March 2022

Mitigating Amateur Radio Interference to VDSL2

Introduction

This document is intended for technically-minded users or those providing technical support to users connected to the **nbn**™ network who are experiencing signal interference between their **nbn**™ service and amateur radio transmissions. It is assumed that the people referencing this document will have a reasonable understanding of electronics, wireless transmission and broadband transmission technology including digital subscriber line (DSL) and very high-speed DSL (VDSL). With that in mind, this document would be suitable for licensed cablers, telecommunications network technicians, operational support staff, network engineers and amateur radio operators.

Throughout this document, the term 'modem' is used as to describe the customer premises equipment that connects to copper wires used in **nbn**™ Fibre to the Node (FTTN) and **nbn**™ Fibre to the Basement (FTTB) areas. A modem is typically included in the customer home gateway which can also commonly referred as the 'router'.

If you are looking for assistance with **nbn**™ Fibre to the Premises (FTTP), **nbn**™ Fibre to the Basement (FTTB), or **nbn**™ Fibre to the Curb (FTTC) performance, you should contact your service provider first. If you are not fluent technically, this document may be a useful reference for your service provider or technician participating in the resolution of your issues.

The Australian Communication and Media Authority (ACMA) is responsible for regulation of amateur (and other) radio spectrum in Australia and their website also has some useful information for amateur radio operators.

DSL and amateur radio transmissions

Some of the frequencies used by amateur radio operators coincide with frequencies used by VDSL2 technology, used by **nbn** to deliver **nbn**™ Fibre to the Node (FTTN) services. Although VDSL2 signals are carried over the same copper wires originally used to carry voice services, the same wires can also pick up signals travelling through the air. When an amateur radio transmitter is keyed on, nearby **nbn**™ services can be affected and there are some simple things that can be done to minimise the interference that may occur.

How the VDSL2 network works

Prior to the deployment of VDSL2 technology for FTTN, FTTB, and FTTC, the main DSL technology employed in Australia was ADSL / ADSL2+ which used signals up to 2 Megahertz (MHz). To achieve much higher speeds than ADSL, VDSL2 expands the DSL signal spectrum to up 17 MHz, which happens to overlap with many Australian amateur radio signal bands.

Under normal conditions, this overlap in spectrum is not a concern. VDSL2 signals should not interfere with amateur radio signals as they are carried over copper wires and transmit at very low power. Maximum VDSL2 transmission is around 28 milliwatt spread across the spectrum between 25 kHz and 17.6 MHz, and microwatt levels into the amateur radio bands themselves. With well-balanced twisted pair copper conductors, the power carrying the VDSL signals remains near-field confined to the tight vicinity around the twisted pair cables and will emit little signal into the surrounding environment. Amateur radio signals should not normally interfere with VDSL2 signals, even though they can be much higher power (especially close to a transmitter), are transmitted into free space, and can be picked up by the wires carrying VDSL2. Technologies like VDSL2 recognise they will be operating in environments where such external signals will exist and use mechanisms to mitigate interference. In this guide, we will explain the theory of these noise immunity mechanisms and some tips to help improve their effectiveness.

nbn's VDSL2 services use the twisted pair copper network, previously used to carry telephone and ADSL services. Twisted pair cables comprise one pair of conductors for each service, with the two conductors in each pair twisted around each other, and not twisted around any other pairs in the cable. The number of twists per metre length differs slightly between each pair to minimise the crosstalk coupling between them.

Neighbourhood 'nodes' which are street cabinets typically no further than 1 km from customer premises, and cables of twisted pair conductors connect the nodes with each home. **nbn**™ FTTC deployment uses the same underlying VDSL2 technology and cable infrastructure, but the node-equivalent-devices, called Distribution Point Units (DPUs), are much closer to customers, typically no further than 200 metres.

Aside from minimising crosstalk interference, another reason for twisting each pair is to ensure other Radio Frequency (RF) signals noise (including amateur radio broadcasts, AM radio broadcasts and any other source of RF) is coupled equally onto each conductor in the pair. When the two conductors in a pair pick up precisely the same signal, this is called 'common mode' or 'longitudinal mode.' Conversely, if you put a signal such as the **nbn**™ VDSL2 signal across (i.e. between) the two wires, this is called 'differential mode' or 'transverse mode.' Both modes of transmission coexist at all times for any twisted pair cables and in an ideal world, common mode and differential mode signals would coexist completely independently from each other.

VDSL2 signals are applied differentially or in 'differential mode' between the two wires and any noise including amateur radio transmissions gets picked up in common mode on both wires together. Ideally then, **nbn**'s node and the user's modem can ignore the common mode interference affecting both wires together and focus on receiving the differential mode signals between the two wires, and the **nbn**™ VDSL2 service theoretically will not be affected.

In real-world operation, there are situations where some of the common mode noise signal that is originally equal on both wires gets converted into differential mode. Now that the noise is differential, it will cause real interference to the VDSL2 signal. The important question therefore is 'what causes a common mode signal to convert into differential mode and trigger the VDSL2 interference?'

Earlier we considered a twisted pair acting like a long-line common mode antenna, but in doing so we assumed ideal-world conditions. Our assumptions relied on two important factors that ensure that strong radio interference gets superimposed precisely equally on both wires and that there is no conversion between common and differential modes:

(a) the wires must be evenly and well twisted end-to-end, and

(b) the entire circuit between the modem and node must be well balanced.

If these two requirements are not fully met, some of the noise which is picked up in common mode will be converted to differential mode and will start to interfere.

Cable balance has to do with the uniformity of the end-to-end impedance of the pair itself as well as between each individual conductor and its surrounding environment. When the cable and all connections are in good order, the balance / impedance is also uniform and there's no conversion between common and differential modes.

However, when;

(a) connections or joints corrode or become wet or;

(b) the ideally uniform and tight twisting of the wires becomes irregular, separated, messy or scrunched up such as they might in a wall cavity near a connection or joint;

then there will likely be an impedance or balance issue. At these places of unbalance, some of the common mode signal is converted into a differential signal and vice versa.

Once there is a conversion and part of the unwanted common mode signal mixes with the desirable differential mode signal, the egg has been scrambled and there can be no subsequent reversing or filtering of this harmful noise. The differentially converted noise interferes directly with the VDSL2 signals and dramatically increases the chance of errors and dropouts.

When common mode noise couples onto a pair, it propagates in both directions down the cable, towards the modem and the node. At every point where the noise encounters a slight balance or impedance change, not only will it convert between common and differential mode, it will divide so that some of the converted noise travels forwards in the original direction, and the remainder reflects backwards in the direction from which it originally came. This means that strong common mode amateur radio noise that originally coupled inside the premises can propagate out into the street network, reach the first or subsequent joint in the street where a proportion of the noise is converted into differential mode. This will then reflect towards the premises and the modem as differential noise.

Strong common mode noise can propagate far into the network and crosstalk onto neighbouring services. Impedance and balance issues on the neighbouring services can then convert the common mode into differential mode that interferes with the neighbours. The unbalance in a neighbouring line can even cause crosstalk of the interference on that line back onto your own service. Frustratingly, this crosstalk means a line fault on a neighbour's service can cause problems for your own service, even when there is nothing wrong with your own line. Remember that once noise has been converted into differential mode, there is nothing that can be done to filter it and it can cause havoc with the original VDSL2 signals.

The challenge therefore is to somehow reduce the amount of strong common mode noise propagating away from the section of cable where it couples in and certainly from propagating out into the street network where it can be reflected in differential mode.

To summarise, amateur radio transmissions will always get picked up by a twisted pair network in common mode. Because this is impossible to avoid, technologies like VDSL2 are designed to work in differential mode only, ignoring common mode signals. The important thing is to ensure that any transmissions that are picked up remain entirely in common mode from end-to-end with ideally no part of that signal being converted into differential mode. This requires good twisting in every cable segment, good joints and connections, and therefore good balance at literally all places along the cable and patch-cord runs.

Minimising interference – cable and connector hygiene

Unfortunately, commonly available indoor telephone cabling and jumper leads, called cat3 cables, are not well twisted. Worse still, the most common telephone-grade jumper / patch cable is not twisted at all – it is flat. These poorly twisted telephone-grade cat3 cables and patch leads are often coloured pale yellow or grey. There is always going to be a slight impedance / balance change when going from one style of cable to another, so there is always going to be some common to differential mode conversion. It cannot be avoided, but it can be minimised.

One way of improving VDSL performance in the presence of amateur radio interference in the immediate vicinity of the transmitter and antenna (meaning within a few tens of metres of either the transmitter, antenna or antenna cable path) is to replace all untwisted or twisted cat3 leads with cat5 or cat6 leads, and to replace any old wall sockets with properly terminated RJ-45 or RJ-11 sockets which are designed to take the twist all the way to the point of connection and to prevent the two wires in the pair from becoming separated.

The average user can easily replace, untwisted ‘flat’ leads between wall plate and modems with off-the-shelf or hand-terminated twisted pair cables. Just remember to get a lead with the right connectors to match your modem – usually RJ-11 6 pin connector, which is slightly smaller than the RJ-45 8 pin connector used for Ethernet.

Warning: Replacing telephone wall sockets, or working on cabling behind wall plates can be dangerous (due to possibility of nearby power cabling) and must only be performed by a licensed cabler. A list of registered cablers can be found at the Australian Registered Cablers website.

If all of the measures suggested in this paper still fail to address the problems then it may help to replace internal wall cabling carrying VDSL with cat5 or cat6 cables and RJ sockets, possibly via a different route to avoid proximity to amateur radio equipment.

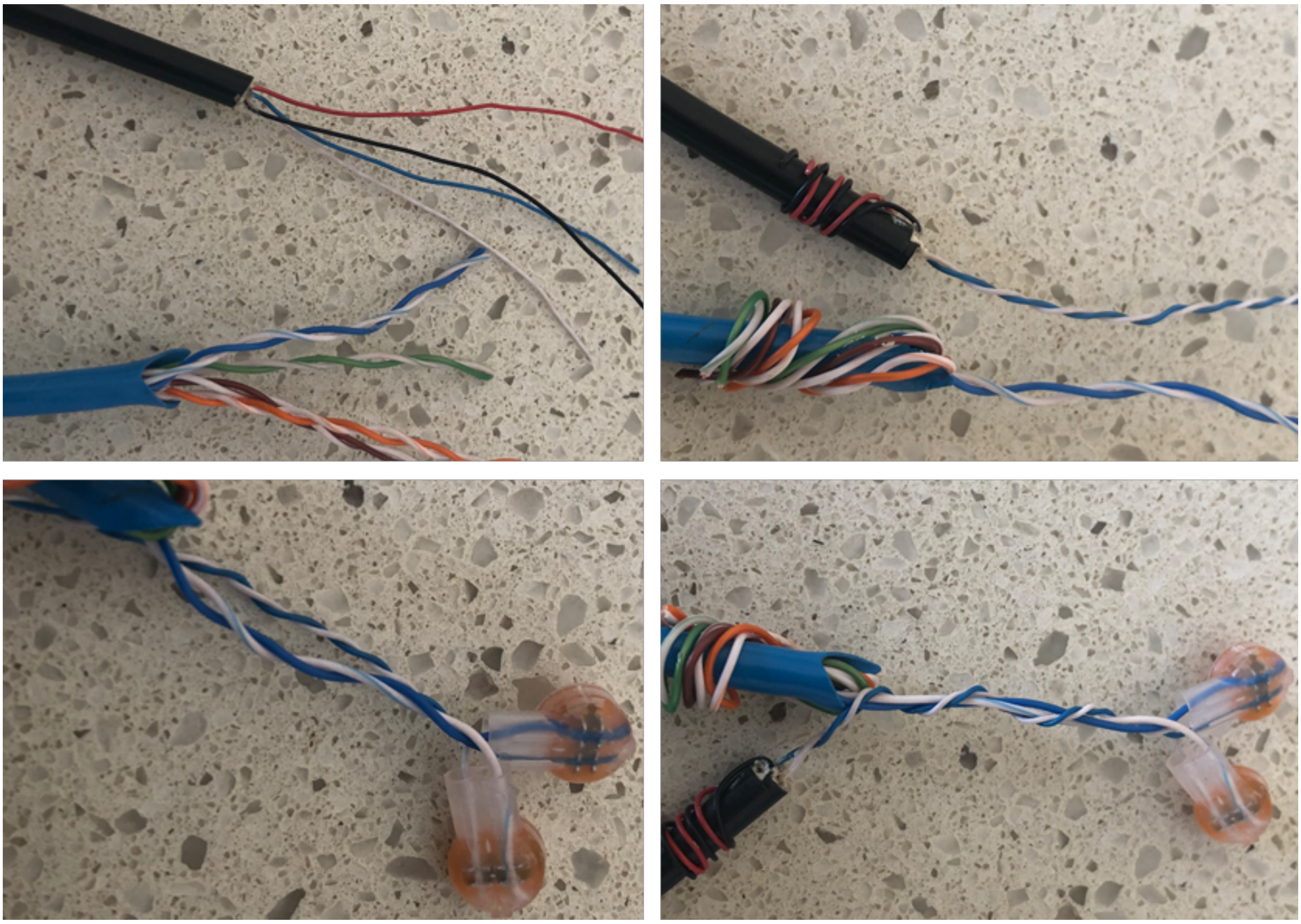

Figure 1 At joints, twist the two conductors as tightly as possible around each other all the way to the termination point

Beyond a few tens of metres from the transmitter and antenna, the main problem will generally be balance. The best way to address balance is to systematically find all old and corroded sockets or connectors and replace them, including both wall sockets as well as jumper cables. When replacing the sockets and connectors, pairs should be carefully twisted all the way into the sockets or connectors so that a cat5-like twist is in place at every possible location. Ensure that all connections are low-resistance and well terminated – as even a small resistance in one leg will cause a significant imbalance and significant conversion of noise between common and differential modes.

Bridged taps may need to be addressed as part of good cable and connector hygiene. A 'bridged tap' is a junction in the twisted pair that was traditionally added so that several different telephone extensions could be scattered around the home. There might have a socket in the kitchen, another in the bedroom and another in the office. Depending upon how the extensions were originally connected, there may be a 'T' junction behind one or more of the wall sockets. In the world of VDSL2, this 'T' junction is called a bridged tap – which is a tap off the main path of the twisted pair to another location in the home.

Bridged taps are notorious for causing sufficient unbalance to convert enough noise from common mode to differential mode as to be a problem. The best solution for VDSL2 technology is to eliminate each bridged tap. the unused cable stubs at the point of the 'T' should be completely electrically disconnected. Generally, bridged taps will be found behind a socket or behind a wall plate.

Warning: Replacing telephone wall sockets, or working on cabling behind wall plates and cables on the street can be dangerous (for example nearby electrical power cabling) and must only be performed by a licensed cabler. A list of registered cablers can be found at the Australian Registered Cablers website.

What to do when perfect balance and twist is simply not enough?

As simple as it sounds, most amateur radio interference problems can be eliminated or substantially improved by carefully addressing twist and balance everywhere along the end-to-end cable path between the modem and node, including the patch leads. In fact, if poor balance and twist is not addressed at every location along the end-to-end cable path, it will be difficult to help restore an unstable VDSL2 service to error-free stability.

Note: All the cables from the first phone socket in your home, the phone cable connecting your home to the street cable, all the street cable to the node cabinet is part of the network operator's infrastructure and only the network operator is permitted to work on it. All cabling from the first phone socket to any other phone sockets and other cabling to equipment like modems are considered 'in-home cabling', which a customer should engage a licensed cabler to perform work on.

Supposing the cable path is well balanced (all joints are in good condition and tidy) but perhaps there might be one section of poorly twisted or flat cat3 cable buried in a wall or concrete floor which is not so straightforward to access and replace. Of course, it will never be certain that the entire end-to-end path is in perfect condition because you can only look at and fix the issues within your premises. However, if you know an in-home section is problematic, you will be sure that amateur radio transmissions are going to couple strongly and be conducted along the twisted pair in common mode. There is one more important approach that might be attempted to reduce the effects of very strong common mode amateur radio noise: construct and deploy longitudinal or common-mode chokes.

A common mode choke is a simple DIY filter, and it can be remarkably effective at reducing the amount of common mode noise entering a modem or being conducted outside a home into the network. A common mode choke can be constructed using a ferrite toroid (ring) and a short length of twisted pair conductors. Chokes can be exceptionally effective at containing common mode noise within the home. But it is important to remember that common mode chokes will not be effective against any of the original common mode noise that has already been converted to differential mode. Using a choke only makes sense after completely addressing the cable twist, balance and socket/connector impedance issues.

How to make a choke

To make a choke, firstly choose an appropriate ferrite toroid made of a ferrite material that has good magnetic properties for the frequency that you are trying to filter. We have achieved good results with chokes made using 'N30' type ferrite material. Not all ferrite materials are equal and if the shop selling you the toroid cannot provide you with good clear data describing the magnetic properties or impedance at the frequencies you transmit on, you might want to conduct an internet search to find another vendor. It is relatively straightforward to find well specified high performance toroids in Australia or delivered to Australia from reputable online vendors. Remember that the current that flows on an **nbn**™ VDSL2 only line (no traditional baseband POTS telephone service) is tiny and in any case, is in differential mode, so magnetic saturation in the ferrite is not going to be an issue. For the **nbn**™ FTTC service, in addition to the differential VDSL2 signals, the power feeding current will not normally exceed 350 mA but as this current is also differential mode, magnetic saturation should also not be an issue. Try to find a toroid with an inner diameter of (say) around 25 – 35 mm so that you can get a decent number of turns through and around it.

To construct the common mode choke, you can undertake the following steps:

1) Take several metres (eg. 5+ metres) of spare cat5 cable and strip off the outer sheath so that you are now holding the four bare twisted pairs.

2) Take one of the twisted pairs and wind / wrap it through and around and through and around the toroid ring until you have made a complete circle of it. You do not need to untwist the cat5 pair – keep it twisted.

3) As you progress around the toroid ring, compact the windings neatly so you can maximise the number of turns. Keep it tightly packed all the way around.

4) After you have covered the circumference of the toroid, you might have 50 turns. Stop winding at that point so there are no overlaps. A small amount of hot glue at the entry/ exit point will keep the ends in place and the windings tight.

5) Terminate the loose ends of the twisted pairs in RJ connectors. You can now substitute this assembly for the jumper that used to connect the wall socket to your modem.

As mentioned above, it is worth the effort to insert a common mode choke both adjacent to the modem and at the socket connected to the cable entering the home to prevent noise egress back into the street network. If necessary, engage a licensed cabler to install the chokes behind the wall plate in the wall cavity, as close to the lead-in cable as possible.

To be effective in preventing conversion of common-mode interference to differential mode, the choke needs to be placed between the point of unbalance and where interference enters the circuit.

Figure 2 Example DIY common mode chokes and a bare N30 ferrite toroid

We have carefully measured the characteristics of home-made chokes such as those above in our labs and achieved 40dB and greater common mode attenuation and virtually zero differential mode attenuation (when the pairs are fully twisted). The ferrites shown in Figure 2 are approximately 35mm and 50mm in diameter. One example (bottom left in Figure 2) is based on a neatly wound twisted pair and the other based on a neatly wound flat pair (to the right in Figure 2) that is twisted tightly at the entry and exit points but flat around the ferrite. The fully twisted choke has slightly superior performance than the flat wound choke due to having lower insertion loss, hence the recommendation to wind common mode chokes using fully twisted pairs.

These examples have used a high-performance N30 ferrite material. When using poorer or unspecified ferrite material or with sloppy windings or terminations, we have measured much lower common mode attenuation.

The designers of FTTN equipment generally include a common mode choke in-line for every port at the node. The reasons to design nodes with integral common mode chokes are obviously the same as mentioned above recommending the use of chokes at the periphery of the home wiring.

Amateur band notching

A few amateur radio operators have approached **nbn** and requested amateur band ‘notching’ as a solution for interference problems.

Some amateur radio enthusiasts might remember the discussions surrounding interference caused by broadband–over–powerline devices into amateur radio receivers. The VDSL2 standards were originally developed around the same time and the standard's authors were cognisant of these powerline interference issues and of the needs of the amateur radio community. They developed a VDSL2 amateur band notching feature that works by reducing the VDSL2 transmit power mask by approximately 30dB within the amateur bands (VDSL2 uses QAM signals which are virtually indistinguishable from white noise). Reducing transmit power reduces pseudo-white-noise interference into amateur radio receivers. Subtly, the effect of the VDSL2 transmit power mask is not to disable use of spectrum, but to constrain the maximum transmit power in masked parts of the spectrum. Notched amateur band frequencies therefore continue to be available to be used by the modem and node, but at much lower power.

The actual frequencies used by a VDSL2 service are not set in concrete but are selected by the node and modem in collaboration from the set of all possible tones between about 20KHz and 17MHz. The choice about which frequencies to use is based on, among other things, the one-off prevailing noise levels that the modem and node measure immediately prior to the modem and DSLAM achieving a synchronisation state or 'coming into sync'. Once in sync, the ensemble of frequencies that the modem and node have chosen are fixed for that sync-session and transmit power levels in those frequencies are based on the maximum power per frequency defined by the mask.

Because an amateur transmitter is overwhelmingly likely to be keyed off at the instant that a node and modem decide whether to use notched frequencies, the notched frequencies may well be chosen to actively carry VDSL2 data. VDSL2 modems typically remain in sync for months at a time if the customer does not power the modem down. This means the ensemble of chosen frequencies may remain static for the long periods between resyncs. Real world noise is temporal – it changes with time, but the VDSL2 standards make a one-off choice about what ensemble of frequencies are going to be available to be used based on a one-off noise measurement.

To get a feeling for what this looks like, the following graphs show actual VDSL2 service transmit levels as a function of frequency. These particular graphed services have had notching applied in the 80 and 40 metre amateur radio bands. The dark blue line shows which frequencies and transmit levels that have been negotiated and are being used by the modem and node. The gaps in the line shows those other frequencies that have been disabled. The notched amateur radio bands are circled in red.

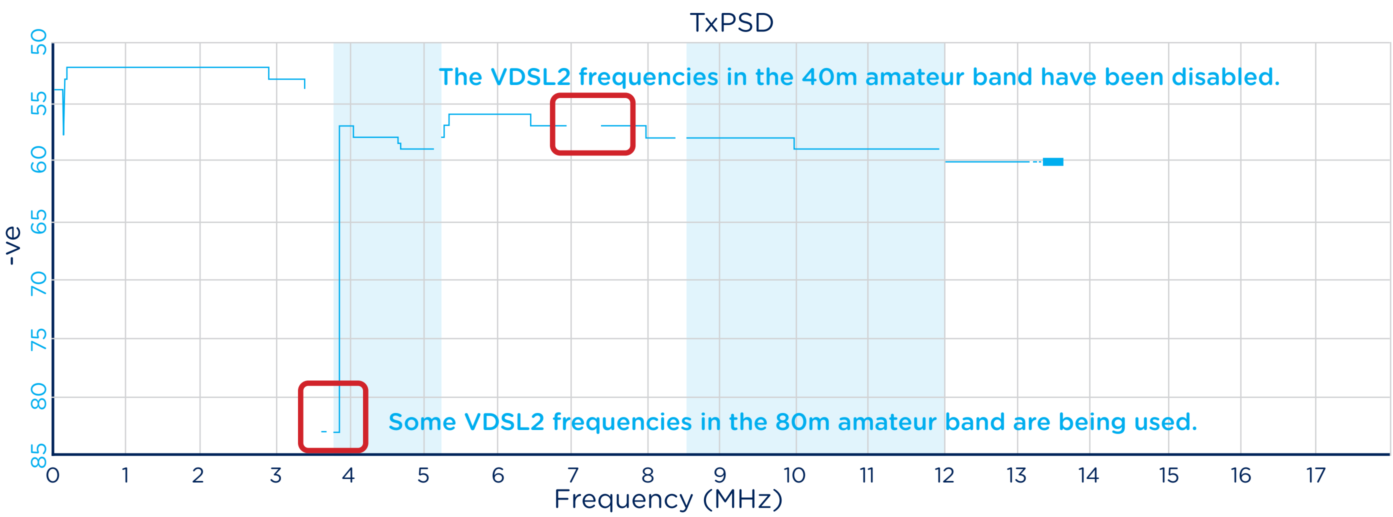

Figure 3. 680 metre twisted pair carrying a 50/20 Mbps service.

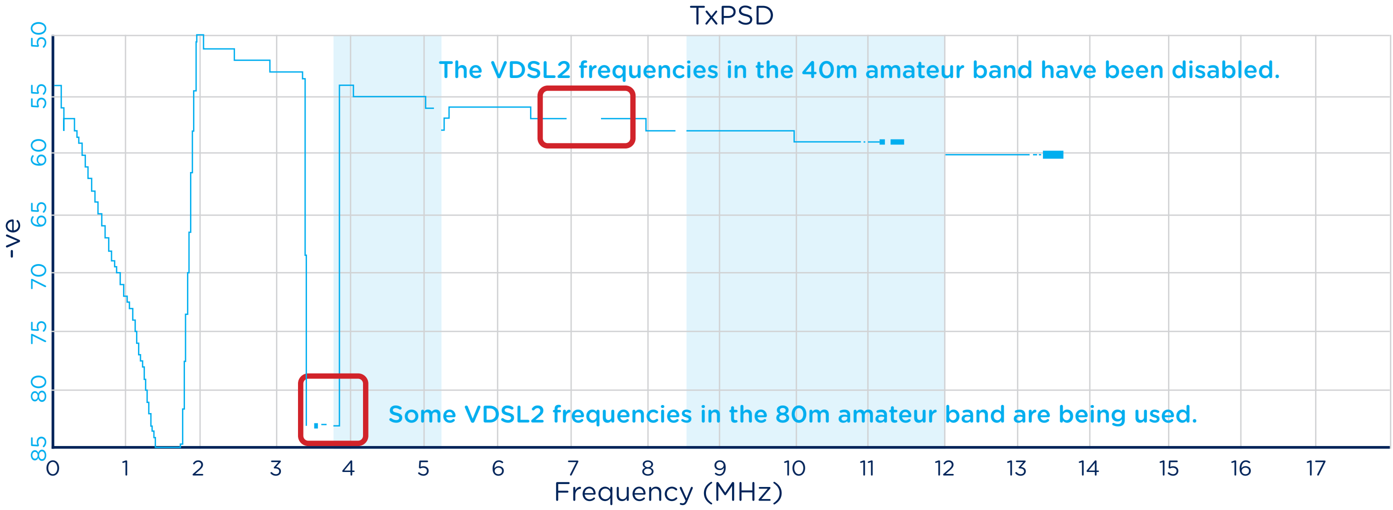

Figure 4. 640 metre twisted pair carrying a 100/40 Mbps service. (Note: additional spectral management has also been applied between 138 kHz and 2 MHz which is unrelated to notching.)

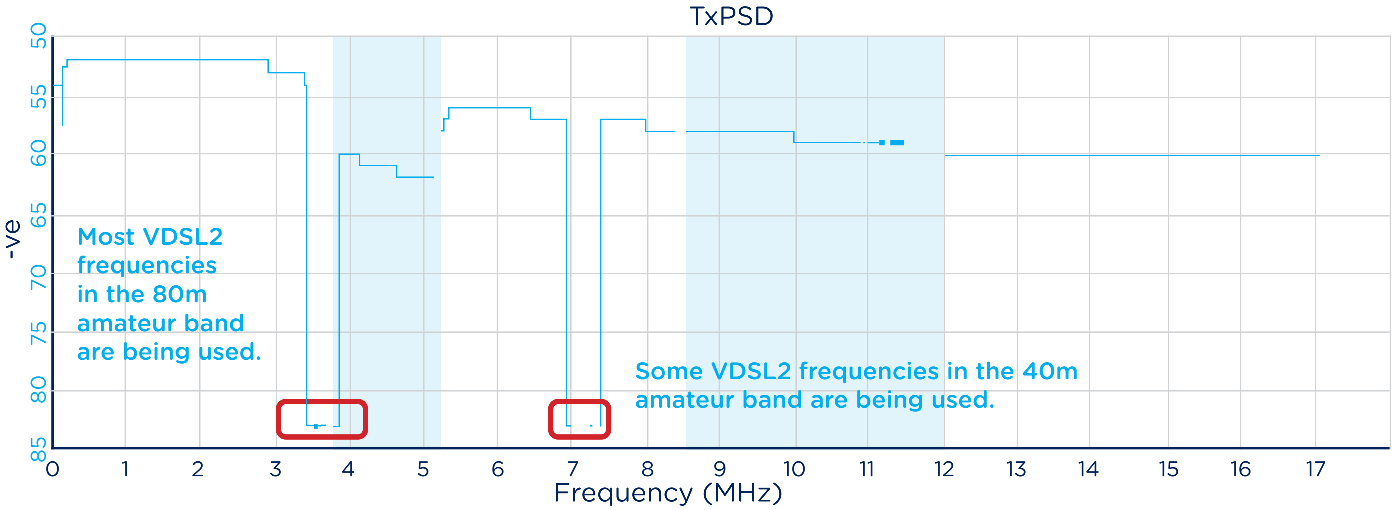

Figure 5. 620 metre twisted pair carrying a 100/40Mbps service. Both bands are still in partial use by the node and modem, despite notching being applied.

The ability for the node and modem to choose to use notched frequencies turns out to be particularly important when the ordered VDSL2 service has a high rate, such as **nbn**'s 50/20Mbps and 100/40Mbps speed tiers. These examples in which the notched frequencies are used sees a normal outcome. The higher the target data rate, the greater the chance that a modem and node will choose to use notched frequencies.

Attenuation plays a part too. The longer the twisted pair run, the greater its attenuation, particularly at the upper end of the VDSL2 band. For longer length twisted pair lines, modems and nodes are more likely to use frequencies in the 160 and 80 metre amateur radio bands (which have the lowest twisted pair attenuation). When a 50/20Mbps or 100/40Mbps service is configured, it is expected that around half of all Australian FTTN services (the half with the longest twisted pairs) would use frequencies in the 160 and 80 metre amateur bands even when notching is applied. Similarly, when a 25/5Mbps service is configured, its expected around a quarter of all Australian FTTN services (the quarter with the longest twisted pairs) would use frequencies in the 80 metre amateur band. VDSL2 may also use notched frequencies in the 40, 30 and 20 metre bands, with increasingly lower probabilities as twisted pair lengths tend towards longer.

If an amateur band frequency is in active use by a node and modem, there will inevitably be a major burst of errors at the instant that an amateur transmitter is keyed on in that band. The severity of the error burst will depend upon how much common mode noise is being coupled into differential mode.

When nodes and modems encounter error bursts, a number of other VDSL2 features kick in to adapt and recover. These mechanisms include so-called ‘Bit Swapping’, ‘Seamless Rate Adaptation’, Retransmission (RTX) and lastly ‘SOS’ that was mentioned previously. Without going into detail, the first three of these mechanisms involve communication between the node and modem, in order to exchange information about (a) spectral reconfiguration and a temporary reduction of the data rate to adapt to the emergence of the new noise source and (b) then retransmitting the lost data.

The communications channel used for emergency reconfiguration is constrained, and if the quantity of required spectral configuration messages exceeds the capacity of the channel, the service will drop out and resync. The drop-out timers are almost instantaneous - to the order of tens or hundreds of milliseconds. Similarly, if the dropped customer traffic cannot be retransmitted successfully within three attempts, the RTX mechanism also provokes a resync. These are the main potential causes for VDSL2 dropouts due to amateur radio interference.

It should now be apparent that the purpose and benefits of VDSL2’s notching capability can be easily misrepresented or misunderstood. VDSL2 amateur band notching was intended to minimise the interference that VDSL2 services might cause to an amateur receiver, not to address VDSL2 service stability in the face of amateur radio interference. Notwithstanding, in some cases notching has indeed been observed to help stability.

Stability improvements because of amateur band notching happen by chance when the modem and node completely disable the frequencies in the band being used by the amateur transmitter. If some frequencies in the impacted band are being used by the modem and node, then VDSL2 dropouts are possible, and their likelihood will depend upon how much of the impacted spectrum is being used. The more impacted spectrum being used by either the node or modem, the greater the burst of error recovery communication that will occur during each error burst, and the higher the chance that the emergency communications channel will be overwhelmed and provoke a drop-out. In accordance with the normal operation of VDSL2 standards, actual spectral usage is determined session by session. The extent to which a band-notched service remains protected against amateur radio interference for the long term will be somewhat of a matter of chance each time the modem resyncs.

Amateur band notching of course does not address and eliminate the root cause of the VDSL2 issues, i.e. the common mode to differential mode noise conversion which then interferes with the differential mode VDSL2 signals. When the amateur operator is transmitting, real noise is picked up in common mode on the twisted pair and is conducted towards the node and towards the modem. Flaws in the cable, joint and connector environment convert the noise to differential mode, and now the noise is differential, the noise problem changes from one of containment using chokes into one of mitigation and work-around using notching.

Regardless of whether amateur band notching provides relief for an unstable VDSL2 service, we can be certain that the connector and joint conditions will only degrade compared with their present condition, increasing noise levels and reducing the effectiveness of notching. The amateur band notching approach is therefore a band-aid. It can provide temporary relief, but it will not work in all situations. With notching as the solution, the root causes (impairments in the twisted pair environment) will remain and inevitably deteriorate. For all of these reasons, VDSL2 notching is generally seen as a last-resort work-around.

Modem dynamic range

Another crucial factor that should be considered is the dynamic range of the modem's receiver. Being a digital system, one of the first stages in the modem or node's receiving process is an analogue to digital conversion (ADC) of the instantaneous line voltage. This conversion is performed across all VDSL2 spectrum in aggregate from 25kHz to 17MHz and the rejection of noise in unused frequencies is performed in the digital domain. Because the filtering is digital, it is critical that the instantaneous voltage on the line can be captured and tracked by both the modem or node's analogue front end and its ADC without clipping. The instantaneous voltage on the line obviously includes the real-world differential mode amateur radio interference, which at that stage has not yet been filtered and is still strongly present in the ensemble of frequencies between 25kHz and 17MHz.

The VDSL2 standards allow a maximum transmit level of approximately 28mW total in each direction, spread more-or-less evenly between 25kHz and 17MHz in the appropriately designated upstream or downstream VDSL2 bands. After transmission through the twisted pair between the node and modem, a typical attenuation at around 7MHz may be around 40dB or even greater. Assuming for this rough exercise that attenuation is flat with frequency, the original 28mW has been attenuated to around 2.8uW of differential power into the nominal 100Ohm termination of the modem or node's receiver.

A nearby amateur rig transmitting at a level of tens or hundreds of watts will likely couple common mode power onto the twisted pair at a level substantially larger than the 2.8uW aggregate differential signal the VDSL2 modem is trying to receive. The very slightest balance imperfections inside the modem's analogue front end or in the twisted pair line balance will see a proportion of the common mode interference converted to differential mode (therefore a common mode choke at the input to the modem can be highly effective). The modem's analogue front end and ADC must track the now-differential component of the interfering signal (plus the actual VDSL2 signal it is attempting to decode) linearly and without clipping.

Linearity and spreading the noise spectrum

A final factor to consider is non-linearities in the twisted pair network (and in the modem's analogue front end). If you can remember your communication / signals theory, you will recall that just as for clipping, the spectral content of a signal is dramatically altered when passing spectrum through non-linear circuit elements such as diode junctions. Through the process of oxidisation, non-linearities arise naturally in the twisted pair copper network in joints, and within the home wiring in sockets and connectors, through the action of humidity and moisture. Formation of copper and other metal oxides gives rise to diode behaviour in joints which is inherently non-linear.

Low-grade so-called 'diode-joints' or 'high resistance joints' are endemic throughout all twisted pair networks and on in-home wiring, permanently present in a significant proportion of active services but normally at such a low level that there is no noticeable impact on the differential VDSL2 signals. A strong common-mode signal however can convert to differential mode in a non-linear diode junction, and the non-linearity can then spread the now wide-band interfering spectrum so broadly that amateur band notching cannot possibly be effective. In some cases where amateur band notching originally provided relief, slow subsequent changes in joints eventually renders the notching work-around ineffective.

Noise from mains power network

Thus far, we have examined noise in the context of network cabling. Even if you have not given mains borne noise much thought in the past, it is worth considering the implications. The main power network can be a surprisingly effective conduit for high frequency noise. If you are sceptical, remember that consumer-grade powerline broadband adapter products work well to reticulate essentially the same spectrum used by VDSL2 technology through even large homes, and effortlessly across phases where a home has more than a single phase. Also, where they were deployed around the world, public access powerline broadband services would cover significant distances through the community and into homes via street-mains and in-home power cables. Mains power cabling can be a great antenna and a great conductor for high frequency signals.

In some cases, noise might be conducted directly out of your transmitter on its mains lead, but more likely, noise will be induced into your, and potentially your nearby neighbours' in-home mains cabling within the vicinity of the antenna and its cable run. Mains borne interference can be conducted out into the street on mains cabling and then be coupled onto network cabling in common mode and then back into the surrounding homes. Points of network cable unbalance either out in the street or within home wiring will convert the common mode noise to differential and the effects on the **nbn**™ service can be similar to those described previously.

Strategies for filtering mains borne noise include appropriately specified clamp-on ferrites around mains conductors and appropriately specified EMC filters for the bands in which you transmit. Clamp-on ferrites behave like a 'single turn transformer' around the mains cable, and data sheets will generally indicate the impedance for one turn. Alternately, you may be able pass the AC power cable feeding a device several times through a larger diameter clamp on ferrite to increase its effectiveness – of course taking care not to damage the power cable.

When choosing clamp on ferrite devices, aim to achieve at least several hundred ohms of impedance in total and remember that multiple clamp-on ferrites can be installed 'in series' to increase the attenuation. As mentioned above, choosing ferrite material for common mode chokes, not all ferrites are equal. If the vendor cannot provide clear data regarding the ferrite characteristics in the bands of interest, look elsewhere.

Smaller ferrite clamps with an impedance of around 100 ohm each in the 40 metre band and with inner diameters of 7 to 10mm can be easily installed onto the mains cable feeding your transmitter. To prevent noise being conducted back out into the community, source ferrite clamps with similar impedance and an appropriately larger inner diameter (e.g. 25mm, depending on requirements). If required, engage a licensed electrical contractor to safely install them onto the supply side mains feed into your meter box.

Conclusion

As outlined in this document, cable twist, connector hygiene and common mode noise filtering are considered as the preferred steps to take when addressing amateur radio noise ingress into a VDSL2 network.

Additionally, addressing cables, joints and introducing chokes and filters are considered as effective steps when fixing the root cause of an interference problem. With good information and advice, amateur operators have generally shown sufficient familiarity and confidence with the described methods and techniques to address noise issues competently and effectively.

Amateur band notching is a fall-back alternative that can sometimes address noise issues, but in general, notching has not proven to be a reliable solution for amateur interference problems.

