Cable Shielding

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**Philips
Components**

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Cable Shielding

Contents

Our range of ferrite cable shields

Introduction

Electromagnetic interference problems can arise anywhere since electromagnetic energy can unpredictably couple into systems, producing unwanted effects.

Electromagnetic interference occurs when three elements come together:
- a source of interference
- a receiver of the interference
- a path of transfer.

According to this simple scheme, minimizing the electromagnetic interference can be attained by eliminating one of the three elements:
- suppressing the source
- protecting the receiver against noise
- reducing the interference transmission.

This brochure concentrates on one of the elements: **transmission of interference**

Any device which suppresses noise between the source and the receiver acts as an EMI shield.
Interferences can propagate in different ways:

- By *radiation* as an electromagnetic wave in free space. Suppression then requires shielding with conductive or absorbing materials.

- By *conduction* via a conductive path. The suppression solution is **ferrites** in the form of beads or cable shields

Conductive coupling is the most common way an interference signal is transmitted to a system.
When studying an interference problem, very often attention is focused on critical components, while system cables are overlooked.
A cable can pick up some noise and bring it to other areas traversed by the cable.

With today's regulations (VDE in Germany, FCC in USA, VCCI in Japan), all electric and electronic products, no matter how trivial they seem to be, have to comply with certain EMC limits, both for emission and reception.

There is a need to suppress common mode EMI not only on internal, but also on external cables of electronic equipment.

PHILIPS COMPONENTS developed a new range of cable shielding products.
There are tubular cable shields for coaxial cable and rectangular cores for flat ribbon cables. Also split types for retrofit solutions are available.
These EMI products provide a high impedance level over a wide frequency range.

Ferrite cable shields are cost-effective, as they suppress any electromagnetic noise and reduce the need for other, more complicated, shielding measures.
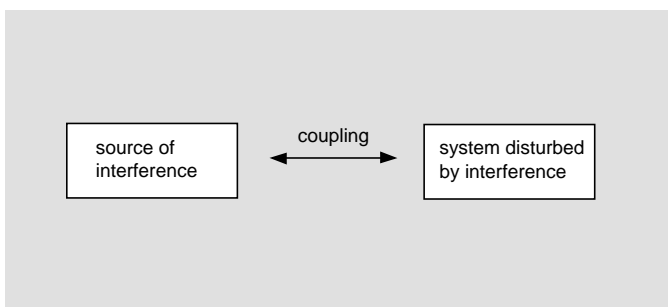

Fig.1 Interference schematic

EMI suppression and cable shielding with ferrites

Ferrite shields provide an excellent method to suppress conducted interferences on cables. Cables can act as antennas and radiate RFI power at frequencies above 30MHz. They are a cost-effective alternative to other suppression solutions, like EMI filters or complete shielding.

Applications for cable shielding are found in telecommunication, instrumentation, electronic data processing (EDP) in places like:

- Internal and external computer data cables (for monitors, printers, CPU, keyboards...)

- Internal and external power cables

- Internal floppy disk and hard disk ribbon cables

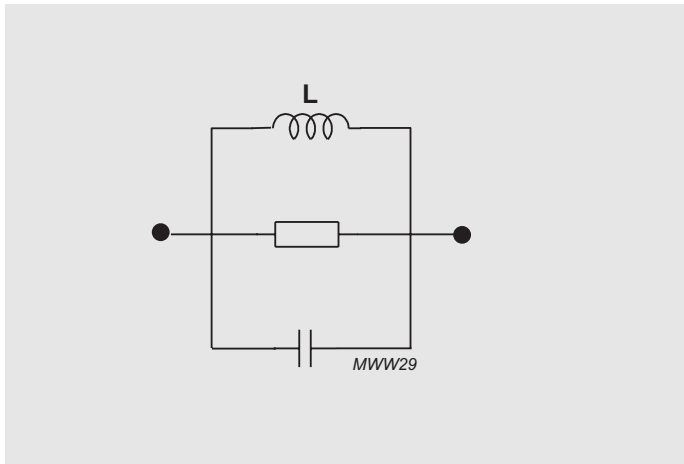- Cables between PC board and data connectors, ...

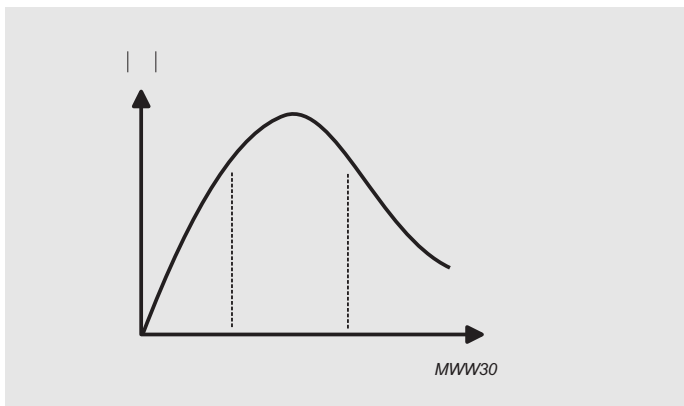*Fig.2 Equivalent circuit of ferrite suppressor*

Fig.3 Impedance versus frequency

Low frequency signals are not affected by a cable shield. At low frequencies a ferrite core causes a low-loss inductance, resulting in a minor increase of impedance ($Z=\omega L$). Interferences normally occur at elevated frequencies and there the picture changes. Magnetic losses start to increase and at the frequency of the so called ferrimagnetic resonance permeability drops rapidly to zero while the impedance reaches a maximum. This impedance, the most important parameter for suppression, becomes almost completely resistive and at very high frequencies even capacitive with losses. While for inductor applications the operating frequency should stay well below the resonance, effective interference suppression is achieved up to much higher frequencies. The impedance peaks at the resonance frequency and the ferrite is effective in a wide frequency band around it.

Around its ferrimagnetic resonance the impedance of a ferrite core is largely resistive, which is a favourable characteristic for several reasons:

- A low-loss inductor can resonate with a capacitance in series, leading to almost zero impedance and interference amplification. A more resistive impedance cannot resonate and is reliable independent of source and load impedances.

- A resistive impedance dissipates interfering signals rather than reflecting them to the source. Oscillations at high frequency can damage semiconductors or affect circuit operation and therefore it is better to absorb them.

- The shape of the impedance curve changes with material losses. A lossy material will show a smooth variation of impedance with frequency and a real wideband attenuation. Interference signals often occur in a broad spectrum.

Often EMI suppression is required on cables carrying DC or AC power. In that case *current compensation* is needed to avoid saturation of the ferrite which would result in loss of impedance.

Current compensation is based on the principle that in cables passing through a ferrite core the carried load and signal currents are generally balanced. These currents generate opposed fluxes of equal magnitude that cancel out and no saturation occurs.

EMI signals however usually travels in the same direction on all conductors (common mode). They cause flux in the ferrite and will be suppressed by the increased impedance.

For high frequency signals, current compensation is a beneficial effect for other reasons than saturation.

In an I/O cable the regular RF signal could be suppressed together with the interference. Since the actual signal is differential mode, current compensation avoids this unwanted damping effect on the actual signal.

A cable shield is mainly active against common-mode interference, although its small stray inductance will also have some effect against differential-mode interference. Ferrite products for cable shielding are available in different shapes and can be:

- **Entire**, for mounting during manufacturing.

  Ferrite cores can for instance be embedded in the plastic cover of the cable or shifted on before mounting the connectors.

- **Split,** for mounting on existing cables.

  This type of product was developed for easy installation when the interference problem is detected after final design. The gap between halves has only little influence on the magnetic performance. Impedance is hardly affected, while current handling capability increases. The two halves are mounted with special clips or plastic cases.
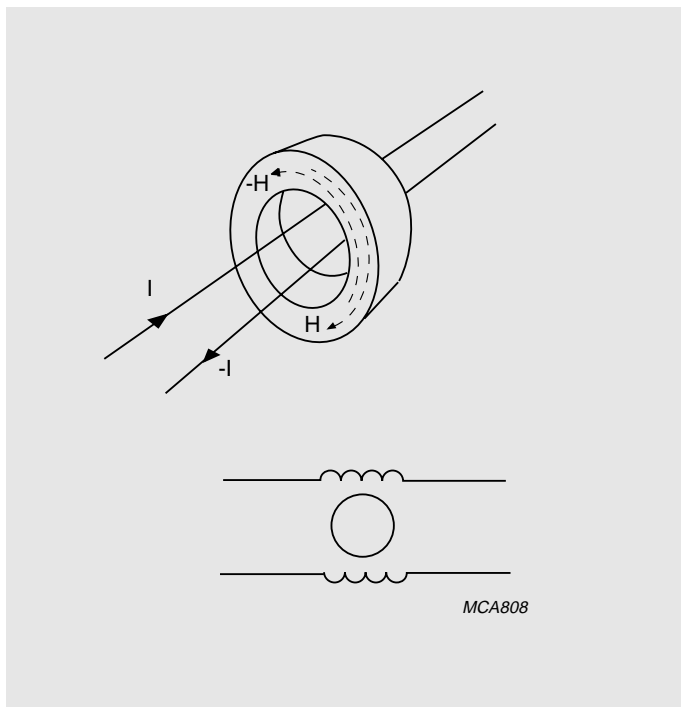

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Fig.4 Current compensation in a ferrite ring core

Ferrite selection

When selecting a ferrite cable shield to solve an interference problem it is necessary to consider some important application aspects:

- The frequency were maximum attenuation is needed will determine material requirements. The most suitable ferrite would offer the highest impedance levels at the interference frequencies, which usually cover a broad spectrum.

- Core shape, which is usually defined by the cable type.

- Installation requirements to decide on an entire or split core type.

- Attenuation/impedance level for maximum suppression.

- Ferrite characteristics as a function of operating conditions. Impedance can vary with temperature or DC current.

Material characteristics

NiZn ferrites used to be the only suitable material for EMI suppression up to GHz frequencies. Their high resistivity (10^5 Ωm) ensures that eddy currents can never be induced in these ferrites. As a result they maintain an excellent magnetic performance up to very high frequencies.

The new MnZn material **3S4**, however, does suppress EMI up to frequencies of 1GHz and higher, making it an attractive alternative to NiZn materials.
Up to now the low resistivity of MnZn ferrites (1 to 10 Ωm) has limited their operation to a maximum of about 30MHz. With **3S4** precise control of material composition has resulted in an increase of its resistivity to a value of 10^3 Ωm, intermediate between the standard MnZn and NiZn grades, but high enough for effective RFI-suppression into the GHz region.

Additional advantage of **3S4** is that it does not contain nickel which is a heavy metal and therefore a potential hazard to the environment. Also, its high permeability gives it excellent low-frequency characteristics.

3S4

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25°C; ≤10kHz; 0.1mT	≈ 1700	
B	25°C; 10kHz;250A/m	≈ 300	mT
	100°C; 10kHz;250A/m	≈ 140	
$|Z|$ (1)	25°C; 3MHz	≥ 25	Ω
	25°C; 30MHz	≥ 60	
	25°C; 100MHz	≥ 80	
	25°C; 300MHz	≥ 90	
ρ	DC; 25°C	≈ 10^3	Ωm
Tc		≥ 110	°C
Density		≈ 4800	kg/m^3

(1) Measured on a bead ∅ 5 x ∅ 2 x 10mm

Characteristics refer to a standard, non-finished ring core of dimensions 25/15/10 mm for all properties,

except for impedance, which is measured on a bead ∅ 5 x ∅ 2 x10mm.

Properties of other products made from this material may be different, depending on shape, size or finishing.
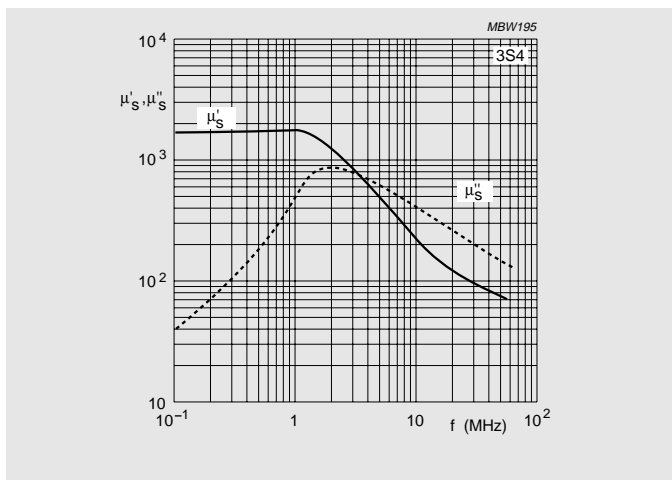
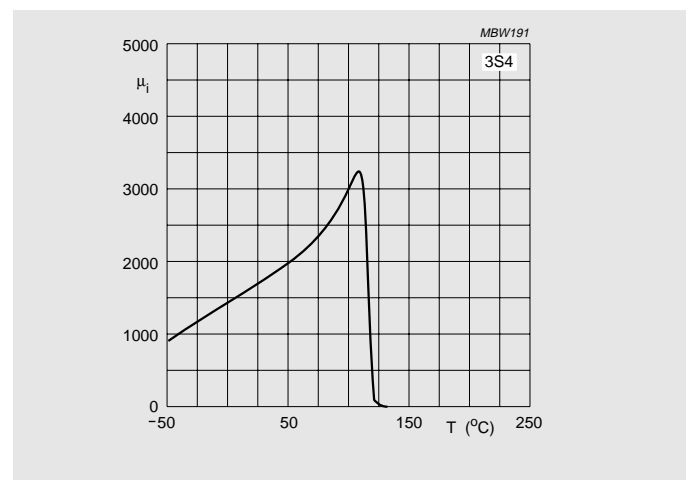*Fig.5 Complex permeability as a function of frequency*

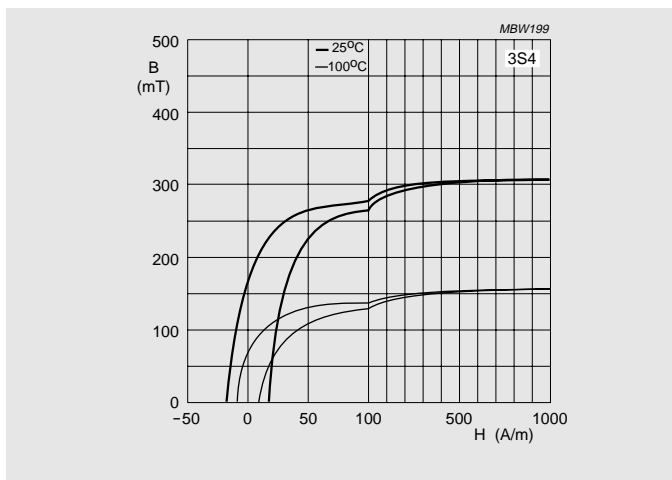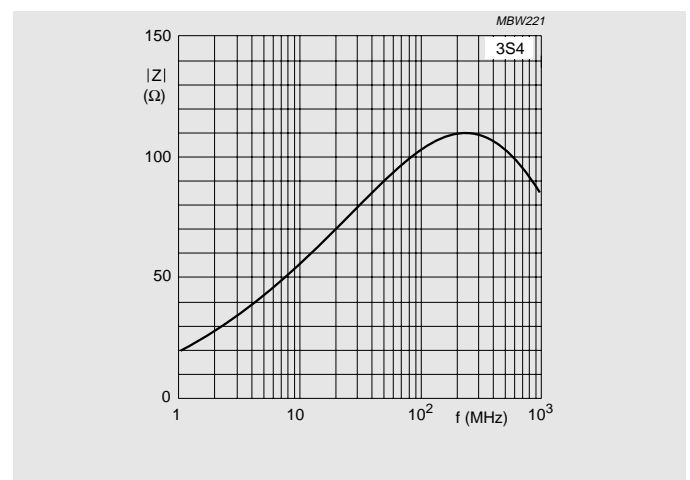*Fig.6 Initial permeability as a function of temperature*

Fig.7 Typical B-H loops

Fig.8 Impedance as a function of frequency

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4S2

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25°C; ≤10kHz; 0.1mT	≈ 700	
B	25°C; 10kHz;250A/m	≈ 270	mT
	100°C; 10kHz;250A/m	≈ 180	
$\lvert Z \rvert$ (1)	25°C; 30MHz	≥ 50	Ω
	25°C; 300MHz	≥ 90	
ρ	DC; 25°C	≈ 10^5	Ωm
Tc		≥ 125	°C
Density		≈ 5000	kg/m^3

(1) Measured on a bead ∅ 5 x ∅ 2 x 10mm

Characteristics refer to a standard, non-finished ring core of dimensions 25/15/10 mm for all properties,
except for impedance, which is measured on a bead ∅ 5 x ∅ 2 x10mm.
Properties of other products made from this material may be different, depending on shape, size or finishing.
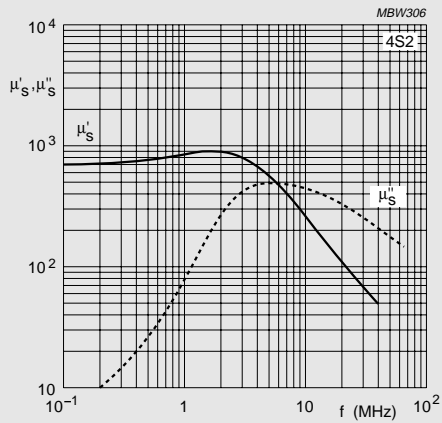

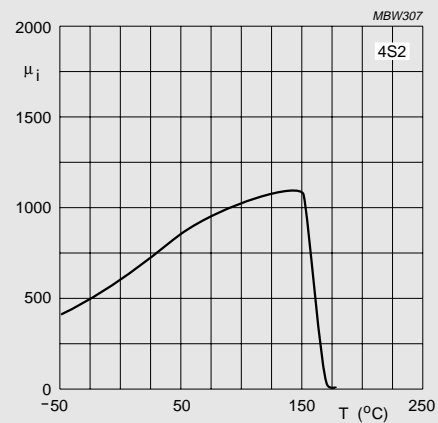Fig.9 Complex permeability as a function of frequency

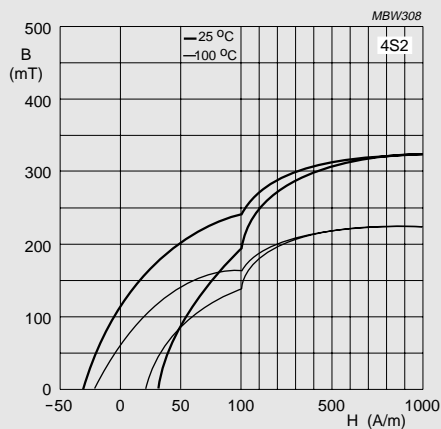Fig.10 Initial permeability as a function of temperature

Fig.11 Typical B-H loops
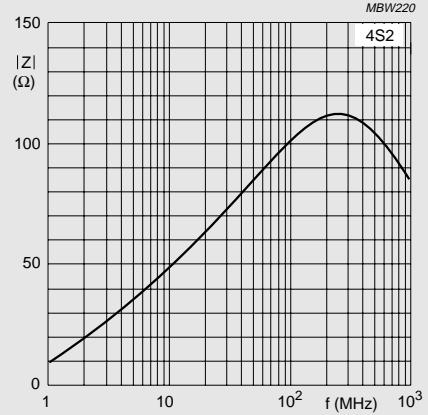

Fig.12 Impedance as a function of frequency

Philips Magnetic Products

4A11

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25°C; ≤10kHz; 0.1mT	700 ± 20%	
B	25°C; 10kHz;250A/m	≈ 270	mT
	100°C; 10kHz;250A/m	≈ 180	
$\tan\delta/\mu_i$	25°C; 1MHz; 0.1mT	≤ 100.10^{-6}	
	25°C; 3MHz; 0.1mT	≤ 1000.10^{-6}	
ρ	DC; 25°C	≈ 10^5	Ωm
Tc		≥ 125	°C
Density		≈ 5100	kg/m^3

Characteristics refer to a standard, non-finished ring core of dimensions 25/15/10 mm for all properties,
Properties of other products made from this material may be different, depending on shape, size or finishing.
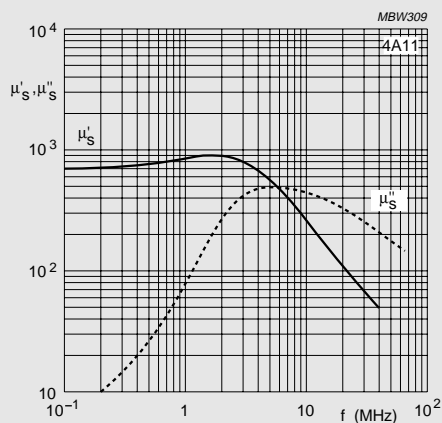

Fig.13 Complex permeability as a function of frequency

Fig.14 Initial permeability as a function of temperature
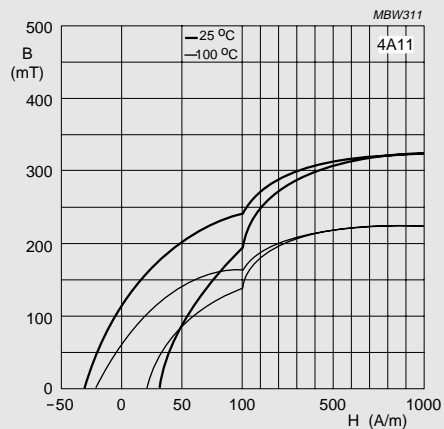
Fig.15 Typical B-H loops

4C65

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25°C; ≤10kHz; 0.1mT	125 ± 20%	
B	25°C; 10kHz;250A/m	≈ 300	mT
	100°C; 10kHz;250A/m	≈ 250	
$\tan\delta/\mu_i$	25°C; 3MHz; 0.1mT	≤ 80.10^{-6}	
	25°C; 10MHz; 0.1mT	≤ 130.10^{-6}	
ρ	DC; 25°C	≈ 10^5	Ωm
Tc		≥ 350	°C
Density		≈ 4500	kg/m^3

Characteristics refer to a standard, non-finished ring core of dimensions 25/15/10 mm for all properties,
Properties of other products made from this material may be different, depending on shape, size or finishing.
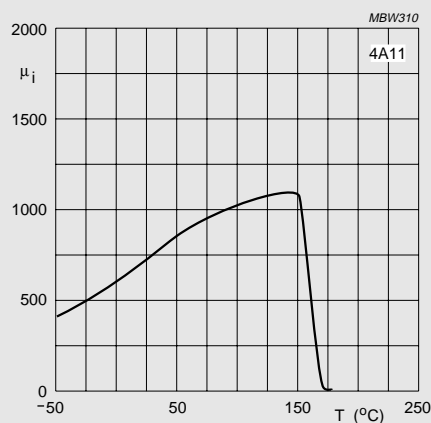

Fig.16 Complex permeability as a function of frequency
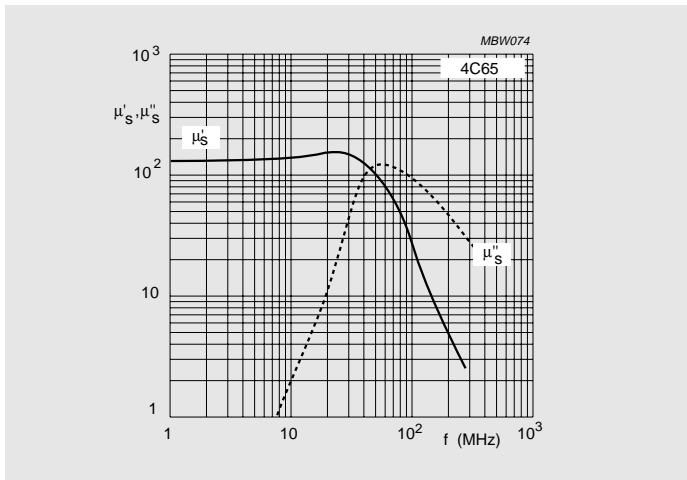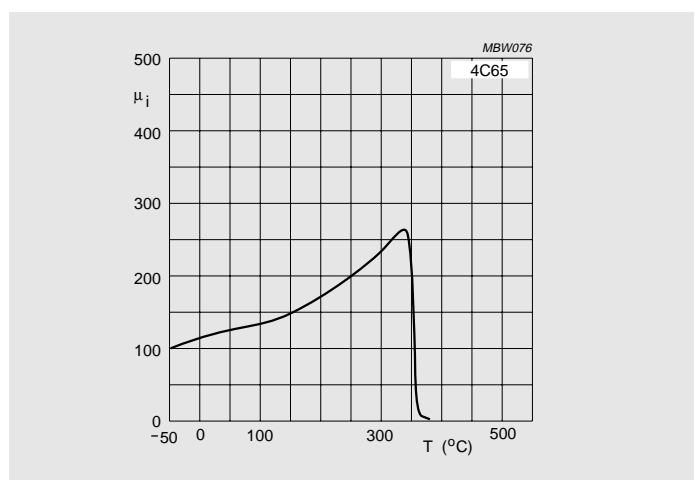

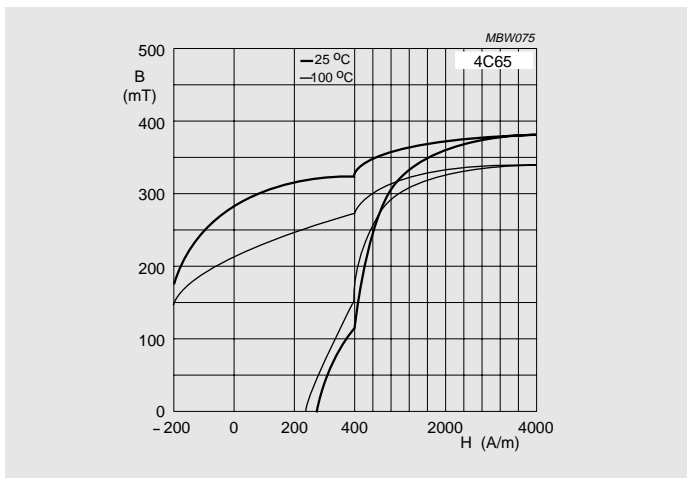Fig.17 Initial permeability as a function of temperature

Fig.18 Typical B-H loops

Ferrite core and its impedance behaviour

The selection of the core type aims at optimising the suppression performance.

- The **inside diameter** is fixed by the cable dimensions. The ferrite should fit closely around the cable to avoid loss of impedance.
- **Impedance** increases mainly with the length of a cable shield or the number of shields. It depends linearly on length and only logarithmically on the outer dimensions.(see page 10)

The most suitable ferrite core will be the largest type with an inner diameter matching the cable outer dimensions. But only if a large size and weight are no problem.

For costs reasons often a smaller size with good suppression properties is preferred.

A simple solution for flexible cable is to wind a few turns on a ring core. The large inner diameter (not fitting the cable) and their shorter length are compensated by using more than one turn:

$$Z \propto N^2$$

where N is the number of turns.

It is not recommended to use more than 2 turns on a ferrite core. Although the higher number of turns results in more impedance, the parasitic inter winding capacitance, which is also proportional to the number of turns, will decrease the frequency where peak impedance occurs. This results in a worse performance at higher frequencies.
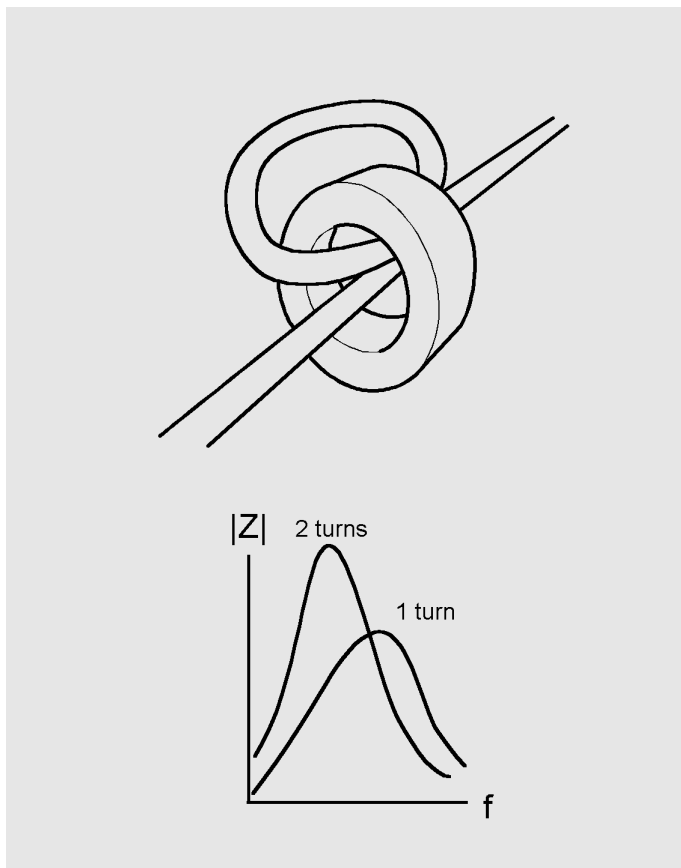

Fig.19 Two turns of cable through a ferrite cable shield

Ferrite location

The position of a cable shield on the cable is an important issue for the best performance in the application.

Fig.20 Ferrite shield close to interference source

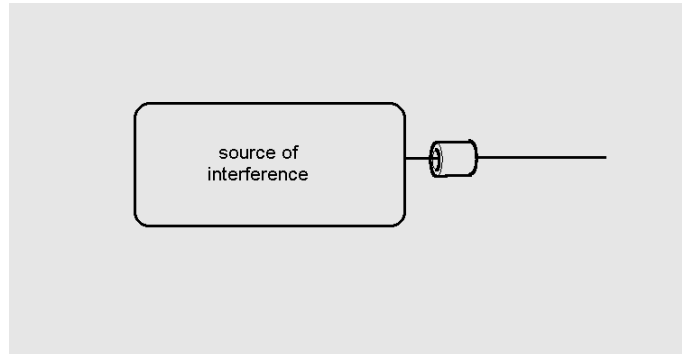For filtering purposes the ferrite suppressor should be fitted as close as possible to the source of interference.

Fig.21 Ferrite shield on I/O cable

When applied on an I/O cable, which passes through a connector of an enclosure, the ferrite shield should be fitted close to this connector. If not, the remaining length of cable can pick up EMI again before leaving the box.
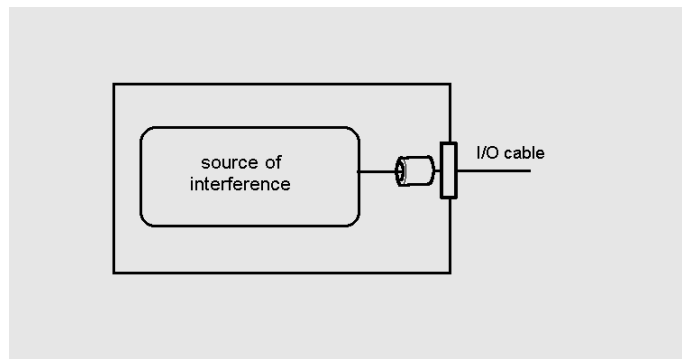

Fig.22 Position of ferrite shields in enclosed systems

If two connected systems are completely enclosed the location of the ferrite core is not that critical, it can be somewhere along the cable.
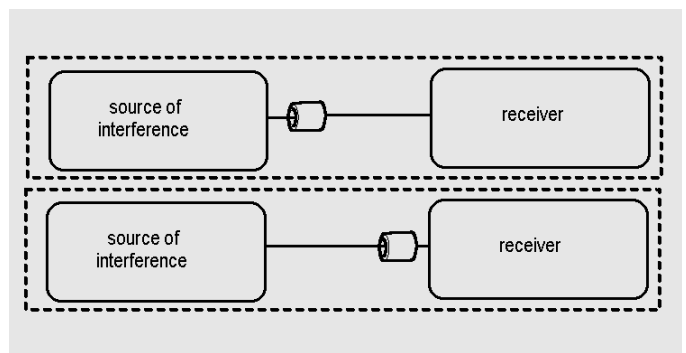

Fig.23 Ferrite shields between 2 EMI sources

In the case of a cable connecting two EMI interference sources, both systems must be protected and shielded with ferrite cable shields.
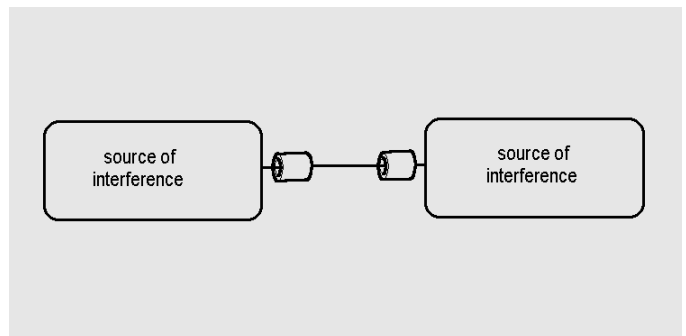
The impedance concept

Material and size

The impedance curve can be derived from a pure material curve, the so called complex permeability curve. As impedance consists of a reactive and a resistive part, permeability should also have two parts to represent this. The real part (μ') corresponds to the reactance, and the imaginary part (μ'') to the losses.

$$Z = j\omega \bullet (\mu' - j\mu'') \bullet L_0 = \omega\mu'' \bullet L_0 + j\omega\mu' \bullet L_0$$
$$Z = R + jX \;\rightarrow\; R = \omega\mu'' \bullet L_0$$
$$X = \omega\mu' \bullet L_0$$
$$|Z| = \sqrt{(R^2+X^2)} = \omega \bullet L_0 \sqrt{(\mu'^2+\mu''^2)}$$

where:
$\omega = 2\pi f$
$L_0 = \mu_0 \bullet N^2 \bullet A_e/l_e$
$\mu_0 = 4\pi \bullet 10^{-7}$
N = number of turns
Ae = effective area
le = effective length

The simplest way to estimate the impedance of a product with different dimensions is taking the impedance curve of a reference core. Two factors have to be corrected: effective magnetic dimensions and number of turns.

$$Z \propto N^2 \bullet A_e/l_e$$

$$Z = Z_0 \bullet (N^2/N_0^2) \bullet (A_e/A_{e0}) \bullet (l_{e0}/l_e)$$

where the parameters with index '0' correspond to the reference core. The number of turns 'N' is always an integer number. Half a turn geometrically is 1 turn magnetically. The effective magnetic dimensions 'A_e' and 'l_e' are calculated from geometric dimensions according to IEC norm 205. In the case of cylindrical symmetry an analytical formula exists:

$$A_e/l_e = L/(2\pi) \bullet \ln(D/d)$$

where:
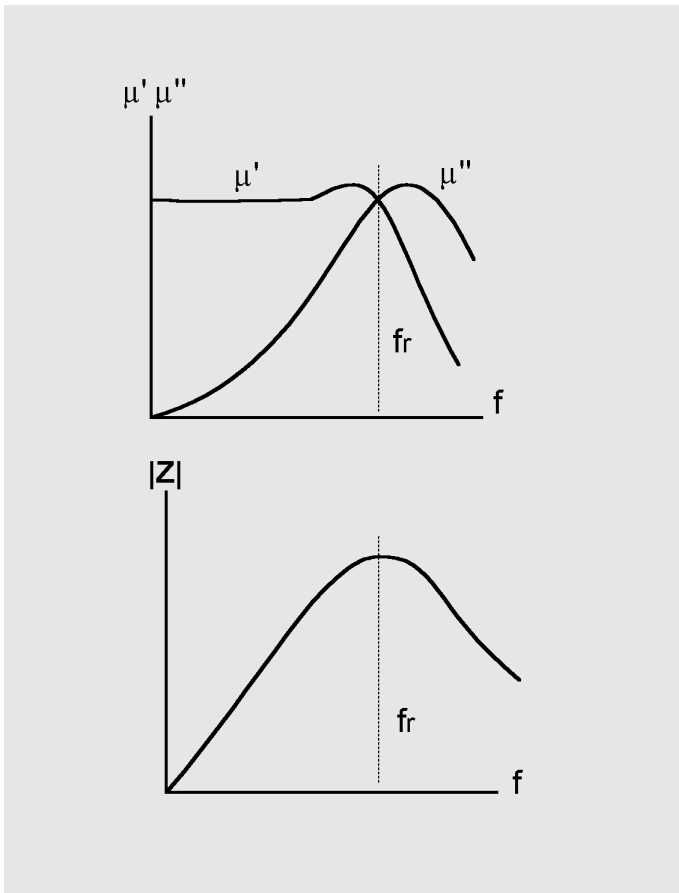D = outer diameter
d = inner diameter
L = height(length)

Bias current

Often a DC supply or AC power current is passing through the inductor to facilitate the regular operation of the connected equipment. This current induces a high field strength in the ferrite core, which can lead to saturation. When current compensation is not possible, the effects of the current have to be taken into account. Impedance then decreases along with permeability, especially in the low frequency region.

A solution is to compensate for the loss of impedance by increasing the length of the core (the longer the core, the higher the impedance). Another way to reduce the negative effect is to introduce a small gap in the ferrite core, but this is only feasible in the bisected types.

The influence of bias current can be calculated rapidly. The induced field strength is directly proportional to the current:

$$H = N \bullet I/l_e$$

Whether this field causes a significant saturation or not, can be seen in a curve of inductance versus bias field. However, this only indicates the decrease of impedance at low frequency. Impedance at high frequency decreases less.

Fig.24 Complex permeability and impedance

Again, impedance can be calculated from reference curves if they show impedance versus frequency with bias current as a parameter. First, the bias current is translated to the current that would induce the same field strength in the reference core, and thus the same amount of core saturation:

$$I_0 = I \cdot (N / N_0) \cdot (l_{e0} / l_e)$$

For a ring core, tube or bead the effective length is:

$$l_e = \pi \cdot \ln (D / d) / (1/d - 1/D)$$

Now the relative impedance decrease must be the same:

$$Z_{bias} = Z \cdot (Z_{0\ bias} / Z_0)$$

with Z again equal to:

$$Z = Z_0 \cdot (N^2/N_0^2) \cdot (A_e/A_{e0}) \cdot (l_{e0}/l_e)$$

In the graphs below some curves of typical impedance with and without DC current are presented.

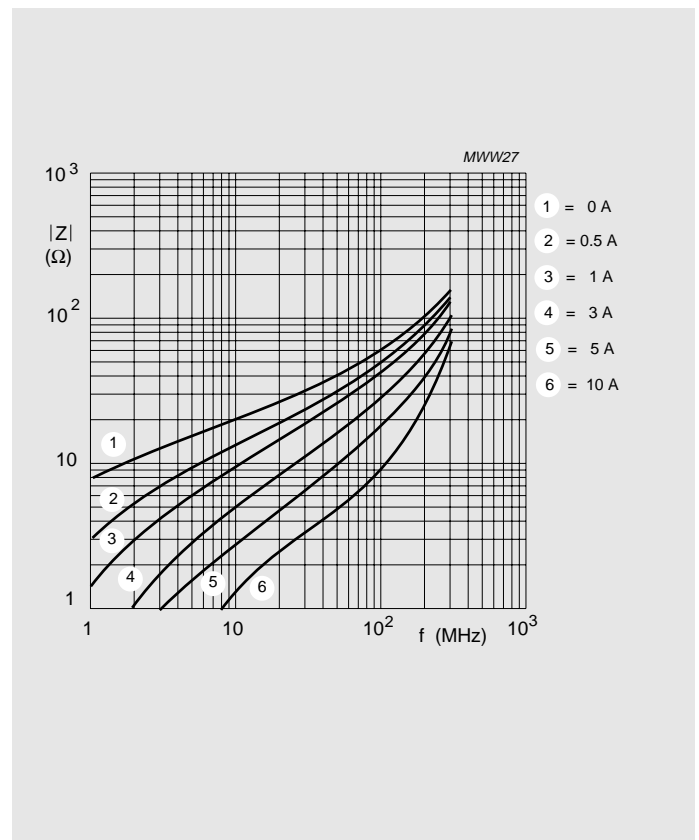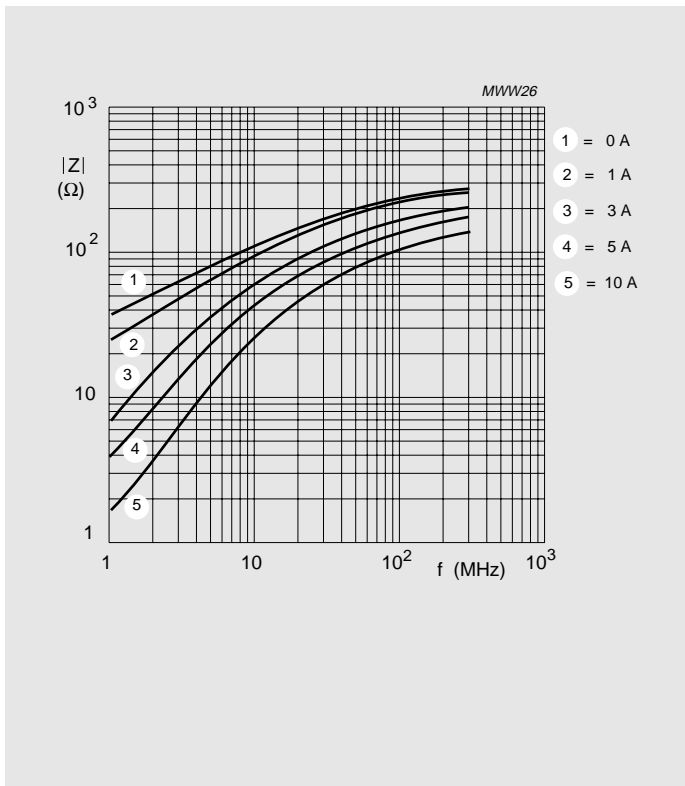*Fig.25 Impedance under bias conditions for CST7.8/5.3/9.8-3S4*

Fig.26 Impedance under bias conditions for CST17/9.5/29-3S4
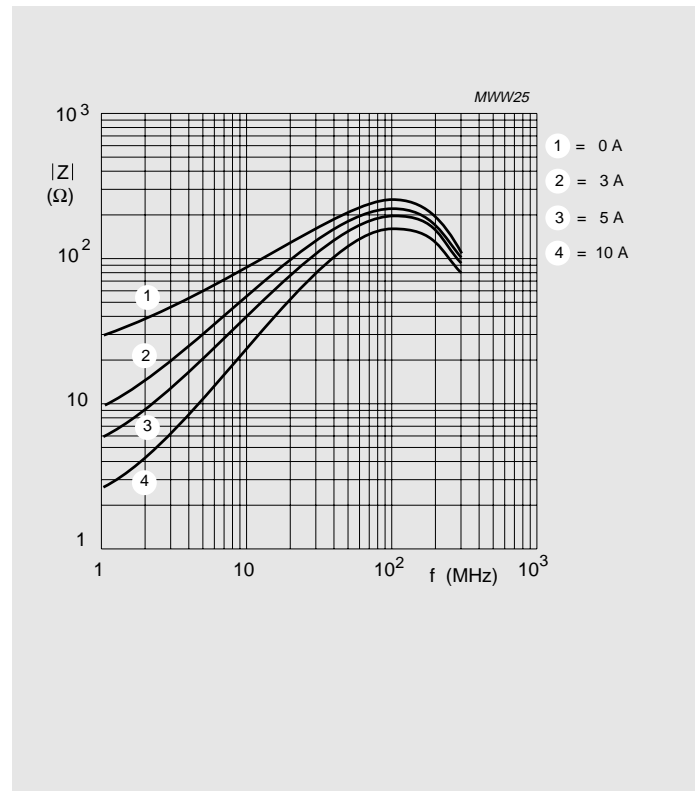
Fig.27 Impedance under bias conditions for CSF38/12/25-3S4

Temperature effects

Since impedance is directly depending on permeability and losses, it is also important to evaluate the effects of temperature on the intrinsic material parameters.
The behaviour of permeability versus temperature is shown in the material graphs on page 7 through 10. In the graphs below it is shown how this effects the impedance behaviour of some cable shields.

Fig.28 Impedance at several temperatures for CST7.8/5.3/9.8-3S4

Fig.29 Impedance at several temperatures for CST17/9.5/29-3S4

Fig.30 Impedance at several temperatures for CSF38/12/25-3S4

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Attenuation concept

When it is necessary to express the effectiveness of a suppressor in decibels (dB), impedance should be converted to insertion loss.

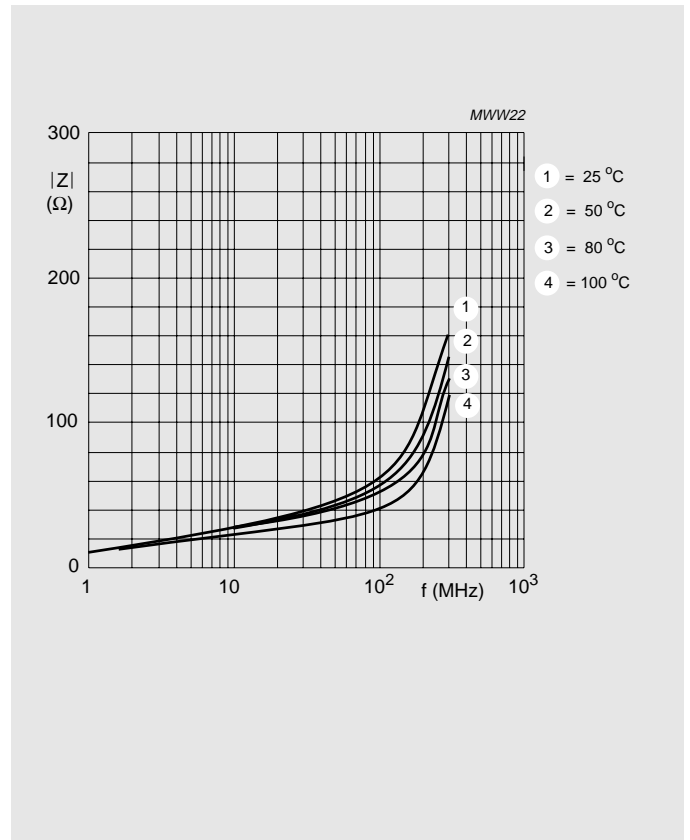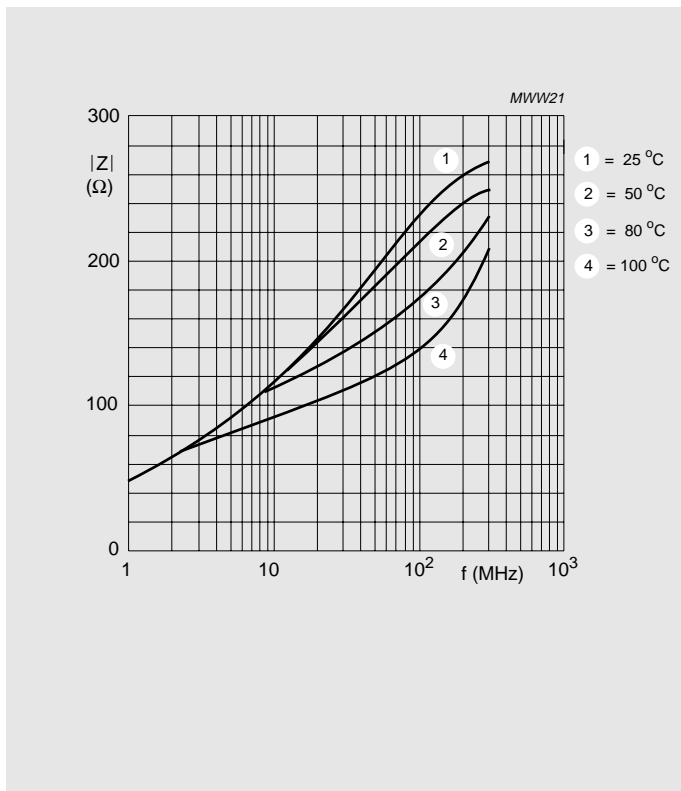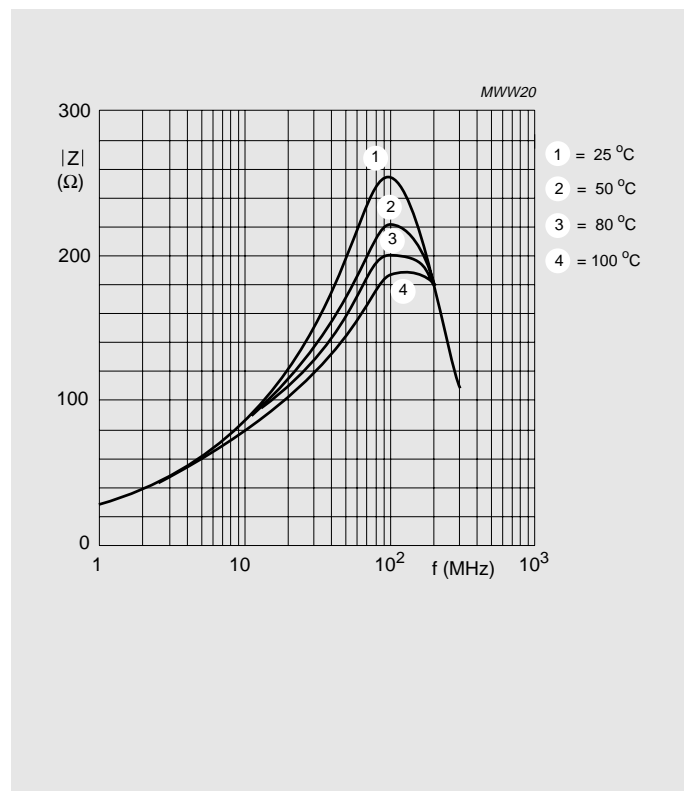Insertion loss is the ratio of the resulting voltage over the load impedance without and with a suppression component:

$$IL = 20 \cdot \log (E_0/E)$$
$$IL = 20 \cdot \log |Z_G + Z_L + Z_S| / |Z_G + Z_L|$$

where:
E = load voltage with inductor
Eo = load voltage without inductor

For a 50Ω /50Ω system:

$$IL = 20 \cdot \log(1 + Z/100) \text{ dB}$$

The decibel seems a practical unit because interference levels are usually expressed in it, but be aware that insertion loss depends on source and load impedance. So it is not a pure product parameter like impedance. In the application source and load will not normally be a 50 Ω fixed resistor. They might be reactive, frequency dependent and quite different from 50Ω.

Conclusion:
Insertion loss is a standardized parameter for comparison, but it will not predict directly the attenuation in the application since it is not a pure product parameter.

It is recommended to check the attenuation values by tests on the real circuit to find deviations caused by actual system impedances. The lower the circuit impedance, the higher the attenuation with the same ferrite core will be.
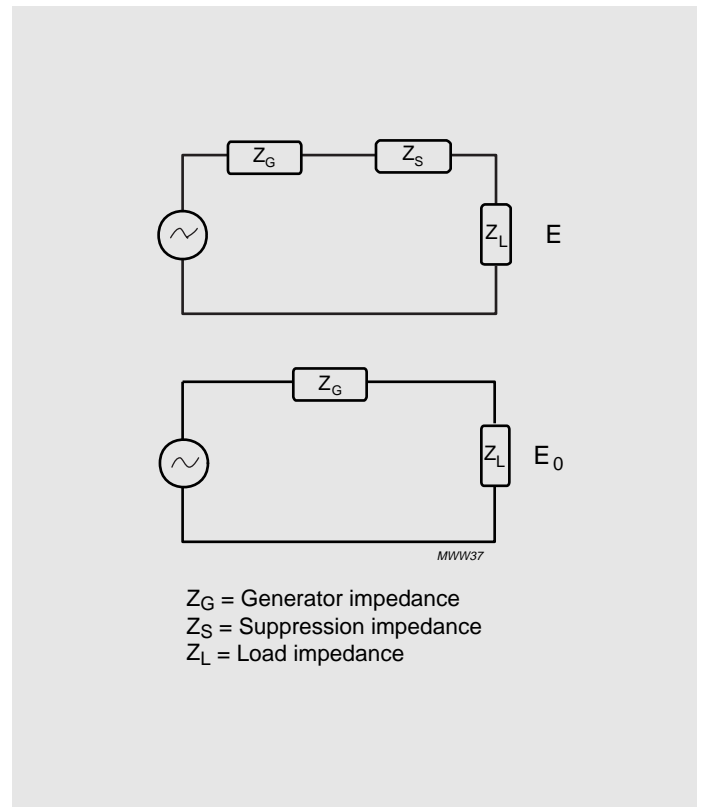

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Z_G = Generator impedance
Z_S = Suppression impedance
Z_L = Load impedance

Fig.31 Suppression basics

Cable Shields for Round Cables
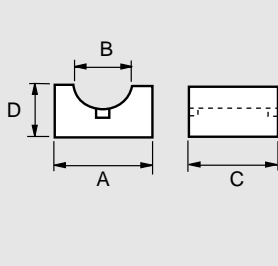
Split types with nylon cases
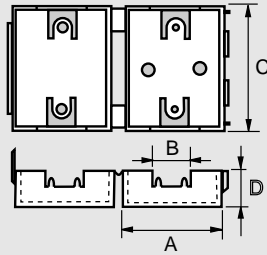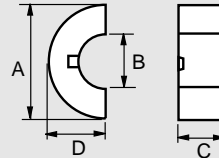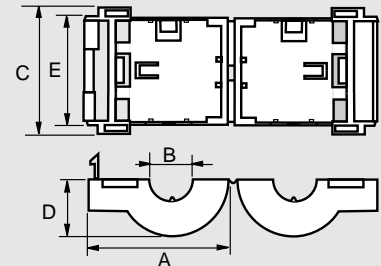
Fig. 1   Fig. 2   Fig. 3   Fig. 4

Fig.32 Cable shields for round cables with matching plastic cases.

Type number	Fig	Ferrite dimensions Case dimensions (mm)					Z_{typ}^{*} (ohms)	
		A	B	C	D	E	25MHz	100MHz
CSA15/7.5/29-4S2-EN	1	15±0.25	6.6±0.3	28.6±0.8	7.5±0.15		165	275
CSA15/7.5/29-4S2	1	15±0.25	6.6±0.3	28.6±0.8	7.5±0.15		165	275
	2	17.9	7.0	32.3	9.2	9.0		
CSA19/9.4/29-4S2-EN	1	18.65±0.4	10.15±0.3	28.6±0.8	9.4±0.15		140	225
CSA19/9.4/29-4S2	1	18.65±0.4	10.15±0.3	28.6±0.8	9.4±0.15		140	225
	2	22.1	10.2	32.3	11.7	9.0		
CSA26/13/29-4S2-EN	1	25.9±0.5	13.05±0.3	28.6±0.8	12.95±0.25		155	250
CSA26/13/29-4S2	1	25.9±0.5	13.05±0.3	28.6±0.8	12.95±0.25		155	250
	2	29.0	13.4	32.5	14.8	18.0		
CSC16/7.9/14-4S2-EN	3	15.9±0.4	7.9±0.3	14.3±0.4	7.95±0.2		50	113
	4	24.7	7.6	22.8	10.2	17.8		

* Minimum allowed Z is typical -20%
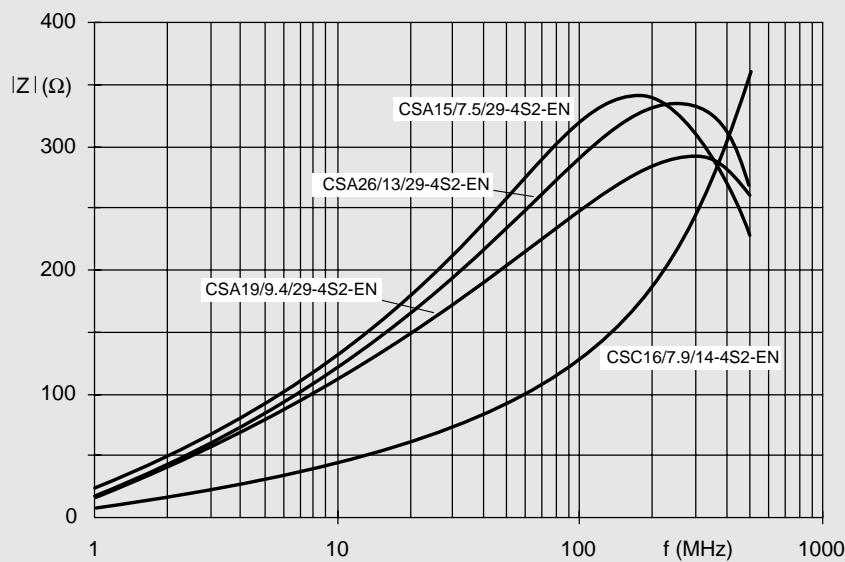
Fig.33 Impedance of split type cable shields as a function of frequency.

Ring Cores (Toroids)
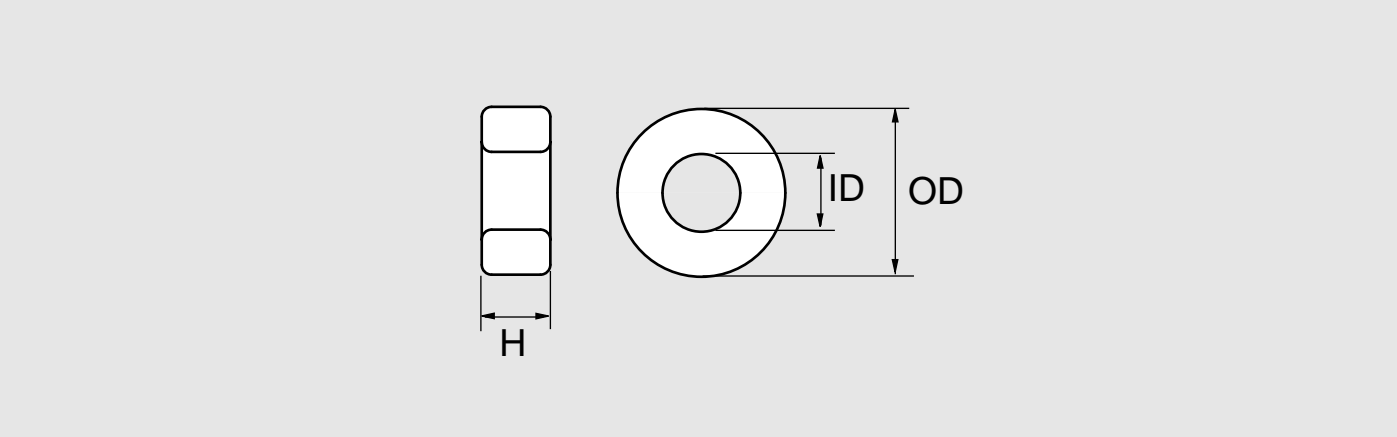
Fig.34 Outline of ring cores suitable as cable shields.

Type number	Dimensions (mm)			AL (nH)
	OD	ID	H	±25%
T23/14/7-3S4	23±0.5	14±0.35	7±0.2	1180
T26/14/7-4C65	23±0.5	14±0.35	7±0.2	87
T36/23/15-4C65	36±0.7	23±0.5	15±0.3	170
T36/23/15-4A11	36±0.7	23±0.5	15±0.3	940
T58/32/18-3S4	58.3±1	32±0.7	18±0.5	3670

Tubular Cable Shields
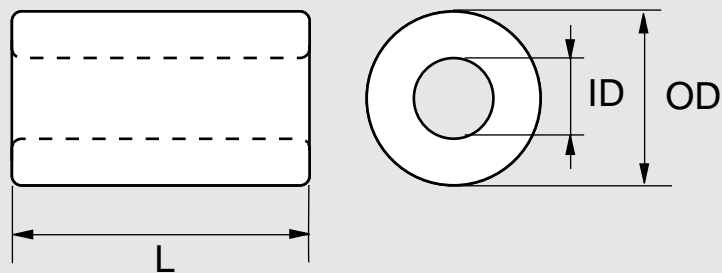
Fig.35 Outline of tubular cable shields.

Type number	Dimensions (mm)			$Z_{typ}(\Omega)$	
	OD	ID	L	25MHz	100MHz
CST7.8/5.3/9.8-3S4	7.8±0.2	5.3+0.3	9.8±0.2	32	50
CST8.3/3.5/10-3S4	8.3-0.4	3.5+0.3	10-0.6	70	96
CST9.5/4.8/6.4-4S2	9.5±0.25	4.75±0.25	6.35±0.35	23	50
CST9.5/4.8/10-4S2	9.5±0.25	4.75±0.15	10.4±0.25	53	80
CST9.5/4.8/19-4S2	9.5±0.25	4.75±0.15	19.05±0.7	100	145
CST9.5/5.1/15-3S4	9.5±0.3	5.1±0.15	14.5±0.45	66	110
CST9.7/5/5.1-4S2	9.65±0.25	5±0.2	5.05-0.45	26	43
CST14/6.4/29-4S2	14.3±0.45	6.35±0.25	28.6±0.75	170	250
CST14/7.3/29-4S2	14.3±0.45	7.25±0.15	28.6±.0.75	143	215
CST16/7.9/14-4S2	16.25-0.75	7.9±0.25	14.3±0.35	70	113
CST16/7.9/29-4S2	16.25-0.75	7.9±0.25	28.6±0.75	130	213
CST17/9.5/13-4S2	17.45±0.4	9.5±0.25	12.7±0.5	55	88
CST17/9.5/13-3S4	17.45±0.4	9.53±0.25	12.7±0.5	55	96
CST17/9.5/29-4S2	17.45±0.4	9.5±0.25	28.6±0.75	125	200
CST17/9.5/29-3S4	17.45±0.35	9.53±0.25	28.55±0.75	125	200
CST17/11/60-3S4	17.2-1.2	11±0.5	60-2.5	200	320
CST19/10/29-4S2	19-0.65	10.15±0.25	28.6±0.75	128	196
CST19/11/12-3S4	19±0.4	10.6±0.3	11.5±0.4	50	75
CST26/13/29-4S2	25.9±0.75	12.8±0.25	28.6±0.8	145	225
CST29/19/7.5-4S2	29±0.75	19±0.5	7.5±0.25	28	47

Notes: 1. Minimum allowed Z is typical -20%

2. Dimension L can be adjusted to application requirements

Fig.36 Impedance of tubular cable shields as a function of frequency.
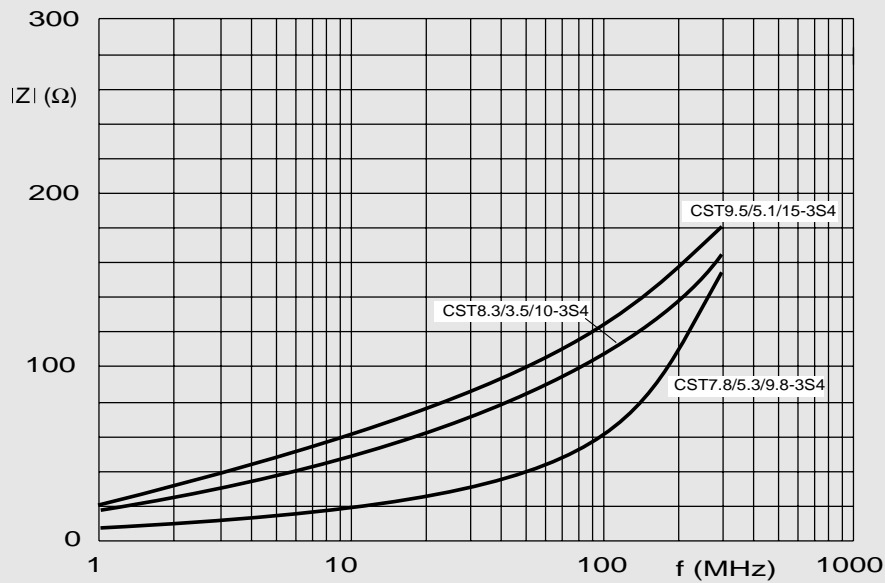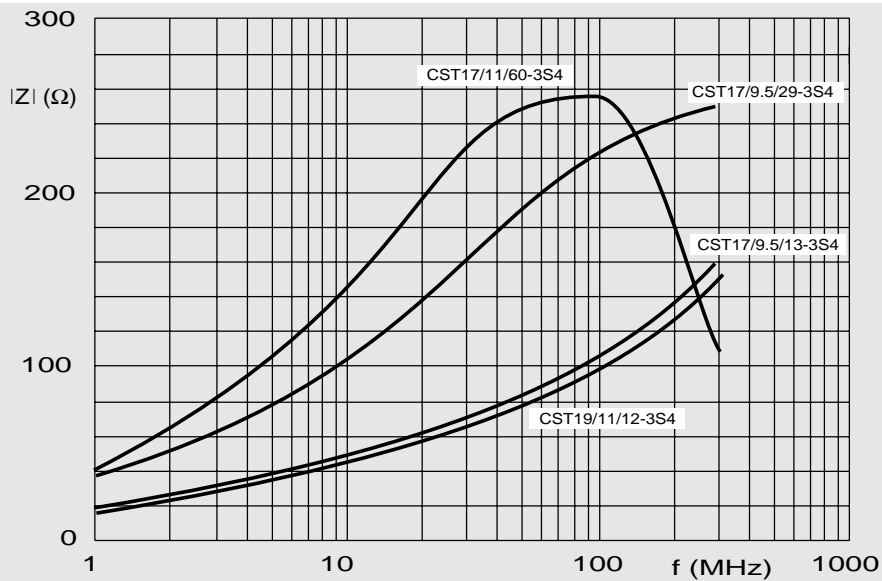

Fig.37 Impedance of tubular cable shields as a function of frequency.

Fig.38 Impedance of tubular cable shields as a function of frequency.

Fig.39 Impedance of tubular cable shields as a function of frequency.

Fig.40 Impedance of tubular cable shields as a function of frequency.

Cable Shields for Flat Cables
Flat cable shields (entire types)
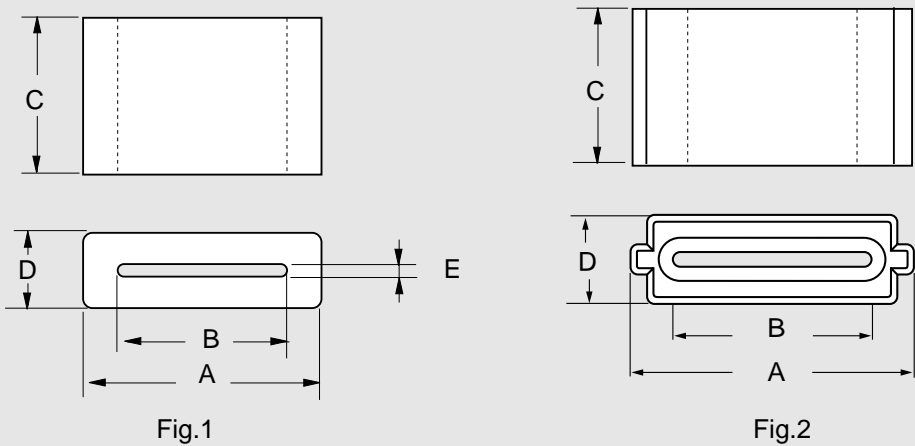
Fig.41 Cable shields (CSF) for flat cables.

Type number		Ferrite dimensions (mm)					$Z^*_{typ}(\Omega)$	
	Fig	A	B	C	D	E	25MHz	100MHz
CSF38/12/25-3S4	1	38.1±1.0	26.7±0.8	25.4±0.8	12.1±0.4	1.9±0.4	110	215
CSF39/12/25-3S4-S	2	38.5±1.0	26.8±0.8	25.4±0.8	12.1±0.4	1.9±0.4	98	196

* Minimum allowed Z is typical -20%

Fig.42 Impedance of flat cable shields (CSF) as a function of frequency.

Cable Shields for Flat Cables
Flat Cable Shields (split types) with nylon Case or metal Clips
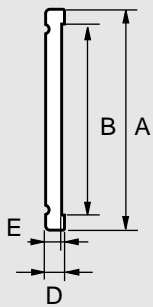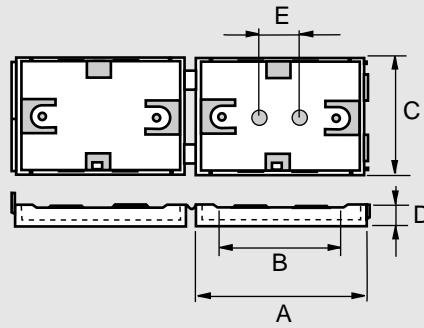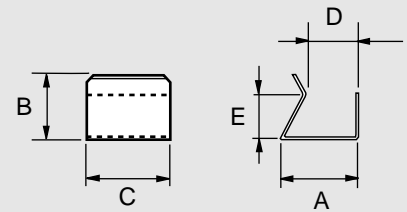
Fig. 1   Fig. 2   Fig. 3

Fig.43 Cable shields for flat cables with matching plastic cases and clips.

Type number	Fig	Ferrite dimensions Case dimensions (mm)					Z_{typ} (Ω)	
		A	B	C	D	E	25MHz	100MHz
CSU45/6.4/29-4S2-EN	1	45.1±0.75	34.4±0.7	28.6±0.7	6.35±0.25	0.85±0.2	96	225
CSU45/6.4/29-4S2	1	45.1±0.75	34.4±0.7	28.6±0.7	6.35±0.25	0.85±0.2	96	225
	2	49.5	34.3	32.3	8.1	20.0		
CSU76/6.4/29-4S2-EN	1	76.2±1.5	65.3±1.3	28.6±0.8	6.35±0.25	0.85±0.2	75	215
CSU76/6.4/29-4S2	1	76.2±1.5	65.3±1.3	28.6±0.8	6.35±0.25	0.85±0.2	75	215
	2	80.8	65.5	32.2	8.1	50.8		
CLI-CSU6.4	3	16.1	11.0	12.7	11.4	8.0		
CSU76/6.4/13-3S4	1	76.2±1.5	65.3±1.3	12.7±0.4	6.35±0.25	0.85±0.2	36	110
CSU76/6.4/15-3S4	1	76.2±1.5	65.3±1.3	15±0.6	6.35±0.25	0.85±0.2	50	159
CSU76/6.4/29-3S4	1	76.2±1.5	65.3±1.3	28.6±0.8	6.35±0.25	0.85±0.2	70	235

Notes:
1. Minimum allowed Z is typical -20%
2. Dimension C can be adjusted to application requirements
3. Clip material: 0.5mm spring steel, zinc (Zn) plated
4. Plastic case material: Flame retardant nylon 66 grade A82, UL94 V-0. Colour: black
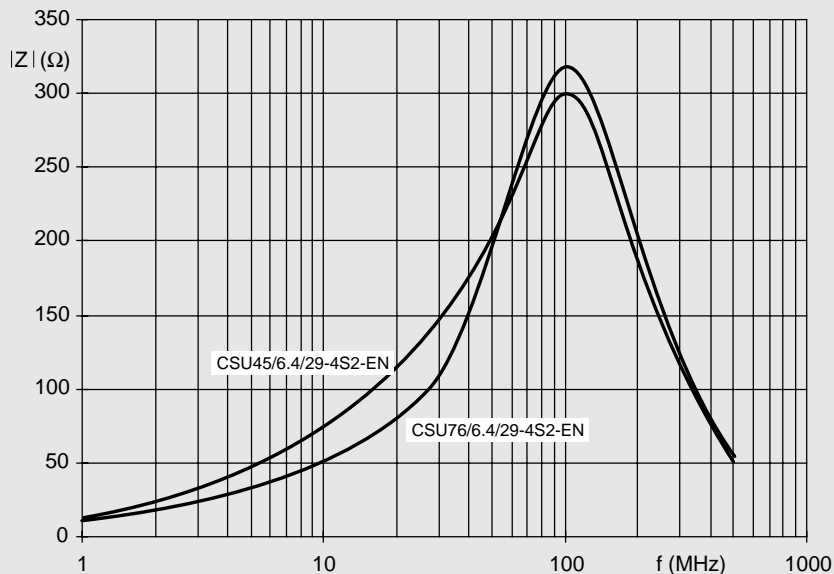
Fig.44   Impedance of flat cable shields as a function of frequency.

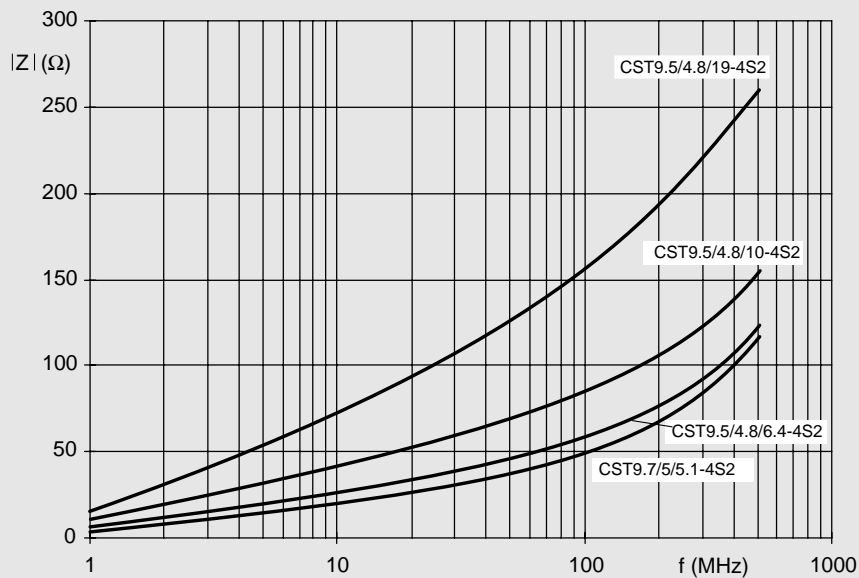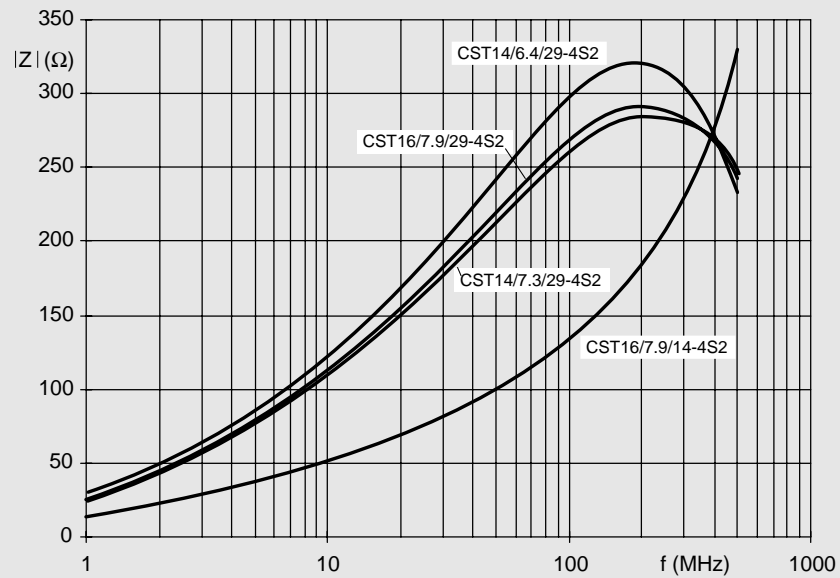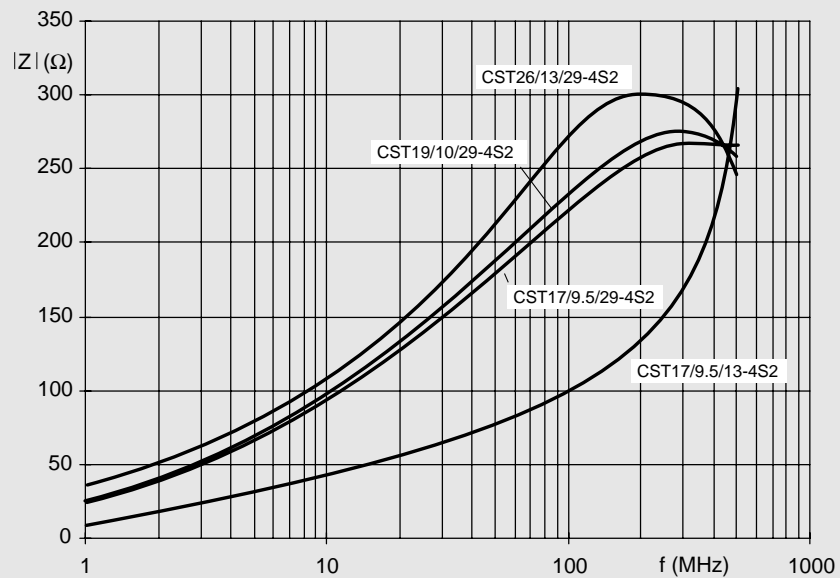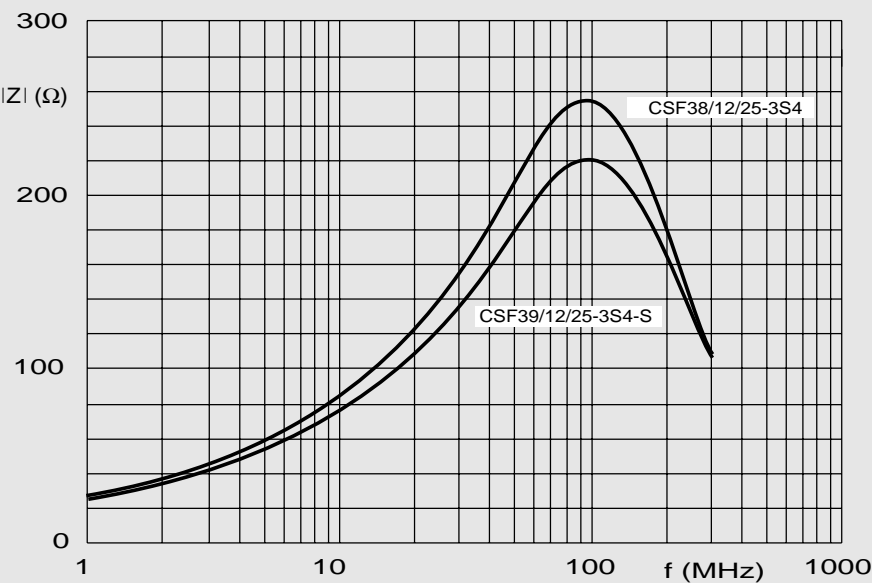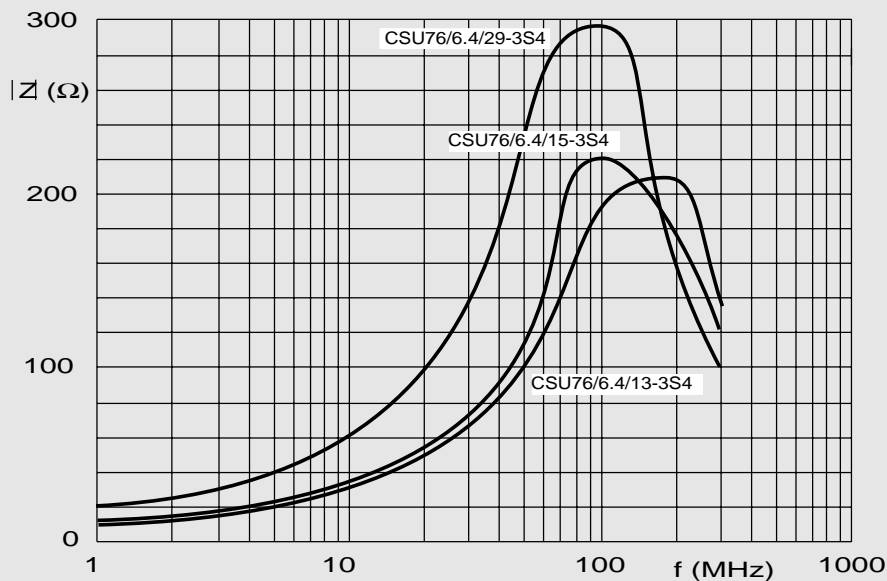*Fig.45 Impedance of flat cable shields as a function of frequency.*

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