PNM Upstream Data Analysis

A Practical Solution for Automatically Locating Upstream Noise and Ingress

A Technical Paper prepared for SCTE by

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1. Introduction

Upstream noise and ingress can pose significant challenges for cable operators in maintaining coaxial cable networks. While Proactive Network Maintenance (PNM) offers numerous advantages for optimizing cable plant performance, it has historically lacked a solution for the reactive tracking of noise. Traditional upstream noise and ingress troubleshooting processes are primarily manual, labor-intensive, and potentially affect customers' service. Introducing the Upstream Data Analysis (UDA), a capability using PNM data that has been in development for a decade. The UDA technique is designed to automatically locate upstream ingress and noise sources. By utilizing the Data Over Cable Service Interface Specification (DOCSIS®) spectrum analyzers embedded in cable modems, the UDA samples the upstream frequency spectrum near the points of ingress, rather than at the receiver. This approach enables quick identification of individual premises and drop cables contributing to upstream noise, potentially resulting in operational efficiency improvements in network maintenance. The authors will provide an analysis of the PNM UDA's capabilities, limitations, and opportunities.

2. Background of Upstream Noise on Coaxial Networks

2.1. The Noise Funnel

The following three figures and text have been adapted from "Understanding and Troubleshooting Cable Upstream RF Spectrum" [3]. Figure 1 illustrates the broadcast nature of the downstream. That is, downstream signals (purple arrows) originating in the fiber optic node (node) are transmitted throughout the coaxial cable feeder portion of the network. In this diagram, the downstream radio frequency (RF) (circled purple) is being measured at the cable modem locations. Note that the measurements exclude the upstream portion (circled green) of the RF spectrum, being blocked by the modem's diplex filter.

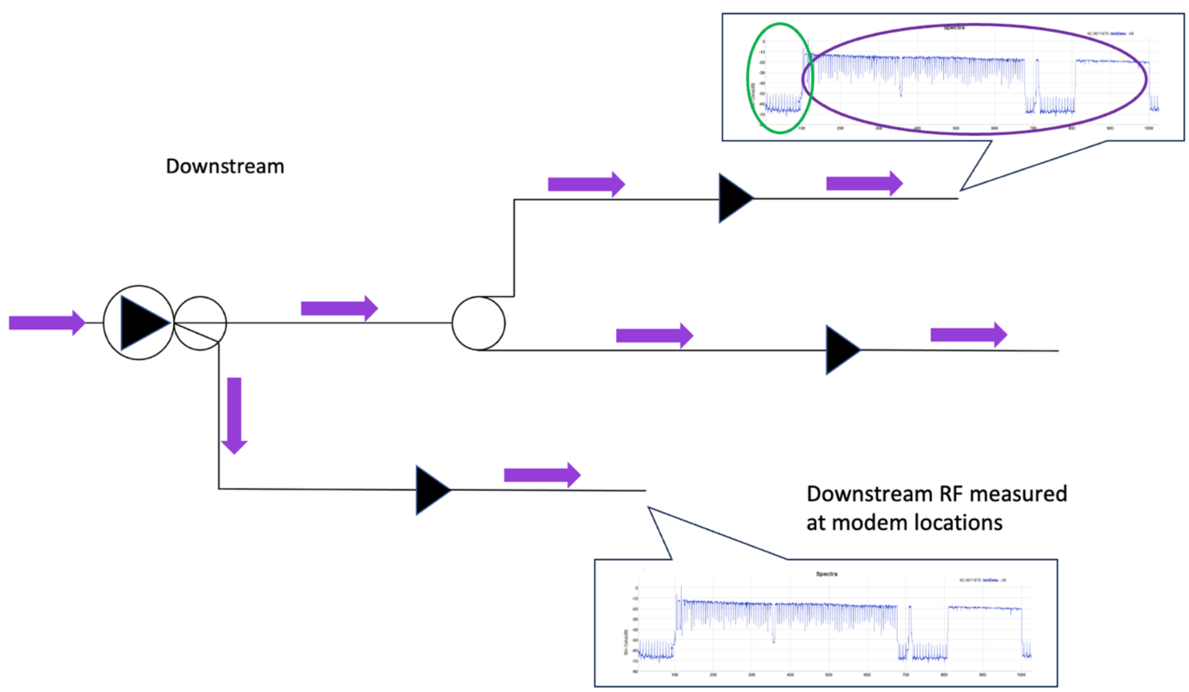

Figure 1 – Broadcast Nature of the Downstream

Figure 2 graphic illustrates upstream operation. Signals coming from subscribers in various parts of the node's service area (blue, green, and red arrows) travel upstream toward the node. Those signals can originate in cable modems, set-tops, status monitoring transponders, and other devices. (Note: In practice, some sort of time division multiplexing is typically used to prevent upstream signals on the same frequencies from interfering with one another. The intended signals operate with grants, using frequency division multiplexing and/or time division multiplexing, so that at any one time and frequency only one intended signal is present.) This figure illustrates the upstream measurements and analysis being done in the receiver. In this typical example, the upstream RF spectrum capture, SNR/MER and FEC, are all measured at the receiver.

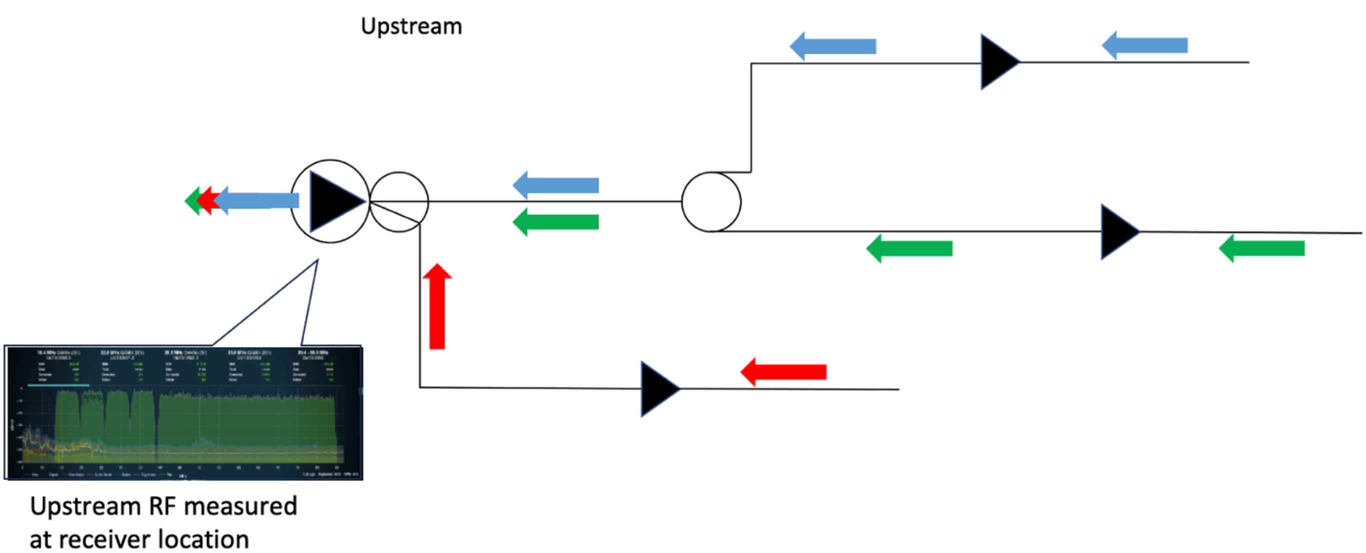

Figure 2 – Upstream Operation

In both the upstream and downstream directions there are intended signals, and undesired signals. Examples of undesired signals would be amplifier noise, ingress, or spurious emissions. Figure 3 illustrates interference of some kind (see the lightning bolt images in Figure 3) that is originating in the lower part of the node's service area. Note the interference is not present in other parts of the coax plant, just the feeder amplifier at the bottom of the graphic. In the upstream direction, all the undesired signals in the upstream frequency spectrum travel to the node – that is, they "funnel" toward the node. Once the interference (lightning bolt in the graphic) reaches the node it affects all signals coming from all parts of the node's service area.

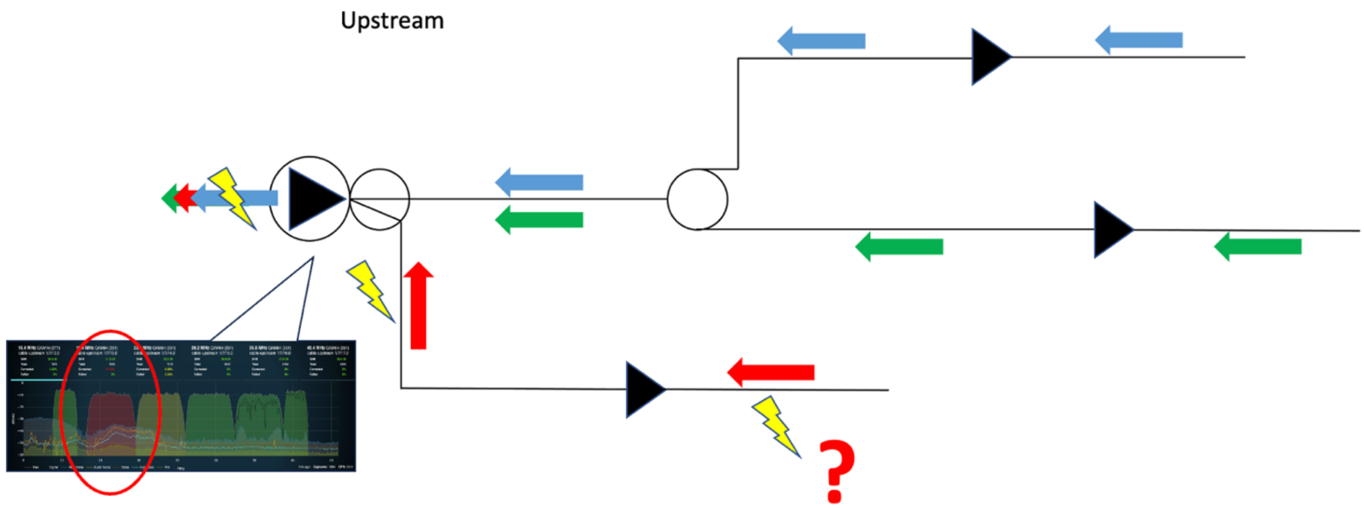

Figure 3 – Reverse Funneling

2.1.1. *Additive Noise, multiple ingress points*

The examples in Figure 1, Figure 2, and Figure 3 show a simple Node + 1 architecture. In other words, there is a maximum of one amplifier in cascade after the node. Calculating downstream carrier-to-noise ratio is simple, considering just one amplifier after the node. In the upstream direction, the CNR calculation must include the contribution of all return actives in the node's service area. In the graphics, there are three amplifiers after the node, so all three must be accounted for when calculating upstream CNR. This is, of course, related to the reverse funneling just discussed. (For more about calculating downstream and upstream CNR, see SCTE 270 2021r1 Mathematics of Cable.) In this figure, note that the upstream ingress is being detected and measured at the receiver. At this point of measurement, there is no way to discriminate the source of the ingress.

2.2. Ingress vs. Egress – Reciprocity

Antenna reciprocity is a fundamental principle of electromagnetics that asserts the transmission and reception characteristics of an antenna are identical. In the context of a coaxial cable network, this principle becomes crucial for understanding ingress and egress. Ingress refers to unwanted signals entering the network, which can cause significant noise and degrade network performance. On the other hand, egress, or signal leakage, refers to the unintended radiation of signals from the network. Antenna reciprocity helps to link these two concepts, as it implies that a point on the network that is vulnerable to ingress is equally likely to have signal leakage or egress. Thus, identifying ingress sources can also help determine potential areas of signal leakage and allow for appropriate remedial actions to ensure optimal network performance.

2.3. Troubleshooting Process

The process of tracking upstream noise in a coaxial cable network typically starts at the node or headend, where the technician begins by identifying and assessing the noise level in the upstream spectrum. This can be done using specialized network diagnostic tools and monitoring software. Once an abnormal noise level is detected, the technician moves down the network, systematically isolating each segment.

Isolation typically involves disconnecting or disrupting the service for each segment one by one. After each disconnection, the technician will check the noise level at the node again. If the noise level decreases significantly or disappears, the disconnected segment is likely to be the source of the noise. If the noise level remains the same, the technician continues the process with the next segment.

This manual troubleshooting method can indeed be time-consuming and disruptive to the network services, especially if the network is extensive. It also requires significant technical expertise to accurately interpret the readings and correctly identify the noise source. Hence, newer methods that leverage automated diagnostic tools and advanced signal processing techniques can be adopted to increase the efficiency and accuracy of the process. These automated systems allow for continuous monitoring and can even predict potential noise issues based on historical and real-time data, possibly reducing the need for manual intervention.

2.3.1. Service Impact

When a coaxial network segment is isolated during troubleshooting, all DOCSIS connections on that segment are disrupted. This disruption has several impacts on the operation of cable modems.

One frequent problem is upstream T3 timeouts. In normal operation, a cable modem sends periodic "ranging" requests to the cable modem termination system (CMTS) to ensure optimal communication. However, when the network is interrupted, these requests cannot reach the CMTS, which results in a T3 timeout error. This signifies that the modem did not receive a response to its ranging request within a specified time.

Similarly, ranging response failures can occur. These happen when the cable modem sends a ranging request but either does not receive a response, or the response is incorrect or malformed. This is another indication that the modem cannot communicate properly with the CMTS.

Eventually, these problems lead to the cable modem re-initializing its connection. This process involves modem resetting and attempting to re-establish communication with the CMTS. This includes another round of ranging requests and responses, setting of upstream and downstream frequencies, and synchronization of time. It is a process that can be time-consuming and disruptive for end-users, particularly if it happens frequently.

In summary, interruptions to a coaxial network can have significant impacts on DOCSIS connections. This can lead to a range of problems, including upstream T3 timeouts and ranging response failures, to cable modems needing to re-initialize their connections. Such disruptions can negatively affect network performance and customer satisfaction, emphasizing the importance of efficient and accurate network troubleshooting.

2.3.2. Upstream Noise Mitigation

Mitigating noise ingress sources in a coaxial cable network is a crucial part of maintaining optimal network performance. Once the source of noise ingress has been localized, various techniques can be implemented, each having different implications to consider.

2.3.2.1. Noise Filters or Traps

These high-pass filters are designed to block the lower frequency spectrum where noise typically resides, allowing only the higher-frequency upstream communications from cable modems to pass. However, the use of noise filters can limit the available spectrum for each subscriber, potentially leading to channel congestion on the reduced set of channels that are permitted to pass.

2.3.2.2. Attenuation or Pads

By reducing the power level of signals entering the network, these pads can lessen the amount of noise infiltrating the system. But they also reduce the power levels received at the modem, necessitating additional transmit power to ensure the signal reaches the intended receiver at the desired level. This approach can lead to insufficient signal power and reduced performance.

2.3.2.3. Disconnecting Noisy Connections

"Hot drops" are connections left by previous customers that, though no longer active, can still inject noise into the system. One straightforward mitigation technique is to completely disconnect these noisy connections. While this solves the immediate noise problem, it complicates the process when a customer wants to re-establish service, requiring a truck roll for reconnection.

2.3.2.4. Automated Profile Management Application (PMA)

This technique allows customers to operate with minimal upstream errors by dynamically adjusting the modulation profile of the upstream channels. While this increases the robustness of the connection, it reduces its capacity due to the lower modulation scheme. PMA is a balancing act between network stability and network capacity. If in time, that the maximum network capacity becomes reached, the noise will ultimately require mitigation to regain that capacity.

3. Spectrum Capture and Analysis

Full Band Capture (FBC) is an important feature used in DOCSIS PNM tools. It enables the cable modem to capture and digitize the entire spectrum available to its receiver, not just the DOCSIS data channels. This allows for a more comprehensive and in-depth analysis of network conditions, including noise and interference issues.

It works by taking advantage of built-in capabilities within many modern cable modems. These modems have an integrated tuner that can rapidly scan the entire downstream frequency range, digitize the signal, and then perform a fast Fourier transform (FFT) on the captured data. This process effectively converts the time-domain signal into the frequency domain, making it possible to analyze the signal's frequency spectrum and identify many impairments.

Once the digitized data has been captured and transformed, it is sent back to the network operator's PNM system. The system can then analyze the data in real-time to identify and diagnose a wide range of network issues, including ingress noise, micro-reflections, and frequency response issues.

3.1. Downstream Frequency Spectrum and Diplex Filters

FBC primarily operates on the downstream spectrum, due to the architecture of a DOCSIS system which can rely on diplex filters for frequency separation.

In a DOCSIS system, the downstream (from the cable operator to the user) and upstream (from the user to the cable operator) data transmissions occur over separate frequency bands. This separation allows simultaneous transmission and reception of data. The device responsible for managing this separation is the diplex filter.

A diplex filter is designed to direct the higher frequency downstream signals to the downstream path (receiver) and lower frequency upstream signals to the upstream path (transmitter). Consequently, the diplex filter effectively isolates the downstream and upstream paths from each other, ensuring that signals intended for one path do not interfere with the other.

Given this arrangement, FBC primarily works on the downstream spectrum because the downstream receiver is shielded from the upstream signals by the diplex filter. The receiver has a broader frequency range than it can capture, and this range contains all the downstream signals that the modem is designed to receive. Once captured, the modem then digitizes the received signals and analyzes them to monitor and assess the quality of the network's downstream spectrum. As a result, FBC provides a comprehensive view of the network's downstream health, which can be invaluable in troubleshooting and proactively managing the network.

3.2. Upstream Frequency Spectrum

While the upstream spectrum is traditionally blocked by the diplex filter from reaching the downstream receiver, advances by DOCSIS receiver chip and modem manufacturers have allowed for limited upstream spectrum analysis. These techniques enable an assessment of the upstream spectrum, providing valuable information from then end-of-line locations in the network and thus contributing to a more comprehensive analysis of the overall network health and localization of ingress sources.

There are diverse ways of implementing spectrum capture from frequency regions that are obscured by filters. These may include additional receivers and RF paths, software, timing, and other methods outside this document's scope.

3.3. Attenuation

Attenuation in coaxial cables refers to the reduction in signal strength as the signal propagates through the cable. This attenuation is influenced by multiple factors, including the frequency of the signal, the length of the cable, the type of cable used, and even the temperature. In general, higher frequencies suffer more attenuation than lower frequencies over the same distance.

As a result of this frequency-dependent attenuation, spectrum measurements taken at different points within the network can look quite different, even if the source of the signal is the same. For example, a high-frequency noise ingress signal that is strong at the point of entry into the network might be significantly weaker when measured further along the network due to the higher attenuation of high frequencies. Conversely, a low-frequency signal might appear consistent in strength across multiple measurement points.

Moreover, the effect of attenuation can also vary based on the specific location of the measurement relative to the point of ingress. If the measurement is taken closer to the point of ingress, the impact of the noise source might be higher due to less distance for attenuation to occur.

Therefore, understanding the impacts of attenuation is crucial for accurate network troubleshooting. Knowing how signal strength changes with frequency and distance can help network technicians to pinpoint the source of noise ingress, determine the severity of the issue, and select the most appropriate mitigation strategy.

3.4. Port-to-port Isolation

Port-to-port isolation is an essential aspect of managing signal integrity in a coaxial RF network. Taps, which are used to distribute signals to individual customers, are specifically designed to have port-to-port isolation. This means they can reject noise or unwanted signals from traveling across input ports, limiting their potential to interfere with other parts of the network.

In the context of a coaxial RF network, when a signal, including any potential noise or ingress, arrives at a tap, it is split into different paths. Each path corresponds to a different output port that is connected to a customer's drop cable. The port-to-port isolation feature of the tap ensures that signals (and potential noise or ingress) on one output port do not interfere with the signals on the other output ports.

In addition to splitting the downstream signals, taps also combine upstream signals from multiple customers. These upstream signals are then sent back towards the node or headend. Here again, port-to-port isolation plays a key role. It allows each customer's upstream signals to be combined without being contaminated by ingress or noise from the other output ports.

Port-to-port isolation can affect measurements taken at various locations within a network. For example, if you measure the signal at a particular tap output port, the measurement will not be significantly affected by noise or ingress entering the network through the other output ports due to the isolation. This means that localized noise issues can be more accurately diagnosed and addressed without being masked or confounded by noise issues on other parts of the network.

So, port-to-port isolation is a crucial mechanism that enables UDA to localize noise sources by helping segment the measurements.

4. UDA Theory of Operation

4.1. Why is this Important?

As previously discussed in Section 2.1, the upstream noise funneling nature of our frequency-divided RF network can be challenging to troubleshoot and repair. Section 2.3 explains the operational practices required to maintain this return spectrum. Collectively, the upstream noise localization and mitigation efforts represent a sizable portion of network maintenance activities for cable operations. By improving the ability to locate these noise sources, cable operators can offer more reliable service, higher capacity, and faster speeds, while improving the operational efficiency for our network maintenance technicians.

4.2. Detection Closest to the Point of Ingress

The DOCSIS PNM specification for FBC does not limit the analysis of upstream RF spectrum from the cable modem’s measurements. However, the presence of the diplex filter in some modem designs precludes the upstream spectrum from being measured using the downstream receiver. This of course, is intentional to protect the sensitive downstream receivers from being exposed to the upstream transmitter’s burst energy. Given the low power of the cable downstream RF energy levels, this most certainly would create a problem in some modem designs. However, as described in Section 3.1, there are some cable modem designs which have been implemented in ways that facilitate the measurement and cable modem’s reporting of the upstream spectrum.

Having the benefit of port-to-port isolation and attenuation properties of the coaxial cable system, these factors can work together as a solution to localize upstream ingress in certain conditions.

5. UDA Sensitivity and Performance

To better understand the potential benefits and limitations of using UDA for localizing upstream noise sources, we must first characterize the sensitivity and performance of the UDA implementations.

5.1. Setup

Figure 4 shows the RF signal path including source (outlet), splitters (including a 2-way and a 4-way splitter), two spectrum analyzers and full band capture compliant cable modems.

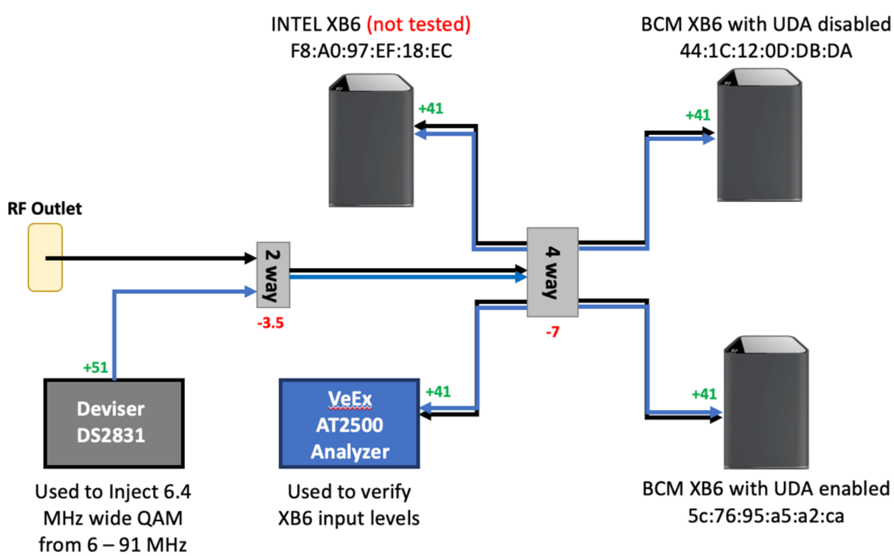

Figure 4 – Spectrum analysis test setup

A flat, 6.4 MHz SC-QAM (single carrier quadrature amplitude modulation) input signal with an RF level of 41 dBmV was achieved at the input of each spectrum analyzer and each XB6 cable modem. The RF spectrum was tested over a frequency range of 6MHz – 91MHz. Figure 5 shows the max hold signal level over the course of the entire test to ensure the input to each device was flat across the whole frequency range tested.

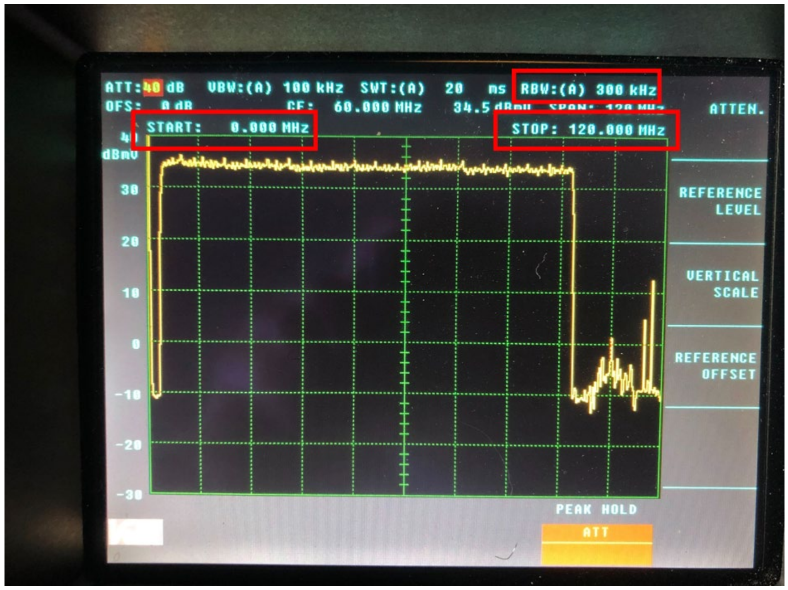

Figure 5 – Spectrum analyzer max hold from 0 MHz to 120 MHz with energy being generated in 6 MHz to 91 MHz

5.1. Measurements

In Figure 6 the UDA enabled devices show 15 – 38 dB more sensitivity, depending on frequency, compared to the same devices with UDA disabled. After the 42 MHz diplex filter cutoff both devices show the same level of sensitivity.

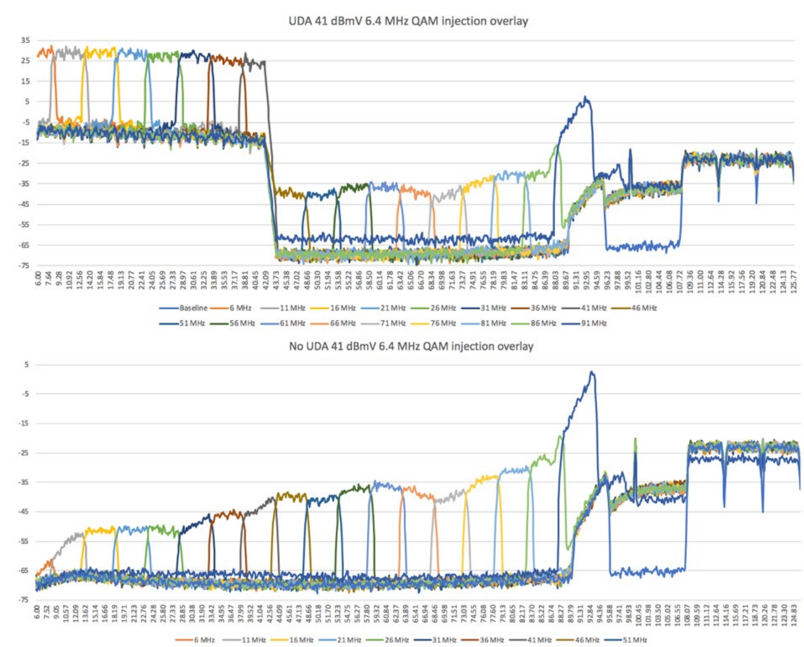

Figure 6 – UDA Enabled capture (top) compared to non-UDA enabled capture (bottom)

Figure 7 and Figure 8 show the minimum signal power levels required to be visible above the noise floor on a UDA and non-UDA device.

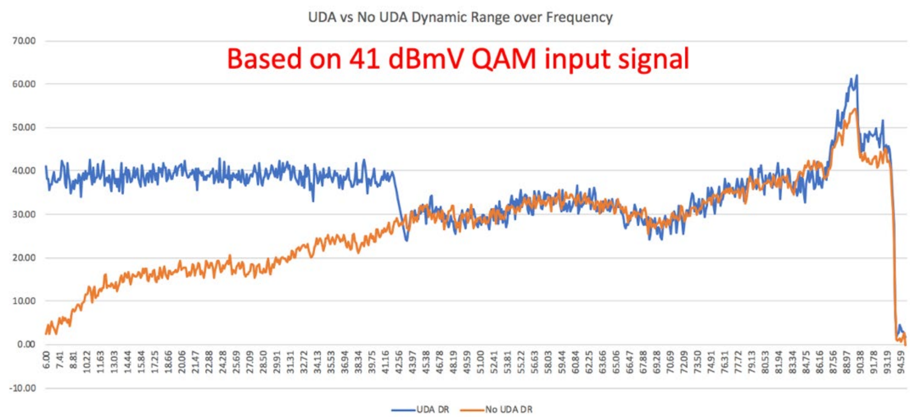

Figure 7 – Direct comparison of UDA and non-UDA noise measurements between UDA (blue) and non-UDA (orange) spectrum capture analysis

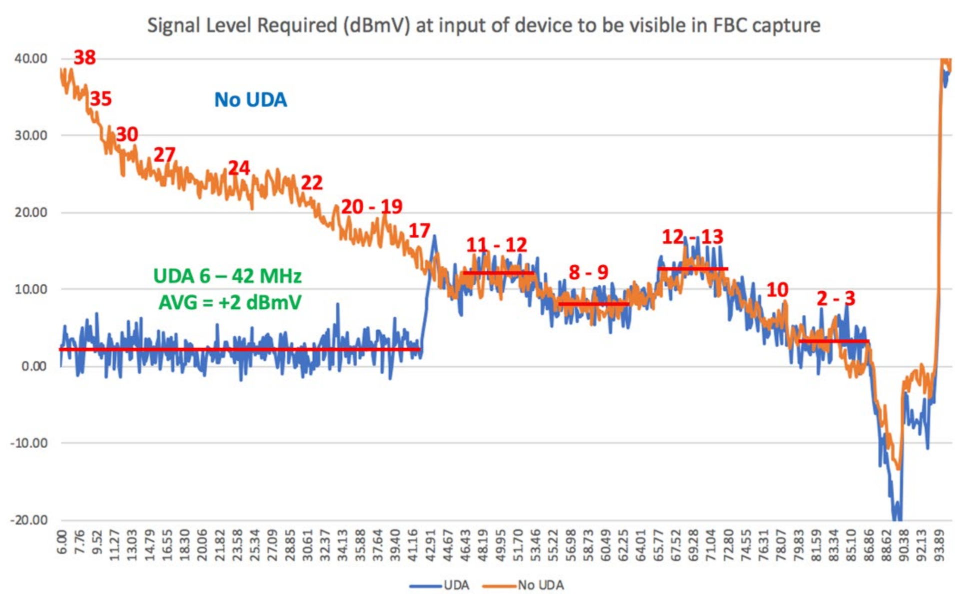

Figure 8 – Minimum power detection levels for UDA (blue) and non-UDA (orange) spectrum capture analysis

5.2. Alternate Setup

To further validate sensitivity on alternate types of equipment and later versions of software, a simplified test was performed using a field-deployed cable modem. In this test, a 2-way splitter was reversed so the spectrum capture sensitivity could be evaluated while circumventing the isolation properties of the two output ports (Figure 9). Five tones were injected at the output port of the 2-way splitter and measured at the upstream burst receiver (Figure 10). Figure 11 shows the bins captured at the UDA-enabled gateway (GW) attached to the input port of the 2-way splitter. A signal level meter (XM) as used to create and inject five tones in the rolloff and guard bands of four upstream SC-QAM channels, The five tones are clearly detected with exceedingly high sensitivity, improved over the initial setup using older cable modem hardware and software.

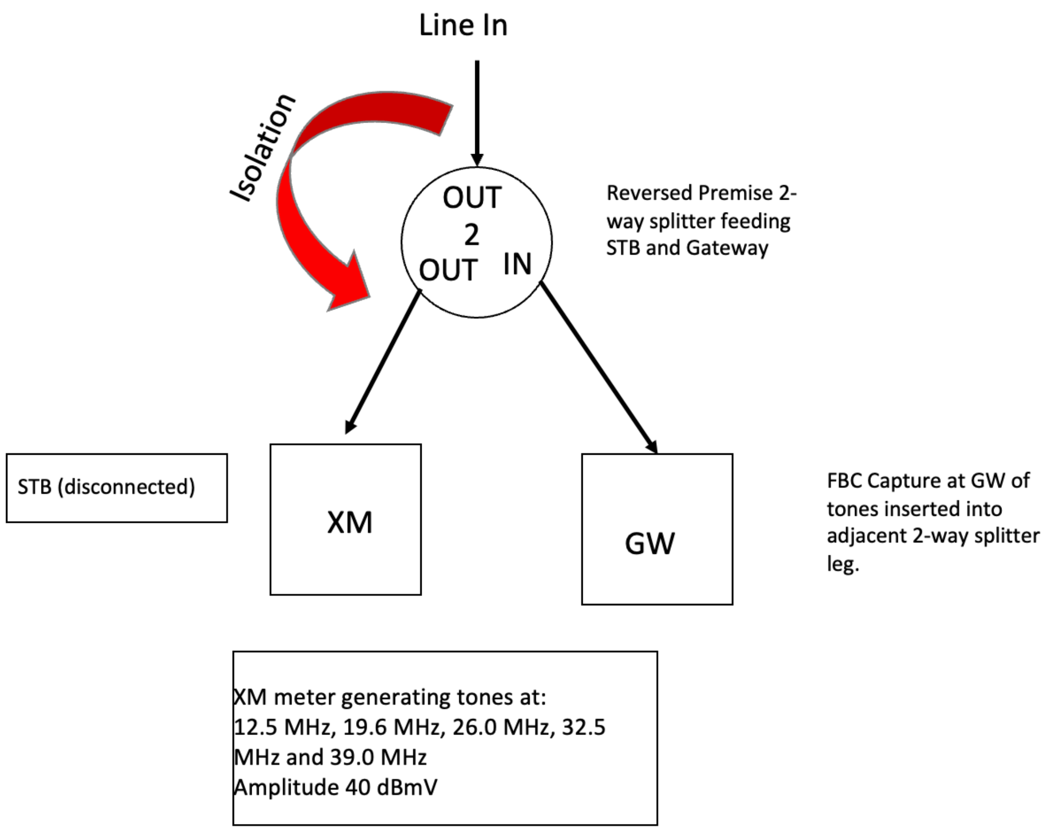

Figure 9 – Alternate setup, using reversed 2-way splitter, injecting five tones with a signal generator (XM)

Figure 10 – Injected tones measured at the upstream burst receiver

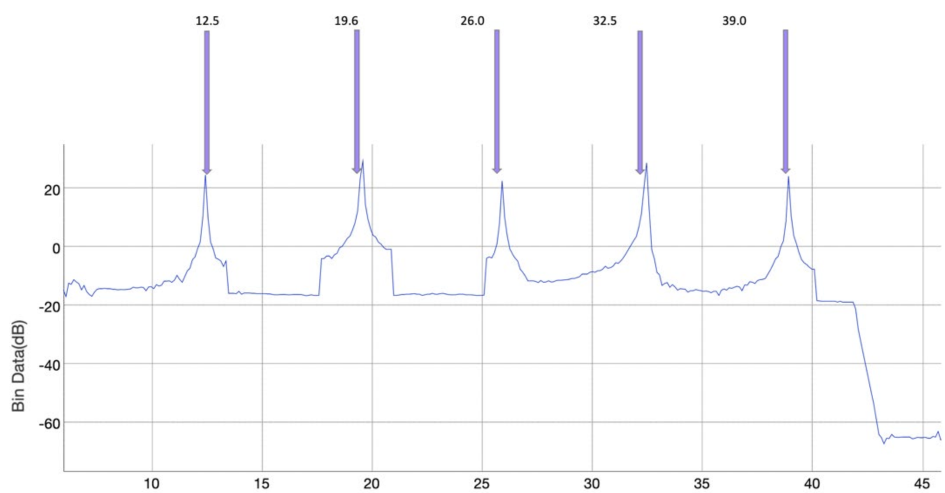

Figure 11 – Injected tones measured using UDA at the cable modem (GW) attached to the 2-way splitter

5.3. Results

Based on the outcome of the test setup and measurements, the following points can be made.

- UDA enabled cable modems offer 15 dB to 38 dB better noise sensitivity in the 5 MHz to 42 MHz band compared to non-UDA devices.
  - Same models tested (Device 1 with UDA enabled and Device 2 with UDA disabled, no other models tested)

- UDA and non-UDA devices have similar sensitivity after diplex filter cutoff frequency.
- If upstream noise originates from the drop side feed or the same outlet as the UDA device and is sufficiently strong to affect the return performance at the node, it should be observable in the FBC spectrum specific to that device with UDA.
- Noise beyond the diplex cutoff frequency will need to be 8 dB to 13 dB higher to be visible due to added filter rejection in that frequency range.
- If noise is on another RF splitter leg and subject to port-to-port isolation, visibility will be drastically reduced (additional testing required to characterize further).
- Attenuation between the point of ingress and point of measurement will also be a determining factor in the usefulness of UDA to detect an impairment.

6. Analysis

Having a better understanding of the UDA sensitivity and performance provides important context for the following analysis.

A statistically significant number of cable modems were analyzed. More than 25% of the sample population of FBC capable modems also supported UDA.

One problem the authors encountered while analyzing the upstream spectrum was the presence of energy produced within the OFDMA (orthogonal frequency division multiple access) channel area. For this reason, that portion of the spectrum as well as some adjacent spectrum, was ignored. Further work needs to be done to better understand this issue.

Another issue encountered was that SC-QAM and OFDMA bursts from nearby devices were often visible, including what appeared to be spurious bursts (unexplained energy in otherwise clean spectrum) was sometimes present. The amplitude of a burst from a nearby device can vary due to transmit power, distance, timing, and port-to-port isolation from the nearby device,

Finally, the spectrum captures are stitched together from multiple, smaller samples. Since the smaller samples are captured at distinct times from each other, this meant that the width of each stitch, approximately 4 MHz, was often the maximum width of the noise or burst that could be observed. Note that this is narrower than the typical width of an SC-QAM channel (6.4 MHz).

For the above reasons, the authors implemented QAM detection logic that was purposefully simplistic and aggressive, trading a high false negative rate for a low false positive rate. In other words, the detector would rather mis-classify noise bursts as QAM versus classifying QAM bursts as noise. Furthermore, the analysis only focused on noise bursts within noisy upstream channels with an average MER of less than 30 dB. Again, this is all to minimize the false positive rate.

6.1. UDA Detection

The first step of the analysis is UDA detection. Due to the much higher noise floor in UDA-capable modems, there is significantly higher power in UDA-capable modems, The UDA detection logic computes the average power in the range of interest, which is 6 MHz to 38 MHz, and compares it to a threshold of 6.363 dBmV. Total UDA power is computed as 10 * log10(sum linear values in UDA spectrum range). The total UDA power threshold (6.363) was computed as an average dBmV of >= -18 within the UDA range (6 - 38 MHz). The spectrum analyzer resolution bandwidth is 117.1875 kHz and 32 MHz of total observed spectrum, comprised of spectrum 273 bins.

Next, the UDA noise floor was computed using the 15th percentile of the values within the UDA spectrum range. The resulting value in dB varies between modems with the majority samples in the range of –14 dB to –18 dBmV. The computed UDA noise floor is used later in the analysis. Further refinement might include removing tilt from the UDA spectrum, or otherwise accounting for tilt in the analysis.

6.2. SC-QAM Detection

The next step of the analysis is SC-QAM detection. The SC-QAM detection logic looks for four or more consecutive samples above a threshold of more than 10 dB above the noise floor. Additionally, single values less than the threshold are permitted, so long as the next sample exceeds the threshold. The regions of spectrum containing SC-QAM bursts are replaced with the UDA noise floor. Further refinement of the SC-QAM detection logic might include detecting the guard bands and the expected lower energy therein.

6.3. Noise Power Computation

Only samples within the spectrum of noisy channels (defined above) are considered. The linear values are summed after the UDA noise floor is removed.

6.4. UDA Issue Detection

The UDA noise power was compared to three thresholds, 8 dB for MINOR, 10 dB for MAJOR, and 12 dB for SEVERE to establish severity.

6.5. Results

The goal was to evaluate the UDA detection method (Section 6.1) of upstream noise in a DOCSIS coaxial cable network. The analysis was conducted for a duration of one week, running UDA analysis hourly.

6.5.1. Issues Detected

a) The UDA analyzer detected between 30 and 200 issues per hour, many of which were repeat occurrences.
b) Over 50% of the UDA issues detected correlated with existing FM radio ingress detection, confirming a known indicator of potential ingress issues.
c) Notable interference was identified at 9.33 MHz, attributed to World's Last Chance Flat-Earthers.
d) Despite the vast range of narrowband ingress detected, the ingress canceler effectively filtered noisy channels, improving the demodulator's performance.

6.5.2. Device Compatibility

Over 25% of the modems with full-band capture support also featured UDA compatibility. Although many device models supported UDA, 90% of these were from the top four models. The two latest UDA firmware models represented approximately 33% of the UDA-compatible devices.

6.5.3. Performance Parameters

a) Spectrum Range: 6 MHz to 38 MHz
b) Upstream MER Threshold: 30 dB.
c) SC-QAM Power dB Threshold: 10 dBmV.
d) Minimum consecutive SC-QAM samples required: 4.
e) UDA total peak power threshold: 6.363 dBmV.
f) Noise criteria were segmented as: MINOR (>8 dB), MAJOR (>10 dB), and SEVERE (>12 dB).
g) For SC-QAM bursts adjacent modems, amplitude varied, whereas OFDMA bursts from the same modem equated to TX power.

6.5.4. Issues & Solutions

The SC-QAM detector, while effective for certain types of interference, was particularly adept at pinpointing narrowband ingress from sources such as citizen band (CB) radio and shortwave radio.

Spurious bursts, which are unexplained data within a clean spectrum, can arise from multiple sources including stitching errors, gain setting errors during data collection, and other potential bugs in modem UDA functionality.

Regarding stitching, issues arose when the sample thickness was less than the SC-QAM width, leading to partial SC-QAM bursts. The extent of these bursts was dependent on channel alignment with stitch points.

To minimize false positives, especially where SC-QAM bursts are misidentified as noise, the SC-QAM detector was kept deliberately simple. This might result in high false negatives where noise bursts could be misidentified as SC-QAM.

7. Field Examples

The following examples were selected from the population described in Section 6. Each of these examples include a spectrum capture from the upstream burst receiver and corresponding capture from the cable modem's location. These examples are intended to illustrate the usefulness for improving the localization of certain types of upstream noise.

7.1. Common Mode Disturbance

Figure 12 and Figure 13 provide an example of a common mode disturbance (CMD) interference which appears as a noise hump around 24 MHz These are typically caused by ground faults in the presence of loose connectors on certain types of modems, set-top boxes, and other types of customer equipment. In this example, all modems are equally impacted by the impairment, however, the primary source of noise can be localized to a single customer location.

Figure 12 – Common mode disturbance at burst receiver, around 24 MHz

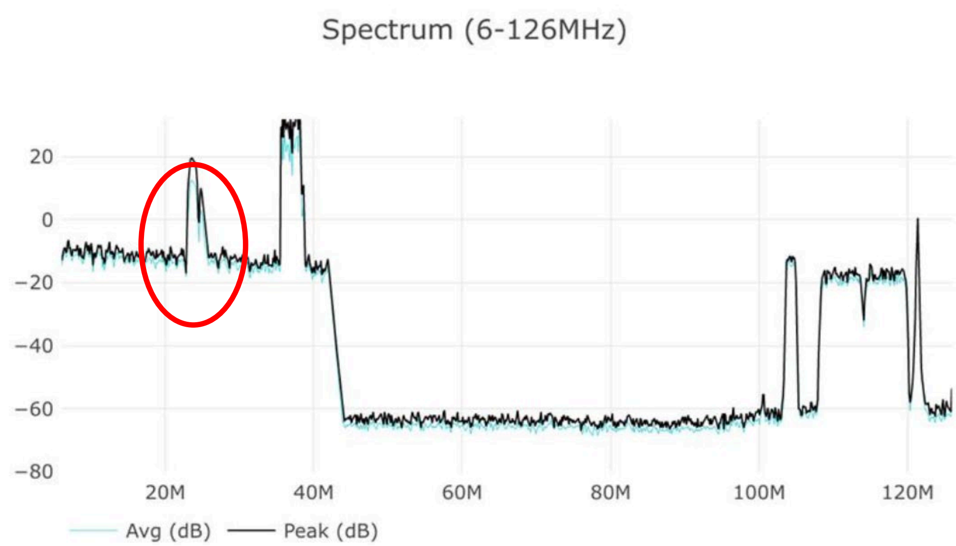

Figure 13 – Same common mode disturbance at cable modem, around 24 MHz

7.2. Switching Regulator Noise

Switching regulator noise is among the most observed types of noise in cable networks. 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.

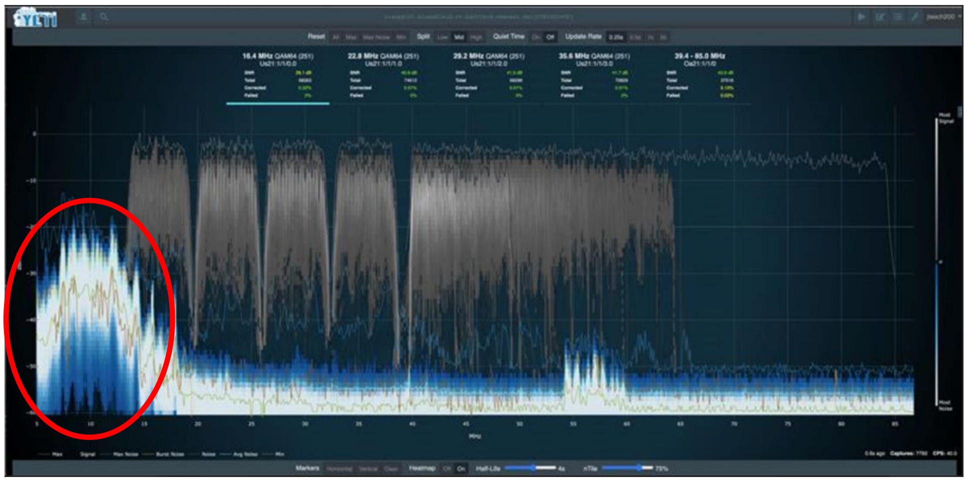

Figure 14 – Switching regulator noise at the burst receiver, centered around 10 MHz

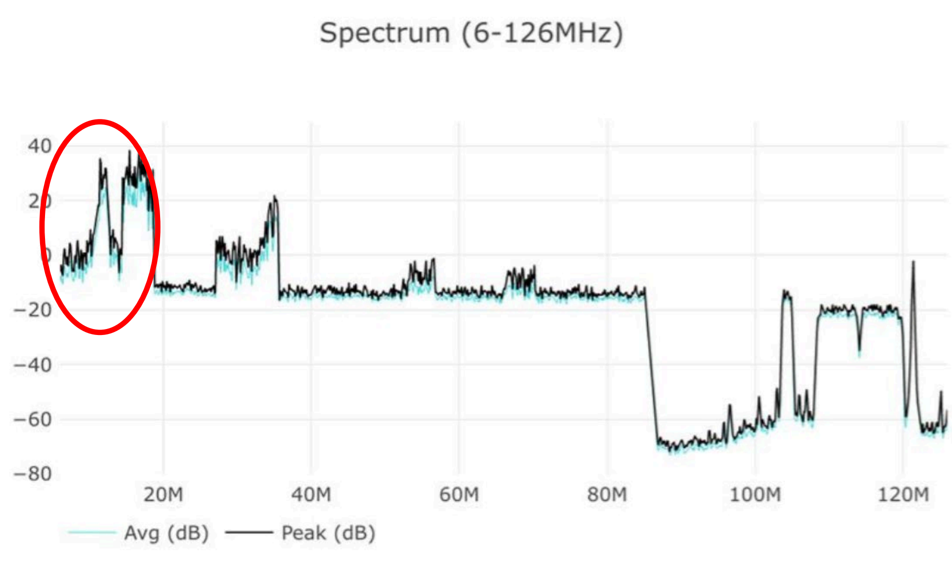

Figure 15 – Switching regulator noise, centered around 10 MHz

7.3. Citizens Band Radio

CB radio operates in the frequency range between 26.965 MHz and 27.405 MHz

Figure 16 – CB Radio Ingress at the burst receiver, around 26.9 MHz

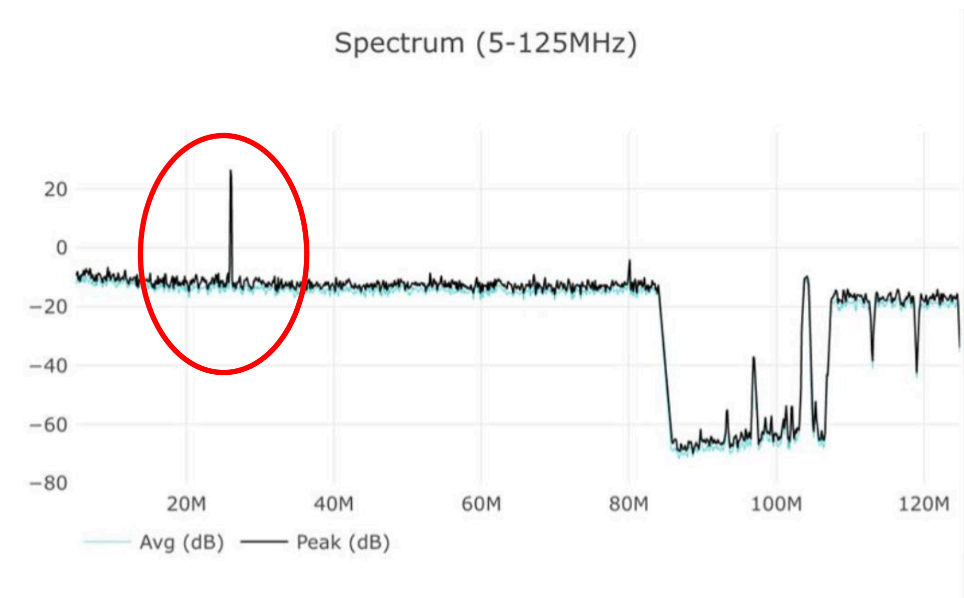

Figure 17 – CB Radio Ingress, around 26.9 MHz

7.4. Spurious Noise

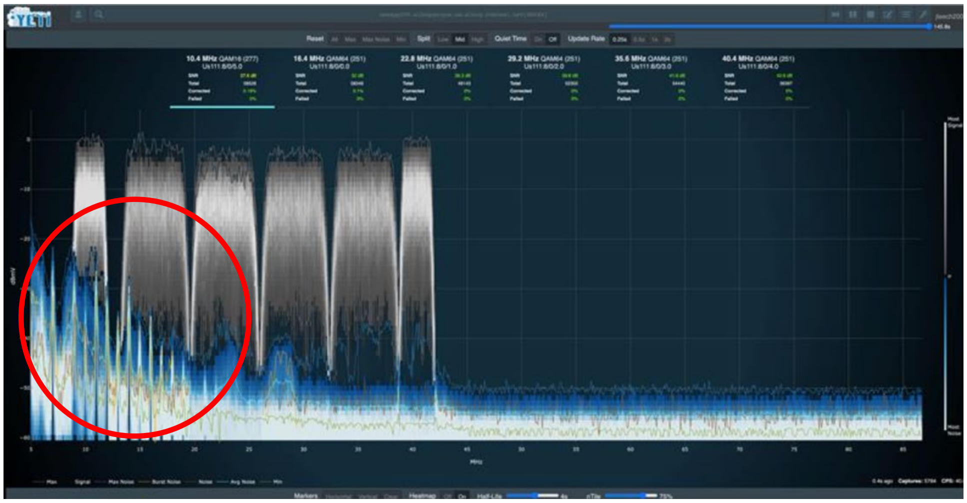

Figure 18 – Powerline gap noise at the burst receiver, below 25 MHz

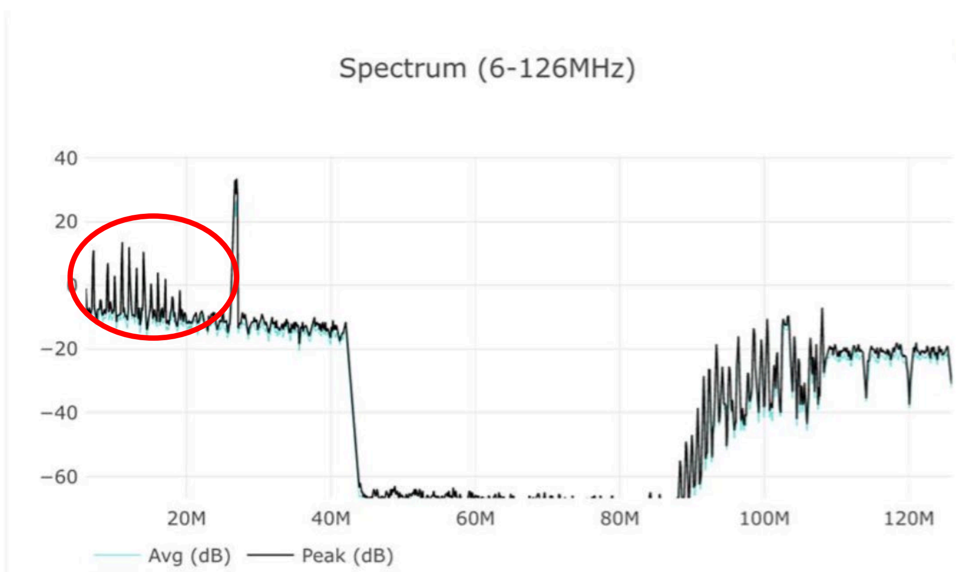

Figure 19 – Powerline gap noise, below 25 MHz

7.5. High-energy Narrow Band Interference

Figure 20 – High-energy narrow band interference at burst receiver, around 15 MHz

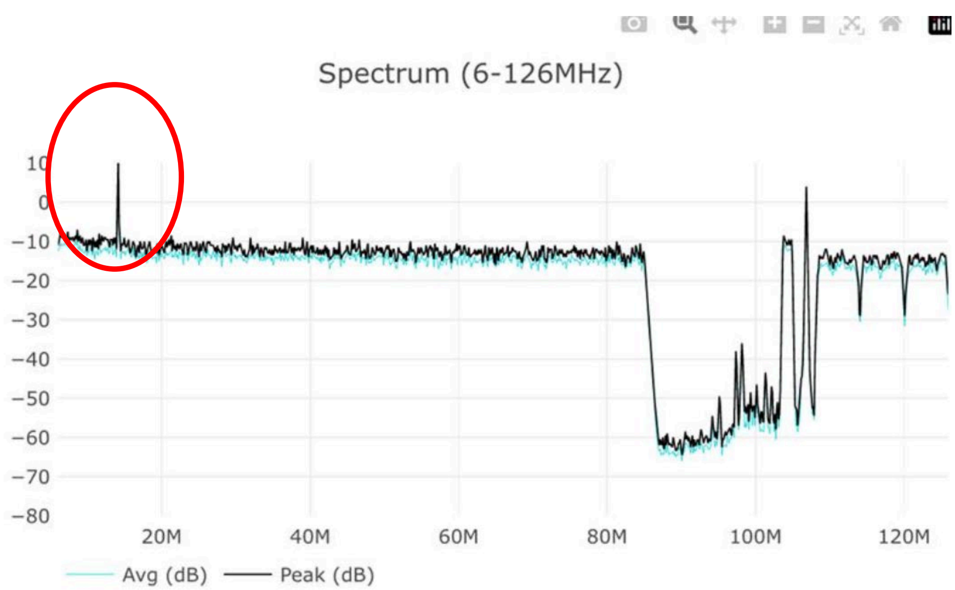

Figure 21 – High-energy narrow band interference, around 15 MHz

7.6. Unknown Interference

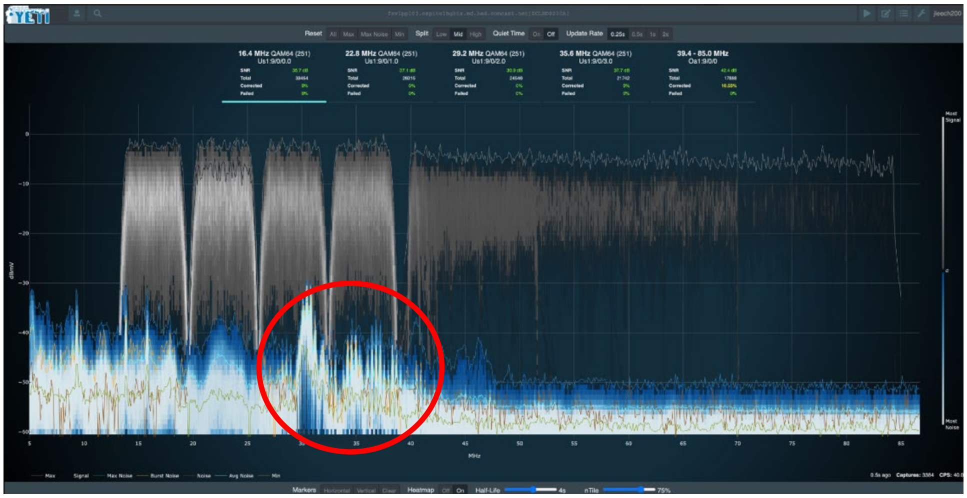

Figure 22 – Unknown interference between 35 MHz and 42 MHz at burst receiver

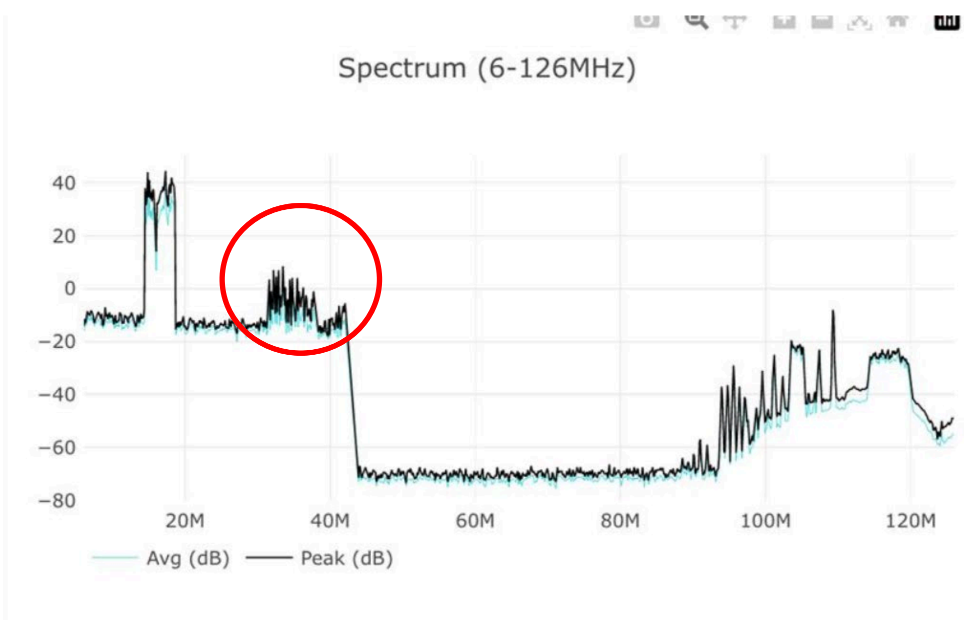

Figure 23 – Unknown interference between 35 MHz and 42 MHz

7.7. Shortwave Radio

Shortwave radio was detected frequently with varying severity. One interesting example is from a shortwave broadcast from a half-million-watt transmitter in Maine, which causes ingress issues throughout the Northeastern United States. The following figures shows the 9.330 MHz transmission.

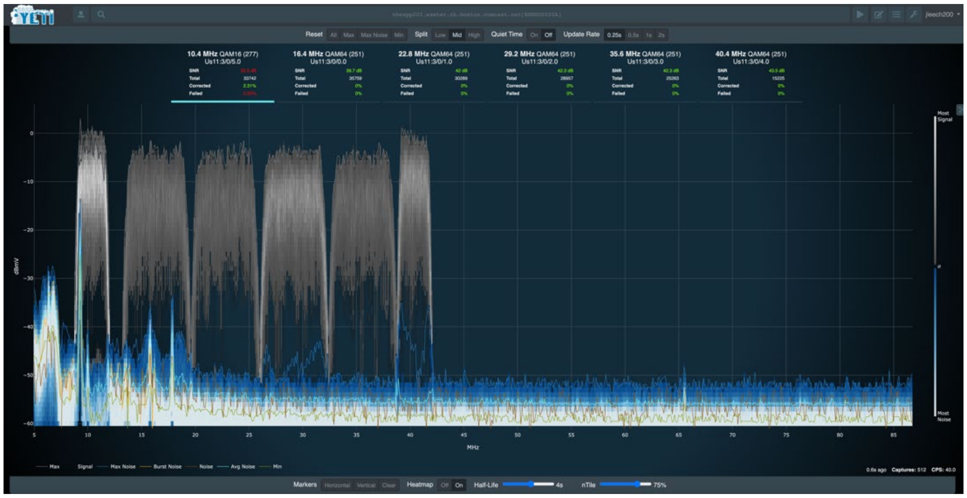

Figure 24 – Shortwave radio ingress, 9.33 MHz at the burst receiver

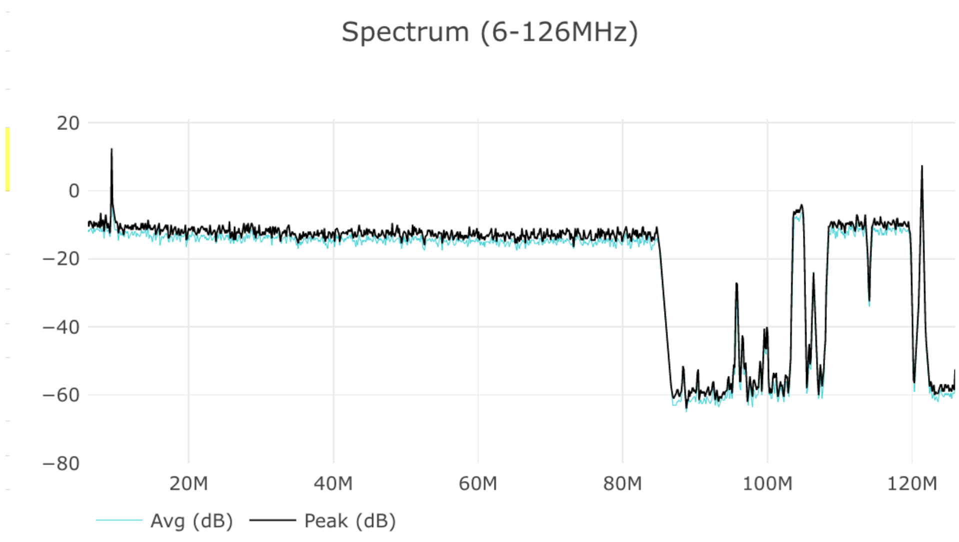

Figure 25 – Shortwave radio ingress, 9.33 MHz

8. Future Work

8.1. Additional analysis

With encouraging initial results, additional areas of interest have been identified.

- Further refine SC-QAM detection and find more noise with acceptable false positive rate.
- Expand the UDA spectrum range to include OFDMA frequency spectrum.
- Examine history, histogram and exponential decay of values.
- Evaluate raw poll values (e.g., not averaged, to remove vs exclude SC-QAM bursts).
- Correlate to upstream burst receiver noise captures.

8.2. FM detection and power level analysis

Given the high correlation (~50%) of FM ingress to other types of interference, FM radio ingress can provide valuable insight into the detection and location of other types of upstream noise. At the time of writing, the authors, along with SCTE NOS (Network Operations Subcommittee) WG 7 (PNM) are performing FM power level analysis useful in pursuing this goal.

Figure 26 shows an example of two different FM ingress problems. The example on the left illustrates two neighbors that have individual ingress problems, while the example on the right is typical of a common network problem.

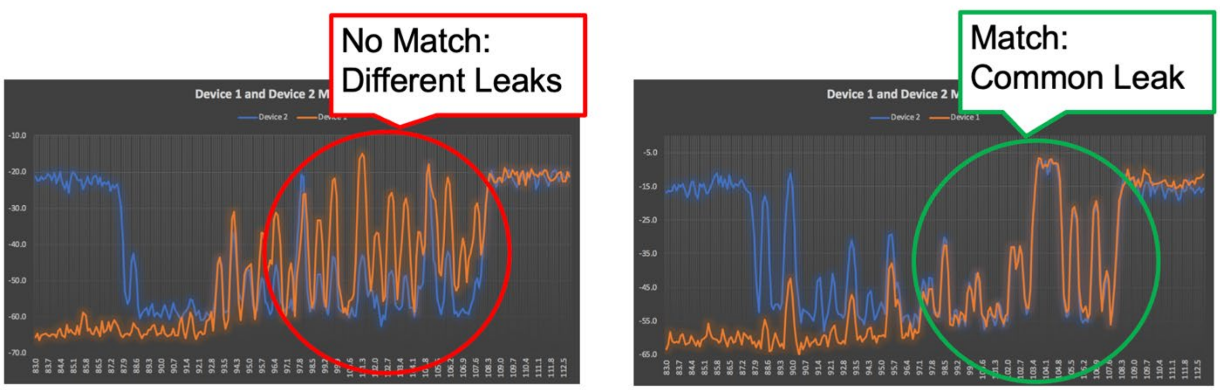

Figure 26 – FM Ingress matching example

9. Conclusion

This exercise has proven that localizing upstream noise with upstream spectrum analysis near the sources of ingress does work! However, there are several limiting factors which reduce the overall effectiveness, including:

- Port-to-port isolation can hide ingress even with the same house across splitters.
- Ingress from drop locations that do not have active equipment will be un-detectable.

- Limited support within deployed cable modem population (25% at time of writing).

Most cable operators would immediately recognize the importance and value of improving the process of detecting, locating, and mitigating upstream noise. This should serve as encouragement that we, as an industry, can finally prevail in the relentless pursuit of this long-standing foe of reliable cable service.

Abbreviations

CB	citizens band radio
CM	cable modem
CMD	common mode disturbance
CMTS	cable modem termination system
CNR	carrier-to-noise ratio
CPE	customer premises equipment
DOCSIS	Data Over Cable Service Interface Specification
dBmV	decibels relative to one millivolt
FBC	full band capture
FEC	forward error correction
FFT	fast Fourier transform
FM	frequency modulation
GW	gateway
MER	modulation error ratio
MHz	megahertz
NOS	network operations subcommittee
OFDMA	orthogonal frequency-division multiple access
PMA	profile management application
PNM	proactive network maintenance
SC-QAM	single channel quadrature amplitude modulation
RF	radio frequency
SNR	signal-to-noise ratio
STB	set-top box
SCTE	Society of Cable Telecommunications Engineers
UDA	upstream data analysis
WG	working group
XM	Xfinity signal meter

Bibliography & References

[1] PNM Best Practices: HFC Networks (DOCSIS® 3.0) CM-GL-PNMP-V03-160725, July 25, 2016, Cable Television Laboratories, Inc.

[2] SCTE 280 2022 Understanding and Troubleshooting Cable RF Spectrum, 2022

[3] SCTE NOS WG 7, Understanding and Troubleshooting Cable Upstream RF Spectrum, Unreleased

[4] A Comprehensive Case Study of Proactive Network Maintenance, Heslip, Thomas, Gonsalves, Wolcott, SCTE CableTec Expo 2016