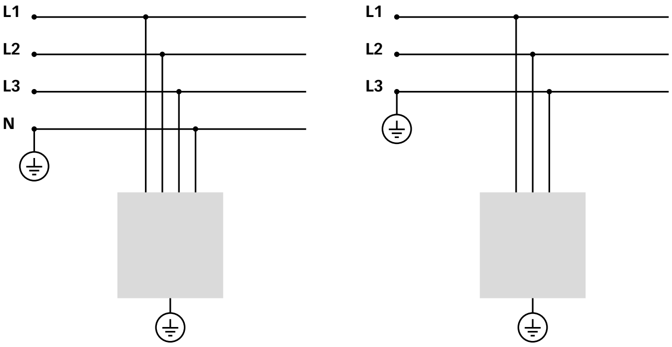
In TN-C systems the protective earth connector and neutral line are combined into one conductor. For a pure TN-C system this is done throughout the system. A system where PE and N are separated in some parts only is called TN-C-S.



TN-C (left) and TN-C-S (right) distribution networks

3.3 TT network

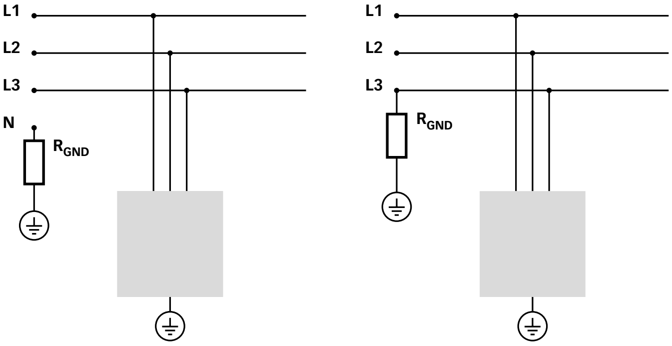
In a TT system the ground points for the system and the installations are electrically separated. Both parts are grounded directly and independently.



TT distribution networks

3.4 IT network

In an IT system there are two possibilities: either all active parts are separated from ground, or one point of the system is grounded via a defined high impedance (R_{GND}).



IT distribution networks

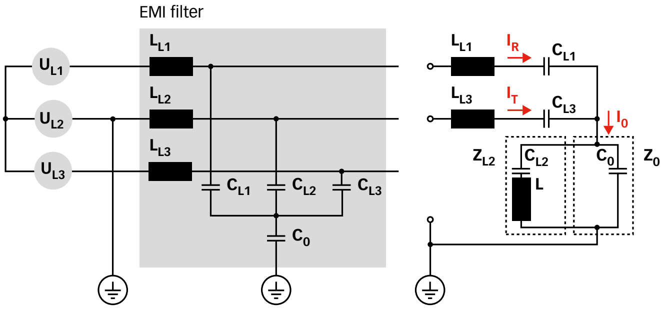
The setup comes with a number of special issues to be considered when using filters. For power networks one always considers the first-fault condition, where one phase is short-circuited to ground. The advantage of an IT system lies in the fact that in such a fault condition the risk of high touch currents is negligible. Inside of the filter, however, the voltage across the capacitors will increase significantly. If the filter is not specifically designed for IT networks, there is a good risk of destruction of the capacitors in the case of a network first fault.

An IT network with a single fault turns into a TN system, but with increased phase voltages. It continues to function, but for safety reasons the first fault should be repaired as quickly as possible. In IT networks, therefore, the insulation of the phases against earth is constantly monitored. If additional resistors are connected between line and earth inside connected equipment, the monitoring system is influenced and might detect non-existing faults. As a result, discharge resistors are not permitted in filters in systems for IT distribution networks.

Schaffner offers a variety of filters especially designed for IT networks, such as FN 258HVIT and FN 3359HV. For more details, please consult the datasheets for the products.

3.5 Network with one grounded phase

Some regions, such as Japan, utilize a power distribution network where one phase is directly earthed.



Power network with grounded phase and filter (left) and equivalent circuit (right)

With this arrangement the impedance towards earth is completely changed, resulting in different voltage drops and leakage currents. The outcome of this is that the standard rating for leakage currents cannot automatically be applied for networks with a grounded phase.

For such applications, Schaffner also offers a dedicated range of products in this catalog. Please consult the datasheets for more information. Further products for the Japanese market are available. Please contact your local Schaffner vendor for more details.

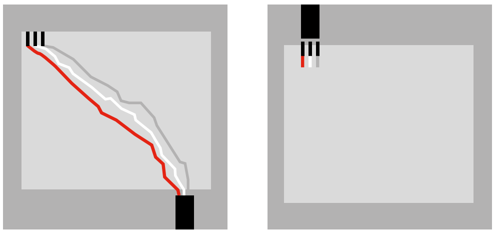
4 Installation instructions

While EMI filters are a proven measure to ensure compliance of products with EMC requirements, they can only be effective if properly installed. Not only is the filter installation itself of utmost importance, however. The planning and implementation of other EMC measures and design rules also contributes to good performance in terms of noise emission.

Where available, manufacturers should always refer to the installation instructions when installing filters. Further information about installation is also available at www.schaffner.com.

4.1 Installation of filters

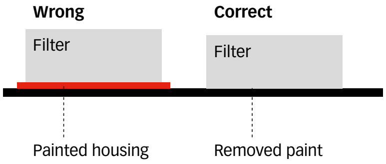
The intention of using filters is to prevent unwanted signals from entering a certain electrical area. In order to do so, the filter should be installed as close as possible to that area. The connection between the filter and source circuit should be kept as short as possible.



Improper (left) and correct (right) placement of filters

Installations as shown in the left figure above should be avoided whenever possible. Even though the connection between the filter and protected circuit is the shortest possible due to the filter design, the cables from the filter to the printed board take the longest possible way inside the enclosure. They can therefore pick up all signals along the board and radiate them like an antenna, thus working as an unwanted interference source. If the connection is kept short, the interference from the board is eliminated at the source while at the same time keeping the distance between AC supply and filter short. The filter will show its maximum effect under these circumstances.

Even more important than the filter position is its connection to ground. Proper grounding is essential for the operation of a filter. Without ground connection, the filter is floating and loses its common-mode attenuation provided by the Y-capacitors. One of the most common problems with grounding is the installation of filters by directly attaching them to enclosures with painted or otherwise treated surfaces, in that way interrupting the ground connection and leaving the filter almost useless. To avoid this problem, the part of the surface where the filter will be installed should be abraded.



Proper ground connection of filters

Abrasion of enclosures, however, is not always an option. Depending on the ambient conditions, surface treatment might be a requirement to avoid corrosion, and conductive coatings might not be available.
When the ground connection is done, care should be taken to have as big a connection area as possible. It is a common misconception that the conventional PE wire will be sufficient for RF grounding purposes. Instead, flat wires should be preferred over round ones and braided wires over solid ones. The flat wire should be connected plainly on both the filter and the ground connection side in order to ensure proper filtering.

4.2 Cable connection and routing

It is said that in an EMC concept the filter contributes about 50% of the total performance. The remaining 50% is achieved through proper EMC design. Two issues are of special importance in this context: the connection of shielded cables and the cable routing inside of equipment.

4.2.1 Shield connections

Shield connections have already been discussed in a previous chapter. Once again, it is important to connect the shield ends of shielded cables on both sides of the cable with the best possible means. The ideal case would be 360° connections on both sides.

4.2.2 Cable routing

Whenever cables are left longer than necessary or routed close to each other, additional antennas and coupling areas are created. The result is often a short-circuit of the noise suppression components, and the attempt to reduce noise fails not because of the suppression component but because of the cabling.

To improve the situation, cables should be shortened to the necessary length and routed in defined ways. Where cable crossings cannot be avoided, a 90° crossing should be used for maximum decoupling. To avoid an EMI short circuit of the filter, special care should be taken never to cross input and output cables of a filter.

4.3 EMC planning

EMC should always go hand in hand with the general design of the product. From the very beginning, designers should consider which noise sources and susceptible circuits they have in their equipment. This makes it possible to physically separate them and avoid problems right from the start rather than having to fight them later.
Next, the cabling should be considered, keeping in mind the recommendation from the previous chapter. It is much easier to plan the cable layout first rather than having to modify it at a later stage. Finally, the filtering components should be planned in as well. Filters are not added at the end to get rid of a problem, they are an integral part of the overall EMC design of a product.
A filter should be located as close to the noise source as possible. When using drive filters, the filter should be placed close to the drive, or in some mechanical designs even under the drive. Mains filters are placed as close to the power inlet as is feasible.
When using filters or reactors, one should always consider the heat dissipation from the filtering component. To avoid overheating, leave sufficient space around the component and ensure air circulation.

Schaffner can support manufacturers with their EMC layout from the early stages of new product ideas or designs. Contact your nearest Schaffner representative for more information.

III Typical applications

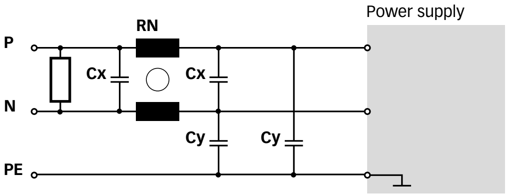
1 Choke applications

1.1 Current-compensated chokes (RN, RD and EV/EH series)

These chokes are used to attenuate common-mode or asymmetric (P/N –> E) interference signals by being connected in series with the phase and neutral lines of an AC power line input. The magnetic fields produced by this winding technique cancel each other out. Full inductance is only presented to interference signals that flow asymmetrically from phase/neutral to earth.

Symmetrical components of the noise are also attenuated by the leakage inductance of the windings. The impedance of the choke at power line frequencies is therefore negligible, resulting in practically zero voltage drop. Current-compensated chokes are used with multiple windings to avoid saturation (loss of effective inductance). An efficient inductor-capacitor combination to protect against line-conducted interference consists of:

- Series inductances in the interference paths
- Cx capacitors between phase and neutral
- Cy capacitors between phases and earth

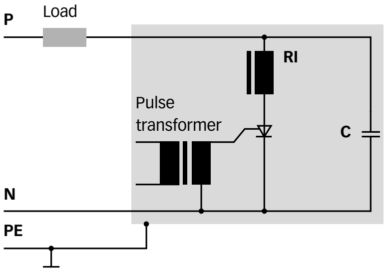


Basic power line filter to remove common and differential-mode noise, based on a current-compensated choke

- In phase-angle control circuits where the desired degree of suppression cannot be achieved by saturating chokes alone
- For suppressing high interference levels from ultrasonic generators, fast rectifiers, switched mains equipment etc.
- For suppressing equipment with no earth connection
- For input filters to protect digital circuitry from mains-borne interference

1.2 Saturating chokes (RI types)

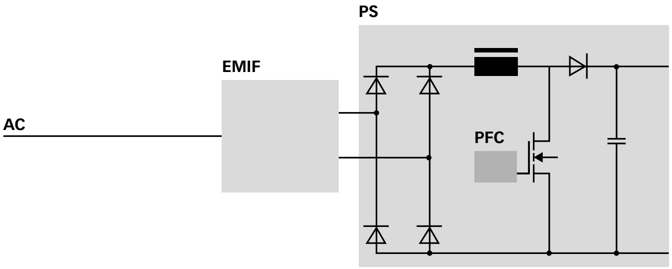
These chokes change impedance at the moment of switching and can be used to attenuate differential-mode or symmetrical (P –> N) interference as generated by phase angle control devices such as thyristors and triacs. Interference levels can be brought within the limits of national and international regulations by using these chokes in conjunction with appropriate suppression capacitors. For optimum attenuation, chokes must be connected as close as possible to the semiconductor switching device. A simple single-stage suppression circuit is shown in the following illustration; this can be made into a dual-stage filter by the load itself and one additional capacitor.



Saturating chokes in series with thyristors

2 Power supply applications.

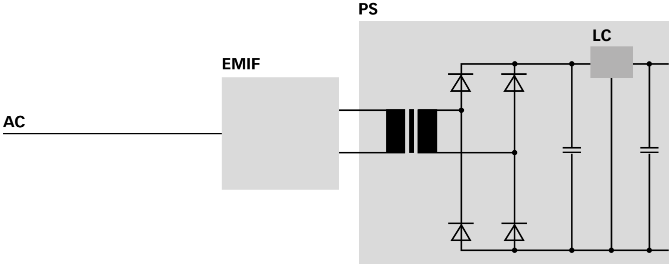
The number of switch-mode power supplies (SMPSs) in electrical and electronic equipment is steadily increasing. They are used not only in traditional applications, such as computers, but also in a growing number of consumer products. At the same time the switching speed of the power supplies is becoming faster, in order to minimize the volume of magnetic devices for the PFC and transformer and to reduce the overall size of the power supply.
While the operational advantages of SMPSs are unquestionable, the negative impacts are becoming increasingly obvious. On the one hand there is an increase in the harmonic distortion of the power networks, which has already resulted in new versions of the relevant standard IEC 61000-3-2. Single-phase harmonic distortion can be eliminated by using front-end power factor correction technologies or harmonic chokes. On the other hand the noise emission due to the high switching frequency is becoming harder to control. Schaffner EMC single-phase filters or IEC inlet filters are designed to minimize EMC emissions from switch-mode power supplies.



EMIF EMI filter
PS Switch-mode power supply
PFC PFC control

Single-phase power line filter with SMPS to remove common and differential-mode noise

Linear power supplies do not generate EMC noise in the same way as switch-mode power supplies. The majority of EMC noise in a system with a linear power supply is a result of the load behavior and, nowadays, the driving digital logic. Single-phase EMC filters or IEC inlet filters help to reduce the EMC emissions to an acceptable level. Additionally the system immunity will be increased to protect against EMC noise from the grid.



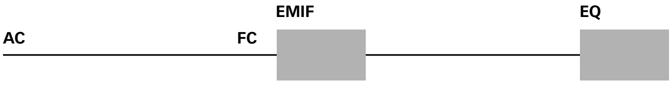
EMIF EMI filter
PS Linear power supply
LC Linear control

Typical linear power supply application with EMC line filter

2.1 Single-phase filters

These are the key element in eliminating system-generated and mains-borne interference. One of the biggest advantages of using a single-phase filter is the rapid availability of the associated safety approvals.

Single-phase filters are used in a wide range of applications, such as control panels, systems, equipment and apparatus, together with power supplies or other electrical functions.

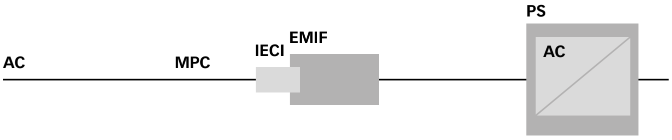


FC Fixed power cord
EMIF EMI filter
EQ Equipment, e.g. switch-mode power supply

Schaffner single-phase filter FN 2030

2.2 IEC inlet filters

IEC inlet filters with a standard IEC connector are a practical solution when you need to meet the requirements of different country-specific mains plugs. The EMC filter function protects your system and suppresses EMI noise while the IEC connector allows you to equip your system with a standard connector to fit country-specific mains cords. The compact dimensions and supplementary options, such as a mains switch, fuse holder or voltage selector, offer numerous advantages to the user. IEC inlet filters are used in a broad variety of applications, typically in conjunction with a power supply. IEC inlet filters with an integrated voltage selector allow country-specific voltages to be selected in linear power supply designs.



MPC Mains power cord with regional plug
IECI IEC inlet plug/connector
EMIF EMI filter
PS Power supply

IEC inlets can be used in test and measurement equipment, medical equipment, consumer goods, power supplies and in various other electrical and electronic applications.

Schaffner IEC inlet filter FN 280 with fuses and switch

3 Medical applications

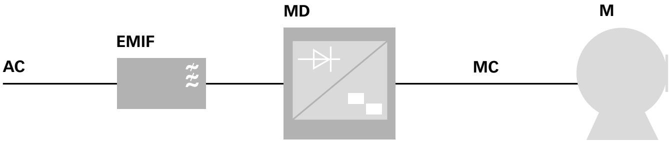
Medical applications sometimes require special EMI filters. Depending on the environment and the use to which the medical equipment is put, the EMC filter may vary significantly from a standard product. Medical electrical equipment or in-vitro diagnostic medical devices have different requirements for leakage current, air and creepage clearances and test voltage, amongst other things. For medical devices with higher safety levels, in accordance with IEC/EN 60601-1, Schaffner offers medical grade versions (B type) of many of its filters, with a lower leakage current, increased air and creepage clearance, discharge resistor and higher test voltage. These filters are available as single-phase or IEC inlet filters, as well as for special three-phase applications.

4 Test and measurement equipment

Test and measurement equipment involves a wide variety of applications. These range from the filter requirements for a power supply through to systems which include power supplies, motors, drives, valves etc. Depending on the requirements, you can select the most appropriate filter from a broad range of single-phase and three-phase filter products.

5 Motor drive applications

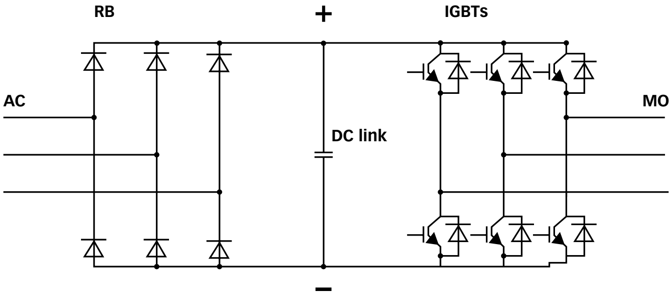
A power drive system acts as a converter of electrical energy into mechanical energy. The inverter within the system is commonly used because of its simplicity. However, inverters are well known EMI sources in many industrial applications as well as an increasing number of consumer products.
The power frequency of the supply network is normally 50Hz or 60Hz. The inverter can actually vary the speed of the output frequency from 0Hz to several 100Hz or >1kHz, depending on the application.



EMIF EMI filter **MC** Motor cable
MD Motor drive **M** Motor

Example of a power drive system

The supply voltage is rectified in the converter section. This section consists of a set of diodes, usually six for a three-phase bridge and four for a single-phase bridge. The DC link consists of a DC capacitor, which stores the rectified energy and releases this energy into the power switching stage. This stage is usually a bank of six transistors. In the example below, the power transistors consist of Insulated Gate Bipolar Transistors (IGBT). The fast-power semiconductors chop the DC voltage into a square wave voltage at the carrier frequency. Control circuits regulate the square wave pause/pulse ratio and generate a three-phase voltage with adjustable power frequency to vary the motor speed. This control mechanism is called Pulse Width Modulation (PWM).



RB Rectifier bridge **MO** Motor output
IGBTs Insulated gate bipolar transistors
Rectifier bridge in a frequency converter

This high frequency switching will cause EMI. Noise from the output motor cable as well as from control and supply cables couples into adjacent cables and systems. Parasitic capacitance to the ground plane enables the noise to exit the installation and get onto the mains distribution network as common-mode noise. The longer the cable, the greater the capacitance to ground and the bigger the common-mode noise currents that will flow.

Schaffner's vast experience in the area of motor drives enables us to provide you with EMC and power quality solutions for both the input and output sides of inverters.

6 Energy regeneration

Today, modern frequency inverters for motor speed control are an integral part of both industrial and residential applications. In regular operation, the motor acts as the consumer of the provided electrical energy. Sometimes, the same motor is also working as a generator; this phenomenon occurs during the braking process of the motor and is known as the regeneration of electrical power. Traditional inverters are not able to use this regenerated energy. Therefore, more and more drive manufacturers equip their inverters with regeneration units in order to utilize this "free" energy for further use.

Energy regeneration inverter systems offer numerous advantages over traditional drives, such as:

- Delivery of generated energy back to the mains power lines for further use
- No problems with unwanted heat dissipation from brake resistors
- No waste of precious energy
- No bulky external brake resistor required
- Higher dynamic characteristics of the system

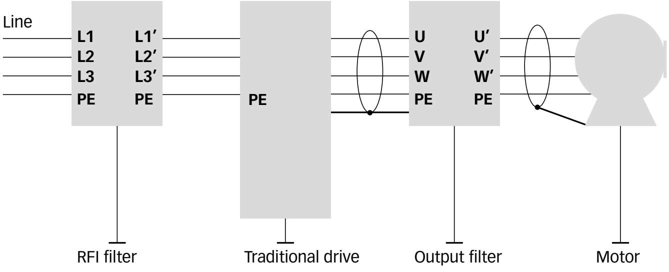
Unfortunately, this innovative technology also gives raise to a considerable number of problems. First of all, in a motor drive system with an energy regeneration unit, all the problems known from traditional motor drive applications also occur (EMI, harmonics, dv/dt, overvoltages, magnetic losses in the motor, motor bearing damage, etc.).

As there is a second converter deployed, electromagnetic compatibility (EMC) also becomes even more critical; today, dedicated draft standards for ER systems already apply.

Furthermore, the energy is being returned to the mains by means of a second converter, which operates in the direction of the mains power lines. The ER converter is conducting the regenerated power via a pulse width-modulated signal toward the net. This mode of operation is extremely critical, as the 50Hz sine wave of the mains power lines and a pulsed regenerative voltage at approximately 1 to 4kHz cannot tolerate each other very well. The commutation from the regenerative converter even causes short circuits between the phases towards the public power grid.

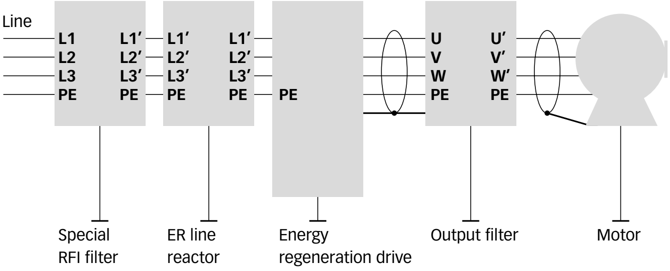
In other words, without a proper solution like those suggested by Schaffner, the operation of ER systems is not guaranteed at all. In order to ensure the function and avoid significant interference effects towards the public network, the returning signal needs to be smoothed and adjusted to the power line requirements by means of additional line-conditioning measures. Compliance, reliability and proper function are prime objectives.

Traditional and ER drive philosophies are very different. The installation and solution of the aforementioned problems have to be just as different. The following block schematic diagram shows the most common interference suppression measure deployed in traditional drive units today.



RFI filter solution for traditional drives

A regenerative drive system requires additional measures: First of all, a traditional RFI filter may not be sufficient to meet the dedicated standards and legislation. It's also necessary to consider that the filter must provide full interference attenuation performance in both directions, no matter which operation is active. This creates much tougher requirements for the filter. Furthermore, ER drives require a special line impedance that cannot quite be compared to a traditional line reactor. Without this line impedance, the ER converter will start producing short circuits between the phases as soon as the system changes into regeneration mode. These short circuits are caused by the IGBT switches (commutation) of the regenerative drive unit.



Installation of additional measures for ER drives

The configuration shown in the figure above deploys large smoothing capacitors directly on the mains power lines. If one of the following phenomena occurs, the operation of an additional line reactor is suggested for the line side of the RFI filter.

- Amplification of harmonics
- Self-excitation of machines or equipment
- Overvoltages caused by switching
- Unsatisfactory function of audio frequency ripple control relays

The following parameters have a key influence on the design of the ER solution:

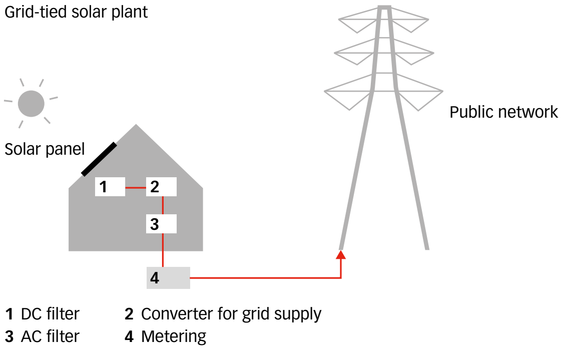
- Kind of modulation and the modulation factor of the drive
- Regeneration switching frequency
- Impedances of the drive
- Cable length
- Special drive peculiarities (circuits to increase the DC link voltage, etc.)

With so many uncertain influences, it does not make much sense to provide a standardized range of filter solutions. The recommendation instead is to find the best solution for a particular ER application by looking directly at the relevant drive and the equipment that incorporates it. With many years of experience in the motor drive sector, Schaffner is the ideal partner for the development and production of fit-and-forget, ER-capable filter and line impedance solutions.

7 Renewable energies

Renewable energy sources like solar power stations or wind parks are becoming increasingly popular. While the means of power generation differs significantly among the natural sources, the conversion process is very similar. We will therefore explain the relation between the application and the solutions by using solar power generation as an example.

Functional model for photovoltaic applications. Through photovoltaic technology, the sun's radiation can be directly converted into electrical energy. The solar cells of a photovoltaic plant generally consist of two layers – a positively conducting and a negatively conducting layer. As soon as light falls on the cell, a voltage is generated. A connected inverter converts the DC voltage that has been so generated into AC voltage and feeds it to the public network.

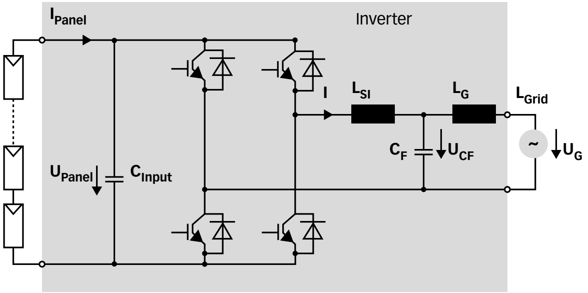


General principle of photovoltaic energy generation

Functional principle of solar inverters. As described above, a solar inverter is used for converting the DC voltage into AC voltage. This involves the present-day modules with complete digital control and high efficiency. For better understanding, the solar inverter can be compared, in the broadest sense, with a regenerating frequency converter for motor control (ER motor drive).

Basically, a distinction is made between two kinds of solar inverters: inverters without transformers and solar inverters with integrated isolation transformers. Although the latter design has clear advantages with regard to the functioning and reliability of the solar module, it is not considered at present because of the additional losses, the greater weight and the size.

In the case of the solar inverter without a transformer, the DC voltage is supported by capacitors and then converted into a 50Hz three-phase voltage by means of a self-commutated converter bridge (such as IGBTs), which is then supplied to the mains power network. What is involved here is not a pure sinusoidal form but a pulsed signal (such as PWM) with a high harmonic content and interference potential.



Principle circuit diagram: single-phase solar inverter (without transformer) with grid connection

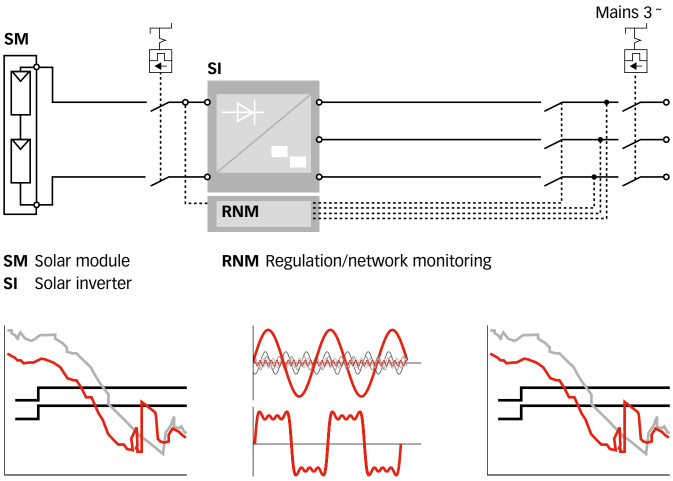
Occurrence of interferences when using solar inverters. As is already known from motor drive technology, every kind of inverter gives enough cause for the use of interference suppression components. This is no different in the case of the solar inverter.

The fast switching processes that occur when the DC voltage is chopped generate a broadband interference spectrum.

The unfiltered connection of the solar inverter to the public supply network would thus be a contravention of the EMC Directive.

However, conducted and radiated interferences occur not only in the direction of the network but also in the direction of the solar module and can adversely affect it in function and efficiency. Whereas the conducted interferences are mostly decoupled in the case of the solar inverter with a transformer, there is a clear need for additional interference suppression components on the DC side in the solar inverter without a transformer.

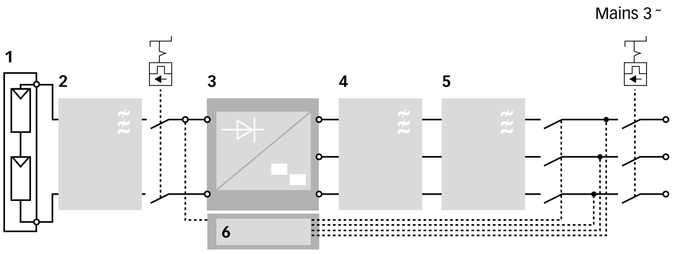
Because of the steep switching edges, the non-sinusoidal, pulsed AC voltage signal at the inverter output also has a considerable harmonic content that is generally well above the permissible limiting values of international standardization (EN 61000-3-2; IEEE 519).



Typical block circuit diagram of a grid-tied solar plant with interferences occurring

Apart from the standardization, the operation of a large number of such plants would pollute and distort the public power network in such a way that reliable operation of grid-tied loads would become impossible.
There is, therefore, a clear need for action. The responsibility for suppressing all the impermissible interferences lies with manufacturers, who must declare their plants safe, reliable and compliant to their customers and government.

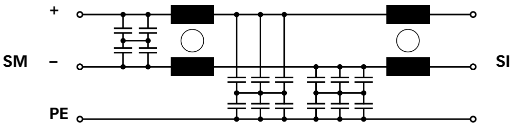
To solve the problems shown in the previous chapters, different products are required that fit the application exactly and need to work together synergistically. The block schematic diagram below will provide a first overview.



1 Solar module
2 DC EMC filter
3 Solar inverter
4 Sinus filter
5 AC EMC filter
6 Regulation/network monitoring

Typical block circuit diagram of a grid-tied solar plant with interference suppression components

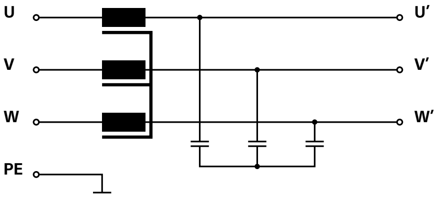
DC EMC filter. The DC EMC filter decouples the solar module and mainly takes care of the suppression of high-frequency, conducted interferences from the inverter. These can have a negative effect on the function, reliability and efficiency of the solar cells and must therefore be kept away from the module. In some applications, an overvoltage protection is installed in addition to the EMC filter; it can, in principle, also be integrated into the filter. The DC filter distinguishes itself primarily by a high admissible nominal operating voltage up to 1000VDC.



SM Solar module
SI Solar inverter

Schematic of a typical DC EMC filter for solar applications

Sinusoidal filter (or LCL filter). A three-phase pulsed AC voltage can be measured at the output of the inverter bridge. As already mentioned in the previous chapters, a pulsed signal cannot just be connected to any public low-voltage network as it is. The LC sinusoidal filter or the LCL filter comes into use here. Its main task is to smoothen the pulsed output signal in order to supply power to the network that is as low in harmonics as possible. The LC or LCL filter can be understood as a network decoupling in the broadest meaning of the term, with the help of which the inverter and hence the entire solar plant becomes network-compatible.
Depending on the customer's wishes, Schaffner can supply the complete LC/LCL filter or just the output reactor.



Schematic of a typical sinusoidal filter for solar applications

AC EMC filter. The high-frequency, conducted interferences can also be measured at the mains input and, to fulfill the EMC Directive, must be reduced below the limiting values. Here, for example, an FN 3359 standard filter can be used, which has proven itself in recent years in numerous applications.

FN 3359-1000-99 with protective covers

8 NEMP applications

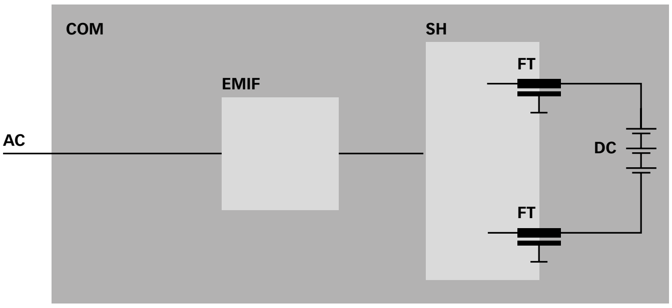
A nuclear electromagnetic pulse (NEMP) is a high intensity, short duration, electromagnetic field produced as a result of a nuclear explosion outside the atmosphere (exo-atmospheric). The most critical threat for technically highly developed nations is an exo-atmospheric burst (at an altitude of more than 40km) producing a NEMP which causes such high voltages and currents in antennas, power transmission networks etc. that it may leave an entire continent without power, telephone or radio communications. Electronic equipment can be protected against a NEMP if it is placed in a special room or housing which screens it from the electromagnetic fields and if all the feed lines to these areas are protected with voltage limiting devices, such as varistors, gas discharge tubes and suppressor diodes. The Schaffner FN 700Z filter series is designed for NEMP protection. Other suitable filters are available on request.

9 TEMPEST applications

Telecommunication or data processing equipment can transmit signals or distribute them along power lines, providing a mechanism for unauthorized people to access classified information. The study and blocking of such sensitive signals is known as TEMPEST. Mains filters with high attenuation over a large frequency range are necessary. The best possible filter solution can only be identified by specifying the requirements precisely. The FN 700Z filter series has been used in many TEMPEST applications. Other suitable filters are available on request.

10 Communication equipment

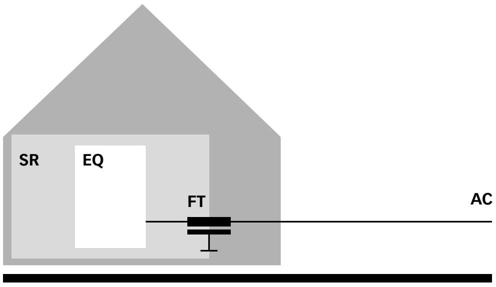
Communication equipment requires clean battery power. Special telecommunication base stations transmitting high frequency signals must be protected using feedthrough capacitors or filters. High frequency noise can be absorbed by the battery cable and may harm the system. Feedthrough capacitors or filters shield the system and short high frequency noise to ground.



COM Communication equipment
EMIF EMI filter
SH Shielded housing/cabinet
FT Feedthrough capacitor or filter

11 Shielded rooms

These rooms are often interference-suppressed using feedthrough capacitors or filters. Typical applications are rooms with sensitive equipment or with upgraded EMI requirements for medical equipment, such as computer tomography or magnetic resonance tomography.



SR Shielded room
EQ Equipment
FT Feedthrough capacitor or filter

Feedthrough capacitors and filters also improve the security of communications and prevent information in higher frequency signals from leaving the room via the mains or power line.

Schaffner offers a wide selection of different feedthrough capacitors and feedthrough filters for AC and DC applications.

IV Abbreviations

AE	Auxiliary equipment
AMN	Artificial mains network
AV	Average
CDN	Coupling/decoupling network
CE	Communauté Européenne
CISPR	Comité International Spécial des Perturbations Radioélectriques
EMC	Electromagnetic compatibility
ER	Energy regeneration
ESD	Electrostatic discharges
EUT	Equipment under test
FCC	Federal Communications Commission
GHz	Gigahertz = 1 billion cycles per second
GRP	Ground reference plane
HCP	Horizontal coupling plane
HF	High frequency
HVAC	Heating, ventilation, air conditioning
Hz	Hertz = cycles per second
ISN	Impedance stabilization network
kHz	Kilohertz = 1000 cycles per second
LF	Low frequency
LISN	Line impedance stabilization network
MHz	Megahertz = 1 million cycles per second
MTBF	Mean time between failures
NEMP	Nuclear electromagnetic pulse
NSA	Normalized site attenuation
PQ	Power quality
PRF	Pulse repetition frequency
PWM	Pulse width modulation
QP	Quasi-peak
R&TTE	Radio and telecommunication terminal equipment
RF	Radio frequency
SMPS	Switch-mode power supply
TEMPEST	Transient electromagnetic pulse emanation standard
THID	Total harmonic current distortion
THVD	Total harmonic voltage distortion
TDD	Total demand distortion
VCCI	Voluntary Control Council for Interference by Information Technology Equipment and Electronic Office Machines
VCP	Vertical coupling plane
VSD	Variable speed drive

V Index

Product index

Ordering information

FN 3270x-yyyy-zz

Connection style

03 = clamp terminal with M4 screw

05 = AMP faston 6.3 x 0.8mm

06 = AMP faston/solder lug combination 6.3 x 0.8mm

07 = wire connections (various sizes)

24 = screw terminal M6

28 = screw terminal M10

29 = safety terminal block 4mm^2

33 = safety terminal block 10mm^2

34 = safety terminal block 25mm^2

35 = safety terminal block 50mm^2

36 = safety terminal block 95mm^2

37 = safety terminal block 150mm^2

40 = safety terminal block 95mm^2

44 = safety terminal block 6mm^2

53 = safety terminal block 16mm^2

71 = jump terminal block with M4 screw

72 = jump terminal block with M5 screw

99 = copper busbars or non-standard connections

KL = terminal block

KS = ring lug

S = copper busbars

Rated current [A]

H = 520VAC filters

HV = 690VAC filters

HVIT = 690VAC filters for industrial IT distribution networks

P = reduced leakage current

L = very low leakage current

Filter family

Examples	**FN 351H-50-33**	FN 351H (520VAC); rated current 50A; with safety terminal block connections
	FN 258L-55-07	FN 258L (very low leakage current); rated current 55A; with wire output connections
	FN 3359-1600-99	FN 3359; rated current 1600A; with busbar connections

schaffner
energy efficiency and reliability

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