



# application data

Issued by: Philips Industrie S.A.  
Bd de l'Europe, 131 B-1301 Wavre (Belgium)

Tél. 10/41 65 11

## ELECTROMAGNETIC INTERFERENCE AND SWITCHED-MODE



Industrial and  
Electro-Acoustic Systems

# PHILIPS



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**PHILIPS**



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## PREFACE

This brochure looks at the causes of EMI (electromagnetic interference) in switched-mode power supplies, outlines the precautions taken by manufacturers, and suggests those that can be taken by users to prevent any spurious signals affecting the functioning of other equipment in a system, however sensitive.

### 1. EMI REVISITED

While at the beginning of the century men were striving hard to transmit radio waves into free space, the ease with which electrical energy is generated today, often requires careful measures to control it or prevent unwanted transmissions.

Electromagnetic interference – unless deliberately produced for jamming purposes – is by definition unwanted!

Where currents are rapidly switched on and off interference voltages are produced. The faster the switching, the wider will be the interference spectrum, possibly up into the MHz range.

Switched-mode power supplies are inherently fast switching devices and in the past have been unjustly labelled as “EMI generators”, not always due to poor designs, but often because of misuse and perhaps a lack of understanding.

Nowadays, with excellent designs conforming to internationally recognised norms, plus a little user education, the proven quality and reliability of switched-mode power supplies means that they can be safely applied even for the most sensitive circuits.

Well-designed, well-constructed and well-installed switched-mode power supply systems already find common use in such critical areas as the medical field, sensitive measuring instruments, computer data-banks, machine control, analytical equipment, etc. without any adverse EMI effects.

### 2. ELECTROMAGNETIC INTERFERENCE

#### 2.1 Phantom Circuits

It is a well-known fact that radio transmission from a circuit is made possible because the basic electrical elements of resistance, inductance and capacitance are present not only in the wiring, but in the free space surrounding it. Likewise, the unwanted EMI uses these “phantom” component paths in wiring and free space, which do not normally appear on circuit diagrams.

These phantom elements are the major causes of undesired signals in equipment, sometimes through common coupling, for example, via a resistive common earth circuit, or by electromagnetic or electrostatic coupling fields.

In practical terms, EMI generated by an interference source inside the equipment, can be transferred to the outside world in many ways.

a. Interference signals can exist as an output voltage or current on connecting cables, e.g. the mains, or the output terminals. It is then called conducted interference.

b. Electric currents varying within a conductor or circuit component produce varying electro-magnetic fields in the vicinity of the current-carrying conductor. The propagation of those fields is called radiation.

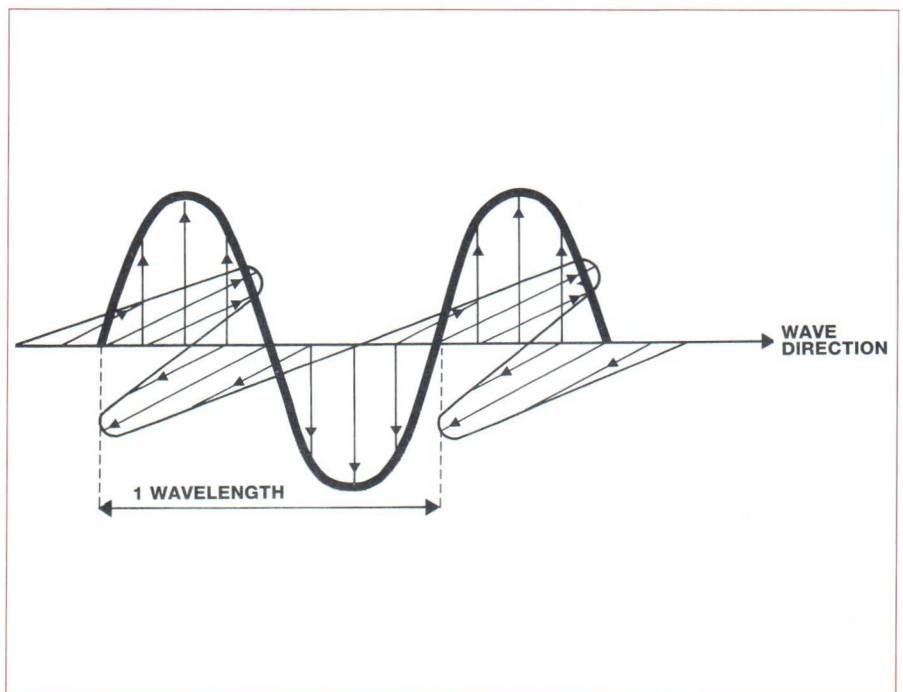


FIG. 1. ELECTROMAGNETIC RADIATED WAVE

## 2.2. Electromagnetic Radiation

Electromagnetic radiation is composed of two inseparable parts: an electric field (E) and a magnetic field (H) at right-angles to each other. These complementary fields vary in intensity and polarity at the frequency of the electric current flow producing them. (FIG. 1)

Fortunately, when considering EMI, the intensity decreases as the electromagnetic field gets further away from the source. (FIG. 2)

The intensity of the E electric field is measured in volts/metre and is high in proportion to the H magnetic field component for high-impedance fields (open-line circuits, rod aerial, etc.)

The intensity of the H magnetic field is measured in amps/metre and is high in proportion to the E electric field component for low-impedance fields (closed-loop circuits, loop aerial, etc.). (FIG. 3)

As seen, all electric fields gradually lose some of their intensity in generating a complementary magnetic field, and vice versa. Also, as the intensity decreases with distance from the current source, fields have a normal impedance of 377 ohms beyond about one wavelength.

Within a distance of one wavelength, fields are called near fields. Such fields may influence nearby circuits by capacitive or inductive coupling. One has to remember that the expression "near field" is not an absolute term but that it has to be considered as a function of the frequency. (FIG. 4)

Electromagnetic fields beyond about  $3\lambda$  are defined as far fields. These are usually referred to as plane waves because the spherical wave-front impinging on a screen at this distance is relatively flat. The far field waves are radiated outwards and not re-absorbed by the source producing them. It will be realised that these distances are important for the interference frequency when designing electromagnetic shields.

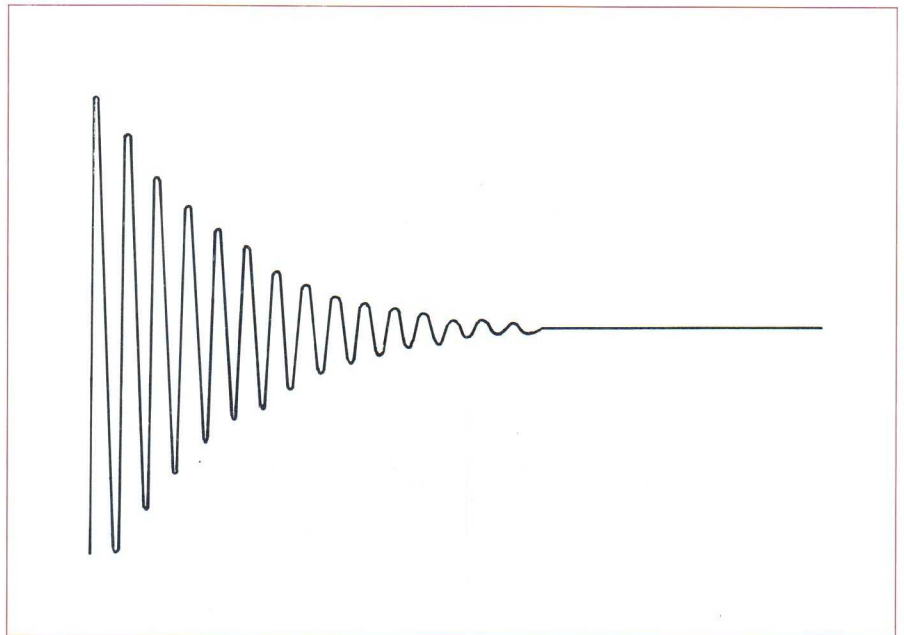


FIG. 2. RADIATION FIELD DECREASING WITH DISTANCE

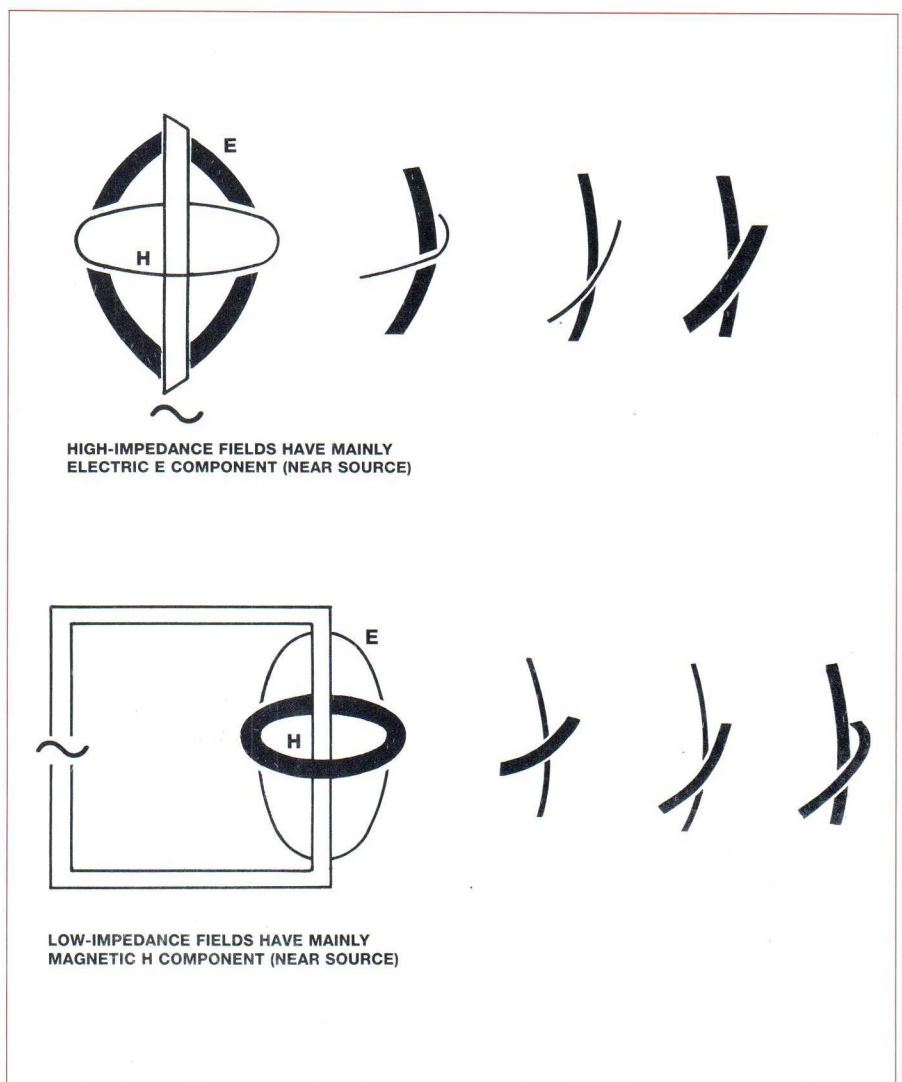


FIG. 3. H-E FIELD RELATIONSHIP VS SOURCE IMPEDANCE

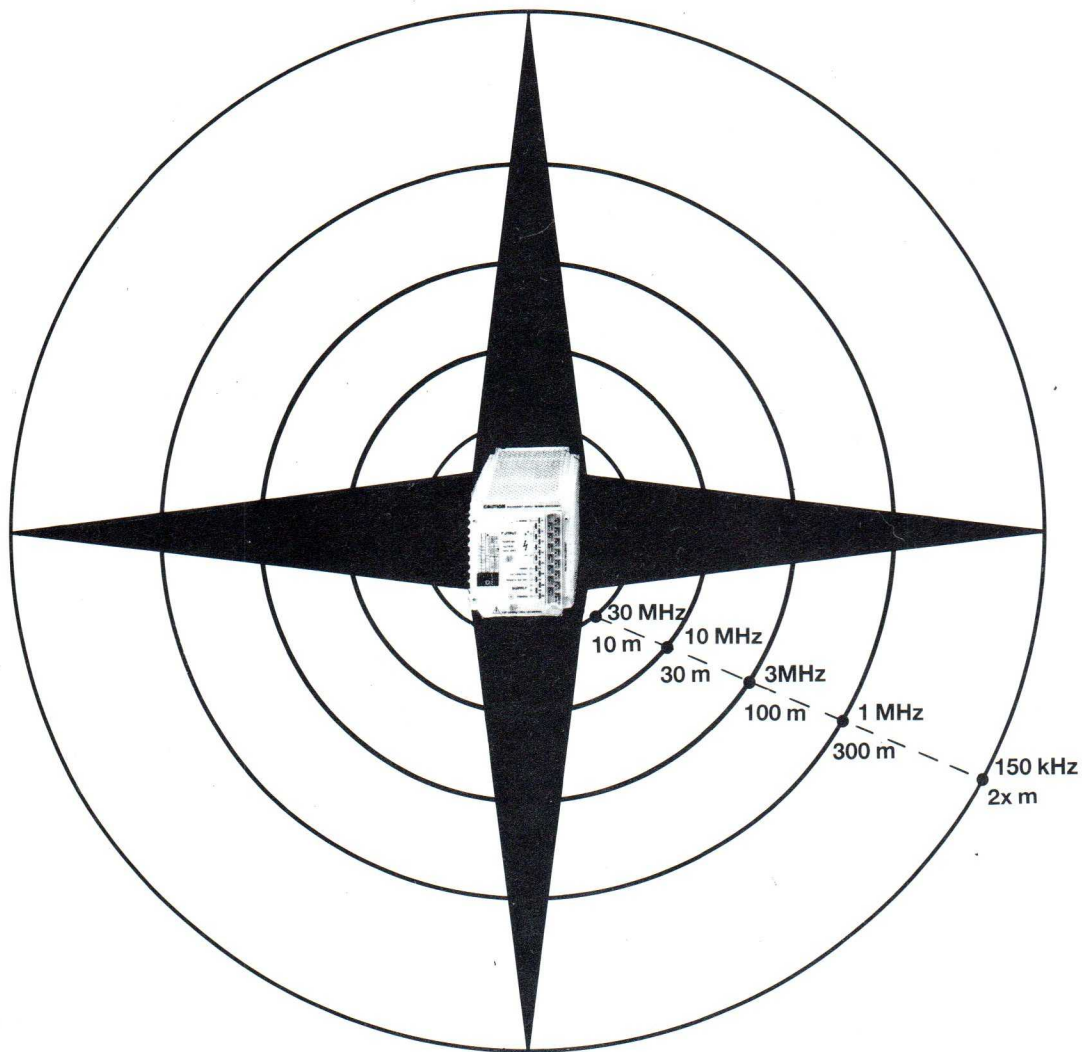


FIG. 4. POLAR DIAGRAM REPRESENTATION OF THE EXTENT OF ONE WAVELENGTH NEAR FIELD OVER 150 kHz TO 30 MHz

### 3. STANDARDS RELATING TO EMI

#### 3.1 Defining the Norms

The value of EMI that can be tolerated and also the basis for measurements are defined in a number of international standards by IEC/CISPR. National regulations such as VDE (West Germany) and FCC (U.S.A.) have been adopted from these recommendations.

Briefly defined, these standards are:

CISPR 11: describing the limits and methods of measurement of EMI characteristics of industrial, scientific and medical radio frequency equipment.

IEC 478-3: especially dedicated to power supplies; gives also EMI tests for d.c. output.

VDE 0871: radio frequency suppression of r.f. equipment for industrial, scientific, medical and similar purposes. Applicable to all equipment using or producing frequencies above 10 kHz, excluding telecommunication equipment, but including data processing installations, computers and office machines. This standard also applies to SMPSs.

VDE 0875: for equipment producing high frequency created by commutation at a frequency lower than 10 kHz (e.g. thyristor controls). Specifications for radio interference suppression of electrical appliances and systems.

More oriented to household appliances and power tools.

CENELEC HD 344: the values are fully covered by VDE standards.

FCC, part 15: two limits for conducted noise, similar to that of the VDE; an A level for industrial equipment and a B level for consumer devices.

The VDE 0871 standard has in fact been adopted by Philips for comparing the level of interference conducted to the mains by their SMPS range, since it has the widest frequency range, includes all other standards and is therefore universally accepted by customers.

The IEC 478-3 has been retained for comparing the output line level.

Frequency range of these standards

Standard	10kHz	150kHz	450kHz	30MHz	300MHz	18GHz	Restriction
CISPR 11		XX					mains 100-415 V
IEC 478-3		XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX					conducted EMI source 25 A
VDE 0871	XX						some surgical instruments
VDE 0875		XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX					if battery powered, no measurements below 30 MHz
FCC part 15			XXXXXXXXXXXXXXXXXXXX				conducted EMI

3.2. Accepted Standards for Conducted EMI

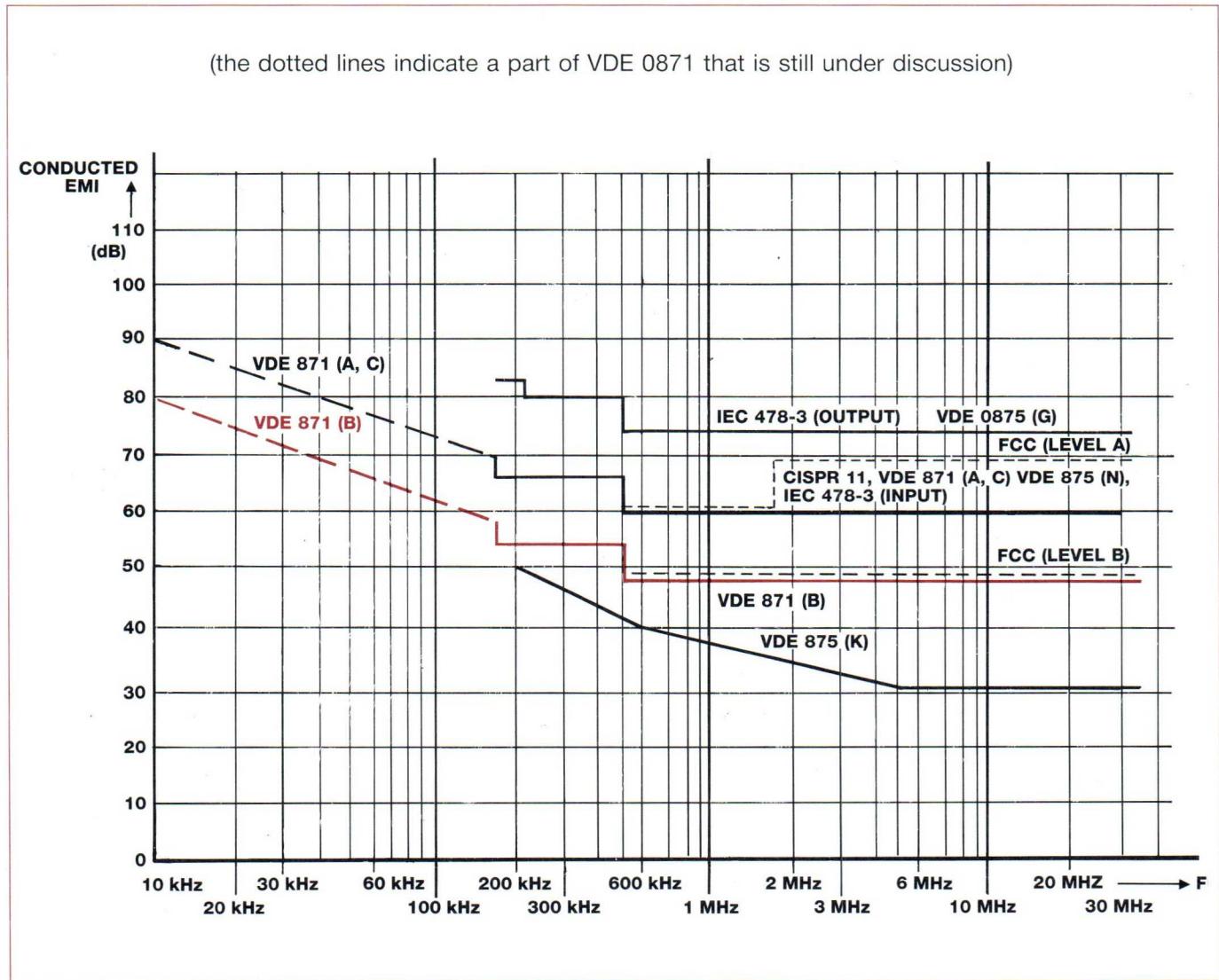


FIG. 5. COMPARISON OF CONDUCTED EMI STANDARDS

### 3.3. EMI Legislation

In many countries, it is now illegal to sell electronic equipment that has not received approval by a specifically certified laboratory.

Especially, the legislation in West Germany, based on VDE standards, is well documented and very strict.

It is worthwhile to have a closer look at this legislation. For equipment, defined under VDE 0871, the "Deutsche Bundespost" (Post office) delivers two kinds of appro-

vals: a general approval ("Allgemeines Genehmigung") and an individual approval ("Einzelgenehmigung"). To obtain a general approval, the equipment shall meet the VDE 0871 level B. It is necessary to perform a type test, under supervision of the VDE. After approval, the equipment can be used without further problems. It may also bear the VDE 0871 EMI bench-mark (Funkschutzzeichen). Any equipment, not meeting the

level B (but still under the A-limit), has to be sent to the VDE office for type-testing. If compliance has been achieved, it is a FTZ number (Fernmelde-Technische Zentralamt), accorded. After installation, the customer needs a licence from the Post office to use the equipment.

This severe legislation justifies the efforts of Philips to meet the VDE 0871 level B.

## 4. EMI IN SWITCHED-MODE SUPPLIES

### 4.1 The Cause

The fundamental cause of EMI in a switched-mode power supply stems from its fast-switching mode of operation as it converts the rectified mains into a rectangular waveform. The switching frequency itself may only be as low as 25 kHz, but the rapid change of voltage and current produces interference over a broad frequency range. The edges generate harmonics, which fall by 20dB per decade, at the lower frequencies. Because switching is not instantaneous however, the slope suddenly becomes 40 dB per decade at a higher frequency. At shorter switching times, the edges get steeper and this critical frequency point is displaced even higher in the frequency spectrum, thus increasing the EMI amplitude. (FIG. 6)

These fast switching currents generated within the circuit, often at high amplitudes, are potential sources of electromagnetic interference through unwanted coupling. Moreover, because the power supply is a source of electrical energy, it is inevitably coupled to other equipment. Often, a power supply feeds sensitive data equipment where the effects of EMI could be serious if action is not taken to eliminate it. (FIG. 7)

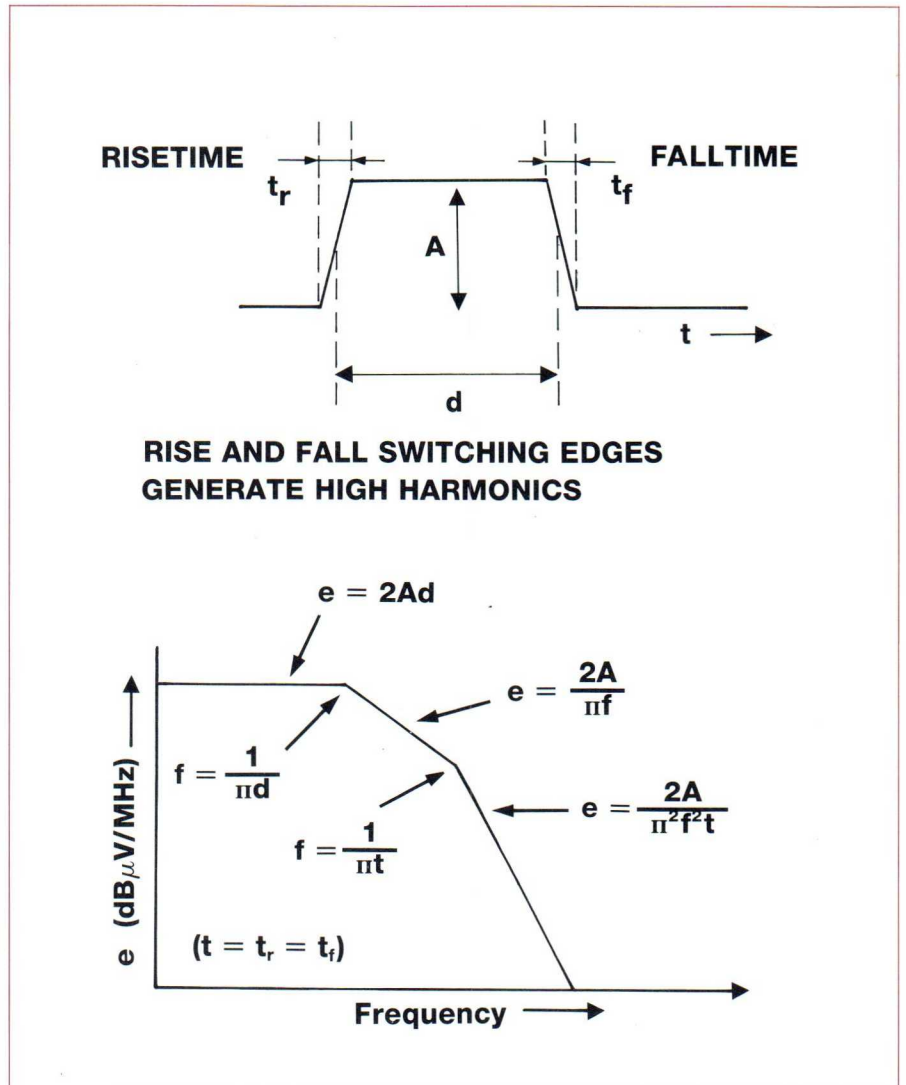


FIG. 6. SPECTRUM OF HARMONIC AMPLITUDES IN SWITCHING WAVEFORM

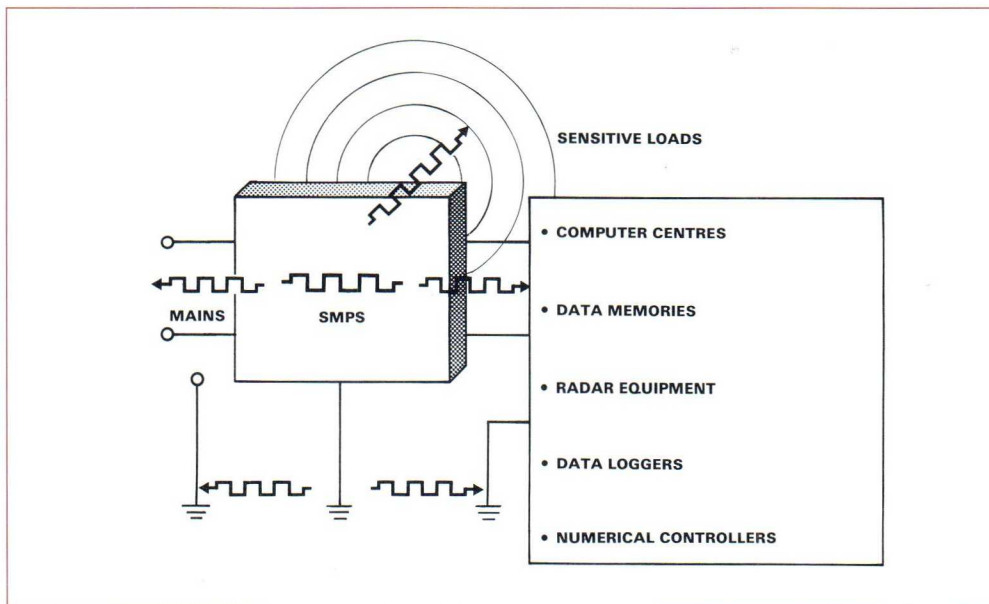


FIG. 7. POTENTIAL SOURCES OF ELECTROMAGNETIC INTERFERENCE

## 4.2 The Cures

Fortunately, various techniques are available at the design and manufacturing stages to suppress interference in switched-mode power supplies to below internationally recognised limits. Briefly, these can be listed as follows:

- \* Electromagnetic shielding
- \* Electrostatic shielding
- \* Earthing
- \* Attention to component and wiring layout.

Interference may either be produced by direct radiation or conduc-

ted via the input and/or output terminals.

The solutions may be best considered by looking at a typical switched-mode power supply circuit to evaluate the possible interference paths it contains. (FIG. 8)

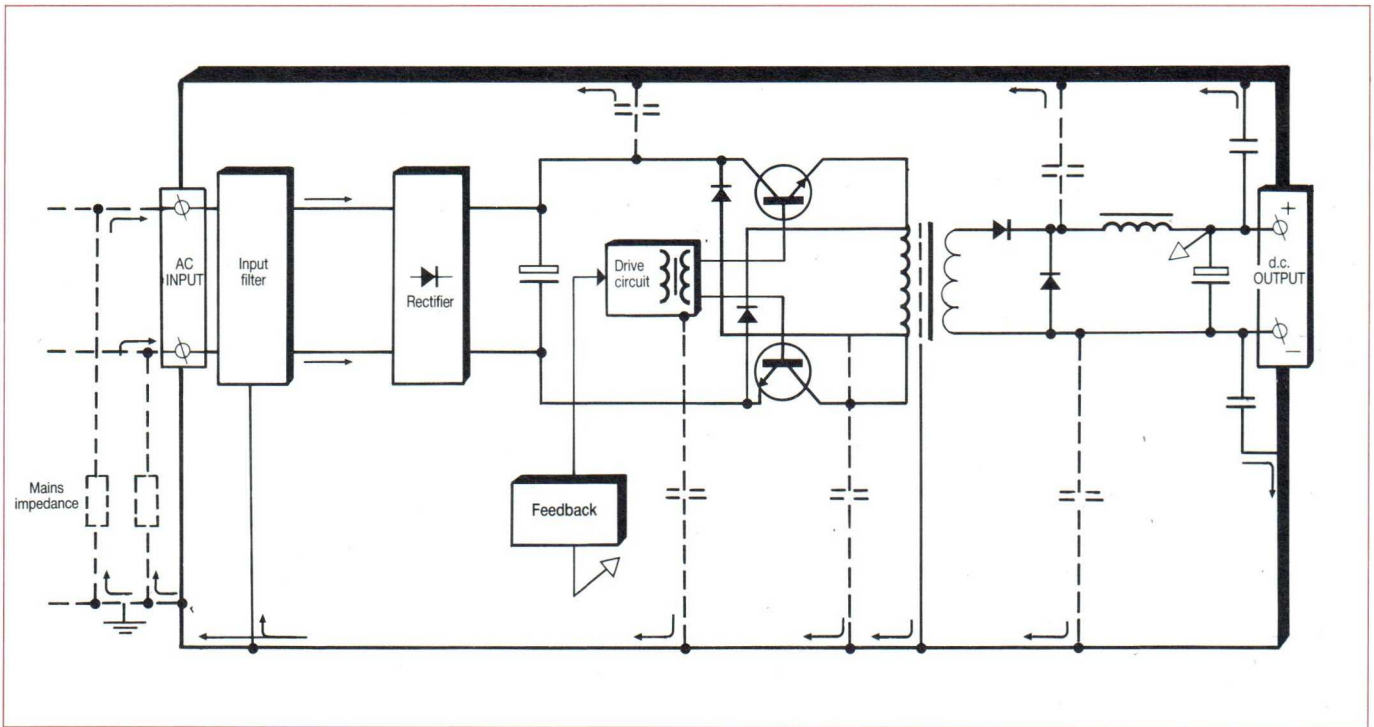


FIG. 8. TYPICAL SMPS CIRCUIT SHOWING INTERFERENCE PATHS

#### 4.2.1. Direct radiation

Although this is more difficult to detect than conducted interference, it is easier to cure by adequate screening. The power supply can be enclosed in a metal box. Ideally, this should be solid and continuous, but for practical purposes, because a power supply must have an input and output and be sufficiently ventilated, openings must be present.

Adequate shielding (80 dB) is provided by copper, aluminium and steel 3 mm thick shields for frequencies from 10 kHz.

Above 1 MHz, most leakage can be attributed to openings in the shields. For EMI above 100 MHz, discontinuities of a few centimetres will make a shield ineffective. The change in field strength obtained with the best shielding designs can be in excess of 120 dB, measured only with specifically designed instruments.

Shield openings that are longer than 0.01 wavelength provide a radiation path for EMI. As shown, in practical cases this situation occurs at frequencies from about 100 MHz. (FIG. 9)

#### a) Reflection and absorption

Energy passing from one medium to another is invariably partly reflected and partly absorbed by the new medium. Familiar examples are light passing from air to water, and sound hitting a wall. Similarly, when EMI strikes a shield some energy is reflected, some is absorbed due to power losses from induced currents and some passes on through the shield after attenuation.

In order to contain or attenuate the EMI, the shielding properties of a material must be as effective as possible. This asks for a material that is a good reflector and yet has good absorbing characteristics for the portion of the energy that passes into it. Fortunately, the total shielding for plane-wave and electric fields can be better than 120 dB for copper, aluminium and steel.

However, it is useful to compare their shielding properties separately in terms of absorption and reflection.

Shield absorption: depends on its conductivity, permeability and thickness.

$$\text{Absorption} = 131.5e\sqrt{fG\mu} \text{ (dB)}$$

where  $e$  = thickness in mm  
 $f$  = frequency in MHz  
 $G$  = conductivity relative to copper  
 $\mu$  = relative magnetic permeability

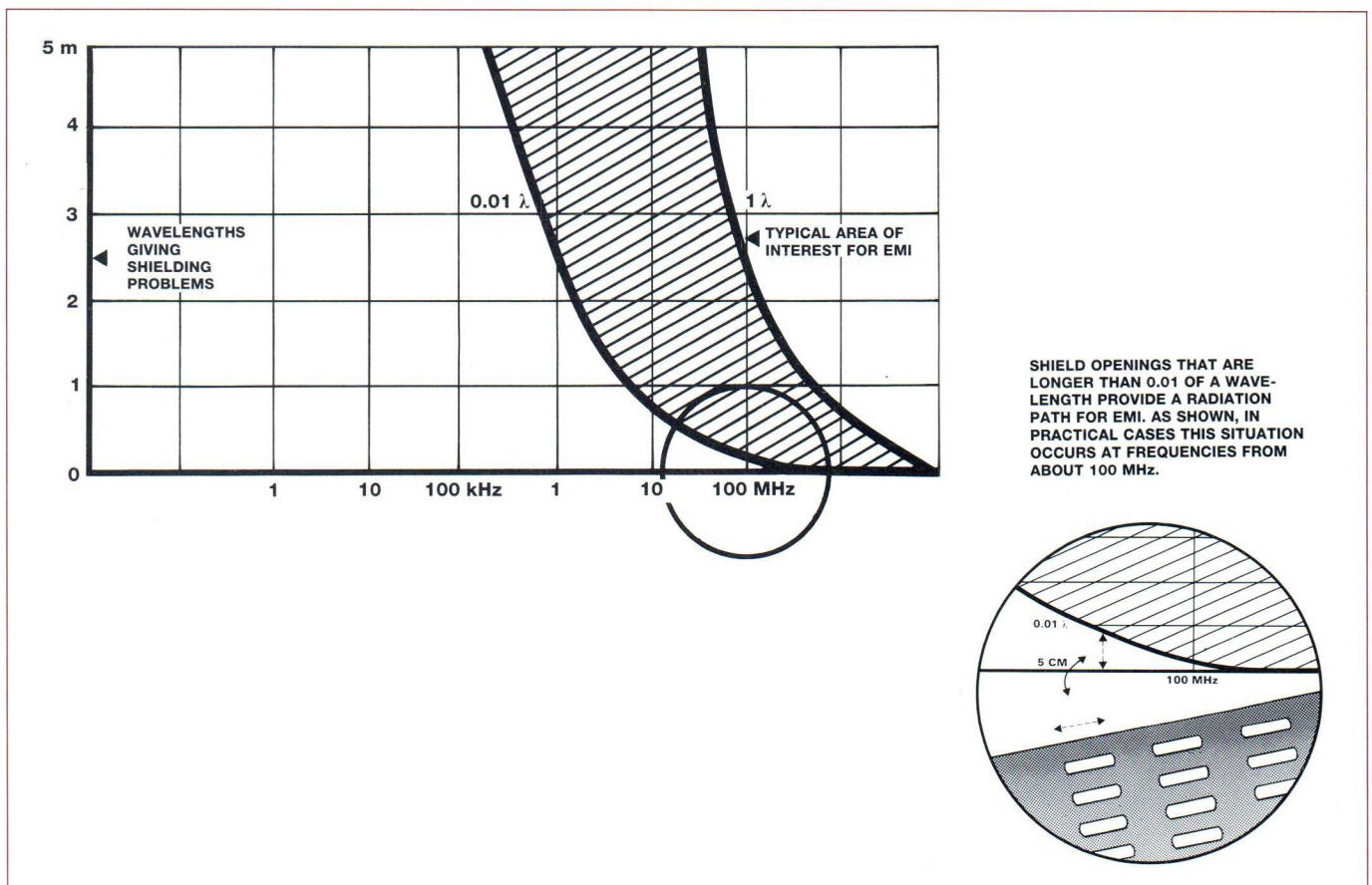


FIG. 9. SHIELD OPENINGS BELOW 0.01 WAVELENGTH REDUCE RADIATION

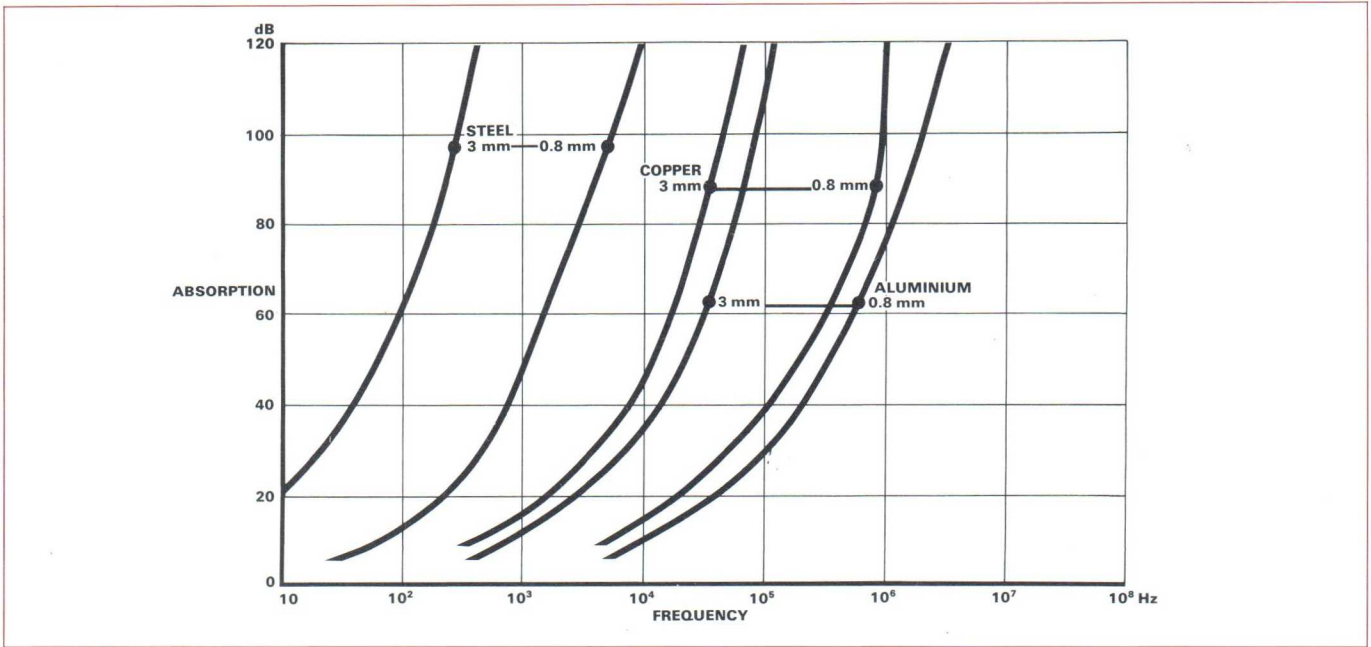


FIG. 10. RELATIVE ABSORPTION PROPERTIES OF SHIELD MATERIALS

Experience has shown that shield thickness is usually chosen between 0.8 mm and 3 mm for mechanical reasons and the absorption effect of such shields in steel, copper and aluminium are shown in Fig. 10. Up to a few kHz, steel is ideal. Above a few MHz, any mechanically suitable metal is a good EMI absorber.

Shield reflection: depends on the impedance of the field.

$$\text{Reflection} = 20 \log \frac{Z_w}{Z_s} \text{ (dB)}$$

$$(Z_w > Z_s)$$

where  $Z_w$  = impedance of wave at shield  
 $Z_s$  = impedance of shield (generally much smaller than  $Z_w$ )

In the practical shields considered, thickness does not affect reflection and for practical purposes a plane-wave is assumed. As shown in Fig. 11, high impedance fields are reflected better than low impedance fields, and low-frequency E fields better than H fields.

Copper and aluminium prove better reflectors than steel for the problematic H fields.

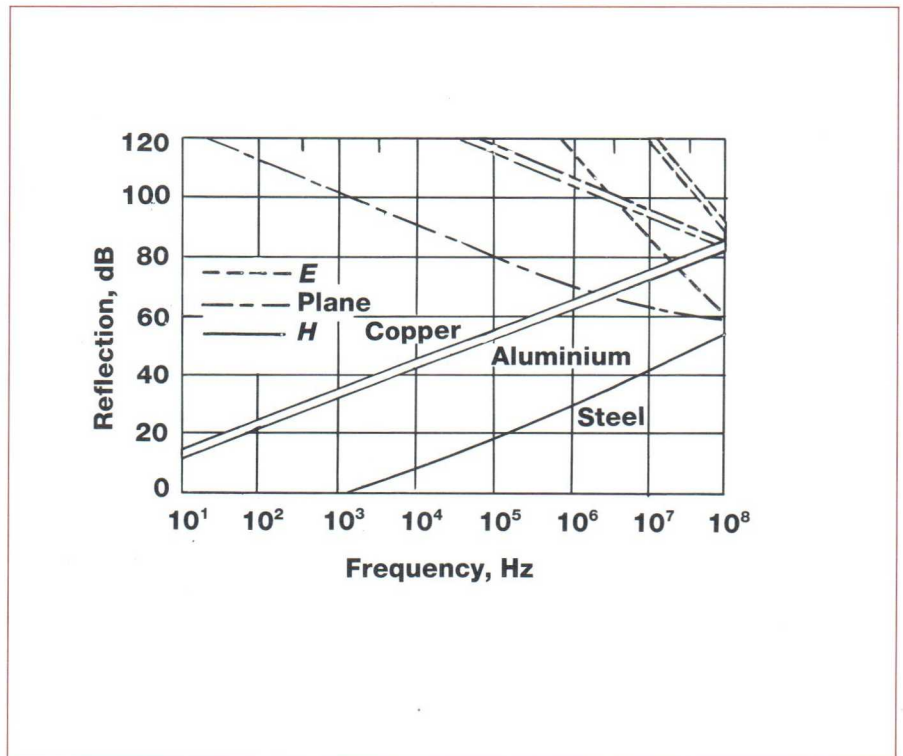


FIG. 11. RELATIVE REFLECTION PROPERTIES OF SHIELD MATERIALS

## 4.2.2. Conducted Interference

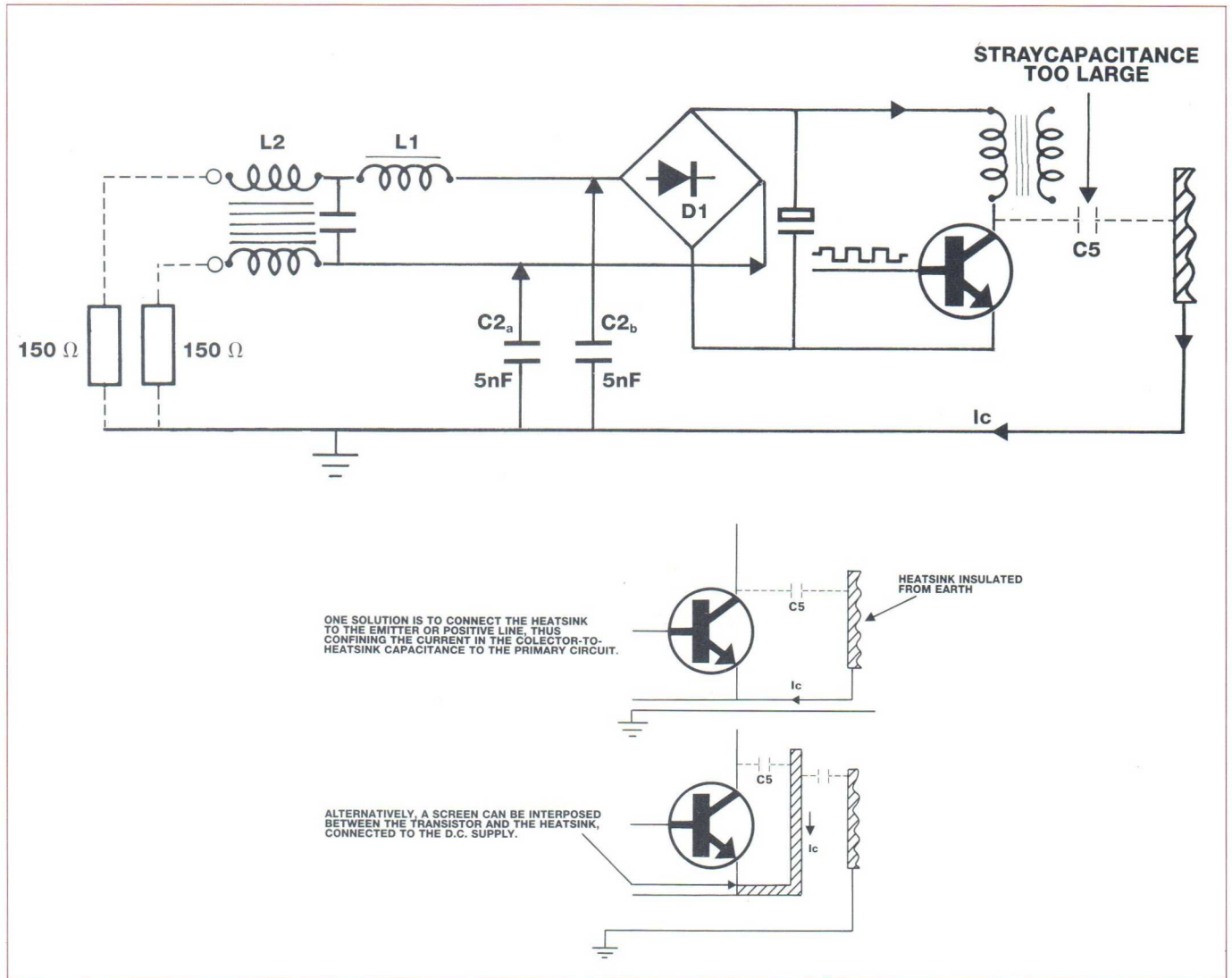


FIG. 12. REDUCING HEATSINK CAPACITIVE COUPLING PATHS FOR EMI

Conduction via input and output terminals is easier to detect, but more difficult to suppress. All aspects of EMI must be taken into account at every stage of design and construction; otherwise, unwanted signals can easily find their way by devious paths to the input and output lines via stray capacitances or inductive and resistive couplings. These paths can be defined by considering the essential elements of the switched-mode power supply shown in Fig. 8:

- switching transistors
- mains filter
- output transformer
- output filter

Each of these stages, together with the wiring layout can contribute to EMI unless carefully designed.

### a) Switching transistors

With switching waveforms of about 500 V on the transistor collector, it requires an attenuation of at least one million to ensure that any EMI reaching the mains is within national specifications.

Using a practical mains filter giving a mains-to-earth attenuation of 100 and considering the first relevant harmonic to be 10 per cent of the peak-to-peak collector voltage, the attenuation required between collector and heatsink must be about 1000 times. This means that the maximum capacitance (C5) from collector to earth must be one-thousandth that of 10 nF, the total of C2 and C3; i.e. it must not exceed 10 pF.

When a mica washer is used between a TO-3 encapsulated transistor and heatsink, the capacitance is typically 100 pF, which would result in ten times the permitted interference.

One solution is to connect the heatsink to the emitter or positive line, thus confining the current in the collector-to-heatsink capacitance to the primary circuit.

Alternatively, a screen can be interposed between the transistor and the heatsink, connected to the d.c. supply. (FIG. 12)

### b) Mains Filter

An iron-cored choke L1 may be used in series with the mains input with a parallel capacitor C1 to attenuate line-to-line interference ( $I_{\text{symm}}$ ), which is usually a maximum at the lower frequencies. The VDE 0871 extends the frequency range for EMI down to 10 kHz instead of 150 kHz as in VDE 0875. Therefore, the filtering should be especially effective for the switching frequencies 25, 33 or 50 kHz.

mode currents that exist between one of the output leads and earth.

### d) Output transformer

The inter-wiring capacitance is also a source of earth coupling for the harmonics of the switching waveform. A solution is provided by an electrostatic screen of non-ferrous metal, such as a copper sheet between primary and secondary, which returns the capacitive current to the supply line. Care must be taken to ensure

this does not form a short-circuited turn; a suitable gap must be left. EMI currents can also be produced in the Ferroxcube transformer core by capacitance between the primary and the core if the latter is simply clamped to an earthed mounting bracket.

If the primary is wound adjacent to the core and capacitance between a high-voltage secondary and core can be ignored, then connecting the core to the positive supply line will reduce EMI. (FIG. 14)

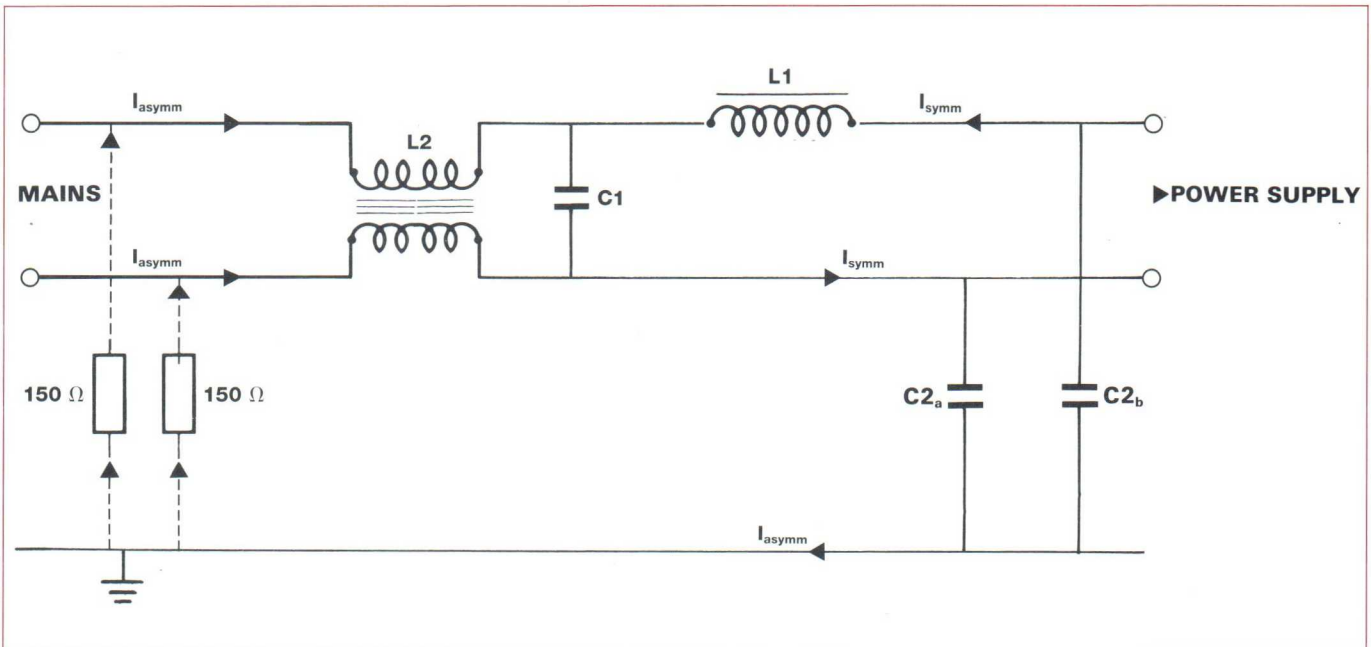


FIG. 13. TYPICAL MAINS FILTER

In the example, the high inductance of the bifilar-wound choke L2 and the two shunt capacitors C2a and C2b limit mains-to-earth interference currents ( $I_{\text{asymm}}$ ) generated in the switching transistor collector-to- heatsink capacitance. (FIG. 13)

The filter network prevents EMI currents flowing into the 150 ohm artificial mains impedances. The 50 Hz currents in the bifilar winding of L2 cancel out and prevent saturation of the core.

### c) Common-mode output currents

The same theory for common-mode input currents can be applied for the output of the power supply to explain the common-

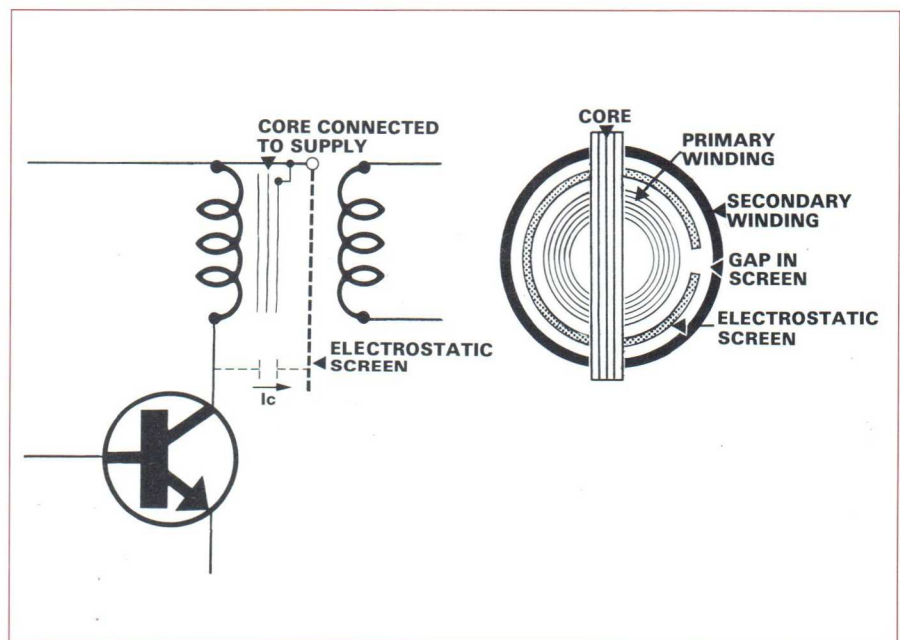


FIG. 14. REDUCING EMI COUPLING IN OUTPUT TRANSFORMER