EMC and Amateur radio

From time to time most Amateur radio operators encounter problems with interference either to, or from, other electrical or electronic devices. With luck these problems occur only within the household, but in other cases it can affect neighbouring properties and services.

In most cases it is possible to fix the problem, but this is very much dependent upon the location of the item, co-operation of the owners and the desirability (or otherwise) of undertaking any modifications.

First it is important to understand how and why interference can occur.

Most domestic equipment is built to a price. If components are not required and can be omitted it makes the equipment cheaper to produce, which hopefully makes more profit for the manufacturers.

The manufacturer has to decide what features are important, and the minimum specification they have to meet in order to fulfil these requirements. In many cases this means that the only reason interference suppression components are fitted to an item is because it is a legal requirement to do so, in order to be able to sell the item. When international bodies define interference suppression they take into account typical operating environments and set the limits appropriately. These limits are intended to be representative and strike a balance between cost to implement and the likelihood of interference occurring.

In most cases this is a good compromise, for example we would expect more money to be spent on aircraft electronics, where there is a safety of life implication, than say on a domestic Satellite set top box, where there is not. However on some occasions there can be a clash, as was recently reported when a spurious signal is being emitted from a set top box, caused problems by interfering with automated monitoring of an international emergency beacon frequency. Fortunately incidents such as this are few and far between. That is until someone starts to operate an Amateur radio station in an urban environment !

The reasons for this are fairly obvious, domestic equipment has a level of immunity to RF signals which is adequate unless someone starts transmitting nearby. Likewise the level of emissions being radiated by the domestic equipment is also likely to be low, and not cause any problems, unless someone nearby wishes to try and receive very weak signals on the same frequencies.

So what can be done about it ? The answers usually given include improve your station grounding, use screened cables, fit some ferrite beads or other filters. Very often all of this is done and (unless you are very lucky) the problem still remains.

The reasons for this may vary, but it’s often because there is a misunderstanding of what is happening and what needs to be done to fix it.

Solutions

First let’s take a look at improving station grounding and why this may (or may not) not help. Many people don’t understand the difference between an electrical safety earth, a lightning earth and an RF earth.

An electrical safety earth is provided to protect people and equipment should a fault condition occur. In order to do this it only needs to provide a sufficiently low resistance path to the premises mains supply earth, such that a fuse will blow or a breaker will trip within a defined period of time. In some cases this can be provided by a simple ground rod or connection to the incoming mains supply where it enters the premises. This is not sufficient or desirable to be used as an RF earth.

A lightning earth is provided to protect property by ensuring that all parts of the property are maintained at nearly the same potential in the event of a nearby or direct hit by lightning. This is achieved by using very thick conductors which are bonded to parts of the building structure such as steel girders and joists all of which are connected to multiple ground spikes in order to provide a very low impedance path to earth. A lightning earth can be used as an RF earth but it may not always be effective, a lot depends upon the length of connecting cables and how they are routed.

An RF earth can range from a single earth spike to a large number of buried radials. Its purpose is to provide something for an unbalanced antenna system to act (or push) against in order to radiate efficiently. A by-product of providing an RF earth may be that all radio equipment in the shack is connected together by a low impedance conductor, which in turn may provide an electrical safety earth, or if a thick enough conductor is used a lightening protection earth. In some cases it may even provide an RF earth, but only if it is properly designed to do so. It's perfectly possible to provide a counterpoise or elevated radial system without any form of earth connection. Generally speaking the larger the radial field, the greater the coupling to earth and the more effective the system becomes (think of it as having a greater 'mass' for the antenna to 'push' against). However it is wrong to believe that connecting an item to an earth, somehow magically provides a conduit for unwanted interference 'demons' to an RF 'underworld'.

If you use an unbalanced antenna such as a Vertical, End fed wire, Off Centre Fed Dipole, you need to be especially careful, as it is very easy for coaxial feeders (and anything they are connected to) to provide an additional path for RF currents, which usually end on mains wiring and so find an easy path into other equipment. If you use balanced antennas then theoretically you don't need an earth connection, although many people like to provide one for additional safety (and to discharge any electrostatic energy which may be induced into the antenna system).

The length of earth connection is important. If a cable is coiled or becomes a significant proportion of a wavelength long, then the RF impedance presented to common mode currents flowing to earth will vary at different points along the cable. The worst case is when a cable is ¼ wave long, as a low impedance at one end of the cable is transformed into a high impedance at the other end. So if you have a transceiver connected to an earth point about 10m away (typical for a first floor radio shack), this is ¼ wave long at 40m (7MHz) so very little RF current will flow along the cable to the ground. If you have a long earth cable, one solution is to make it ½ wave (or multiples of ½ wave) long, by doing this you ensure the same impedance at each end of the cable. However this is almost impossible to arrange if you are operating on different Amateur radio bands, as ½ wave on 40m is ¼ wave on 80m. Conversely if you have a ¼ length of wire (or odd multiples of ¼ wave) but don't connect the far end to ground you have a 'tuned' counterpoise wire which will present a low common mode impedance at the near end.

Balanced antennas cause a lot fewer problems, because they do not require an earth connection or counterpoise to work. However it is still necessary to use a good quality Balun (or Baluns) in order to prevent stray common mode currents on the feeder from unbalancing the antenna and negating this advantage. The radiation pattern of balanced antennas also tends to be more predictable, so it may be possible to orientate the antenna in order to reduce the RF field strength in the directions which cause problems. An example of this is to try and ensure that any property is 'end on' to a dipole, and not broadside to it.

Screening

The second item to consider is screening. How does a screen work ? Apart from at low frequencies where an electrostatic screen may be used, the purpose of a screen is to contain signals to and from electrical circuits and wiring within the screen or enclosure. If we put a self-contained transmitter and antenna within a perfect closed metal box, which had a good electrical connection along all of its seams. We would not be able to detect the transmitted signal outside of the box.

In practice although the signal will be attenuated to a very large extent by the box, we may still be able to detect a small proportion of the transmitted energy. This is often because the box has dimensions which are a reasonable proportion of the wavelength of the signal being transmitted, so RF currents can be setup across the metal surface of the box, causing the transmitted signal to be re-radiated to the outside world. This only tends to occur when the size of the box becomes greater than $1/10^{th}$ of a wavelength, so at HF frequencies this does not present much of a problem. At VHF frequencies and above, other techniques have to be used in order to minimise this effect. Adding an earth connection will not make any difference to this configuration.

In coax cables the signal flows along the centre conductor and returns along the inside of the outer conductor. In a perfectly balanced system the current flowing in one direction along the centre conductor would be equal and opposite of that returning along the outer screen. These currents which carry the (usually) wanted signal are referred to as operating in a differential mode. Because the currents are equal and opposite to each other the magnetic fields produced by each conductor cancel each other out, and no signal is radiated external to the cable. Providing the circuits at each end of the cable are able to design correctly to transmit and receive differential mode signals, this arrangement works very well.

However in practical systems there is always some degree of unbalance. This results in a common mode current (usually unwanted) being carried along both conductors in the same direction and amplitude as each other. In coaxial cables at RF frequencies, due to the skin depth of the conductor, the common mode current is carried on the outside of the screen. This can result in the signal being radiated, especially if the cable is a significant proportion of a wavelength long. Screen cables only work if the screen is connected at both ends. For example some people recommend using screened CAT 5 or 6 Ethernet cables without realising that in many case there is no way the screen can be effective, because screened connectors are not being used at both ends of the cable (or in the equipment it is connected to).

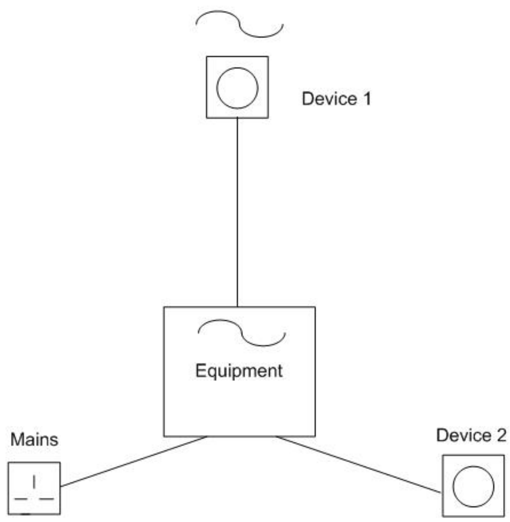
One way to maintain balance and prevent currents from flowing on the screen of a conductor is to use a balance to unbalanced (Balun) transformer at each end of the cable. This forces equal and opposite currents to flow along the wire signal pair and breaks the current path flowing on the outside of the screen. However for this to work properly the Balun has to introduce a sufficiently high common mode impedance to impede current flow on the outer screen. At low RF frequencies this requires a significant amount of ferrite. A point which is often not realised when just a single snap on ferrite suppression core is added to a piece of equipment and nothing seems to improve.

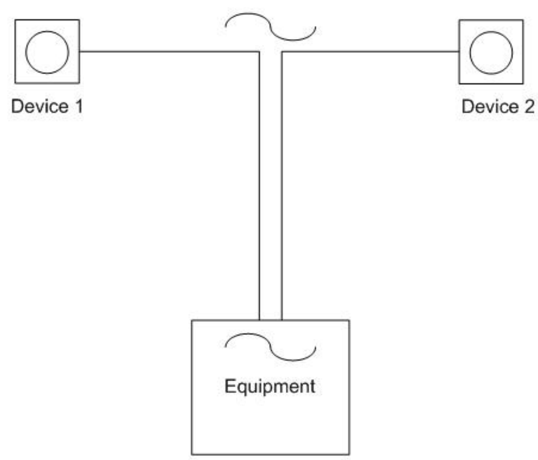
Common Problems

So let's take a look at some common problems.

Imagine we have a piece of equipment, it could be a PC, a TV or an audio system. It contains some electronic circuits and components which are susceptible to RF signals, and some which have the potential to radiate unwanted RF signals. If it is self-contained, battery operated with no external wires, and housed within a small metal enclosure, which is physically much smaller than a wavelength in size. It should not present any problems. As soon as you start to connect it to anything else you may start to encounter some difficulties.

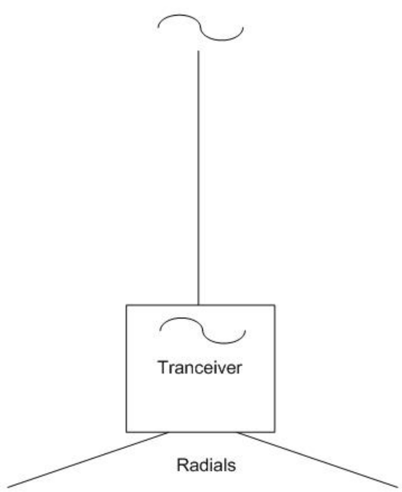
Do these diagrams remind you of anything ?

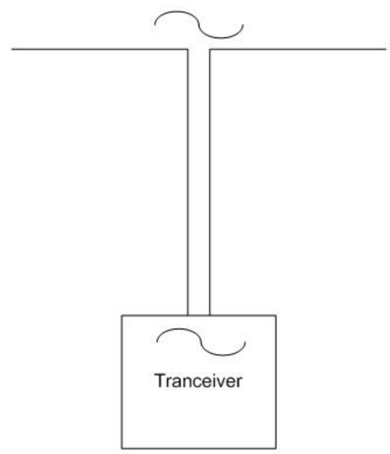




They represent common scenarios which can be found in most homes. An item of equipment which is connected other items. It could be a PC connected to a monitor, keyboard and mouse, A TV connected to an antenna and DVD player, or an audio system with separate speakers.

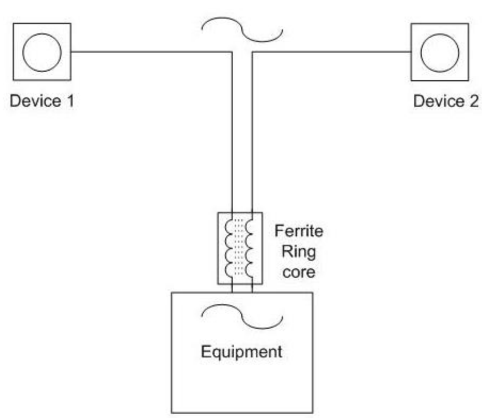
Now compare them with a typical amateur radio transceiver connected to an antenna system.

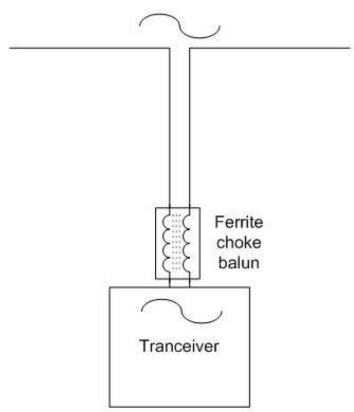




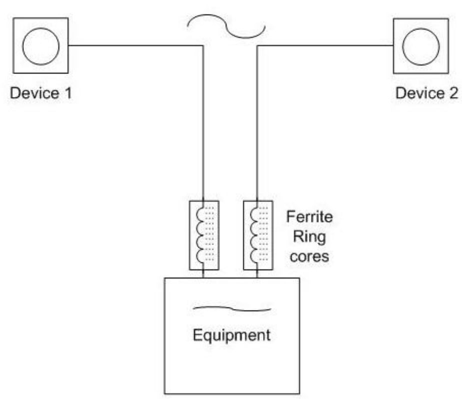
Similar aren't they ? The separate cables in the first set of diagrams form simple antenna systems which allow signals to enter and leave the equipment. Just like an amateur radio transceiver which can't transmit or receive signals until the antenna is connected.

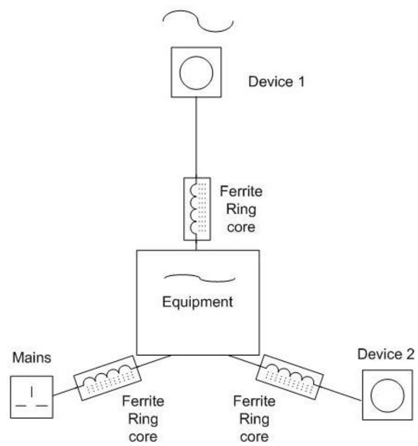
Also note that it's no good wrapping all the cables through one common ferrite ring if the cables go to different termination point. It's just like adding a Balun on the output of your transceiver.





In order to prevent unwanted signals from entering and leaving the equipment separate ferrite chokes have to be fitted on all the leads, as close to the equipment as possible.





Don't underestimate how much ferrite you need to use on the LF bands. One clip-on bead will make very little difference. The choice of materials suitable for this purpose at LF and HF frequencies is limited. In general I would suggest using type 31 or 43 ferrite material. Do not rely on unknown materials to provide sufficient choking impedance. Many ring cores or clip on ferrite suppression cores being sold on eBay or at radio rallies have been designed for use with computer equipment or in switched mode power supplies, and do not work well in this application.

Some of the most useful ferrite materials I have found are type 31 ferrite cores which can be obtained from Mouser Electronics.

FT 240-31 2.4" ferrite ring core

Mouser part number 623-2631803802 costs approx. £5.00 per ring.

You need to use about 18 turns for best results from 1.8 to 7MHz.

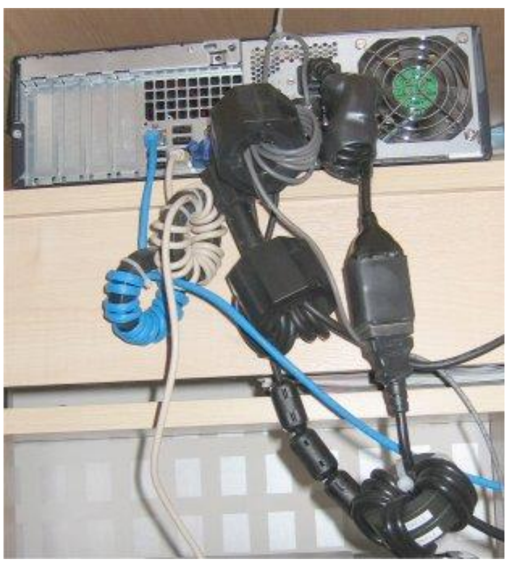
If you can't get connectors through a 2.4" core try Mouser part number 623-0431177081 which costs about £10.00 per clip-on choke.

It's big (about 2" diameter) but works well for LF band problems with about eight turns through it.

Problem solving

I found the easiest way to deal with interference problems (and many other pieces of equipment especially PC’s) was to initially unplug as many of the leads as possible (ideally just leaving the power cable). Check for interference on each of the Amateur bands. Then add chokes and filters as appropriate to the cable(s) until you have achieved the best reduction you can achieve. You may have to spend some time doing this. Then connect the rest of the cables back in one by one and repeat the process. If you have the PC connected to other equipment such as printers you may have to add a choke at each end of the cable to achieve the best results. For example I found that Ethernet cables generally seemed to require about 12 to 14 turns on an FT240-31 ferrite ring core at each end of the cable.

Here’s a photo of the back of a PC with various ferrite chokes installed. Note that the AC mains supply had to have two ferrites cokes and an in line AC filter installed before the level of emissions could be reduced on all the required frequencies. Some of the other cables (VGA) also had to have extra types of ferrite cores installed in order to reduce the level of emissions on the VHF bands. I also replaced the existing fan finger guard with some fine wire mesh. Which I installed inside the PC power supply module. This reduced the near field emissions from the PC by a further 10dB.

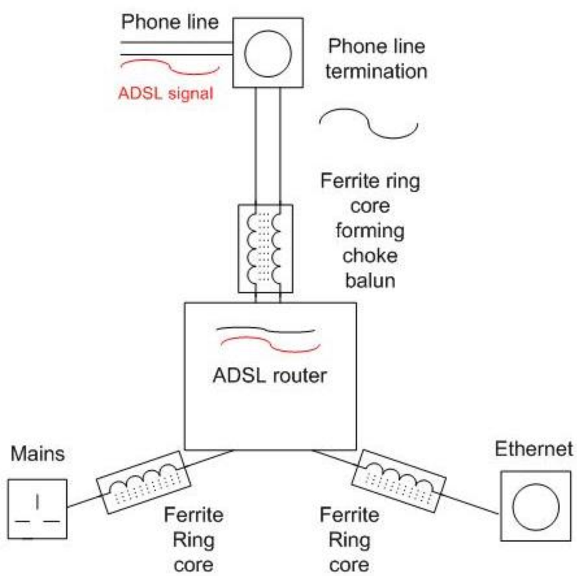


Don’t forget that some switched mode power supplies will also need chokes on both the AC and DC power cables.

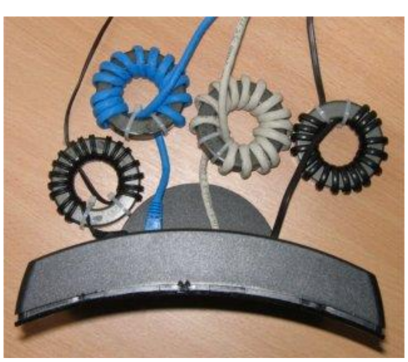
ADSL interference

ADSL routers (which are used to provide broadband internet over existing phone lines) present additional problems. Ferrite can be is used as a choking Balun on the phone line pair to remove the unwanted common mode component, whilst preserving the wanted, but much lower level differential mode ADSL signal. In this case the twin cable from the phone line is wrapped though a ferrite ring in order to minimise unwanted common mode interference in the 1.8 to 4MHz frequency range where this seems to be most problematic. I'd recommend 18 turns on a FT240-31 core for this purpose.

Individual ferrite chokes have to be fitted on each of the cables going into the ADSL router, especially the phone line and DC power leads. Put them as close to the router as possible. As well as dramatically reducing the likelihood of ADSL disconnection when transmitting, it also helps reduce ADSL hash on RX. Incidentally, even if you don't have an EMC problem, adding ferrite chokes can improve the ADSL S/N ratio and broadband data speed.



Pictures showing an actual ADSL router installation. In this case an additional ferrite ring had to be added to the plug in switched mode power supply in order to reduce the level of RF 'hash' being radiated by the DC supply lead.



A further complication in UK telephone systems is line imbalance. One of the main contributory factors is the addition of a 'bell' capacitor and third 'anti-tinkle' wire which is connected to one of the line pair when it enters the BT line termination box at the premises. All the internal wiring has this wire present, which results in a major unbalance of the line pair at RF frequencies.

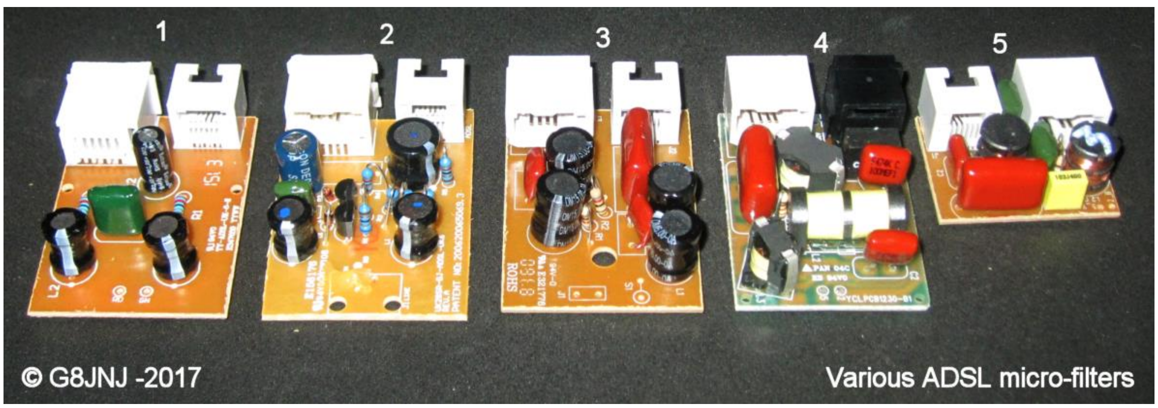
You may be able to improve things by disconnecting the third wire, as described here

http://www.kitz.co.uk/adsl/socket.htm

I found it more effective to use a BT 'line accelerator' iPlate module, which fits in line with the termination box faceplate. This incorporates a choke in series with the third wire and a choking Balun on the signal pair.

http://www.shop.bt.com/products/bt-iplate---bt-broadband-accelerator-58LT.html?q=iplate

If at all possible avoid using plug in micro-filters, as these vary quite considerably in quality.



Number 1 – has very little in the way of filtering and the third “anti-tinkle” wire is not filtered at all.

Number 2 – has slightly better filter components but unfortunately also includes diodes and transistors, which may cause problems when used near a transmitter.

Number 3 – is better still, as it incorporates some bifilar wound chokes.

Number 4 – probably the best as it includes two bifilar wound chokes on good sized ferrite cores.

Number 5 – is a much smaller version and is similar to number 3.

Ethernet cables

A further factor is any Ethernet or USB connections from the ADSL router to PC’s and other equipment. Remember the immunity (and level of unwanted emissions) of equipment is only as good as the weakest link in the chain, so it’s no good putting ferrites on just one cable, or mixing types, you need to be consistent.

The big problem with digital services is that they either work or do not work – there is not much ‘middle ground’. So you can't easily tell how much of a problem you have got.

To be successful in fixing ADSL router problems you need to be able to monitor the router S/N ratio whilst transmitting at different power levels. The ADSL router will have this information hidden away somewhere, so you may need to look through all the setup menus before you find it.

Measure the S/N without transmitting, then transmit a CW carrier and increase the power until the S/N degrades by a known amount, say 6dB.

Stop transmitting and add some ferrite rings.

Transmit again, wind up the power until you get the same S/N as before and see how much of an improvement you have achieved.

Experiment with the number of turns and placement until you can no longer achieve better results.

Initially you may not be able to run 400W, but you will be able to operate at progressively higher power levels as you gradually sort it out.

VDSL interference

VDSL (FFTC) services such as BT infinity present more complex problems as the frequency range used by the VDSL service is much greater than that used for ADSL and includes several amateur bands.

This website contains lots of information about VDSL and the frequencies in use.

http://www.kitz.co.uk/adsl/adsl_technology.htm#frequencies

Note that the VDSL carrier frequencies are spaced at regular intervals of 4.3125 kHz right up to 17.6MHz

The RSGB also have a useful leaflet explaining how to identify VDSL interference.

http://rsgb.org/main/files/2012/11/VDSL-Interference-v3b-.pdf

There tend to be two main issues with VDSL:-

1. Interference to the service from amateur transmissions causing a reduction in speed or dropping the service completely.

2. Interference from services to reception of the amateur bands due to radiation from overhead phone lines and in house wiring.

Although it is not always possible to completely resolve these issues, it may be possible to considerably improve things just by implementing a few changes. Fixing the first issue generally tends to lessen the second as much as is practicable.

The main thing is to ensure is that your own property is wired correctly.

The incoming phone line should be terminated with the correct filtered face plate which splits the VDSL signal and phone connections into separate paths.

This is usually installed where the phone line enters the property and typically looks something like this.

The reason for using this is to ensure that all of the phone wiring in your home is isolated from the VDSL signal feeding your modem. Without this the phone wiring can pick up and reradiate unwanted noise and interference to and from the VDSL modem.

Do not use plug in micro-filters and earlier faceplates that were supplied with ADSL modems as these are not likely to be suitable for VDSL.

There are also a lot of very poor quality filters being sold which do not provide any (or very little) isolation of phone connections, so it’s worthwhile spending a bit more money in order to get a good product.

In most cases the VDSL port is simply connected across the line. Sometimes it has DC blocking capacitors and some filters may have additional common mode chokes. However the main difference between them is how the analogue phone line is filtered off from the VDSL port. I have seen some filters that just have a couple of chokes and a single capacitor, whilst others provide very thorough filtering and common mode choking on all the phone connections including the problematic third "anti-tinkle" bell wire which is present in older installations and can cause major imbalance in the RF domain.

The main issue is with the components used for the phone line low pass filter. The pictures of ASDL micro-filters shown earlier in this document provides a good indication of the sort of quality variation you can expect to see.

Some of the large value inductors on small ferrite bobbins can have self-resonances within the VDSL band and the way the third wire is handled can also be problematic. Some use individual inductors that pass DC current, to the phone which can result in core saturation. The better ones use proper bifilar wound chokes which avoid this problem.

In addition to using a proper filtered face-plate it is also worthwhile to add some additional external choking Baluns onto the phone line before it enters the filtered faceplate.

Note that you may need to use more ferrite than you think.

Optimise the material and number of turns for the frequency that is causing you problems.

The Balun charts on Steve, G3TXQ's website are equally applicable for the design of EMC chokes.

http://www.karinya.net/g3txq/chokes/

Be consistent with the placement of chokes on any equipment such as modems or routers. The choking will only be as effective as the weakest link.

If you have done all of the above and you find that the VSDL connection still drops when you transmit, you can try another other technique that often helps to fix specific problems.

Notch Filters

As a last ditch method, it’s possible to add a series tuned notch filter across the line feeding the VDSL modem.

For example I'm at the end of a 1.2Km length of overhead line which is near the limit for VDSL FFTC, so most of my broadband service is provided by carriers in the lower portion of the VDSL spectrum.

I found that 1/2 a watt on 1.8MHz would drop the service completely, even though the incoming line, VDSL feed and modem were liberally smothered in ferrite. I experimented with different bandpass, low pass / high pass and notch filters before finally settling on a simple series tuned circuit.

It is placed in the differential mode path across the pair feeding the VDSL modem. Its purpose is to minimise the level of the unwanted 1.9MHz signal entering the modem on a downstream channel. I'm not sure what the effect would be on the level of emissions from the modem on an upstream channel and obviously it wouldn't do much for emissions on a downstream channel, in fact it may make things worse by forcing up the level at the cabinet end in order to compensate for the increased amount of line attenuation.

I selected the L/C values in order to obtain sufficient notch depth across the portion of the band I wished to use. I could have notched out the whole band but this dropped my VDSL speed from the 13Meg I can normally just about achieve down to 4Meg.

I used a 27uH moulded choke, tuned with a series capacitor of about 270pF. This gave me a 200KHz wide notch, and my speed dropped only slightly down to 12.5Meg. Since fitting the notch I have tested at power levels up to 250w CW and the VDSL connection does not drop out.

Note that if you do decide to add a notch filter make sure you use capacitors with at least 100v working and preferably silver mica or polystyrene types.

I made the filter up as a short male - female adaptor, so if required it's easy enough to unplug as necessary for line tests etc.

By applying these measures to deal with interference to VDSL the same measures will also help to reduce interference from VDSL to your reception of the Amateur bands.

However it will not help resolve issues with VDSL to neighbouring properties, unless you are able to persuade the owners to take similar action. This may be possible if you suggest that it could improve the speed and reliability of their Broadband service, but if they have not noticed any problems and already have a fast reliable connection they may not be interested.

General advice for dealing with BT

BT's broadband service is OK until you have a problem, then it can become a nightmare.

It's almost impossible to get hold of anyone who is an engineer and understands any technical issues. The best you will usually manage is someone working in an off-shore call centre who has to work their way down a standard script every time they answer a call. You can't by-pass this process and it's only if you can ever get a good engineer to visit that you will make some progress.

It’s useful to be able to gather some statistics to back up your argument before embarking on the formidable quest of dealing with BT.

If you have a BT home Hub 5 open up the 'Troubleshooting' page and then select 'Helpdesk'
You may need to use a password to enter these pages.

This will give you a static page showing all the main parameters, but you will need to do a refresh (F5) of the page if you change anything.

One other parameter worth knowing is your 'IP profile' this is the maximum downstream rate you can receive as set by the DLM (“Dynamic Line Management”, is the BT / Openreach system used to control the speed and stability of Fibre Optic Broadband (FTTC) connections).

Monitoring the IP Profile is a good long term method of determining how stable your line speed is and if you are causing interference to your VDSL connection from your amateur transmissions or from any other local noise sources.

You can find this out by using BT's on-line speed test page

http://speedtest.btwholesale.com/PerformanceTesterWS/

Run the first test page and then select 'Further Diagnostics'

You will need to enter your phone number then run the test.

The detail to look out for is the " IP Profile for your line is"

This will tell you what maximum limit has been placed on the speed of your connection.

The DLM tries to maintain a good compromise between the noise margin on the line (typically 6dB if the line is stable) and the best reliable speed.

If your line is subject to noise or interference the DLM will adjust the noise margin to a larger figure in order to improve the headroom which will have the effect of reducing your speed. If you already have a good speed then this is not likely to be a major problem. However if you speed is already quite low, then any interference can result in the speed dropping to an unacceptable level.

The issue with this is that if you have badly interfered with the VDSL signal at some point, it can take several weeks for the line speed to recover. Officially BT / Openreach have no means of remotely resetting the DLM (which sits in the street cabinet), but I have on occasions when complaining to their call centre about a drop in speed, manged to get them to perform some action which has brought the speed and IP profile back up to an acceptable value, although sometimes this took a day or so to happen.

If you do get an engineer to visit its worthwhile doing some research beforehand so that you can throw in a few technical terms they are likely to be familiar with.

Understand and mention terms like, FTTC, DSLAM, DP, DLM etc. in the conversation and they start to take things seriously.

This website is a very useful resource if you ever need to know anything about ADSL & VDSL.

http://www.kitz.co.uk/adsl/index.htm

If an engineer does visit, ask for a line balance and noise test and see if the engineer if they will show you the test results on the test set. They are not supposed to do this, but often will do so if you ask nicely. In my case having seen the results and getting the engineer to place them on the BT / Openreach fault records database helped enormously when I kept on asking for the fault to be reopened, as it allowed me to leapfrog the " we will have to send an engineer out to investigate" every time.

For further information about ferrite choke Baluns and general interference suppression see:-

http://audiosystemsgroup.com/RFI-Ham.pdf

And

http://www.yccc.org/Articles/W1HIS/CommonModeChokesW1HIS2006Apr06.pdf

For lots more useful information.

M.Ehrenfried – G8JNJ – V1.3 – 20/02/2017

www.g8jnj.net

EMC and Amateur radio.pdf

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G8JNJ EMC and Amateur Radio ADSL PC VGA Choke Balun EMI Interference