DATA SHEET

Applications
Soft Ferrites

Philips
Components

PHILIPS

Soft Ferrites

Applications

APPLICATIONS

Introduction

Soft ferrite cores are used wherever effective coupling between an electric current and a magnetic flux is required. They form an essential part of inductors and transformers used in today's main application areas:
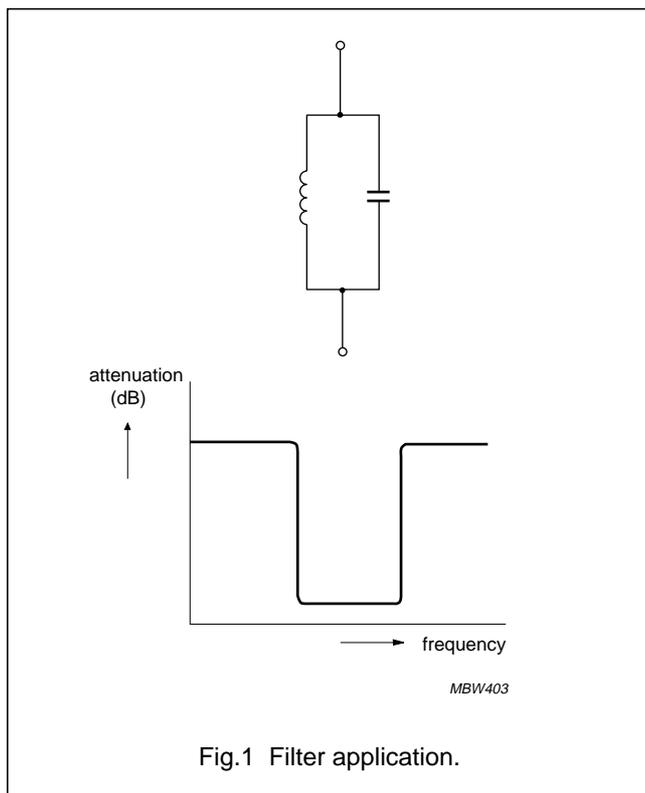
• Telecommunications

• Power conversion

• Interference suppression.

The function that the soft magnetic material performs may be one or more of the following:

FILTERING

Filter network with well defined pass-band.

High Q-values for selectivity and good temperature stability.

Material requirements:

• Low losses

• Defined temperature factor to compensate temperature drift of capacitor

• Very stable with time.

Preferred materials: 4C6, 3D3, 3H1, 3H3, 3B7.

INTERFERENCE SUPPRESSION

Unwanted high frequency signals are blocked, wanted signals can pass. With the increasing use of electronic equipment it is of vital importance to suppress interfering signals.

Material requirements:

• High impedance in covered frequency range.

Preferred materials: 3S1, 4S2, 3S3, 3S4, 4C65, 4A11, 4A15, 3B1, 4B1, 3C11, 3E25, 3E5.

Fig.1 Filter application.

Fig.2 Suppression application.
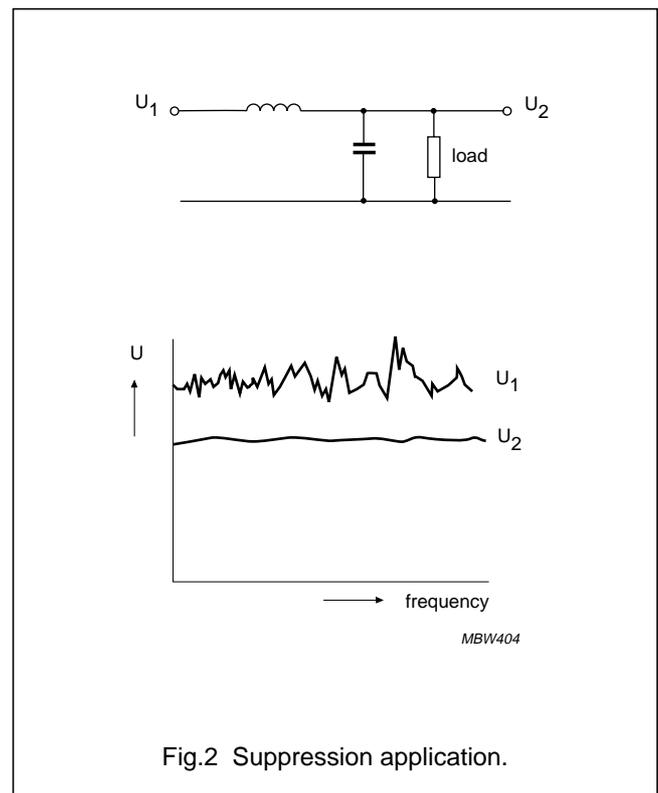
Soft Ferrites

Applications

DELAYING PULSES

The inductor will block current until saturated. Leading edge is delayed depending on design of magnetic circuit.

Material requirements:

- High permeability (μ_i).

Preferred materials: 3E25, 3E5, 3E6, 3E7.
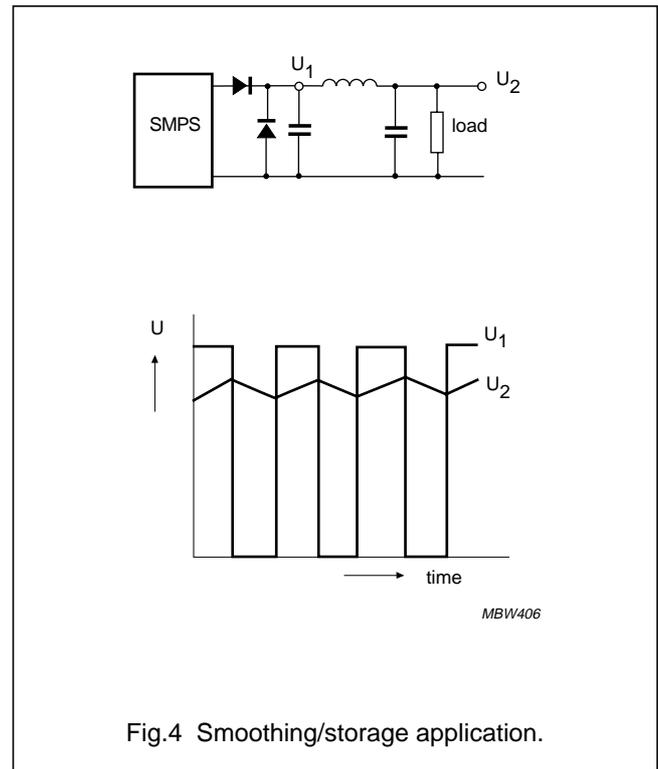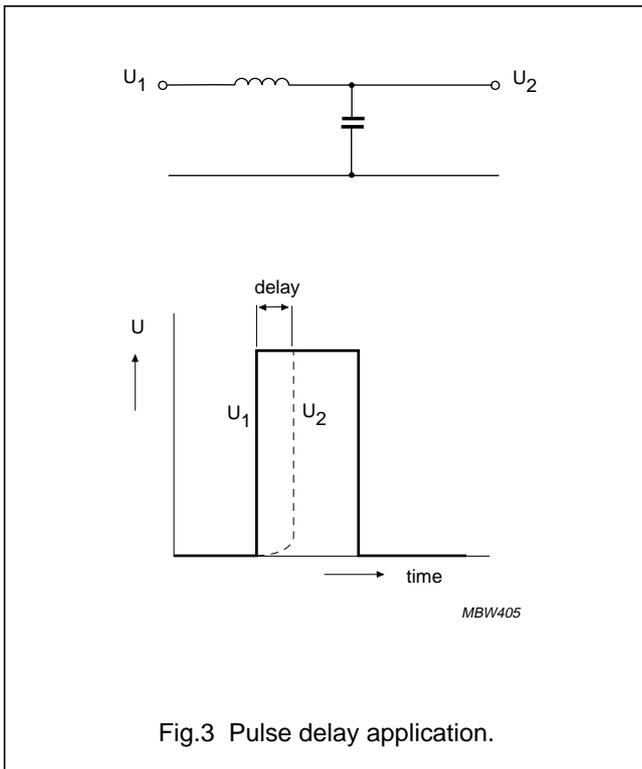

Fig.3 Pulse delay application.

STORAGE OF ENERGY

An inductor stores energy and delivers it to the load during the off-time of a Switched Mode Power Supply (SMPS).

Material requirements:

- High saturation level (B_s).

Preferred materials: 3C15, 3C30, 3C85, 3C90, 2P-iron powder.

Fig.4 Smoothing/storage application.

Soft Ferrites

Applications

PULSE TRANSFORMERS/GENERAL PURPOSE TRANSFORMERS

Pulse or AC signals are transmitted and if required transformed to a higher or lower voltage level. Also galvanic separation to fulfil safety requirements and impedance matching are provided.

Material requirements:

- High permeability
- Low hysteresis factor for low signal distortion
- Low DC sensitivity.

Preferred materials: 3B7, 3B8, 3C81, 3H1, 3H3, 3E1, 3E4, 3E25, 3E5, 3E6.

POWER TRANSFORMERS

A power transformer transmits energy, transforms voltage to the required level and provides galvanic separation (safety).

Material requirements:

- Low power losses
- High saturation (B_s).

Preferred materials: 3C15, 3C30, 3C81, 3C85, 3C90, 3F3, 3F4, 4F1.

Fig.5 Pulse and general purpose transformer.

Fig.6 Power transformer application.

Soft Ferrites   Applications
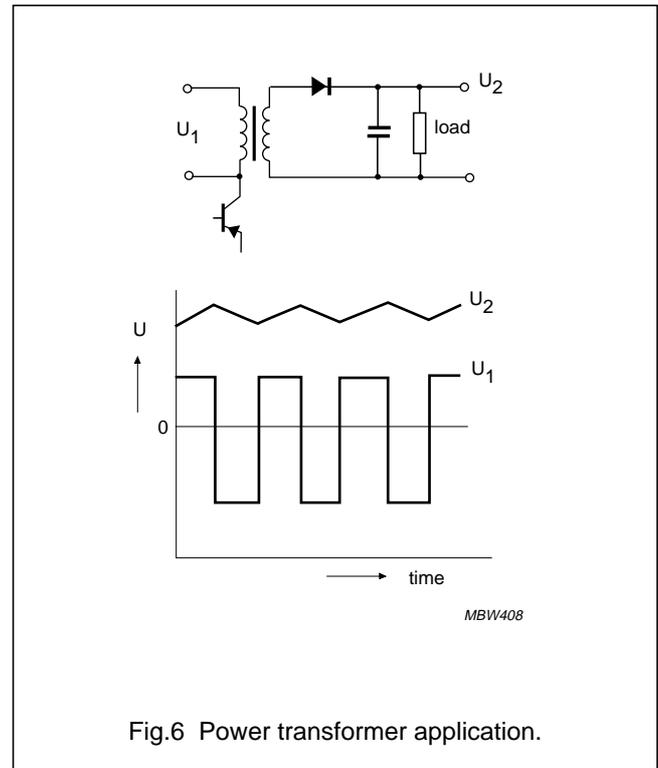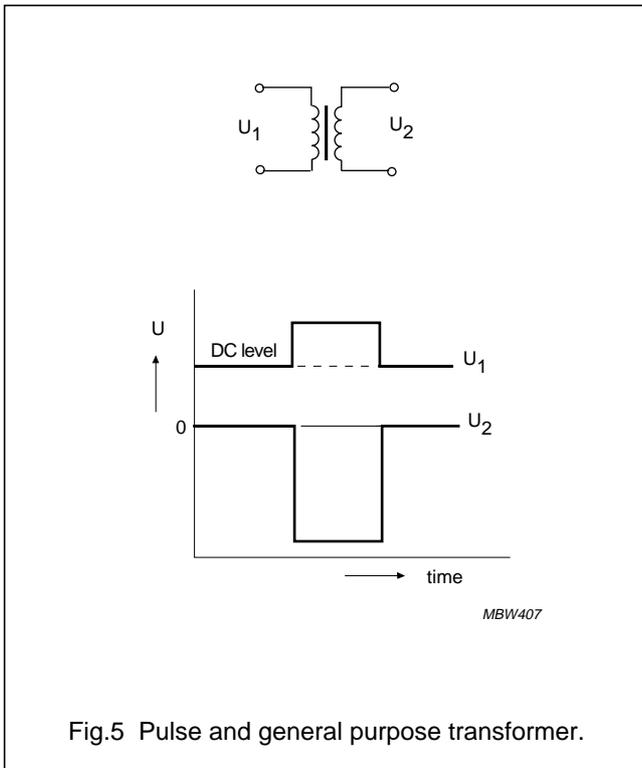
TUNING

LC filers are often used to tune circuits in audio, video and measuring equipment. A very narrow bandwidth is often not wanted.

Material requirements:

• Moderate losses up to high frequency
• Reasonable temperature stability.

Preferred materials: 3D3, 4A11, 4B1, 4D2, 4E1.

Fig.7 Tuning application.

Soft Ferrites

Applications
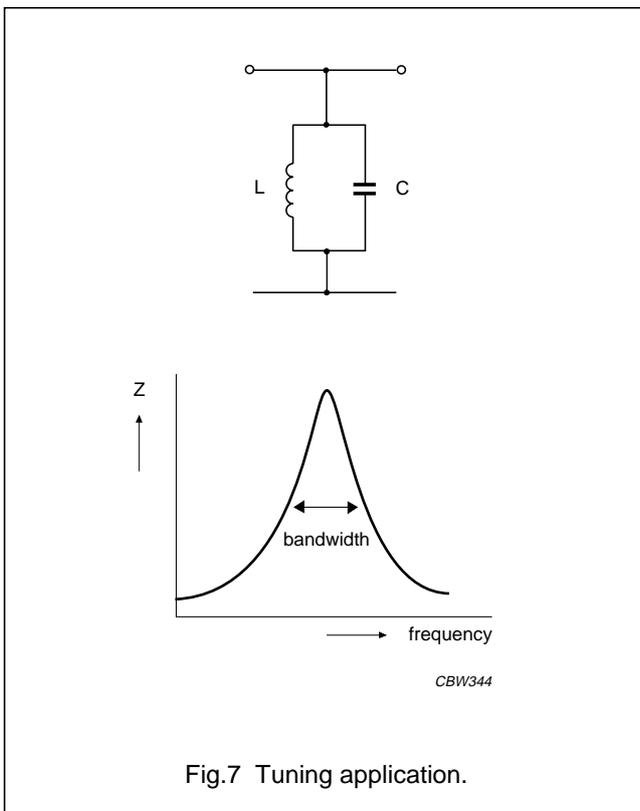
Ferrites for Telecommunications

Telecommunications is the first important branch of technology where ferrites have been used on a large scale. Today, against many predictions, it still is an important market for ferrite cores.

Most important applications are in:

- Filter inductors
- Pulse and matching transformers.

FILTER COILS

P cores, RM cores and X cores have been developed specially for this application.

The P core is the oldest design. It is still rather popular because the closed shape provides excellent magnetic screening.

RM cores are a later design, leading to a more economic usage of the surface area on the PCB. X cores also have this advantage plus more room to get the leads out of the coil.

For filter coils, the following design parameters are important:

- Precise inductance value
- Low losses, high Q value
- High stability over periods of time
- Fixed temperature dependence.

Q VALUE

The quality factor (Q) of a filter coil should generally be as high as possible. For this reason filter materials such as 3H1, 3B7, 3B9, 3H3, 3D3 and 4C6 have low magnetic losses in their frequency ranges (100 kHz, 2 MHz and 10 MHz respectively).

Losses in a coil can be divided into:

- Winding losses, due to the DC resistance of the wire eddy-current losses in the wire electric losses in insulation
- Core losses, due to hysteresis losses in the core material eddy-current and residual losses in the core material.

Losses appear as series resistances in the coil:

$$\frac{R_{tot}}{L} = \frac{R_0}{L} + \frac{R_{ec}}{L} + \frac{R_d}{L} + \frac{R_h}{L} + \frac{R_{e+r}}{L} \quad (\Omega/H)$$

As a general rule, maximum Q is obtained when the sum of the winding losses is made equal to the sum of the core losses.

DC resistive losses

The DC resistive losses in a winding are given by:

$$\frac{R_0}{L} = \frac{1}{\mu_e} \times \frac{1}{f_{Cu}} \times constant \quad (\Omega/H)$$

The space (copper) factor f_{Cu} depends on wire diameter, the amount of insulation and the method of winding.

Eddy-current losses in the winding

Eddy-current losses in a winding are given by:

$$\frac{R_{ec}}{L} = \frac{C_{wCu}V_{Cu}f^2d^2}{\mu_e} \quad (\Omega/H)$$

Where C_{wCu} is the eddy-current loss factor for the winding and depends on the dimensions of the coil former and core, and V_{Cu} is the volume of conductor in mm^3, d is the diameter of a single wire in mm.

Dielectric losses

The capacitances associated with the coil are not loss free. They have a loss factor which also increases the effective coil resistance:

$$\frac{R_d}{L} = \omega^3 LC\left(\frac{2}{Q} + \tan\delta_c\right) \quad (\Omega/H)$$

Hysteresis losses

The effective series resistance due to hysteresis losses is calculated from the core hysteresis constant, the peak flux density, the effective permeability and the operating frequency:

$$\frac{R_h}{L} = \omega\eta_B\hat{B}\mu_e \quad (\Omega/H)$$

Eddy-current and residual losses

The effective series resistance due to eddy-current and residual losses is calculated from the loss factor:

$$\frac{R_{e+r}}{L} = \omega\mu_e(\tan\delta/\mu_i) \quad (\Omega/H)$$

Soft Ferrites   Applications

INDUCTOR DESIGN

The specification of an inductor usually includes:

- The inductance
- Minimum Q at the operating frequency
- Applied voltage
- Maximum size
- Maximum and minimum temperature coefficient
- Range of inductance adjustment.

To satisfy these requirements, the designer has the choice of:

- Core size
- Material grade
- A_L value
- Type of conductor (solid or bunched)
- Type of adjuster.

FREQUENCY, CORE TYPE AND MATERIAL GRADE

The operating frequency is a useful guide to the choice of core type and material.

- Frequencies below 20 kHz:
  the highest Q will be obtained with large, high inductance-factor cores of 3B7, 3H1 or 3H3 material. Winding wire should be solid, with minimum-thickness insulation.

  Note: high inductance factors are associated with high temperature coefficients of inductance.

- Frequencies between 20 kHz and 200 kHz:
  high Q will generally be obtained with a core also in 3B7, 3H1 or 3H3. Maximum Q will not necessarily be obtained from the large-size core, particularly at higher frequencies, so the choice of inductance factor is less important. Bunched, stranded conductors should be used to reduce eddy-current losses in the copper. Above 50 kHz, the strands should not be thicker than 0.07 mm.

- Frequencies between 200 kHz and 2 MHz:
  use a core of 3D3 material. Bunched conductors of maximum strand diameter 0.04 mm are recommended.

- Frequencies between 2 MHz and 12 MHz:
  use a core of 4C6. Bunched conductors of maximum strand diameter 0.04 mm are recommended for frequencies up to 5 MHz. Solid conductors should be used at frequencies between 5 MHz and 12 MHz.

SIGNAL LEVEL

In most applications, the signal voltage is low. It is good practice to keep wherever possible the operating flux density of the core below 1 mT, at which level the effect of hysteresis is usually negligible. At higher flux densities, it may be necessary to allow for some hysteresis loss and inductance change.

The following expression for third harmonic voltage U_3 may be used as a guide to the amount of distortion:

$$\frac{U_3}{U_1} = 0.6 \tan \delta_h$$

For low distortion, materials with small hysteresis loss factors should be used (e.g. 3H3).

DC POLARIZATION

The effect of a steady, superimposed magnetic field due to an external field or a DC component of the winding current is to reduce the inductance value of an inductor. As with other characteristics, the amount of the decrease depends on the value of the effective permeability. The effect can be reduced by using a gapped core or by choosing a lower permeability material.

A_L VALUE

Since the air gap in ferrite cores can be ground to any length, any value of A_L can be provided within the limits set by the core size. In practice, the range of A_L values has been standardized with values chosen to cover the majority of application requirements.

If a core set is provided with an asymmetrical air gap, this air gap is ground in the upper half. This half is marked with the ferrite grade and A_L value.

Most pre-adjusted cores are provided with an injection-moulded nut for the adjuster.

Continuously variable adjusters can be supplied for pre-adjusted cores of most A_L values. These are specially recommended for filter coils. Maximum adjustment range is 10% to 30%, depending on core type and adjuster.

The A_L factor is the inductance per turn squared (in nH) for a given core:

$$L = N^2 \times A_L \quad (nH)$$

The measured A_L value of a core will depend slightly on the coil used for this measurement.

Soft Ferrites

Applications

For very low A_L values (e.g. 16 to 25) the contribution of the stray inductance will be quite high, resulting in a marked influence of the position of the coil in the core and its number of turns.

INDUCTANCE ADJUSTERS

A major feature of a filter core assembly is its adjustment mechanism. It allows the cores to be set to a very accurate value (0.1%).

The inductance adjustment is achieved by inserting a tube or cylinder, manufactured from ferrite or carbonyl-iron powder into the central hole of the core. This acts as a partial magnetic shunt across the air gap. The adjuster consists of this tube moulded into a thermoplastic carrier which has been threaded at one end. This screws into a nut which is injection moulded or cemented into the lower half of the core. The magnetic tubes are centre-less ground to give very close diameter tolerances.

INDUCTANCE STABILITY

The stability of a correctly assembled inductor depends mainly on the stability of the ferrite's permeability.

The permeability of a ferrite material may change with temperature, time, mechanical pressure, magnetic polarization and other factors. The most important changes affecting the inductance stability of the assembly are:

- Variation of permeability with temperature (temperature coefficient)
- Variation of permeability with time (disaccommodation).

Changes in inductance may also occur due to:
- Movement of the adjuster after final setting
- Movement of the coil former
- Relative movement of the core halves
- Movement of the mechanical components of the assembly.

Small movements of this kind are usually caused by changes in temperature, mechanical vibration or shock.

The achievement of acceptable long-term inductance stability is mainly a matter of careful assembly and suitable stabilizing treatment before final adjustment. If the inductor is to be used in a critical circuit, it should be artificially aged by temperature cycling. The long-term change in inductance of an assembly so treated should not be greater than 500×10^{-6}, assuming an ambient temperature between 25 °C and 40 °C that does not vary by more than 15 °K.

The change in inductance of an RM core assembly using clips with earth pins when subjected to *"IEC 60068-2-6, test F_c"* (vibration conditions) is less than 1000×10^{-6}. Such severe conditions are unlikely to be encountered in practice.

Bump tests of RM-core assemblies with earth pins *("IEC 60068-2-29, test Eb")* have also been carried out. The observed change in the inductance of RM6-R cores of 3H1 material was less than 300×10^{-6}.

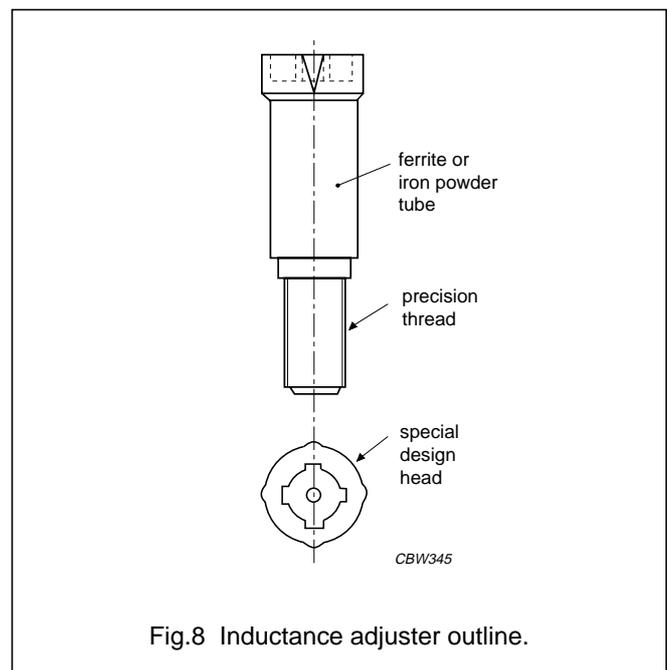Figure 8 shows the principle outline of a typical adjuster.

Fig.8 Inductance adjuster outline.

Soft Ferrites

Applications

The data sheets include lists of recommended adjusters for the A_L values in various grades. The table also lists the maximum inductance variation. In some cases, the choice of adjuster is optional and depends on the application. For that reason, a suggestion is given for minimum, average and maximum inductance variation where applicable.

Figure 9 shows a typical curve of a specified adjuster in a core set, pre-adjusted on A_L.

Fig.9   Typical curve of a specified adjuster in a core set, pre-adjusted on A_L.
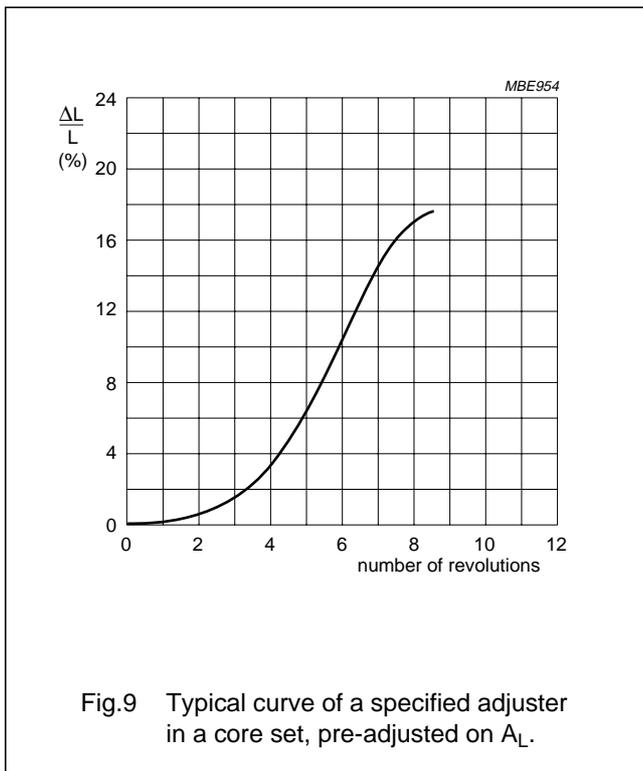
Dependent on size, the screw-head of the adjuster is suited for tools of M1.4, M1.7 and M2.6. An adjusting tool, combining M1.4 and M1.7 is available (catalogue number 4322 058 0326) as well as a tool combining M2 and M2.6 (catalogue number 43222 058 0327). For customers who wish to make the adjuster tool themselves, the four outlines are depicted in Fig.10.

The threads of both the nut and the adjuster have close tolerances (4H) to allow smooth rotation without backlash or friction.

Fig.10 Dimensions (in mm) of tools for adjusters.
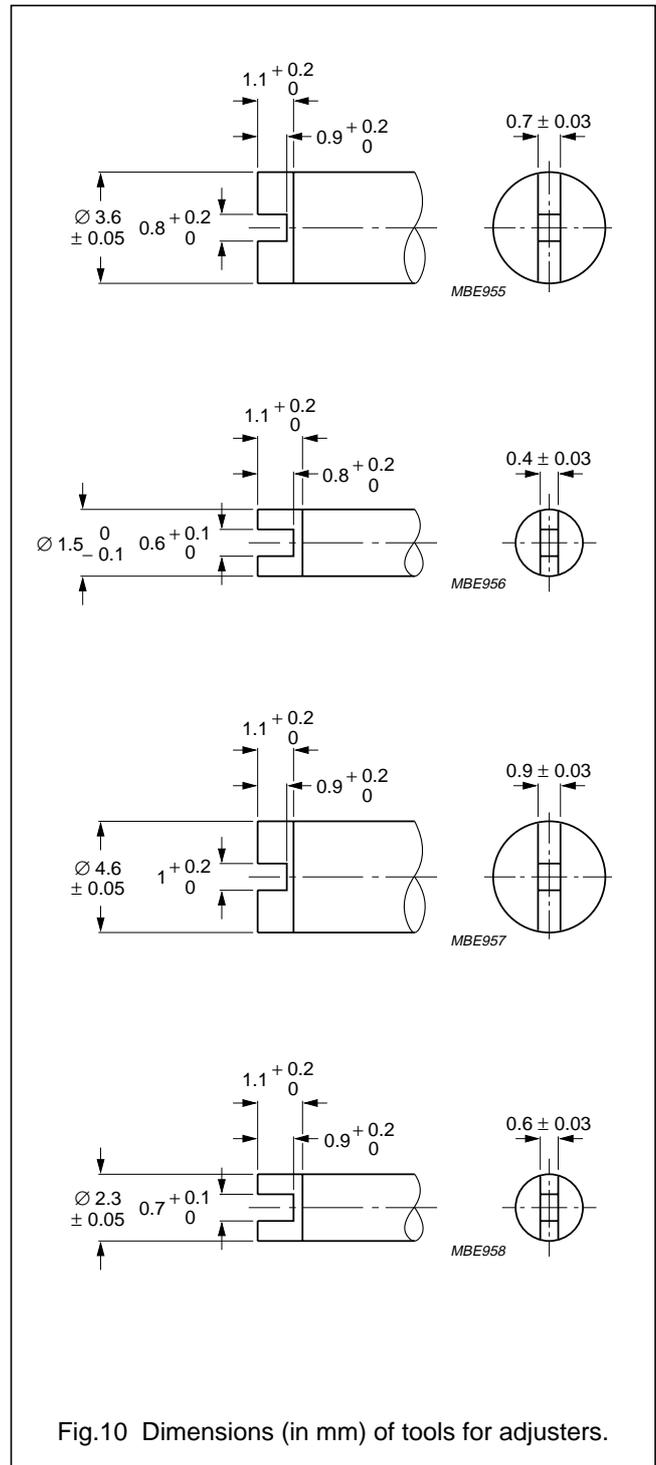
Soft Ferrites

Applications

PULSE AND SIGNAL TRANSFORMERS

Pulse and signal transformers, also known as wideband transformers, are frequently used in communication systems, including modern digital networks such as, for example ISDN and XDSL.

They provide impedance matching and DC isolation or transform signal amplitudes. Signal power levels are usually low. In order to transmit analog signals or digital pulses without much distortion, good wideband characteristics are needed.

The principal function of the transformer core is to provide optimum coupling between the windings.

The general equivalent circuit of a signal transformer is shown in Fig.11.

The elements of the circuit depicted in Fig.11 may be defined as follows:

E_s = source voltage

R_s = source resistance

R_w = total winding resistance = R1 + R2, where R1 is the primary winding resistance and R2 is the secondary winding resistance referred to the primary

L = total leakage inductance = the primary inductance with the secondary shorted

L_p = open circuit inductance

R_p = the shunt loss resistance representing the core loss

N1, N2 = the primary and referred secondary self or stray capacitance respectively

R_b = load resistance referred to the primary turns ratio.

A high permeability core with polished pole faces results in a large flux contribution, improving the coupling. Open circuit inductance will be high, leakage inductance is kept low compared to this main inductance.

Ring cores are very suitable since they have no air gap and make full use of the high permeability of the ferrite.

The frequency response of a practical transformer is shown in Fig.12.
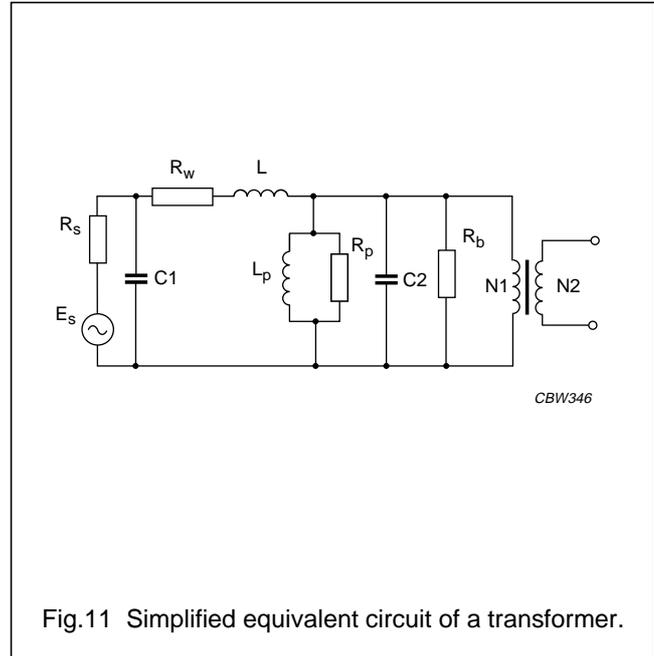

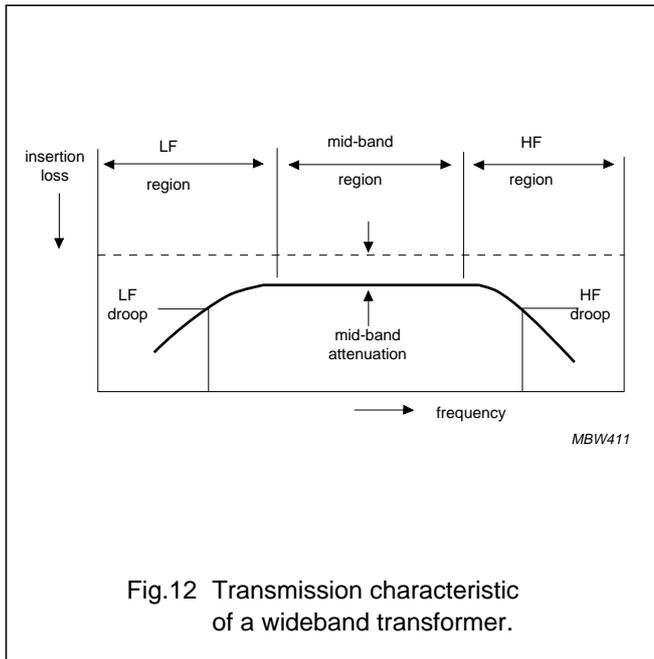Fig.11 Simplified equivalent circuit of a transformer.

Fig.12 Transmission characteristic of a wideband transformer.

Soft Ferrites

Applications

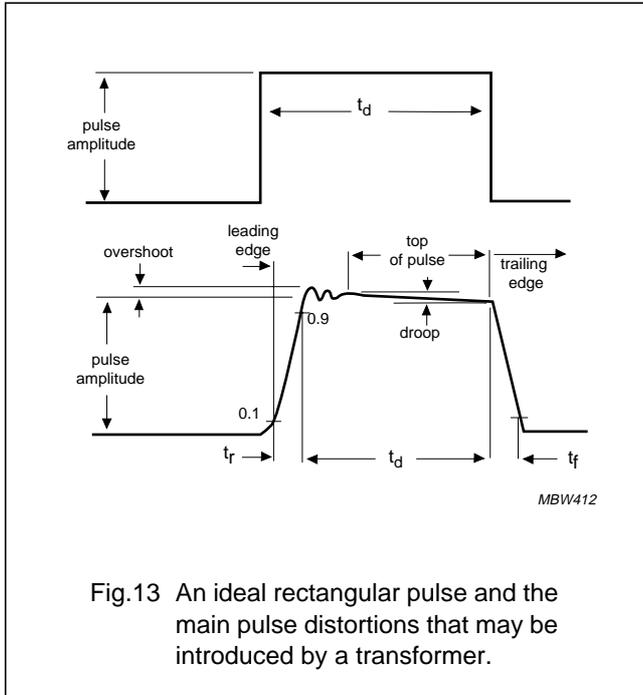The corresponding distortion of a rectangular pulse by the same circuit is shown in Fig.13.

Fig.13 An ideal rectangular pulse and the main pulse distortions that may be introduced by a transformer.

The shunt inductance (L_p) is responsible for the low frequency droop in the analog transformer since its reactance progressively shunts the circuit as the frequency decreases. In the case of the pulse transformer, the shunt inductance causes the top of the pulse to droop, because, during the pulse, the magnetizing current in L_p rises approximately linearly with time causing an increasing voltage drop across the source resistance.

The winding resistance is the main cause of the mid-band attenuation in low frequency analog transformers. In a pulse transformer, it attenuates the output pulse but usually has little effect on the pulse distortion.

The high frequency droop of an analog transformer may be due to either the increasing series reactance of the leakage inductance or the decreasing shunt reactance of the self-capacitances, or a combination of both as the frequency increases. In a pulse transformer, the leakage inductance, self-capacitances and the source or load resistance combine to slow down, or otherwise distort the leading and trailing edge responses.

Suitable core types for this application in the material grades 3E25, 3E1, 3E4, 3E5 and 3E6 are:

- P cores
- RM cores
- EP cores
- Ring cores
- Small ER cores
- Small E cores.

If the signal is superimposed on a DC current, core saturation my become a problem. In that case, a lower permeability material grade such as 3H1, 3B7, 3B8, 3C81 or 3C85 is recommended.

Soft Ferrites

Applications

Ferrites for Power conversion

Power conversion is a major application area for modern ferrites. Originally designed for use as line output transformers in television receivers, power cores are now being used in a wide range of applications. The introduction of Switched Mode Power Supplies (SMPS) has stimulated the development of a number of new ferrite grades and core shapes to be used in the manufacture of power transformers, output chokes and input filters.

Power transformers and inductors generally operate under loss or saturation limited conditions which require special power ferrites with high saturation levels and low losses.

Output chokes must tolerate high DC currents; this means a gapped magnetic circuit or a special material with very high saturation level such as iron powder.

Input chokes prevent mains pollution generated by the SMPS. Therefore grades are used which provide maximum blocking impedances at the switching frequencies.

SWITCHED MODE POWER SUPPLY CIRCUITS

The basic arrangement of a Switched Mode Power Supply (SMPS) is shown in Fig.14.

In this configuration, the power input is rectified and filtered, and the resulting DC voltage is chopped by a switch at a high frequency. The chopped waveform is applied to the primary of a transformer and the secondary output is rectified and filtered to give the required DC output. The output voltage is sensed by a control circuit which supplies a correction signal to the drive circuit to vary the ON/OFF time of the switched waveform and compensate for any change at the output.
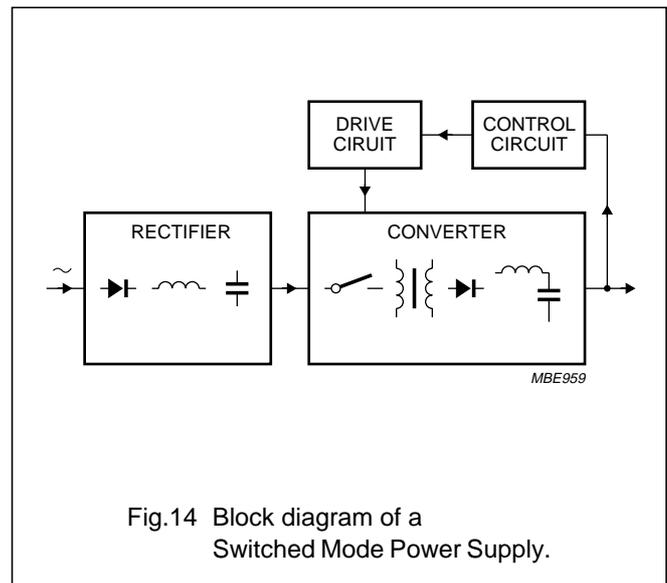

Fig.14 Block diagram of a
Switched Mode Power Supply.

Numerous circuit designs can be used to convert DC input voltage to the required DC output voltage. The requirements for the transformer or inductor depend largely on the choice of this circuit technology.

If the circuits are analyzed in this way, three basic converter designs can be distinguished, based upon the magnetic converting device.

These are:

• Flyback converters

• Forward converters, and

• Push-pull converters.
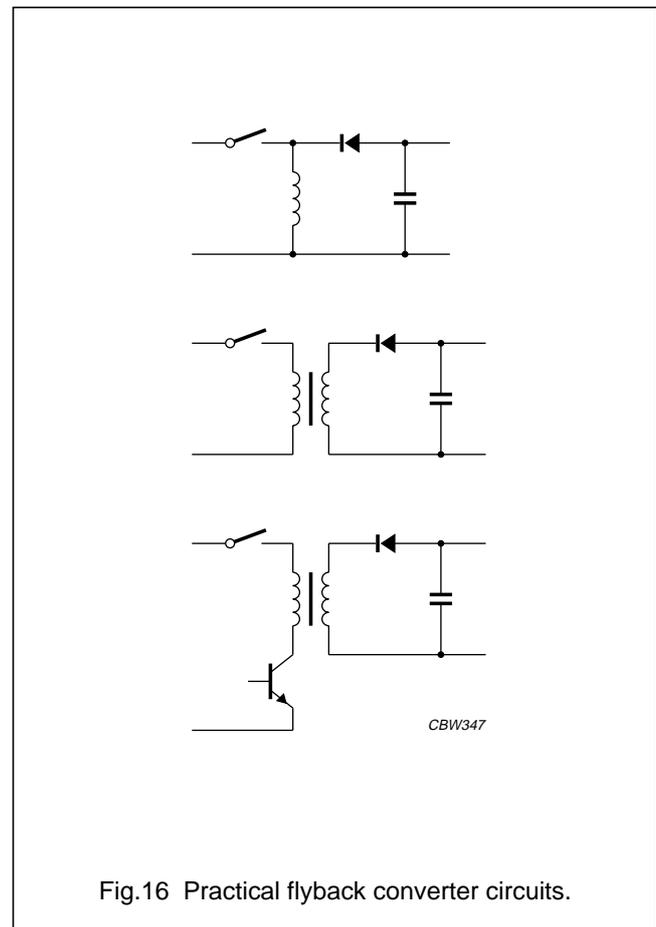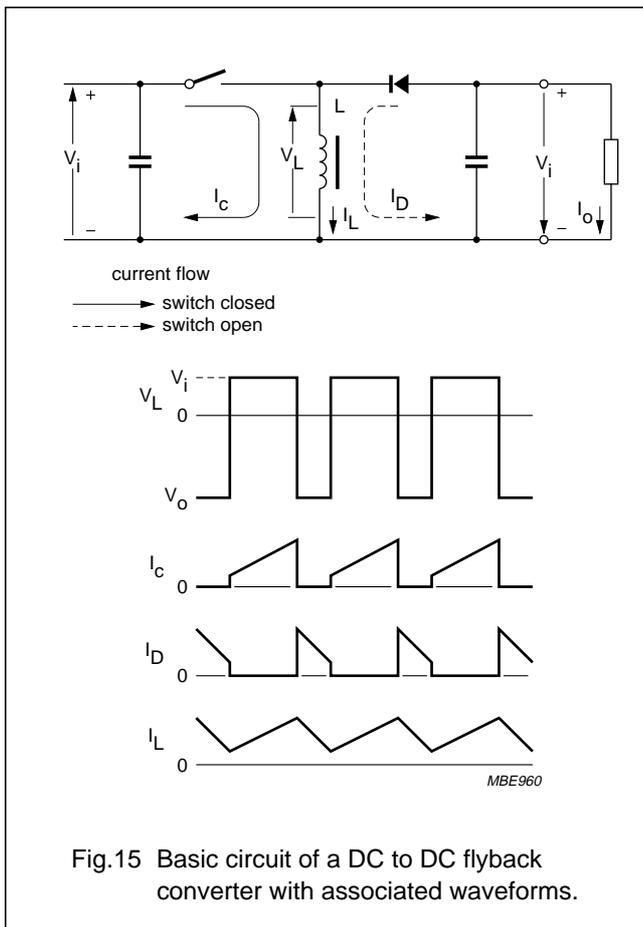
Soft Ferrites

Applications

FLYBACK CONVERTER

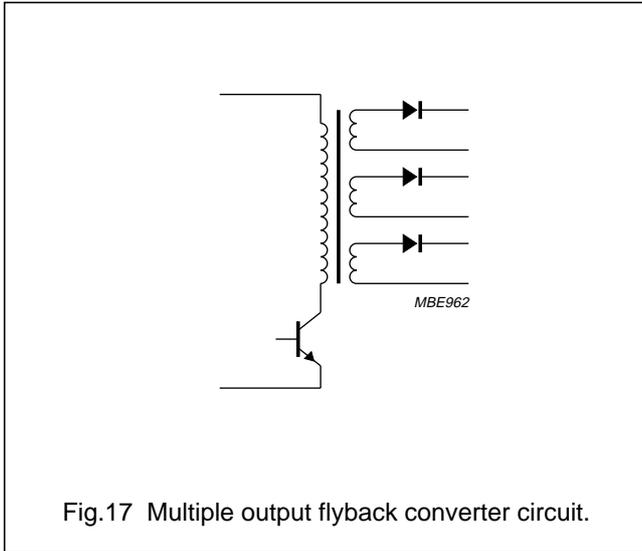Figure 15 shows the basic circuit of a flyback converter and its associated waveforms.

When the switch is closed (transistor conducts), the supply voltage is connected across the inductor and the output diode is non-conducting. The current rises linearly, storing energy, until the switch is opened. When this happens, the voltage across the inductor reverses and the stored energy is transferred into the output capacitor and load. By varying the conduction time of the transistor at a given frequency the amount of energy stored in the inductor during each ON cycle can be controlled. This allows the output of the SMPS to be controlled and changed.

This basic circuit can be developed into a practical circuit using an inductor with two windings (see Fig.16).

In a flyback converter, all the energy to be transferred to the output capacitor and load is, at first, stored in the inductor. It is therefore possible to obtain line isolation by adding a secondary winding to the inductor (although an inductor with more than one winding appears in schematic diagrams as a transformer, it is referred to as an inductor in accordance with its function).

Another advantage of the flyback converter is that no smoothing choke is required in the output circuit. This is important in high-voltage supplies and in power supplies with a number of output circuits (see Fig.17).

Fig.15 Basic circuit of a DC to DC flyback converter with associated waveforms.

Fig.16 Practical flyback converter circuits.

Soft Ferrites   Applications

Fig.17 Multiple output flyback converter circuit.

A disadvantage of this type of converter is that the output capacitor is charged only during the transistor's OFF cycle. Hence the output capacitor ripple current is high when compared with the other types of converters.

Another disadvantage of the flyback converter concerns the energy stored in the inductor. The inductor is driven in one direction only; this requires a larger core in a flyback design than for an equivalent design using a forward or push-pull converter.

FORWARD CONVERTER

The basic circuit of the forward converter, together with its associated voltage and current waveforms is shown in Fig.18.

When the switch is closed (transistor conducts), the current rises linearly and flows through the inductor into the capacitor and the load. During the ON cycle, energy is transferred to the output and stored in the inductor 'L'. When the switch is opened, the energy stored in the inductor causes the current to continue to flow to the output via the diode.

As with the flyback converter, the amount of energy stored in the inductor can be varied by controlling the ON/OFF cycles. This provides control of the output of the forward converter.

A more practical forward converter circuit with a line-isolation transformer is shown in Fig.19.

Fig.18 Basic circuit of a DC to DC forward converter with associated waveforms.

Fig.19 Forward converter with line isolation.
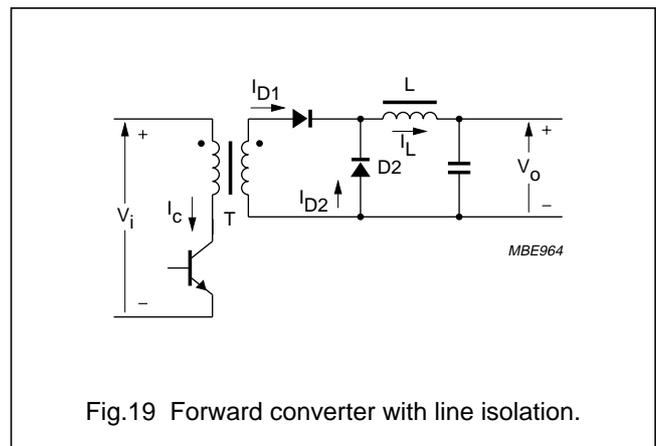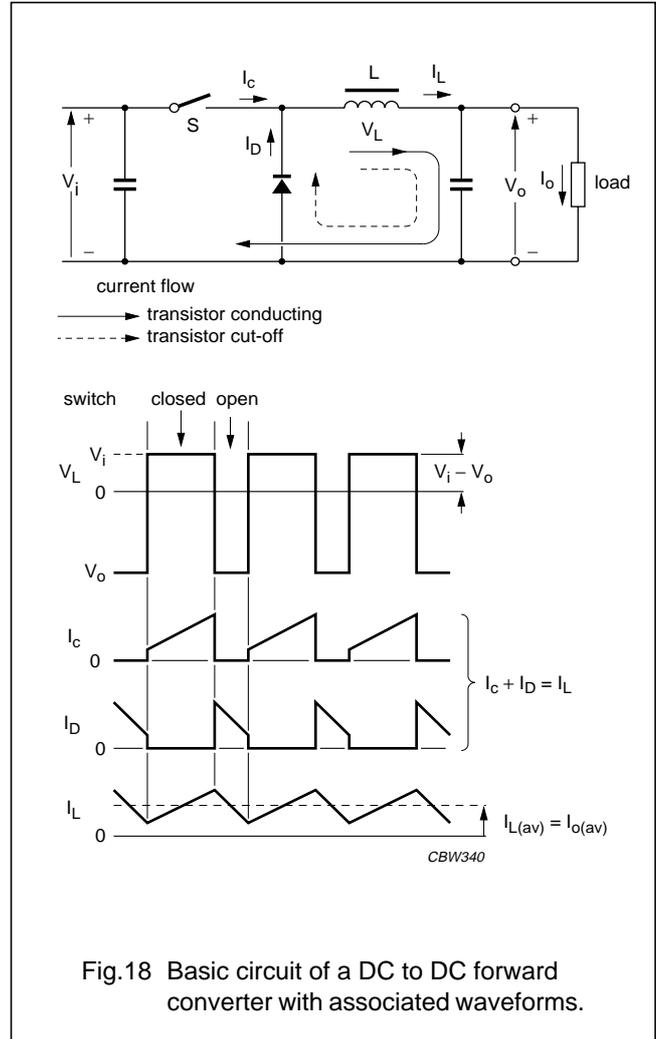
Soft Ferrites

Applications

PUSH-PULL CONVERTER

The basic circuit of the push-pull converter, with voltage and current waveforms is shown in Fig.20.

The push-pull converter is an arrangement of two forward converters operating in antiphase (push-pull action). With switch S1 closed (Fig.20a) diode D2 conducts and energy is simultaneously stored in the inductor and supplied to the load. With S1 and S2 open (Fig.20b), the energy stored in the inductor continues to support the load current via the parallel diodes D1 and D2, which are now acting as flywheel diodes. When switch S2 closes (Fig.20c), diode D1 continues to conduct, diode D2 stops conducting and the process repeats itself.
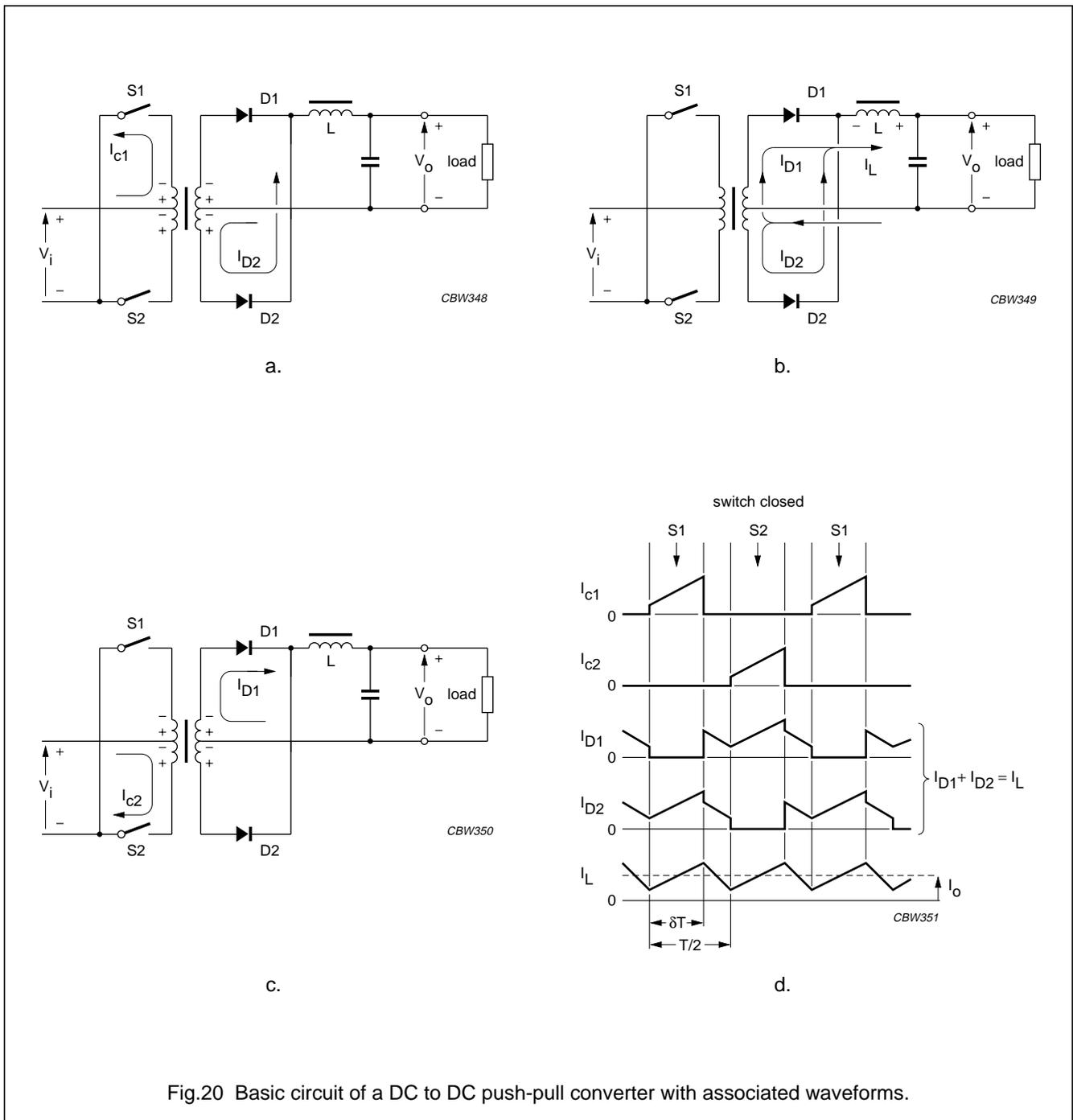
Fig.20 Basic circuit of a DC to DC push-pull converter with associated waveforms.

Soft Ferrites

Applications

A push-pull converter circuit doubles the frequency of the ripple current in the output filter and, therefore, reduces the output ripple voltage. A further advantage of the push-pull operation is that the transformer core is excited alternately in both directions in contrast to both the forward and flyback converters. Therefore, for the same operating conditions and power throughput, a push-pull converter design can use a smaller transformer core.

Multiple outputs can be constructed by using several secondary windings, each with its own output diodes, inductor and smoothing capacitor.
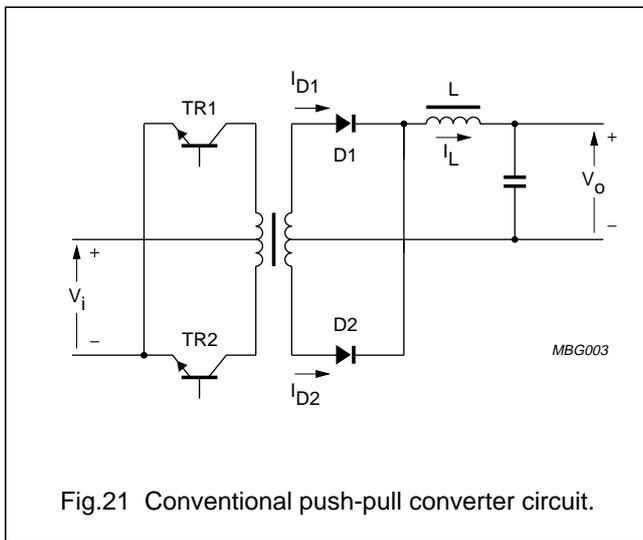
Fig.21 Conventional push-pull converter circuit.

CONVERTER SELECTION

In each of the three basic converter designs there are several different circuit possibilities. In the flyback and forward converters, single and two-transistor designs can be used. If two transistors are used, they will switch simultaneously. This type of circuit preference is determined by the allowable collector-emitter voltage and collector current of the transistor. In push-pull converter designs, the primary of the transformer can be connected in several ways (see Fig.22).

Depending upon how the transformer primary is driven, it is possible to differentiate between single-ended (see Fig.22a), push-pull (see Fig.22b) and full-bridge circuits (see Fig.22c). Decisions on circuit details are determined by the transistor capabilities.
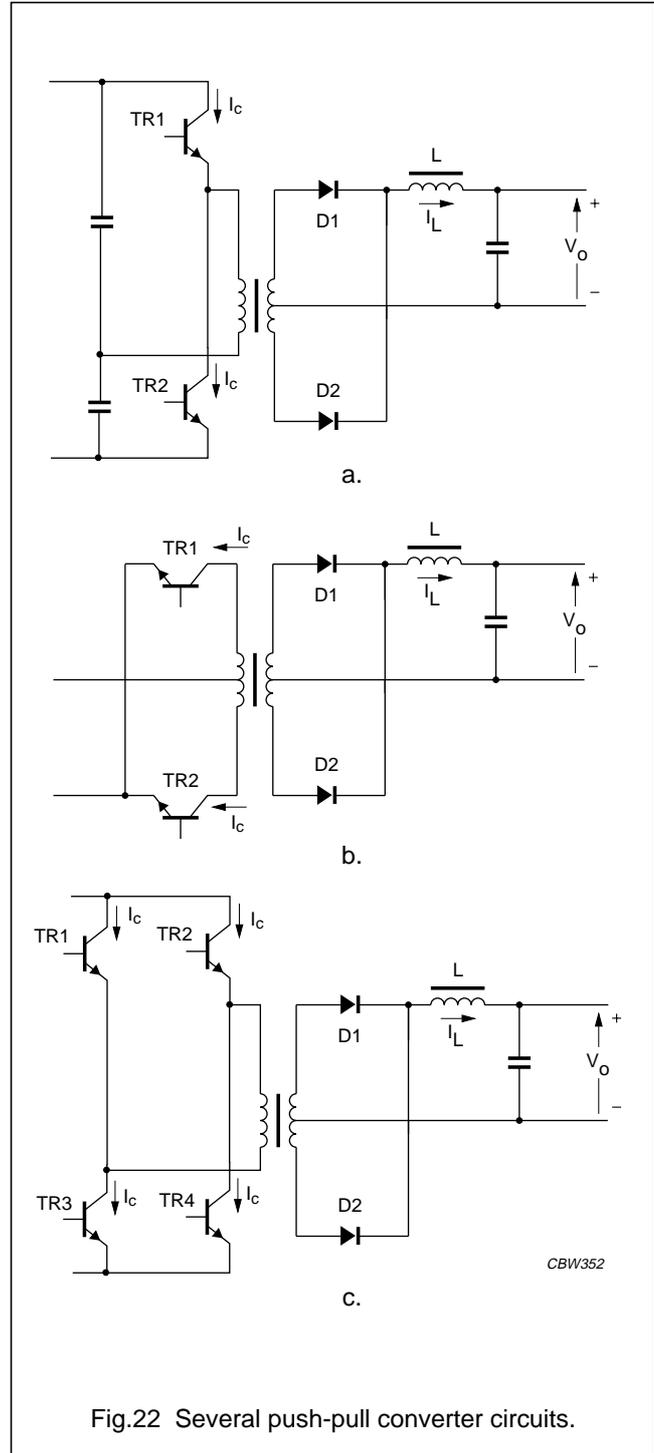

Fig.22 Several push-pull converter circuits.

Soft Ferrites

Applications

For a practical converter design, the first selection that should be considered is the type of converter circuit to use. To aid in this initial converter circuit selection, Fig.23 offers a rough guide to the type of converter, its output voltage and power capability. This selection has to be considered along with other requirements, including line isolation, ripple content, overall efficiency, multiple outputs, etc.

Table 1 summarizes the most significant properties of a converter design. It shows the relative strengths and weaknesses of the three types of converters with regard to these characteristics.

For a high performance, high power, single output supply, where ripple is well below 1%, the push-pull design is the obvious choice. For smaller power versions of this type of supply, the forward, or double-forward converter provides a useful alternative to push-pull converter.

In high-voltage supplies, the flyback converter is the most suitable circuit and should be considered as a preference. In multiple-output supplies, the flyback converter is again normally the first choice because it avoids the necessity of providing a number of output windings on the inductor, together with a single diode and capacitor for each.
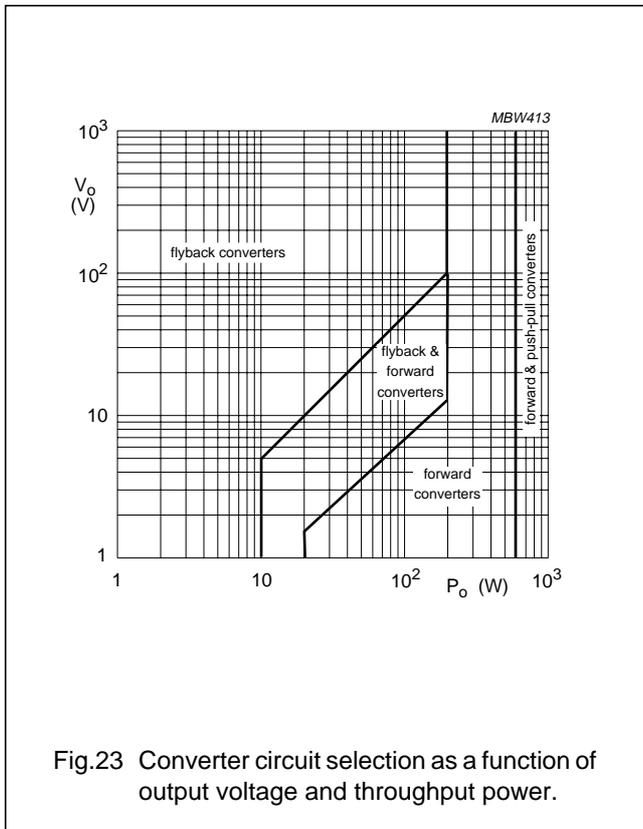
Fig.23 Converter circuit selection as a function of output voltage and throughput power.

Table 1 Converter design selection chart (I)

FUNCTION	TYPE OF CONVERTER CIRCUIT[1]		
	FLYBACK	FORWARD	PUSH-PULL
Circuit simplicity	+	0	−
Number of components	+	0	−
Drive circuitry	+	0	−
Output ripple	−	0	+
Choke volume	not required	0	+
Transformer volume	−	0	+
Mains isolation	+	−	+
High power	−	0	+
High voltage	+	0	0
Multiple outputs	+	0	0

Note

1. '+' = favourable; '0' = average; '−' = unfavourable.

Soft Ferrites

Applications

CORE SELECTION

Table 2 shows which core type could be considered suitable for the different types of converter design.

The power-handling capability of a given core is determined by frequency and material grade, its geometry and available winding area, and by other factors which depend on the specific application.

Table 2   Converter design selection chart (II)

FUNCTION	TYPE OF CONVERTER CIRCUIT[1]		
	FLYBACK	FORWARD	PUSH-PULL
E cores	+	+	0
Planar E cores	−	+	0
EFD cores	−	+	+
ETD cores	0	+	+
EC cores	−	0	+
U cores	+	0	0
RM cores	0	+	0
EP cores	−	+	0
P cores	−	+	0
Ring cores	−	+	+

Note

1.   '+' = favourable; '0' = average; '−' = unfavourable.

Operating frequency

The preferred operating frequency of a Switched Mode Power Supply is greater than 20 kHz to avoid audible noise from the transformer. With modern power ferrites the practical upper limit has shifted to well over 1 MHz.

Ambient temperature

Ambient temperature, together with the maximum core temperature, determines the maximum temperature rise, which in turn fixes the permissible total power dissipation in the transformer. Normally, a maximum ambient temperature of 60 °C has been assumed. This allows a 40 °C temperature rise from the ambient to the centre of the transformer for a maximum core temperature of 100 °C. There is a tendency however towards higher temperatures to increase power throughput.

Flux density

To avoid saturation in the cores the flux density in the minimum cross-section must not exceed the saturation flux density of the material at 100 °C. The allowable total flux is the product of this flux density and the minimum core area and must not be exceeded even under transient conditions, that is, when a load is suddenly applied at the power supply output, and maximum duty factor occurs together with maximum supply voltage. Under steady-state conditions, where maximum duty factor occurs with minimum supply voltage, the flux is reduced from its absolute maximum permissible value by the ratio of the minimum to maximum supply voltage (at all higher supply voltages the voltage control loop reduces the duty factor and keeps the steady-state flux constant). The minimum to maximum supply voltage ratio is normally taken as 1 : 1.72 for most applications.

Soft Ferrites

Applications

SELECTING THE CORRECT CORE TYPE

The choice of a core type for a specific design depends on the design considerations and also on the personal preference of the designer. Table 3 gives an overview of core types as a function of power throughput and this may be useful to the designer for an initial selection.

Each of the core types has been developed for a specific application, therefore they all have advantages and drawbacks depending on, for example, converter type and winding technique.

Table 3   Power throughput for different core types at 100 kHz switching frequency

POWER RANGE (W)	CORE TYPE
<5	RM4; P11/7; R14; EF12.6; U10
5 to 10	RM5; P14/8
10 to 20	RM6; E20; P18/11; R23; U15; EFD15
20 to 50	RM8; P22/13; U20; RM10; ETD29; E25; R26/10; EFD20
50 to 100	ETD29; ETD34; EC35; EC41; RM12; P30/19; R26/20; EFD25
100 to 200	ETD34; ETD39; ETD44; EC41; EC52; RM14; P36/22; E30; R56; U25; U30; E42; EFD30
200 to 500	ETD44; ETD49; E55; EC52; E42; P42/29; U37
<500	E65; EC70; U93; U100

Choice of ferrite for power transformers

A complete range of power ferrites is available for any application.

3C15

Low frequency material with improved saturation level. Suitable for flyback converters e.g. Line Output Transformers.

3C30

Medium frequency material with improved saturation level. Suitable for flyback converters e.g. Line Output Transformers.

3C85

Medium frequency (<200 kHz) material for industrial use.

3C90

Medium frequency (<200 kHz) material for industrial use. Lower losses than 3C85.

3C94

Medium frequency material (<200 kHz).
Very low losses, especially at high flux densities.

3F3

High frequency material (up to 700 kHz).
Top material for modern high frequency designs.

3F35

High frequency material (up to 1 MHz).
Very low losses, around 500 kHz.

3F4

High frequency material (up to 3 MHz).
Specially recommended for resonant supplies.

4F1

High frequency material (up to 10 MHz).
Specially recommended for resonant supplies.

Soft Ferrites

Applications

Performance factor of power ferrites

The performance factor ($f \times B_{max}$) is a measure of the power throughput that a ferrite core can handle at a loss level of 300 mW/cm^3. This level is considered to be acceptable for a good medium size transformer design. From the graph it is clear that for low frequencies there is not much difference between the grades, because the cores are saturation limited. At higher frequencies, the differences between the grades increase. There is an optimum operating frequency for each material grade. It is evident that in order to increase power throughput or power density a high operating frequency and a better ferrite should be chosen.

OUTPUT CHOKES

Output chokes for Switched Mode Power Supplies have to operate with a DC load causing a bias magnetic field H_{DC}.

In a closed ferrite circuit, this can easily lead to saturation. Power ferrites such as 3C85 or 3F3 start saturating at field strengths of about 50 A/m. Permeability drops sharply, as can be seen in the graphs of the material data section. The choke loses its effectiveness.

There are two remedies against this effect:

• The use of gapped ferrite cores

• The use of a material with allow permeability and high saturation.
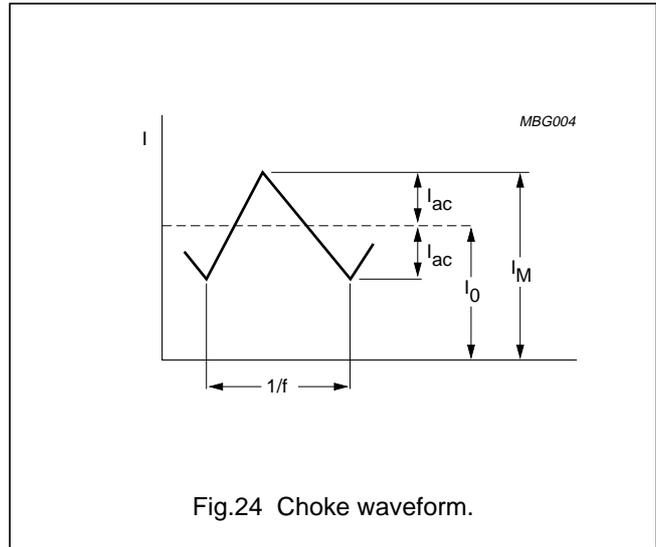
Fig.24 Choke waveform.
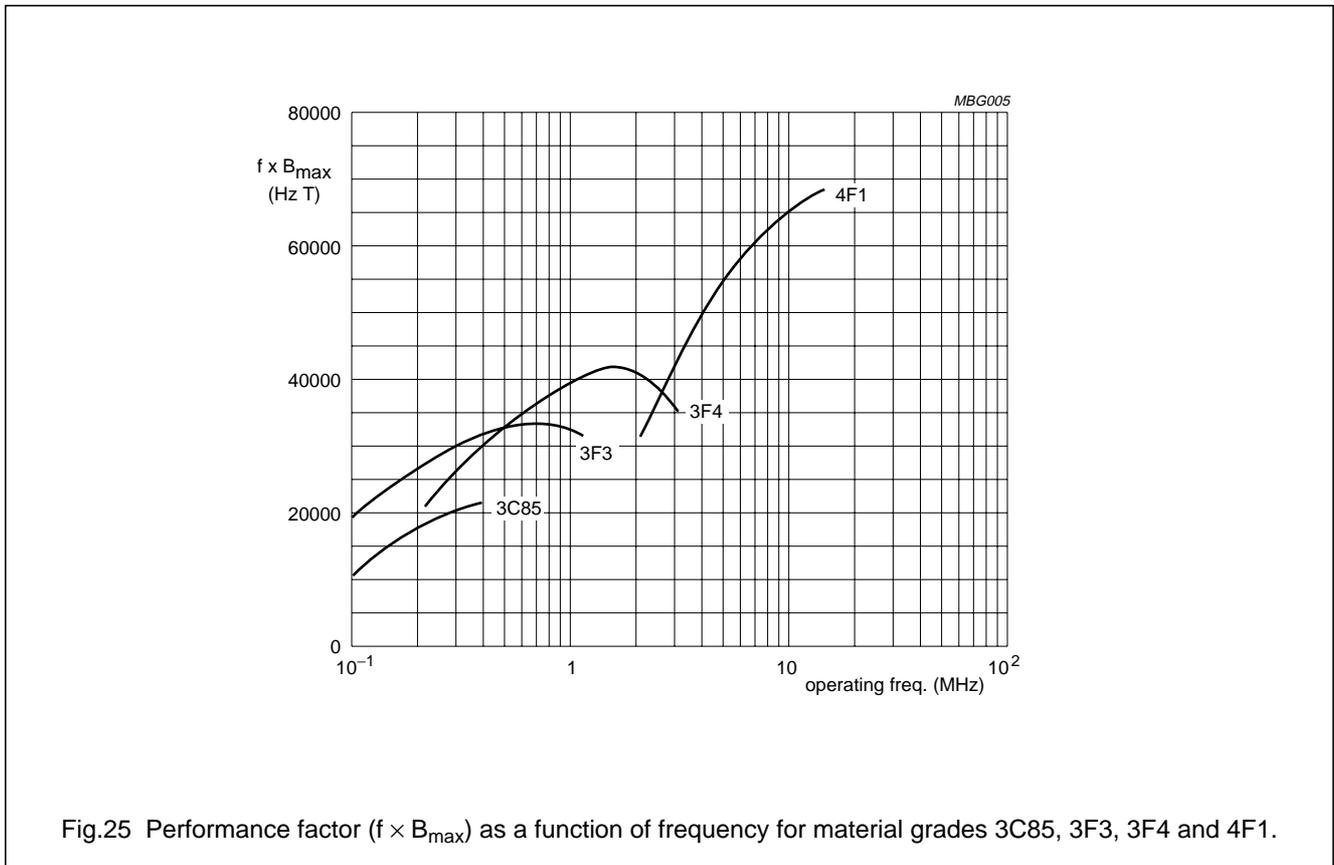
Fig.25 Performance factor ($f \times B_{max}$) as a function of frequency for material grades 3C85, 3F3, 3F4 and 4F1.

Soft Ferrites

Applications

GAPPED CORE SETS

The effect of an air gap in the circuit is that a much higher field strength is needed to saturate a core.

For each operating condition an optimum air gap length can be found. In a design, the maximum output current (I) and the value of inductance (L) necessary to smooth the ripple to the required level are known. The product I^2L is a measure of the energy which is stored in the core during one half cycle.

Using this I^2L value and the graphs given for most core types, the proper core and air gap can be selected quickly at a glance. There is a choke design program on the disc *"Soft Ferrite Design Tools"* (9398 402 12011) for a more detailed design, including the required number of turns. This program also covers design of inductors on open magnetic circuits like bobbin cores and rods.
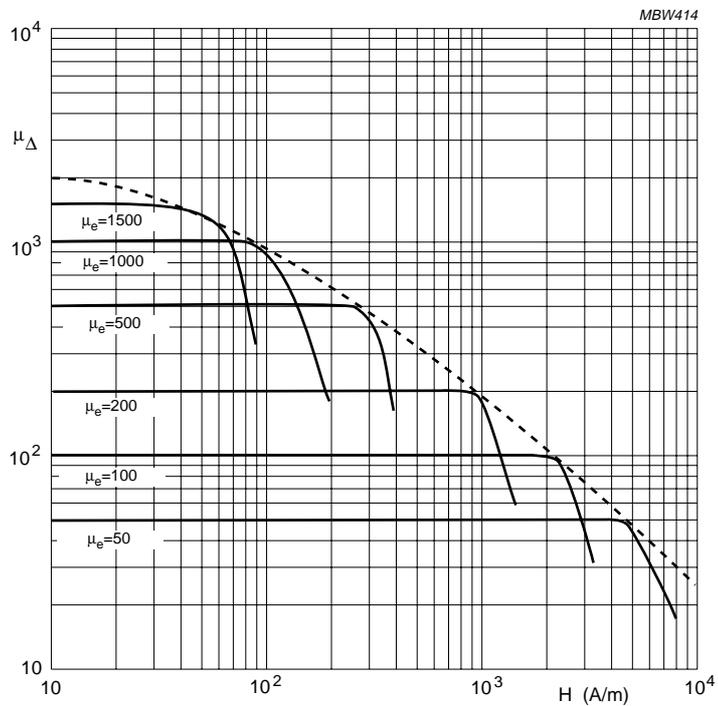
Fig.26 Effect of increased gap length.

Soft Ferrites

Applications

Fig.27 I^2L graph for E cores.

Fig.28 I^2L graph for planar E cores (valid for E + E and E + PLT combinations).

Soft Ferrites

Applications

Fig.29 I^2L graph for EC cores.

Fig.30 I^2L graph for EFD cores.

Soft Ferrites

Applications

Fig.31 I^2L graph for EP cores.

Fig.32 I^2L graph for ER cores.
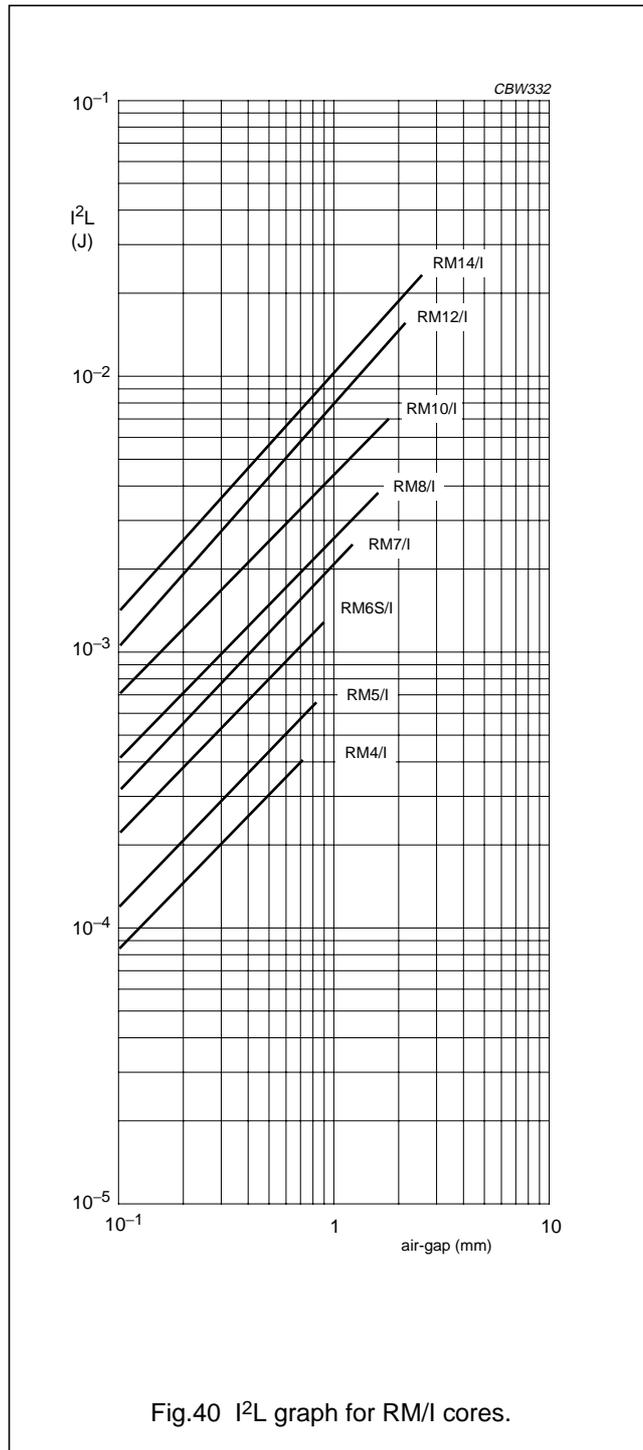
Soft Ferrites

Applications
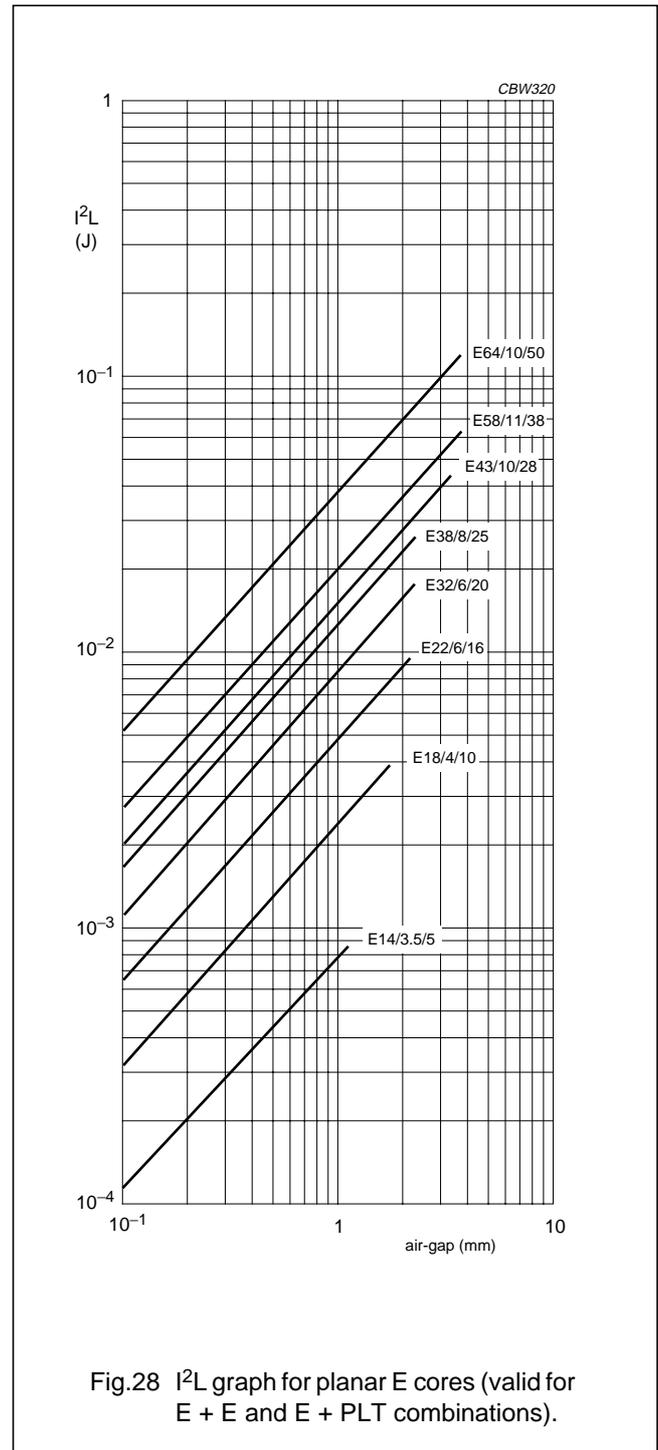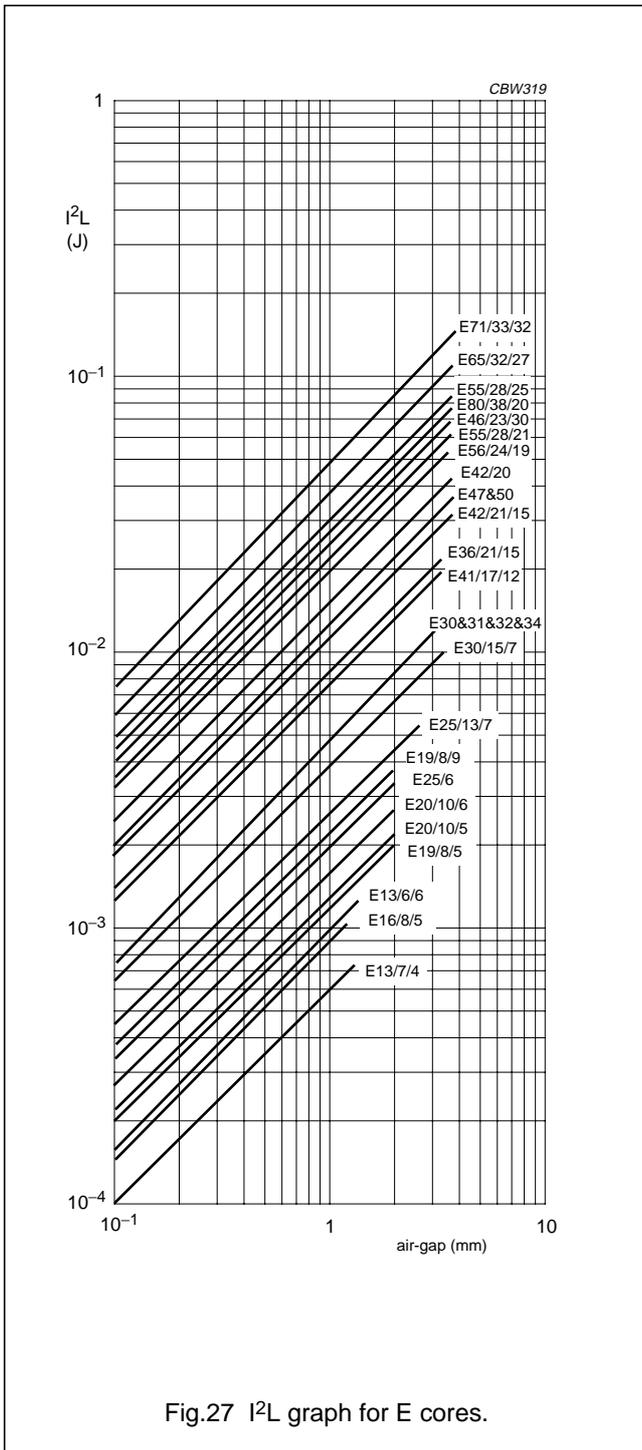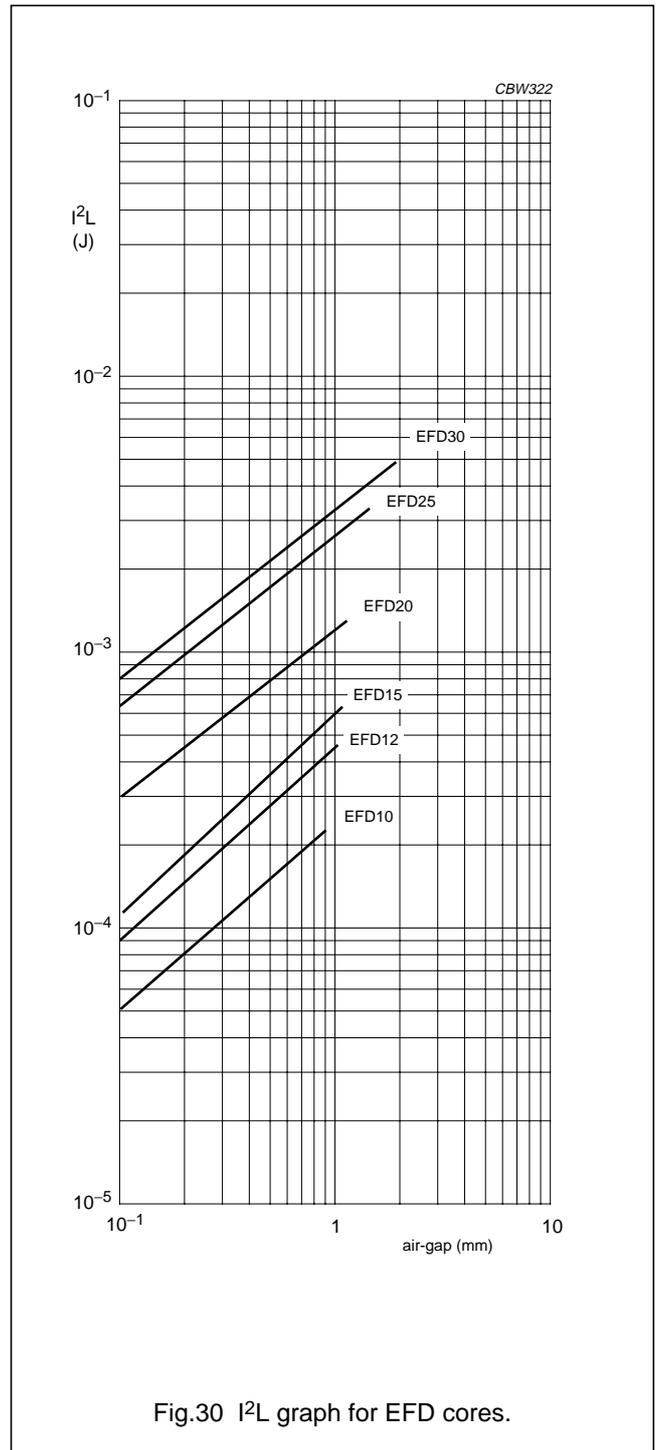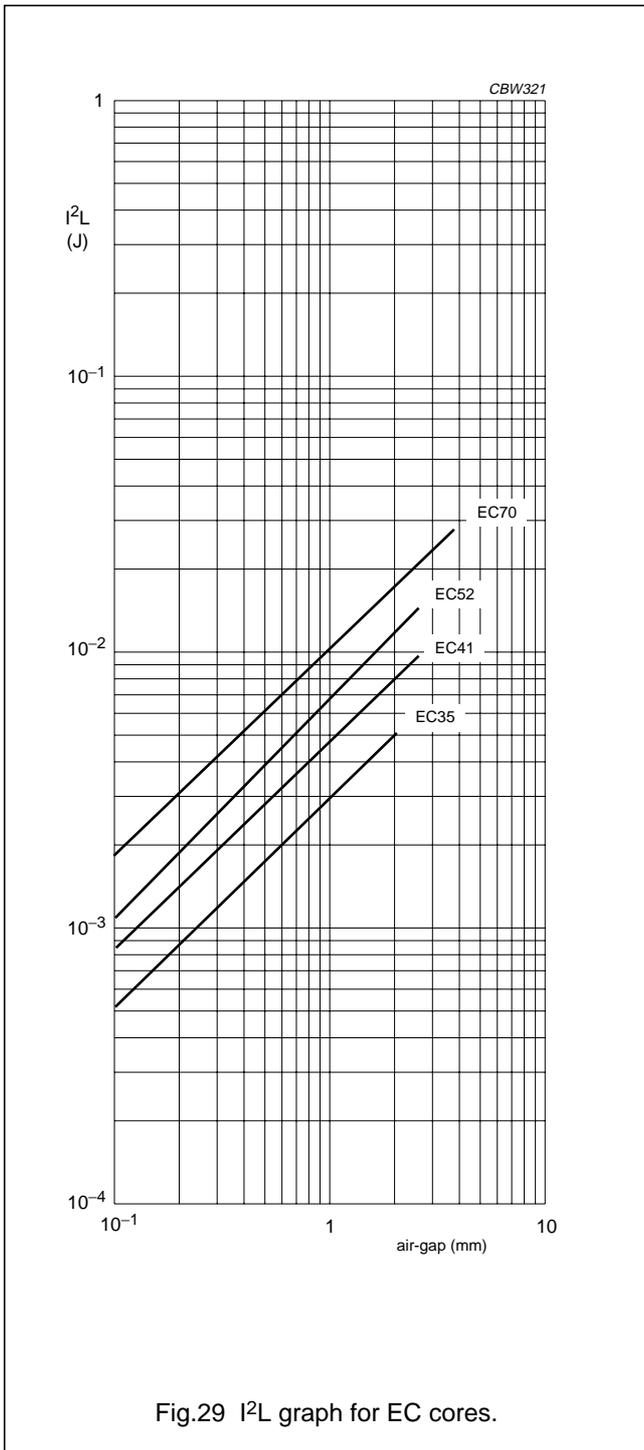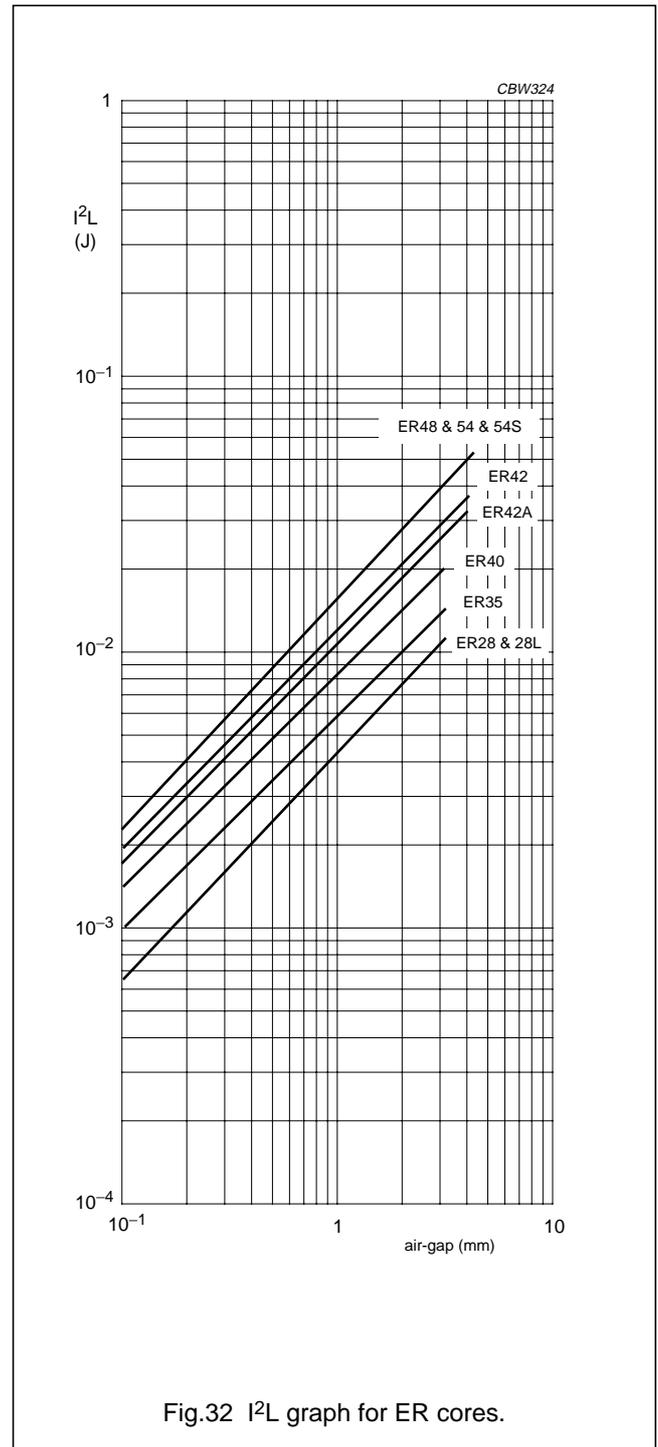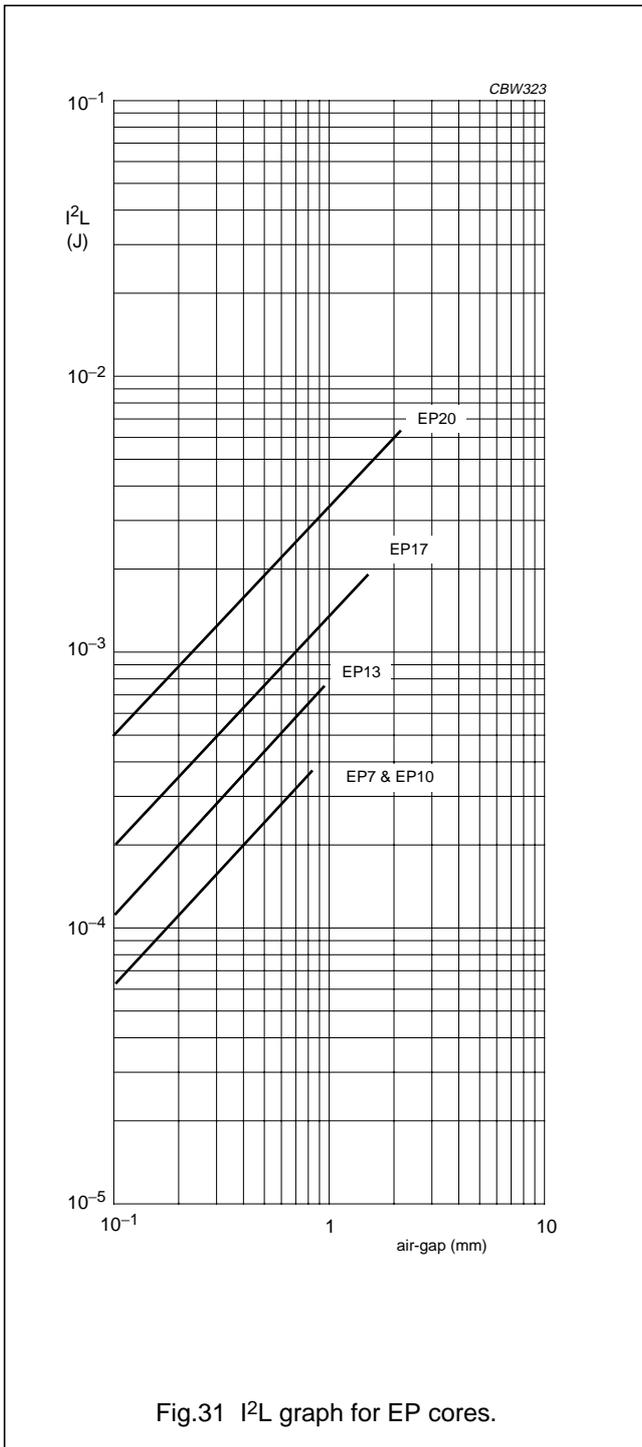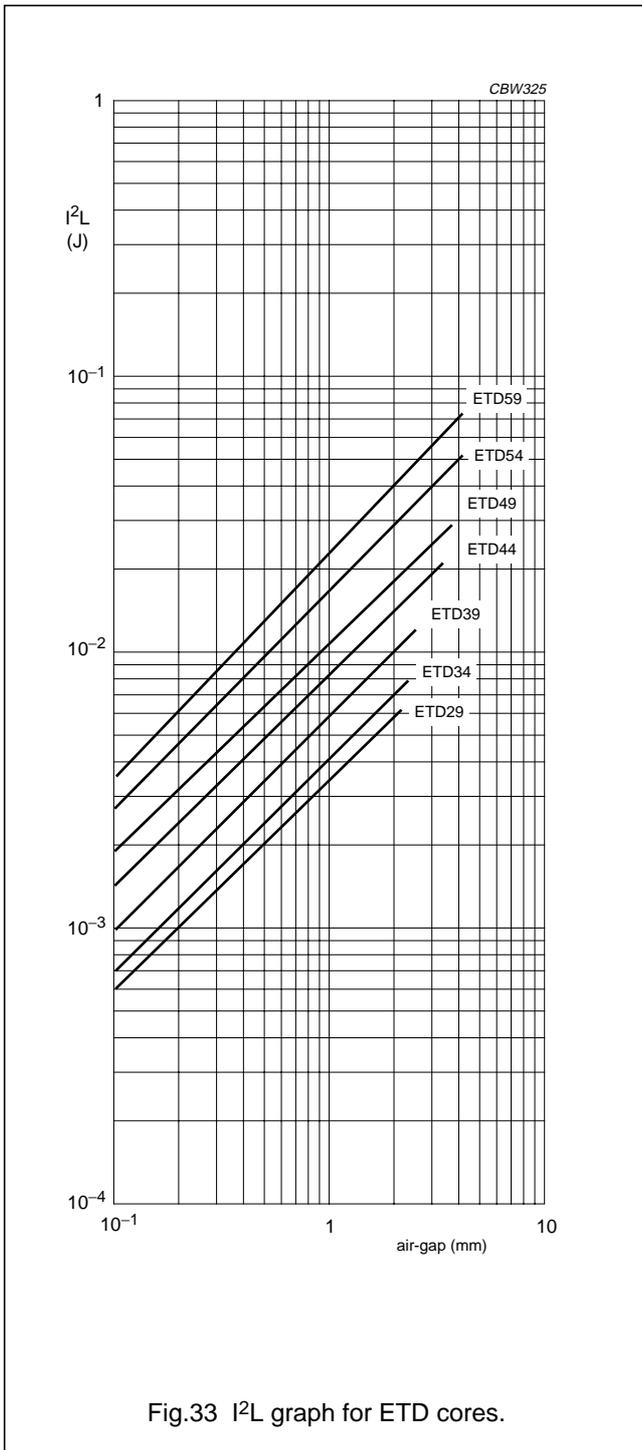
Fig.33 I^2L graph for ETD cores.
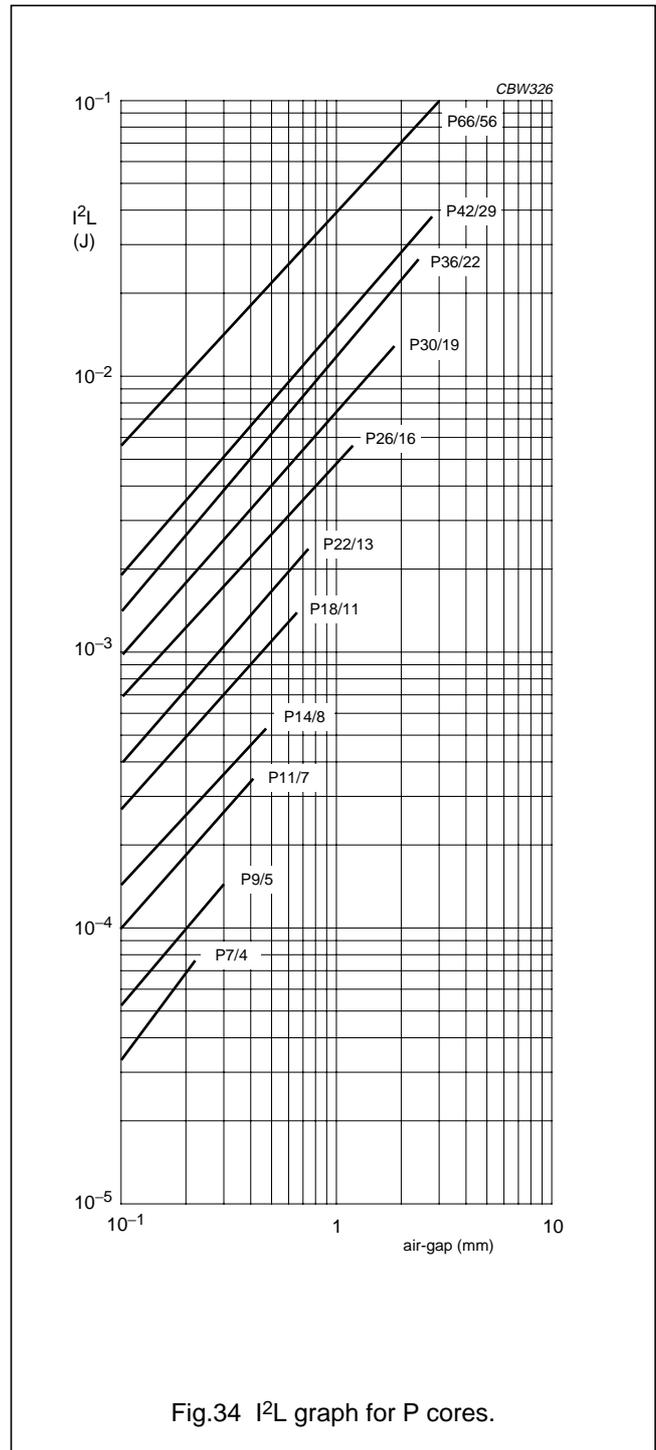
Fig.34 I^2L graph for P cores.

Soft Ferrites   Applications

Fig.35 I^2L graph for P/I cores.

Fig.36 I^2L graph for PT cores.

Soft Ferrites

Applications

Fig.37 I^2L graph for PTS cores.

Fig.38 I^2L graph for PQ cores.

Soft Ferrites

Applications

Fig.39 I^2L graph for RM cores.

Fig.40 I^2L graph for RM/I cores.

Soft Ferrites

Applications

Fig.41 I^{2}L graph for RM/ILP cores.

Fig.42 I^{2}L graph for U cores.

Soft Ferrites

Applications

IRON POWDER RING CORES

Ring cores made from compressed iron powder have a rather low permeability (max. 90) combined with a very high saturation level (up to 1500 mT). The permeability is so low because the isolating coating on the iron particles acts as a so called distributed air gap. Therefore, our 2P ring core range can operate under bias fields of up to 2000 A/m.

INPUT FILTERS (COMMON MODE CHOKES)

MBW416

Fig.43 Common mode choke.
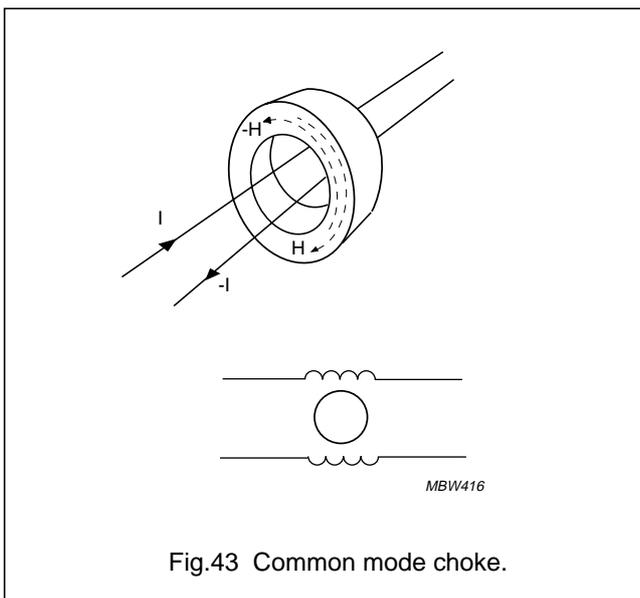
To avoid the conduction of switching noise from a SMPS into the mains, an input filter is generally necessary. The magnetic circuit in these filters is usually a pair of U cores or a ring core.

Since the noise signal is mainly common mode, current compensation can be used to avoid saturation.

Two separate windings on the core cause opposing magnetic fields when the load current passes through them (current compensation). The common mode noise signal however, is blocked by the full inductance caused by the high permeability ferrite.

If, for some reason, current compensation is not complete or impossible, high permeability grades will saturate. In that case one of the power grades may be a better compromise. Another important factor in the design process is the frequency range of the interference signal. High permeability ferrites have a limited bandwidth as can be seen from Fig.44.

These materials only perform well as an inductor below the frequency where ferromagnetic resonance occurs. Above this cut-off frequency, a coil will have a highly resistive character and the Q-factor of the LC filter circuit will be limited an thus, also the impedance. A better result could have been obtained with a grade having a lower permeability. Figure 45 provides a quick method of choosing the right ferrite for the job. A design program for a complete current-compensated input filter is provided on our *"Soft Ferrite Design Tools"* disc (9398 402 12011).
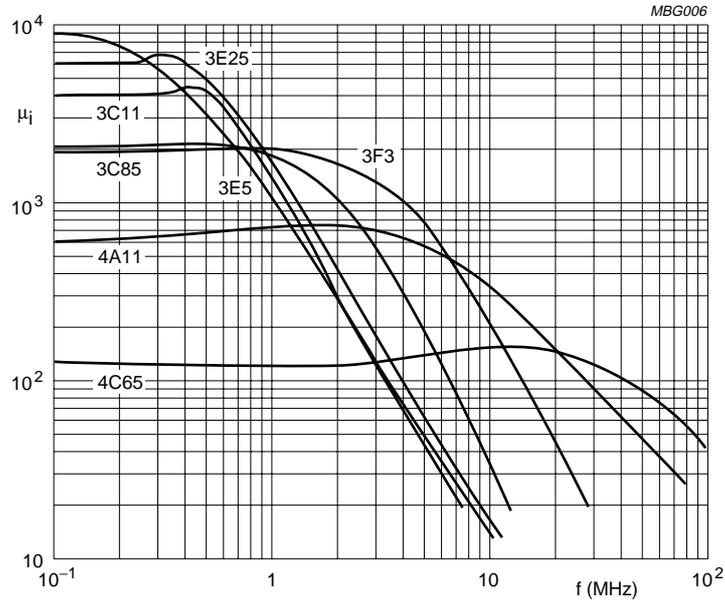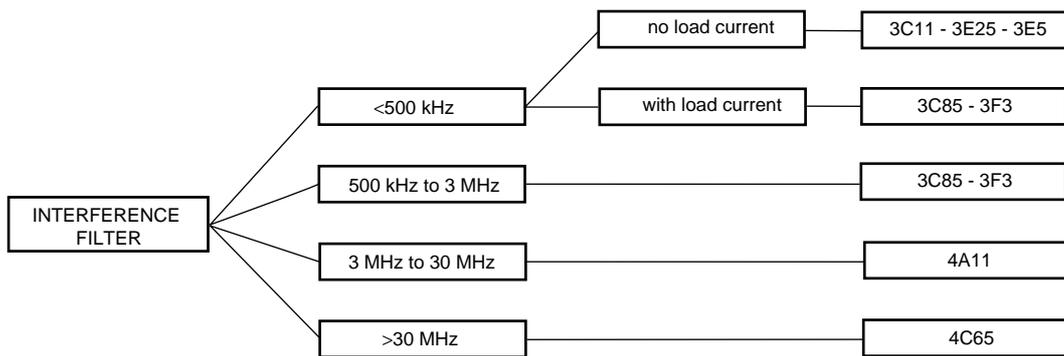
Soft Ferrites   Applications

Fig.44 Permeability as a function of frequency of different materials.

Fig.45 Selection chart for materials used in input filters.

Soft Ferrites

Applications

MAGNETIC REGULATORS

Saturable inductors provide a means of efficiently regulating several independent outputs in a SMPS by blocking varying amounts of energy from the secondary of the transformer. This eliminates the need for feedback between secondary and primary and allows improved isolation of input and output. The circuits required are both simple and economic and can be easily integrated.

A schematic of a saturable inductor circuit (without regulation) together with associated waveforms is shown in Fig.46.

TYPICAL CYCLE CHARACTERISTICS

During a typical cycle:

- Switch SW1 is closed (point A on timing diagram), the inductance of the saturable inductor limits the rate of current rise until the core becomes saturated.

- With the core saturated (point B), the only impedance to current flow is the very small resistance of the inductor, which can be regarded as a short circuit with power being transferred unimpeded to the load resistor.

- Switch SW1 is opened (point C). Because the saturable inductor has a rectangular B-H loop, the flux remains unchanged even when H has fallen to zero. Since there has been no change in flux, there is no inductance and the current can fall instantaneously.

- Switch SW is re-closed (point D). As the flux in the core is still saturated and remains unchanged, there is no resistance to the current flow to the load.

A schematic of a regulated circuit and its associated waveforms is shown in Fig.47.

In this circuit, the inductor is saturated while switch SW1 is closed, thus reducing the period during which energy is conducted from the transformer to the load. Varying the level of this control current modulates the main output voltage waveform (see Fig.48), thus regulating the output voltage across the load.

The 3R1 ferrite material is an excellent alternative to amorphous metal for the cores of saturable inductors of SMPS.

Remark:

The performance of 3R1 is comparable to that of amorphous metal making it an excellent material for applications such as output regulation and spike suppression. When 3R1 ring cores are driven exactly at their natural mechanical resonant frequencies a magneto-elastic resonance will occur.
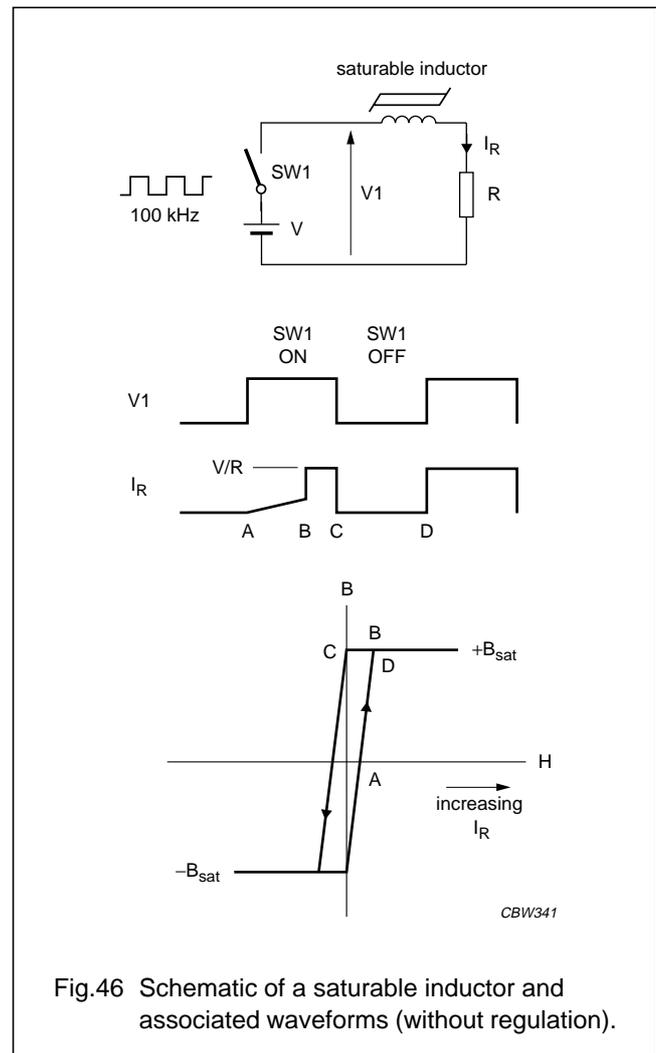

Fig.46 Schematic of a saturable inductor and associated waveforms (without regulation).

With large flux excursions and no mechanical damping, amplitudes can become so high that the maximum tensile stress of the ferrite is exceeded. Cracks or even breakage of the ring core could be the result. It is advised not to drive the toroidal cores at their radial resonant frequencies or even subharmonics (e.g. half this resonant frequency).

Resonant frequencies can be calculated for any ring core with the following formula:

$$f_r = \frac{5700}{\pi\left(\dfrac{D_o + D_i}{2}\right)} \quad kHz$$

where:

f = radial resonant frequency (kHz)

D_o = outside diameter (mm)

D_i = inside diameter (mm).

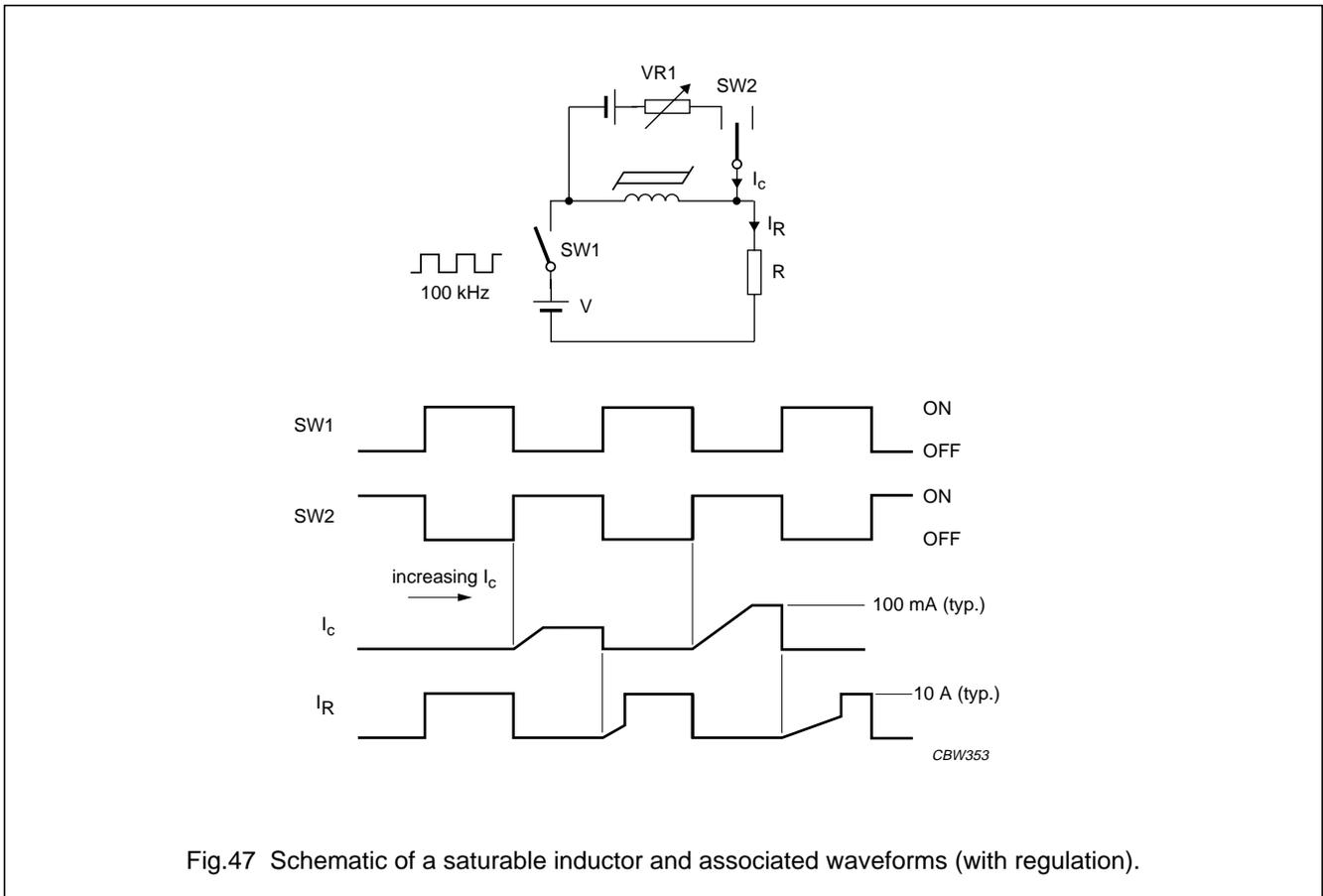## Soft Ferrites   Applications

Fig.47 Schematic of a saturable inductor and associated waveforms (with regulation).
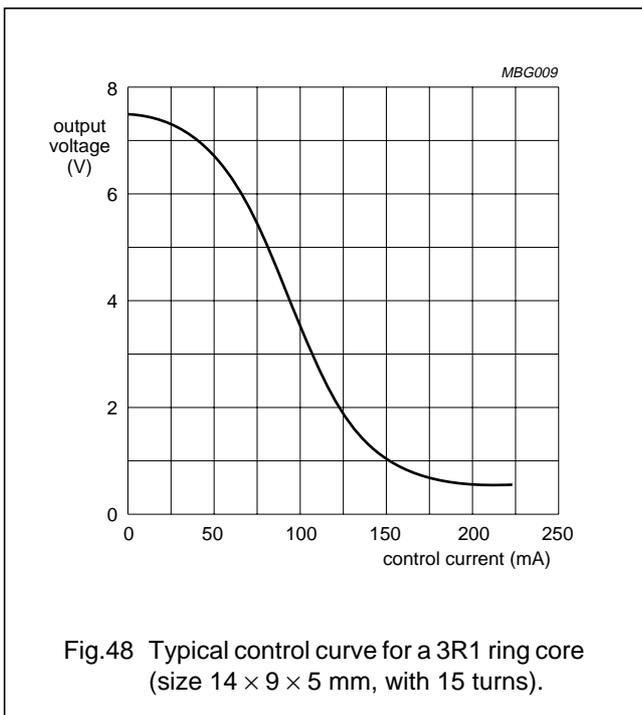

Fig.48 Typical control curve for a 3R1 ring core
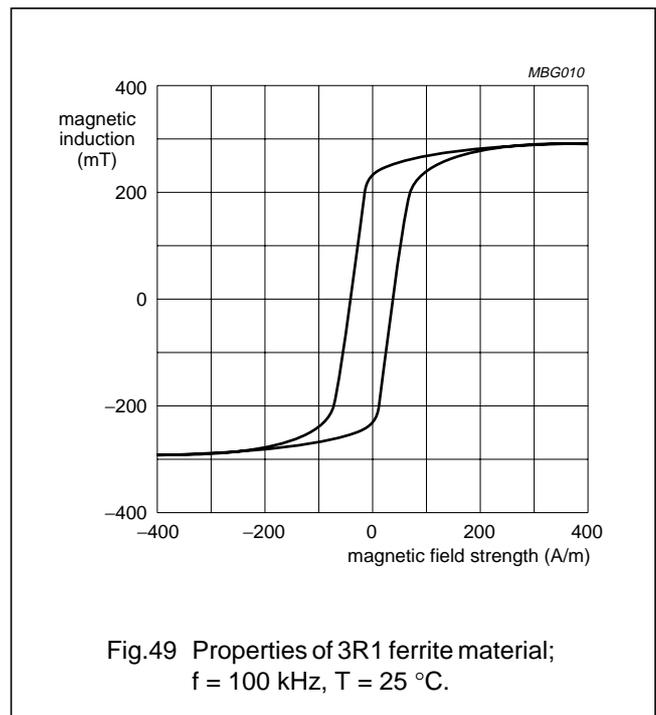(size 14 × 9 × 5 mm, with 15 turns).

Fig.49 Properties of 3R1 ferrite material;
f = 100 kHz, T = 25 °C.

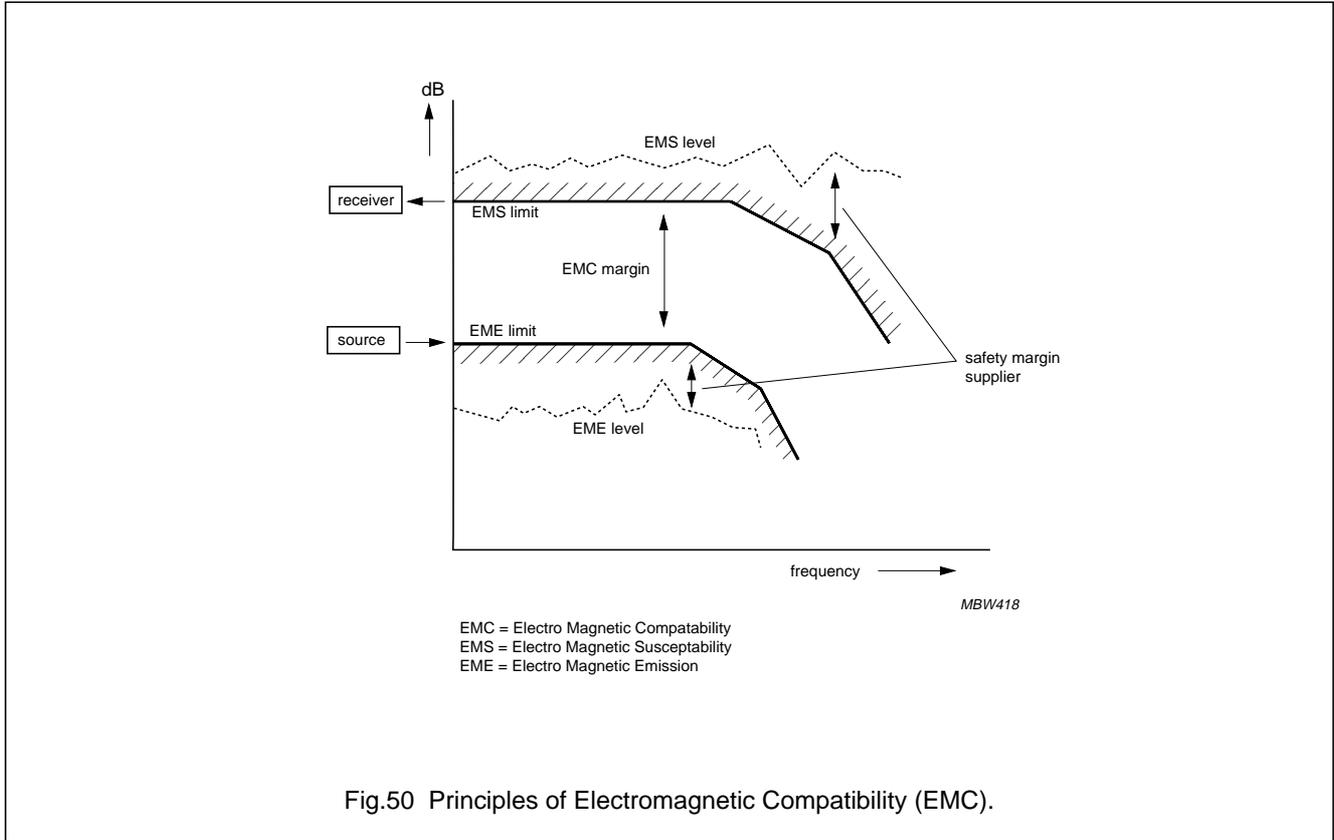**Ferrites for Interference Suppression and Electromagnetic Compatibility (EMC)**

EMC = Electro Magnetic Compatability
EMS = Electro Magnetic Susceptability
EME = Electro Magnetic Emission

Fig.50 Principles of Electromagnetic Compatibility (EMC).

With the ever increasing intensive use of electronic equipment Electromagnetic Compatibility (EMC) has become an important item. Laws specify limits of the level of interference caused by equipment (EME) and also the sensitivity of equipment to incoming interference (EMS).

Limiting curves are defined by organizations such as CISPR and FCC. Since the density of equipment increases, laws will become more stringent in the near future.

During the design phase, problems with interference can be avoided to some extent. Often additional suppression components such as capacitors and coils will be necessary to meet the required levels. Inductive components are very effective in blocking interfering signals, especially at high frequencies. The principles of suppression are shown in Fig.51.

Capacitors are used as a shunt impedance for the unwanted signal.

Unfortunately for high frequencies, most capacitors do not have the low impedance one might expect because of parasitic inductance or resistance.
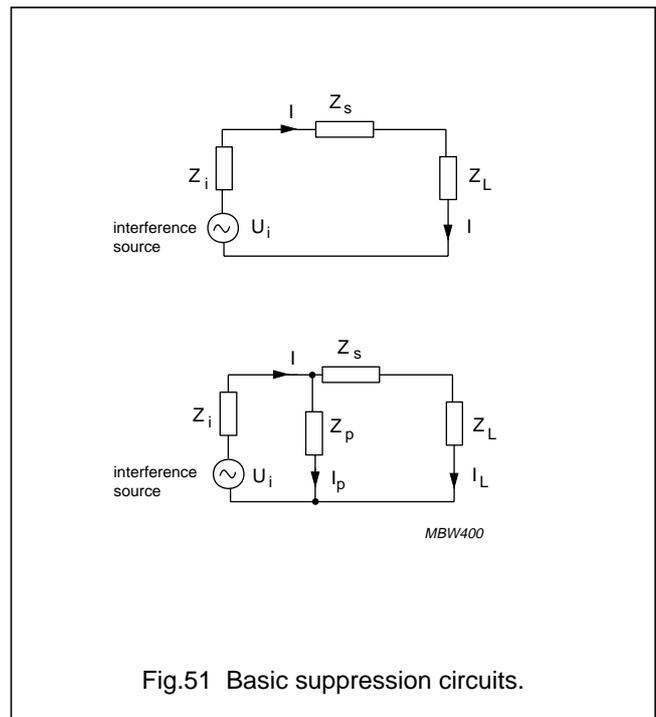

Fig.51 Basic suppression circuits.

Soft Ferrites   Applications

Inductors are used in series with the load impedance. They provide a low impedance for the wanted signal, but a high impedance for the interfering, unwanted, signal.

Philips have a full range of ring cores, beads, beads on wire, SMD beads, wideband chokes and cable shields to suit every application. Rods and tubes are also often used for this application after they have been coiled by the user.

SAMPLE BOXES

As the design process in these areas is often based on trial and error, we have assembled 6 different **designers' sample boxes**. Each box is filled with a selection from our standard ranges, which aims at a specific application area. The boxes also contain a booklet with full information about the products and their applications. These sample boxes are:

- Sample box 9: SMD beads and chokes
- Sample box 10: Cable shielding
- Sample box 11: EMI suppression products.

INTERFERENCE SUPPRESSION BEADS

A range of beads is available in two material grades, especially developed for suppression purposes.

They can easily be shifted on existing wires in the equipment:

- 3S1 for frequencies up to 30 MHz
- 4S2 for frequencies from 10 to 1000 MHz.

The material grades and beads are fully guaranteed for their main feature, impedance as a function of frequency.

The grade 3S1 has a high permeability and is therefore rather sensitive for DC load. In applications where a high DC current is flowing 4S2 can be a better choice (see Figs 52, 53 and 54).
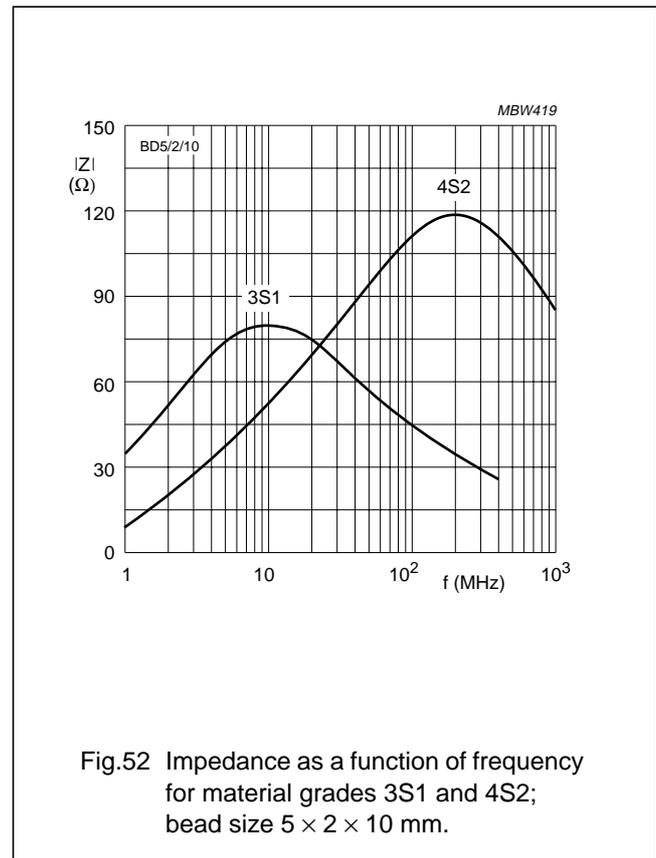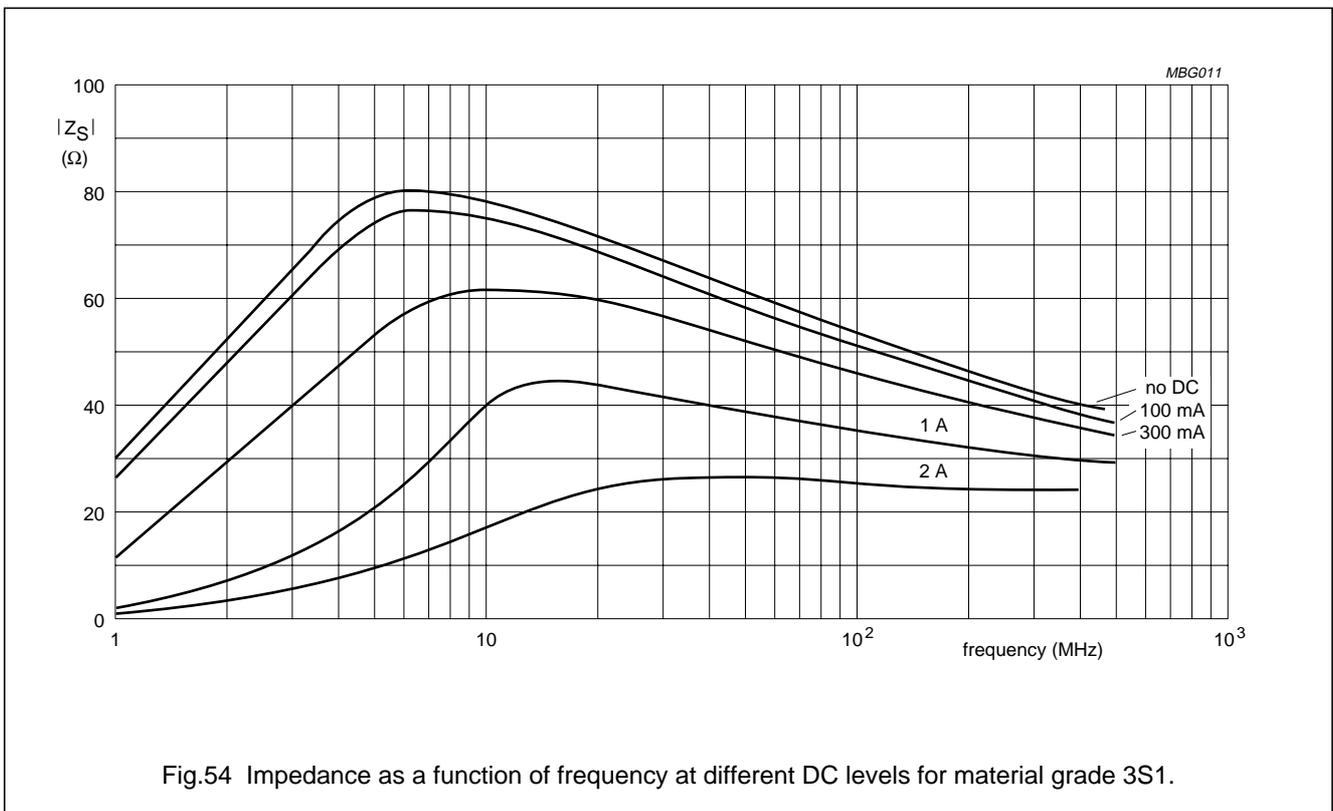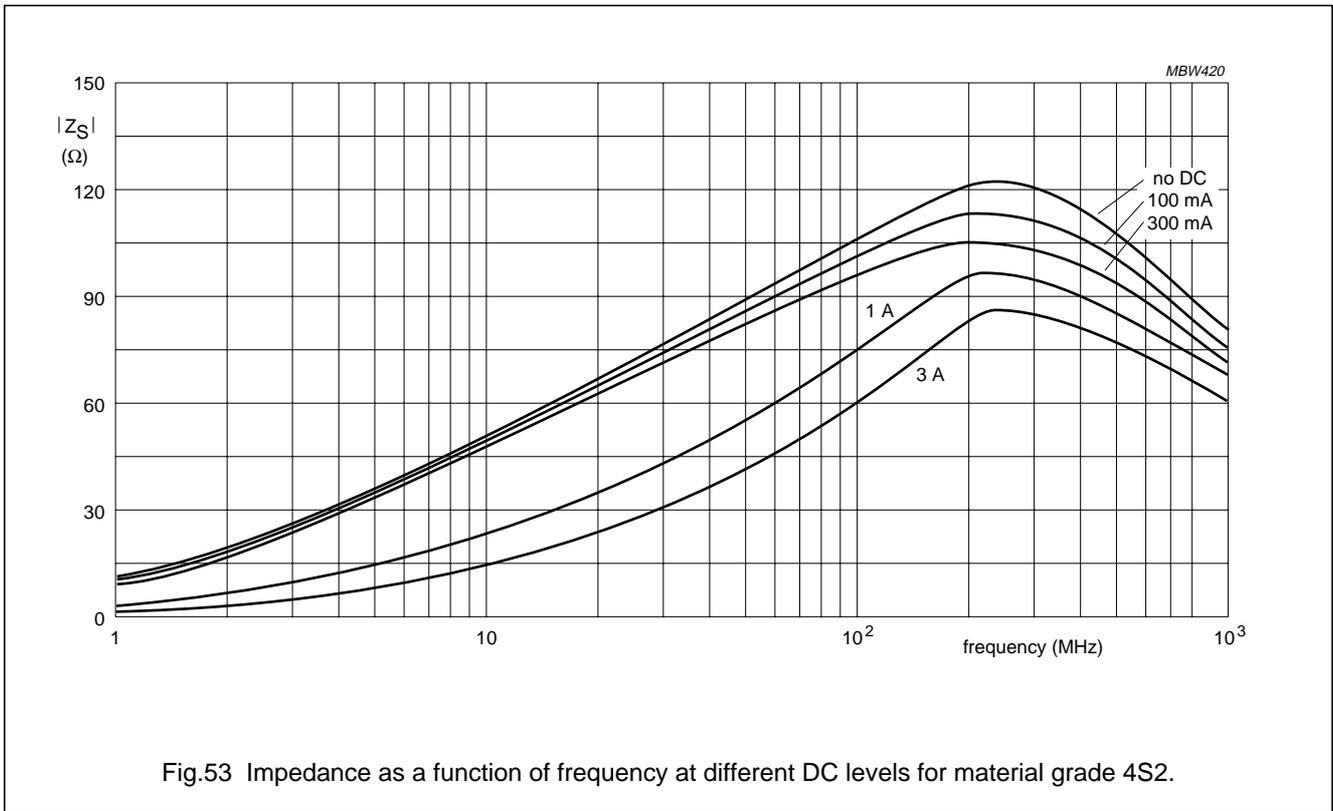

Fig.52 Impedance as a function of frequency for material grades 3S1 and 4S2; bead size $5 \times 2 \times 10$ mm.

Soft Ferrites   Applications

Fig.53 Impedance as a function of frequency at different DC levels for material grade 4S2.

Fig.54 Impedance as a function of frequency at different DC levels for material grade 3S1.

Soft Ferrites

Applications

BEADS ON WIRE

This product range consists of suppression beads, already mounted on pre-soldered 0.6 mm wire and taped on standard reels. These can be handled by automatic placement machines.

SMD FERRITE BEADS

In response to market demands for smaller, lighter and more integrated electronic devices a series of SMD beads was added to our range. They are available in different sizes and 2 suppression ferrite grades.

Basically these beads consist of a ferrite tube with a rectangular cross-section and a flat tinned copper wire which is bent around the edges and forms the terminals of the component. This design offers many superior mechanical and electrical features.

Some examples of their impedance as a function of frequency and the influence of bias current are given in the graphs.
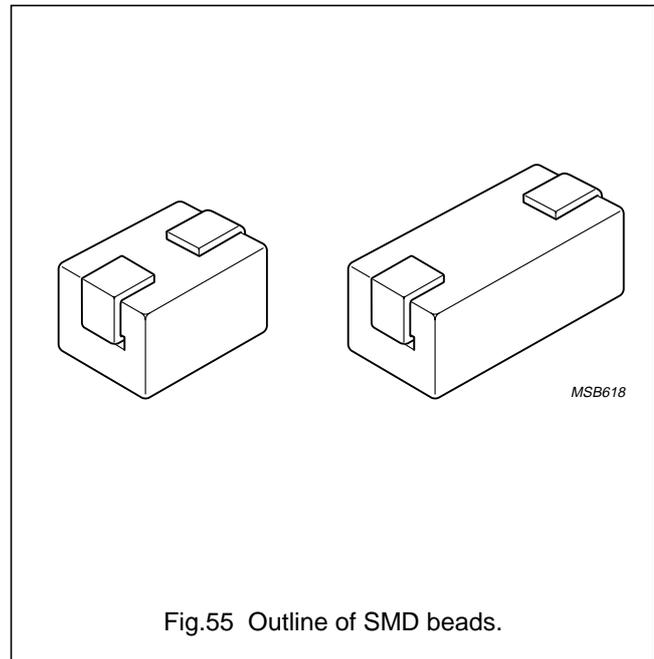
Fig.55 Outline of SMD beads.
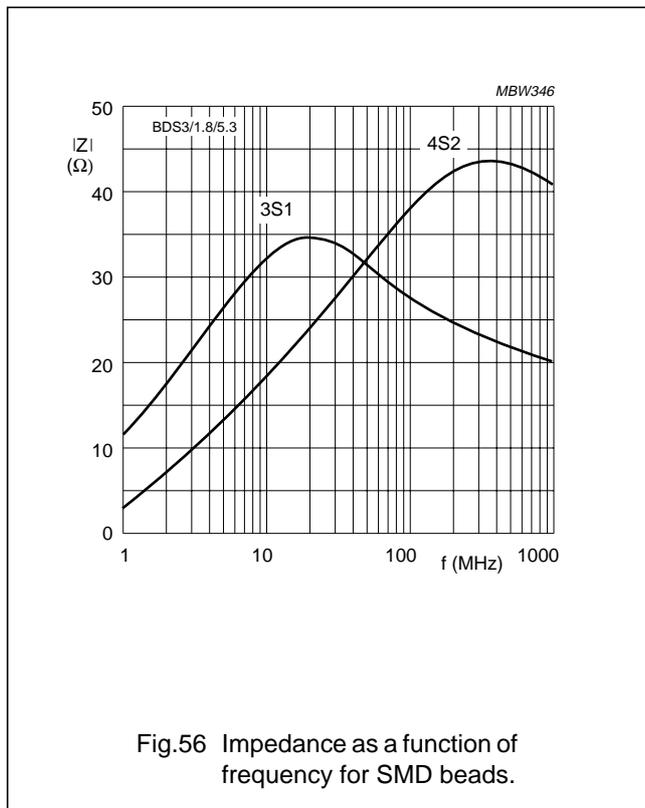
Fig.56 Impedance as a function of frequency for SMD beads.
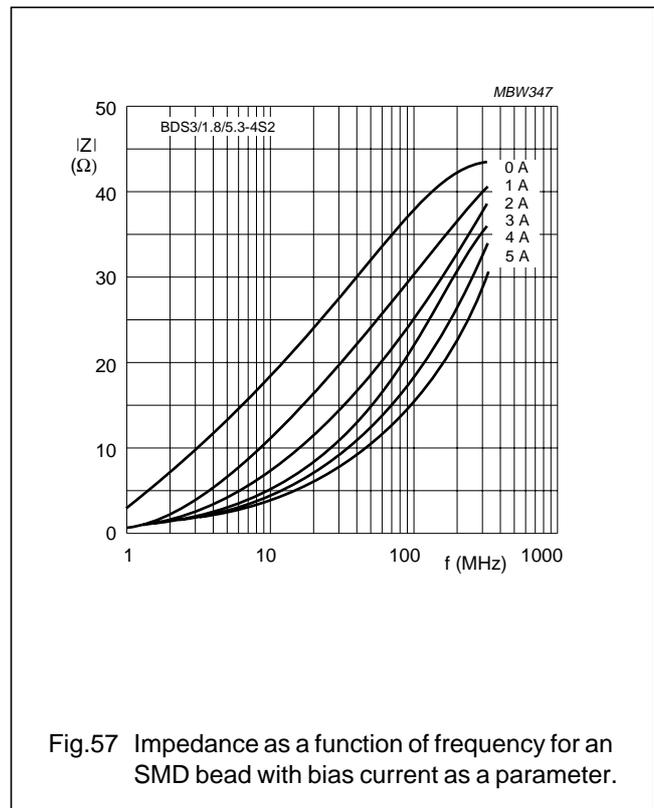

Fig.57 Impedance as a function of frequency for an SMD bead with bias current as a parameter.

Soft Ferrites   Applications

SMD FERRITE BEADS FOR
COMMON-MODE INTERFERENCE SUPPRESSION

Philips Components has introduced a new range of soft
ferrite SMD beads for common-mode interference
suppression.

With standard suppression methods in a signal path, the
wanted signal is often suppressed along with the
interference, and in many modern applications (EDP for
instance) this leads to unacceptable loss of signal.

In Philips' new interference suppression beads, a pair of
conductors within a single soft ferrite block are connected
along their lengths by an air gap.

Common-mode signals (interference signals passing in
the same direction along the input and output channels of
a device, an IC for instance) serve to reinforce the
magnetic flux around both conductors and are therefore
attenuated.

In contrast, the wanted signal passing along the input and
output channels serves to cancel the flux around the
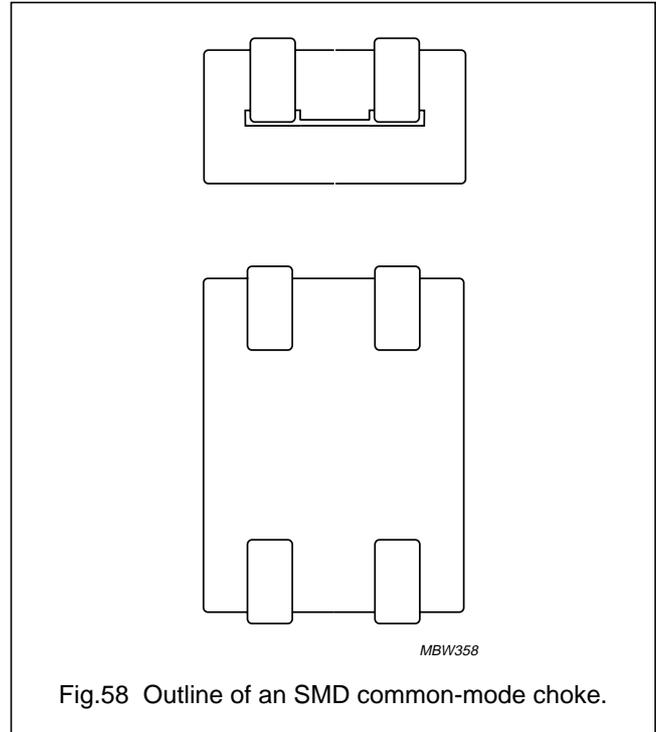conductors and therefore passes unattenuated.
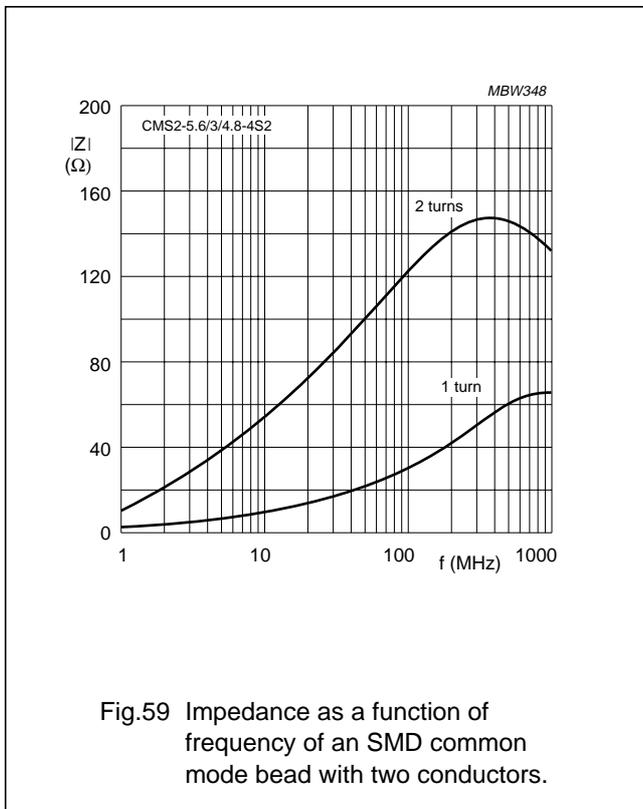

Fig.58 Outline of an SMD common-mode choke.

Fig.59 Impedance as a function of
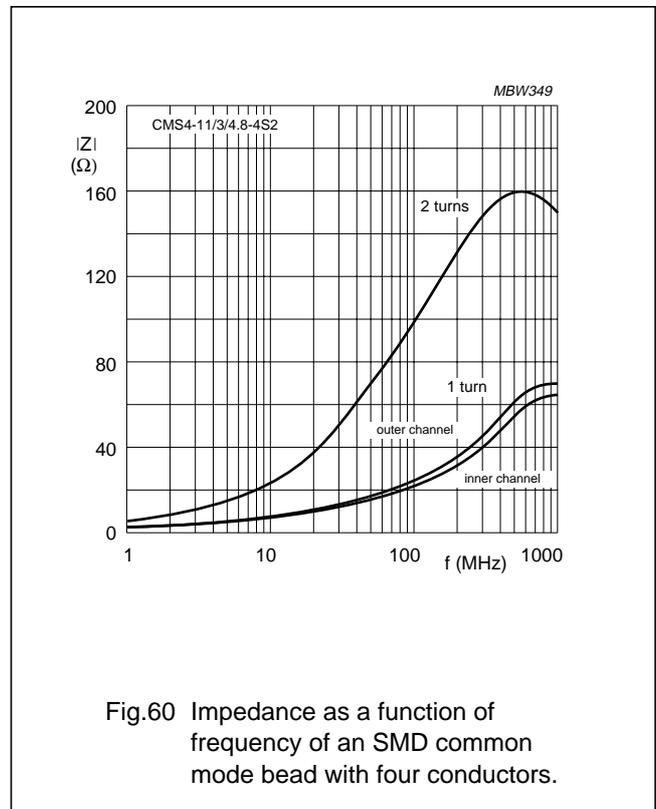frequency of an SMD common
mode bead with two conductors.

Fig.60 Impedance as a function of
frequency of an SMD common
mode bead with four conductors.

Soft Ferrites

Applications

WIDEBAND CHOKES

Wideband chokes are wired multi-hole beads. Since they have up to $2\frac{1}{2}$ turns of wire their impedance values are rather high over a broad frequency range, hence their name.

The magnetic circuit is closed so there is little stray field. The DC resistance is very low since only a short length of 0.6 mm copper wire is used.

These products already have a long service record and are still popular for various applications.

Recently the range was extended with several new types, e.g. with isolation and taped on reel.
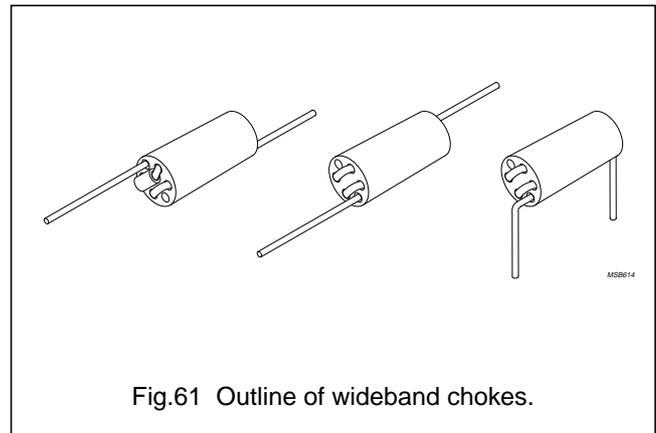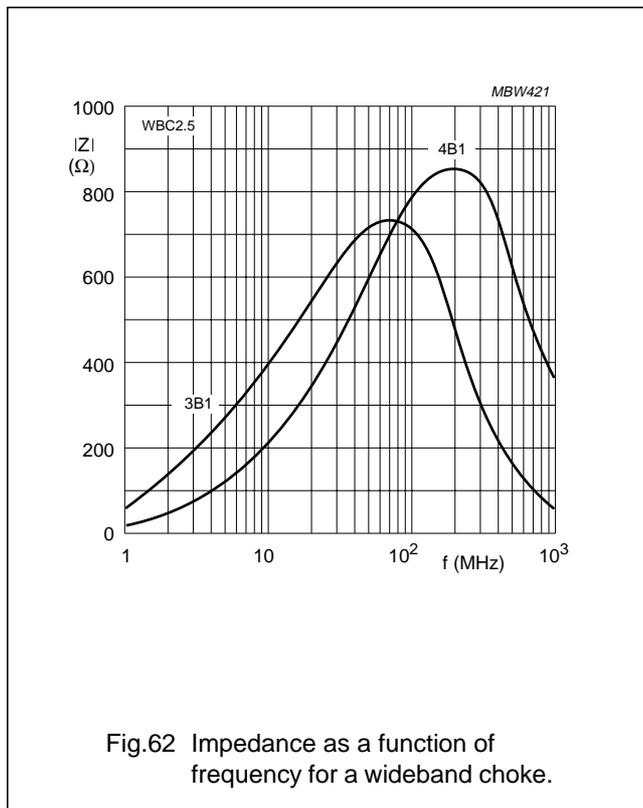

Fig.61 Outline of wideband chokes.

Fig.62 Impedance as a function of
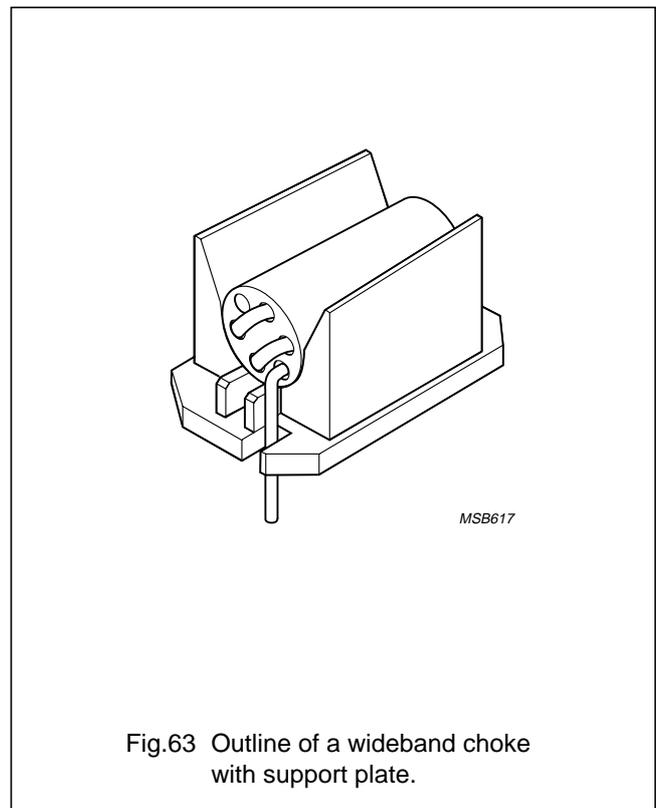frequency for a wideband choke.

Fig.63 Outline of a wideband choke
with support plate.

Soft Ferrites

Applications

SMD WIDEBAND CHOKES

SMD wideband chokes are an alternative to a SMD bead when more impedance or damping is required.

The design of this product is based on our well known range of wideband chokes.

In these products the conductor wire is wound through holes in a multi-hole ferrite core, thus separating them physically and reducing coil capacitance.

The result is a high impedance over a wide frequency range, a welcome feature for many interference problems.

The present SMD design preserves the excellent properties and reliability of the original wideband chokes by keeping the number of electrical interfaces to an absolute minimum.
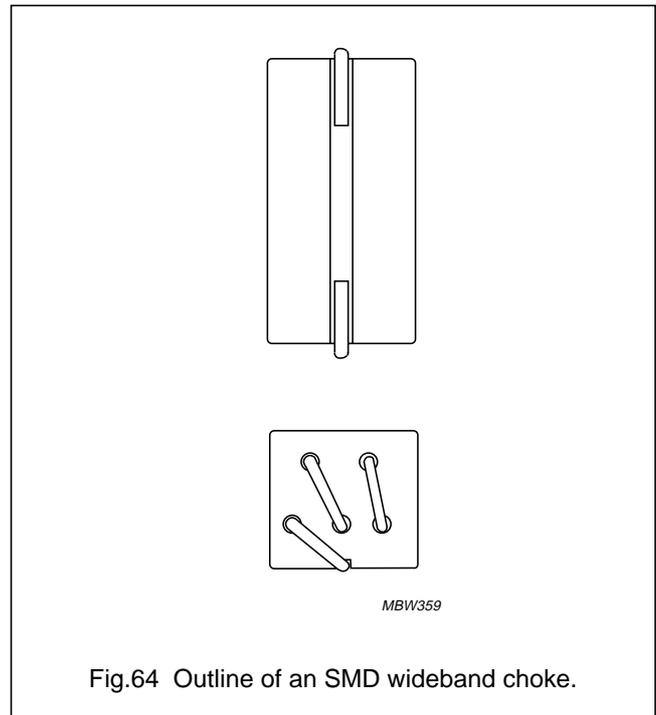

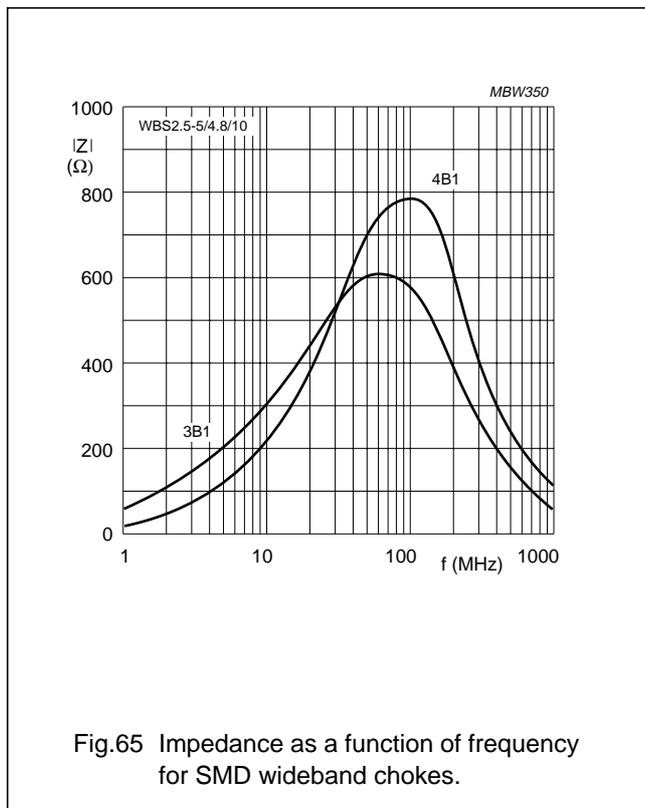MBW359

Fig.64 Outline of an SMD wideband choke.

Fig.65 Impedance as a function of frequency for SMD wideband chokes.

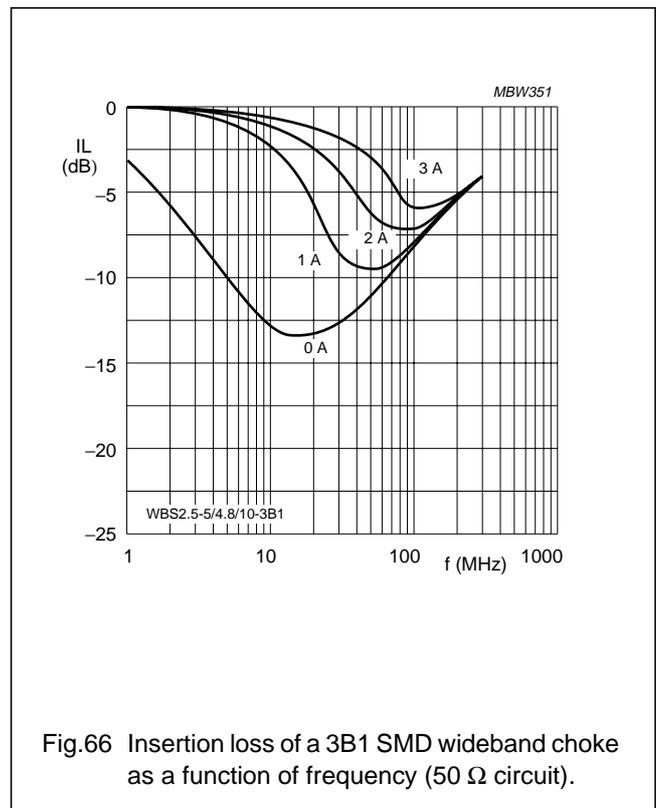

Fig.66 Insertion loss of a 3B1 SMD wideband choke as a function of frequency (50 Ω circuit).
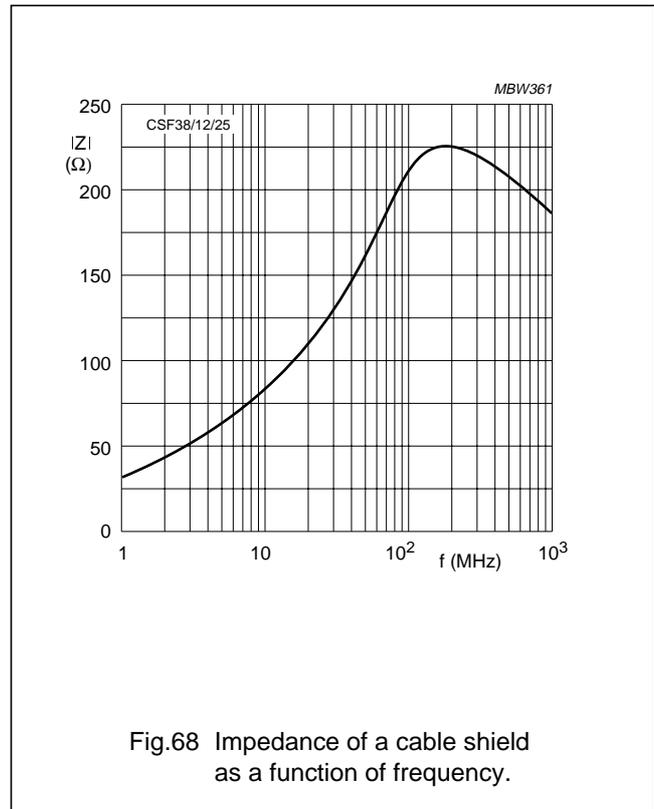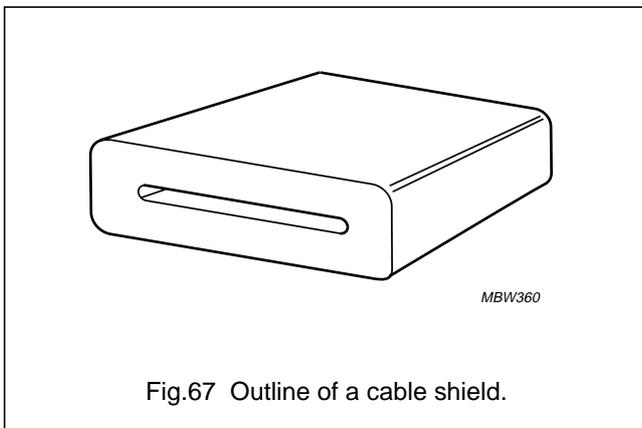
Soft Ferrites   Applications

CABLE SHIELDS

New in our range are so-called cable shields. These products are an effective remedy against common-mode interference on coaxial or flat cables. They come in several shapes: round tubes, rectangular sleeves and split sleeves to mount on existing cable connections.

Our new suppression material 3S4 is very suitable for this application. It combines a high permeability (1700) for high impedance in the lower frequency range with an excellent high frequency behaviour for true wideband suppression.

Fig.67 Outline of a cable shield.

Fig.68 Impedance of a cable shield as a function of frequency.

Soft Ferrites

Applications

RODS AND TUBES

Rods and tubes are generally used to increase the inductance of a coil. The magnetic circuit is very open and therefore the mechanical dimensions have more influence on the inductance than the ferrite's permeability (see Fig.69) unless the rod is very slender.

In order to establish the effect of a rod on the inductance of a coil, the following procedure should be carried out:

- Calculate the length to diameter ratio of the rod (l/d)
- Find this value on the horizontal axis and draw a vertical line.

The intersection of this line with the curve of the material permeability gives the effective rod permeability.

The inductance of the coil, provided the winding covers the whole length of the rod is given by:

$$L = \mu_0 \mu_{rod} \frac{N^2 A}{l} \ (H)$$

where:

N = number of turns
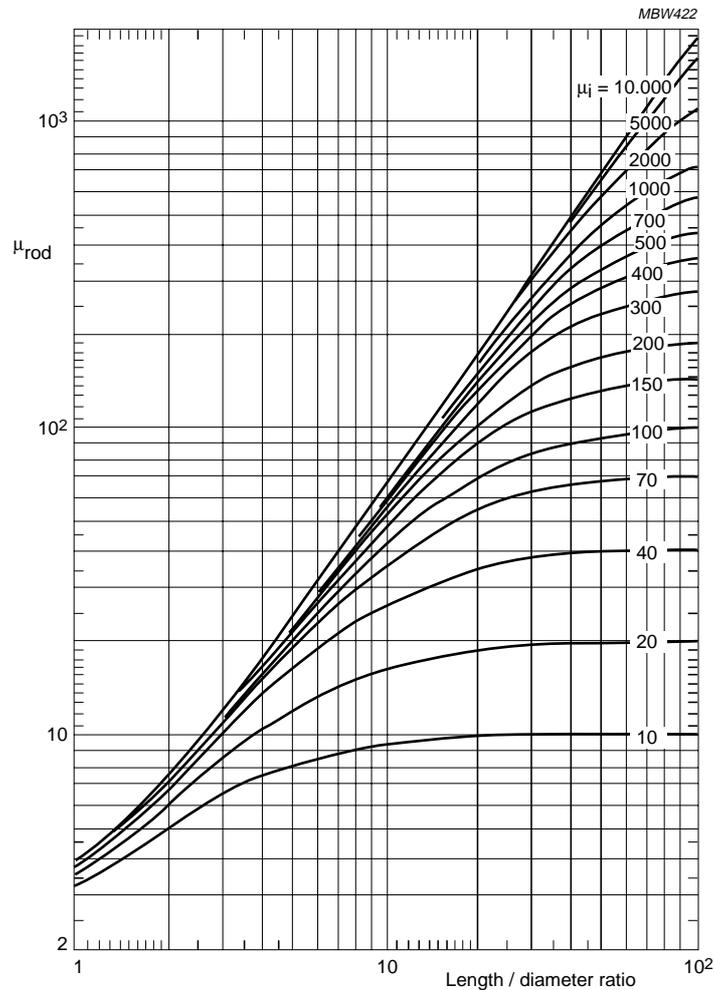
A = cross sectional area of rod

l = length of coil.

Fig.69 Rod permeability (μ_{rod}) as a function of length to diameter ratio with material permeability as a parameter.

Philips Components – a worldwide company

Australia: Philips Components Pty Ltd., NORTH RYDE,
Tel. +61 2 9805 4455, Fax. +61 2 9805 4466

Austria: Österreichische Philips Industrie GmbH, WIEN,
Tel. +43 1 60 101 12 41, Fax. +43 1 60 101 12 11

Belarus: Philips Office Belarus, MINSK,
Tel. +375 172 200 924/733, Fax. +375 172 200 773

Benelux: Philips Nederland B.V., EINDHOVEN, NL,
Tel. +31 40 2783 749, Fax. +31 40 2788 399

Brazil: Philips Components, SÃO PAULO,
Tel. +55 11 821 2333, Fax. +55 11 829 1849

Canada: Philips Electronics Ltd., SCARBOROUGH,
Tel. +1 416 292 5161, Fax. +1 416 754 6248

China: Philips Company, SHANGHAI,
Tel. +86 21 6354 1088, Fax. +86 21 6354 1060

Denmark: Philips Components A/S, COPENHAGEN S,
Tel. +45 32 883 333, Fax. +45 31 571 949

Finland: Philips Components, ESPOO,
Tel. +358 9 615 800, Fax. +358 9 615 80510

France: Philips Composants, SURESNES,
Tel. +33 1 4099 6161, Fax. +33 1 4099 6493

Germany: Philips Components GmbH, HAMBURG,
Tel. +49 40 2489-0, Fax. +49 40 2489 1400

Greece: Philips Hellas S.A., TAVROS,
Tel. +30 1 4894 339/+30 1 4894 239, Fax. +30 1 4814 240

Hong Kong: Philips Hong Kong, KOWLOON,
Tel. +852 2784 3000, Fax. +852 2784 3003

India: Philips India Ltd., MUMBAI,
Tel. +91 22 4930 311, Fax. +91 22 4930 966/4950 304

Indonesia: P.T. Philips Development Corp., JAKARTA,
Tel. +62 21 794 0040, Fax. +62 21 794 0080

Ireland: Philips Electronics (Ireland) Ltd., DUBLIN,
Tel. +353 1 7640 203, Fax. +353 1 7640 210

Israel: Rapac Electronics Ltd., TEL AVIV,
Tel. +972 3 6450 444, Fax. +972 3 6491 007

Italy: Philips Components S.r.l., MILANO,
Tel. +39 2 6752 2531, Fax. +39 2 6752 2557

Japan: Philips Japan Ltd., TOKYO,
Tel. +81 3 3740 5135, Fax. +81 3 3740 5035

Korea (Republic of): Philips Electronics (Korea) Ltd., SEOUL,
Tel. +82 2 709 1472, Fax. +82 2 709 1480

Malaysia: Philips Malaysia SDN Berhad,
Components Division, PULAU PINANG,
Tel. +60 3 750 5213, Fax. +60 3 757 4880

Mexico: Philips Components, EL PASO, U.S.A.,
Tel. +52 915 772 4020, Fax. +52 915 772 4332

New Zealand: Philips New Zealand Ltd., AUCKLAND,
Tel. +64 9 815 4000, Fax. +64 9 849 7811

Norway: Norsk A/S Philips, OSLO,
Tel. +47 22 74 8000, Fax. +47 22 74 8341

Pakistan: Philips Electrical Industries of Pakistan Ltd., KARACHI,
Tel. +92 21 587 4641-49, Fax. +92 21 577 035/+92 21 587 4546

Philippines: Philips Semiconductors Philippines Inc.,
METRO MANILA, Tel. +63 2 816 6345, Fax. +63 2 817 3474

Poland: Philips Poland Sp. z.o.o., WARSZAWA,
Tel. +48 22 612 2594, Fax. +48 22 612 2327

Portugal: Philips Portuguesa S.A.,
Philips Components: LINDA-A-VELHA,
Tel. +351 1 416 3160/416 3333, Fax. +351 1 416 3174/416 3366

Russia: Philips Russia, MOSCOW,
Tel. +7 95 755 6918, Fax. +7 95 755 6919

Singapore: Philips Singapore Pte Ltd., SINGAPORE,
Tel. +65 350 2000, Fax. +65 355 1758

South Africa: S.A. Philips Pty Ltd., JOHANNESBURG,
Tel. +27 11 470 5911, Fax. +27 11 470 5494

Spain: Philips Components, BARCELONA,
Tel. +34 93 301 63 12, Fax. +34 93 301 42 43

Sweden: Philips Components AB, STOCKHOLM,
Tel. +46 8 5985 2000, Fax. +46 8 5985 2745

Switzerland: Philips Components AG, ZÜRICH,
Tel. +41 1 488 22 11, Fax. +41 1 481 7730

Taiwan: Philips Taiwan Ltd., TAIPEI,
Tel. +886 2 2134 2900, Fax. +886 2 2134 2929

Thailand: Philips Electronics (Thailand) Ltd., BANGKOK,
Tel. +66 2 745 4090, Fax. +66 2 398 0793

Turkey: Türk Philips Ticaret A.S., GÜLTEPE/ISTANBUL,
Tel. +90 212 279 2770, Fax. +90 212 282 6707

United Kingdom: Philips Components Ltd., DORKING,
Tel. +44 1306 512 000, Fax. +44 1306 512 345

United States:

- Display Components, ANN ARBOR, MI,
Tel. +1 734 996 9400, Fax. +1 734 761 2776

- Magnetic Products, SAUGERTIES, NY,
Tel. +1 914 246 2811, Fax. +1 914 246 0487

- Passive Components, SAN JOSE, CA,
Tel. +1 408 570 5600, Fax. +1 408 570 5700

Yugoslavia (Federal Republic of): Philips Components, BELGRADE,
Tel. +381 11 625 344/373, Fax. +381 11 635 777

Internet:

- Display Components: www.dc.comp.philips.com
- Passive Components: www.passives.comp.philips.com

For all other countries apply to:
Philips Components, Building BF-1, P.O. Box 218, 5600 MD EINDHOVEN,
The Netherlands, Fax. +31-40-27 23 903.

COD19   © Philips Electronics N.V. 1998

Printed in The Netherlands

Let's make things better.

**Philips
Components**

PHILIPS