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Network Operations Subcommittee

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SCTE 280 2022

Understanding and Troubleshooting Cable RF Spectrum

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1. Introduction

1.1. Executive Summary

The DOCSIS® 3.0 specification introduced a feature known as full band capture (FBC), enabling cable modems to report radio frequency (RF) spectrum data. This creates an unprecedented opportunity to observe RF performance in ways that were previously impossible. Most operators now have access to spectrum analysis functionality at nearly every location where FBC-capable DOCSIS customer premise equipment (CPE) have been installed. While there is plenty of material available that explains spectrum analysis, SCTE's Network Operations Subcommittee Working Group 7 (NOS WG7) members have discovered and cataloged many cable-specific nuances and have compiled a significant amount of material on this topic.

This Industry Reference (IR) discusses the fundamentals of cable RF, impedance, resolution bandwidth, return loss, noise, velocity of propagation (VoP), and other parameters. An understanding of these topics is especially useful when examining different cable environments and architectures. This Industry Reference also covers the differences in spectrum analysis tools such as FBC vs. traditional frequency-swept spectrum analyzers. Finally, it provides an in-depth analysis and means to identify many common cable impairments (including examples). Among the examples are problems such as damaged coaxial cables, loose connectors, faulty amplifiers, water-soaked drops, bad or missing terminations, and more. The goal of this document is to help cable operators, especially technicians, be successful in finding and fixing cable plant failures that disrupt RF transmission, thus impacting service.

1.2. Scope

The material contained within this document applies directly to DOCSIS 3.0 and higher compliant CPE which have implemented full band capture functionality. It does not include non-DOCSIS connected devices such as MoCA or Wi-Fi, which may have similar but different capabilities.

1.3. Benefits

This Operational Practice provides a valuable tool to cable field operations and engineers to better interpret cable RF spectrum performance. The document also provides operational perspectives about detecting, interpreting, and repairing problems that are often unique to coaxial cable networks. The intent of this document is to produce consistent interpretation and treatment of problems, improve repair times, and reduce rework caused by misinterpretation.

1.4. Intended Audience

The intended audience of this document is primarily field-facing technicians, but the document is also useful for analysis and repair teams. It also may be useful for software designers and systems engineers.

1.5. Areas for Further Investigation or to be Added in Future Versions

At the time of writing, a document addressing the upstream is planned. Among the topics being considered is cable modem upstream diagnostic analyzer (UDA), which will offer cable operators important capabilities when it eventually becomes widely available. Another is upstream triggered spectrum capture (UTSC) in the CMTS or RPD.

2. Normative References

The following documents contain provisions which, through reference in this text, constitute provisions of this document. The editions indicated were valid at the time of subcommittee approval. All documents are subject to revision and, while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

No normative references are applicable.

2.2. Standards from Other Organizations

No normative references are applicable.

2.3. Published Materials

No normative references are applicable.

3. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

3.1. SCTE References

No informative references are applicable.

3.2. Standards from Other Organizations

[CTA] Cable Television Channel Identification Plan (CTA-542-D R-2018)

3.3. Published Materials

Hranac, R., “What is RF? It's Like Magic,” December 2011, *Communications Technology*

Hranac, R., “Radio Frequency,” *Broadband Library*, https://broadbandlibrary.com/radio-frequency/

4. Compliance Notation

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5. Abbreviations

AC	alternating current
AGC	automatic gain control
CATV	community antenna television (now cable television)
CB	citizens band
CPD	common path distortion
CPE	customer premises equipment
CTA	Consumer Technology Association
CW	continuous wave
dB	decibel
dBc	decibel carrier
dBmV	decibel millivolt
DC	direct current
DOCSIS®	Data-Over-Cable Service Interface Specifications
DS	downstream
DUT	device under test
FBC	full band capture
FCC	Federal Communications Commission
FFT	fast Fourier transform
FIR	far infrared
FM	frequency modulation
GHz	gigahertz
GSM	global system for mobile communications (originally groupe spécial mobile)
HE	headend

HFC	hybrid fiber/coax
HPNA	HomePNA Alliance (formerly Home Phoneline Networking Alliance)
HRC	harmonic related carrier
Hz	hertz
IP	Internet Protocol
IRC	incremental related carrier
kHz	kilohertz
log	logarithm
LTE	long-term evolution
MDU	multiple dwelling unit
MER	modulation error ratio
MHz	megahertz
MoCA	Multimedia over Coax Alliance
nm	nanometer
NASA	National Aeronautics and Space Administration
NOS	Network Operations Subcommittee
OEM	original equipment manufacturer
OFDM	orthogonal frequency division multiplexing
OOB	out-of-band
OP	operational practice
OSI	Open Systems Interconnection (the standard’s full name is “ISO/IEC 7498-1 Information technology – Open Systems Interconnection – Basic Reference Model: The Basic Model – Part 1”)
PNM	proactive network maintenance
QAM	quadrature amplitude modulation
RBW	resolution bandwidth
RF	radio frequency
RFI	radio frequency interference
RL	return loss
RxMER	receive modulation error ratio
SC-QAM	single carrier quadrature amplitude modulation
SCTE	Society of Cable Telecommunications Engineers
SE	shielding effectiveness
SLF	super low frequency
SNR	signal-to-noise ratio
STB	set-top box
STD	standard
THz	terahertz
TV	television
UDA	upstream diagnostic analyzer
UE	user equipment
UHF	ultra high frequency
US	1) upstream; 2) United States
UV	ultraviolet
VHF	very high frequency
VLF	very low frequency
VoP	velocity of propagation
WG	working group
WWII	World War II

6. What is RF?

The material in this section is adapted from an article by Ron Hranac that originally appeared in the December 2011 issue of *Communications Technology* magazine, and is used with permission of the author.

Since the creation of the very first cable systems in the late 1940s, the cable industry has embraced and been based upon RF technology. These days we've also embraced the digital world- and a subset of digital technology called Internet protocol or IP – but RF is still needed in most cable networks to transport digital data to and from devices in our subscribers' homes. The answer to the question in the title of this section is far more complicated than it initially seems.

A good place to start is with an explanation of the letters R and F, which together are an abbreviation for radio frequency. But what's radio frequency? Here's one very high-level perspective: It's that portion of the electromagnetic spectrum from a few kilohertz to about 300 GHz (Figure 1 illustrates a graphic representation of the electromagnetic spectrum). 300 GHz is the beginning of the far infrared (FIR) portion of the electromagnetic spectrum.

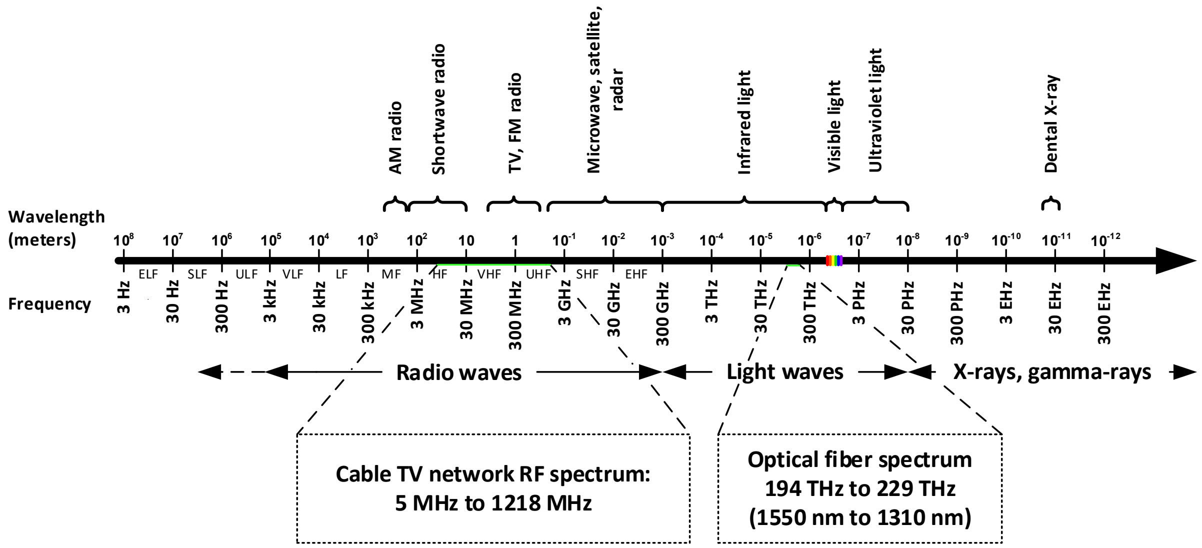


Figure 1 - Graphic illustration of the electromagnetic spectrum

Radio frequency also can be defined as a rate of oscillation within the 3 kHz to 300 GHz range. More on this in a moment. Before too much eyeball glaze factor sets in, it might be helpful to talk about frequency, and wavelength, and the electromagnetic spectrum, and…

See, this is more complicated than it initially seems. So back to the basics it is.

Direct current, abbreviated DC, is an electric current that is unidirectional, as a result of a voltage source whose output maintains the same polarity. An example is the output of a flashlight battery. DC is not RF, nor is it part of the electromagnetic spectrum. Alternating current, abbreviated AC, is an electric current that periodically reverses or alternates in direction, as a result of a voltage source whose output periodically reverses or alternates in polarity. Examples include AC from a household electrical outlet and RF signals.

Here's an interesting point: RF is a form of AC, but an electrical outlet's AC technically isn't considered to be RF. One reason is that RF is generally accepted to have a frequency higher than about 3 kHz (there are some exceptions), and the frequency of the electric current from the wall outlet is a *lot* lower. More on that in a moment.

In case you were wondering, sound waves are not RF, and they are not part of the electromagnetic spectrum. An RF signal can have the same frequency as a sound wave, and most people can hear a 5 kHz audio tone. Your ears pick up physical vibration that is sound. No one can hear a 5 kHz RF signal.

Just what is frequency? It's the number of times, typically per second, that a repetitive event happens – the previously mentioned rate of oscillation. In the case of AC from a North American household electrical outlet, the polarity changes through a complete cycle of values 60 times each second. A sinusoidal AC signal varies continuously. That variation can be measured in terms of parameters such as amplitude and degrees. A full cycle of change comprises 360 degrees (a measure of phase), and if that cycle is completed in one second the frequency is one cycle per second or one hertz (Hz). As noted previously, AC from a household electrical outlet has a frequency of 60 cycles per second or 60 Hz. A local FM radio station's transmitted signal might have a frequency of 103,500,000 Hz, or 103.5 MHz (megahertz).

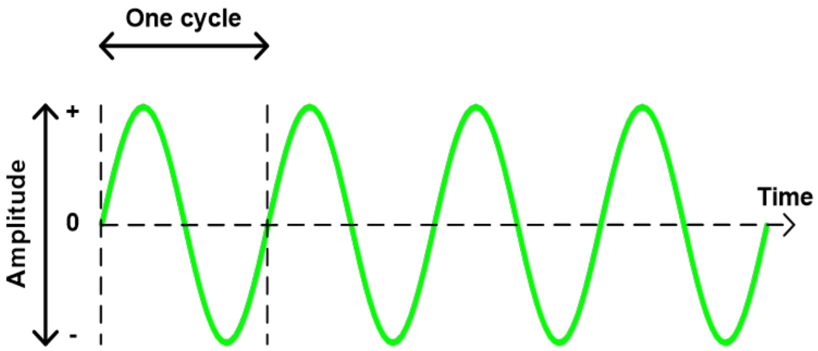


Figure 2 - Sinusoidal AC waveform

Figure 2 shows a sinusoidal AC waveform on a graph of amplitude in the vertical axis versus time in the horizontal axis, the result is the classic sine wave. One way to characterize a sinusoidal AC waveform is by its wavelength, which is a measure of the distance between the same points on adjacent cycles, for instance, from one cycle's peak to an adjacent cycle's peak. Another definition of wavelength is the distance that a wave travels through some medium in the period of a single cycle.

Related to frequency is wavelength, an electromagnetic wave's speed of propagation (speed at which the wave moves) divided by its frequency in cycles per second. Wavelength is commonly represented by the symbol λ. If you could see an electromagnetic signal's waves, wavelength would be the distance from a point on one cycle's wave to the same point on the adjacent cycle's wave. Yet another related term is period, which is the duration in time of each cycle of a repetitive event and is the reciprocal of frequency. See how wavelength, distance, and time relate?

Electromagnetic waves can be thought of as analogous to the ripples that occur when one tosses a rock into a pond of water. For example, throw a rock in the water, then count the number of waves per second that go by a wooden post sticking out of the water. That's the frequency. Next, measure the distance between adjacent water ripples' peaks or valleys to determine the wavelength. Finally, measure the time that it takes for each wave or ripple to pass the wooden post; that's the period.

NASA defines the electromagnetic spectrum as "the full range of frequencies, from radio waves to gamma rays…" and Wikipedia says it's the "range of all possible frequencies of electromagnetic radiation." Electromagnetic radiation is a form of energy comprising oscillating electric and magnetic fields (the electric and magnetic components are orthogonal, or perpendicular to each other, and also are orthogonal to the direction of propagation), and which exhibits wave-like behavior as it zips along through space. The wave-like behavior allows electromagnetic radiation to be categorized based on wavelength. Going from electromagnetic radiation's longest wavelengths and lowest frequencies to the shortest wavelengths and highest frequencies, the list looks like this: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays.

Unlike the visible light portion of the electromagnetic spectrum, RF can't be seen. Its presence and various characteristics such as frequency, wavelength, and amplitude can be detected and measured with specialized test equipment. Examples of that test equipment include signal level meters and spectrum analyzers.

RF energy propagates through free space at the speed of light and is made of photons. "Wait a minute," you say, "I thought photons are what light is made of." That's true, because light's a form of electromagnetic radiation. But so are radio waves, microwaves, infrared, ultraviolet, X-rays, and gamma rays. The energy per photon (not the same as signal level) is low at long wavelength electromagnetic radiation such as RF, and high at short wavelength electromagnetic radiation such as gamma rays. From an abstract point of view RF is really, really low frequency light, or light is really, really high frequency RF. Making things a bit more interesting: RF energy coupled to a conductor produces electrical current (think electrons) that travels on or near the surface of the conductor, a phenomenon known as skin effect.

An RF signal can convey information if one or more characteristics of that signal are varied: amplitude, frequency, or phase. We can't see or hear RF, but we can see and hear pictures and sound that it carries. RF can be transmitted via a conductor such as coaxial cable, and it can be transmitted over-the-air or through the vacuum of space. It can be used to cook food or heat a cup of coffee. Pretty cool, this thing we call RF. As some of my data colleagues say, "it's like magic."

7. Fundamentals of the RF Spectrum Display

The spectrum analyzer is a common tool used for installing, troubleshooting, and maintaining RF on cable plant. A spectrum analyzer is a test instrument that displays amplitude versus frequency, with amplitude in the vertical axis of the display and frequency in the horizontal axis. See Figure 3 for an example. Spectrum analyzers can be very sophisticated, expensive, and complicated to operate. Spectrum monitors are generally much simpler to use (and have limited capabilities compared to true spectrum analyzers). Spectrum monitors also display amplitude in the vertical axis and frequency in the horizontal axis, and are more typical of what is used in some cable field instruments and cable modem full band capture (FBC) functionality.

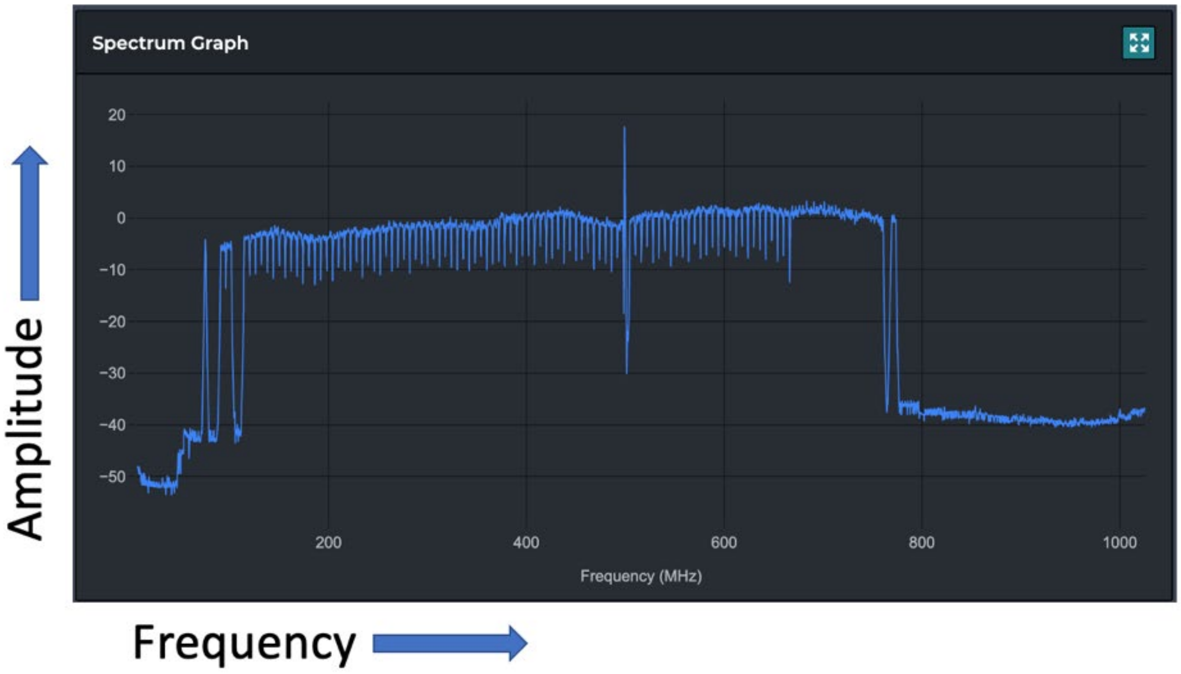
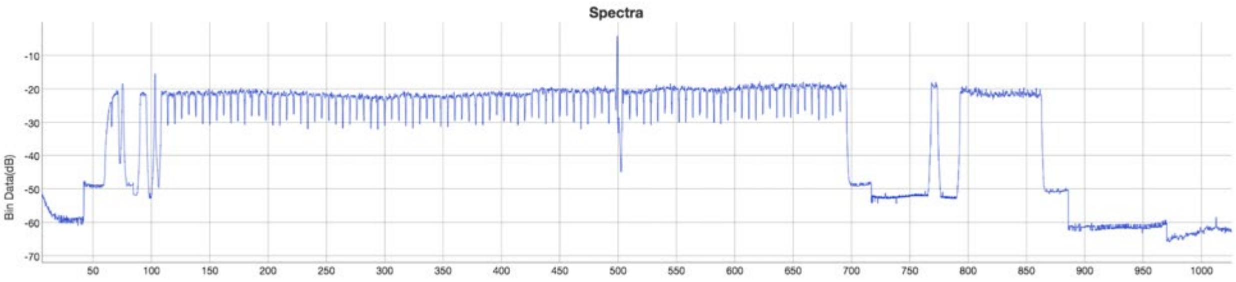


Figure 3 - Amplitude vs. frequency

In this example we can see the downstream RF spectrum in a cable network. Among the signals that are displayed are an out-of-band (OOB) telemetry signal at 72.75 MHz for set-top boxes, several single carrier quadrature amplitude modulation (SC-QAM) digital signals starting at 108 MHz to about 700 MHz, a continuous wave (CW) carrier at 499.25 MHz, and an orthogonal frequency division multiplexing (OFDM) signal at the upper end of the spectrum. More on these later.

FBC-capable modems can contain one of several different variations of communications chips (silicon). At the time of this writing, there are five or six major variations in these chips, which can produce slightly different FBC results. Among the chip variations, there are also different software revisions, which influence the FBC output. These differences are usually associated with:

- Different amounts of averaging, which has a smoothing effect vs. spurious appearance (see Figure 4);
- Inconsistent resolution bandwidth (RBW) settings, which can make the results look blocky; (see Figure 5 and Figure 6) or
- Inconsistent processing and response times, resulting in timeouts, which result in unavailable data.



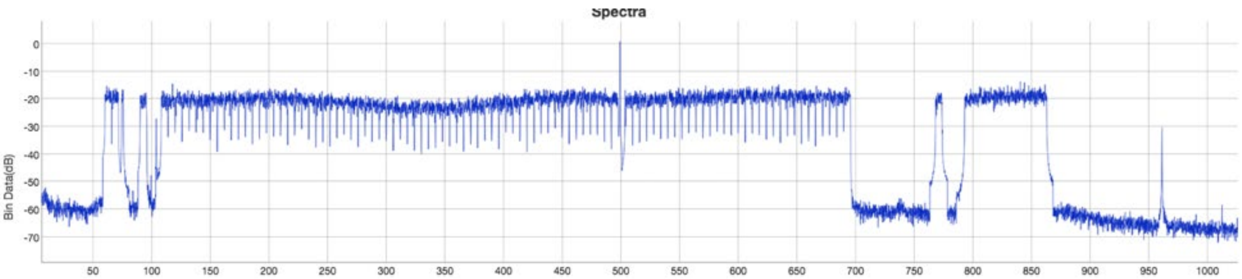
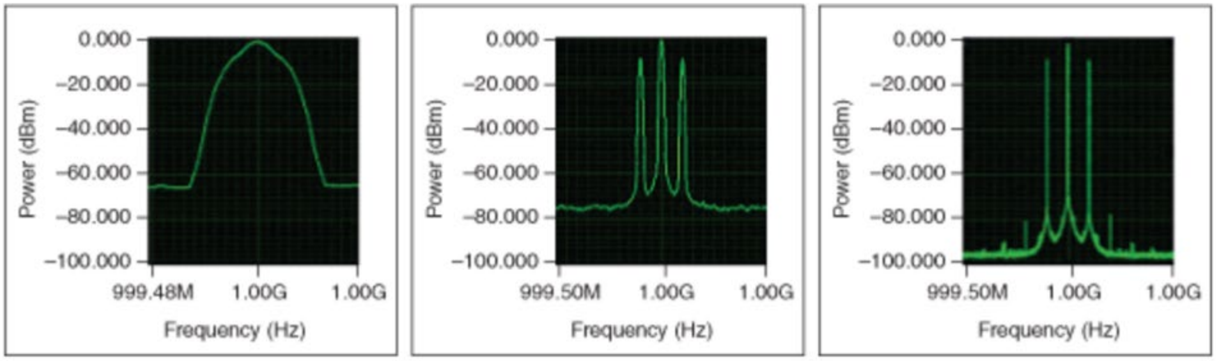


Figure 4 – Differences in spectrum averaging



RBW = 100 kHz

RBW = 10 kHz

RBW = 100 Hz

Figure 5 - Resolution bandwidth

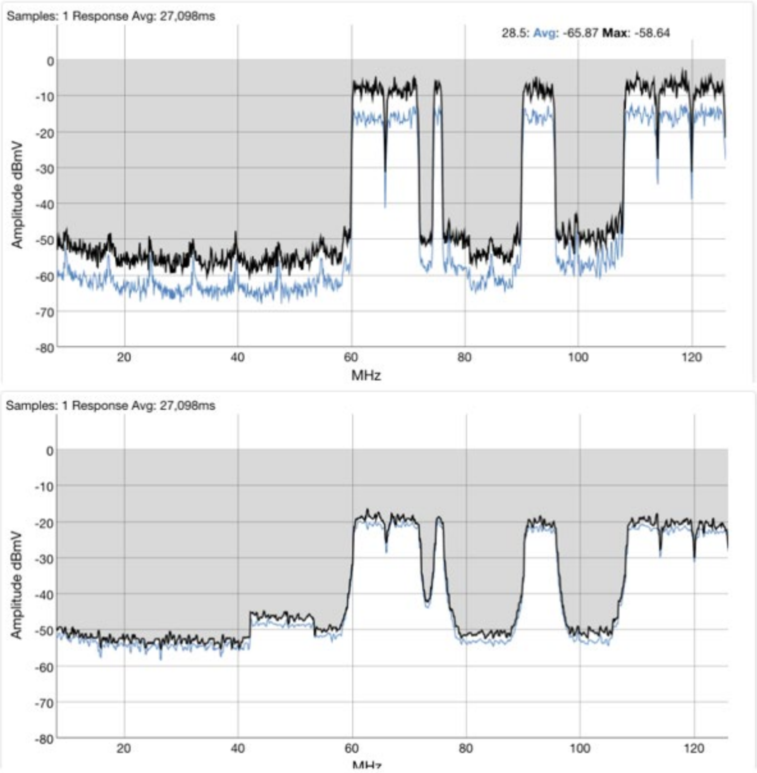
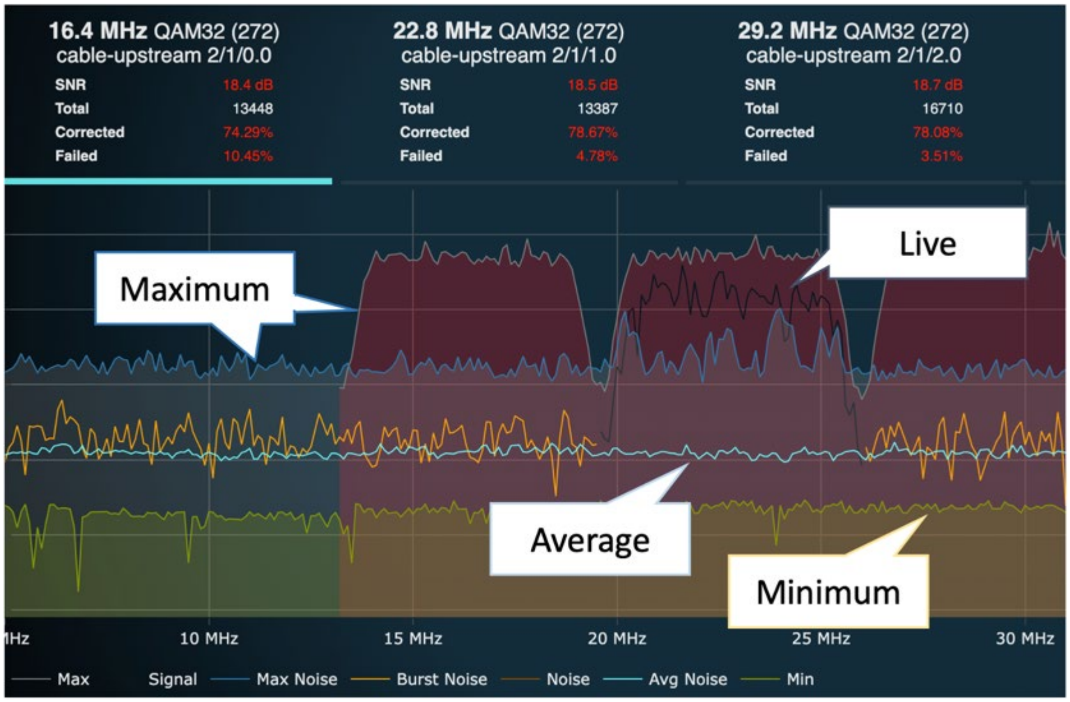


Figure 6 – Resolution bandwidth compared, 117 kHz (top) and 300 kHz (bottom)

Signals can be visualized on a spectrum analyzer in different ways that highlight various signal properties. The spectrum is represented on the screen in what is often referred to as a "trace" (Figure 7). Among the most common visualized traces are: live, minimum, maximum and average. The live trace is the visual representation of the energy in a given portion of spectrum, or span, in the designated sample or capture time. The minimum, or Min trace is the representation of the lowest amount of energy in the span under test across a number of samples. Similarly, the maximum or Max trace is the representation of the highest amount of energy in the span under test across a number of samples. Average then is the average amount of energy in the measured span across a number of samples. All of these traces can be useful and can provide details of what activity is occurring in the portion of the spectrum that is being observed.



16.4 MHz QAM32 (272) cable-upstream 2/1/0.0		**22.8 MHz** QAM32 (272) cable-upstream 2/1/1.0		**29.2 MHz** QAM32 (272) cable-upstream 2/1/2.0	
SNR	18.4 dB	SNR	18.5 dB	SNR	18.7 dB
Total	13448	Total	13387	Total	16710
Corrected	74.29%	Corrected	78.67%	Corrected	78.08%
Failed	10.45%	Failed	4.78%	Failed	3.51%

Figure 7 – Typical spectrum analyzer trace functions

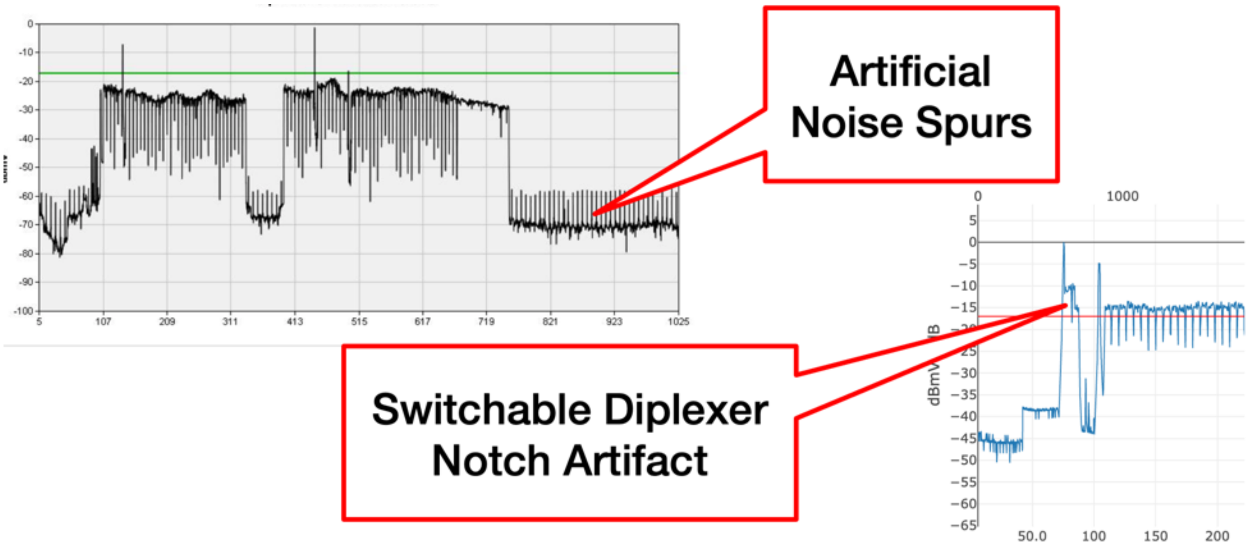


Figure 8 – Measurement artifacts

In Figure 8, some devices report spurs in the noise floor. These spurs are generated inside of the modem and are not present in the actual RF spectrum. They are artifacts of the capture and stitching process. These are artifacts created by the cable modem, so they *should* be ignored. Some devices have switchable diplexers which also report a notch around 85 MHz. The notch does not exist in the spectrum at the input of the cable modem.

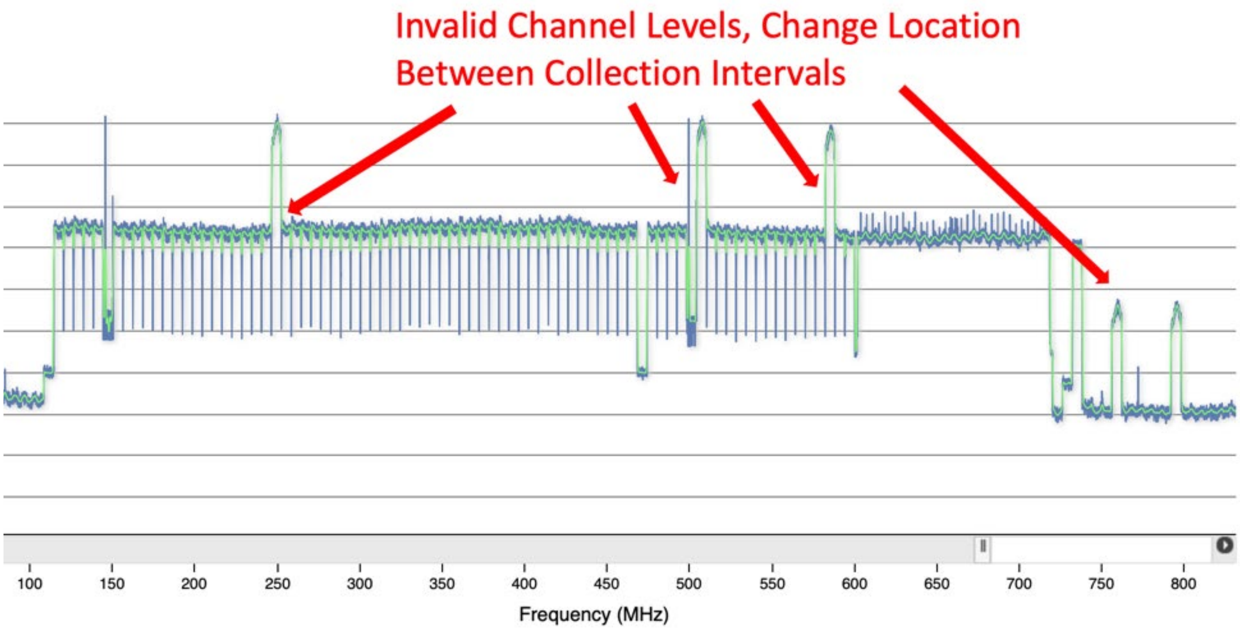


Figure 9 – Incorrect power reporting

Figure 9 shows an example of a firmware related issue on a specific DOCSIS chip (silicon). The raised channels are artificially high and change location in frequency over time. These devices *should* be updated to the latest firmware to resolve the incorrect reporting issue.

Conventional cable architectures provide two-way signal transmission on separate spectral bands. Amplifiers and cable modems use diplex filtering to separate upstream transmissions from downstream transmissions. Upstream signals travel from the subscriber premises toward the node in the narrower lower frequency band (typically from 5 MHz to as high as 204 MHz). Downstream signals travel from the node in the much wider upper frequency band (up to 1.2 GHz). Such diplex filtering prevents two-way transmission within the same bandwidth.

Figure 10 shows two examples of different diplex filter configurations within the cable modem. The region marked “Diplexer Rejection” is the upstream frequency spectrum which is blocked (filtered) from the cable modem’s downstream receiver. The frequency range of the diplex filter can differ, depending on modem configurations such as sub-split, mid-split and high-split.

Also illustrated in Figure 10 is the upstream diagnostic analyzer (UDA) feature, available in some newer cable modems. The label “UDA Spectrum” displays the measurements that were taken from the upstream frequency spectrum using a separate receiver included in some modems.

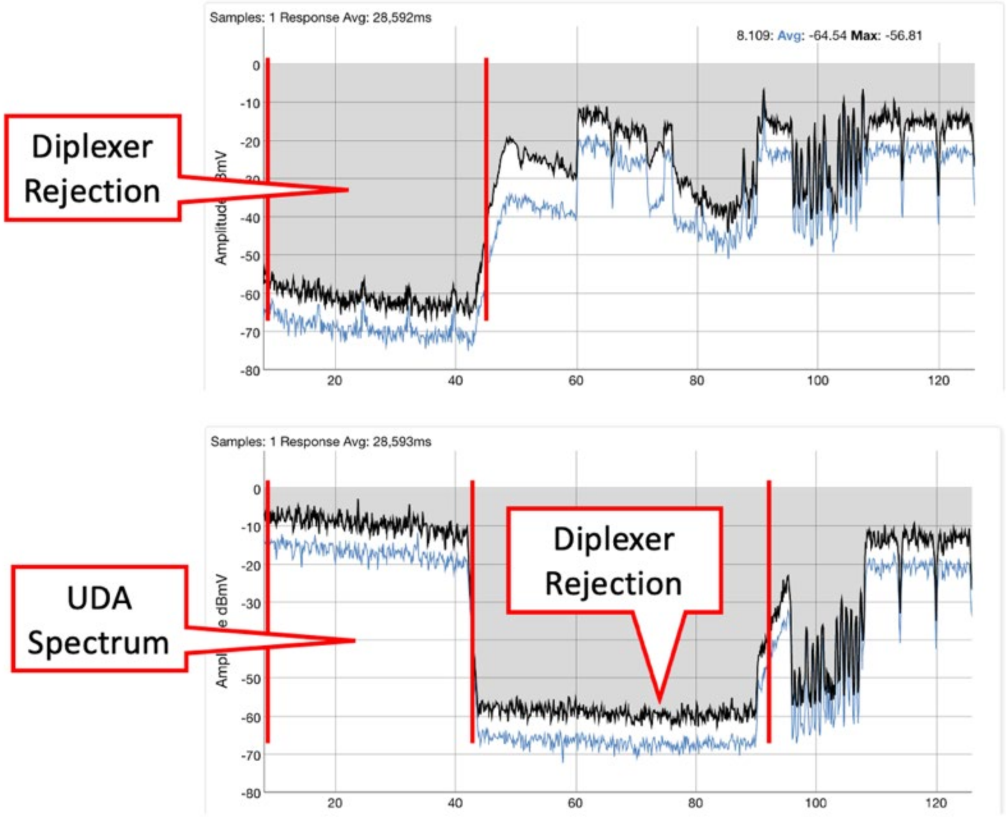


Figure 10 – Diplexer rejection and UDA spectrum

Figure 11 shows the same frequency spectrum captured with two different types of spectrum analyzers. The first (left) is the display of a traditional frequency-swept spectrum analyzer. The graphic on the right of Figure 11 is the display of a digitally tuned FFT spectrum capture.

Frequency-swept spectrum analyzers can be configured to capture short duration, spurious energy. These can be effective at detecting electrical impulse noise and other spurious interference.

Some instruments are available with full-band spectrum capture technology that uses overlapping FFT analysis and result presentation. It captures a complete upstream spectrum in one shot and can take thousands of full-band shots per second. While one measurement is being captured the previous measurement is simultaneously being processed for display, which effectively turns the meter into a near real-time spectrum analyzer. Because the meter is continuously capturing the whole upstream band, any transient impulse noise is detected and displayed.

Swept spectrum analyzers can scan, tuning to one frequency at a time taking measurements within the RBW then moving to the next frequency. This continues until it reaches the highest measurement frequency and then starts over at the beginning. If the analyzer scan is not already tuned to the frequency at the instant of a transient signal, then that event may not be detected or measured. Detection depends on the duration of the transient signal and whether the analyzer scan is at the noise frequency, so the noise is within the detection RBW. This is why max hold is often used in swept spectrum analyzers for capturing impulse noise and other transient signals.

Regardless of old or new, spectrum analyzers are an essential tool for analyzing and troubleshooting performance of communication network issues that impact our customers and their experience. Learning the basic skills of spectrum analysis are timeless and valuable to cable engineering personnel.

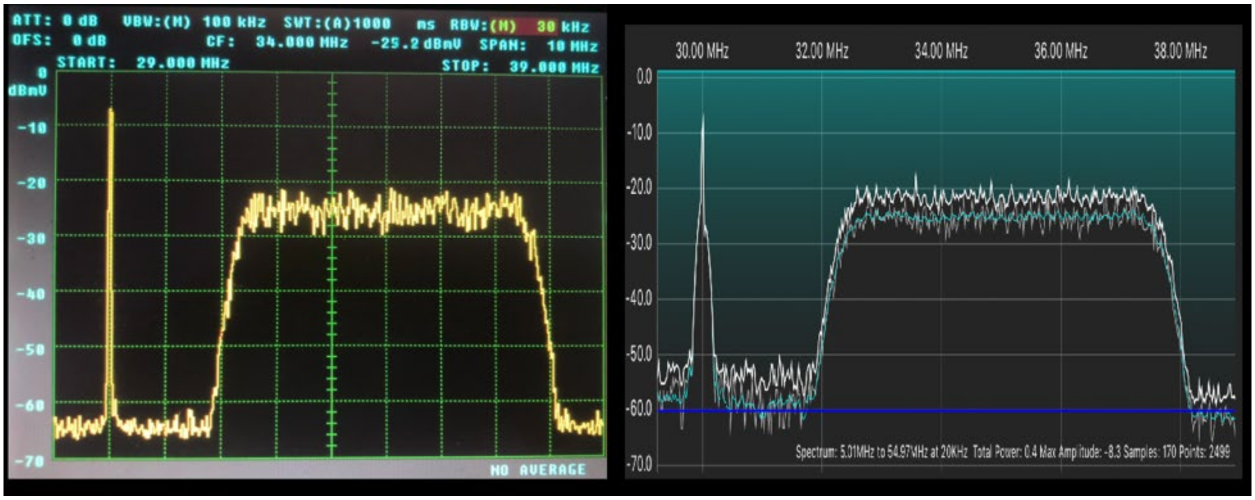


Figure 11 - Frequency swept spectrum (left) and FFT spectrum capture (right)

Many cable operators carry multiple types of signals on their networks (Figure 12). A predominant signal type is known as single-carrier quadrature amplitude modulation (SC-QAM) which is 6 MHz or 8 MHz wide and sometimes referred to as a “haystack” (by its appearance). The North American channel plan uses 6 MHz wide channels, while the European plan is 8 MHz.

The second type is called orthogonal frequency-division multiplexing (OFDM), which can be between 24 MHz and 192 MHz wide and can exist anywhere in the RF spectrum. This signal is used by DOCSIS 3.1 and later modems and gateways, to achieve higher speeds and increased bandwidth.

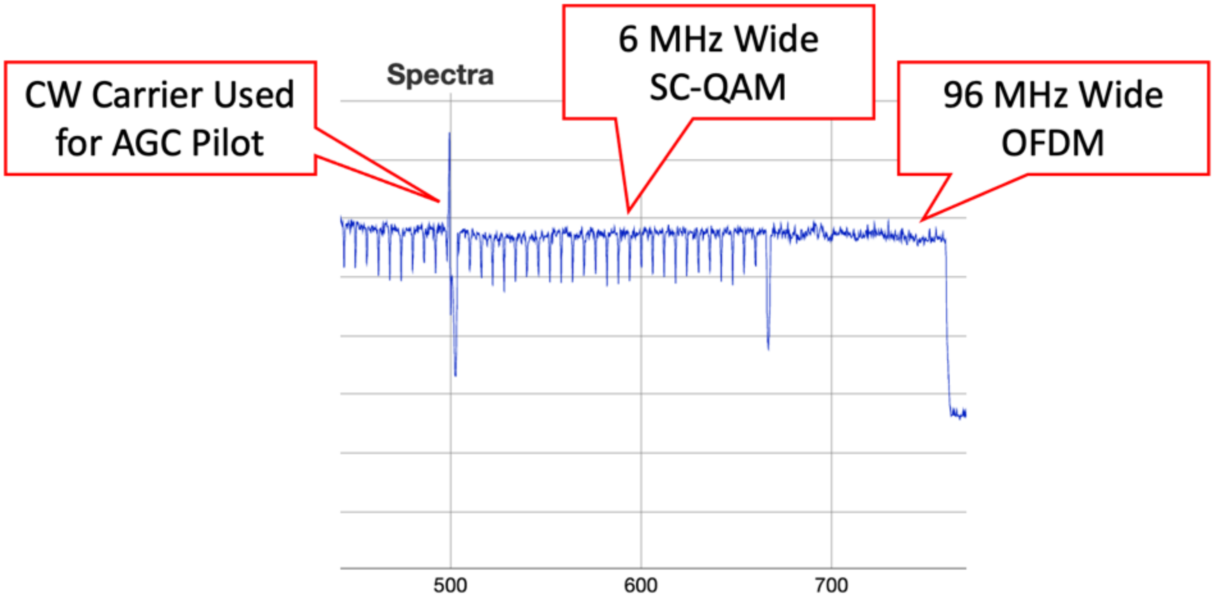


Figure 12 - Common cable RF signals

Although the cable industry has largely abandoned analog television channels, some cable networks still carry them. The carriage of analog television signals is terribly inefficient, compared to digital, and is usually replaced with SC-QAM whenever possible. Analog television can also still be found in some multiple dwelling units (MDUs), such as large condominium complexes and places where local communities insert their own programming, combined with the operator's.

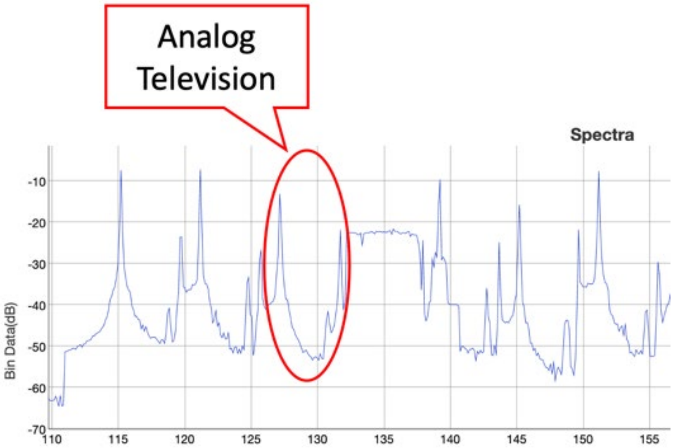
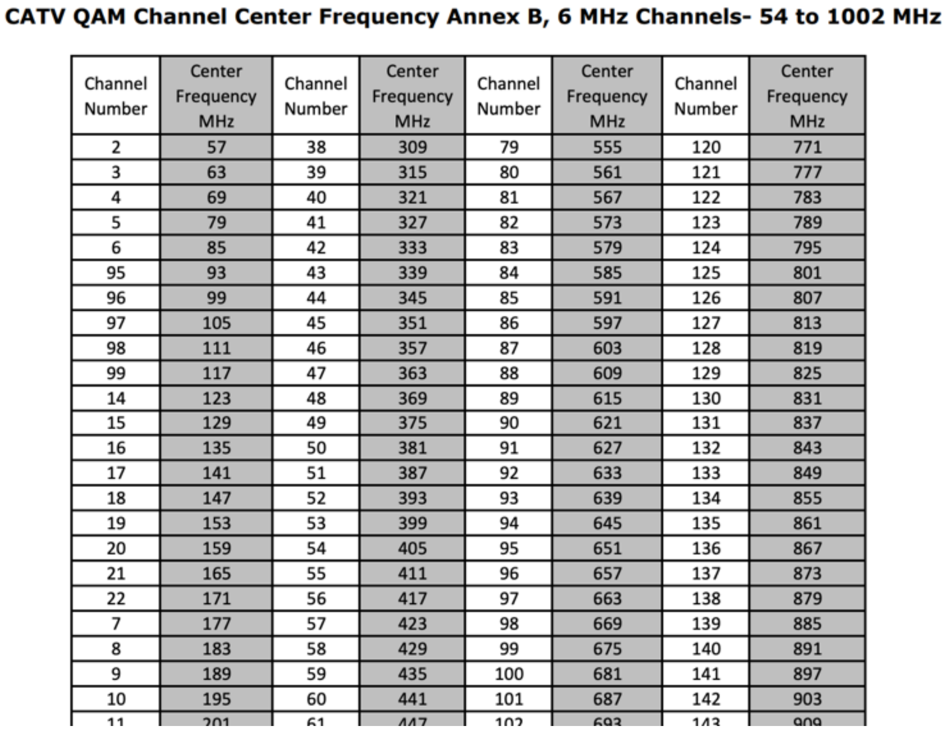


Figure 13 – Analog television signals

Analog television (Figure 13) channels typically look like two closely-placed spikes of RF, one containing picture information and the other containing the audio. Finally, the RF spectrum *may* have at least one or more "pilot carriers," which are typically unmodulated tones used by our network to automatically adjust amplifier signal levels, to cope with the effects of temperature changes.

The SC-QAM, OFDM, and analog channels reside in predictable locations in the RF spectrum, because we use what is called a "channel plan." The channel plan is a simple set of rules that makes sure our transmitters and receivers can communicate in a consistent manner. An example is shown in Figure 14.



CATV QAM Channel Center Frequency Annex B, 6 MHz Channels- 54 to 1002 MHz

Channel Number	Center Frequency MHz	Channel Number	Center Frequency MHz	Channel Number	Center Frequency MHz	Channel Number	Center Frequency MHz
2	57	38	309	79	555	120	771
3	63	39	315	80	561	121	777
4	69	40	321	81	567	122	783
5	79	41	327	82	573	123	789
6	85	42	333	83	579	124	795
95	93	43	339	84	585	125	801
96	99	44	345	85	591	126	807
97	105	45	351	86	597	127	813
98	111	46	357	87	603	128	819
99	117	47	363	88	609	129	825
14	123	48	369	89	615	130	831
15	129	49	375	90	621	131	837
16	135	50	381	91	627	132	843
17	141	51	387	92	633	133	849
18	147	52	393	93	639	134	855
19	153	53	399	94	645	135	861
20	159	54	405	95	651	136	867
21	165	55	411	96	657	137	873
22	171	56	417	97	663	138	879
7	177	57	423	98	669	139	885
8	183	58	429	99	675	140	891
9	189	59	435	100	681	141	897
10	195	60	441	101	687	142	903
11	201	61	447	102	693	143	909

Figure 14 - Examples of channel plans

All of the RF channels, regardless of modulation type, have some empty space between them. This area, called a "guard band," is intentional. In fact, it's required, to avoid a channel creating interference with its neighboring channel. The OFDM guard band width is configurable. OFDM channels *may* also contain exclusion bands that are intentionally left unused. See Figure 15.

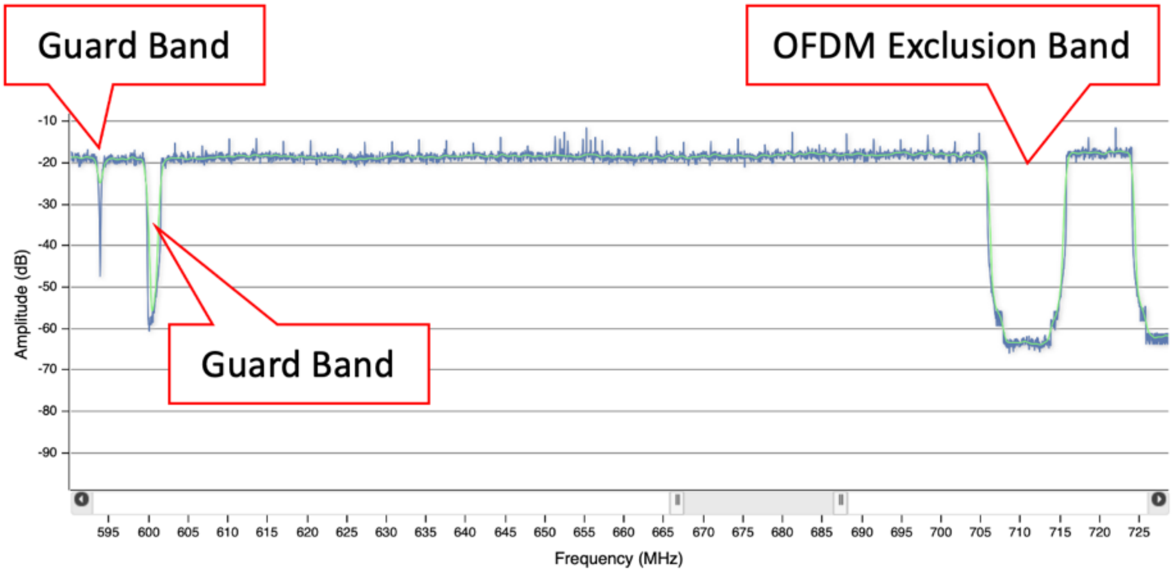


Figure 15 - Guard bands, exclusion bands and channel separation

There are also different types of channel plans, so that identifying where given RF channels exist in the spectrum is straightforward. For example, the Consumer Technology Association standard CTA-542 R-

2018 defines 6 MHz channel plans for cable networks, including standard (STD), incremental related carrier (IRC), and harmonic related carrier (HRC) channels.

So: Yes, there are channel plans. But! Not all channels are necessarily occupied at any given time. Our engineering teams are sometimes required to move channels around to make room for more. That means there are likely to be intentional gaps of vacant spectrum – which is normal (Figure 16).

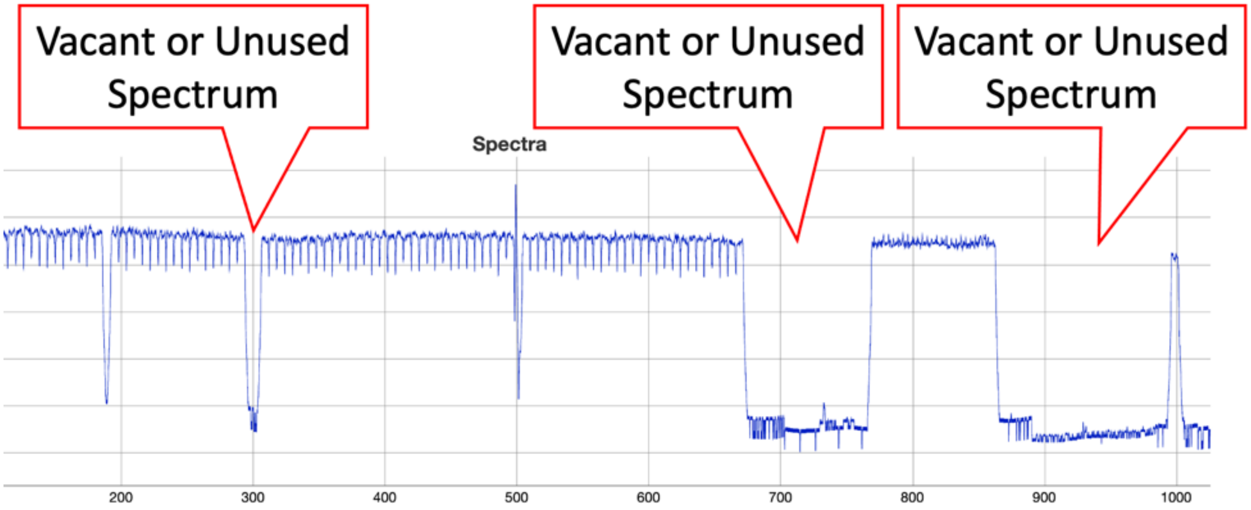


Figure 16 - Vacant spectrum

Assuming all things are normal, you *should* be able to interpret the different elements of the RF spectrum. You *should* be prepared to see a variety of things which don't fall into the categories explained thus far. (Which is kind of the point of this entire exercise.) We'll try to help you spot some of the most common issues and to steer you away from common pitfalls in your troubleshooting efforts.

With the analyzer built-into CPE, it may be possible to compare spectrum from various locations in the network to determine whether an impairment is local to a home, the drop cable, or outside plant.

8. The Cable Network

Most cable networks comprise a combination of optical fiber and coaxial cable for signal distribution, an architecture known as hybrid fiber/coax (HFC). Cable operators can take advantage of a concept known as frequency reuse, which allows the cable network to carry signals on frequencies inside of its cables and components that are used for entirely different purposes in the over-the-air environment. If the cable network's shielding integrity remains intact, the over-the-air environment and the cable network can coexist without interference to one another.

It is important that cable networks use high-quality components which are installed and maintained to high standards. When cable network performance is degraded, the quality of signals in the network can be affected. For instance, if the coaxial cable's shielding integrity is degraded, then RF signals inside of the cables can leak out and cause harmful interference to over-the-air users; this is known as signal leakage or egress. Going the other direction, over-the-air signals can leak into the network and interfere with the cable company's signals, a phenomenon known as ingress.

Additional information about the cable network, coaxial cable characteristics, RF shielding integrity, impedance mismatches, and several other topics can be found in Appendix A.

9. Impairments

The following sections describe common spectral impairments that might be seen when viewing the RF spectrum.

9.1. Adjacent Channel Alignment

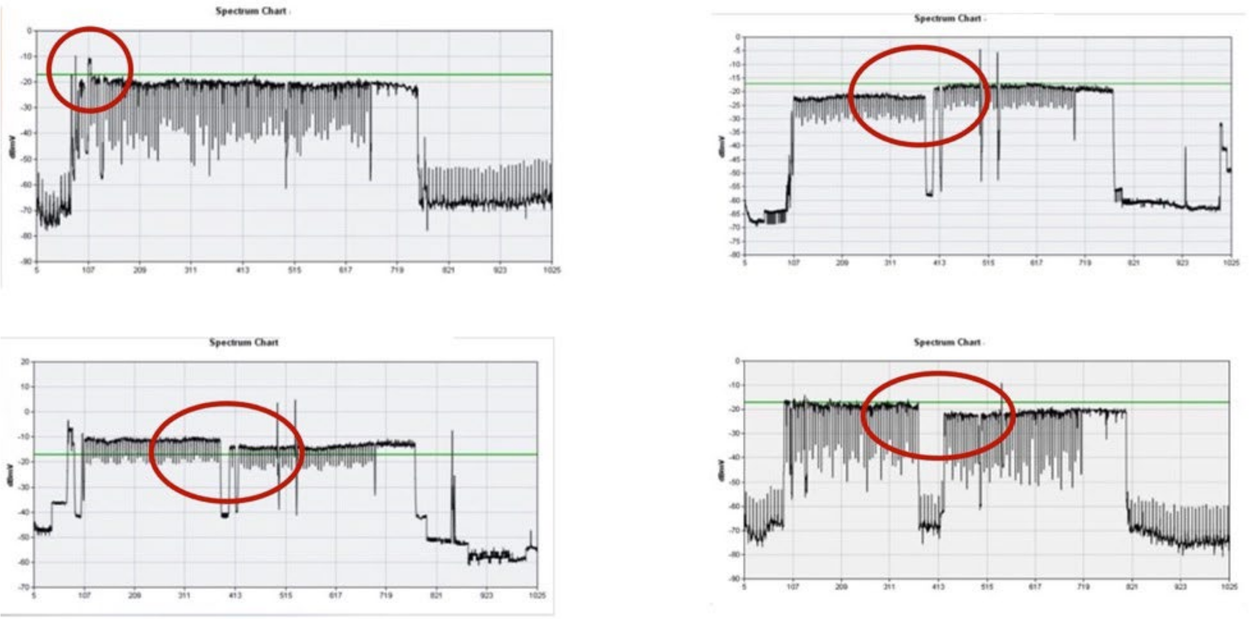


Figure 17 - Adjacent channel alignment examples

Definition: One or more channels or blocks of channels that are combined at improper power levels. This is almost always a headend (HE) or hub problem but there are cases where it is caused by local insertion (MDUs, bulk properties, etc.). See Figure 17.

Adjacency misalignment is an RF impairment recognizable as a difference in channel power between adjacent channels or groups of channels. It *may* be observed multiple times at different points in the spectrum. Adjacency misalignment issues can be attributable to RF combining or source issues at the headend or hub or in a node utilizing a broadcast/narrowcast overlay or a split band configuration when the two spectrums are not combined correctly.

When adjacency misalignment is observed, the lower power channels *may* indicate poor performance, seen as a poor modulation error ratio (MER) when the delta between channels is large. This condition can manifest as lost packets, video tiling, freezing, or in very extreme cases, black screens at a customer's home. Because adjacency misalignment is introduced very early in the downstream signal path, it has the potential to impact a significant number of customers.

9.1.1. Headend / Hub Alignment

Figure 18 shows FBC data from a single CPE indicating a misalignment between adjacent SC-QAM channels.

Figure 18 - Adjacent misalignment in SC-QAM channels at a CPE

Figure 19 shows data extracted from multiple CPEs connected to the same node and/or transmitter. The channel alignment issue will be found at either the headend or the node. These issues are most commonly the result of misalignment of headend modulators and signal sources and incorrect padding and alignment with narrowcast and broadcast channels.

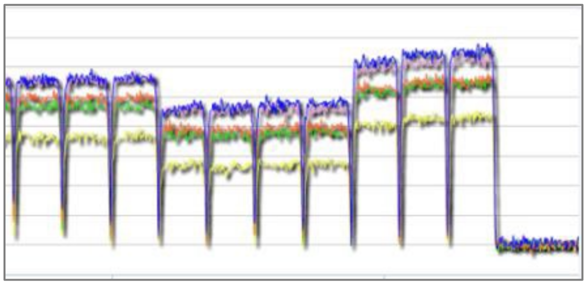


Figure 19 - Adjacent misalignment in multiple CPEs with the same node and/or transmitter

9.1.2. *Local Insertion*

Occasionally, but less common, localized channel insertion at MDUs, hotels, etc., can occur at improper levels. The following example in Figure 20 illustrates this condition. Note the distinctive rolloff caused by a notch filter prior to insertion of the local channel in Figure 20, significantly impacting the two adjacent SC-QAM channels.

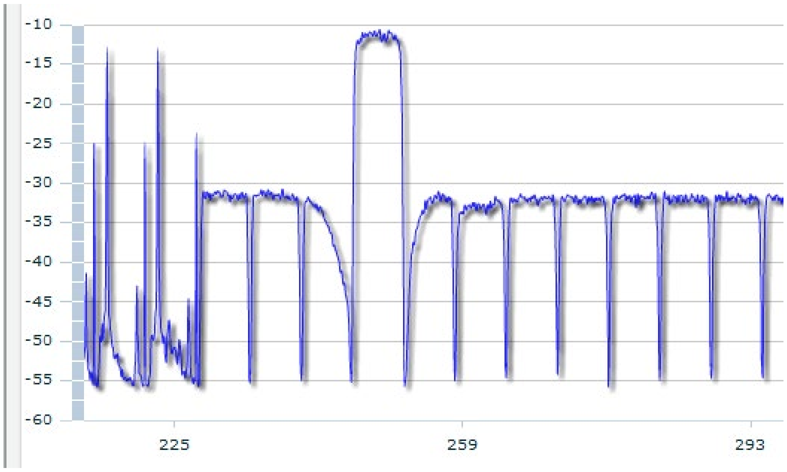


Figure 20 – Example of incorrect local RF channel insertion with notch filter

9.2. Filters and Missing Channels

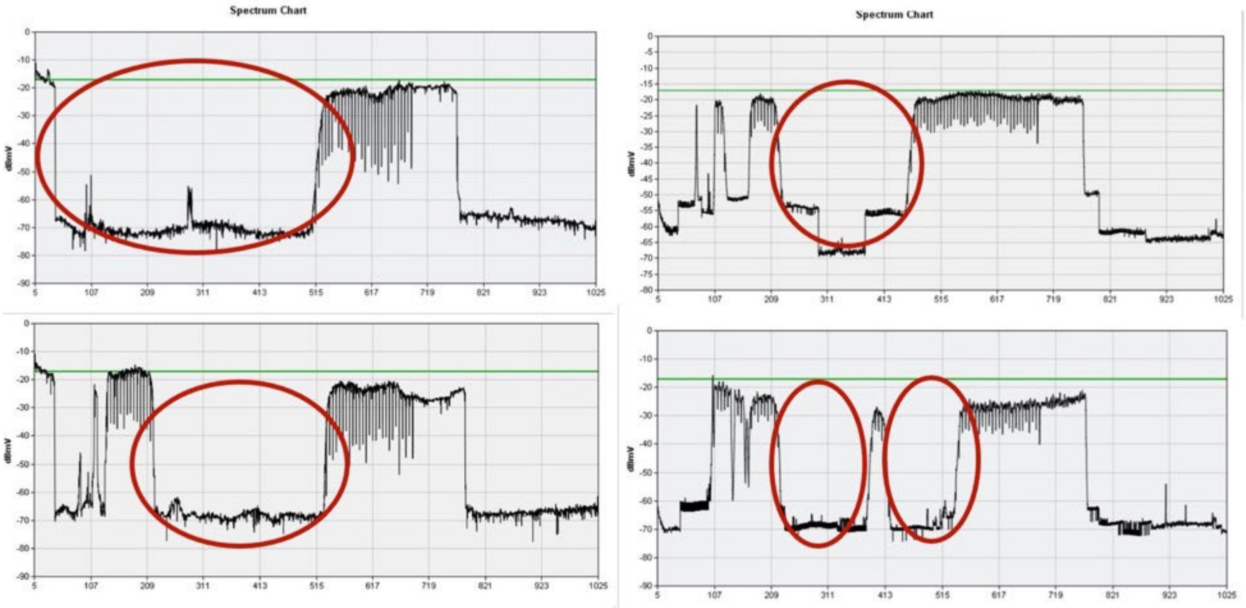


Figure 21 – Filters and missing channel examples

Filtering is an RF impediment that *may* affect multiple channels at a time. Filters, commonly referred to as traps, have been and continue to be used to remove unwanted signals in the RF path based on the customer's service. When viewed at the CPE or other test equipment, the presence of a filter is characterized by the lack of channels in a specified bandwidth. See Figure 21. Figure 22 shows examples of the frequency response characteristics of different types of filters.

(a) band-pass filter—passes frequencies within a specified range and rejects frequencies outside that range

(b) band-stop filter—rejects frequencies within a specified range and passes frequencies outside that range

(c) low-pass filter—passes frequencies below a specified frequency and rejects frequencies above and

(d) high-pass filter—passes frequencies above a specified frequency and rejects frequencies below.

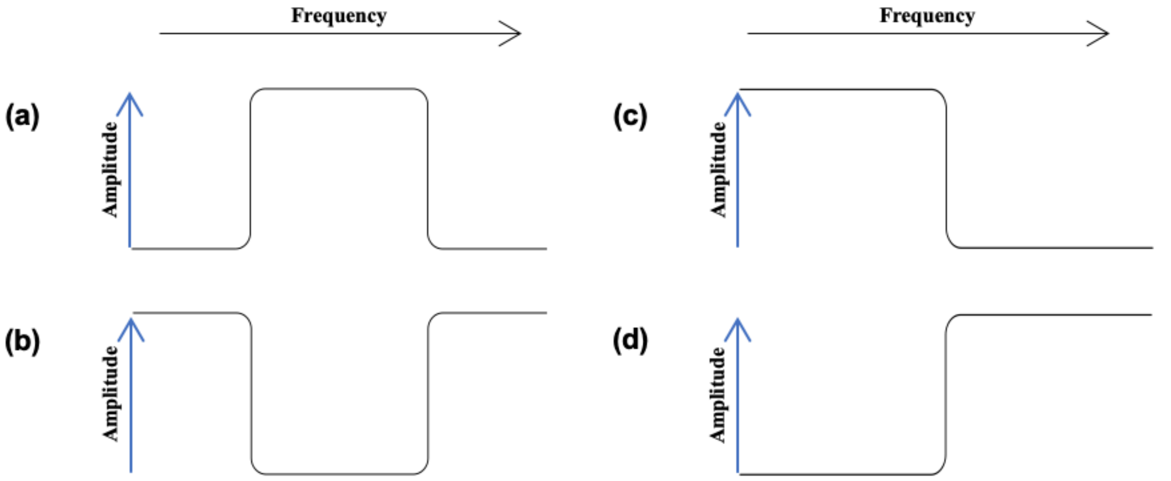


Figure 22 - Filter types: (a) band-pass filter, (b) band-stop filter, (c) low-pass filter, (d) high-pass filter

Figure 23 shows example FBC data for two kinds of filters.

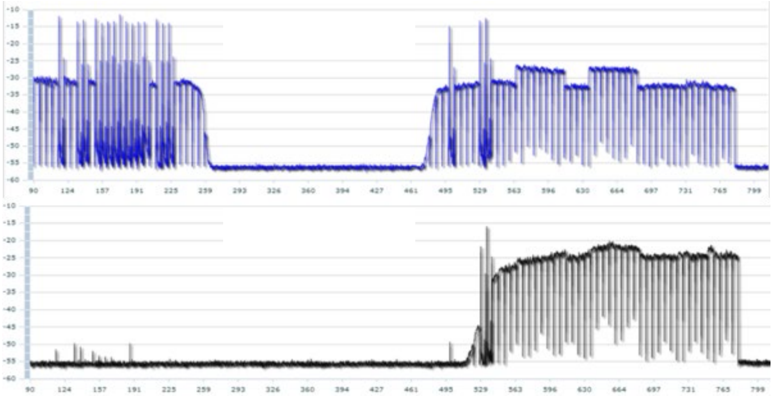


Figure 23 - Example spectra of band-stop and high-pass filters

Three common types of filters are found in the field:

9.2.1. Video Filter / Trap

The video filter/trap is a bandstop or notch filter that blocks signals in a specified frequency range but passes signals in frequencies below and above the filter's band edges. For example, in Figure 24, the video filter/trap blocks signals in the approximately 150 MHz to 400 MHz range but passes signals below and above those frequencies.

In the past, many operators used traps and filters as a means of conditional access control. Negative traps were used to block a signal or signals (and were typically installed at the tap) and had to be removed in order for a subscriber to receive premium channels. Positive traps were used to remove a jamming carrier inserted between a premium channel's visual and aural carriers. In order to receive the premium channel, a positive trap had to be installed in the drop, typically at the tap.

Some video filter/traps were used for data-only service, blocking most of the video channels but passing the data channels.

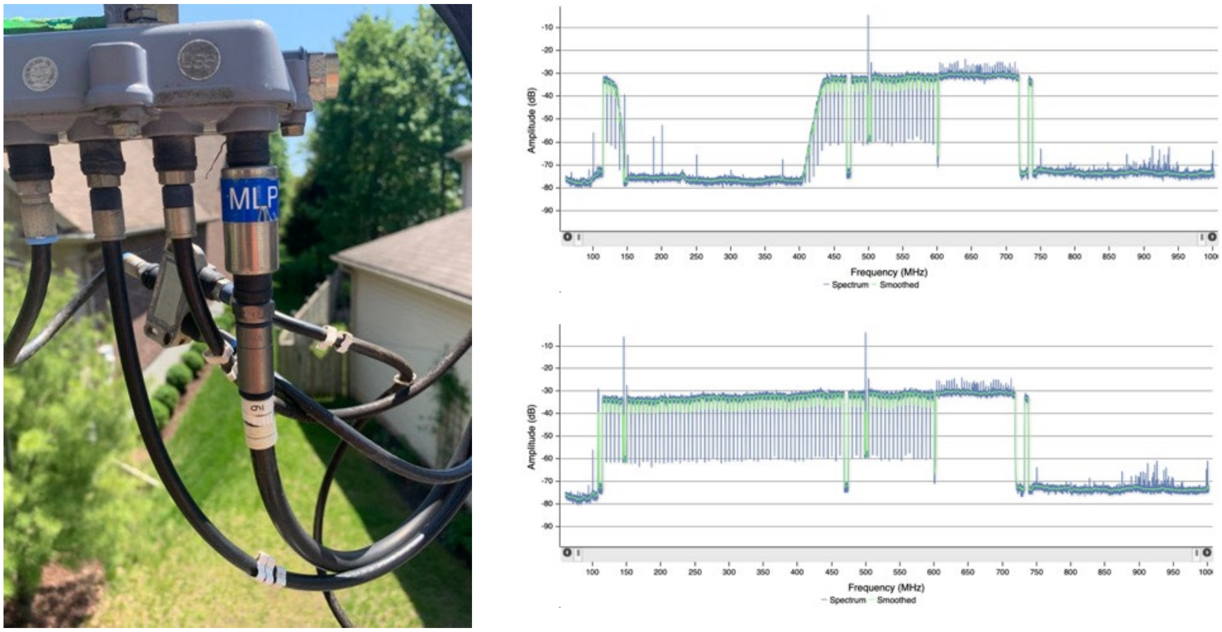


Figure 24 – Video trap / filter (left), before (top right) and after (bottom right)

9.2.2. Noise Filter / Trap

Noise filters are typically high-pass filters that block part or all of the upstream spectrum but pass the downstream spectrum. This type of filter is typically used to prevent interference coming from a drop from affecting the node’s entire service area, because of what is called the funneling effect. In Figure 25, the upstream noise is significantly reduced after installation of the filter.

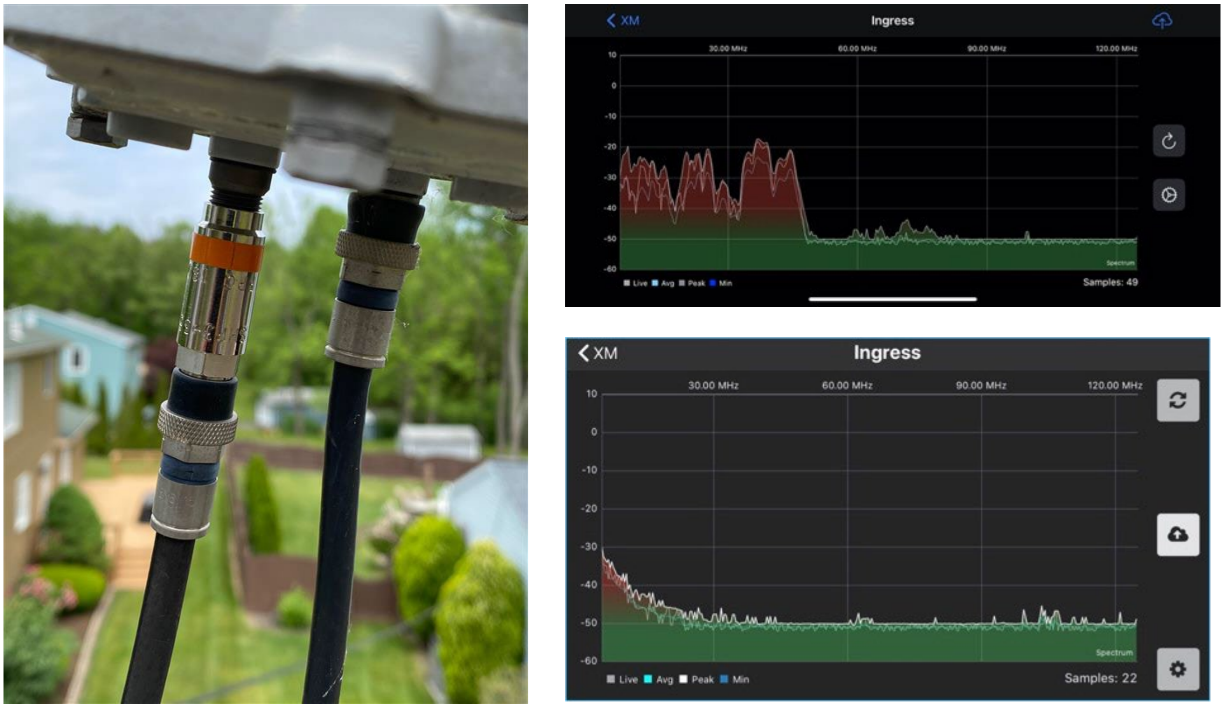


Figure 25 – Noise trap / filter (left), before (top right) and after (bottom right)

9.2.3. MoCA Filter

MoCA filters are typically installed at the tap port or at the side of the house to prevent the MoCA signal from entering the distribution network. Although there no formal specification, the filter also provides a reflection point to enhance the performance of MoCA within the house. As of DOCSIS version 3.1, MoCA and DOCSIS can share the same frequency spectrum, this is illustrated in Figure 26. It is possible for FBC in the cable modems to “see” a MoCA signal coming from one or more devices in the home. An example of capturing MoCA signals can be seen in Figure 27. DOCSIS 3.1 modems are required to operate up to 1200 MHz, but some cable modems have the capability to detect energy as high as 1794 MHz.

Figure 26 – DOCSIS 3.1 and MoCA signals could share the same frequency spectrum

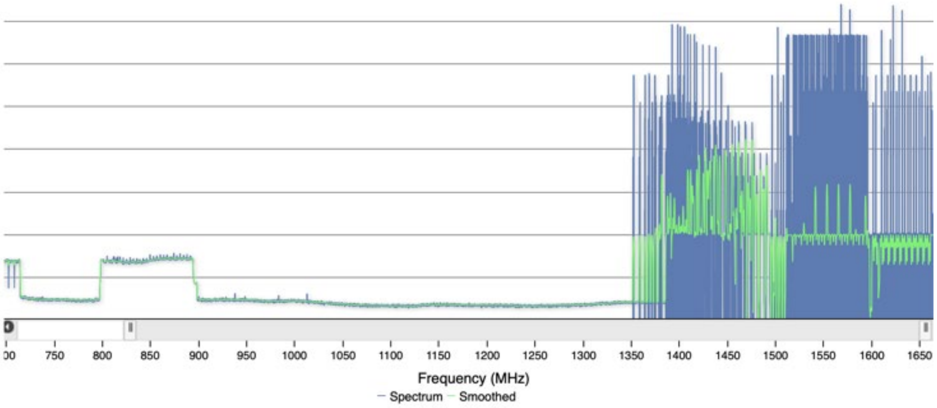


Figure 27 – MoCA signals detected above 1350 MHz using FBC

9.3. Suckout

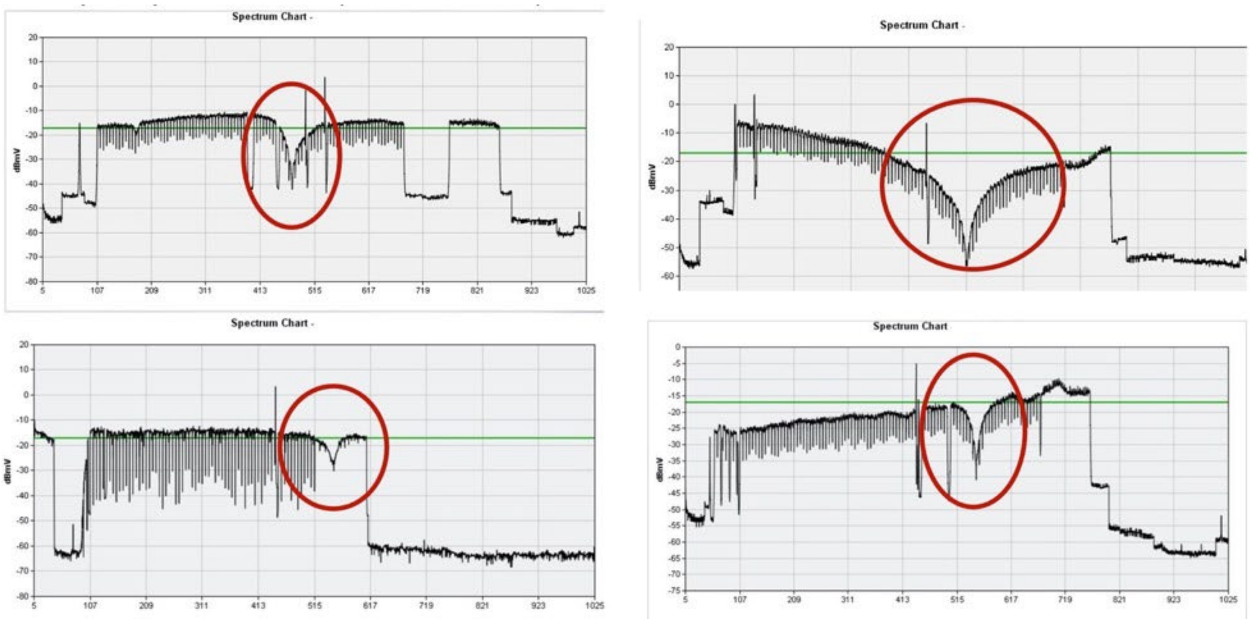


Figure 28 - Suckout examples

Suckouts are caused by impedance mismatches in the cable plant. A suckout is a half-period of a long standing wave, caused by a very short reflection. See Figure 28. Impedance mismatches are discussed further in Section 9.7.

A suckout is type of standing wave, most commonly seen as a single notch RF impairment that often spans multiple channels. Typically, suckouts are caused by mechanical or grounding issues in active or passive network elements such as seizures, connectors, lids, or fittings. They can be attributable to multiple mismatches evenly spaced through the network. Each mismatch adds to the width and depth of the notch at the frequency of the suckout. An example is the repetitive impedance discontinuities created by the so-called "mold spike" in some disc-style dielectric cables. At a simpler level, a suckout is the result of an impedance mismatch.

9.3.1. Craft Related

Craft related issues are often a common cause of suckouts in the frequency response. Examples include loose seizure mechanisms (see Figure 29), assembly screws, module retainer screws, improper hardline connector pin length, improperly torqued housing lids, kinks in the cable and so on.

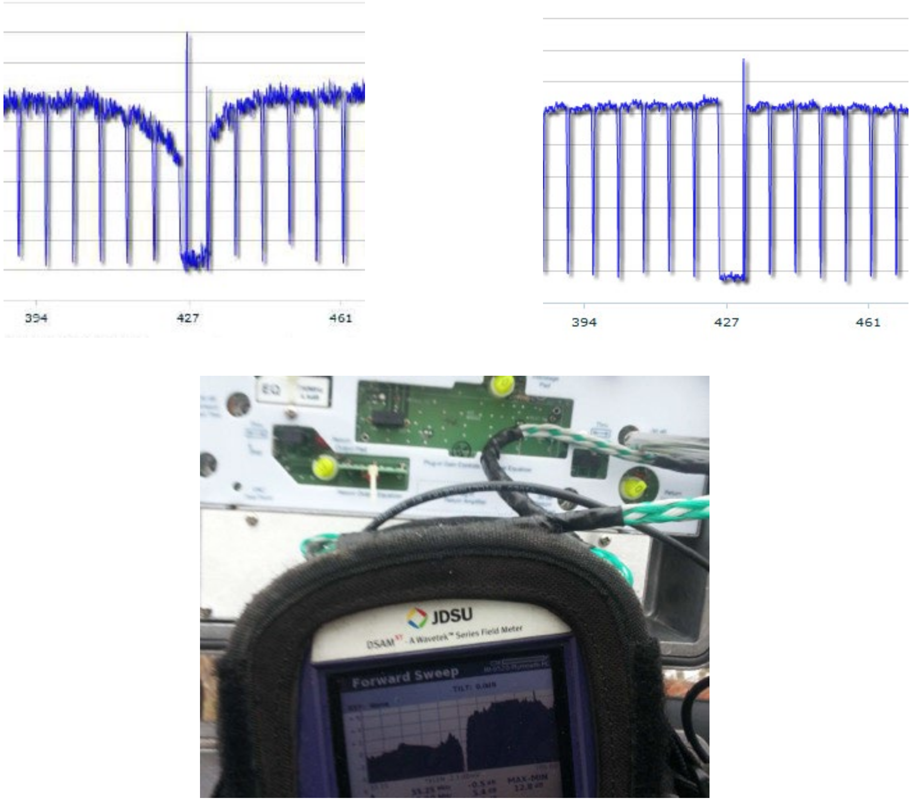


Figure 29 – Loose seizure screw (bottom), before (top left) and after (top right)

9.3.2. Manufacturing

Common causes: Cold solder joints, module grounding, some 3rd party accessories not meeting OEM specification, casting and other manufacturing defects. One example of the latter is the so-called mold spike (Figure 30) in a particular type of hardline cable that resulted in a suckout in the frequency response.[1]

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[1] A mold spike suckout is a frequency response suckout caused by the repetitive spacing of an impedance discontinuity in a disk-dielectric hardline coaxial cable. The so-called mold spike was related to the physical dimensions of the mold used to place groups of disks over the cable's center conductor during manufacture. The spacing between groups of disks caused a structural return loss (SRL) spike in the 500 MHz to 600 MHz range, which in turn could result in a suckout in the frequency response at the same frequency. The mold was later redesigned to place the SRL spike above 1 GHz.

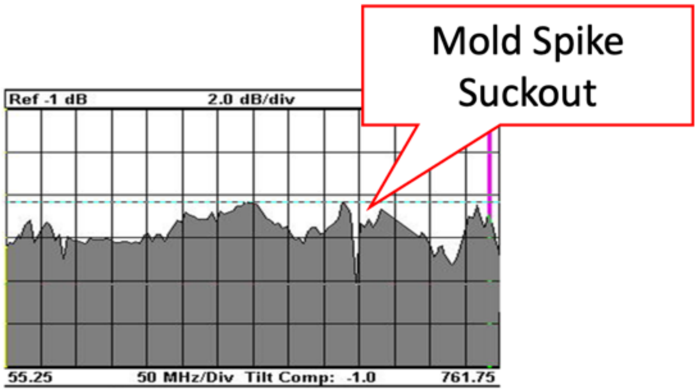

Figure 30 – "Mold spike" suckout

Impact on the customer depends on the depth and width of the notch. The notch can happen anywhere along the RF distribution path, making it one of the more complex issues to troubleshoot. FBC tools can assist in determining where in the network the issue *may* originate. Examining the spectrum from several CPEs associated with the node can determine if the issue is affecting multiple CPEs or a single CPE.

Anecdotally, operators have seen the suckout issue as one of the most prevalent RF impairments affecting spectral performance; however, no quantification has been made to date on the prevalence and scale of the impairments. From a customer point of view, a suckout *may* or *may not* have a significant impact on their service experience, depending on the services subscribed to and the location of the suckout in the spectrum. Figure 31 and Figure 32 provide additional examples of suckouts.

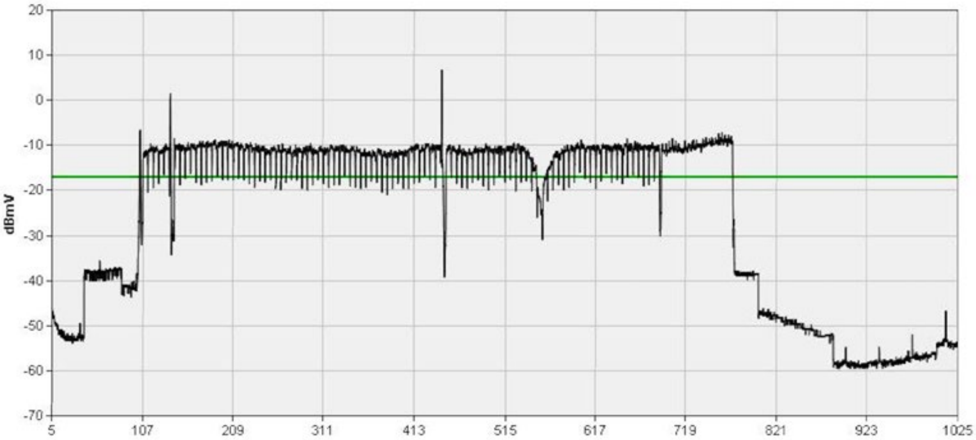

Figure 31 - Suckout as demonstrated by PNM

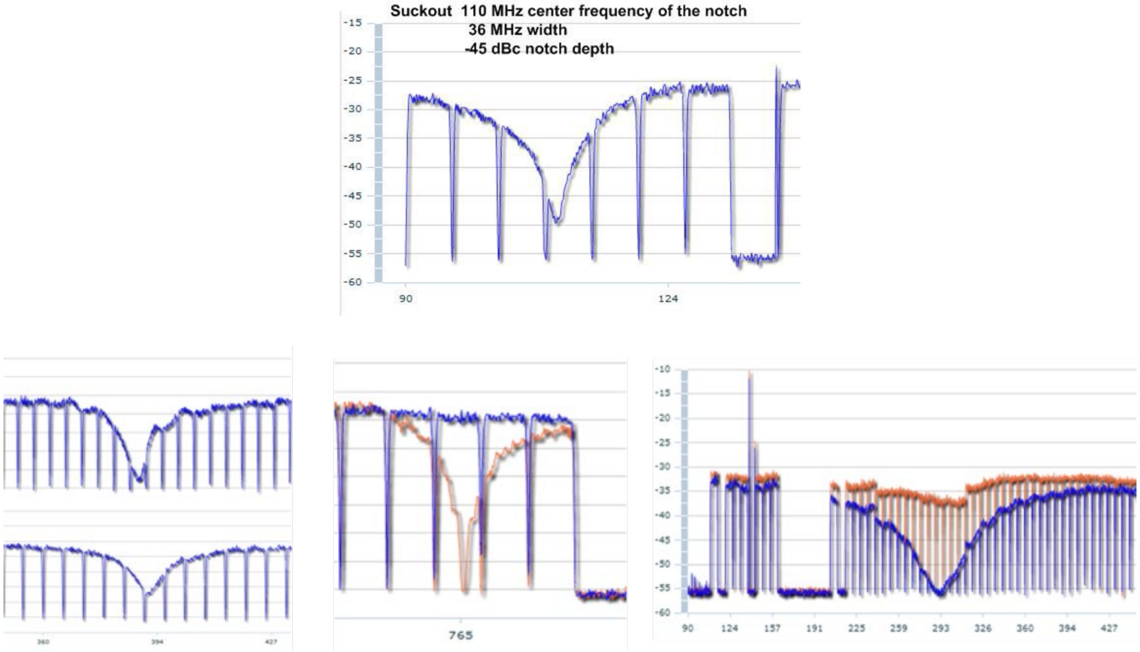

Figure 32 - Expanded view of suckouts and impact on several digital channels

9.4. RF Ingress, Noise and Distortion

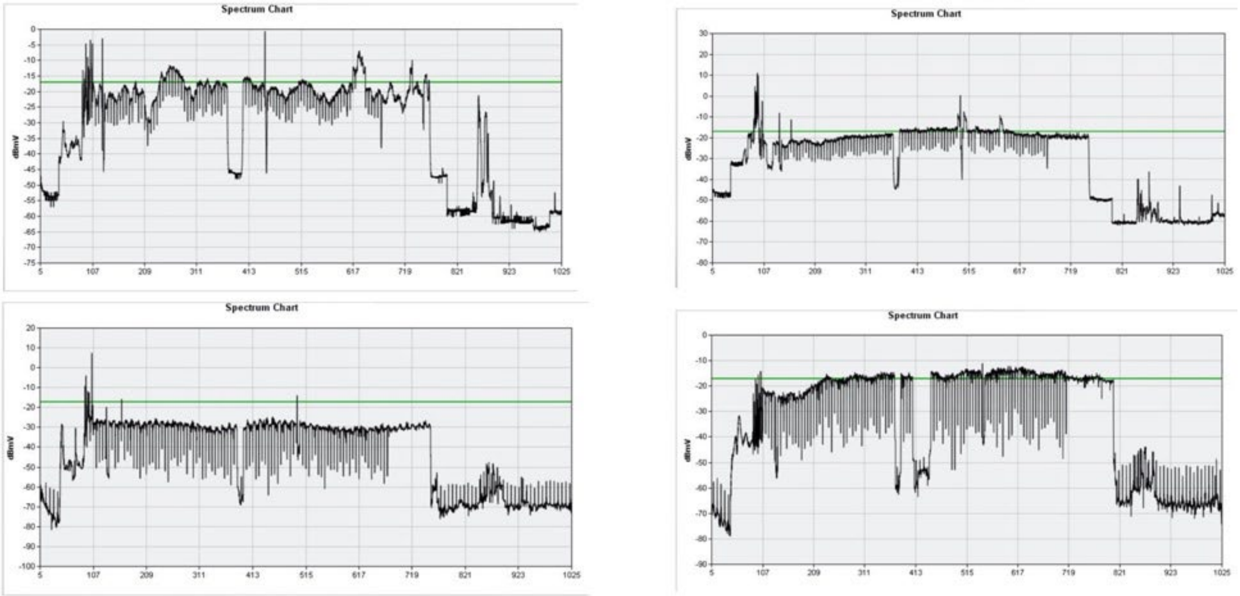

Figure 33 – RF ingress examples

These are examples of ingress across the full spectrum. Usually accompanied by high-energy FM relative to the downstream carrier power level. See Figure 33.

The cable industry is in a unique position of being able to take advantage of something known as frequency reuse, which means that cable operators can transport signals in their networks on frequencies that are often used for completely different purposes in the over-the-air environment. Frequency reuse is possible because the coaxial cable and other components comprise a closed network. If any portion of a closed network's shielding integrity is compromised or degraded, signals inside the network can leak out and potentially interfere with over-the-air users; this is called signal leakage or egress (an analogy is a leaky water pipe or garden hose). Going the other direction, compromised or degraded shielding integrity can result in over-the-air signals "leaking" into the cable network and potentially interfering with the cable company's signals. The latter is commonly called RF ingress.

Ingress can happen anywhere the cable network's shielding effectiveness has degraded, such as loose, improperly installed, or damaged connectors; cracked shielding; rodent chews; warped or loose amplifier or passive device housing lids; and so forth. Generally speaking, there are two major types of ingress. The first is narrow-band ingressors such as shortwave and FM band broadcast radio signals; Citizens Band (CB), ham (or amateur), and other two-way radio signals; and broadcast TV, cellular (including LTE), and similar signals. The second is wide-band ingressors such as power line gap noise and other impulse or bursty noise signals. Wide-band ingressors can, for instance, occupy much or all of the upstream spectrum.

9.4.1. Direct Pickup

Direct pickup interference is similar to ingress, except that the interference enters a susceptible set-top box, cable modem, TV set, piece of test equipment, or other device *directly*, often without any cables or other external devices physically connected. If the susceptible device's outer case or cover is inadequately shielded, then the internal wiring, printed circuit board traces, and/or components can directly receive interfering over-the-air signals. In some CPE – especially older models – ventilation holes and case or cover seams can have physical dimensions and/or shapes that allow them to behave like UHF slot antennas. Sometimes affected devices have poor common mode rejection and are susceptible to common mode currents traveling on the outer surface of cabling (coax, power, video and audio, etc.) connected to the device. Any one of these, or a combination, can contribute to a device being affected by direct pickup interference.

One very important point: signal leakage, ingress, and direct pickup interference can happen on any frequency. The affected frequency (or frequency range) depends on several factors, such as the nature of the cable network shielding defect, the proximity of the shielding defect to over-the-air transmitters and towers, signal levels, and more. Figure 34 illustrates a variety of common ingress types.

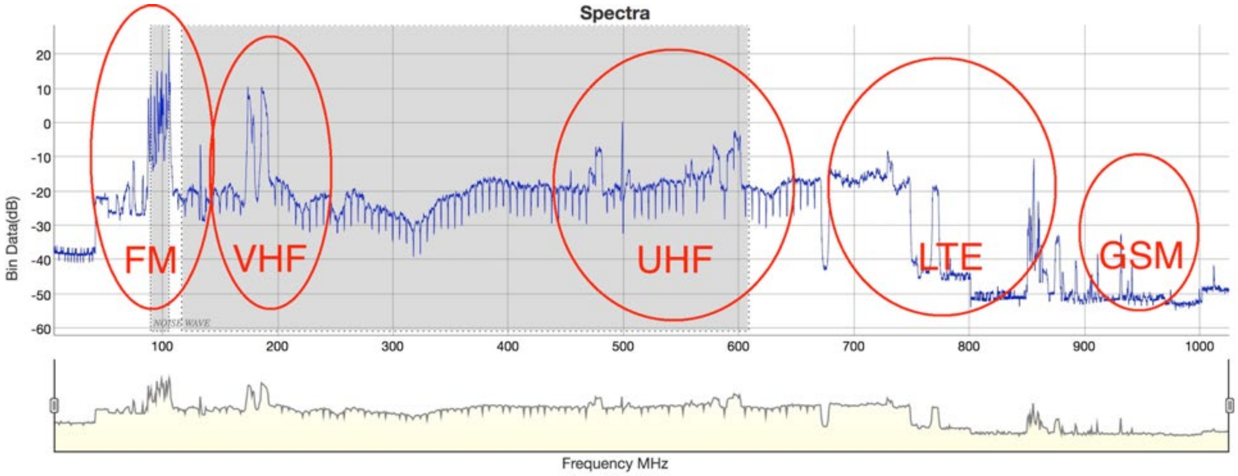

Figure 34 – FM, VHF, UFH, LTE and GSM ingress example

9.4.2. FM Ingress

FM ingress is the result of over-the-air FM radio signals entering the plant from FM radio broadcasting sources. FM ingress affects cable network downstream frequencies between approximately 88 MHz and 108 MHz, the spectrum assigned to FM broadcasting in the Americas (other regions of the world *may* use somewhat different frequency ranges). In the U.S., the FCC allocates FM channels spaced 200 kHz apart at odd intervals of 0.1 MHz (e.g., 88.1 MHz, 88.3 MHz, 88.5 MHz, and so on). The occupied bandwidth of a broadcast FM signal can vary from about 200 kHz to a bit more than 300 kHz. In some cases, cable operators *may* intentionally carry FM and digital radio programming in the 88 MHz to 108 MHz spectrum, which *may* look like over-the-air ingress. Depending on the types of carriers being transmitted by the cable operator in the FM band, ingress in this frequency range can be difficult to differentiate from the cable network's signals.

Figure 35 shows FM ingress caused by loose connectors. It is also common to see VHF, UHF and cellular ingress where FM ingress is detected.

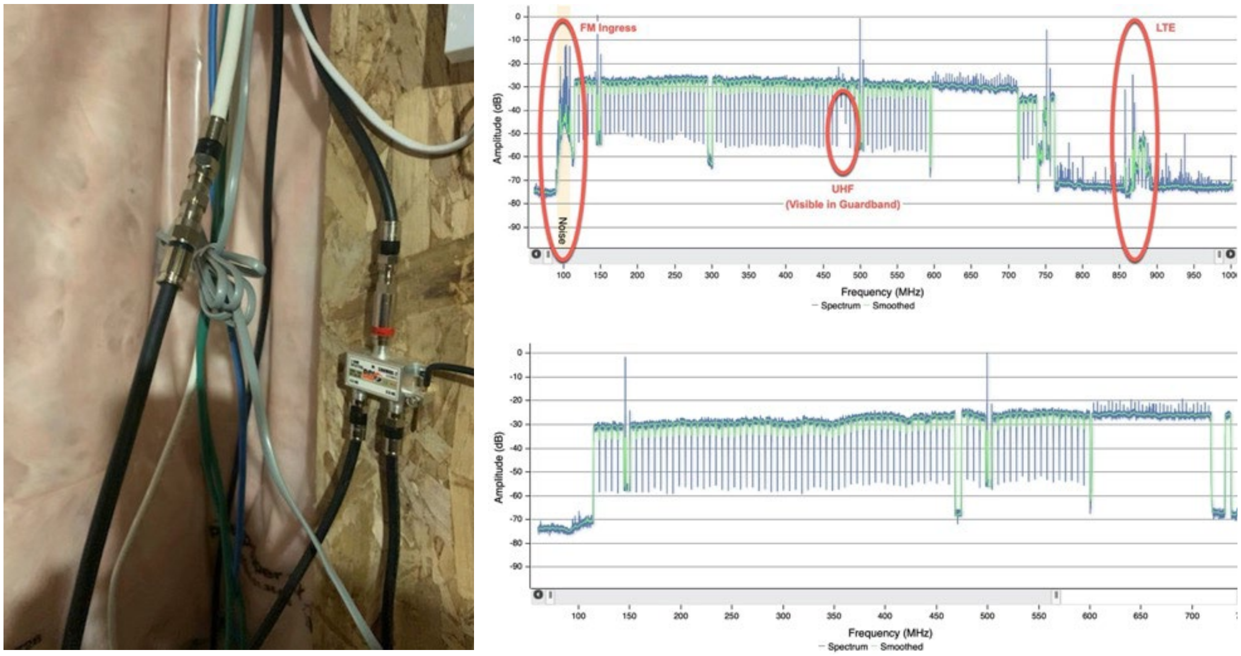

Figure 35 – FM Ingress, before (top right) and after (bottom right)

9.4.3. Cellular Ingress

Cellular ingress is the result of cellular devices (user equipment, or UE) and base station transmissions leaking into the cable plant. As an example, cellular interference exists above ~600 MHz (Figure 36).

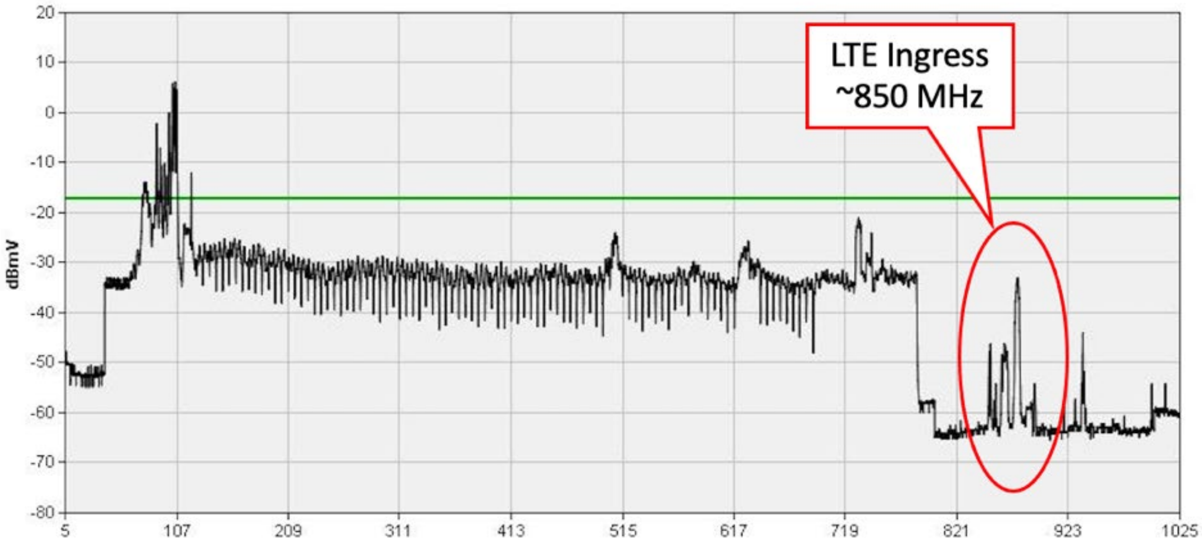

Figure 36 – LTE Ingress

9.4.4. Other VHF and UHF Ingress

VHF ingress covers any ingress not classified as FM ingress in the range 90 MHz to 300 MHz.[2] Interference in these bands can arise from numerous sources, including broadcast television, radio location, amateur radio, land mobile, marine radio, aeronautical navigation and communications, and military communications. Using FBC can be a very effective way of detecting VHF and FM ingress near the ingress locations. Figure 37 shows two VHF television channels leaking in through a damaged drop cable. VHF channels 2 and 6 on this same node can be seen interfering with the upstream OFDMA channel in this mid-split configuration (Figure 38).

UHF ingress covers any ingress not classified as cellular ingress in the range of 300 MHz to 3 GHz. Interference in these bands can arise from numerous sources, including broadcast television, amateur radio, land mobile, mobile satellite, aircraft navigation and communications, and military communications.

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[2] Technically speaking, the very high frequency, or VHF band, covers 30 MHz to 300 MHz.

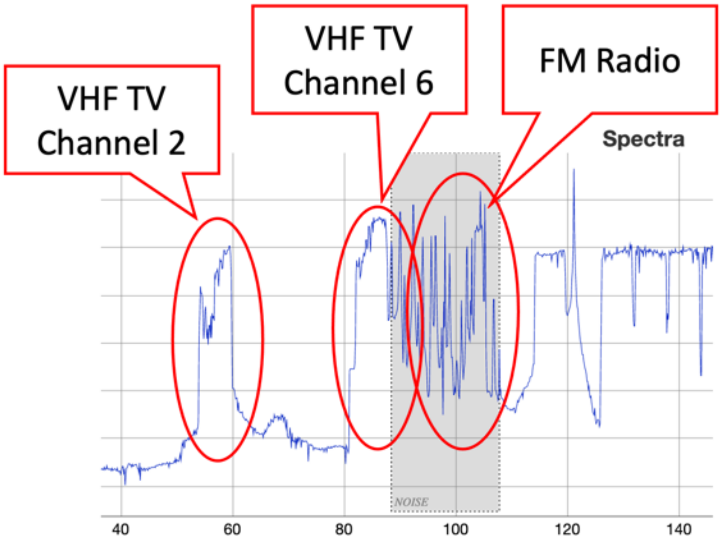
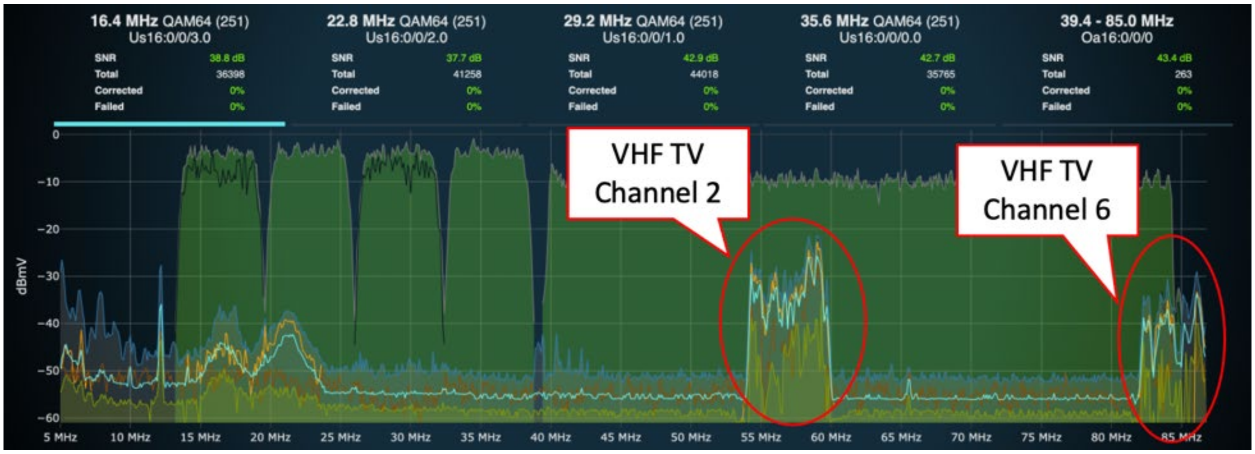


Figure 37 – VHF and FM ingress in downstream capture using FBC



	16.4 MHz QAM64 (251) Us16:0/0/3.0	22.8 MHz QAM64 (251) Us16:0/0/2.0	29.2 MHz QAM64 (251) Us16:0/0/1.0	35.6 MHz QAM64 (251) Us16:0/0/0.0	39.4 - 85.0 MHz Oa16:0/0/0
SNR	38.8 dB	37.7 dB	42.9 dB	42.7 dB	43.4 dB
Total	36398	41258	44018	35765	263
Corrected	0%	0%	0%	0%	0%
Failed	0%	0%	0%	0%	0%

Figure 38 – VHF ingress in mid-split upstream spectrum at the burst receiver

9.4.5. Switching Regulator Noise

Some switching (or switch-mode) power supplies in customer premises equipment, wall warts and other devices can generate interference that can affect cable network operation. The interference often appears as harmonics or spurious signals that are spaced at intervals of the power supply's switching rate – for instance, every 50 kHz. When switching regulator noise enters the network as ingress, it often appears in the upstream spectrum. If severe enough, it can appear at higher frequencies.

9.4.6. Power line Gap Noise

Power line gap noise is usually caused by sparking – and sometimes arcing – on power lines and related hardware. Power line gap noise is a type of interference that can affect over-the-air radio communications. If the power line gap noise enters a cable network as ingress, it can interfere with the cable network’s signals (especially in the upstream, where it is seen as impulse or burst noise). Wide bandwidth RF energy is generated by the sparking, and very near the source can appear at frequencies into the UHF spectrum. Power lines can radiate gap noise interference like an antenna and can couple it to the cable network via conduction such as code-required neutral bonds. Specialized test equipment is used by electrical utility radio frequency interference (RFI) investigators to troubleshoot power line gap noise. Some cable operators use this equipment to locate the suspected source, then communicate that information to the local power company. Caution: Working in the vicinity of power lines is dangerous and *should* be left to trained utility personnel. In no cases *should* one hit the base of a utility pole with a sledgehammer or similar in an attempt to locate the source of gap noise. This can possibly damage electrical hardware on the pole, and under worst-case conditions cause energized hardware to fall to the ground.

9.4.7. Common Path Distortion

Common path distortion (CPD) is a well-known impairment that affects a cable network’s return path. CPD comprises nonlinear distortions other than those generated in active devices, and which appear in the upstream spectrum. CPD is not ingress, and it’s technically not noise even though it can appear to be noise-like. In an all-digital cable network, second order CPD looks similar to the downstream SC-QAM haystacks, except that they appear on the noise floor of the upstream. Third order CPD (or a combination of second and third order CPD) looks like an elevated noise floor, as illustrated in Figure 39.

CPD occurs when downstream RF signals pass through a diode-like nonlinearity, typically at interfaces where corrosion has formed in the signal path common to the downstream and upstream spectrums (loose seizure screws, defective end-of-line terminators, etc.). The resulting oxide layer behaves somewhat like a semiconductor diode, and can be just a few molecules thick, making it fragile and susceptible to being affected by wind, vibration, temperature changes, and so on. All of the aforementioned, in addition to varying downstream RF signal levels, complicate location and troubleshooting of CPD sources.

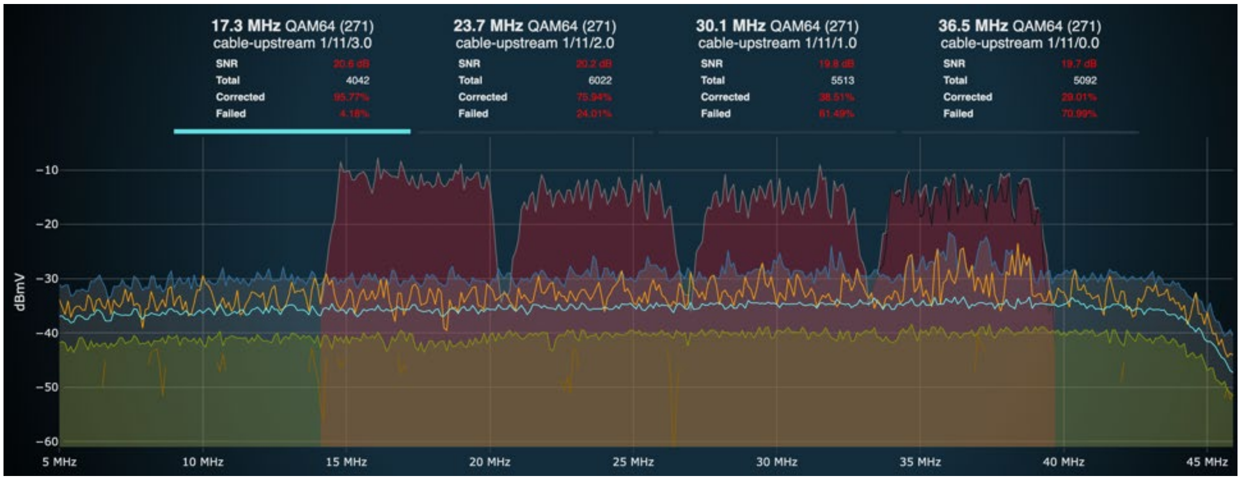
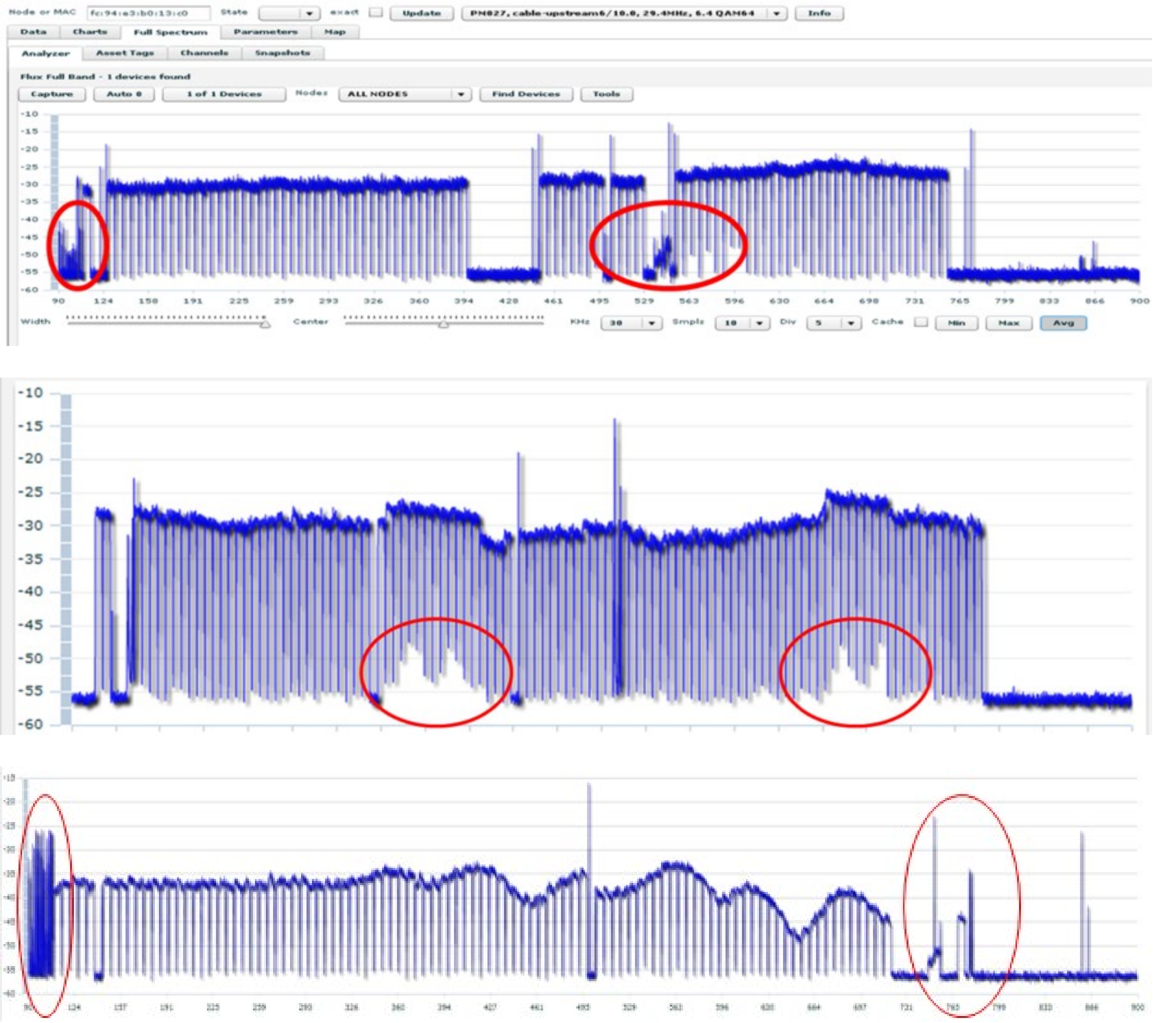


Figure 39 – CPD noise (top) caused by loose seizure screw (bottom) on amplifier output

As shown in the previous sections, there are numerous sources of ingress into a cable network, and accordingly, their profiles can be quite complicated to characterize, identify, and fix. Ingress introduced early in the downstream path has a much higher probability of a having negative customer impact, depending on the frequency, bandwidth, and amplitude of the ingress signal. If the plant fault is significant, the ingress can severely impair the downstream signal to the CPE.

Ingress can also sit close to the noise floor under the CTA channels. Such cases *may* be seen in the guard bands between channels as an observable increase in the noise or a sharp spike in the captured spectrum. Measuring wide band ingress under the CTA channels is difficult and highly dependent on the resolution at which the spectral response is captured.

Ingress can be sporadic in nature and is frequency independent. An ingress signal at 100 MHz does not mean that ingress at a higher frequency such as 700 MHz signal will be present; the opposite is also true. In other words, the shielding defect(s) that allows ingress is not necessarily uniform across frequency. Sometimes the ingress can be worse at lower frequencies, sometimes it's worse at higher frequencies, and sometimes it's seen across much of the spectrum. If the conditions in the plant allow an ingress signal at UHF channel 21 (512 MHz to 518 MHz) not only can that ingress signal affect two of the cable network's CTA channels (Ch. 72 and 73), but one *may* or *may not* see ingress at other frequencies such as 100 MHz and 700 MHz. As can be seen in the examples of ingress in Figure 40, ingress *may* appear throughout the spectrum. The second illustration in the figure shows the potential of using the guard bands to evaluate potential ingress issues. Figure 41 shows a significant ingress event with multiple issues, the ingress in the FM band being the most evident. It also shows periodicity issues that *may* clear up when the source of the ingress is found.



Node or MAC: fc:94:e3:b0:13:c0
PN027, cable-upstream6/10.0, 29.4MHz, 6.4 QAM64
Flux Full Band - 1 devices found
Nodes: ALL NODES
KHz: 30 Smplz: 10 Div: 5

Figure 40 - Examples of ingress

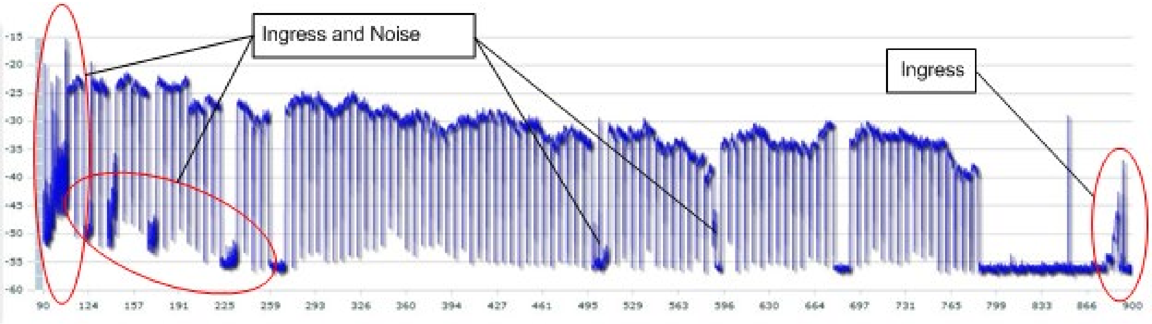
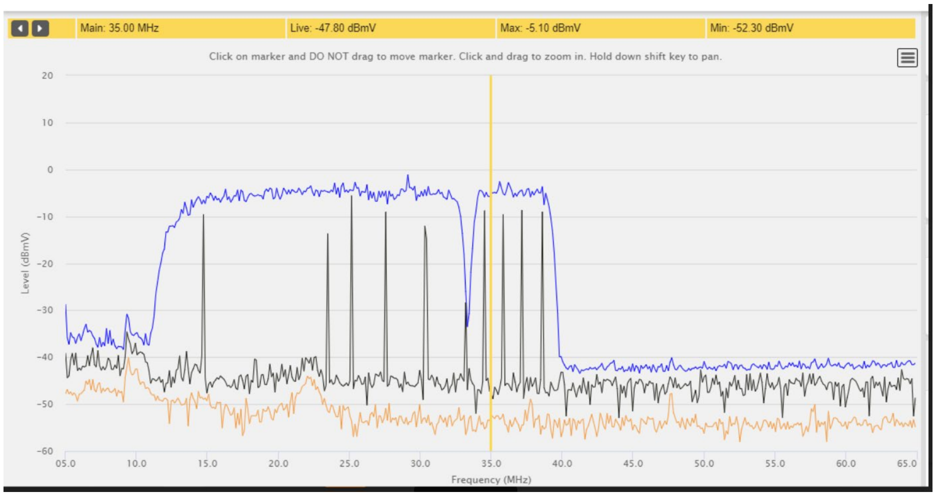


Figure 41 - Example of a significant ingress event with several types of ingress

9.4.8. HPNA

HomePNA Alliance (HPNA) devices and technology use twisted pair or coaxial cable to communicate wideband signals, and can potentially interfere with cable signals under certain conditions. This class of upstream interference falls under the HPNA umbrella and can cause serious degradation of return path signals. HPNA interference can occur when there is insufficient isolation between broadband networks and other home networks that deploy signals using the HomePNA Alliance protocols. Example sources of HPNA interference include Ethernet extenders, telephone systems, HPNA set-top boxes and gateways that are incorrectly connected to the active cable network. See Figure 42 and Figure 43 for examples.



Main: 35.00 MHz

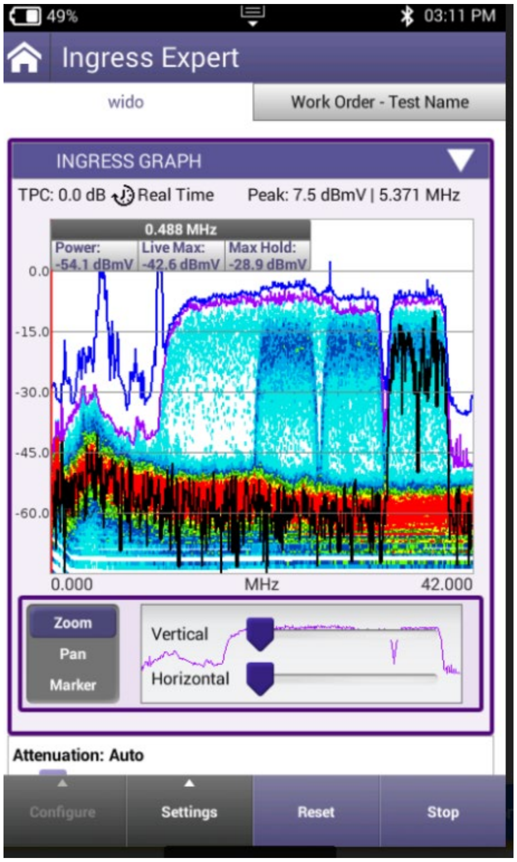
Live: -47.80 dBmV

Max: -5.10 dBmV

Min: -52.30 dBmV

Click on marker and DO NOT drag to move marker. Click and drag to zoom in. Hold down shift key to pan.

Figure 42 – HPNA Interference



TPC: 0.0 dB Real Time Peak: 7.5 dBmV | 5.371 MHz

0.488 MHz

Power: -54.1 dBmV

Live Max: -42.6 dBmV

Max Hold: -28.9 dBmV

Attenuation: Auto

Figure 43 – Another example of HPNA interference

9.5. Resonant Peaking

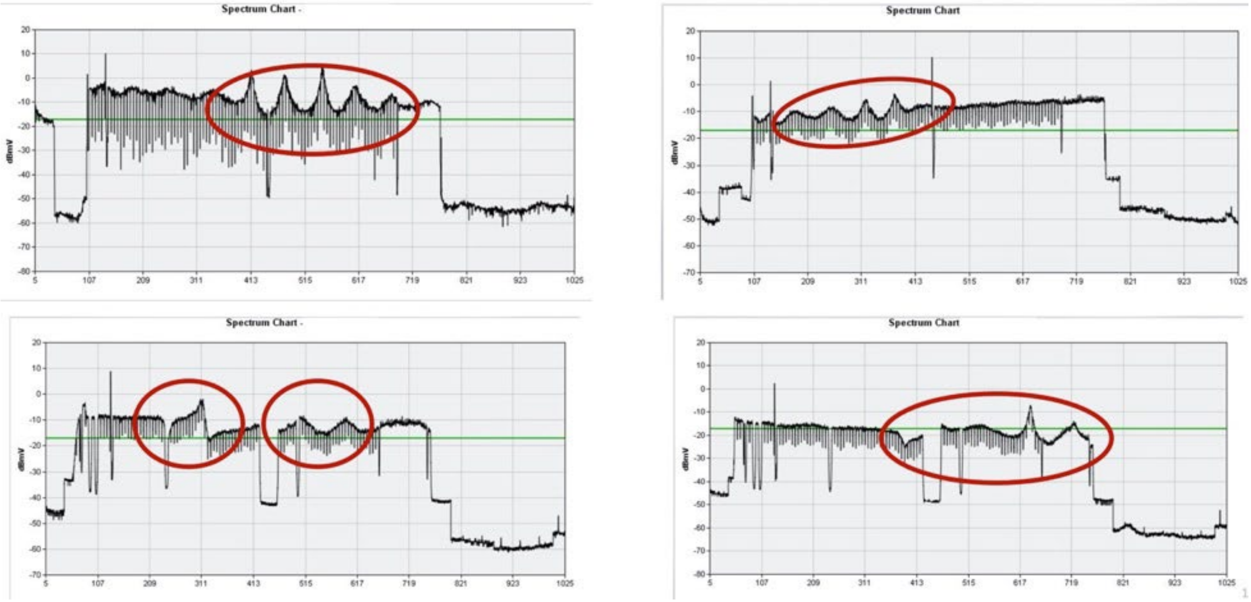


Figure 44 – Resonant Peaking Examples

Definition: Frequency specific gain, caused by grounding problems in actives, usually caused by amplifier module seating, oxidization and/or loose screws. Different equipment types are illustrated below. Peaks can change frequencies and sometimes include a suckout. See Figure 44.

Resonant peaking is an RF spectrum impairment that can affect a series of cable channels. It is easily recognized when viewing the full spectrum and observing the frequency response. Resonant peaking is observed as an upward change in amplitude that peaks and then reduces in amplitude. Typically, the issue occurs in an active device such as a node or amplifier. A faulty passive element in the plant can sometimes exhibit what appears to be a peak.

Resonant peaking can affect signal levels, phase across a signal, group delay variation, and RxMER. If the resonant peak falls on an AGC pilot, the AGC functionality in the network will be impacted.

It is important to note that resonant effects can be intermittent in nature, and sometimes vary in frequency. As such, they can be complicated to diagnose. The peaking can also be temperature dependent in that temperature variability can change the effectiveness of the grounding or shielding or the quality of the connection.

The location in the delivery path where the resonant peak occurs will determine the overall impact. The peak’s relationship to the AGC can impact the performance of the other channels being distributed.

- If the peak happens at the amplifier gain control carrier, the amplifier or series of amplifiers will react on a decibel-for-decibel basis to impact adjacent channels or the full spectrum.
- If the peak happens away from the control carrier, the impact will be observed in the SNR and RxMER performance.

This impairment can manifest at the CPE as poor RxMER, poor codeword performance, and packet loss, which could result in slow data transfer speeds, tiling, or freezing, depending on which channels are affected. The following figures show examples of the effects of resonant peaking. In Figure 45, it is seen at 716 MHz and has an impact on four channels on either side of the resonant peak.

Figure 45 - Example of resonant peaking affecting adjacent channels

9.5.1. Grounding

A common cause of resonant peaking in an active device is an oscillation created by poor or degraded grounding within the affected device. That poor grounding can be the result of loose hardware (e.g., captive screws/bolts) in modules, module covers, printed circuit boards, etc., as well as the connectors between the module and chassis.

In many cases removing and reseating the module in the housing will resolve the problem, as will tightening connectors and/or hardware. In some instances, the connector(s) between the module and housing needs to have the ground "spring" replaced.

Resonant peaking is evidence of an undesired RF oscillation occurring inside of an active device. Oscillators in electronic circuits often work by virtue of what is called controlled feedback (uncontrolled feedback can also cause oscillation). For an analogy, think of being in an auditorium when someone with a handheld microphone gets too close to a loudspeaker. The result is a "howling" tone, which is uncontrolled feedback causing the auditorium's audio system to become an oscillator. Much the same thing can happen in a cable network amplifier housing, when a (usually) grounding issue results in RF feedback inside of the housing, creating the equivalent of an RF oscillator. The result shows up as resonant peaking in the frequency response.

Often the resonant peaking can be fixed long-term by removing the affected amplifier module from the housing, reseating it, then properly tightening captive hardware. Some people have found that opening and closing the housing lid, or bumping/hitting the housing resolves the problem. More often than not, this fix is only temporary.

Figure 46, Figure 47 and

Figure **48** show examples of resonant peaking with different makes and models of amplifiers.

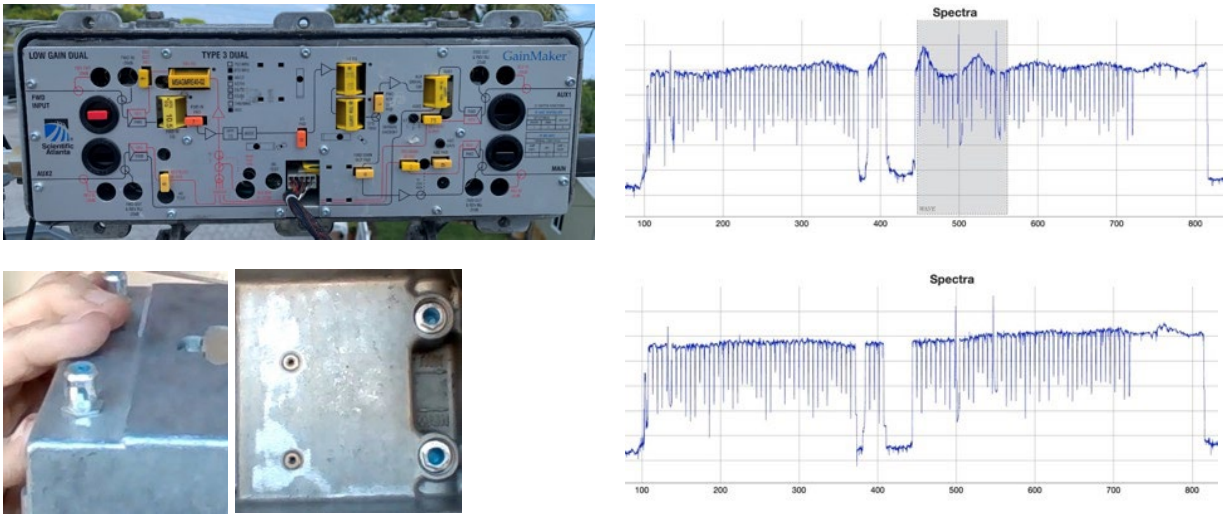
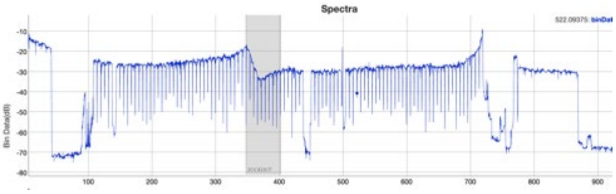


Figure 46 – Resonant peaking, example 1



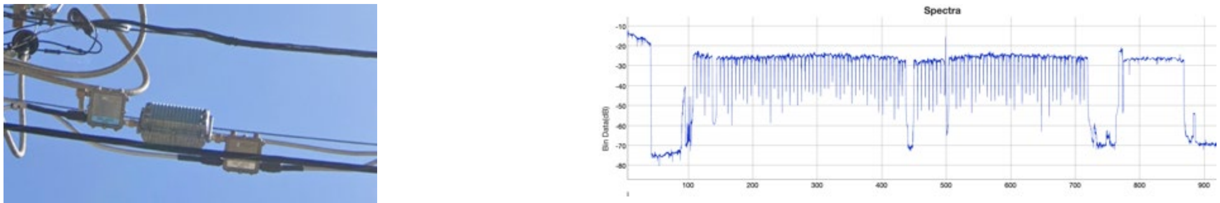


Figure 47 – Resonant peaking, example 2

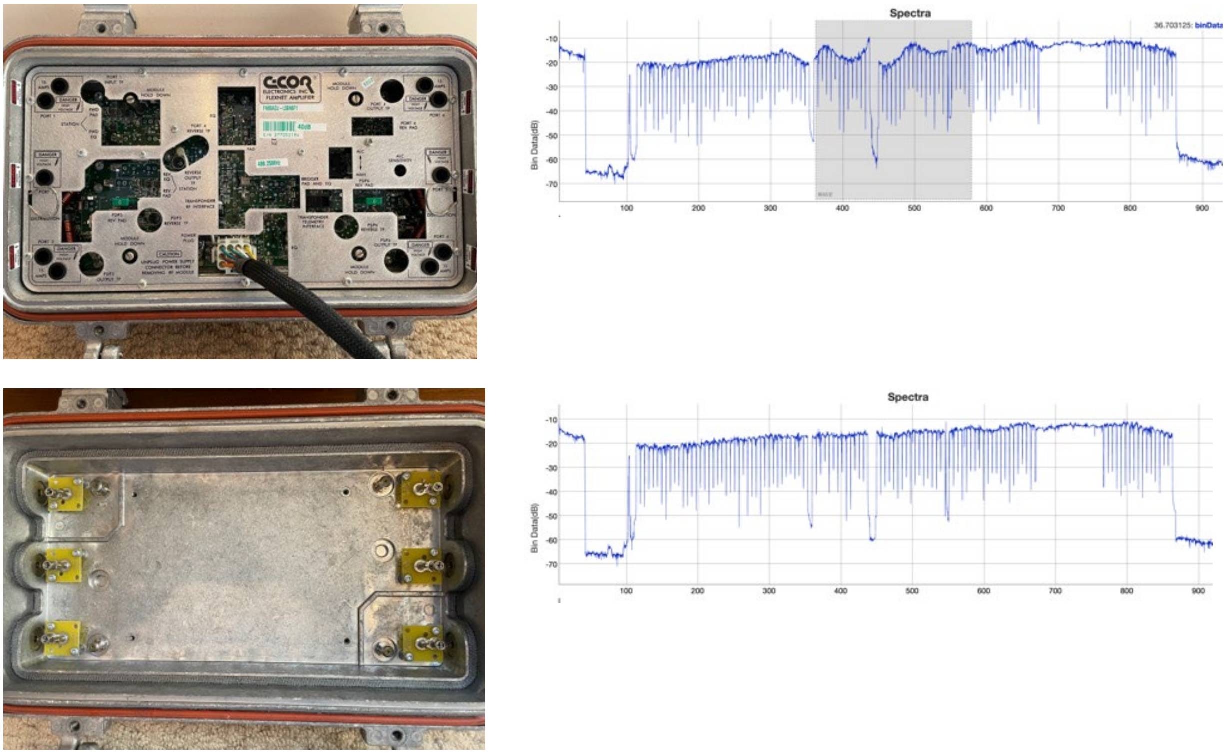


Figure 48 – Resonant peaking, example 3

9.5.2. Improper Alignment Techniques

Incorrect adjustment of active devices, and misalignment of adjustable equalizers (called trim networks or mop-up equalizers) can degrade the frequency response. In older amplifiers, fixed inductors (coils) can be physically stretched, compressed, and so forth, which also affects frequency response.

In years past it was not unusual for technicians to make adjustments inside of amplifiers in an effort to optimize the frequency response flatness. Those practices sometimes continue today, to the detriment of system performance.

9.6. Rolloff

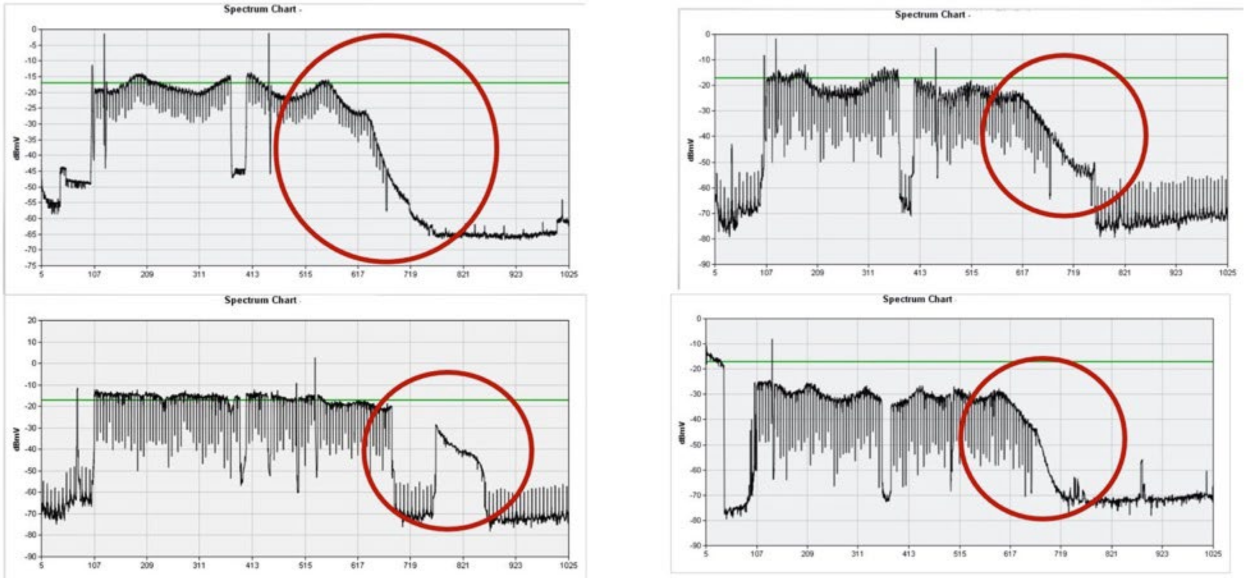


Figure 49 – Rolloff examples

Rolloff is most commonly caused by water-soaked passive network elements, and is often found with water damaged cables or devices, caused by water migration through the cable. *“High frequencies can’t swim.”* See Figure 49.

Spectral rolloff is characterized by a gradual, non-linear decrease in amplitude and power over the frequency band. It is most often found towards the high end of the frequency range, closer to 1 GHz. There are numerous reasons why rolloff can appear in the spectrum. Keep in mind that there could be a high frequency suckout at the downstream’s upper band-edge that looks like rolloff.

9.6.1. Filters

Devices in the network have a pass band through which frequencies will pass with a minimal loss of signal strength. Typical pass bands used to design components in the past are 450, 550, 650, 750, and 870 MHz. In some cases, cable networks transmit signals at frequencies slightly above these pass bands. If components designed for these pass bands are in the network, they *may* be identified by rolloff of the spectrum above their designed pass bands as signals are added. Components with the same pass band characteristics will be shown as additive and will produce a sharper rolloff. In these cases, the signal strength at high frequencies degrades at a much more rapid pace than lower frequencies, resulting in spectral rolloff than can affect the customer depending on how far the customer’s device is from the point of transmission.

9.6.2. Incorrect Network Components

Individual elements along the transmission path, such as amplifiers and less commonly defective cable, can produce roll-off characteristics, especially when a signal must propagate through numerous amplifiers that are not configured correctly for the network. For example, equalizers in these nodes or amplifiers *may* have an upper limit of 750 MHz though the plant is trying to pass 870 MHz. Another potential issue is network devices that are bandwidth limited because of physical characteristics such as the design of the center conductor seizure mechanism.

Some networks *may* use older coaxial cable that was not designed for the extended frequencies in use today. As an example, the coax *may* have typical losses up to 650 MHz but the greater losses would be anticipated at higher frequencies. There are other contributors to additional loss in a coaxial cable such as water migration damage caused by improper installation or a plant fault at a connector. Loss *may* appear as rolloff or excess loss depending on where in the network it occurs.

9.6.3. Improper Alignment

Network designs that have an equalizer placed mid-span between the amplifier and the end-of-line can have the same roll-off issue if the equalizers were designed for a lower frequency than what is trying to be passed.

9.6.4. Environmental

In more limited and extreme cases, what appears to be rolloff *may* be something else. A large suckout at the high end of the spectrum with only one side of the suckout visible appears to be a rolloff upon a quick visual inspection. Similarly, a standing wave can sometimes be misidentified as a suckout or a rolloff.

In addition to the cable, which is often a primary victim of water ingress, it’s also common for the water to migrate and damage peripheral components. When additional network elements are damaged, multiple problems can become compounded and worsened. Among the most common examples are taps, splitters, splices, block splices and all the different filters and pads installed in the drop network.

In the following example, a water-soaked drop was the primary source of water ingress. However, the tap was physically located at a lower elevation on the pole than where the water entered the cable. With water accumulating over time and the influence of gravity, the water eventually migrated into the tap. A closer look at Figure 50 – High-frequency rolloff (right) caused by water-soaked tap (left) clearly shows water droplets in the upper left and lower right corners of the tap faceplate. The circuit also shows rust and other signs of corrosion. The subsequent frequency responses were captured before and after the faceplate was replaced. The FBC spectrum in Figure 47 represents a typical high-frequency roll-off starting around 500 MHz, becoming dramatically worse at 750 MHz (nearly 30 dB). In this case, the OFDM channel was significantly impacted, causing severely degraded service performance.

Spectral rolloff *may* cause tiling or freezing of video channels. Depending on the slope of each individual channel in the rolloff and the power level at the receiver, the quality of service *may* be very poor or nonexistent.

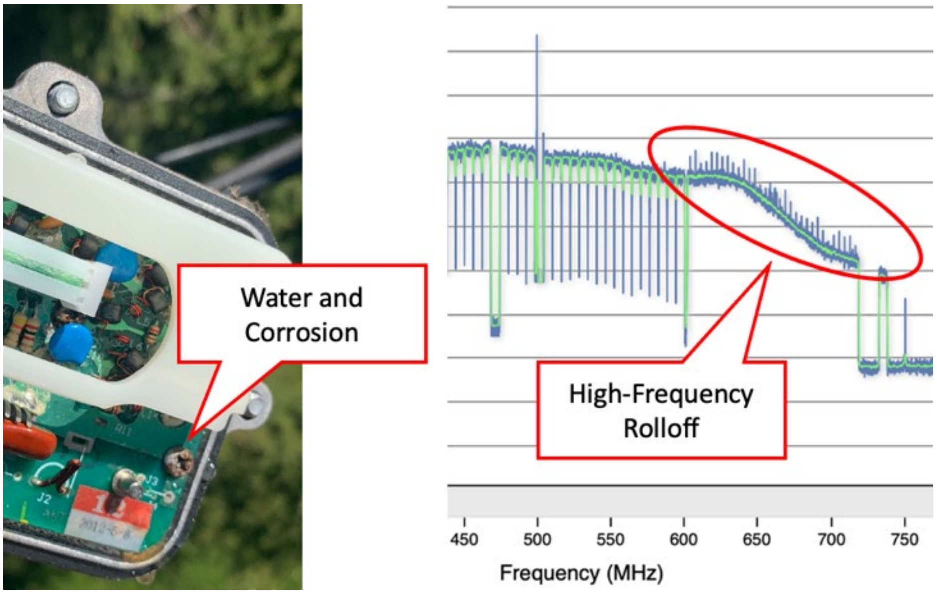


Figure 50 – High-frequency rolloff (right) caused by water-soaked tap (left)

Anecdotally, field technicians have observed rolloff as one of the more prevalent RF impairments on the plant. However, to date, no actual quantification of the prevalence of this impairment has been made. To that point, as the rolloff decreases the channel power of each channel in the rolloff region, the likelihood of a poor customer experience, and eventually a corresponding negative customer service interaction, can be correlated.

In both examples shown in Figure 51, the rolloff appears to start at approximately 750 MHz. The end of the rolloff is not shown because of the lack of additional carriers above 780 MHz. The slope per channel above 760 MHz *may* be impacting the performance of those channels.

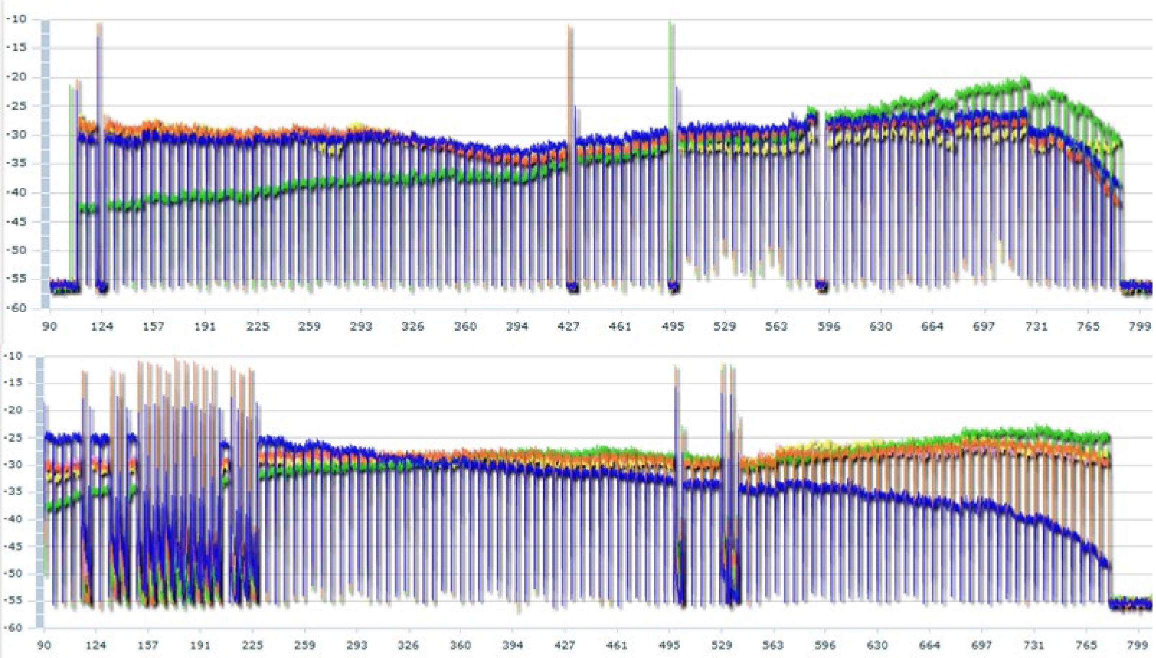


Figure 51 - Examples of spectral rolloff at the high end of the frequency spectrum

9.7. Standing Waves

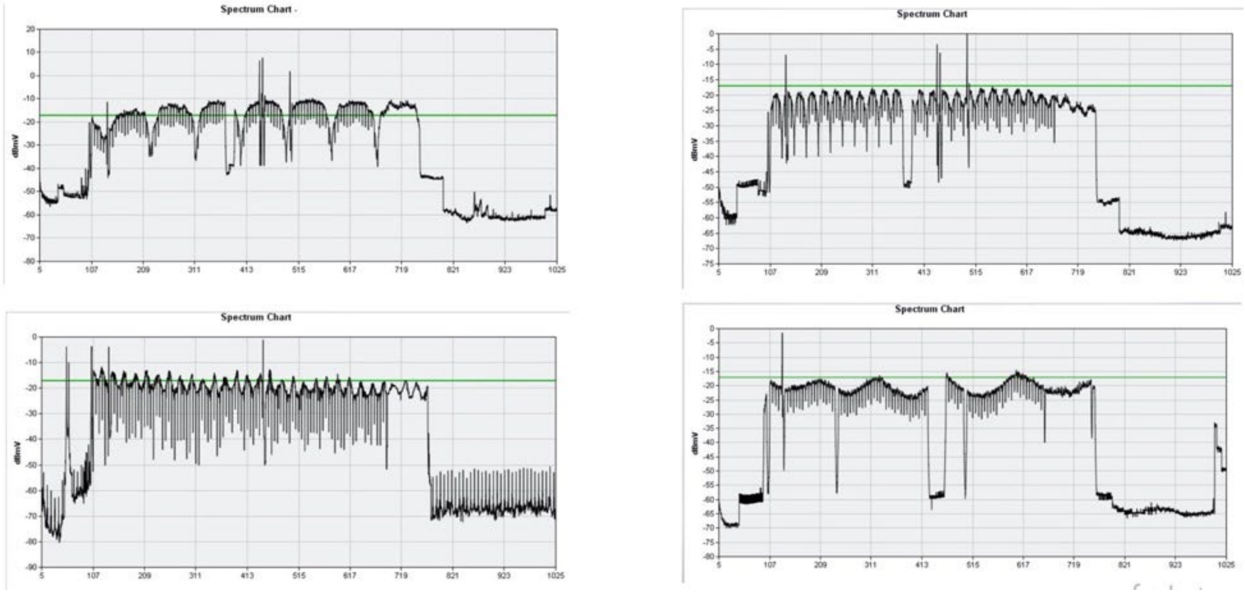


Figure 52 – Standing wave examples

Definition: Periodic (repeating frequency) waves or ripples are caused by impedance mismatches on the cable system. See Figure 52 and Section A.2.5 for further information about impedance mismatches.

Standing waves indicate RF impairments that will impact the entire spectrum. The plant impairments are most often caused by impedance mismatches somewhere between the node and the modem. In the downstream, when seen by a cable modem, energy reflects off of the second impairment, back to the first, and then some of that energy continues downstream, but delayed, causing an impact to the signal that appears as a standing wave in the spectrum data. When observed in a spectrum display, the standing wave will appear as a periodic amplitude change or a sine wave-like appearance.

The height of the peaks of the standing wave will vary. The greater the delta in megahertz between the peaks, the shorter the length of the echo. The user can examine the spectrum display to determine the distance between impedance mismatch points in feet, the echo tunnel end points, by multiplying 492 times the velocity of propagation for the cable divided by the peak-to-peak frequency in megahertz of the wave.

A mismatch can be caused by any active or passive network element (e.g., amplifier, splitter) that connects to the coaxial cable that eventually leads into the customer's home. Operators can utilize FBC data such as those shown in Figure 53, to measure the exact prevalence and impact of this RF impairment. Using the data from multiple CPEs associated with a node can help determine if the standing wave event is isolated or affecting several customers.

Note: As mentioned previously, impedance mismatches cause reflections. Reflected waves interact with incident waves to produce a distribution of fields in the transmission line (the coaxial cable) known as standing waves. The presence of standing waves in coaxial cable can cause amplitude ripple in the frequency domain. The term standing wave is often used to describe amplitude ripple, although technically speaking amplitude ripple is not the same thing as a standing wave.

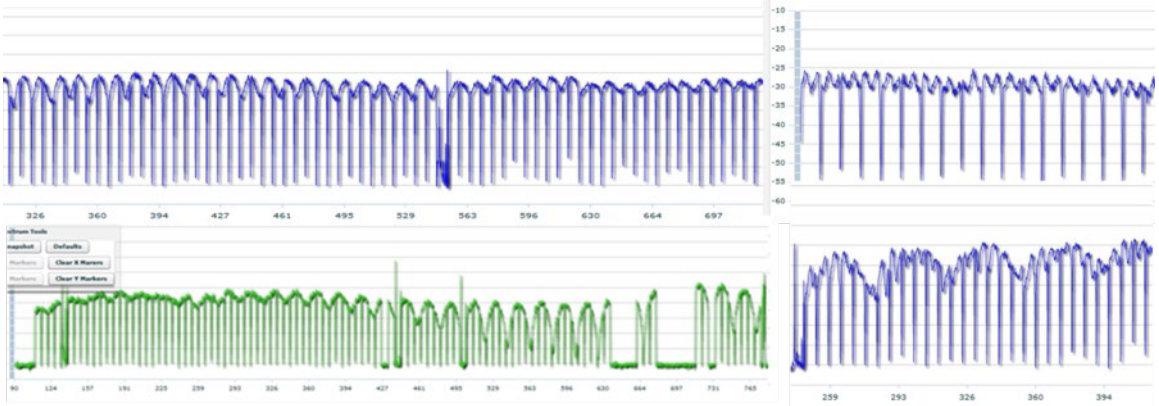


Figure 53 - Example of standing waves

9.7.1. Compound Standing Wave

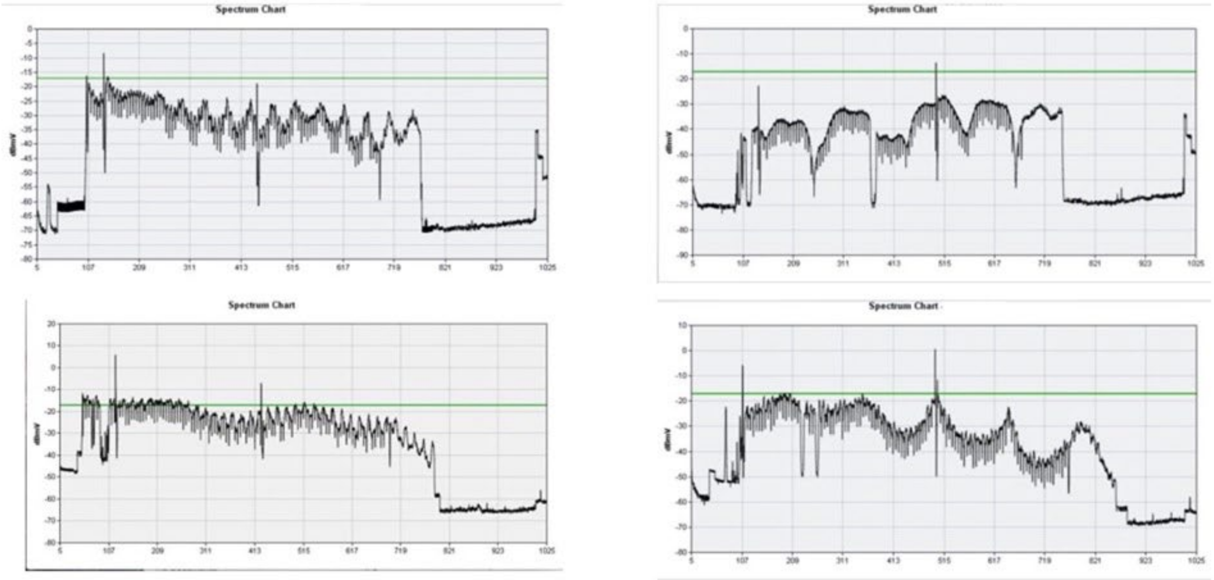


Figure 54 – Compound standing wave examples

Definition: Multiple standing waves which are superimposed, caused by more than one standing wave being added to another. See Figure 54.

When more than two impedance mismatch exists in the signal path, multiple reflections can occur. The result is compound amplitude ripple, which shows up as amplitude ripple superimposed on another amplitude ripple (Figure 54). This could be an indication of multiple impairments.

Any two impedance mismatches will result in a standing wave showing on a spectrum capture. Therefore, more than two impedance mismatches result in overlapping standing waves.

9.7.2. Non-Uniform Magnitude Standing Wave

Because of the physical properties of the transmission line, standing waves can also be subject to attenuation, creating ripples with a non-uniform magnitude. In Figure 55, the ripples magnitude is nearly 20 dB peak-to-null at 100 MHz and eventually attenuates to around 5 dB at 800 MHz. Although less common, sometimes the attenuation decreases with frequency. Figure 56 shows an example of low-frequency ripples attenuation in a non-uniform standing wave.

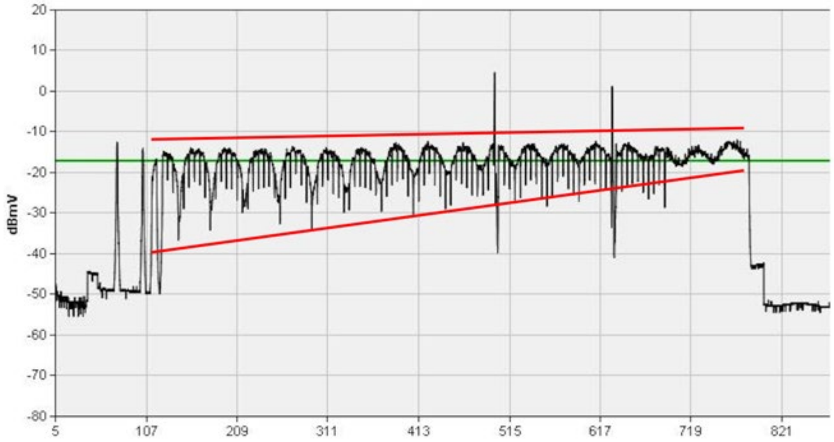


Figure 55 – Non-uniform standing wave with high frequency attenuation

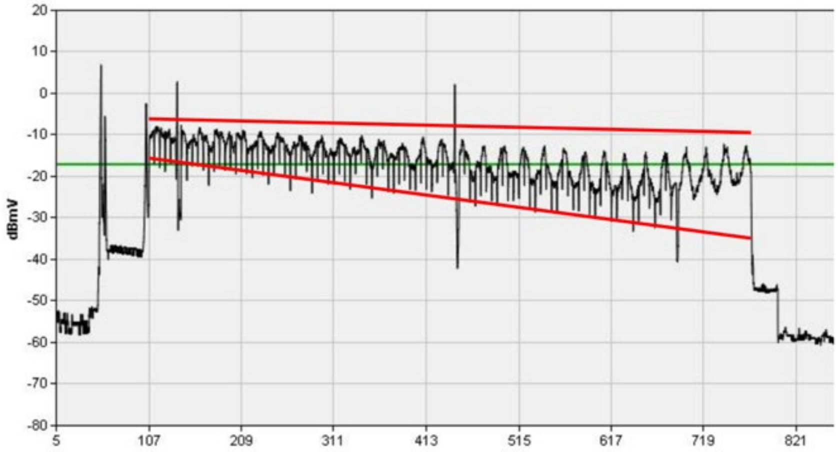


Figure 56 – Non-uniform standing wave with low frequency attenuation

9.7.3. Non-Periodic Wave (Water Waves)

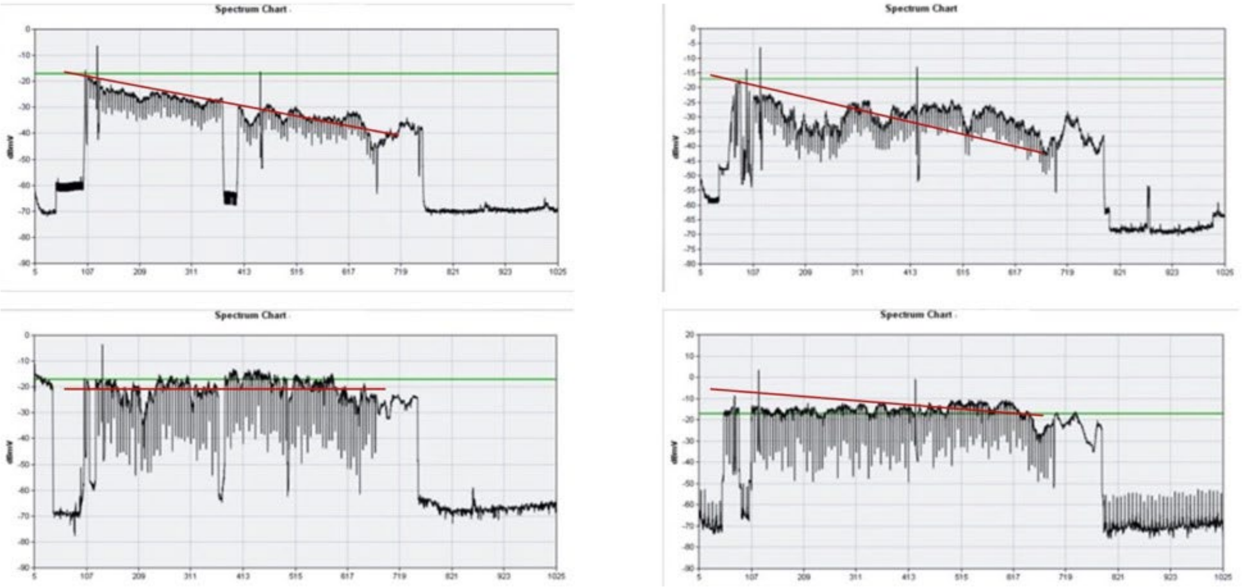


Figure 57 – Water wave examples

Definition: Non-periodic standing waves, caused by water presence in cables. High-frequency pockets of attenuation and sometimes large tilt are common in drop cables. The RF spectrum impact through hardline cables will look slightly different. See Figure 57 for examples of impaired frequency response caused by water in subscriber drop cables.

When water enters coaxial cable, several things happen to create the distinctive frequency response shown in Figure 58. Why does water in coaxial cable have that effect on RF? The presence of water in the cable's dielectric changes the dielectric constant, which changes the velocity of propagation, characteristic impedance, and attenuation (see the Appendix for more information on the characteristics of coaxial cable). Further complicating the water-related degradation is the fact that the water is not uniformly distributed throughout the length of the cable. That, in turn, results in randomly distributed, localized variations in the cable's velocity factor, impedance (think micro-reflections) and attenuation, causing a non-periodic shape in the frequency response.

The severity of this problem will depend on the amount of water present in the cable and other factors such as temperature and system RF levels. These problems have been observed to coincide with rainy weather and tend to be variable, sometimes completely clearing when the water drains or evaporates. The amount of customer impact can be measured with downstream receiver power levels, tilt, per-channel RxMER, and codeword errors or packet loss, which *may* inform the repair prioritization.

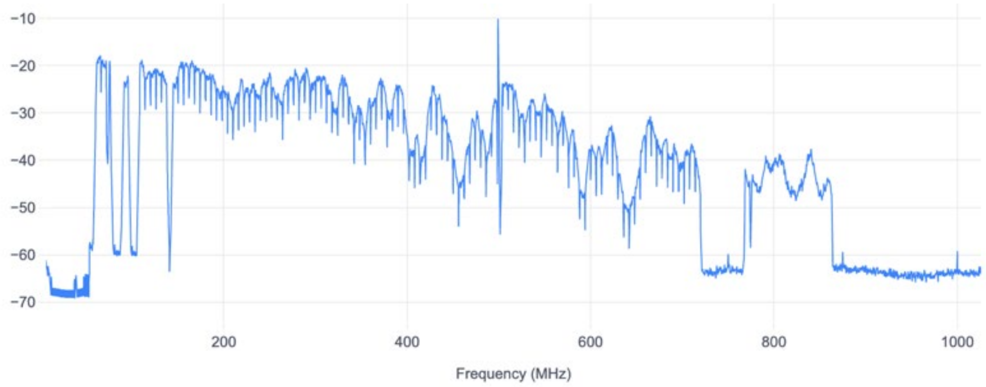


Figure 58 – Typical frequency response of water soaked drop cable

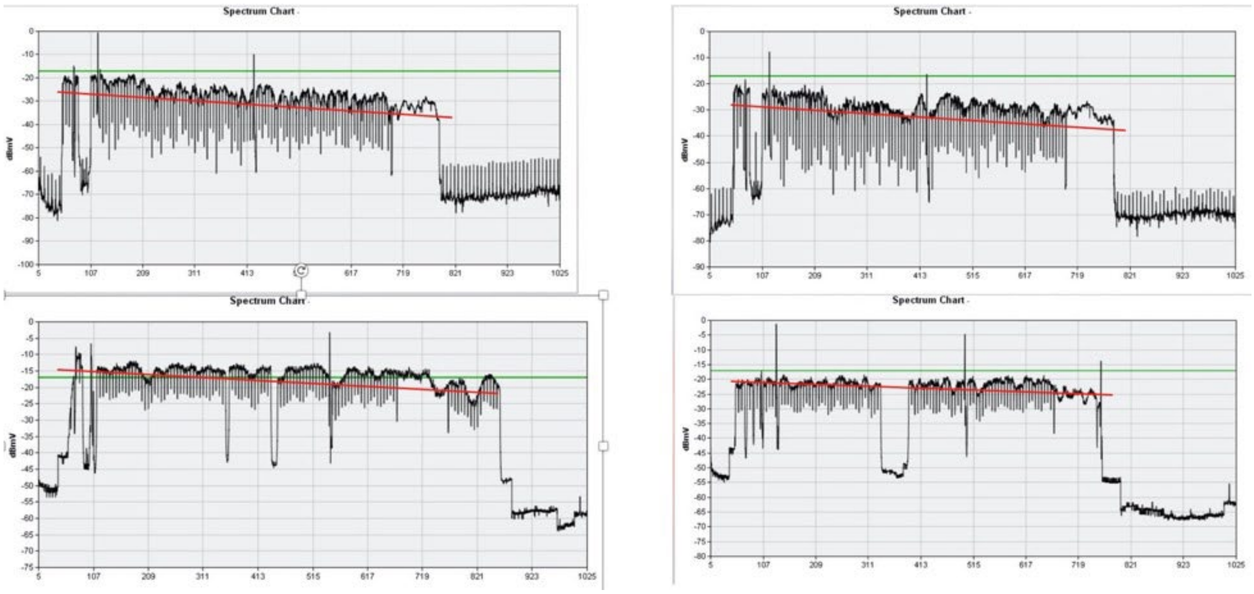


Figure 59 – Additional water wave examples

Figure 59 shows additional examples of water waves.

9.8. Tilt

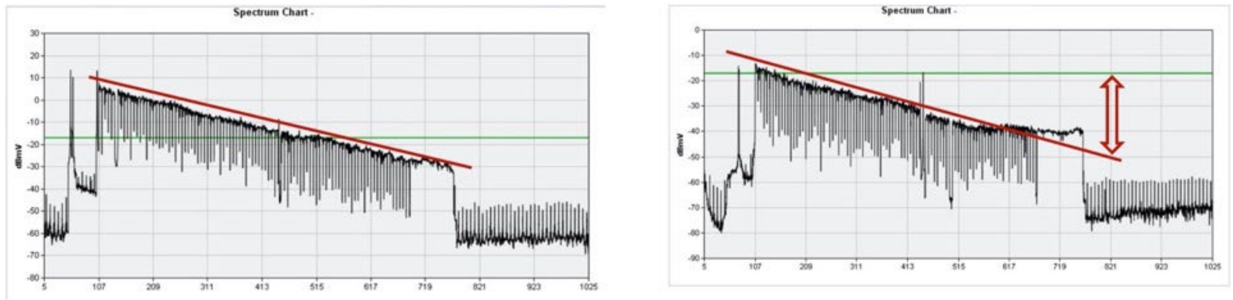


Figure 60 - Tilt examples

Definition: Not necessarily indicating a problem, often caused by measurements made near amplifiers, ends-of-line or improper amplifier setup. The tilt *may* be in either direction (positive or negative tilt). Notice the power relative to the 0 dBmV reference (green line) in Figure 60. Note: The green line appears to be at about -18 dBmV, but that is because of the RBW used in the FBC display.

Spectral tilt is an RF characteristic that *may* or *may not* be an impediment depending on several factors. Tilt is defined as the amplitude difference between signals at specified frequencies, typically the lowest to highest. In the network, signals at a lower frequency will have less loss than signals at a higher frequency.

Tilt is introduced into the spectrum at the node output for an optical transport or at the headend for a coax distribution network. The purpose of introducing tilt is to compensate for the anticipated signal losses in the network. In a coax distribution network, tilt also adds the performance benefit of making a flat spectrum possible after a length of cable, as well as improving nonlinear distortion performance in the actives. When the tilt compensation is calculated correctly, the delta between signals at a termination device will be minimized and each signal will have the same amplitude as the termination device (CPE).

It is possible that a positive tilt introduced into the network will be seen as a negative tilt at the CPE farthest from the node or amplifier (see Figure 61), but a negative tilt *should* not cause issues if it is operating within the system design parameters.

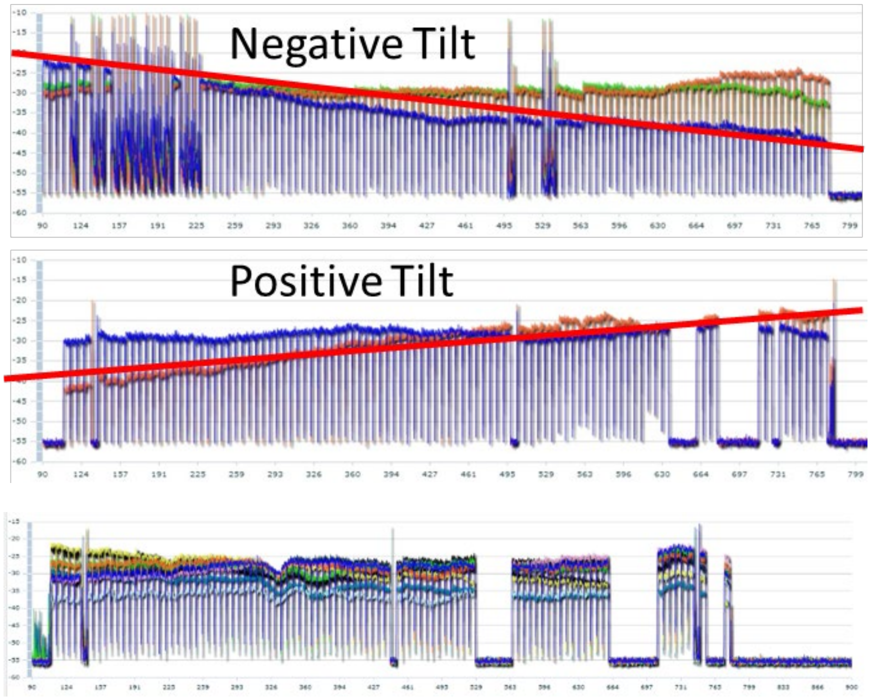


Figure 61 - Examples of tilt: negative only, positive only, and both negative and positive

9.9. Excessive Flat Loss

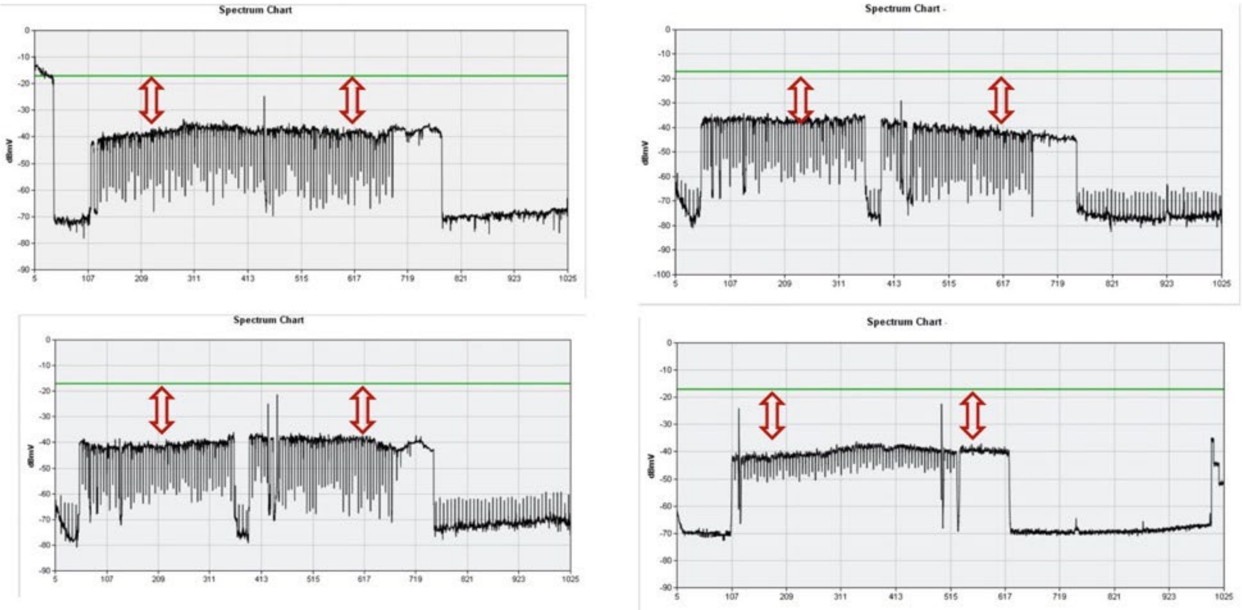


Figure 62 – Flat loss examples

Excessive flat loss is caused by excessive attenuation, not associated with cable loss or tilt**.** Usually, the cause is excessive splits or improper padding. Notice low signal levels compared to 0 dBmV channel (a common amplitude reference for customer terminal input signals) power indicated by the green reference line in Figure 62.

In some cases, restoring power levels can be achieved by removing unnecessary splitters or reducing the number of splits in the customer drop. For example, a customer might unknowingly purchase and install a splitter with an unnecessarily large number of ports, without understanding the effect on signal levels.

9.10. Pullout

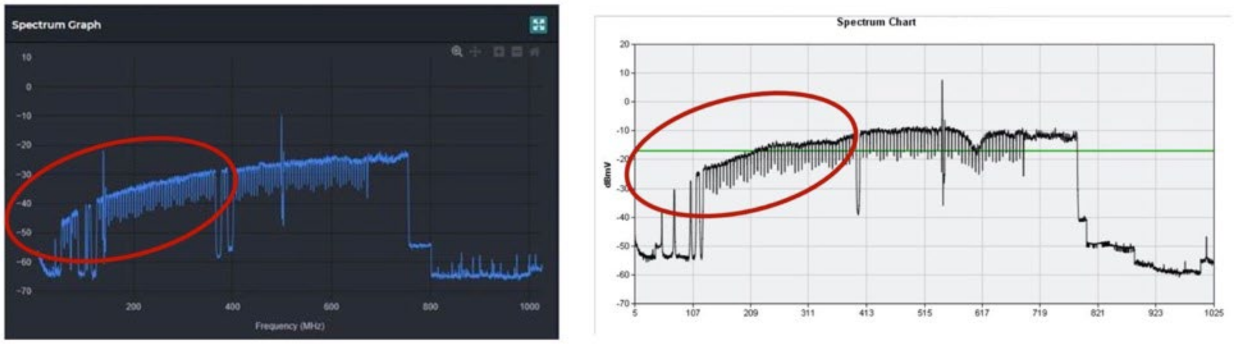


Figure 63 – Low-frequency rolloff / pullout examples

Typically caused by physical separation of shielding or center conductor on hard line (aka. pullout or sucked out connector). *"Low frequencies can't jump"*. See Figure 63.

As used in this document, "suckout" describes a (usually) narrow bandwidth notch in the amplitude-versus-frequency response of the RF spectrum. The term "suckout" (and more commonly the term "pullout") also is used to describe what happens when hardline coaxial cable contracts longitudinally during cold weather and pulls out of the connector at an active or passive device. In extreme conditions, the cable and connector can be pulled out of the housing. See Figure 64 for an example of a cable that pulled out of a connector. The full spectrum frequency response, before and after the repair are shown in Figure 65.

Figure 64 – Pullout or shield separation

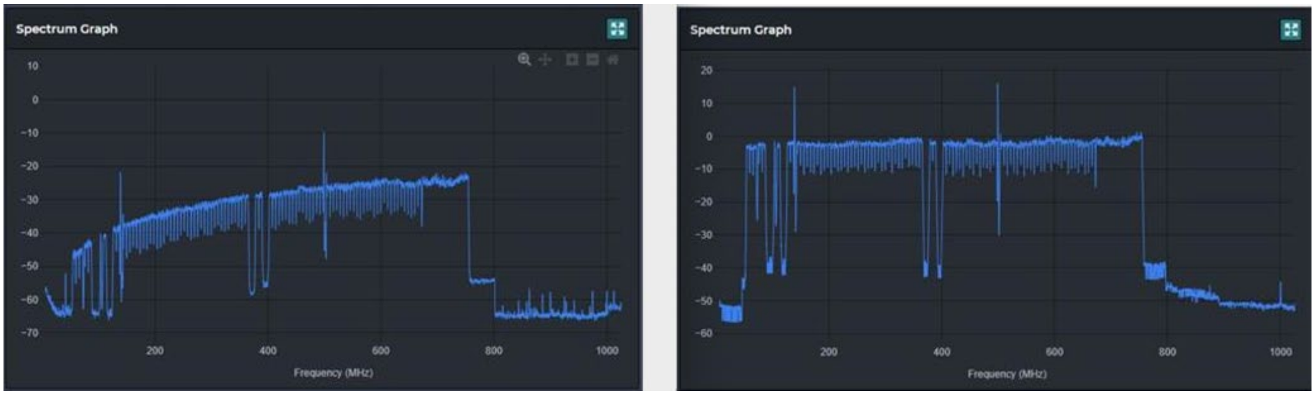


Figure 65 – Pullout impaired RF spectrum, before and after repair

Appendix A

This section includes more in-depth information about various topics mentioned in earlier sections.

A.1 Properties of Coaxial Cable

A.1.1 Construction

Coaxial cable, or coax, is a type of electrical cable – specifically a transmission line – consisting of an inner conductor (or center conductor) surrounded by a concentric conducting shield, with the two conductors separated by a dielectric (insulating material); many coaxial cables also have a protective outer sheath or jacket. See Figure 66.

Some of the more important characteristics of coaxial cable include impedance, attenuation, shielding effectiveness, and DC loop resistance. If any of these characteristics is not within specification, the quality of signals carried in the cable network and even the RF spectrum within that network can be impacted. Each of the aforementioned characteristics is discussed in more detail in the following sections.

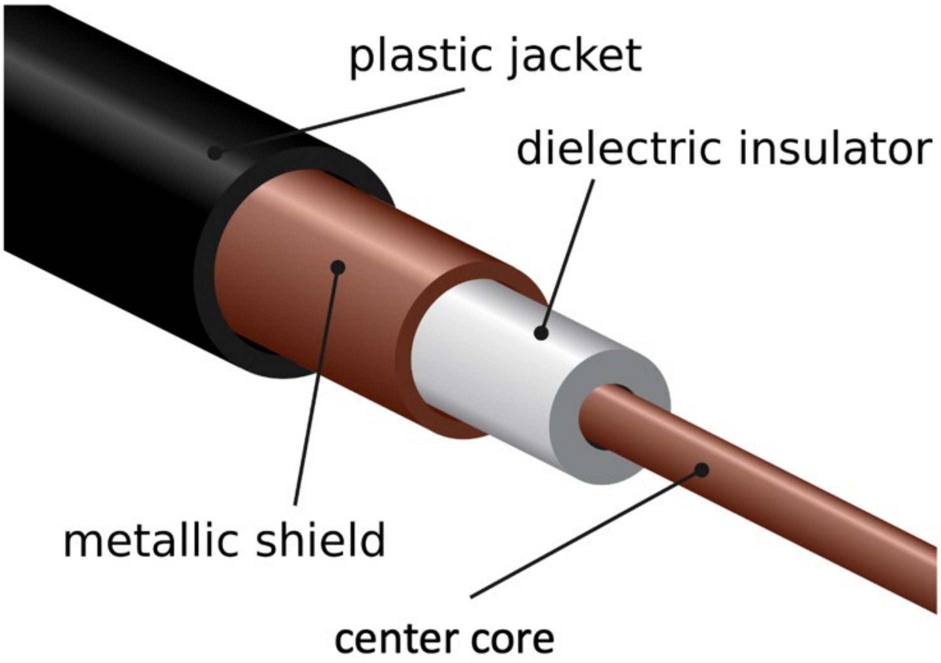


Figure 66 - Cross section of coaxial cable

A.1.2 Impedance

So, what is impedance, and why is it important? Let’s start with what.

Impedance is the total opposition to current in a component, device, or circuit, and is expressed in ohms. Impedance is further defined as the frequency domain ratio of voltage to current. Impedance in an AC circuit, including RF, is a complex value and includes both resistance and reactance – that is, both magnitude and phase. Impedance can be thought of as a way to describe the concept of AC resistance. Resistance in a DC circuit also is expressed in ohms but has only magnitude. DC resistance is sometimes called “DC impedance.”

The impedance of the coaxial cable is determined by the electrical properties of the dielectric material and the physical geometry of the cable. Among the most important features of the coaxial cable’s geometry is the ratio of the inner diameter of the shield to the outer diameter of the center conductor, Figure 67.

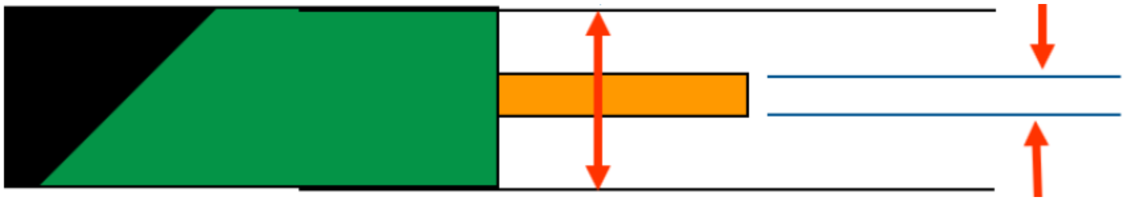


Figure 67 – Center conductor outer diameter and shield inner diameter

Okay, this is all fascinating, but what does that *actually* mean? Well, just based on this definition, a couple of things jump out right away. If impedance is impacted by the shape (geometry) of the cable, and the position (or size) of the center conductor relative to the outer shield, then cables that are crushed, kinked, dented, or twisted will experience a change in the impedance. Remember that winter when you heated up a piece of cable to get the connector on? Well, the dielectric material probably melted a little, and allowed the center conductor to shift its position. The melted dielectric also had its properties changed! Sound familiar? Those are just a couple of examples of the causes of impedance mismatches related to changes in the cable's geometry or shape.

But let's get back to impedance. The standard (nominal) impedance for cables and components used in CATV systems is 75 ohms. There are many different types of coaxial cables, with varying impedance values. So why do we use 75 ohm cables? The actual reason is likely lost to history. However, in the late 1920s Bell Labs testing found that coaxial cable with an impedance of 30 ohms has the best power handling capability, 60 ohms offers the best performance for higher voltage, and 77 ohms has the best attenuation performance.

Early tree-and-branch cable network architectures had long trunk amplifier cascades, so the attenuation performance of 75 ohm impedance coax could well have been a factor to help reduce the number of amplifiers needed. One story says that early cable operators took advantage of the availability of surplus 75 ohm coaxial cable from WWII (that impedance was reportedly used on ships and in aircraft to minimize weight, because of 75 ohm coax's smaller diameter center conductor compared to the center conductor in the same size 50 ohm impedance coax).

In any event, the goal in HFC networks is to transfer as much signal (RF power) as possible from the source, through the coaxial cable, and to the destination at the output of the coax, such as a modem or a set-top box. Having a well maintained and impedance-matched coaxial network allows us to efficiently transfer that signal to the load, while maintaining the frequency response of those signals.

It is critical that we maintain 75 ohm nominal impedance in our HFC systems. The best way to make sure that the maximum amount of RF signal level is transferred from one device to the next, is to make sure that the impedance between the two components is the same. As mentioned previously, in a coaxial network, all the RF interfaces are designed to have a nominal impedance of 75 ohms.

When both the source and the end-points have the same impedance, the impedances are said to be "matched." In a matched condition, all the power sent from the source is absorbed by the load (except that lost to attenuation through the cable). If the impedances of the source and the load are not equal, a portion of the power sent from the source is reflected. This reflected power is returned to the source. The difference between the transmitted power and the reflected power (in decibels) is called the return loss or RL – not to be confused with return path attenuation. For example, if a signal of +20 dBmV is sent from a source to a slightly mismatched load and a signal at a level of +2 dBmV is reflected back toward the source, we say the load has a return loss of 18 dB.

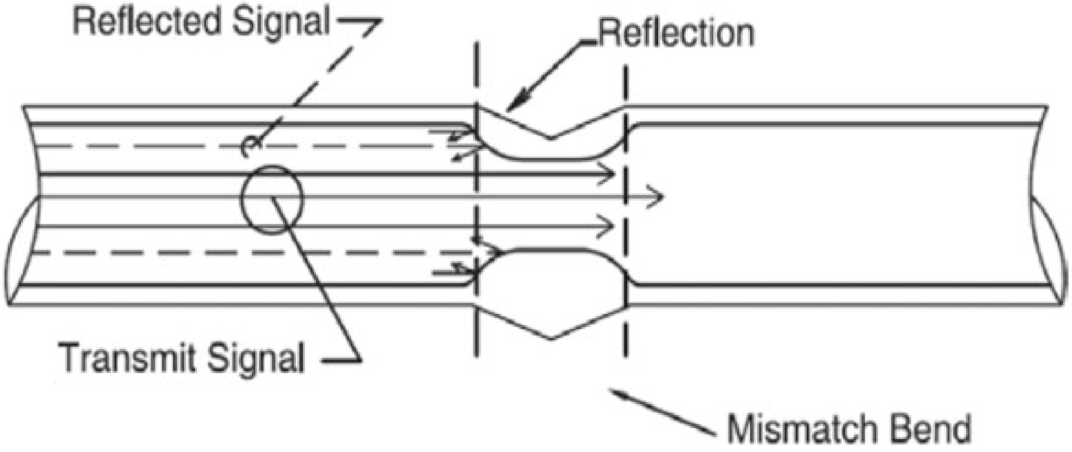


Figure 68 - Reflected signals due to change in cable geometry

From a practical standpoint, it is nearly impossible to achieve a perfect impedance match. Most HFC systems have a goal for return loss greater than or equal to about 16 dB to 18 dB at all RF interfaces. Poor return loss or an equivalently poor impedance match can result in poor frequency response in the network. This produces ripples (standing waves) in the signal with many peaks and valleys. This variation in signal level can result in degraded signal quality, and impact the services delivered to our customers at the affected frequency or frequencies. Observing the overall frequency response is so important and will show things that aren't obvious in a limited measurement of a few channels. Running a full spectrum scan to see the entire downstream bandwidth offers an excellent view of the overall linearity (or not) of the forward path.

As mentioned earlier, the impedance of the cable is partially dependent on the physical geometry or shape of the cable. The relationship between the inner conductor and outer conductor can then affect the impedance of a segment of cable. We tend not to think too much about minor anomalies in either drop cables, or in feeder cables if they aren't exhibiting any symptoms of egress or shielding defects. But these anomalies can affect the delivery of cable signals to the subscriber terminal.

This strong dependence on cable geometry places constraints on the use of coaxial cable. Coaxial cables *should not* be kinked or forced into sharp bends as this will change the characteristic impedance, illustrated in Figure 68.

A.1.3 Attenuation

As RF signals pass through a given length of coaxial cable, a reduction in signal level (attenuation) occurs. According to *Modern Cable Television Technology, 2nd Ed.*,[3] there are four reasons why RF signals are attenuated in coaxial cable:

- Radiation out of the cable due to imperfect shielding

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[3] *Modern Cable Television Technology, 2nd Edition*, by Walter Ciciora, James Farmer, David Large, and Michael Adams. Morgan Kaufmann Publishers, 2004. ISBN 1-55860-828-1

- Resistive losses in the cable conductors
- Signal absorption in the dielectric of the cable
- Signal reflection due to mismatches between the cable and terminations or along the cable due to nonlinear impedance

The majority of the attenuation is from resistive losses in the conductors, although the dielectric does play a role (especially at higher frequencies). Because of a phenomenon known as skin effect, RF current travels on or near the surface of a metallic conductor.[4] The higher the frequency, the shallower the region in which the RF current propagates. A good analogy is to think of, say, the cable's center conductor as the equivalent of a hollow tube. At lower frequencies the thickness of the "tube" is greater; at higher frequencies the thickness of the "tube" is less. As such, skin effect results in the effective AC resistance being greater at higher frequencies than at lower frequencies, resulting in the cable's attenuation being greater at higher frequencies than at lower frequencies.

Table 1 summarizes attenuation versus frequency, in decibels per 100 feet, for a commonly used half-inch diameter hardline feeder cable and for a commonly used Series 6 drop cable. Note that the larger cable has lower attenuation per unit length, and that attenuation is greater at higher frequencies than it is at lower frequencies.

Table 1 - Published attenuation for 0.500 hardline and Series 6 coaxial cable.

Frequency (MHz)	.500 hardline cable (dB/100 ft)	Series 6 drop cable (dB/100 ft)
5	0.16	0.58
55	0.54	1.60
211	1.09	3.05
300	1.31	3.55
450	1.63	4.40
550	1.82	4.90
750	2.16	5.65
865	2.34	6.10
1002	2.54	6.55
1218	2.83	7.21

A.1.4 Shielding effectiveness

The shielding effectiveness of coaxial cable is largely a function of the characteristics of the outer conductor. The outer conductor is essentially a metallic tube that surrounds the coaxial cable's center conductor and dielectric material. The thickness of the outer conductor (the "tube" wall thickness) is a key factor in the cable's shielding effectiveness. As mentioned previously, a phenomenon known as skin effect causes RF current to propagate on and near the surface of a metallic conductor. Skin depth is the depth in a metallic conductor at which the RF current density is about 37% of the value at the surface of the conductor. Skin depth is greater at lower frequencies, and less at higher frequencies. For example, the skin depth in a copper conductor is about 0.001 inch at 5 MHz and 0.00009 inch at 750 MHz. Assuming the outer conductor of coaxial cable is sufficiently thick relative to the skin depth for the operating

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[4] For more information on skin effect and skin depth, see the article "Skin Effect and Skin Depth" by Ron Hranac, in the Summer 2020 issue of *Broadband Library* (https://broadbandlibrary.com/skin-effect-and-skin-depth/).

frequencies of interest – and the outer conductor completely surrounds the center conductor and dielectric – the RF shielding of the outer conductor will be quite good. (Note: The thickness of the outer conductor of a commonly used 0.500 hardline coaxial cable is 0.024 inch). Well, the shielding effectiveness will be quite good unless the cable's shielding integrity is compromised for some reason: environmental damage, tree limb abrasion, rodent damage, loose connectors, etc. Section A.2.1 discusses shielding and shielding integrity in more detail.

A.1.5 DC loop resistance

Another property of coaxial cable that is of interest to cable operators is DC loop resistance. Because the center conductor and outer conductor are metallic, they have some resistance per unit length. Coaxial cable manufacturers specify that resistance over a given length such as 1,000 feet. For example, the outer conductor resistance of 1,000 feet of a commonly used 0.500 inch hardline coaxial cable is 0.37 ohm, and the resistance of 1,000 feet of the same cable's center conductor is 1.35 ohm. The DC loop resistance the sum of those two values, or 1.72 ohm. (Imagine taking a 1,000 ft. length of coaxial cable, shorting the outer conductor and center conductor at one end, and measuring the resistance between the center and outer conductors from the other end. The measured value is the DC loop resistance.) The reason coaxial cable's DC loop resistance is of interest to cable operators is because that parameter is used when doing cable network line powering calculations for the 60 volts or 90 volts AC carried in the cables to operate nodes and amplifiers.

A.1.6 Velocity of propagation and velocity factor

One of the parameters often found on a spec sheet for coaxial cable is velocity of propagation (VoP). For instance, the published nominal VoP for a widely used Series 59 headend cable is 85%, and a common .500 hardline cable has a published VoP of 87%. What do these numbers mean, and where do they come from?

According to the National Institute of Standards and Technology the speed of light in a vacuum is 299,792,458 meters per second, which works out to 983,571,056.43 feet per second or 186,282.4 miles per second. The reciprocal of the speed of light in feet per second is the time it takes for light to travel 1 foot: 1.02E-9 second, or 1.02 nanosecond. In other words, light travels a foot in a vacuum in about a billionth of a second. Light is part of the electromagnetic spectrum, as is RF. That means RF travels at the same speed that light does in a vacuum.

VoP is the speed at which an electromagnetic wave propagates through a medium such as coaxial cable, expressed as a percentage of the speed of light in a vacuum. Based on this definition, RF travels through the previously mentioned Series 59 headend cable at 85 percent of the speed of light in a vacuum, or 836,035,397.97 feet per second. RF travels through the .500 hardline cable at 87 percent of the speed of light in a vacuum, or 855,706,819.09 feet per second. The time it takes for RF to travel through 1 foot of each of these cables is 1.20E-9 second (1.20 nanosecond) and 1.17E-9 second (1.17 nanosecond) respectively.

Velocity factor is VoP expressed in decimal form. For instance, the Series 6 headend cable's 85% VoP equals a velocity factor of 0.85. (Note: Transmission line theory often uses velocity factor instead of VoP. The ratio of the speed of what are called "transverse electromagnetic waves" in a vacuum to their speed in a dielectric gives a parameter called the index of refraction. The reciprocal of index of refraction is the velocity factor.)

What happens if something degrades or damages coaxial cable's dielectric? A good example is the presence of water in the dielectric, which will change the VoP (and velocity factor). If the VoP is changed from the cable's original value, the cable's impedance and attenuation will be affected.

A.2 Cable and Component Performance

A.2.1 A Closer Look at Shielding and Shielding Integrity

Legacy hybrid fiber/coax, or HFC, architectures are very capable of delivering high quality service to our customers today, provided that the networks are properly maintained and aligned in accordance with what are known as the five “pillars” of plant maintenance.

The pillars of maintenance that we are referring to are: shielding integrity, impedance, optical link optimization, amplifier set-up and alignment (unity gain, where applicable), and power plant. These pillars of maintenance can be considered somewhat analogous to the layers in the OSI model[5] in data network communications. While the elements in the maintenance pillars aren’t necessarily dependent on each other like the layers in the OSI model, they are all critical components to a properly operating HFC network or node service area.

The first of the pillars that we are going to deep dive into is shielding integrity, sometimes referred to as shielding effectiveness. Shielding integrity, or rather shielding effectiveness is defined as: The level difference in dB between the RF energy coupled with and without the shield in place, therefore, measuring the RF shielding effectiveness of the device under test (DUT). In other words, how effective is the shielding in coaxial cable in keeping unwanted signals OUT, and desired signals IN? There is a minor distinction between the two that need to be emphasized. Shielding effectiveness is a figure of merit assigned to a component that is being tested in its new or ideal state. Shielding integrity is a value assigned to a component in its current condition. As we know, many components in our systems have been in place and exposed to harsh environmental conditions for many years. Their shielding integrity values will naturally degrade over time because of expansion and contraction due to temperature variation, exposure to UV radiation, environmental conditions, vibration, or flexure due to wind, etc.

Every node’s service area is a very intricate circuit, comprising thousands of individual components, and the shielding effectiveness of that “circuit” is a composite and cumulative measurement of all those components combined.

A.2.2 Shielding effectiveness in coaxial cables

Both hardline (trunk and feeder) cable, and soft (drop) cables have shielding effectiveness ratings. Hardline cables, for example, when not impaired, can withstand a tremendous amount of external energy without allowing ingress. In Figure 69, effectiveness is measured across a wide range of frequencies (the horizontal axis), with the shielding effectiveness in the vertical axis., Note that shielding effectiveness can vary by frequency. The higher the shielding effectiveness value in decibels, the better the cable’s shielding performance. This particular cable has a measured shielding effectiveness that exceeds 120 dB across the frequency range being tested. This cable was measured with a hardline connector properly installed, so we can assume that this cable and connector combination has at least 130 dB of shielding effectiveness when considered together.

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[5] Open Systems Interconnection (the standard’s full name is “ISO/IEC 7498-1 Information technology – Open Systems Interconnection – Basic Reference Model: The Basic Model – Part 1”). The OSI model’s seven layers include the physical layer (Layer 1), data link layer (Layer 2), network layer (Layer 3), transport layer (Layer 4), session layer (Layer 5), presentation layer (Layer 6), and application layer (Layer 7).

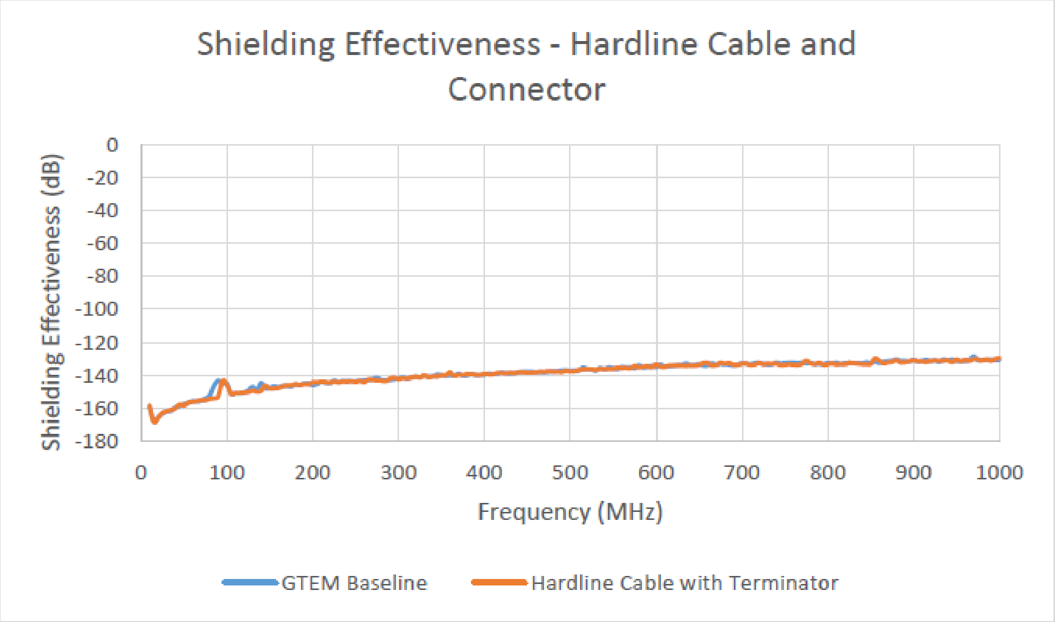


Figure 69 – Hardline cable and connector shielding effectiveness

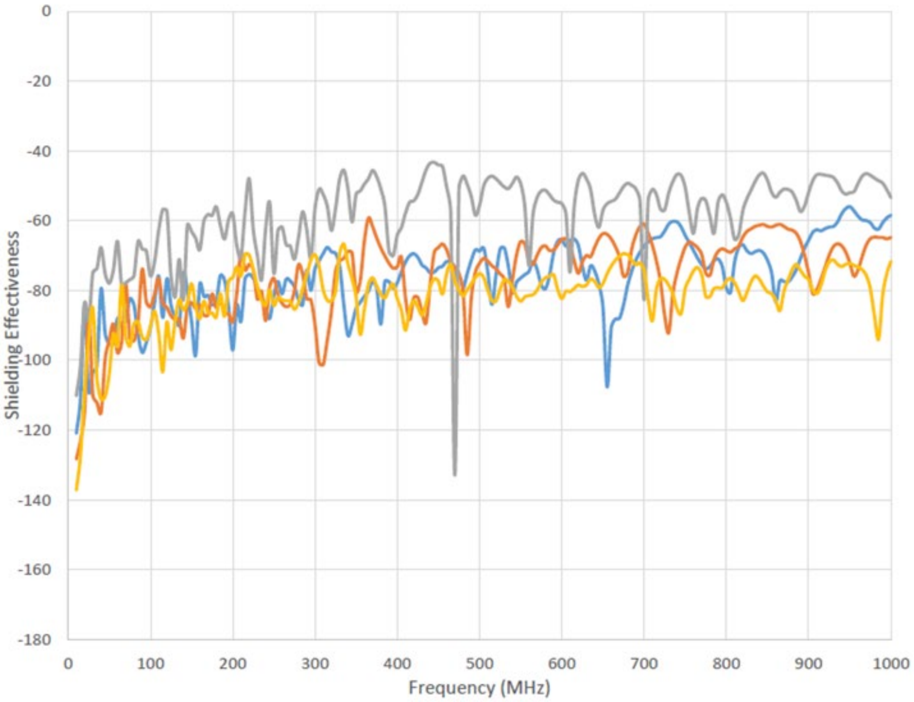


Figure 70 – Shielding effectiveness of four different tri-shield drop cables after 30,000 flexures

In Figure 70, several different types of drop cable were measured for shielding effectiveness after being flexed 30,000 times in a machine designed to stress the cables. This gives us a sense of the cables' shielding after the equivalent of many years of blowing in the wind. You can see the effectiveness ratings vary from 120 dB to 50 dB between various cables at different frequencies. In an unflexed condition, tri-shield drop cables routinely have between 100 dB and 120 dB of shielding effectiveness. In any given node's service area, you would expect to have drop cables across a wide variety of these conditions, and possibly worse.

A.2.3 Shielding effectiveness in connectors

Shielding effectiveness in drop connectors has been an area of much attention and development, especially over the past 10 years or so. The newest drop connectors are designed, engineered and constructed to maintain their shielding effectiveness and ground plane, even when not properly tightened. We refer to these as "continuity" connectors. Hardline, or trunk and feeder connectors do not have the same "continuity" design as drop connectors, and therefore are more susceptible to improper installation.

In a typical coaxial connector, the nuts are designed with a hexagonal shape, or having six sides. So, each "flat side" equals 1/6th of a complete circle, or 60 degrees. Figure 71 illustrates the shielding effectiveness of a hardline connector, loosened from tight in 60 degrees increments, or 1/6th of a turn each time. As previously mentioned, hardline connectors have very high shielding integrity values, but those values deteriorate rapidly when loosened. In this example, one complete turn reduced the SE by a factor of a million (RF power-wise), or more than 60 dB depending on the frequency.

	Shielding Effectiveness (dB) with Connector Loosened by (x) Degrees of Rotation						
Freq (MHz)	**Tight Connectors**	**60°**	**120°**	**180°**	**240°**	**300°**	**360°**
650 MHz	-123.7	-119.6	-86.9	-84.8	-65.0	-63.9	-63.2
750 MHz	-125.7	-122.2	-92.3	-92.5	-81.3	-69.5	-62.5
600-695 MHz	-123.5	-124.3	-88.8	-87.2	-66.8	-66.3	-65.2
700-795 MHz	-125.1	-125.4	-92.7	-91.4	-76.4	-66.8	-62.2

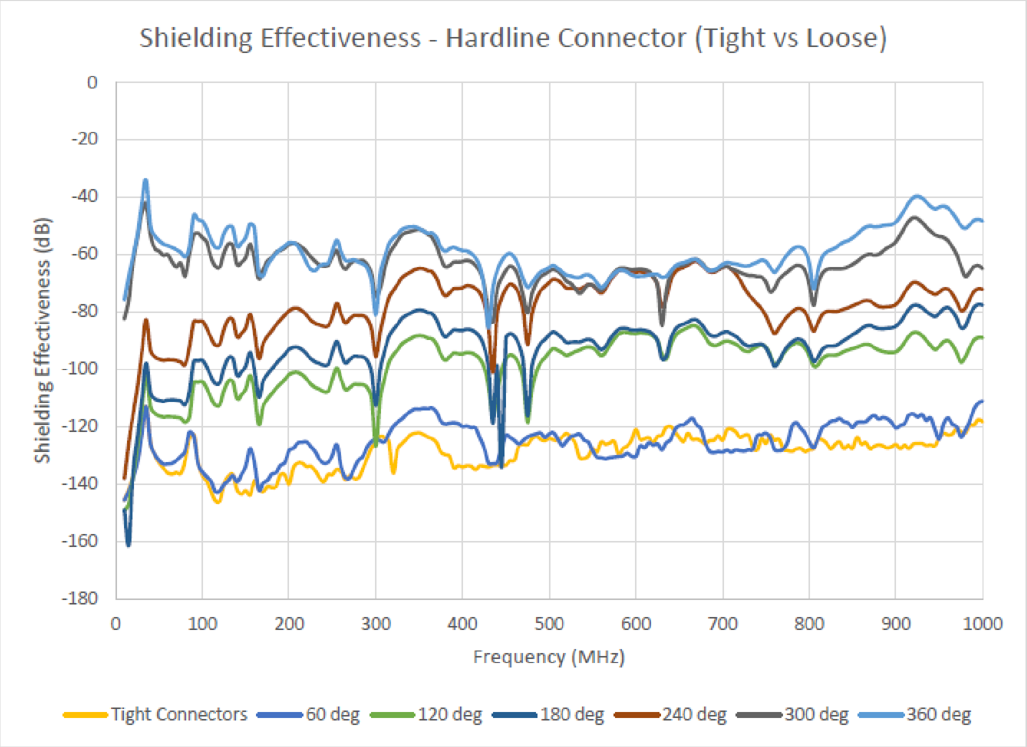


Figure 71 – Shielding effectiveness impact when loosening hardline connector nut 1/6th of a turn at a time

A.2.4 Shielding effectiveness in passive devices

There are splitters, couplers, taps and power inserters in both the drop systems and in the trunk and feeder systems. These devices also have a shielding effectiveness (SE) value, which can vary greatly depending on the application.

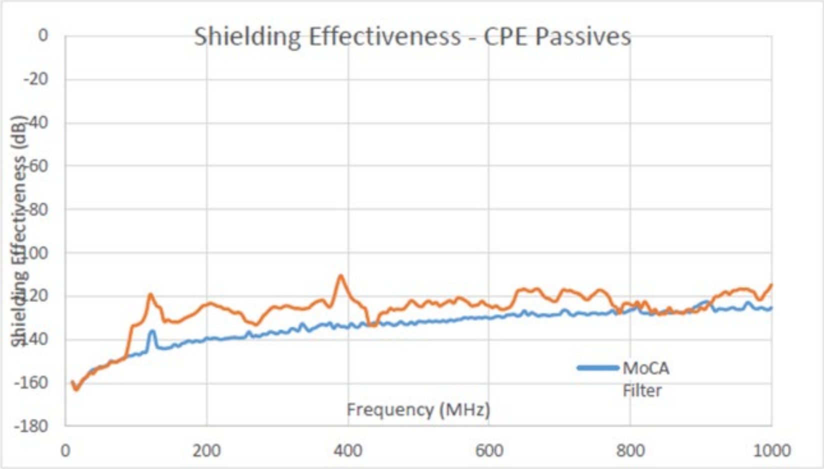


Figure 72 – Shielding effectiveness of drop splitters with properly tightened connectors

In Figure 72, a MoCA splitter and two-way drop splitter are overlaid on the same display. Both of them have a high shielding effectiveness rating with the connectors properly tightened, and are sealed units, which *should* not have any additional installation complexity, or craft sensitivity, beyond ensuring that the connectors attached to them are tight.

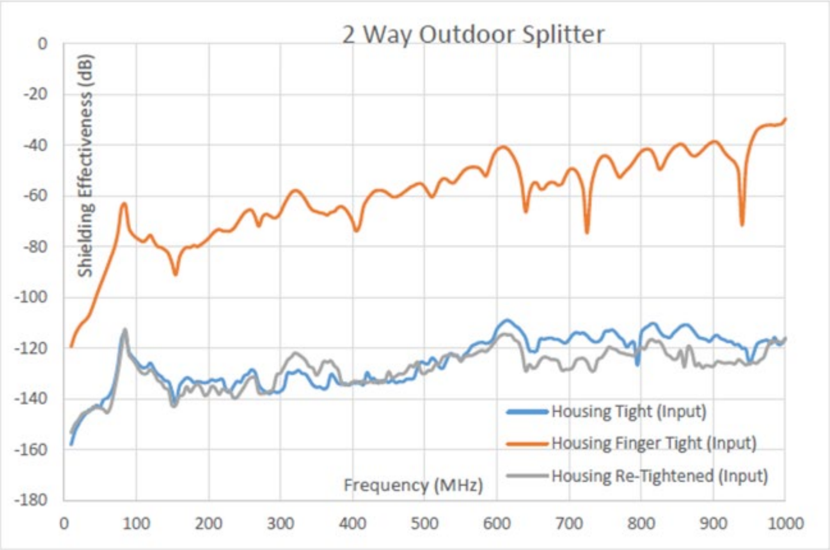


Figure 73 – Hardline splitter with loose faceplate

In Figure 73, the hardline splitter also has an SE value greater than 110 dB, unless the splitter faceplate isn’t properly torqued. If the splitter faceplate isn’t properly tightened, there can be a reduction of shielding as much as 90 dB. Untightened tap faceplates can exhibit the same loss of shielding when not properly tightened and can be further impaired if the unused tap ports are not properly terminated.

Line power inserters follow a similar trend with other line passives in shielding effectiveness where the tightness of the faceplates are concerned. Drop-style power inserters can also be used with house amplifiers and present a significant vulnerability to the SE of a drop network.

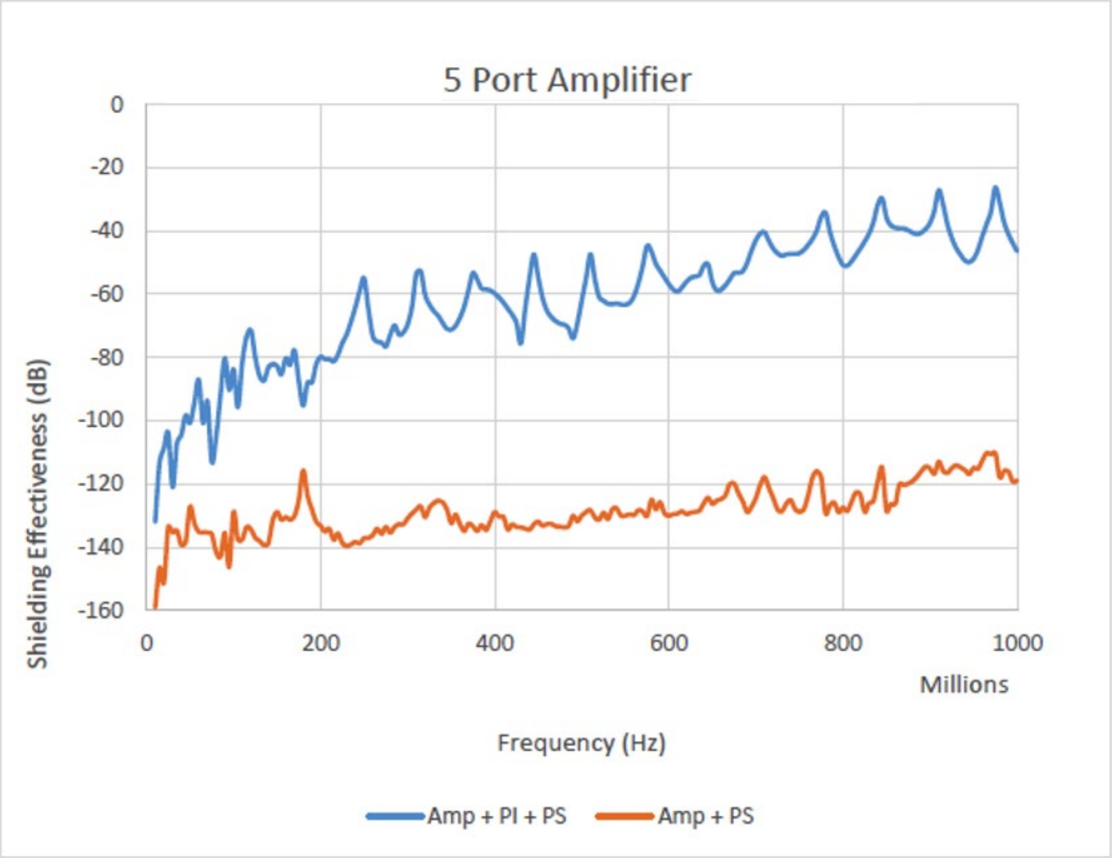


Figure 74 – House amplifier with external power inserter

In this example (Figure 74), though extreme, the use of a poorly shielded power inserter, when coupled to a house amplifier, can reduce the SE value of the amplifier by 80 dB!

So, what does all this mean? You've heard it said that a chain is only as strong as its weakest link. Coaxial cable networks are very much the same as that proverbial chain. Each component in the network has a shielding integrity value that can affect the performance of the entire network. In our roles, we tend to think of this primarily in terms of upstream ingress, where one drop cable with impaired shielding integrity can allow ingress to impact the performance of an entire node's service area. It is also probable that a shield defect in a drop cable can cause any number of impairments in a customer's video, voice or internet services. The over-the-air environment is full of signals that are in the same frequency ranges as our CATV signals. If the shield is impaired or defective, those signals can enter the cable network, and be transmitted along with the intended cable signals, ultimately corrupting both.

How do we ensure the shielding integrity of our cable networks? Well, the simplest and most widely accepted practice is to intentionally measure for signal leakage or egress. The shielding values we have spent so much time defining as the ability to keep unwanted over-the-air signals out of the network, similarly, will determine how much of the cable network's signals leak into the over-the-air environment. As some of the previous figures have shown, the shielding integrity values can be frequency dependent. Therefore, measuring leakage at various frequencies can be useful in finding shielding impairments in the various types of equipment that make up the coaxial cable plant, or network. Doing a leakage rideout in a node's service area and investigating every detectable leak >5 microvolts/meter at any frequency is a great way to identify any shielding defects that *may* be present in the plant. Once these areas of shielding defect are identified, there are various types of test equipment available to isolate the component or span that needs to be repaired or replaced. Leakage receivers that look for active downstream channels or test signals, or "pressure testers" that work in conjunction with a high-level transmitter, are highly effective in various portions of the network.

Why is shielding integrity so important, you might ask? Why have we spent so much time defining the shielding values of various components? More and more communications and entertainment signals are being transmitted over-the-air, and in frequencies that are also used by CATV systems. This is a trend that will certainly continue in the coming years. If the shielding integrity of the coaxial network is compromised, our ability to deliver high quality services to our customers is significantly inhibited and will result in an increased volume of negative customer transactions, like service calls, line problems, or outages.

The good news is, that shielding integrity problems are relatively easy to find and fix and can result (when repaired) in immediate improvements in the quality of service to our customers.

We aren't going to go into the reasons why certain types of shielding defects will leak or cause ingress at different frequencies, but there are many good publications that are available to provide additional details.

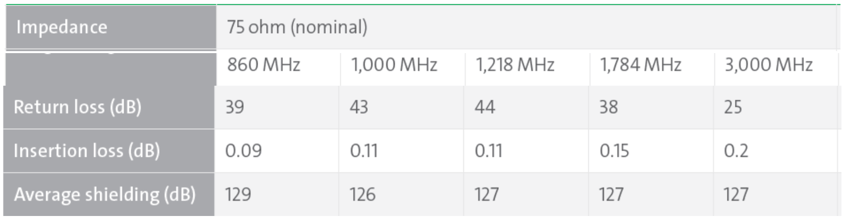
A.2.5 Impedance Mismatches and Reflections

Now that we have previously defined what impedance is, and some things that can affect it, let's dig into some of the routine causes of impedance mismatches. We are going to break these into hardline cables and drop cables.

Hardline cables: Trunk and feeder cable outer conductors (sheath/shield) are made of a semi-rigid aluminum, which is susceptible to damage in any number of ways. Cables can be damaged during the construction phase, while the cable is being pulled off the reel, through the pulley, shaped or lashed. The coax can be stretched, kinked, crushed, or otherwise physically deformed. Post construction, the care and maintenance of the hardline is particularly vulnerable near the pole, where the expansion loops are formed, and are subject to direction changes. Straps that are overly tightened, can prevent the natural travel of the cable during expansion and contraction of the cable (due to temperature changes). These stress points can result in kinks and bulges in the hardline, which over time can result in breaks. Lashing wire that is broken can allow the cable to sag or stretch, placing stress on the cables near the attachment hardware at the pole. Having properly lashed spans allows the cable to be properly supported across the entirety of the span. Branches or limbs s that fall on the cable can cause dents or tears, power lines that come in contact our cable, can cause burns or holes in the hardline plant. The outside plant environment is rich with potential causes of damage to the cable's shield or geometry. Let's not even talk about squirrels (Figure 75). In many cases shield integrity defects are or can become impedance mismatch problems.

Figure 75 - Coaxial cable destroying rodent

Earlier we mentioned that the connection of various RF interfaces can result in impedance mismatch. These interconnects happen at every hardline device: nodes, amplifiers, taps, couplers and splices. We know that every component is not exactly 75 ohms, so there are natural mismatches built into every one of these connection points. It is important then, that the splicing and construction of hardline cable and connectors be given the utmost care, to prevent any craft errors that would cause any potential impedance mismatches.



Impedance	75 ohm (nominal)				
	860 MHz	1,000 MHz	1,218 MHz	1,784 MHz	3,000 MHz
Return loss (dB)	39	43	44	38	25
Insertion loss (dB)	0.09	0.11	0.11	0.15	0.2
Average shielding (dB)	129	126	127	127	127

Figure 76 - Return loss values of a hardline connector at various frequencies

A.2.6 Connectors

While we usually think of impedance as a factor in the cable based on the ratio between the center conductor and the shield, we often overlook that connectors are subject to the same physics. Our hardline connectors, 90º degree angle adapters, extensions and even active/passive receptacles all require care and handling when it comes to connectorization and build quality. Often times we fail to see the geometric relationship in say, a 90º degree adapter. Leaving a center conductor too long in a 90º junction will cause an impedance mismatch even if the pin is not touching the shield (Figure 77). Remember that the impedance is largely dictated by the ratio of the center conductor to the shield.

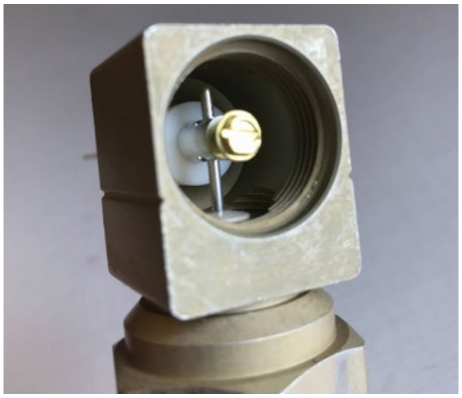


Figure 77 - 90-degree adapter

In a similar fashion center pins that are too long in an amplifier *may* also cause impedance mismatch. In this next example notice how the plastic keeper is pushed up against the connector socket (Figure 78). The center conductor is clearly too long in this instance causing an impedance mismatch. When the pin is cut to length you *should* be able to slide a credit card between the end of the plastic keeper and the connector socket. In all cases the center conductor length *should* follow the guidance of the equipment manufacturer.

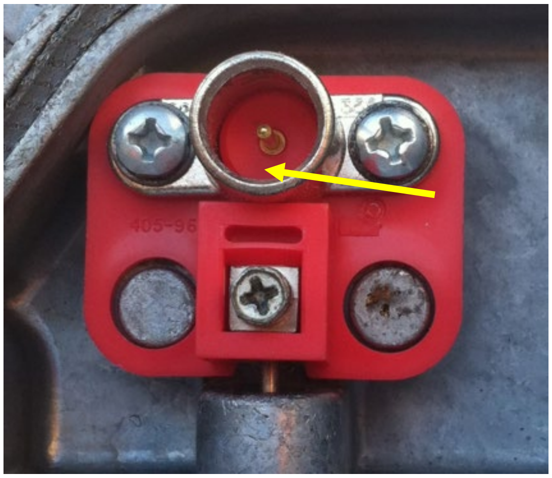


Figure 78 - Seizure assembly mechanism

Many, if not all of the vendor product guides will cover construction specifications typically including pin length (Figure 79) and in some cases torque values. Following these measurements is very important for optimum results.

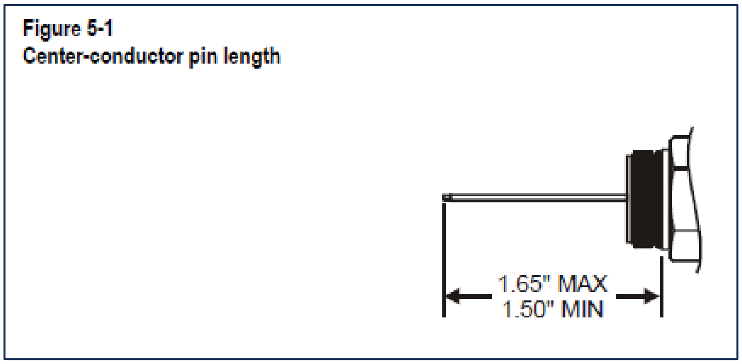


Figure 79 – Center-conductor pin length

A.2.7 Drop Cables

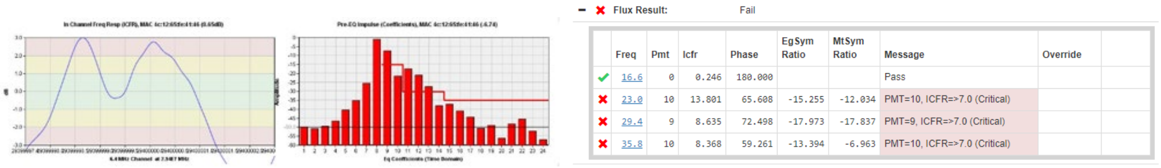
Like the interconnects in the hardline plant, the drop systems are made up of many different components: ap ports, bonding blocks, cable segments, splitters, amplifiers, wall plates, etc. Each of these components can introduce a mismatch, if either the outer conductor, or inner (center) conductor are not precisely connected through them. Further, all these interfaces need to be properly tightened. A perfectly installed F-connector can cause an impedance mismatch if not properly tightened. Cable routing is another common cause of a mismatch. We've all seen the cables pinched under doors, kinked at a 90-degree angle around a corner, or compressed by a staple or clip. Those are so common that we tend not to even consider them as problems, unless there is an impairment in the customer's services. Behind the wall plate inside the electrical box is another space that very often results in a kinked cable, which can cause an impedance mismatch. Many times, drops come unattached from the pole or home, suffer some change to the geometry, and we re-hang them rather than replace them. In order to maintain that nominal impedance, it is best to replace those segments with a new piece of cable. Figure 80 shows a cross section of a kinked cable.

Figure 80 – Cross-section of kinked coaxial cable

A.2.8 Symptoms

We have discussed what impedance is, and some common causes of mismatches. How do we identify them? We have several tools that are very good at indicating the symptoms of impedance mismatches. Several PNM tools have been around for over a decade and have been incorporated into many cable operators' regular maintenance tools. Some field meters are also excellent at identifying and isolating impedance mismatches in both the drop system and the distribution system. Using the the PNM spectrum analyzer is an easy way to reveal standing waves and notches – a common indicator of an impedance mismatch. Our PNM tools can be used to isolate the location of an impedance mismatch, Figure 81.

Since coaxial cable is a transmission line that moves RF over time and is subject to return loss degradation and reflections it is possible to measure the physical width of an impairment. Coaxial cable has a property known as velocity of propagation. Typical hardline 75 ohm cable has a VoP of 87% of the speed of light in a vacuum (when VoP is expressed in decimal form, it's called velocity factor, e.g., 87% VoP = 0.87 VF). The absence of any significant waves, suckouts or other distortions is indicative that the circuit is impedance matched. As we have learned, when a mismatch does occur, there is a resulting reflection. The periodicity (or shape) of the reflection says a lot about its mechanical properties. Short echo cavity reflections can be caused by a loose or poorly installed connector attached to a piece of CPE, as shown in Figure 81.



− ✗ Flux Result: Fail

	Freq	Pmt	Icfr	Phase	EgSym Ratio	MtSym Ratio	Message	Override	
✓	16.6	0	0.246	180.000			Pass		
✗	23.0	10	13.801	65.608	-15.255	-12.034	PMT=10, ICFR=>7.0 (Critical)		
✗	29.4	9	8.635	72.498	-17.973	-17.837	PMT=9, ICFR=>7.0 (Critical)		
✗	35.8	10	8.368	59.261	-13.394	-6.963	PMT=10, ICFR=>7.0 (Critical)		

Figure 81 – Pre-equalization frequency and time domain response

Longer echo cavities are more indicative of a longer segment of the cable network, like those found in the hardline plant (Figure 82). Other symptoms or indications that a mismatch is present in the network include: in-channel frequency response problems, as well as downstream frequency response issues, like standing waves, suckouts and frequency notches.

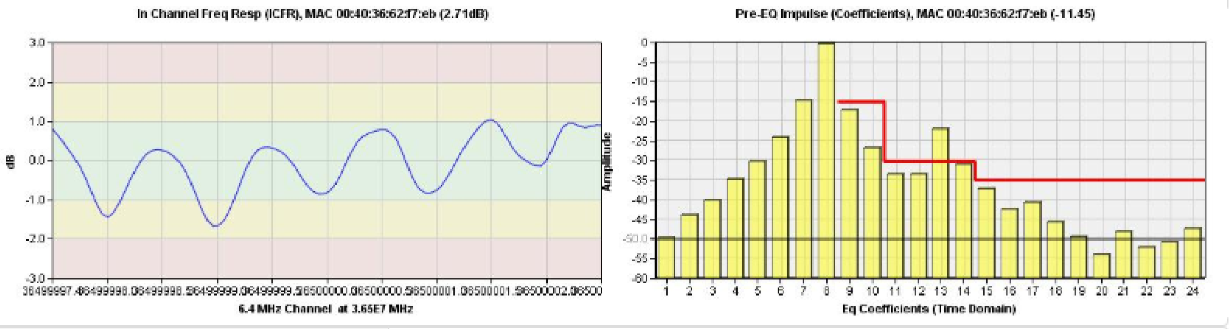


Figure 82 – 5T echo response in frequency (left) and time (right)

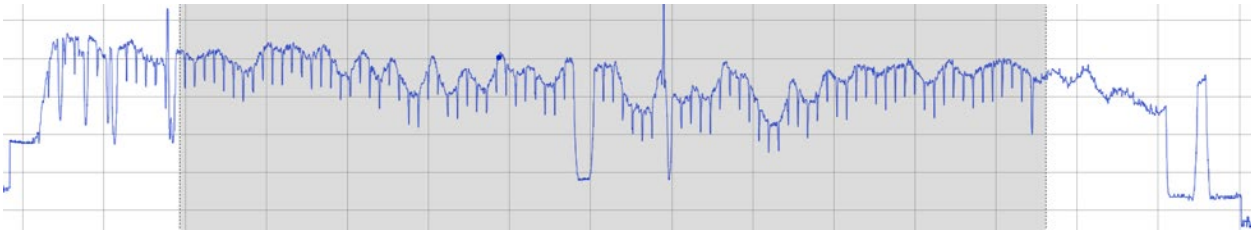


Figure 83 – Full spectrum frequency response problem caused by impedance mismatches (water)

So, wrapping this all up: It *may* seem like an uphill battle to ensure that our cable system has 75 ohm matched impedance at every point in the network. It's really not. Now that we know what we are looking for, what causes it, and how to fix it, if we look at each segment of the cable plant that we work on every day, using our eyes, intelligence tools, and test equipment, finding and fixing impedance mismatches (Figure 83) really isn't very hard.