23 Electromagnetic Compatibility

Electromagnetic compatibility (always abbreviated to 'EMC') is the ability of various pieces of electrical and electronic equipment to operate without mutual interference. So far as amateur radio is concerned, the object is to achieve good EMC performance: that is, not to suffer from received interference or to cause interference to others.

In practice, the amateur must endeavour to minimise interference caused by his (or her) station and, where appropriate, increasing the immunity of susceptible local domestic radio and electronic equipment. Complementary to this is interference to amateur reception. In recent years this has become increasingly important. The number of potential interference generators in the typical home is increasing all the time and in addition, the transmission of high speed data on cables which are less than optimum from the EMC point of view, may become a serious problem.

Most national administrations have enacted legislation defining minimum EMC standards which products on sale to the public must meet. These standards lay down maximum permitted emitted interference, and also the minimum immunity which equipment must have to unwanted signals. In the UK the standards are issued by the British Standards Institute, and are harmonised to the common standards of the European Community. In general, EMC standards are framed round a normal domestic or industrial radio environment, and fall short of what would be ideal from the radio amateur's point of view. Amateurs tend to generate high field strengths and attempt to receive smaller signals than other radio users in a typical residential area.

So, for the radio amateur, interference breaks down into two major categories:

- Interference caused by operation of the transmitter.
- Interference to reception, usually simply called radio frequency interference or RFI.

INTERFERENCE CAUSED BY THE TRANSMITTER

This is a common occurrence and most amateurs have suffered from it at some time or other. In all too many cases it has been the cause of bad feeling with neighbours. Fortunately, in recent years, the number of cases of serious disagreements with neighbours has declined markedly. This is due to a number of factors one of which is the coming of the EMC regulations which have made EMC a major factor in the design of all types of domestic electrical and electronic equipment. An even more important factor, however, is the appreciation by amateurs themselves of the need to design and operate their stations to minimise all types of interference.

Interference from the transmitter also falls into two categories.

- Interference caused by the legitimate amateur signal, on the normal operating frequency, breaking through into some piece of susceptible equipment. This is usually called breakthrough to emphasise that it is not really a transmitter fault, but rather a defect in the equipment which is being interfered with.
- Interference due to unwanted emissions from the amateur station. The general name for unwanted emissions is spurious emissions.

Nowadays, breakthrough is much more likely to be a cause of interference than spurious emissions, but before jumping to any conclusions carry out a few simple checks.

First consider what sort of equipment is affected. If it does not use radio in any way, then the cause must be breakthrough of some sort. If the susceptible equipment makes use of radio in some way (usually broadcast radio or TV but it could be some form of communication or control device) then the cause could be either breakthrough or a spurious emission from the transmitter. The next step is to find out if the interference only occurs when the equipment being interfered with is tuned to specific frequencies. If so, check whether similar equipment in your own house (or in neighbours' houses) is affected when tuned to the same frequencies. In effect, if your transmitter is radiating a

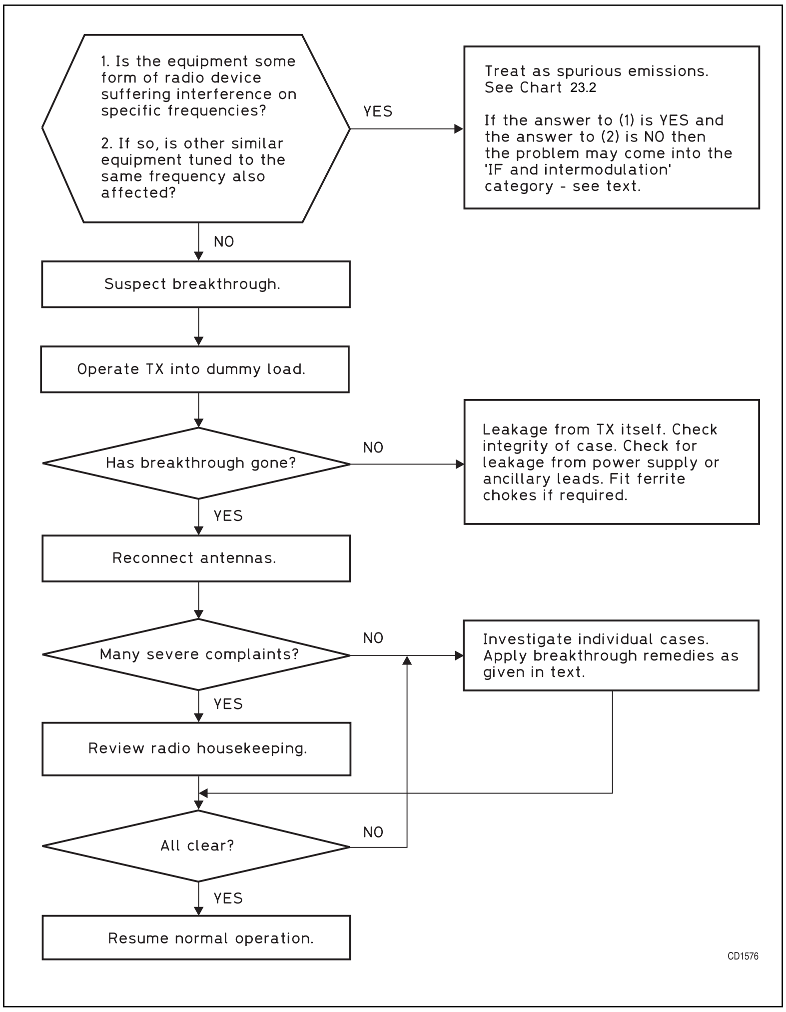

Chart 23.1: Breakthrough

spurious signal, then anything tuned to that frequency is likely to be affected. **Charts 23.1 and 23.2** show the general procedure.

BREAKTHROUGH

All electronic equipment is to some extent vulnerable to strong radio frequency fields and is a potential EMC threat. Any amateur who lives in close proximity to neighbours will have to give some thought to the avoidance of breakthrough. This can be tackled in two ways:

- By installing and operating the station so as to reduce the amount of radio frequency energy reaching neighbouring domestic equipment. The term good radio housekeeping has been coined to cover all aspects of this activity.
- By increasing the immunity of the affected installation to the amateur signal.

Good Radio Housekeeping

The essence of good radio housekeeping is keeping your RF under reasonable control, putting as much as possible where it is wanted (in the direction of the distant station) and as little as possible into the local environment.

It is fortunate that installations designed to achieve this are also likely to minimise the pick-up of locally generated interference - adding a bonus to good neighbourliness.

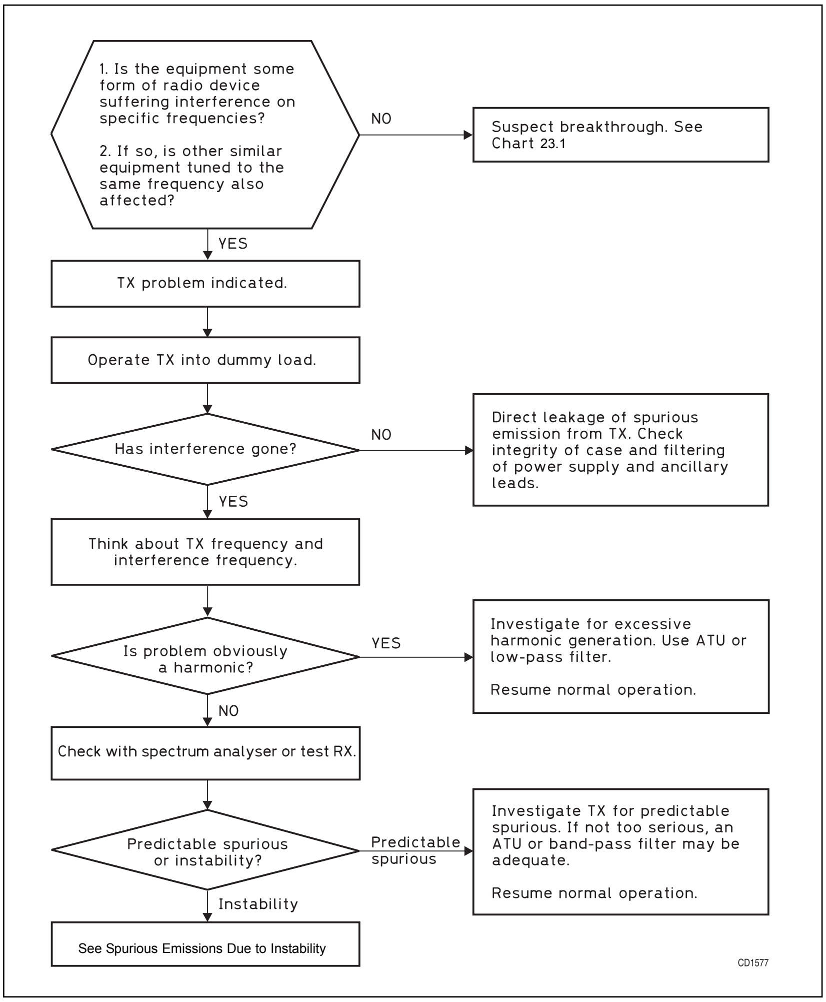

Chart 23.2: 'Predictable' spurious emissions

Where a station is to be installed in a typical urban environment, in close proximity to neighbours, it is essential to plan with EMC in mind

Antennas

It is always good practice to erect any antenna as far from houses as possible, and as high as practical, but for HF operation the relatively long wavelengths in use give rise to special problems. In locations where breakthrough is likely to be a problem, HF antennas should be:

- Horizontally polarised. House wiring and other leads tend to look like antennas working against ground, and hence are more susceptible to vertically polarised signals.
- Balanced, to minimise out-of-balance currents, which can be injected into the house wiring, particularly in situations where a good earth is not practical. These currents will also give rise to unwanted radiation.
- Compact, so that the whole of the radiating part of the antenna can be kept as far from house wiring as possible. Try to avoid antennas where one end is close to the house while the other end is relatively far away. This encourages direct coupling between the near end and the house wiring, inducing RF currents which will be greater than would otherwise be the case.

The sort of thing to aim for is a dipole, or small beam, located at least 15m from the house (and neighbouring houses), and fed with coaxial cable via a balun (**Fig 23.1**). This is not too difficult to achieve above 10MHz, but at lower frequencies

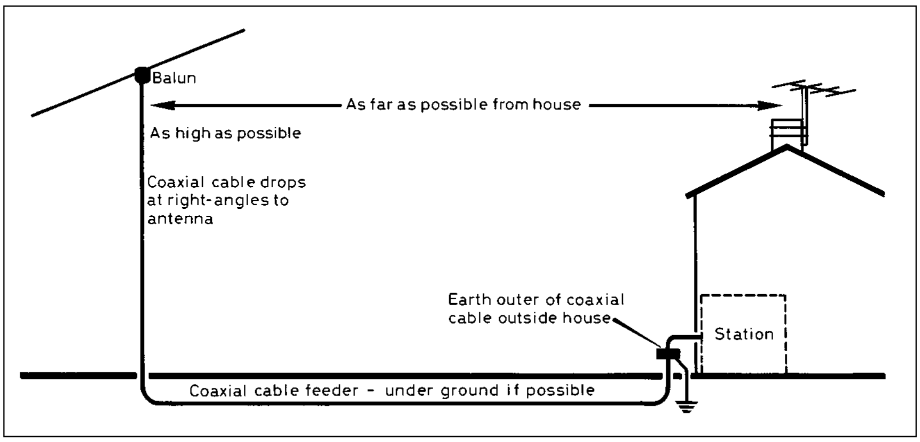

Fig 23.1: Antenna and feeder system with EMC in mind

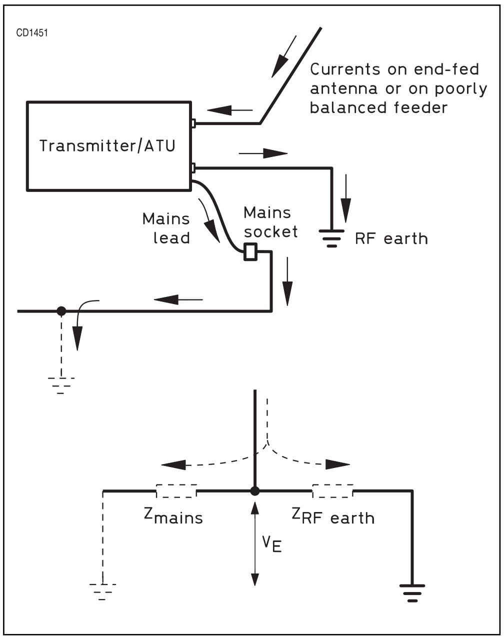

Fig 23.2: Earth current divides between RF earth and mains. The current down each path will depend on the impedances. The transmitter earth terminal will be at V_E relative to 'true' earth potential

a compromise is usually necessary. A balanced feeder can be used, but coaxial feeder is convenient and allows the use of ferrite chokes to reduce any unwanted currents which may find their way on to the braid.

Earths

From the EMC point of view, the purpose of an earth is to provide a low-impedance path for RF currents which would otherwise find their way into household wiring, and hence into susceptible electronic equipment in the vicinity. In effect, the RF earth is in parallel with the mains earth path as in **Fig 23.2**. Good EMC practice dictates that any earth currents should be reduced to a minimum by making sure that antennas are balanced as well as possible. An inductively coupled ATU can be used to improve the isolation between the antenna/RF earth system and the mains earth [1]. The impedance of the mains earth path can be increased by winding the mains lead supplying the transceiver and its ancillaries onto a stack of ferrite cores as described below for breakthrough reduction.

Antennas which use the earth as part of the radiating system - ie antennas tuned against earth - should be avoided since these inevitably involve large RF currents flowing in the earth system. If this type of antenna must be used, arrange for it to be fed through coaxial cable so that the earth, or better some form of counterpoise, can be arranged at some distance from the house.

The minimum requirement for an RF earth is several copper pipes 1.5m long or more, driven into the ground at least 1m apart and connected together by thick cable. The connection to the station should be as short as possible using thick cable or alternatively flat copper strip or braid.

Where the equipment is installed in an upstairs room, the provision of a satisfactory RF earth is a difficult problem, and sometimes it may found that connecting an RF earth makes interference problems worse. In such cases it is probably best to avoid the need for an RF earth by using a well-balanced antenna system.

For more on choosing antennas and earths, see the antenna chapters in this book.

WARNING: Protective Multiple Earthing (PME)

Some houses, particularly those built or wired since the middle 'seventies, are wired on what is known as the PME system. In this system the earth conductor of the consumer's installation is bonded to the neutral close to where the supply enters the premises, and there is no separate earth conductor going back to the sub-station.

With a PME system a small voltage may exist between the consumer's earth conductor, and any metal work connected to it, and the true earth (the earth out in the garden). Under certain very rare supply system faults this voltage could rise to a dangerous level. Because of this supply companies advise certain precautions relating to the bonding of metal work inside the house, and also to the connection of external earths.

WHERE A HOUSE IS WIRED ON THE PME SYSTEM DO NOT CONNECT ANY EXTERNAL (ie radio) EARTHS TO APPARATUS INSIDE THE HOUSE unless suitable precautions are taken.

A free leaflet *EMC 07 Protective Multiple Earthing* is available on request from RSGB, or from the.RSGB EMC Committee web site [7]

Operating from Difficult Locations

If there is no choice but to have antennas very close to the house or even in the loft, then it will almost certainly be necessary to restrict the transmitted power. Some modes are more likely to give breakthrough problems than others, and it is worth looking at some of the more frequently used modes from this point of view.

SSB is a popular mode but also the most likely to give breakthrough problems, particularly where audio breakthrough is concerned.

FM is a very EMC friendly mode, mainly because in most cases the susceptible equipment sees only a constant carrier turned on and off every so often.

CW has two big advantages. First, providing the keying waveform is well shaped, the rectified carrier is not such a problem to audio equipment as SSB. The slow rise and fall gives relatively soft clicks which cause less annoyance than SSB. The second advantage is that it is possible to use lower power for a given contact than with SSB.

Data modes used by amateurs are generally based on frequency-shift keying (FSK), and should be EMC friendly. All data systems involve the carrier being keyed on and off - when going from receive to transmit, and vice versa - and consideration should be given the carrier rise and fall times just as in CW.

Passive Intermodulation Products (PIPs)

This phenomenon is a fairly unusual aspect of good radio housekeeping but one which has turned up from time to time since the early days of radio. Traditionally it is known as the rusty bolt effect. It occasionally causes harmonic interference to be generated by amateur transmissions, but far more often it simply degrades receiver performance without being identified as a problem.

All mixing and harmonic generating circuits use non-linear elements such as diodes to distort the current waveform and hence to generate the required frequency components. A similar effect will be produced whenever the naturally produced semiconductor layer in a corroded metal joint forms an unwanted diode. These unwanted diodes are usually most troublesome in the antenna system itself, particularly in corroded connectors. In the case of a single transmitter the effect simply causes excessive harmonic radiation, but where two or more transmitters are operating in close proximity the result can be spectacular intermodulation product generation. On receive, the result is much-reduced receiver intermodulation performance, and in severe cases there will be a noticeably high background noise level which consists of a mishmash of unwanted signals. The best way to avoid troubles of this sort is to keep the antenna system

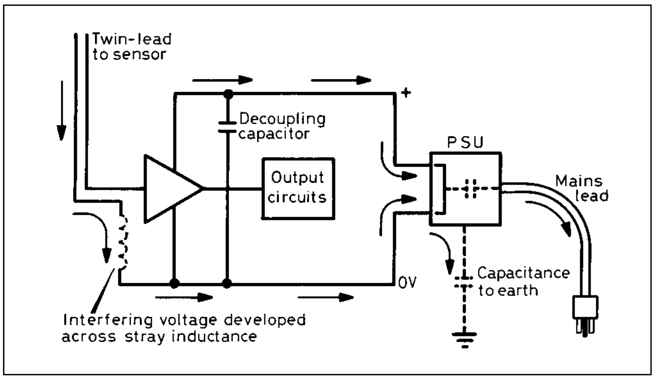

Fig 23.3: Path of RF signal in a typical sensor/alarm device

in good repair and to examine all connections every few months. PIPs can be generated in corroded metal gutters and similar structures not directly associated with the antenna system. The solution is to clean up or remove the corroded metalwork or, where this is not possible, to short-circuit the corroded junctions with a conductive path. It is obviously good practice to keep antennas away from doubtful metalwork.

Dealing with Breakthrough at the Receiving End

Breakthrough is simply unwanted reception, and the basic mechanism by which signals are picked up is the same as for any other reception. Breakthrough can occur to such a wide range of equipment that for the sake of general discussion it is simpler to assume some non-specific device, in other words a black box.

For signals to get into our black box, they must be picked up on a wire which is a significant fraction of a wavelength long, which means that on HF the external leads are the most common mode of entry and direct pick-up by the equipment itself is unlikely unless the transmitter field strength is very high. At frequencies above about 50MHz pick-up by wiring inside the black box becomes more likely but only if the box is made of non-conducting material.

Fig 23.3 shows how unwanted RF signals might get into the black box - in this case, some sort of alarm circuit is assumed with a sensor connected by twin cable, and an amplifier and power supply inside the box. The sensor lead acts as a crude earthed antenna so that electromagnetic energy from the transmitter causes currents to flow in the antenna formed by the sensor lead, through any stray impedance between the input connection and the 0V rail, and through the power supply to earth. These currents are called common-mode currents because they flow on both conductors in the cable in phase - in effect they act as if the pair of wires were one conductor. The wanted signals are differential, flowing in one direction on one wire, and the reverse direction in the other. Common-mode and differential currents are illustrated in **Fig 23.4**.

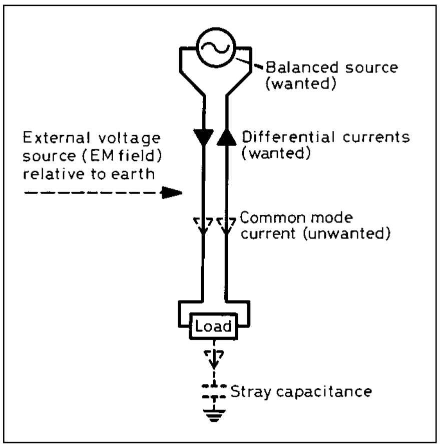

Fig 23.4: Differential-mode and common-mode currents

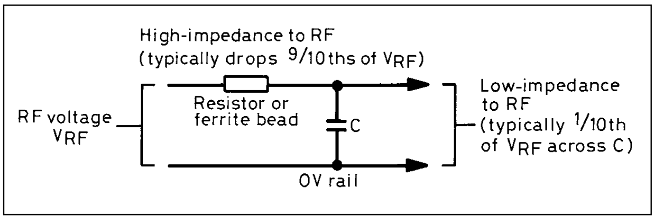

Fig 23.5: The principle of by-passing or decoupling

The key to avoiding breakthrough is to prevent the unwanted signals picked up on the external lead from getting into the circuits inside the box. There are two ways of doing this:

- Bypass the unwanted RF by providing a low-impedance path across the vulnerable input circuit.
- Use a ferrite choke to increase the impedance of the unwanted antenna where it enters the black box, effectively reducing the currents getting into the sensitive internal circuitry.

Bypassing the unwanted RF

The principle of bypassing is to arrange for a potential divider to be formed in which the majority of the unwanted signal is dropped across a series impedance, as shown in **Fig 23.5**. In some instances the series element may be a ferrite bead or, where circuit conditions permit, a low-value resistor, but in many cases no series element is used and the stray series impedance of the lead provides the series element. A ceramic capacitor with a value in the region of 1 to 10nF would be typical. It is important to keep the leads as short as possible, and to connect the 'earthy' end of the capacitor to the correct 0V point - usually the point to which the amplifier 0V is connected, and to which the inputs are referred. ('0V' in this context has much the same meaning as 'ground', but avoids any confusion with other meanings of 'ground' used in radio discussions such as in 'capacitance to ground' etc.)

Generally, bypassing is not very practical in domestic situations and is included as food for thought for anyone building their own equipment. It is inadvisable for the amateur to attempt to modify commercial equipment unless he (or she) has expert knowledge - in particular, never attempt to modify equipment belonging to someone else.

Ferrite chokes

Ferrite chokes are also used to form a potential divider to the unwanted RF currents, though in this case the series impedance is increased outside the black box, and the stray capacitance or resistance inside the box forms the shunt element (**Fig 23.6**).

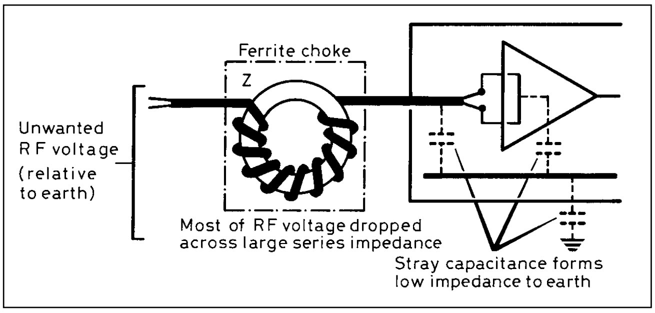

Fig 23.6: The series choke. The impedance of Z forms a potential divider with stray capacitance

The great benefit of this technique is that it does not involve any modification inside the box. All that is required is to wind the susceptible lead on to a suitable ferrite core. Ferrite cores which are designed for EMC purposes have a reasonably high permeability, which is combined with a relatively high loss at the frequencies of interest. This enables a high impedance to be achieved without resonance effects becoming dominant. Further information on core types will be found in Appendix 3 of [1] and in [2].

A very important feature of this type of ferrite choke is that it acts only on the common-mode interfering currents - differential-mode wanted signals will not be affected. The go and return currents of the differential signal are equal and opposite at any instant, and so their magnetic fields cancel out (except in the space between the wires) and there is no external field to interact with the ferrite.

The most popular core for EMC use is the toroid or ring, because the ring shape means that the magnetic field is confined inside the core, giving a relatively high inductance for a given material. Where a toroid cannot be used, either because the lead is unusually thick, or because large connectors cannot be removed, it may be possible to use the ferrite yoke deflection assembly from a scrap TV set. (Take great care when removing a scrap yoke assembly. Imploding CRTs can cause serious injury. In addition the EHT connection can be at high potential due to stored charge long after the power has been switched off.) In some circumstances split ferrite cores can be used. Another option is to wind the lead on a length of ferrite rod such as that used for medium-wave radio antennas, though in this case large number of turns will be required. Further information can be found in Appendix 3 of [1] .

How many turns?

The inductance of a ferrite ring choke is proportional to the length of ferrite through which each turn passes (ie the thickness or 'depth' of the ring) and also to the square of the number of turns. Traditionally cores about 6.5mm thick have been used, two of these being stacked to give an effective thickness of 13mm or so. To make a choke for HF frequencies, 12 to 14 turns on two such rings should be satisfactory. For VHF, fewer turns should be used - about seven turns on a single ring will be effective at 144MHz. At the time of writing the ferrite cores available from the RSGB are about 12.7mm thick so that one of these rings is equivalent to two of the thinner rings. It is most important to use the correct type of ferrite ring. There is a very wide range of ferrite materials, and some rings are unsuitable for EMC purposes. The simplest way to ensure that the correct rings are obtained is to purchase them from a reliable supplier, advertising rings specifically for EMC purposes. Ferrite rods require more turns (20 or more) to make an effective choke, and are generally only effective above 20MHz.- see Appendix 3 of [1].

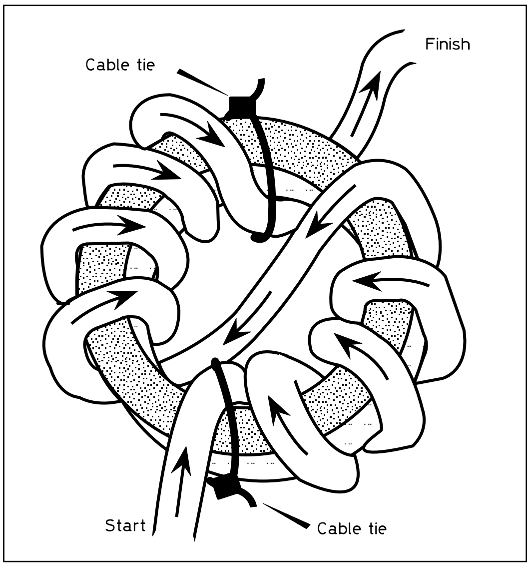

Fig 23.7: Winding a ferrite choke for minimum shunt capacitance

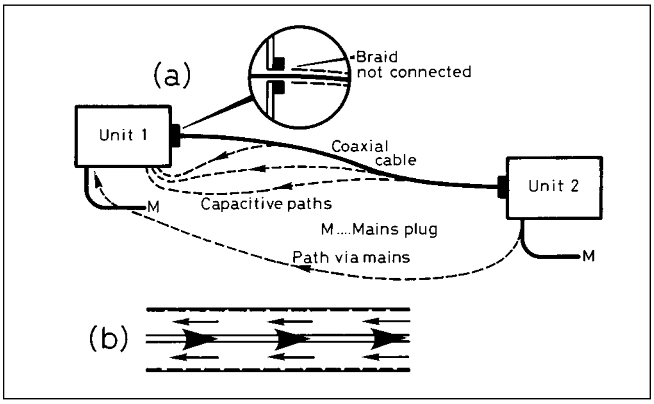

Fig 23.8: (a) Broken braid connection causes the current which would normally flow on the inner surface of the braid to return by random paths. (b) In a correctly connected coaxial cable the currents balance, giving no external field

The shunt capacitance across a ferrite ring choke can be minimised by winding the core as in **Fig 23.7**.

Breakthrough to TV and Video Equipment

TV installations started to become more complicated in the early eighties, with the coming of the domestic video cassette recorder (VCR). Since then we have seen satellite TV and digital terrestrial TV. This means more interconnections between the various units and "set-top" boxes. It is no longer realistic to talk of a typical TV installation and the following discussion assumes a simple installation with TV set and a video recorder to illustrate the way in which breakthrough occurs. In general the mechanism in more complex installations is basically the same.

In any TV installation, the most vulnerable point is the antenna input, and in the majority of cases eliminating unwanted signals at this point will clear up the problem. The most common route for the unwanted signals to get in to the set is via the braid of the coaxial feeder. The small size of UHF TV antennas makes it unlikely that large interfering signals will be picked up on the antenna itself, unless the frequency is relatively high - above about 100MHz or so.

First have a look at the general installation. Are the coaxial connectors correctly fitted with the braid firmly gripped and making good electrical contact with the outer connection of the plug? Ideally the centre pin of antenna connectors should be soldered, to avoid poor contact, but in most installations it will not be. Corrosion of the connector at the end of the cable coming down from the antenna may indicate that water has got into the cable; the commonest cause is chaffing or splitting of the sheath, though it could be a failure of the seal at the antenna itself.

In a complicated installation comprising several units, make sure that all connectors are correctly mated, and that coaxial leads are correctly 'made-off' with the braid properly connected. In many cases, equipment will work satisfactorily with the braid of an interconnecting cable disconnected. In this case the return path for the signals in the cable is via random earth paths through other parts of the system. This reduces the immunity of the installation to breakthrough, and allows the leakage of radio frequency interference (**Fig 23.8**).

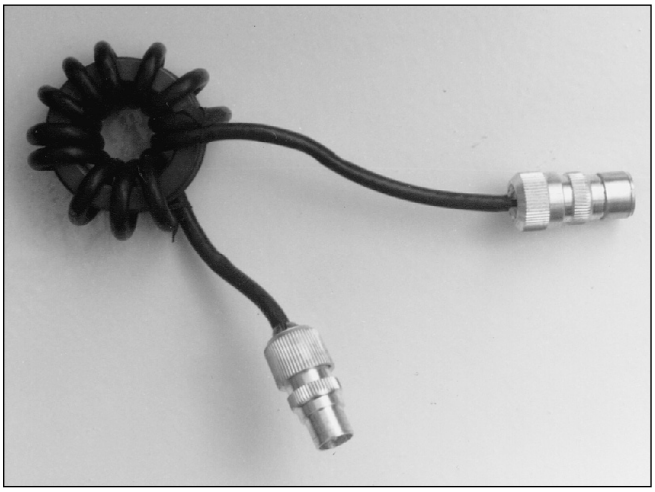

Fig 23.9: A ferrite ring choke suitable for TV coaxial down lead

TV antenna amplifiers

A well-designed masthead amplifier which is correctly installed, close to the TV antenna, is unlikely to give problems at HF because the length of cable, before the amplifier, is short compared to the wavelength of the amateur signal, but at VHF the conditions could be very different.

Problems arise if the unwanted signal reaching the input to the amplifier is large enough to drive it into non-linearity and cause cross-modulation. Masthead amplifiers get their DC power supplies through the coaxial feeder, so that any filters or braid-breakers must pass (and not short-circuit) the required DC supply. Unless specific information is available, it is best to use only ferrite-ring chokes in the down leads from such amplifiers.

Indoor amplifiers are much more likely to cause problems, especially where HF is concerned, but fortunately they can be easily removed from the circuit for test purposes. Many amplifiers have several outputs, allowing more than one set to be operated from the same TV antenna. If the amplifier has to be retained in the installation it should be considered as part of the TV set (or sets), and the standard techniques, using chokes and filters, on the antenna side of the amplifier will still apply.

TV amplifiers vary in input bandwidth. Some will accept all signals from about 40MHz and below up to the top of the UHF TV band. Others are designed for UHF only. In countries such as the UK where all terrestrial TV is on the UHF bands it is obviously better to choose a UHF only amplifier.

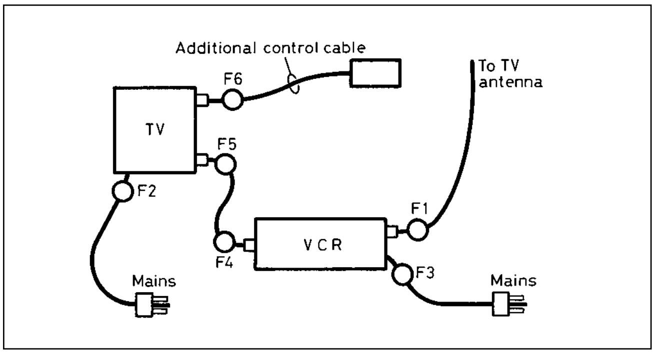

Fig 23.10: Typical domestic TV installation, showing positions of ferrite chokes. F1: antenna coaxial feeder choke (or filter). F2/F3: mains chokes. F4/F5: coaxial chokes on RF lead (VCR to TV). F6: Choke on additional leads to controls or external speakers or displays

Chokes and filters for TV installations

The simplest way of choking-off signals travelling down the braid is to use a ferrite ring choke; used in this way it is often called a ferrite-ring braid-breaker. The low-loss cable commonly used for UHF TV is not suitable for winding on to the core. It is best to make the choke separately, using a length of smaller-diameter coaxial cable, with suitable TV connectors at each end. Fig 23.9 shows a choke for HF breakthrough. The coaxial cable used for the choke should, of course, be 75 ohms , but there is no need to use low-loss cable since the length involved is quite short.

Braid-breakers and filters are available from a number of commercial manufacturers, and these are usually effective provided that the correct type is used. Some devices are simply braid-breakers, with no filtering of signals travelling down the inside of the coaxial cable, while others include high-pass or band-stop filters optimised for specific bands, so it is important to study the specification before making a decision. In some instances it may be necessary to use two devices (for instance, a braid-breaker in series with a high-pass filter) to achieve the desired rejection. Further information on braid-breakers and filters can be found in Appendix 3 of [1] and in [2].

The RSGB stocks suitable braid-breakers and filters. Information can be found on the Society's web site, http://www.rsgb.org.

Fitting the chokes and filters

Try the chokes and filters in order, starting with the antenna choke (F1 in Fig 23.10). Do not remove a device if it does not seem to work - in many cases of breakthrough, the unwanted signals enter the installation by more than one route, and the observed interference is the result of the signals adding or subtracting. If a ferrite choke is only partially successful, another should be tried in series to increase the rejection, but it is usually not worthwhile to go beyond two. When the sources have been identified, chokes which are not needed can be removed.

The chokes fitted to the mains leads (F2 and F3 in Fig 23.10) are made by winding the cable onto ferrite rings in the same way as for a braid-breaker. It goes without saying that in this case it is essential to avoid damaging the cable in any way. If the cable is unusually thick it may be necessary to use fewer turns and more rings.

Due to the closed magnetic circuit in a toroidal core, it is not necessary to pull the cable tight onto the ferrite material - all that is required is for the winding to be secure and the ends not too close together.

Modern TV installations usually use a SCART cable to connect the VCR or set-top box to the TV set. This is to be preferred from the EMC point of view. If an RF link is used it may be necessary to fit chokes on either end of the coaxial cable between the VCR/set top box and the TV set, depending which unit is susceptible. Where it is necessary to fit a ferrite choke to a relatively thick lead such as a SCART lead, it may be possible to use a ferrite yoke from a scrap TV set. (See "Ferrite chokes" above).

Radio and Audio Equipment

In general the approach to radio and audio problems is the same as that for TV, though there are differences of emphasis. Interference caused by the braid of the antenna feeder acting as an unwanted antenna is still a serious problem, but the larger elements on a VHF broadcast antenna make direct pick-up of interference (which is then passed down the feeder in the normal way) more likely.

The leads to the remote speakers of a stereo system frequently pick up interference and this can usually be cured by winding the appropriate number of turns on to a ferrite ring (or pair of rings) to form a choke at the amplifier end of the lead. Where this is not possible, a split core or a ferrite rod can be used.

Where breakthrough to a portable radio is experienced, there is not very much that can be done from the outside of the set since there are no external leads to choke. However, it is often possible to move the set to a position where the interference is negligible. Frequently portables only give trouble when operated from the mains, and in this case a ferrite choke in the mains lead is likely to be effective.

IF and Intermodulation Breakthrough

In many cases of interference to radio and TV, breakthrough is caused by overloading RF circuits or by rectified RF affecting audio or control circuits. In addition, radio and TV sets can suffer from more subtle forms of breakthrough. These fall into four categories:

- IF breakthrough, where the IF of some piece of radio equipment falls in or near an amateur band. The most common example is a transmission on the 10MHz band getting into the 10.7MHz IF of a VHF receiver. This is breakthrough caused by insufficient IF rejection in the receiver.
- IF breakthrough caused by harmonics of the amateur transmitter being picked up in the receiver IF, for example, the second harmonic of the 18MHz band entering the IF of a TV set. (The standard TV IF band in the UK includes 36MHz.) A less likely possibility is the third harmonic of 3.5MHz entering the 10.7MHz IF of a VHF receiver. In cases of this sort the fault lies with the transmitter which is radiating too much harmonic energy - it is no excuse to say that the susceptible receiver should be better designed.
- Image interference. This where a signal on the 'wrong side' of the local oscillator beats with it to give the IF. It is fairly common on the 1.8MHz band, where amateur signals give image responses on medium-wave receivers. For instance, a receiver with a 455kHz IF, tuned to 990kHz (303m) would have a local oscillator of 1445kHz. This would beat with a strong amateur signal on 1.9MHz, which would be tuned in on the medium-wave band like any other signal. This is a case of breakthrough caused by poor image rejection of the susceptible receiver.
- Amateur signals intermodulating with the harmonics of the local oscillator or other oscillators in the susceptible equipment, causing spurious responses. These give rise to interference may be tuneable at the receiver, but is nevertheless a case of breakthrough.

Security Systems

Breakthrough to security systems has become a problem in recent years. Experience has shown that the standard breakthrough measures such as ferrite chokes and by-pass capacitors, are rarely effective. The most usual cause of breakthrough to security systems is poor immunity in the passive infra red sensors (PIRs). The solution is to replace the offending units with ones which are more immune to RF signals. Occasionally the control panel has been found to have insufficient immunity, but this is unusual. More information will be found in the RSGB's leaflet EMC 03 *Dealing with alarm EMC problems* [3]. The best place to find up to date information on security system problems is the 'EMC' column of *RadCom*.

Most security systems are professionally installed, and it is up to the installer to ensure that it is sufficiently immune to operate in the environment in which it is installed. A well installed system with suitably immune PIRs is unlikely to be affected by an amateur station practising reasonable radio housekeeping.

If a complaint of breakthrough to a security system is received, it is advisable to be open with the complainant and to carry out checks to see exactly what the problem is. As in all breakthrough problems check your station and your radio housekeeping, before going any further. Once you are sure of the problem, advise the complainant that the installer should be approached, and give them a copy of the RSGB's Leaflet EMC 02 *Radio Transmitters and Home Security Systems* [4].

All new installations should be using CE marked units, including the PIRs, though the mark may not always be on the unit itself. It could be on the instruction or on the packing.

Breakthrough to Telephones

The main problem with modern telephones is breakthrough, caused by rectification and amplification of RF currents, and the solution is to avoid the RF getting into the equipment in the first place. There are two courses of action:

- First check your radio housekeeping.
- Prevent common-mode interfering currents getting into vulnerable circuits by fitting ferrite chokes as close to the susceptible units as possible.

Most households have extension telephones connected by plug and socket to the 'line jack' provided by the telephone company and these may involve quite long lengths of interconnecting cable. At the start of an investigation, unplug any extension units and their cables, leaving only the instrument near the line jack connected. Clear any breakthrough on this, and then reconnect the extension leads and telephones one by one, dealing with breakthrough problems as they arise. In some cases it may be necessary to re-route vulnerable extension leads, but in most cases liberal use of ferrite chokes will prove effective. Some telephones may have unusually poor immunity. If this is suspected check by substituting a known good unit. In such cases replacing the telephone may be the most practical option.

Breakthrough may be caused by signals being picked up on the lines before they come into the house. Commercial filters are available which fit into the master line jack, but at the time of writing the only one available in the UK is really intended to deal with medium wave broadcast signals and is only effective on the lower HF bands. However the 'microfilters' used for self-install ADSL have characteristics which might make them useful in cases of HF breakthrough [5]. Where it is suspected that the problem is due to a fault on the lines themselves, contact the authority responsible for the lines, but before doing this it is important to ensure that your radio housekeeping is in order and that you are operating reasonably with regard to all the circumstances.

Breakthrough to Internet Access Systems

This is a very quickly developing field. At the time of writing there are three types of access system:

- Fibre and cable systems
- Radio systems using frequencies above 1GHz.
- Systems which use the telephone lines.

The first two of these do not appear to give rise to many problems. It remains to be seen whether there will be problems should the use of these systems become more widespread.

The dial-up modem which was once the most popular means of internet access is being replaced by DSL systems. DSL stands for Digital Subscriber Line and there is a whole family of DSL systems. The common one in the UK is ADSL. There have been few cases of breakthrough to dial-up modems reported and even fewer to ADSL systems, even though there are now millions of ADSL installations in the UK. It is possible that, in future,

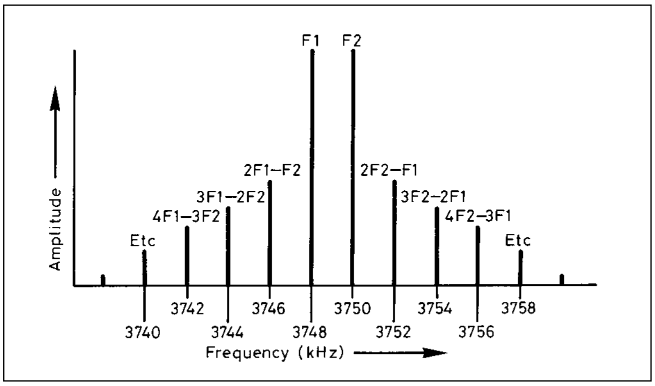

Fig 23.11: Odd-order 'intermods' from a tow-tone SSB signal on the 3.5MHz band

enhanced DSL systems using a wider RF bandwidth might give rise to breakthrough problems. The best place to look for the latest information is in *RadCom* and on the RSGB web site.

INTERFERENCE CAUSED BY UNWANTED EMISSIONS FROM THE TRANSMITTER

As mentioned above, where interference is caused by spurious emissions from a transmitter, the interference can only be to equipment which uses radio in some way, and will be evident on similar equipment in the vicinity which is tuned to the same frequency. This is in contrast to breakthrough which is dependent on the susceptibility of the 'victim' equipment rather than any defect in the transmitter.

Spurious emissions fall into two major categories:

- Predictable spurious emissions which are generated as part of the process of carrier generation, and hence are (at least in principle) predictable.
- Oscillations caused by faults in the design or construction of a transmitter. These give rise to unexpected emissions which can occur on almost any frequency. This is known as instability.

Predictable Spurious Emissions

The commonest predictable spurious emissions are harmonics of the carrier. These harmonics are simply a measure of the distortion of the sine wave which constitutes the carrier; an absolutely pure sine wave would have no harmonic content. In practice the object is to generate a carrier which is as undistorted as possible, and where necessary to filter it so that harmonics are kept to a negligible level.

The other major class of spurious emissions is the products caused by multiplication and mixing processes in the transmitter. In almost all modern transmitters the carrier is generated by mixing the outputs of oscillators (fixed and variable) to produce the final frequency. In most cases there are several mixer stages and at each stage unwanted products will be generated as well as the wanted signals.

The secret of good design is to make sure that unwanted products are at frequencies widely separated from the wanted signals so that they can be readily filtered out. As with harmonics, the object is to ensure that everything except the wanted output is attenuated to a negligible level.

How small 'negligible' is depends on the frequency bands in use and the power of the transmitter. As a general rule on HF, harmonics should be at least 50dB, and other spurii at least 60dB, below the carrier. On VHF the figures should be 60dB and 80dB respectively.

There is another class of predictable spurious emissions, and this is splatter - the generation of unwanted intermodulation products by the modulation process in an SSB transmitter. The important intermodulation products are the odd-order products because they appear close to the carrier and hence cannot be filtered out. (See also the Building Blocks chapters.) There will always be some intermodulation products generated in any SSB transmitter, and the object is to design and operate the transmitter in such a way that they are kept within reasonable bounds. About 35 or 40dB down on the carrier is a reasonable target to aim for (see **Fig 23.11**).

Identifying and Rectifying Predictable Spurious Emissions

Interference caused by harmonics of a transmitter can usually be identified by consideration of the frequencies on which interference is evident and the frequency on which the transmitter is operating. For instance, if the problem is interference to a VHF broadcast signal on 100.5MHz when the transmitter is operating on 50.25MHz, then it is very likely that second-harmonic radiation is the culprit. Where excessive harmonic radiation is suspected, first check the transmitter and its adjustment and, if the problem persists, fit a low-pass filter as in **Fig 23.12**. Note that the filter comes after the VSWR meter and, where an ATU is used, it should come after the filter.

With non-harmonic spurious emissions (which are often just called spurious, spurii or spurs) the situation is more difficult. The best procedure is to set up some way of monitoring the output from the transmitter to see if any excessive spurious signals are present. If a spectrum analyser or measuring receiver is available the task will be simple, but in most cases resort will have to be made to a general-coverage communications receiver. This can be used to tune round the frequencies on which interference is experienced while the transmitter is operated.

All receivers have spurious responses which can be difficult to differentiate from transmitted spurious emissions, and these will become much worse if the receiver is overloaded. Make sure that the signal from the transmitter, as received on the test receiver, is not greater than about S9 plus 20dB; this will avoid overloading and at the same time enable fairly weak spurious signals to be detected. Once the spurious signal has been identified, the transmitter should be investigated; the frequency of the spurious signal will often indicate the stage which is likely to be at fault. Where the problem is not too severe, using an ATU on HF or a suitable band-pass filter on VHF may be all that is required.

If a spectrum analyser or a measuring receiver is available it should be connected up as in **Fig 23.13**. It is good practice to start with more attenuation than is expected to be required and

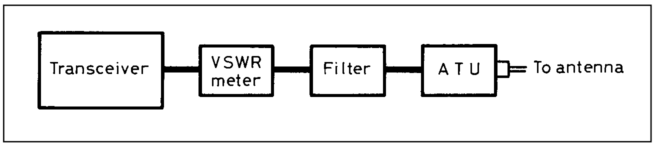

Fig 23.12: Position of the filter. The ATU ensures that the filter sees a 50-ohm load

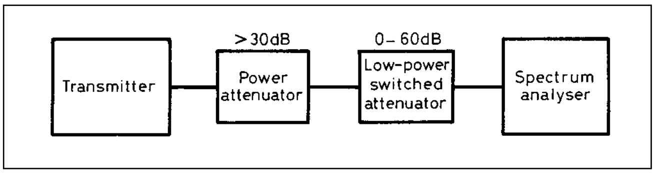

Fig 23.13: Connecting a spectrum analyser to a transmitter

to remove it to establish the desired level. Remember that the attenuator connected to the transmitter must be capable of handling the full transmitter power. More information on suitable high-power attenuators will be found in Chapter 6 of [1].

Where a communication receiver has to be pressed into service, it will probably be simpler to set up the receiver with a short antenna some distance from the transmitter. In such an arrangement the magnitude of any spurious signals detected will be dictated by the antenna characteristics at the receiver, but the technique will none the less be adequate to show up serious spurious emissions.

Spurious Emissions Due to Instability

This is caused by unintentional feedback in some stage of a transmitter causing oscillation. Instability also falls into two categories:

- Direct instability where feedback in one of the amplifying stages of the transmitter causes oscillation on or near the normal operating frequency.
- Parasitic oscillation, where incidental inductance and capacitance cause oscillation at a frequency far removed from that at which the circuit would normally operate.

Both these effects are serious but direct instability is perhaps the most dangerous because it can result in very large spurious signals being generated at a frequency where the antenna can be expected to be a good radiator. In very bad cases the spurious signal can be comparable with the normal output power, causing widespread interference. Fortunately both types of instability are rare in modern, well-designed, transceivers but care should be exercised when repairs have been carried out. This is particularly true where power transistors have been replaced with 'near-equivalents'. The way to avoid instability is by employing good design and construction, with particular reference to layout, screening and decoupling. Where appropriate, parasitic stoppers should be included. See the chapters on transmitters.

Evidence of instability

The two main indicators of instability are bad signal reports and erratic operation of the transmitter. If instability is suspected and suitable test gear is not available, the best procedure is to arrange for a report from someone who can receive you at good strength, and who knows what they are looking for. Ask them to look as far either side of your signal as possible, looking for unstable signals coming and going in sympathy with your main signal. Vary the drive and loading conditions of the transmitter - though in some modern transceiver the ability to do this may be limited. It is important to remember that a transmitter may be stable when operating into a good 50 ohm load but unstable when connected to an antenna.

Erratic operation usually means that the RF output and power supply current varies unpredictably as the drive is varied or as the ATU is tuned but, before jumping to the conclusion that the transmitter is faulty, make sure that the problem is not caused by poor station lay-out. It is not uncommon for RF from the transmitter to find its way into the power supply, or into ancillaries. This can cause very erratic operation. In a modern commercial transceiver, which is normally well behaved, this is more likely to be the cause of erratic operation than instability in the transceiver itself. Check the antenna/earth arrangements, and review your radio housekeeping - see Chapter 3 of [1].

Frequency halving

A spurious emission which doesn't come into either of the above categories is frequency halving. This occurs in bipolar transistor power amplifiers, when the input and output conditions are such that the parameters of the device are modified between one cycle and the next. The result is a significant output at half the input frequency. The practical effect is that an output at half frequency appears at certain tuning conditions. Divisions other than two are possible but less common. Harmonics are also present in the output and often the most obvious symptom of this effect, is a 'harmonic' at one and a half times the nominal frequency. When tuning a VHF power amplifier into a dummy load, it is advisable to make sure that it is tuned well away from any frequency halving condition otherwise a change of load, such as connecting an antenna, may cause it to change to the halving condition.

INTERFERENCE TO RECEPTION (RFI)

Background Interference Level

On HF there will always be noise picked up by the antenna, however well it is sited - this is usually called the ambient noise. This noise may be either man made or natural, and in most cases is much greater than the thermal noise generated in the front-end of the receiver. The 'bottom line' of this noise is the galactic noise plus the natural static from atmospheric discharges which are always taking place somewhere in the world and are propagated by the ionosphere. Added to this is the man made noise from electrical and electronic devices of various sorts. As frequencies rise into the VHF region, the external noise reduces and becomes 'whiter', until above about 100MHz the thermal noise in the receiver front-end predominates.

There is a great deal of misunderstanding about the ambient noise level on the HF bands. A casual measurement using the 9kHz bandwidth, usually used for EMC measurements, could give the impression that the noise level is so high that relatively high levels of broadband emissions would not cause a significant problem. Arguments such as this have been used in attempts to justify relaxations of the EMC standards. However this is a complete misunderstanding of the HF electromagnetic environment.

Sources of noise in typical residential location tend to fall into two broad categories. Firstly there are the traditional sources such as motors and other sparking devices. Sometimes these can cause quite high levels of interference but in most cases they are in use for only a limited time. The other category is interference from electronic equipment such as computers. In this case the interference may be present for a large part of the day,

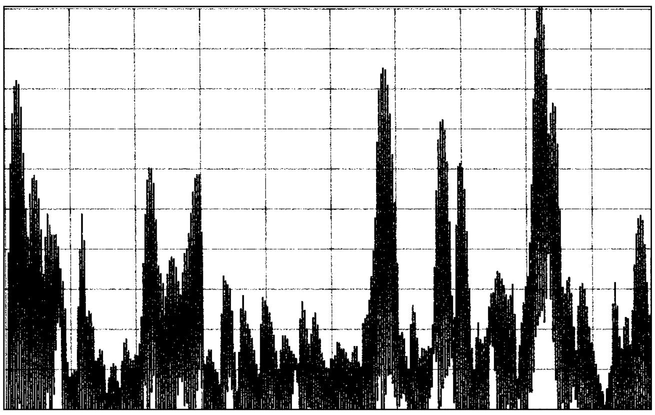

Fig 23.14: Plot taken in the 9kHz IF bandwidth of a measuring receiver tuned to 7.025MHz. Resolution bandwidth 100Hz; vertical scale 5dB/division; horizontal scale 1kHz/division. The bottom line of the graticule represents -15dBµV (-122dBm) at the receiver input. The antenna was an inverted-V dipole

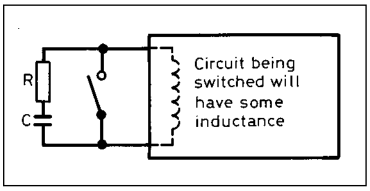

Fig 23.15: A resistor and capacitor used to absorb the energy released when contact is broken

but usually the interference approaches the maximum level permitted by the EMC standards only on a few narrow frequency bands. The upshot is that, if the ambient noise is observed on a reasonably sited antenna such as that illustrated in Fig 23.1, a "floor" will be seen consisting of the natural noise, mentioned above, plus an aggregate of distant man made sources. This is fairly constant in any location and has been called the ambient noise floor. To this will be added occasional bursts of higher level broadband interference from local sources, and discrete emissions from computer-like sources, which may or may not fall into the frequency band of interest.

A typical example might be the 7MHz amateur band in a reasonably quiet suburban location around about midday. In an audio bandwidth, the floor of the noise might be in the region of -110dBm. **Fig 23.14** illustrates this. The plot is taken from a spectrum analyser connected to the IF output of a measuring receiver tuned to 7.025MHz. The IF bandwidth of the receiver is the 9kHz "CISPR" bandwidth normally used for HF EMC measurements. This is displayed at 1kHz per division, with a resolution bandwidth of 100Hz. The plot was taken on a Sunday morning, in a typical suburban location.

HF communication services such as amateur radio has grown up coping with localised, intermittent, wideband noise bursts or with discrete emissions, but widely distributed continuous high levels of broadband interference such as might be generated by inappropriate broadband data transmission technologies would be a very much more serious problem.

It is a general rule of radio that good transmitting antennas are also good receiving antennas but, so far as HF is concerned, this is modified by the fact that the ambient noise sets a limit to small-signal reception. For HF reception it may be better to mount a relatively poor antenna in a good location than to have an efficient antenna mounted where the man made noise is high. In difficult situations a relatively small active antenna mounted high up and well away from noise sources may out-perform a much larger antenna which cannot be so well sited - see Chapter 7 of [1]. Tips on identifying and tracking down sources of interference can be found in the leaflet *Interference to amateur Radio Reception* EMC 04 [6]

Suppressing Interference at Source

Impulsive interference

Where mechanical contacts are concerned, there are a number of well-tried remedies based on the principle of absorbing the energy which would otherwise be released when the contact is broken. The energy is initially stored in the magnetic field, due to the normal operating current flowing in any inductance which may be present in the circuit, and in many cases this will be considerable. When the contact is broken, the magnetic field collapses and a large voltage appears for a short period as the contacts open, causing a spark. Radio frequency currents are exchanged between the inductance and capacitance in the vicinity of the contact, using the ionised air of the spark as a bridge.

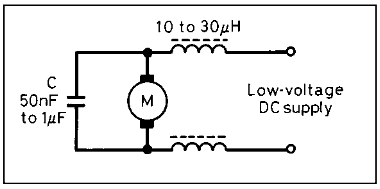

Fig 23.16: Suppressing a small low-voltage DC motor

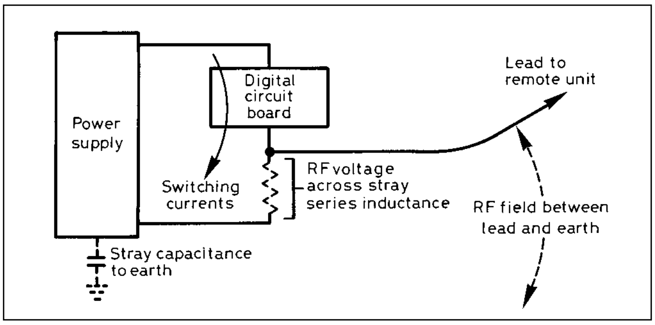

Fig 23.17: External lead, nominally at 0V, acting as an unwanted antenna

The traditional way of absorbing the energy is to connect a resistor and capacitor across the contacts as in **Fig 23.15**. This effectively quenches the spark, by dissipating the unwanted energy in the resistor. The capacitor should be between 0.01 and 0.1µF and the voltage rating must be several times the voltage being switched. Special capacitors rated for use on AC mains are available, and these must always be used where mains voltages are involved. Units containing a resistor and capacitor in one encapsulated unit can be purchased from component suppliers.

Small, low-voltage DC motors can be suppressed by using a shunt capacitor of between 0.05 and 1µF, and series ferrite cored chokes of 10 to 30µH, as in **Fig 23.16**. The chokes are more effective at higher frequencies, and may not be required if only low frequencies are involved. Mains motors are best dealt with by purchasing a suitable mains filter. This should be installed as close to the machine as practical.

Interference from digital equipment

It is relatively easy to reduce the leakage of interference from digital equipment at the design stage - it is really a matter of good engineering practice. Good decoupling and the provision of a substantial ground plane for the common 0V rail is a good start. It is important to prevent external leads having energy coupled into them from shared return paths, and so acting as antennas (**Fig 23.17**). Ideally, interference-generating circuits should be completely screened. The screen should be connected to the common 0V point through a path which has the lowest possible impedance. Leads should be decoupled where they pass out through the screen.

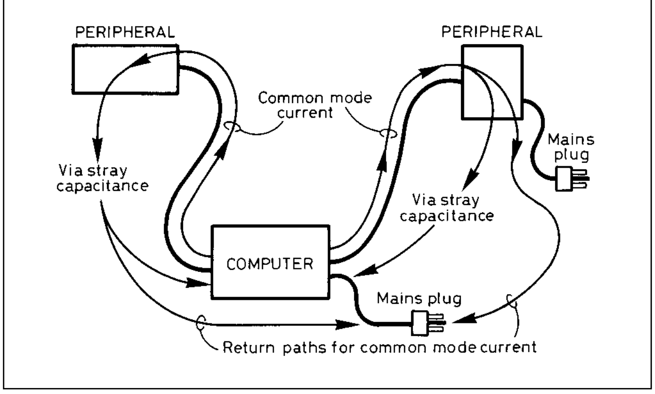

Fig 23.18: Common-mode current paths

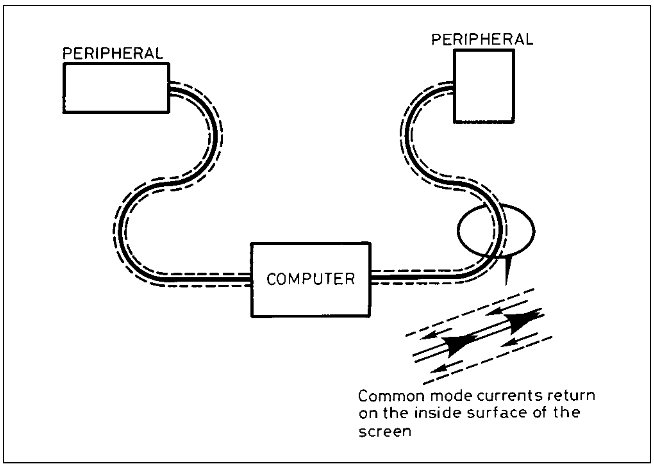

Fig 23.19: Screening confines common mode currents

In situations where interference reduction is a major factor, for instance where digital control circuits are actually part of the receiver, special attention should be paid to screening and feedthrough capacitors should be used on all leads except those carrying RF. It is important to choose the correct value - too large a capacitance will distort fast digital signals. So far as possible, the screen should be continuous and, where there are any joints, there must be good electrical contact along the mating surfaces.

Interference from computer installations

Most modern computer installations are put together from units complying with the requirements of the relevant EMC standards. If the various units are connected together using, good quality screened leads, then the EMC performance should at least be reasonable. At HF frequencies most RFI problems are caused by common-mode currents flowing on the interconnecting leads, as illustrated in Fig 23 18. Where a screened lead is used to connect two units together, the screen has two functions. As might be expected, it does reduce radiation by forming an electrostatic screen around the conductors, but more importantly it provides a low-impedance path back to the computer for the common-mode currents which would otherwise leak back by devious routes, as illustrated in Fig 23.19.

As with all electronic equipment the 0V arrangements on the computer are a compromise, and this sometimes leads to emissions along the lines of Fig 23.17, even if the lead is screened. In such cases a ferrite choke on the lead can be beneficial in reducing RFI. Information on reducing RFI from home computers will be found in [1].

Mains filters

There are a large number of proprietary devices available, mainly advertised as preventing disturbances on the mains from entering computers and similar equipment, but they can be effective against RF interference entering or leaving radio equipment. Simple filters consist only of capacitors but more complicated devices include inductors, usually in a balanced arrangement as in Fig 23.20. Most filters do not include any inductance in the mains earth line, but there are some more expensive ones which do. Some devices also include semiconductor surge suppressers which serve to limit mains spikes.

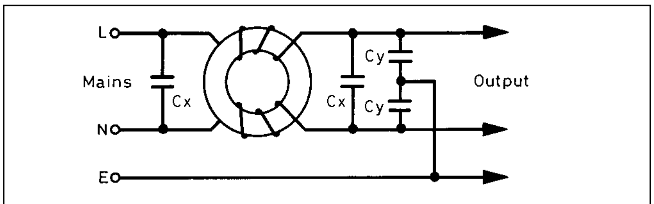

Fig 23.20: Mains filter with balanced inductor (the action of the coil is similar to a very large number of turns of two-core lead on a ferrite ring)

When considering a mains filter, make sure that it contains components to suppress both differential and common-mode currents. Some mains filters are sold with a simplified circuit diagram, and if this indicates that it contains an arrangement similar to Fig 23.20, then the filter will probably give a reasonable degree of attenuation to both modes. If a mains filter is being considered as an interference reduction measure, it is worth trying a ferrite choke made by winding the mains lead on a ferrite ring, before buying a mains filter. A ferrite choke of this sort has the advantage of reducing common-mode currents on all three conductors (live, neutral and earth). It may be more effective, particularly at higher frequencies and will certainly be much cheaper.

Reducing the Effects of Interference at the Receiver

Where it is not possible to suppress the interference at source, the only solution is to attempt to mitigate its effects at the receiver. There are two traditional techniques available: the first is some form of noise limiter or blanker and the second is by cancellation.

The noise limiter has been around for a long time, but in recent years the it has been displaced by the blanker, which does a similar job in a rather more complex way, and generally much more effectively. More information on this topic will be found in the chapter on HF receivers.

Cancellation is a very powerful tool for dealing with received interference and deserves to be much more widely known. The principle is to receive both the wanted signal and the interference on two antennas and to adjust conditions so that the interference is cancelled, leaving the wanted signal largely unaffected. This is not as difficult as it sounds, and is well worth considering in cases of severe interference. Further information on cancelling will be found in Chapter 7 of [1]

Digital signal processing (DSP) techniques are now being used in receivers to enhance the extraction of wanted signals from interference. These techniques can be very powerful, but determining what can be achieved in any particular situation is a matter of practical testing. If you are attempting to combat specific interference, study all the information, and if possible arrange a test on the interference in question..

INTERNET ACCESS USING TELEPHONE LINES AND MAINS WIRING

Systems Using Telephone Lines - the DSL Systems

ADSL (Asymmetric Digital Subscriber Line)

At the time of writing many households are changing to broadband internet access, and many of these are using systems in which data signals are transmitted to the subscriber's house over the telephone lines. The basic principle is to spread the data signals over relatively broad frequency bands so that transmission rates greatly exceed those obtainable with a dial-up modem. Almost all of these are ADSL (Asymmetric Digital Subscriber Line) which may use frequencies up to about 1.1MHz, but many lower cost systems do not use the whole frequency range, so that energy is concentrated at lower frequencies. It is likely that bandwidths will increase to facilitate services such as home entertainment, pushing the maximum frequency up to about 2.2MHz. ADSL systems have a range of a few kilometres and usually signals are fed into the telephone line at the exchange. At the beginning of 2005 there were over four million subscribers in the UK. So far there have been very few cases of interference, either to or from amateur radio stations reported, so it is not possible to give useful advise on identifying and fixing EMC problems. Information will be published in *RadCom* and on the RSGB EMCC web site [7] as it becomes available.

VDSL (Very high frequency Digital Subscriber Line)

This version of DSL uses frequencies in the HF band and could be more of a problem to amateur radio. At the time of writing it is not deployed in the UK to any significant extent. Because of the high frequencies involved the signals have only a short range - about a kilometre - so its deployment is likely to be more specialised. It is interesting to note that the ETSI VDSL Standard calls for systems to have the potential to be "notched" for the amateur bands should the need arise.

Since all DSL systems use the existing telecommunications cables the powers which can be injected are limited by mutual interference considerations in the cables (cross talk). This has the effect of putting a ceiling on potential radio interference, independent of the EMC Standards.

Systems Using the Electricity Supply Cables

PLT (PLC) (Powerline Telecommunication or Communication)

This is the use of electricity wiring to carry data signals. Low frequency signalling on electricity supplies has quite a long history, but this involves very low frequencies, and is completely different from the internet access systems which use frequencies in the HF band.

PLT is not really a single identifiable technology but a name for systems which use the electricity cabling to carry high speed data signals. It is worth noting that while information on frequencies and launch powers on DSL systems are in the public domain, similar information on PLT is not readily available.

There are two categories of PLT, Access PLT which provides internet access via the electricity supply cables and In-House PLT which uses the electricity wiring to link together computer equipment in the same house.

Access PLT: The proposed systems vary in detail, but in the UK they involve injecting the data signals at the electricity sub-station. The signal travels up the cable and into the houses supplied by the sub-station.

In-House PLT: This links computers and other devices using the electricity wiring as the transmission medium. At the time of writing most in-house PLT systems are based on a specification agreed by an organisation of interested companies. This includes notches for the amateur bands. It is known that wider bandwidth systems are being considered, but, to date, no information is available.

The situation on all aspects of PLT is changing rapidly. Information will be published in *RadCom* and on the RSGB EMCC web site [7] as it becomes available.

FURTHER ASSISTANCE

Where an EMC problem fails to yield to the procedures that have been discussed in this chapter, it is time to call for some help. In most cases this means contacting your National Society. In the UK, the RSGB's EMC Committee has set up a countrywide network of EMC co-ordinators to advise members on EMC problems. Contact information is published in the *RSGB Yearbook* [2] and on the EMC Committee web site [7] which also has general EMC information and links to other sites. The EMCC web site can be accessed via the main RSGB site.

REFERENCES

[1] *The RSGB Guide to EMC*, Robin Page-Jones, G3JWI, RSGB, 1998.

[2] *The RSGB Yearbook*, RSGB, published annually

[3] ‘Dealing with Alarm EMC problems’, leaflet EMC 03. Available from RSGB*

[4] ‘Radio Transmitters and Home Security Systems’, leaflet EMC 02. Available from RSGB*

[5] ‘EMC’ column, *RadCom*, Feb 2005

[6] ‘Interference to Amateur Radio Reception’, leaflet EMC 04. Available from RSGB*

[7] RSGB EMC Committee web site. Follow the link from http://www.rsgb.org

** The EMC leaflets can be downloaded from the RSGB EMC Committee web site, (see above)*