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Simulating Vectored VDSL2 and Industry Code C658

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VDSL2 and the new era of spectrum sharing…

- During the era of ADSL and ADSL2+ competition, Communications Alliance developed an industry code to support the harmonious sharing of spectrum using Unconditioned Local Loops
  - That code was called C559
  - C559 described how ***legacy*** DSL technologies could coexist in shared cable bundles

- In 2014, Vectored VDSL2 technology was introduced into the nbn™ access network
  - C559 does not cover VDSL2 and could not easily be adapted
  - Communications Alliance embarked on a new project to develop a Code to facilitate harmonious deployment of Next Generation Broadband Services
    - including Vectored VDSL2 and G.fast
    - Participating was (and continues to be) open to all of industry and interested parties

- In 2018, industry code C658 was published...

Quick overview of the presentation

- Where the new Industry Code applies, and its objectives
- The necessity of simulating outcomes when developing the Code
- How do you simulate VDSL2? – crash course
- Interesting lessons we learned along the way - how to rapidly identify faults!

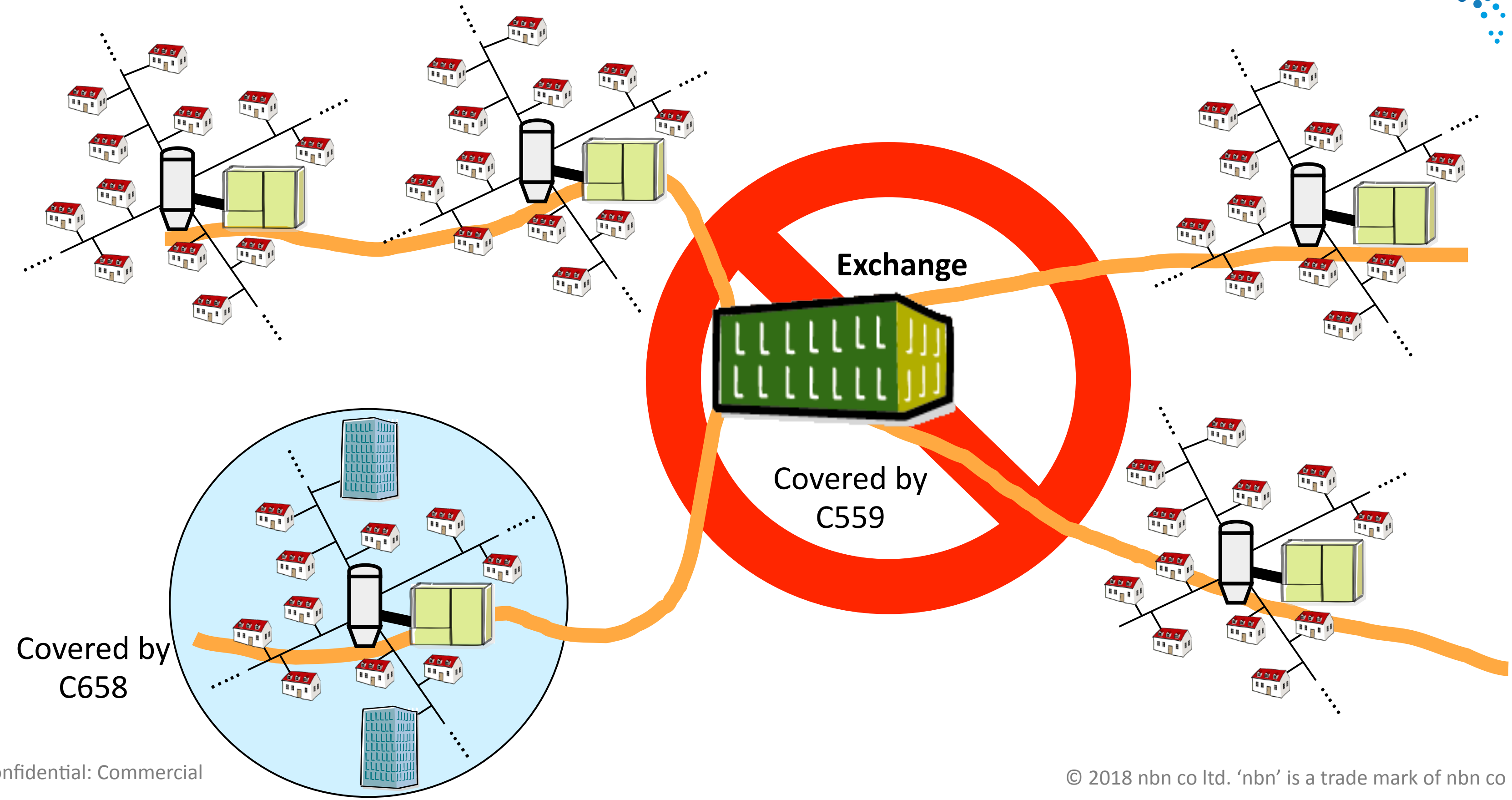
Industry Code C658:2018

- Applies to all non-Unconditioned Local Loop Services (non-ULLS) systems deployed from either a network node or from within an MDU
    - Includes Network, Building and Campus systems

- Aims to protect all 'Next Generation Broadband Systems'
    - Including VDSL2 (vectored and non-vectored) and G.Fast

- Achieves its aims by managing spectrum in 'Shared Cable Bundles' where there is potential for crosstalk between conductors and between cables
    - Includes groupings of separate nearby cables that run together for some or all of their routes (eg different cables using the same cable tray or duct)

C658 applies to node, building, campus, mall deployments



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The objectives of Industry Code C658:2018

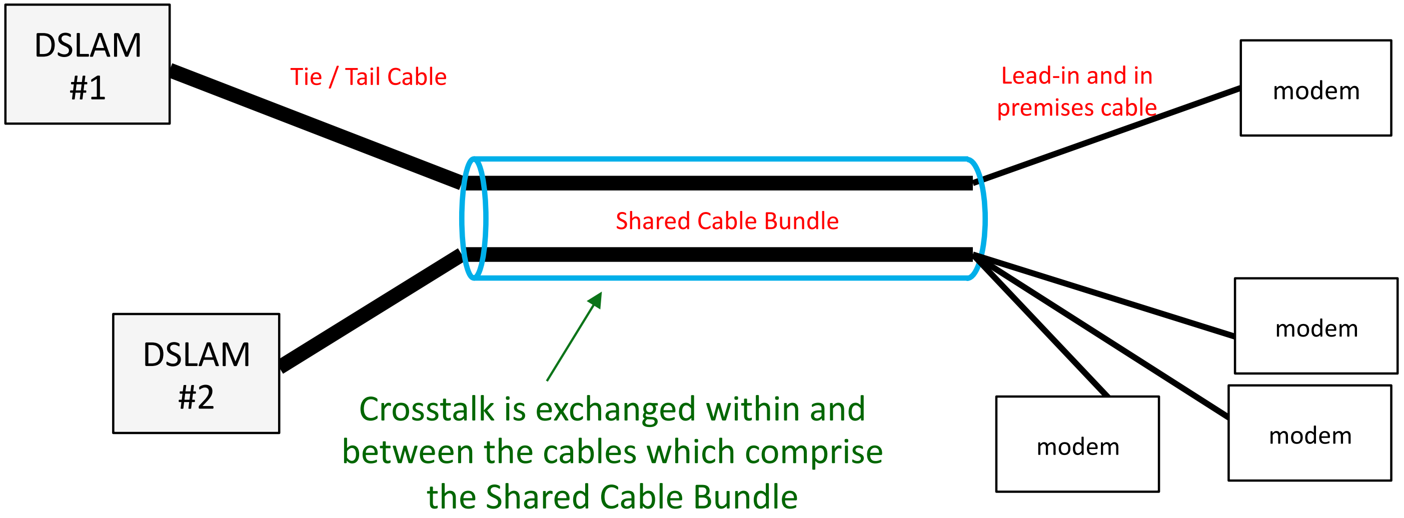
(as stated within the Code)

- to **facilitate competition** in the deployment of Next-Generation Broadband Systems
- to **minimise** the potential for **interference** between systems
- to **ensure** a minimum level of **performance** per Government policy
    - Minimum 25 Mbps peak wholesale download data rates
- to **protect** the performance of certain **legacy systems** (e.g. ADSL2+)
    - while those systems are deployed in the same Shared Cable Bundle as a next−generation broadband system
- to provide flexibility and scope for **technology upgrades** (e.g. G.Fast)

- To a large degree, the Code aims to ‘share spectrum harmoniously’

Achieving the Code's objectives by defining limits that are calculated through simulation

- The key technical parameters and aspects that govern DSL performance
  - Cable Attenuation
  - Noise, including Crosstalk
  - Mitigation strategies such as Vectoring, Spectral Separation, DPBO and UPBO



Predicting Rates at a Glance

1. Determine how much of your signal gets received by the modem

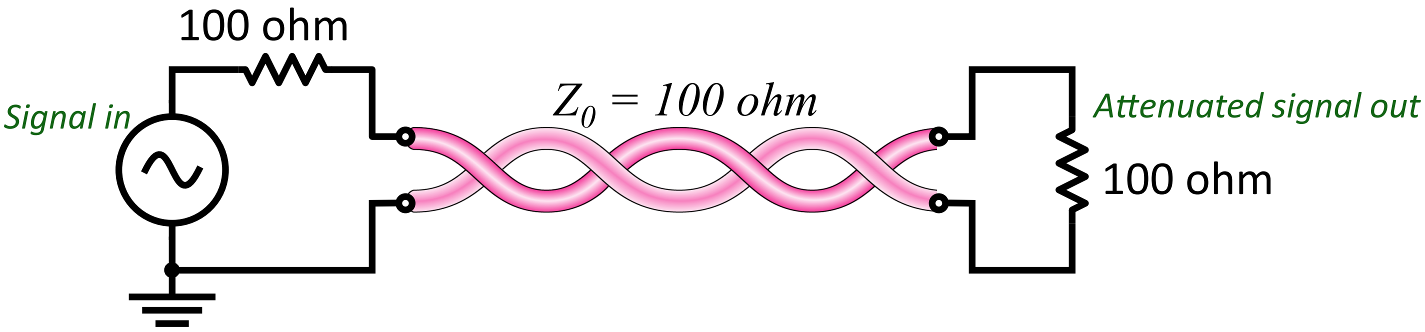
2. Determine the crosstalk and noise that are received

3. Then calculate the Signal to Noise Ratio (SNR)

4. Then Voila! Determine the bit rate

Twisted pairs create a balanced transmission medium

Each twisted pair carries one service



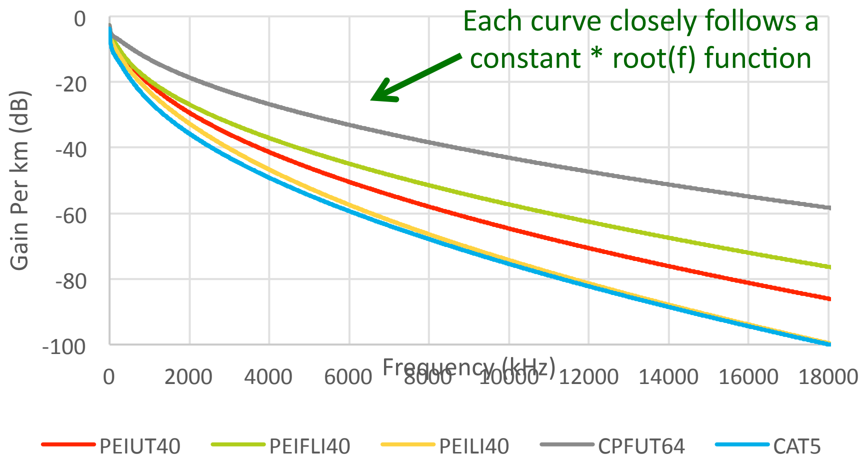
Twisted pairs work to keep out noise because of their 'balance' and symmetry.
Electromagnetic noise is superimposed approximately evenly onto balanced conductors in a twisted pair.
When balanced, the noise between conductors is minimal!

Faults and impairments upset the balance.
Unbalanced pairs are susceptible to added noise and crosstalk.

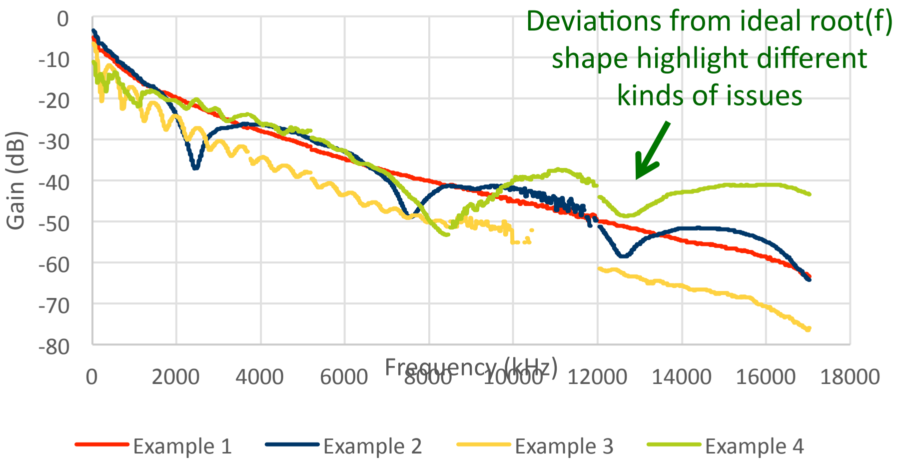
Attenuation (or Hlog)

- Attenuation is a function of cable type, length, frequency (and any impairments)

Nominal attenuation of common Australian twisted pair cable types



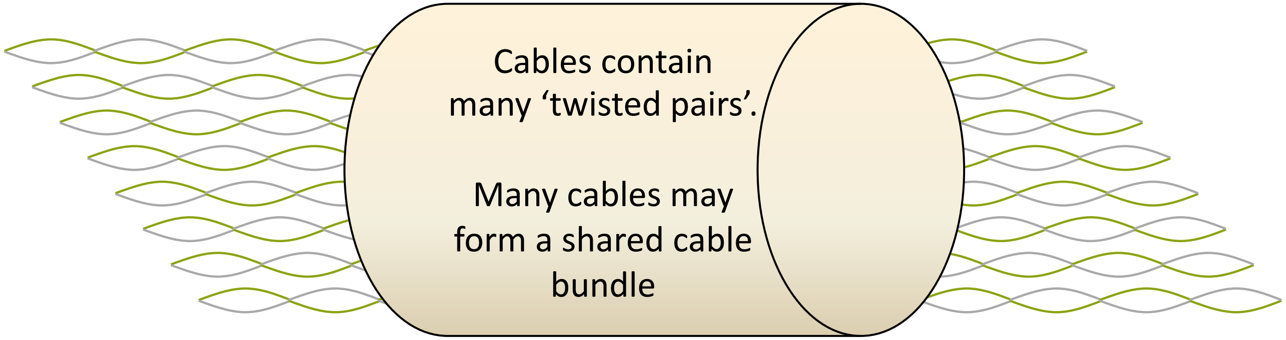
Attenuation (Hlog) measurements from various actual services over the **nbn**™ access network



Crosstalk happens within and between cables

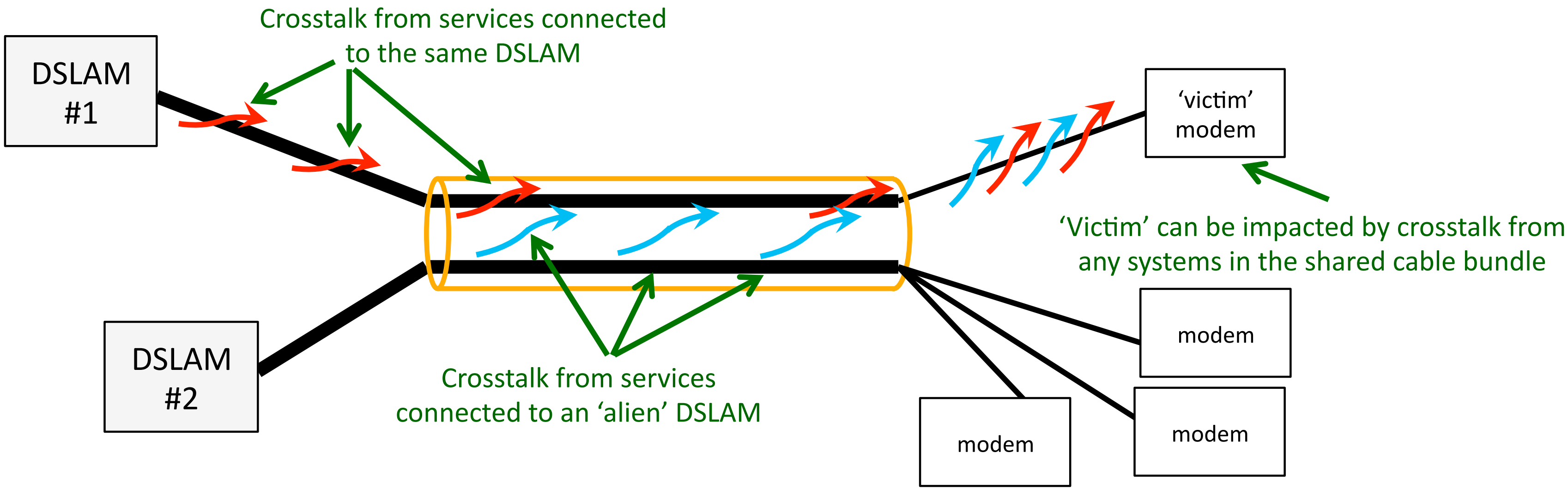
- For Australian cable, twisted pairs are bound together in bunches of ten (‘a binder’)
- Binders are bunched together into cable sheaths
- Cable sheaths are bunched together in ducts or on trays (‘shared cable bundle’)

- The phenomena of crosstalk and noise mean that spectrum needs to be ‘shared’ between all of the individual pairs in the shared cable bundle



Crosstalk from an alien DSLAM dominates

- Crosstalk from services on the same DSLAM can be partially ‘canceled’ by vectoring
- Crosstalk from an alien system cannot
- The alien crosstalk dominates the outcome



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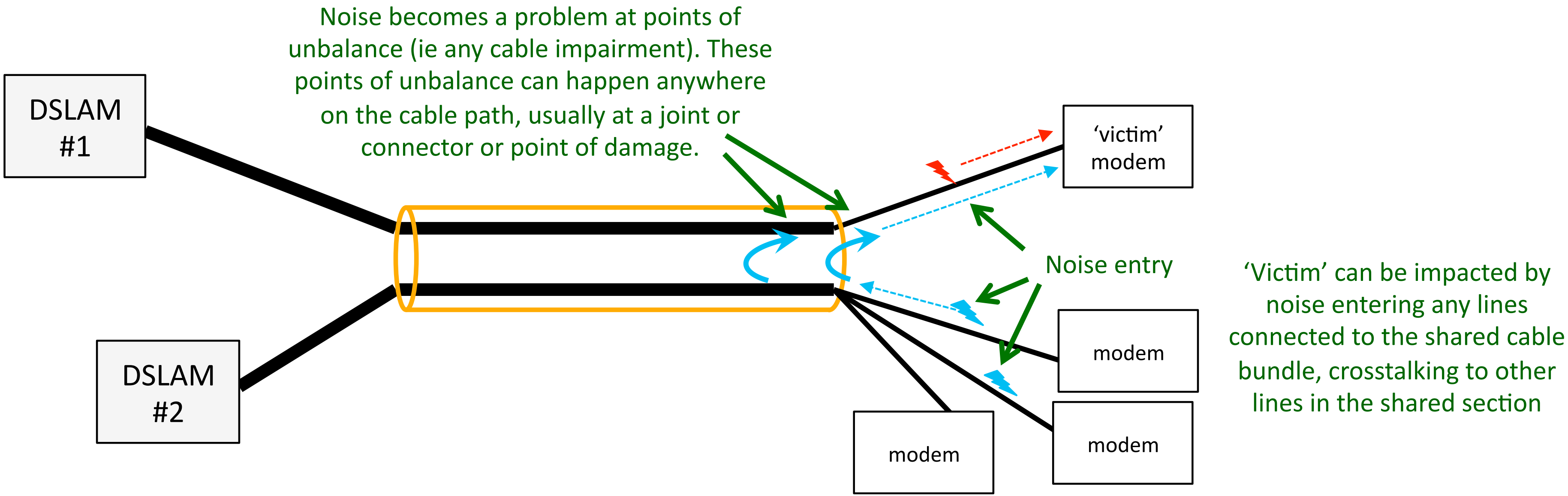
Noise (or 'quiet line noise' / QLN)

- The majority of electrical noise impacting DSL originates in customer premises
- Noise originating in one home can 'crosstalk' to other lines feeding other homes
- Noise is generally only problematic when a line is unbalanced



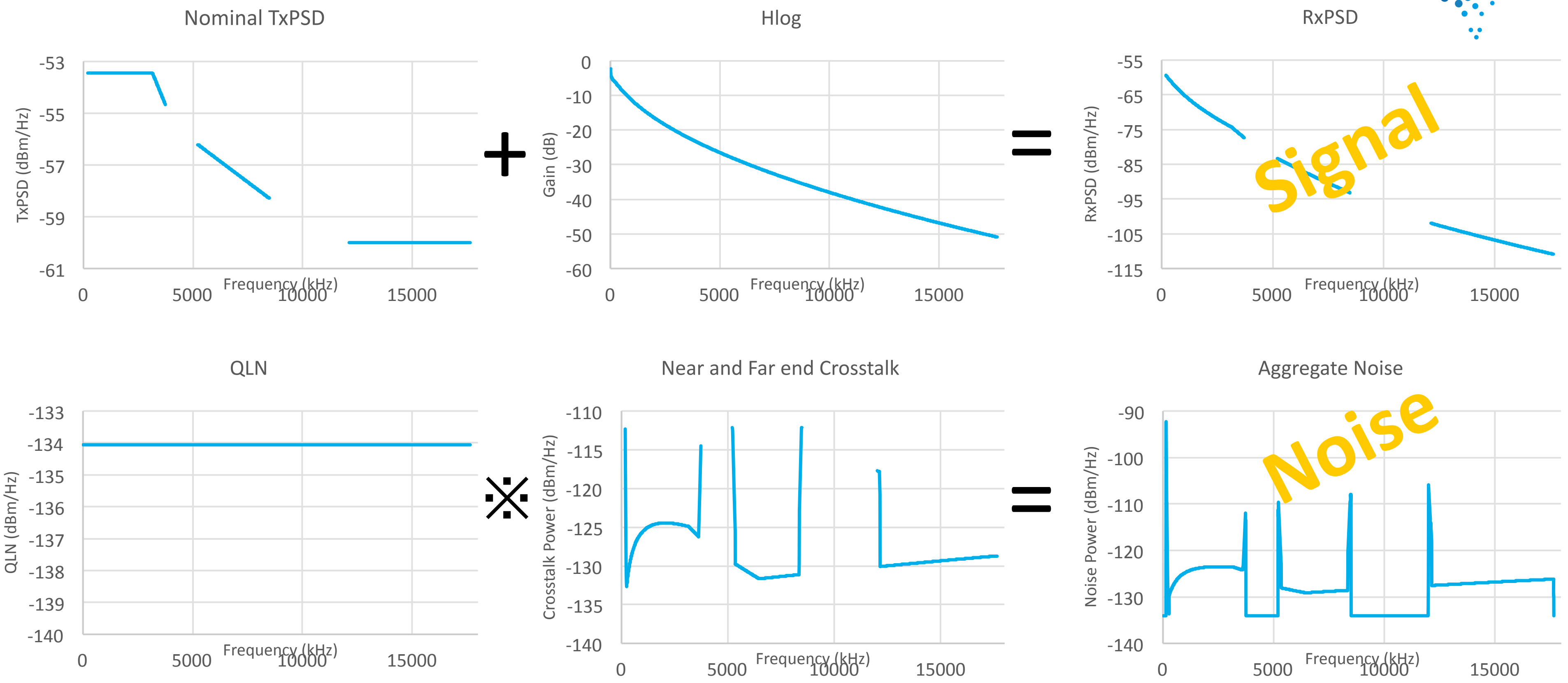
Approach it this way if you like maths!
Its all in the C658 Code!

Predicting / Calculating DSL performance

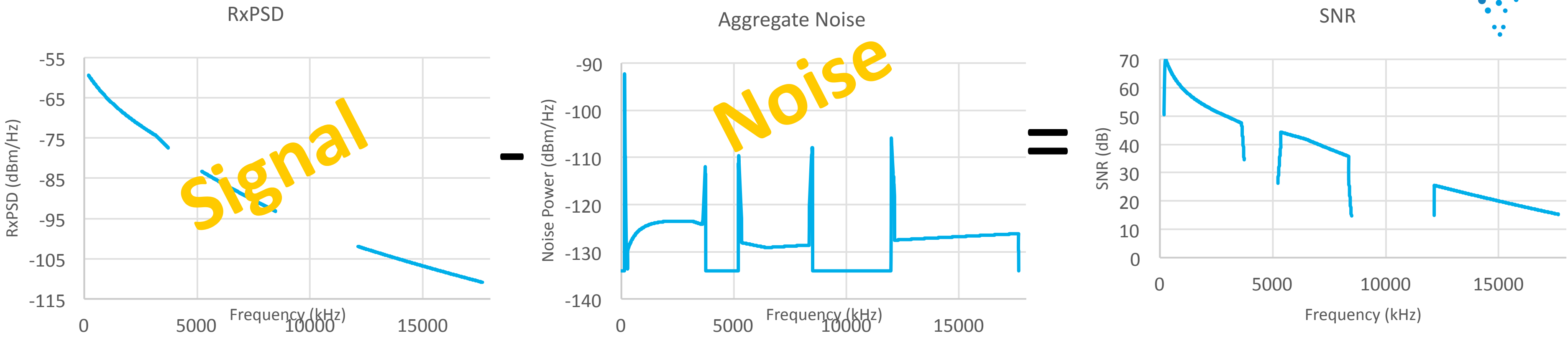
- **Apply the Shannon/Hartley theorem to determine the raw layer 1 bit rate**
  - QAM Symbol Rate = 4000 per second, tones are those carriers conveying a QAM signal downstream or upstream
    - $BitRate = QAMSymbolRate \times \sum_{lowest\ tone}^{highest\ tone} \log_2 (1 + SNR_{linear} / Gap_{linear})$
  - Received Signal level is sum of Transmitted Signal and Attenuation (Attenuation == Hlog)
    - $RxPSD_{dB} = TxPSD_{dB} + Attenuation_{dB}$
  - Received Noise level is a power sum of QLN and Crosstalk
    - (or a power sum of QLN and Vectored Crosstalk)
    - For the purpose of predicting, assume similar levels of noise and crosstalk typical in any international deployment
    - $ReceivedNoise_{dB} = QLN_{dB} ※ Crosstalk_{dB}$
  - SNR is the linear ratio between Received Signal level and Received Noise level
    - $SNR_{linear} = 10^{(ReceivedSignal_{dB} - RxPSD_{dB})/10}$
  - The Gap is a constant particular to QAM modulation, the desired noise margin, and Trellis Coding gain

Approach it this way if you don't like maths!

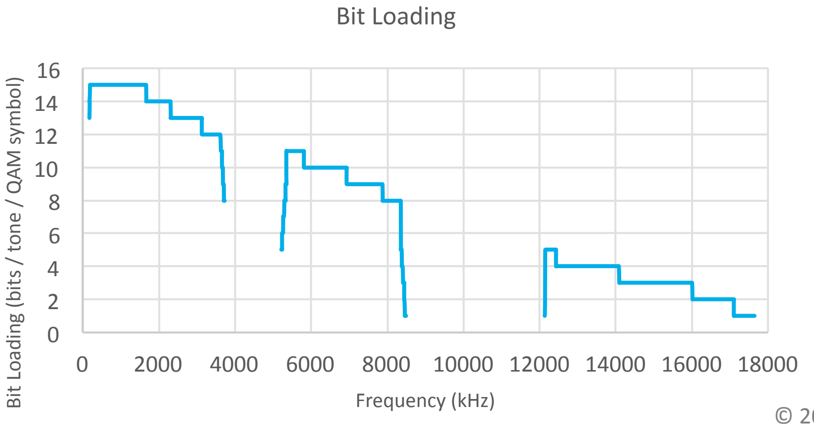
Summing signal and noise to determine SNR



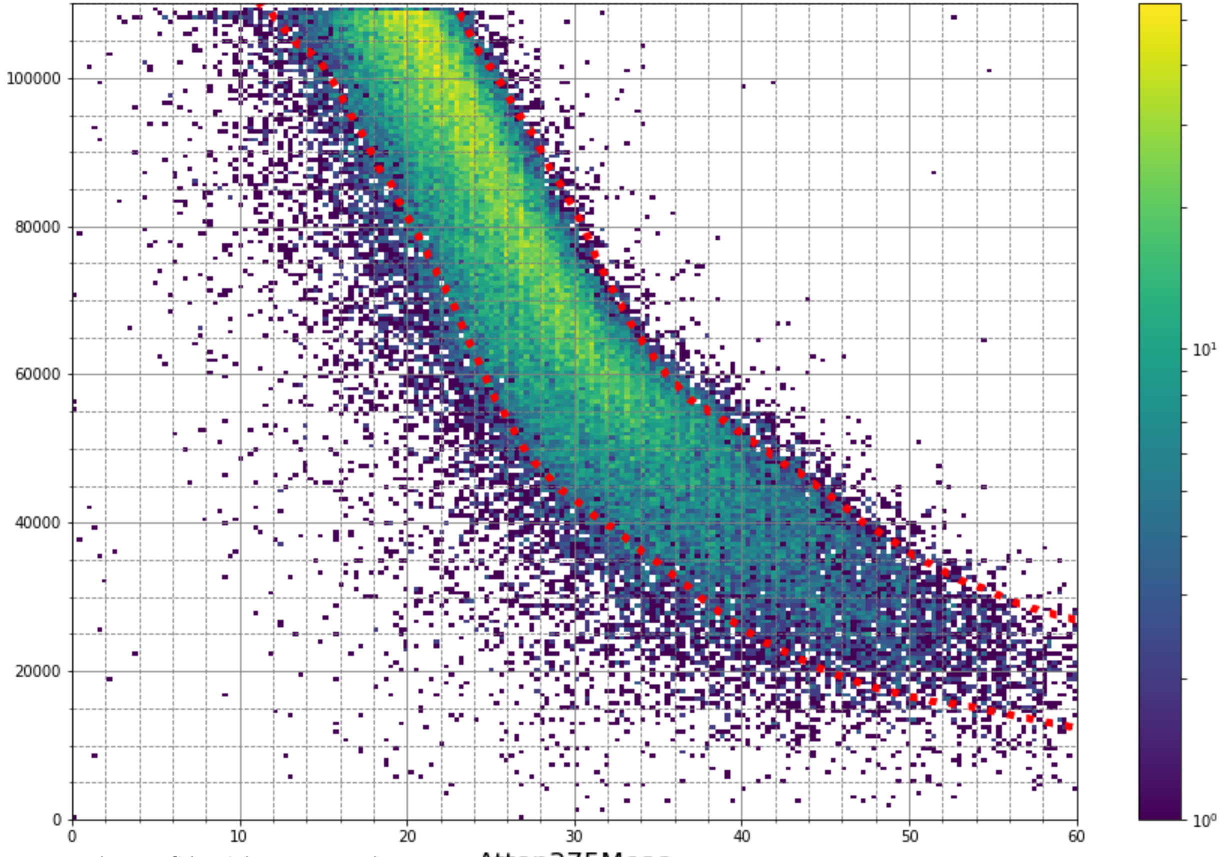
Summing signal and noise to determine SNR



Apply the Shannon/Hartley theorem to determine the raw layer 1 bit rate



Correlation with reported attainable rates



0th and 99th percentile rates derived from simulation

N ~= 113k FTTN services from across the national **nbn**™ access network footprint.

~36% of services in this sample have an attainable VDSL2 DS rate of 110Mbps and are not included in the plot.

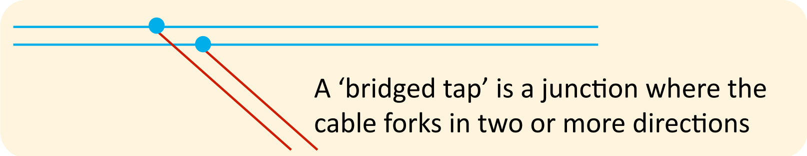
The remaining ~64% of services appear in the plot.

What did we learn?
The best performance barometer is the Hlog

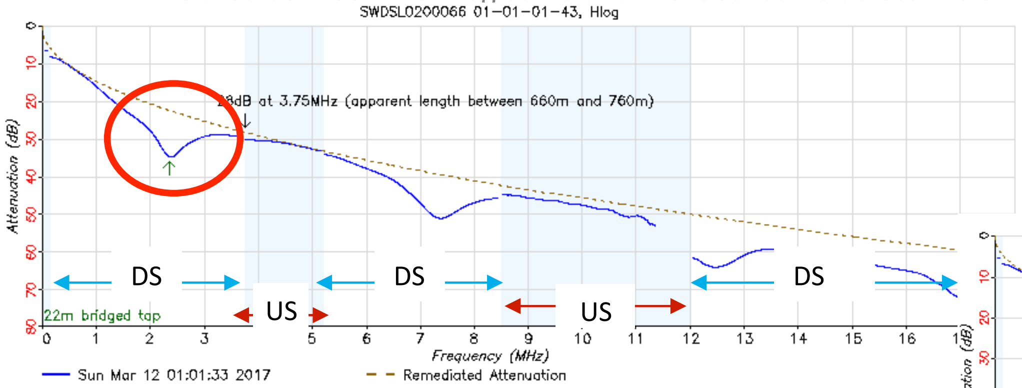
- The most useful and most important data gathered by VDSL2 DSLAMs and modems is arguably the Hlog!
  - Collected at sync time, at every resync
  - RSP techs can access the Hlog from any modems in their fleet using TR-069 (or a test modem)
  - RSP techs can trigger and access the Hlog from the nbn™ service portal (via LQD / normal init)
  - nbn techs can access the Hlog via nbn's DSLAMs

- An interpreted **Hlog reliably suggests whether a line problem is present or not**
  - So it **suggests when there is no line problem** – (eg problem might be wifi rather than DSL)
- If a problem is present, the Hlog suggests WHAT kinds of line problem are present
- But the **Hlog cannot suggest *where* a line problem is located**
  - Use a TDR device to find the location!
- **Understanding Hlogs enables faster and more accurate diagnoses, and problem resolution!**

Bridged Taps

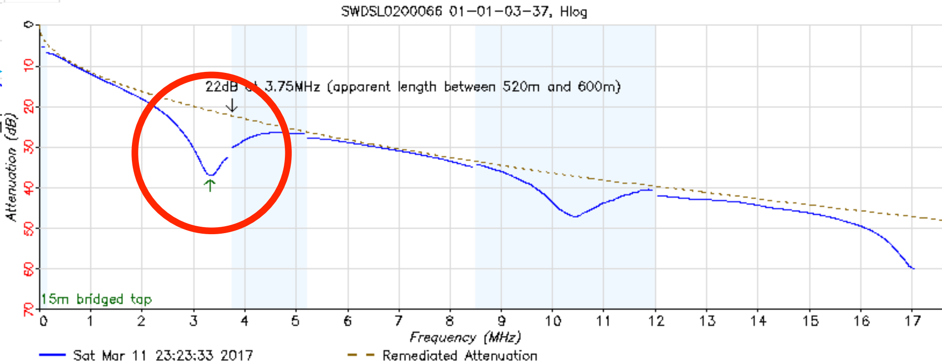


- Bridged taps cause a periodic repetition in the Hlog, at odd harmonics
- The first null frequency tells you the length of the bridged tap
- Each null is an odd quarter wavelength multiple of the bridged tap length
  - Propagation of signals in a cable is approx. 2×10^{8} metres per second
  - $BTlength = PropagationSpeed_{meterPerSec} / Frequency_{Hz} / 4$
- The area between the Hlog curve and the ideal curve across the entirety of used spectrum is directly proportion to the service

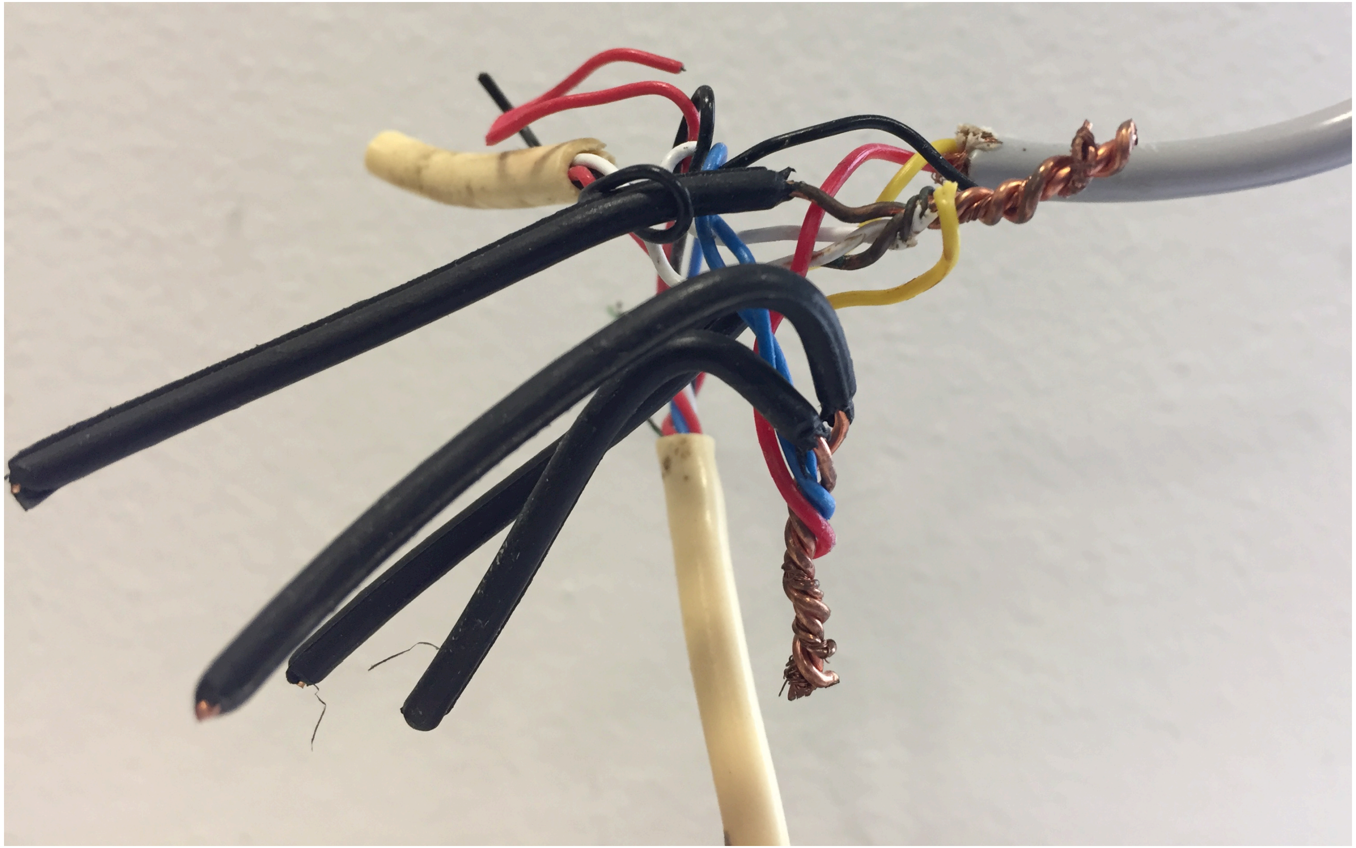


The BT above mainly impacts DS only

The BT below impacts both DS + US



We call this one ‘Bridget’



This is a ‘typical’ example of ‘Star Wiring’ which is frequently found in End User Premises. This one has three bridged taps plus the VDSL2 modem. ‘Bridget’ has a distinctive ‘DIY’ look-and-feel.

Star Wiring was originally installed for the purpose of having multiple telephone or fax machines / sockets. It can profoundly impair VDSL2.

When we removed ‘Bridget’, the sync rate improved from 15/3 to 36/9.

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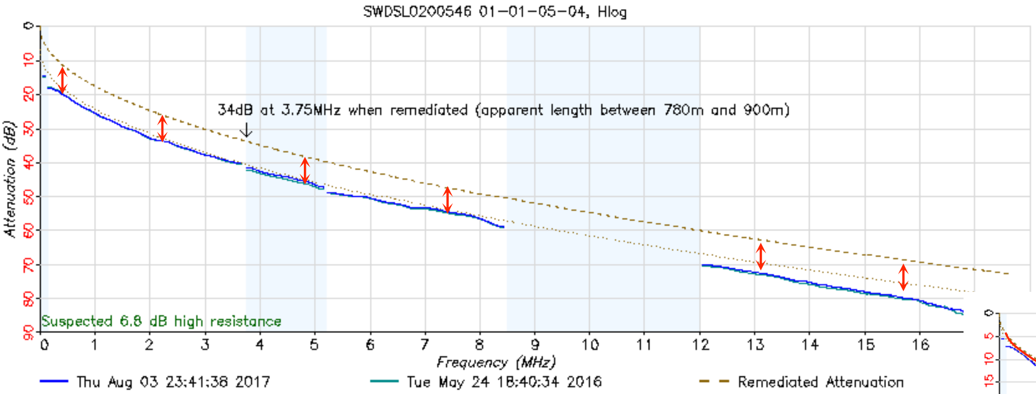
High Resistance Joints

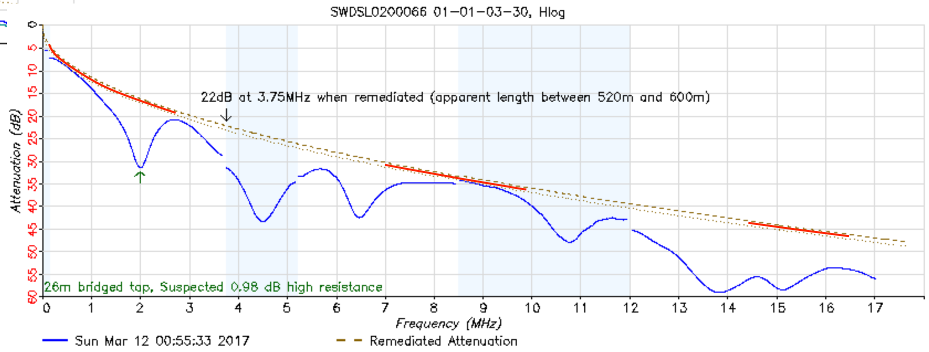
A 'high resistance joint' is a junction where a connection is degraded

- HR issues cause the Hlog curve to drop by a constant that's independent of frequency
- The added resistance of the HR directly causes a small bit rate drop due to the increased attenuation
- HR problems however are also an imbalance in the 'balanced' twisted pair, which causes significantly greater noise levels
  - Significantly greater noise levels cause proportionately greater loss of bit rate than the attenuation aspect of the HR
  - Significantly greater noise levels can increase the risk and frequency of drop outs



The HR above affects DS and US equally

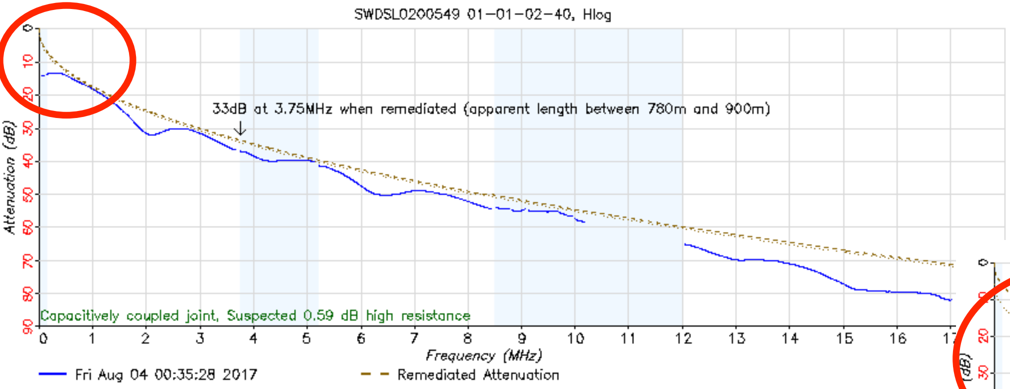
The HR below is combined with two BTs



Capacitively Coupled Joints

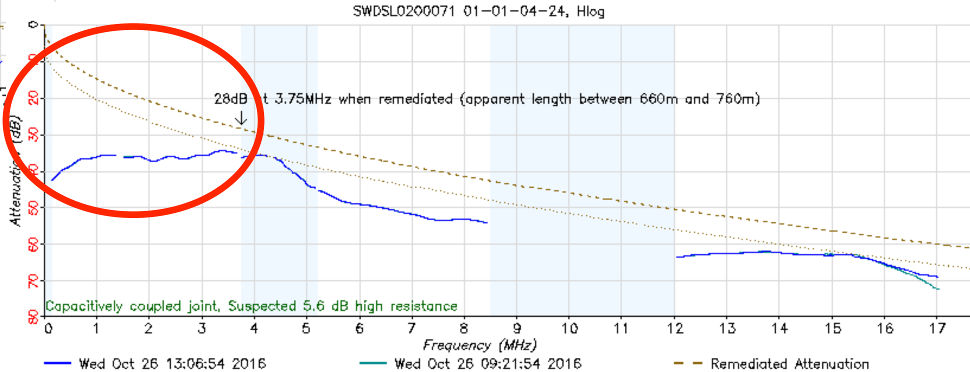
A 'capacitively coupled joint' is a junction where one leg of the connection has broken apart

- Capacitive coupling causes the Hlog curve to droop at the lower frequencies
- The capacitance directly causes a very small bit rate drop due to the increased attenuation at lower frequencies
- 'One Leg' problems however are also an imbalance in the 'balanced' twisted pair, which causes significantly greater noise levels
  - Impacts of capacitive joint imbalance are comparable with impacts from an HR imbalance
- Frequently, capacitive coupling is combined with an HR
- Frequently, the cause of capacitive coupling is old/corroded/oxidised sockets/connectors within the end user's home

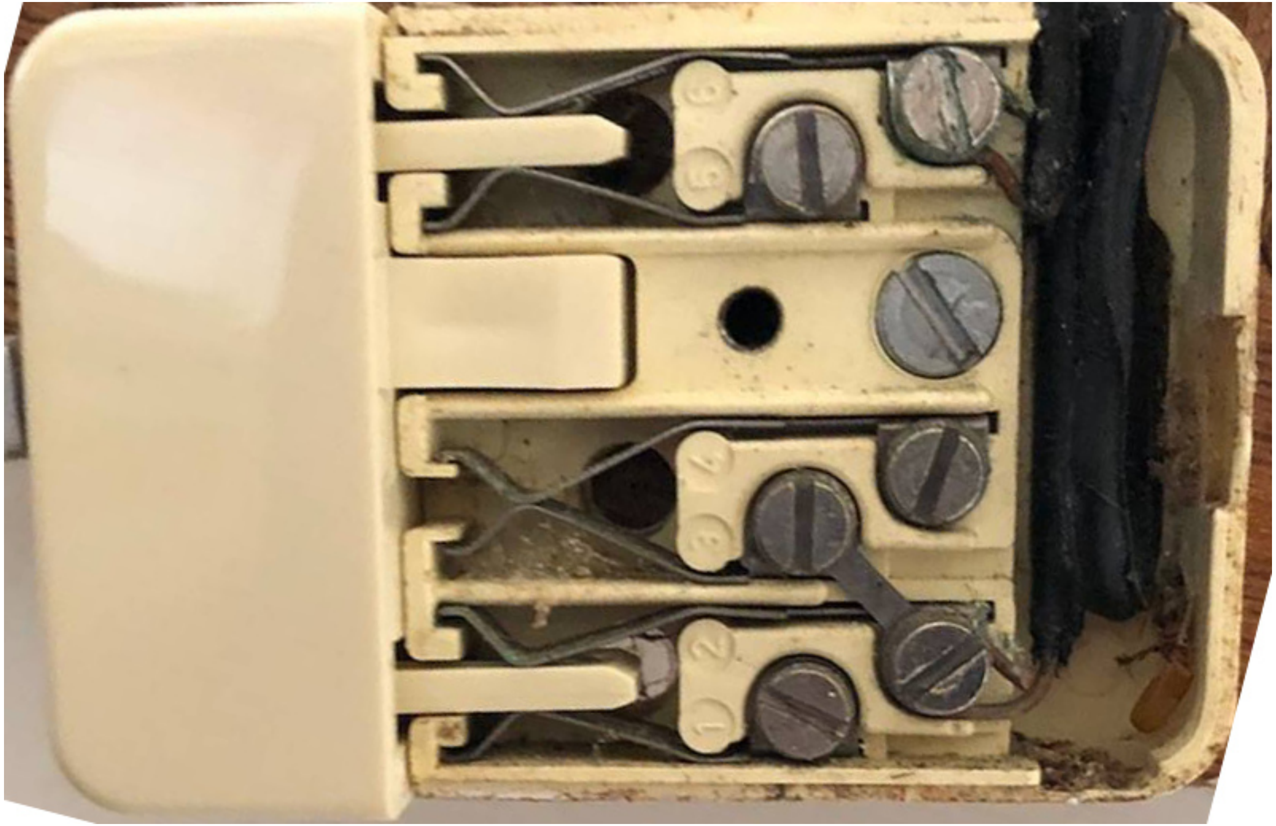


The OneLegOpen above is combined with a small HR, and the two problems together cause the Hlog ripples

The OneLegOpen below is combined with a HR



We call this one ‘Gammy’



This is a ‘typical’ example of a ‘One-Leg’ problem which is also frequently found in End User Premises. The copper has corroded over the passage of time. It no longer makes a good connection.

Gammy was causing both a ‘one-leg’ as well as a ‘high resistance’ degradation, and the service was experiencing high noise. Although still achieving a 100 Mbps download rate, the added noise was causing drop outs. When we removed ‘Gammy’, the drop outs ceased.

Conclusion…

- The original DSL spectrum sharing Code was written in the era of legacy DSL
  - A new Code has been developed for Next Generation Broadband systems
  - New methods to model Next Generation BB performance were developed
  - The model has proven to be reliable and accurate

- The modelling pointed towards using Hlog to characterise service issues
  - Hlog data is available to RSP tech support by querying the modem fleet or the nbn™ service portal
  - Hlog data is available to nbn tech support by querying the DSLAM fleet
  - Smooth Hlogs that follow root(f) indicate impairment-free lines
  - The attenuation implied by root(f) indicates the intrinsic capacity of the line
  - Hlog interpretation is an efficient means to assess line condition