Electromagnetic Compatibility - Introduction

Electromagnetic compatibility (interference suppression) aims at maintaining an environment in which electrical and electronic apparatus can operate without being unduly affected by spurious signals. It covers two fields:
1. The prevention of excessive polluting signals being sent out from electrical appliances, industrial equipment and electronic devices.
2. The protection of sensitive devices by making them immune to spurious signals not regarded as excessive by national and international regulations, and controlling the emission of interference.

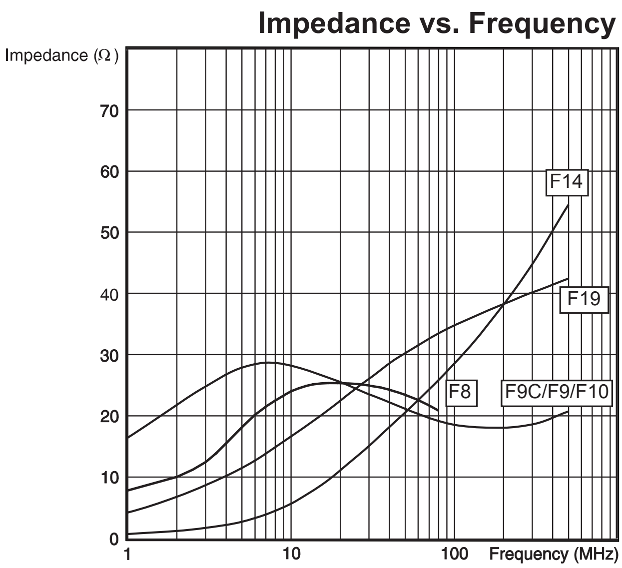
There are two ways in which spurious signals can propagate from their sources to the endangered devices:
1. By conductance - mains pollution, earth coupling, common current or voltage tracks.
2. By radiation - disturbance sources include elements capable of acting as transmitters.

Ferrite components are efficient and cost effective for the prevention of - and protection against - spurious signals transmitted by conductance and radiation. Enclosures reduce the radiation but still require an addition of ferrite components on wires entering and leaving the enclosure. When fitted around conducting leads ferrites provide efficient means of suppressing RF signals. At high frequencies where the value of Q falls to below 1, a ferrite component will provide a series impedance, the resistive component acting in effect as a resistor in series with the circuits being protected, while the reactive component serves as a series choke. Ferrite components used in this manner provide an insertion loss to prevent high frequency leakage from screened boxes or parasitic oscillations arising from spurious feedback, and serve to suppress interference. This form of protection is possible because, at frequencies far removed from application as inductive components, the losses in ferrite are very high. A ferrite component assembled on a lead produces no effect on the operation of equipment because, at low frequencies, the series impedance is very low. The component does not cause a voltage drop at the low frequencies but acts as a suppressor at high frequencies where the loss resistance is very high. In addition, the reactance is also high despite gradual decrease in permeability.

As frequency increases the contribution of reactance to the total impedance diminishes and the resistive component, more efficient for suppression, becomes predominant.

Suppression components are offered in a number of ferrite materials, optimising impedance over a wide range of frequencies. The most popular materials are described below:
F8 - A low permeability for Manganese-Zinc ferrites with peak suppression performance in the range 1MHz to 30MHz
F9C/F9/F10 - A high permeability for Manganese-Zinc ferrites with peak suppression performance up to 10MHz.
F19 - A very high permeability for Nickel-Zinc ferrites offering peak performance over a wide range from 20MHz to 200MHz.
F14 - A lower permeability for Nickel-Zinc ferrites offering peak performance at high frequencies >200MHz.

A graphical representation of material performance is shown below.



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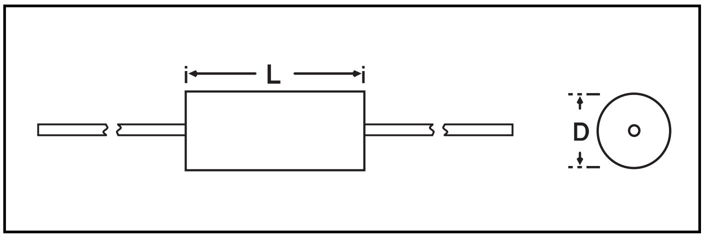
Axial Leaded Choke Cores

In their simplest form, chokes are ferrite rods with a single winding, preferably wound close to the rod, as distant turns hardly couple with the ferrite and contribute little to the inductance of a choke. Such chokes may be used as LC filter components or inserted in the lines to and from devices producing asymmetrical interference. At low frequencies, the reactance is low and does not affect the flow of desired currents, but at higher frequencies the reactance is high enough to attenuate the interference, generating in, or endangering the protected device.



The axial leaded choke is basically a rod with two unconnected lead-out wires. These wires are used to terminate the winding and support the choke on the board. Current rating is determined by the diameter of the wound wire.

As with all rods the calculation of inductance is derived from experimental data. An approximate calculation is:

$$L = \frac{(A_r \times N^2 \times \mu_r)}{L_r \times 10^9} \times (2 - L_c/L_r)$$

Where: L = Inductance (Henrys)
A_r = Cross-sectional area of rod (mm^2)
L_c = Length of coil
L_r = Length of rod
μ_r = Rod permeability

Component specifications

Part No.	Dimensions				Material Grade	Rod Perm. (μ)	Cross Sect. Area (mm^2)
	O.D. (D)	Length (L)	Lead dia.	Lead Length			
43-016-31	4.00 ±0.15	20.00 ±1.00	0.80	25.40	F14	20	12.56
43-051-31	5.33 ±0.20	16.00 ±0.47	0.70	38.00	F14	11	22.30

Lead: Tin coated copper wire.

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Beads, Tubes and Toroidal Cores

Conductors can be threaded through beads and tubes or around toroidal cores to suppress interfering signals. Their action as an EMC suppression component is based on very high losses in the ferrite when the frequency is well above the normal recommended spectrum for inductor use.

At low frequencies, the losses are very low - the value of Q is 10 or more up to 500kHz, and the impedance is of an essentially reactive nature. At 5MHz, the losses having increased fairly rapidly, Q = 1 and the impedance is composed of numerically equal reactive and resistive parts. At still higher frequencies, the resistive constituent is predominant.

As the impedance is, in general, directly proportional to the length of the bead, impedance can be built up as necessary by simply threading more beads onto the conductor.

The attenuation, introduced by the reactive component of the impedance, is lower than that caused by a resistive component of the same numerical value. An inserted reactance acts by reflecting the interference back to the source with possible complications such as standing waves and enhanced radiation, while a resistance absorbs the power of interference signals; this is greatly preferred.

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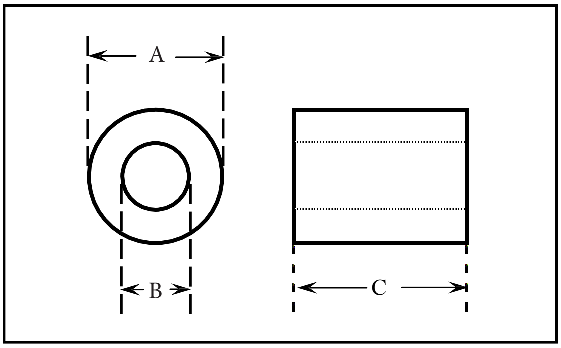
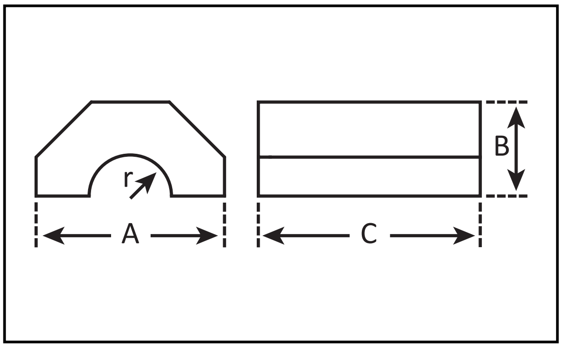
Beads

Cylindrical beads are amongst the simplest components for suppression use and are threaded over conductors, as the impedance is, in general, directly proportional to the length of the bead. It should be noted that at frequencies above the material's optimum range, it is advisable to use several shorter beads in preference to a single long bead. The below table lists preferred sizes with impedance values given for guidance only.

Type 1



Type 2



Beads - Component specifications

Part No.	Dimensions (mm)			Material Grade	Core Constant C_1 (mm^{-1})	Single turn impedance Z(Ω):		
	O.D. (A)	I.D. (B)	Length (C)			10MHz	25MHz	100MHz
Type 1								
35-534-31	2.66	1.01	3.55	F14	1.83	-	-	-
35-002-31	3.50	1.20	3.00	F14	2.11	-	28	37
35-002-38	3.50	1.20	3.00	F19	2.11	17	25	34
35-011-31	4.00	1.50	5.00	F14	1.37		43	58
35-011-38	4.00	1.50	5.00	F19	1.37	26	38	53
35-018-31	4.00	1.50	9.50	F14	0.67	-	82	110
35-018-28	4.00	1.50	9.50	F8	0.67	-	-	-
35-022-28	4.00	1.50	15.85	F8	0.40	-	-	-
35-014-28	4.00	1.50	19.05	F8	0.34	-	-	-
35-033-35	4.00	2.00	5.08	F29	1.78	-	-	-
35-032-28	4.00	2.00	5.00	F8	1.95	-	-	-
35-032-38	4.00	2.00	5.00	F19	1.95	18	27	37
35-035-31	4.00	2.00	20.00	F14	0.45	-	-	-
35-035-32	4.00	2.00	20.00	F16	0.45	-	-	-
35-035-35	4.00	2.00	20.00	F29	0.45	-	-	-
35-048-31	4.10	2.00	3.20	F13	2.74	-	-	-

	Width (A)	Height (B)	Length (C)	Inside Radius (r)					
Type 2									
M-HEX-SPLIT/ F19	22.86 ±0.83	11.68 ±0.51	25.40 ±0.82	4.75 ±0.254	F19	-	-	150	240

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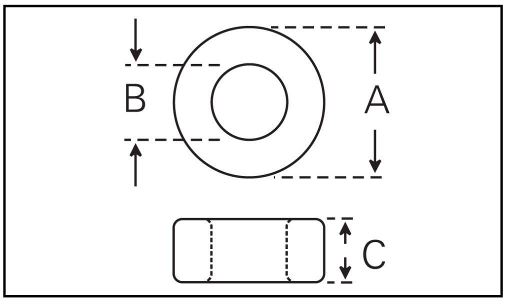
Toroidal cores



Toroidal cores are advantageous in that multiple turns are possible in situations where a bead does not provide the desired level of attenuation. The below table lists cores manufactured in ferrite grades used for EMC. Also listed are typical single turn impedance values at 10, 25 & 100MHz and are provided for guidance only.

Toroidal cores - Component specifications

Part No.	Dimensions (mm)			Coating	Material Grade	Core Constant C_1 (mm^{-1})	Single turn impedance Z(Ω):		
	O.D. (A)	I.D. (B)	Height (C)				10MHz	25MHz	100MHz
28-9615-31	5.20	2.40	3.18	Parylene	F14	2.70	-	-	-
28-501-31	6.35	3.18	1.52	Enamel	F14	5.98	-	-	-
28-001-31	6.35	3.18	1.52	-	F14	5.98	-	-	-
28-704-37	6.35	3.18	3.00	Epoxy	F10	3.03	-	-	-
28-702-31	6.35	3.18	3.96	Epoxy	F14	2.29	-	-	-
28-502-28	6.35	3.18	3.96	Enamel	F8	2.29	-	-	-
28-003-31	6.35	3.18	7.92	-	F14	1.15	-	-	-
28-503-31	6.35	3.18	7.92	Enamel	F14	1.15	-	-	-
28-070-38	9.52	4.75	3.18	-	F19	2.84	11	17	25
28-570-36	9.52	4.75	3.18	Enamel	F9	2.84	-	-	-
28-070-C36	9.52	4.75	3.18	-	F9C	2.84	-	-	-
28-107-37	10.00	6.00	4.00	-	F10	3.08	-	-	-
28-013-31C	11.93	6.86	9.30	-	F14	1.22	-	-	-
28-511-31	12.70	6.35	3.18	Enamel	F14	2.85	-	-	-
28-511-28	12.70	6.35	3.18	Enamel	F8	2.85	-	-	-
28-712-31	12.70	6.35	6.35	Epoxy	F14	1.43	-	-	-
28-512-28	12.70	6.35	6.35	Enamel	F8	1.43	-	-	-
28-712-36	12.70	6.35	6.35	Epoxy	F9	1.43	-	-	-
28-019-38	12.70	7.90	6.35	-	F19	2.08	-	-	-
28-759-36	16.70	9.60	5.00	Epoxy	F9	2.28	-	-	-
28-763-C36	16.70	9.65	6.35	Epoxy	F9C	1.81	-	-	-

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Toroidal cores - Component specifications cont.

Part No.	Dimensions (mm)			Coating	Material Grade	Core Constant C_1 (mm^{-1})	Single turn impedance Z(Ω):		
	O.D. (A)	I.D. (B)	Height (C)				10MHz	25MHz	100MHz
28-129-38	17.50	9.60	14.00	-	F19	0.75	46	64	96
28-129-38S	17.50	9.60	14.00	Epoxy	F19	0.75	46	64	96
28-522-31	19.05	12.70	6.35	Enamel	F14	2.44	-	-	-
28-522-28	19.05	12.70	6.35	Enamel	F8	2.44	-	-	-
28-723-37	19.05	12.70	9.52	Epoxy	F10	1.62	-	-	-
28-795-38	22.10	13.70	12.70	Epoxy	F19	1.05	29	46	69
28-095-38	22.10	13.70	12.70	-	F19	1.05	-	-	-
28-795-C36	22.10	13.70	12.70	Epoxy	F9C	1.05	-	-	-
28-780-36	25.00	15.00	10.00	Epoxy	F9	1.23	-	-	-
29-0625-31	25.40	12.70	6.35	-	F14	1.43	-	-	-
28-090-31	25.40	12.70	12.70	-	F14	0.71	-	-	-
28-033-31	25.40	19.05	14.30	-	F14	1.53	-	-	-
28-760-36	31.50	19.60	7.00	Epoxy	F9	1.89	-	-	-
28-756-C36	31.50	19.60	12.50	Epoxy	F9C	1.06	-	-	-
28-096-38	38.10	19.60	12.70	-	F19	0.74	41	65	97
28-797-C36	38.10	19.60	25.40	Epoxy	F9C	0.37	-	-	-
28-042-31	38.10	25.40	12.70	-	F14	1.22	-	-	-
28-742-36	38.10	25.40	12.70	Epoxy	F9	1.22	-	-	-
28-744-C36	38.10	25.40	15.87	Epoxy	F9C	0.98	-	-	-
28-043-31	38.10	25.40	19.05	-	F14	0.81	-	-	-
28-543-28	38.10	25.40	19.05	Enamel	F8	0.81	-	-	-
28-743-36	38.10	25.40	19.05	Epoxy	F9	0.81	-	-	-
28-7132-37	49.00	31.80	19.00	Epoxy	F10	0.76	-	-	-
28-089-31	54.00	15.00	19.00	-	F14	0.26	-	-	-
28-053-31	63.00	26.00	19.00	-	F14	0.37	-	-	-
28-061-36	63.00	38.00	25.00	-	F9	0.50	-	-	-
28-761-36C	63.00	38.00	25.00	Epoxy	F9C	0.50	-	-	-
28-761-37P	63.00	38.00	25.00	Epoxy	F10	0.50	-	-	-

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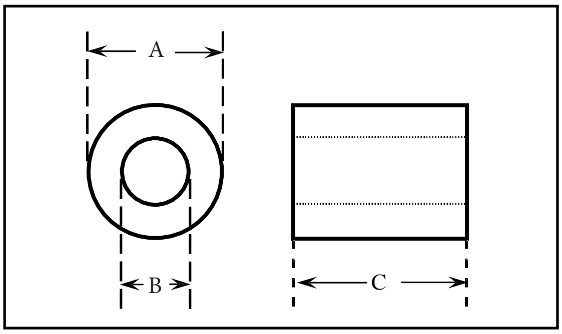
Tubes



These offer high impedance for single turn applications, e.g. EMI suppression of 4, 7, 9 and 13mm coaxial cable used for data transfer between computers and hardware, e.g. computer keyboard and printer cables.

Tubes - Component specifications

Part No.	Dimensions (mm)			Material Grade	Core Constant C_1 (mm^{-1})	Single turn impedance Z(Ω):		
	O.D. (A)	I.D. (B)	Length (C)			10MHz	25MHz	100MHz
9.5x4.8x14.5/ F19	9.50	4.80	14.50	F19	0.635	47	78	115
28-155-38	10.00	6.00	15.00	F19	0.820	46	64	96
28-010-38S	12.30	5.12	25.40	F19	0.286	112	157	243
28-074-38	14.30	7.30	28.60	F19	0.327	92	150	220
28-076-38	17.50	9.60	28.50	F19	0.367	82	136	218
28-112-38	28.50	13.60	28.50	F19	0.303	93	145	250

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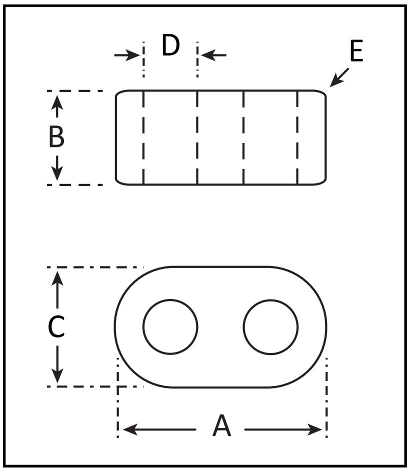
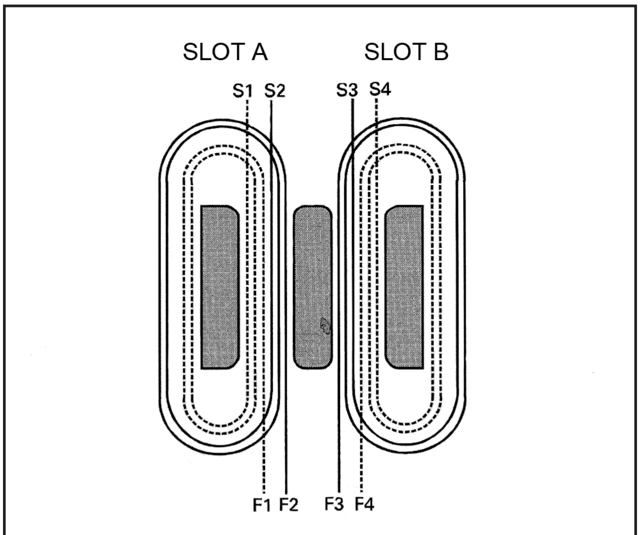
Transformer (Balun) Cores

Originally designed for balun transformers, matching balanced to unbalanced circuits in the television frequency spectrum, these cores can also be used for wideband and pulse transformers and interference suppression.

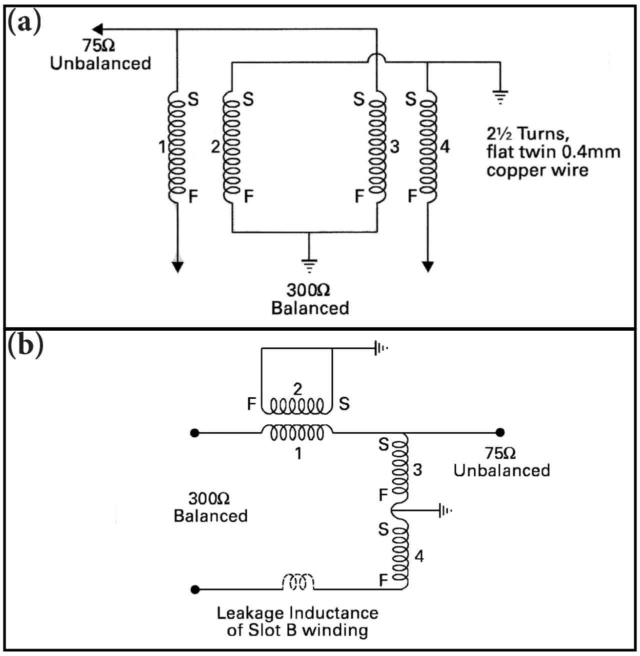


The insertion loss of transformers wound on cores manufactured from ferrite grade F14 and connected according to the information presented in the diagrams below, is approximately 0.5dB between 40 and 220 MHz; above 220 MHz the insertion loss gradually increases, reaching 1dB at 800 MHz.

The diagram below illustrates winding arrangements and the circuit diagrams show alternative connections of a balun transformer designed to match a balanced 300Ω impedance to an unbalanced 75Ω impedance. It will be noticed that the only purpose of windings 1 and 2 is to introduce an inductance to balance the leakage inductance of windings 3 and 4 which form a centre-tapped auto-transformer.



Winding Arrangement
Windings may be terminated as in (a) or (b);
Turns ratio adjusted to give the approriate matching



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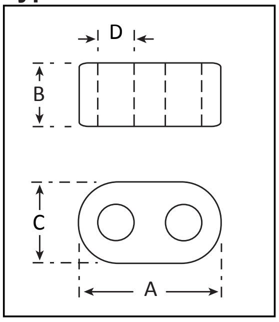
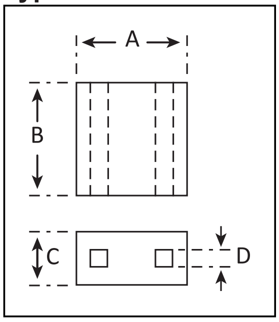
Balun & Multi-Aperture Cores

Multi-aperture cores are designed as suppression components which are compact in size and provide high resistive impedance over a wide frequency band. These cores avoid the self resonance effects experienced with single aperture cores wound with multiple turns.

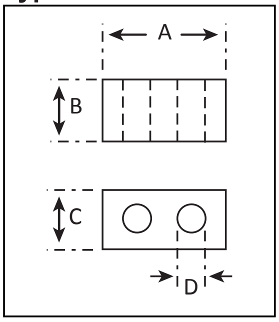
Type 1



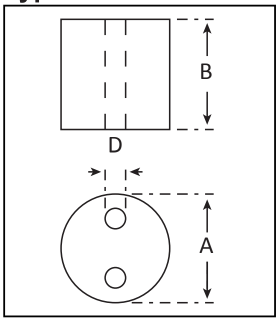
Type 2



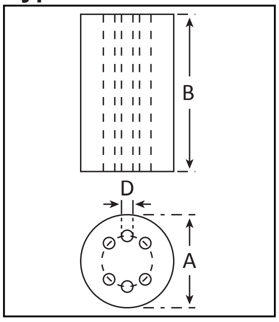
Type 3



Type 4



Type 5



Balun & Multi-Aperture Cores - Component specifications

Part No.	Dimensions (mm)				Material Grade	Single turn impedance Z(Ω):		
	Width (A)	Length (B)	Height (C)	Hole size (D)		10MHz	25MHz	100MHz
Type 1								
42-000-C36	5.08	3.05	3.05	1.19	F9C	-	-	-
42-034-C36	6.99	3.18	4.06	1.85	F9C	-	-	-
42-044-38	6.99	6.35	4.06	1.85	F19	-	-	-
42-702-31	13.20	6.60	7.40	3.80±0.20	F14	-	-	-
42-001-31	13.20	13.50	7.40	3.80±0.20	F14	-	-	-
Type 2								
42-003-36	10.80	10.90	5.40	2.00	F9	-	-	-
Type 3								
42-303-31	7.92	4.75	4.50	2.29	F14	-	-	-
Type 4								
35-000-31	6.35	6.35	-	1.27	F14	-	-	-
Type 5								
35-001-31C	5.97-6.35	10.03±0.38	-	0.86±0.13	F14	-	-	-
35-001-38	5.97-6.35	10.03±0.38	-	0.86±0.13	F19	-	-	-

Filter Inductor Design

The outputs of Switched Mode Power Supplies require smoothing to reduce the ripple voltage to acceptable levels. Iron powder toroids offer a definitive solution in the performance of this function. When used with a suitable capacitor, an iron powder toroid acts as an excellent LC filter. As there are no intentional air gaps i.e. closed magnetic path, one great advantage of Iron powder toroids is extremely low stray magnetic field levels.

A typical filter inductor design is shown below:

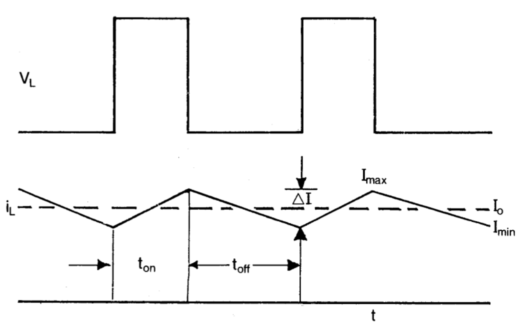


Figure 1

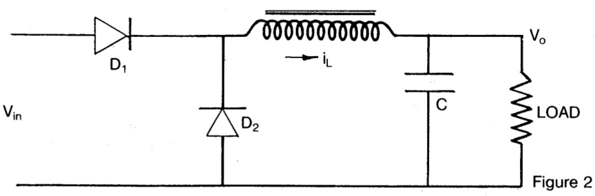


Figure 2

V_L = instantaneous voltage across inductor
i_L = instantaneous current across inductor
I_o = mean d.c. current
V_o = output voltage (d.c)
ΔI = peak to peak ripple current

Figure 1 shows typical waveforms of voltage and current through the filter inductor (figure 2) in a forward converter. For a given switching frequency, the turn-off time, t_{off}, can be calculated from:

$$t_{off} = \frac{1}{f}\left(1 - \frac{V_o}{V_{in}}\right)$$

where,
f = switching frequency
V_o = output voltage
V_{in} = input voltage

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Iron Powder Toroidal Cores

Iron Powder cores are pressed from selected grades of iron powder mixed with bonding material. High resistivity is required to reduce eddy current losses and for this purpose the iron powder is subjected to an acid treatment producing an insulated layer on the surface of each individual particle. A feature of the manufacturing process is that minute air gaps appear between the particles causing the permeability of the pressed core to be severely reduced. Because of these gaps it is difficult to saturate and these cores are used in applications where it would be impossible to utilise similar sized ferrite cores.

Iron Powder Toroidal cores are typically used for application in SMPS chokes, RFI suppression and light dimmers.

Two grades of high permeability Iron Powder are available: **1003 (22)** and **1005 (22A)**.

Specifications for the most popular sizes are shown below:

Iron Powder Toroidal Cores - Component specifications

Part No.	Dimensions (mm)			Material Grade	Effective Length (mm)	Effective Area (mm^2)	Effective Volume (mm^3)	Core Constant C_1 (mm^{-1})	AL Value (nH)*	LI^2 max (mJ)**
	O.D. (A)	I.D. (B)	Height (C)							
17-749-22	13.20	7.80	5.40	1003	31.51	14.25	449	2.21	34	0.38
17-732-22	14.80	8.00	6.40	1003	33.65	20.92	704	1.61	47	0.54
17-750-22A	20.30	12.70	6.40	1005	50.01	23.75	1187	2.11	41	0.89
17-730-22A	24.70	12.70	9.70	1005	54.00	54.00	3064	1.00	97	2.14
17-736-22	27.10	15.00	6.70	1003	62.43	39.37	2457	1.59	47	-
17-742-22A	33.00	19.80	10.00	1005	80.00	63.00	5040	1.28	77	3.60
17-746-22A	39.90	24.10	14.50	1005	96.39	112.10	10800	0.859	109	-
17-769-22A	50.80	31.80	25.40	1005	125.10	236.90	29645	0.528	179	-

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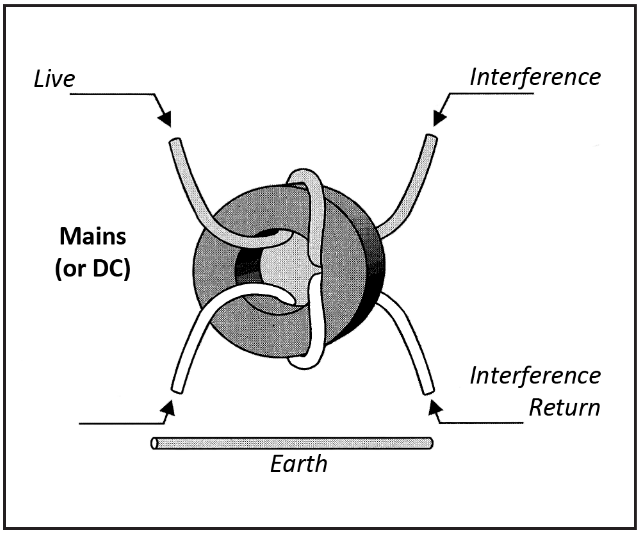
Balanced (4-terminal) Chokes

Balanced (4-terminal) chokes are ferrite toroidal cores having two windings inserted into the forward and return current conductors in such a manner that the magnetic flux of one winding opposes the flux induced by the other (as shown below). They are used when interference generated in the 'load' is of balanced (common mode, asymmetrical) nature. This type of choke presents very small impedance to the load currents, but a very high one to the spurious signals, thus protecting the mains from pollution. Because of the imperfection of cancelling effects (leakage inductance), there is some residual flux density in the core, the effect of which is reduced if the ferrite grade used has high saturation.



F9C has been specifically developed to combine the desirable feature of high saturation induction (B_S = 460mT) with high permeability (μ_i = 5000).

Epoxy Coated Ferrite Toroidal Cores - Component specifications

Part No.	Dimensions (mm)			Material Grade	Effective Length (mm)	Effective Area (mm^2)	Effective Vol. (mm^3)	Core Constant C_1 (mm^{-1})	AL Value
	O.D.	I.D.	Height						
28-763-C36	16.70	9.65	6.35	F9C	39.45	21.84	861	1.81	3470
28-795-C36	22.10	13.70	12.70	F9C	54.15	52.33	2833	1.04	5997
28-756-C36	31.50	19.60	12.50	F9C	77.30	73.00	5645	1.06	6000
28-797-C36	38.10	19.60	25.40	F9C	84.29	226.49	19090	0.37	16800
28-744-C36	38.10	25.40	15.87	F9C	97.06	99.41	9648	0.98	6435

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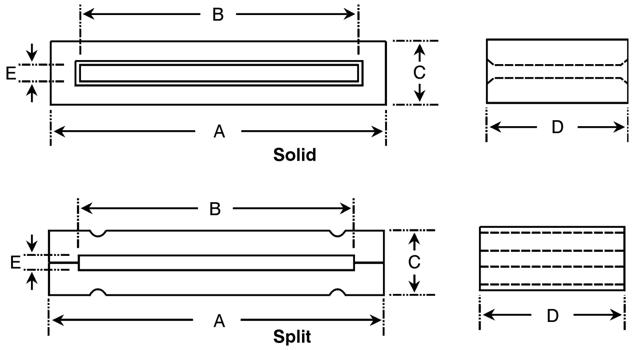
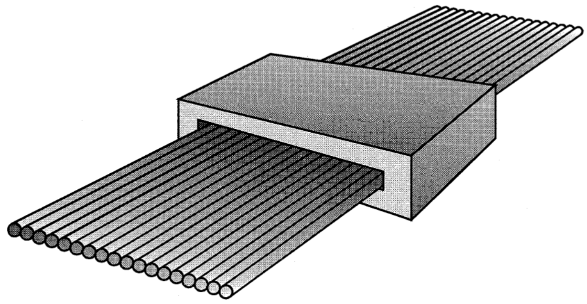
Flat Ribbon Cable Suppressors

A simple method of suppression of RFI in ribbon cables is offered by Neosid Flat ribbon cables suppressors in F19 material.

These components are available in two types: the solid single piece version through which the cable is threaded, and the split version which may be conveniently fitted to existing equipment assemblies.



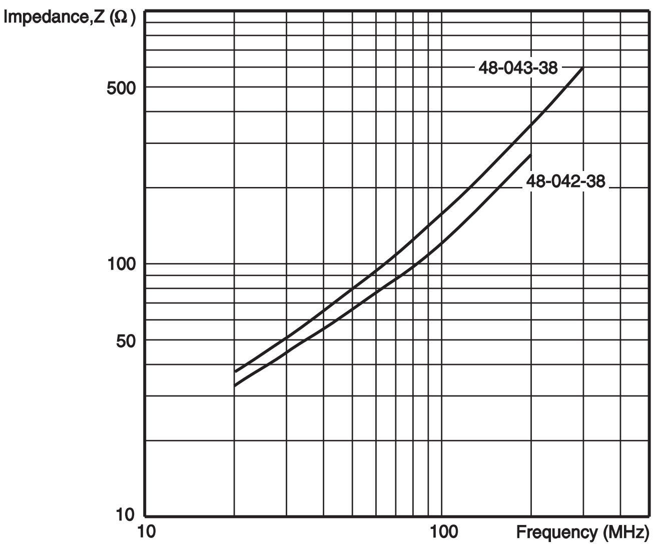


Dimensions & Electrical specification

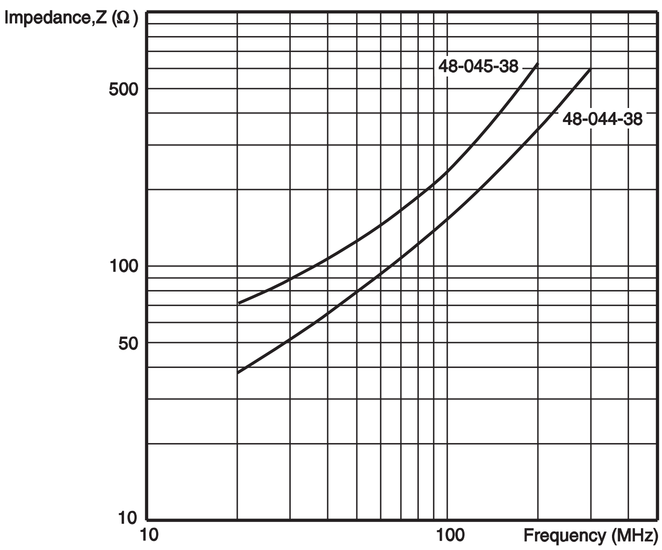
		Cable	Dimensions (mm)					Impedance Z (Ω)	
Part No.	**Type**	**Size**	**'A'**	**'B'**	**'C'**	**'D'**	**'E'**	**25MHz**	**100MHz**
48-042-38	Solid	16 Way	28.0±0.6	23.0±0.5	7.7±0.25	7.0±0.25	1.5±0.25	39	122
M48-043-38	Solid	34 Way	60.0±1.3	48.3±1.0	12.0±0.25	12.7±0.25	1.9±0.25	50	130
M48-044-38	Split	34 Way	60.0±1.3	48.3±1.0	12.7±0.5	12.7±0.4	1.7±0.5	50	130
48-045-38*	Split	50 Way	76.2±1.5	65.3±1.0	12.7±0.5	28.6±0.6	1.66±0.4	90	250

*Can be clamped together using clips 76-061-95

Typical Impedence vs. Frequency



Typical Impedence vs. Frequency



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Glossary of Terms

Symbol	Unit	Definition
A_L	Henrys	**Inductance Factor** is the inductance per turn squared in nH (L/n^2).
A_e	mm^2	**Effective cross sectional area** of core.
ℓ_e	mm	**Effective magnetic path length**.
V_e	mm^3	**Effective volume of core**.
C_1	mm^{-1}	**Geometric Core constant ($\sum \ell / A$)**
μ_i	-	**Initial (or intrinsic) permeability** is the ration between flux density ΔB in a closed ring core, and the applied field strength ΔH at very low a.c. fields ($\Delta H>0$)
B_{sat}	mT	**Saturation Flux Density** is the maximum flux density achieved with a field of 796A/m (or 10 Oersteds) applied.
B_{rem}	mT	**Remanent Flux Density** is the flux density remaining in the core (following magnetisation to saturation) in the absence of an applied field.
H_C	A/m	**Coercive Force** is applied field strength required to reduce the remanent flux density to zero.
η_B	10^{-6}/mT	**Hysteresis Material Constant** is the hysteresis loss normalised to unit intrinsic permeability and unit flux density.
Θ_C	°C	**Curie Temperature** is that temperature above which ferrite materials lose their ferromagnetic properties and permeability drops to 1. This phenomenon is completely reversible and ferromagnetic properties return when the temperature is reduced to below Θ_C.
ρ	Ω-cm	Electrical **Resistivity** of ferrite material
μ_a	-	**Amplitude Permeability** is the core permeability at relatively high applied field strengths. μ_a is usually specified at given flux densities and temperature.
P_v	mW/cm^3	**Power Loss Density** (sometimes referred to as PLD) is the power loss in the core per unit volume at specified flux densities and temperatures.
$\frac{\tan \delta_{(r+e)}}{\mu_i}$	10^{-6}	**Relative Loss Factor** is the loss coefficient normalised to intrinsic permeability, associated with low field strength conditions.
$\frac{\Delta\mu}{\mu_i^2 \cdot \Delta T}$	10^{-6}/°C	**Temperature Factor** is the proportional rise inductance per degree Celsius normalised per unit intrinsic permeability.

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