Using PNM Tools to Identify Misaligned Amplifiers

A Technical Paper prepared for SCTE by

Mike O'Dell
Distinguished Engineer
Comcast
michael_odell@cable.comcast.com

Westley Darby
Engineer, Quality Assurance
Comcast
westley_darby@cable.comcast.com

Jason Rupe
Distinguished Technologist
CableLabs
j.rupe@cablelabs.com

Andy Martushev
Distinguished Engineer
Comcast
andy_martushev@cable.comcast.com

Alex Zayvelev
Senior Access Engineer
Comcast
alexander_zayvelev@comcast.com

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1. Introduction

Broadband networks widely use Proactive Network Maintenance (PNM) tools to identify impairments actively. While PNM has successfully identified upstream cable and common plant impairments, this paper explores whether PNM telemetries can also identify improperly aligned amplifiers that cause low Modulation Error Ratio (MER) and other performance issues. We must also identify some technical considerations necessary to create PNM tooling that can correlate plant impairments to amplifier misalignment, **Figure 1**.

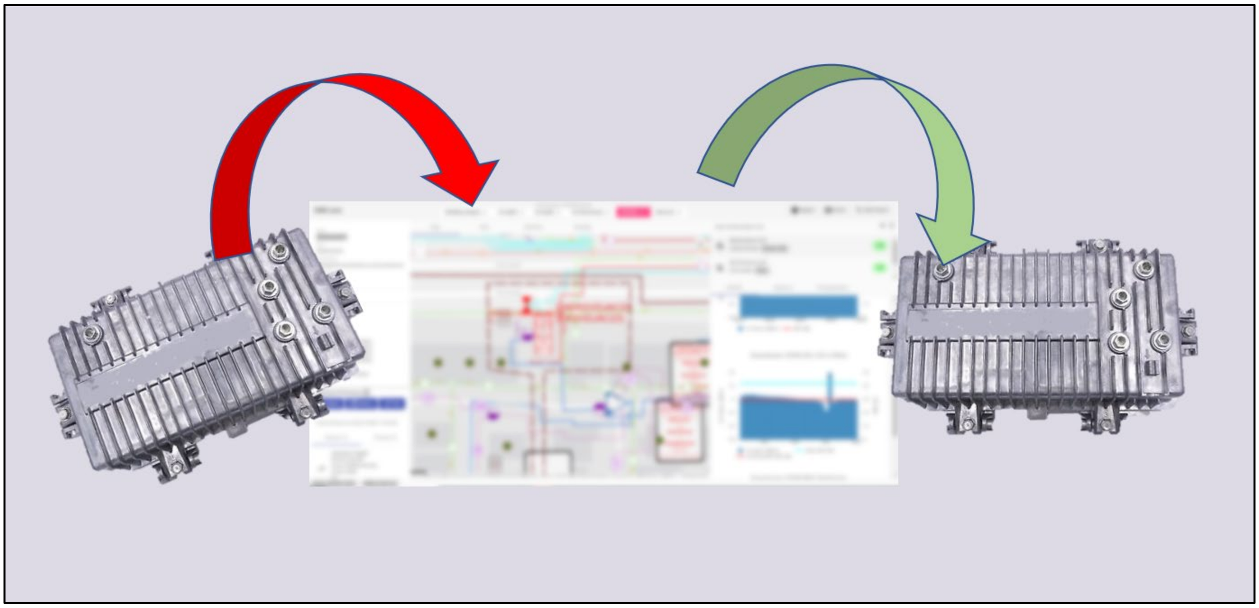

Figure 1- PNM Tools for Amplifier Alignment

2. Background

2.1. Inspiration

There are challenges to constructing and enabling a modern CATV network at scale. It is an effort that operators worldwide are undertaking and facing many of the same issues. The evolution to a DOCSIS 4.0, or 10G Network, requires a transformative process that touches many of the core components of the network. It may require Cable Modem Termination System (CMTS) replacements, core network upgrades, optical node replacements, and other plant components like amplifiers and passives. This work requires a workforce that can be less tenured and experienced in the nuances of amplifier setup and operation but, by necessity, is focused on splicing and activation volume. It also requires generating and receiving new signal types and frequencies with which we don't have history or expertise.

Some timing considerations became apparent in our 10G Network rollout process. As mentioned, the primary stages of network development and deployment have been ongoing for a year or more. CMTS transitions that happened a year ago, or more have yet to generate a portion of their full potential where Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA) signals are concerned. Likewise, amplifiers that are mid-split capable and have been in place for a year or more still carry sub-split, 750 MHz channel plans. It was this exact scenario that served as the inspiration for this effort. With CMTS upgrades, Remote-Phy node installations, and amplifier upgrades and activations, the plan was to enable the spectrum. When the fateful event happened, it wasn't rainbows and confetti. We created a service outage.

Technicians scrambled, and difficult conversations were had. Amplifier misalignment during installation and activation was ultimately determined. Why didn't we realize it at the time? Why did all of our monitoring tools work fine? Why weren't there service calls or other indicators to identify the problem? How were the customer services working before? All valid questions. This was the beginning of a long journey of discovery into amplifier characterization and setup, training, communications, business partner relationships, testing, tool development, and, hopefully, a smoother path to future spectrum enablements.

This paper recounts many things considered part of that learning journey- from developing, deploying, and using PNM tools, testing, measuring, and characterizing amplifiers to approaching future spectrum enablements.

2.2. PNM

It has been over a decade since we gained access to spectrum data from cable modems. In PNM, the focus is often on the signal in the spectrum capture and the search for spectrum impairments impacting those signals. We collect downstream statistics based on the RF signal, and our analysis of the various PNM tests also focuses on the RF signal quality. Utilizing MER values from cable modems to analyze the noise floor and examining that against the noise floor of the device, we can infer much about the non-linearity of the noise floor, which could indicate an amplifier misalignment issue.

Further, by examining the Modulation Error Ratio per carrier or Receive MER (RxMER) per subcarrier, we can utilize these powerful downstream measurements to determine if that noise is uniform across the spectrum range, potentially indicating more precisely what amplifier alignment issue is present.

By adding amplifier alignment troubleshooting to the PNM set of tools, we can make maintenance operations more efficient. Managing PNM as an opportunity to manage network health ahead of service impact, planned maintenance can be optimized better by combining issues and optimizing travel time and technician effort.

As described by Brady Volpe: "No longer is it [PNM] seen as a shiny gimmick or a novelty to detect the poltergeist in the network before it goes bump in the night. It is a go-to network maintenance tool with the added benefits of workforce optimization" [1].

2.3. Amplifier Characterization

While we desire our signal distribution networks to operate as linearly as possible, we expect and have known instances where non-linearities can occur. CATV amplifiers, for example, while an essential component in defining the capacity and performance of a Hybrid Fiber Coax (HFC) network, can be a source of such non-linearities. Understanding the behaviors and performance characteristics of these necessary devices can help determine when and where their misalignment could result in impairments or, at the very least, act as inhibitors to the optimal performance of the amplifier chain or cascade.

Historically, characterizing or measuring amplifier performance used categories like Carrier-to-Noise Ratio (CNR), Composite Second Order (CSO) distortions, or Composite Triple Beat (CTB). While these have been useful and meaningful when delivering analog video signals over long cascades of amplifiers as a measure of video signal quality, many of today's networks strictly carry digitally modulated data channels, with modulation orders of up to 4096 Quadrature Amplitude Modulation (QAM). Those historical measures aren't invalidated, but the evolution of DOCSIS and data delivery network technology have resulted in much wider broadband carriage systems. Since coaxial cables are still a fundamental and primary transmission medium and have a strong frequency-dependent loss [2], the resulting increased gain of amplifiers can present instances to significantly and negatively impact the designed signals that those amplifiers carry. Understanding amplifier performance using other measures, including, but not limited to, Carrier-to-Thermal noise (CTN), Carrier-to-Composite noise (CCN), Carrier-to-Intermodulation noise (CIN), Bit Error Rate (BER), and MER can be helpful in understanding and even predicting amplifier behavior across known Total Composite Power (TCP) ranges [3].

2.4. NPR

Using Noise Power Ratio (NPR) measurements to determine network performance is not new. NPR has been the standard performance measurement for characterizing upstream analog optical transport links for many years.

The ANSI/SCTE 119 (2018) Standard defines that "NPR is a test method that examines the amount of noise and intermodulation distortion in a channel. A test signal, comprised of flat Gaussian noise band limited to the frequency range of interest and with a narrow band (channel) of the noise deleted by a notch filter or other means, is injected into the Device Under Test (DUT). The NPR is measured at the output of the DUT as the test signal is swept across a power range". [4]

When charting NPR curves, **Figure 2**, typically, the total input or composite power is on the horizontal axis, and the noise power ratio is on the vertical axis:

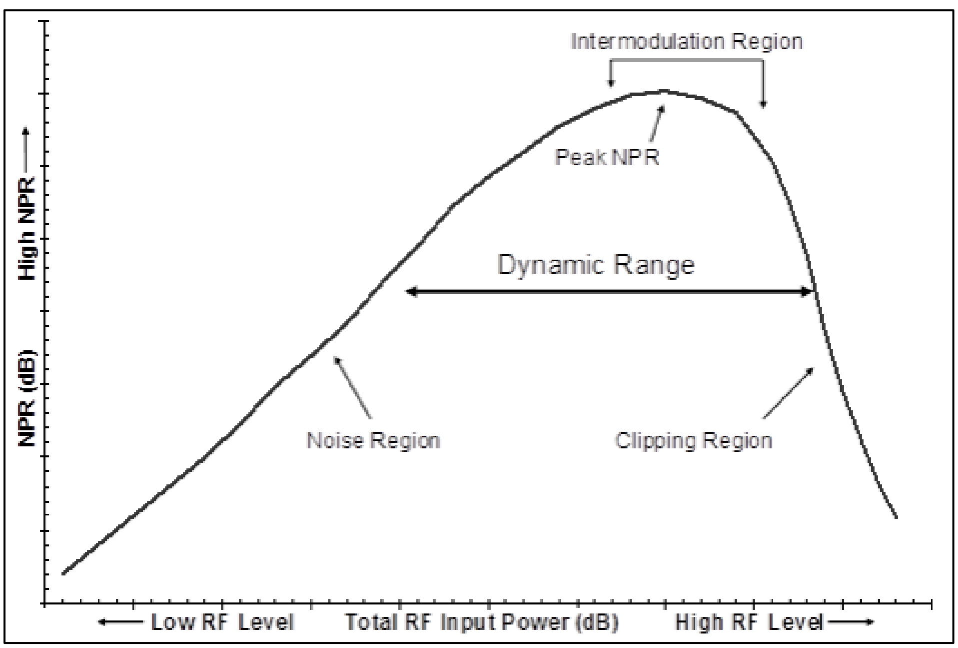

Figure 2- Typical NPR Curve Format

Another way to think of this chart is with a signal quality measure on the vertical axis, like MER. The signal quality improves as the total RF input power increases through the noise region. The peak signal quality potential exists in the intermodulation or transition region at the curve's apex. As the total RF input power increases, the signal quality declines rapidly through the clipping region, where the amplifier's performance becomes non-linear.

At the extreme lower end of the noise region, the system's power is low and has very little differentiation from the noise. Signals in this region, when subject to high gain, result in high amplitude signals of poor quality because the amplified noise also has high amplitude. Signals in the intermodulation or transition region continue to have higher quality as their relative relationship to the system's noise increases. Past the peak NPR point, continuing to increase the signal into the clipping region while still "separating" from the noise floor results in the system becoming non-linear and generating intermodulation distortions. In a system deploying only digitally modulated channels, these distortions can appear as an elevation in the system's noise, even though they may be second or third-order distortion products.

3. MER Curve

Similarly, specific amplifiers can be tested and characterized for performance by introducing high-quality QAM signals across a broad range of frequencies and input powers to create an MER curve. This is a distinctly different methodology than that used in creating an NPR curve, but the results are similarly informative of the relationship between power, noise, and signal quality.

This method of characterizing amplifiers can help quantify how a particular amplifier behaves when aligned according to regionally standardized input and output design levels and relative to the output signal quality of the optical nodes deployed. Varying numbers of channels can create this MER curve.

Using a power per 6 MHz channel (amplifier input) power measurement on the horizontal axis to graph the (amplifier output) MER curve according to the desired input and output channel or channels directly relates to the designed output levels of the amplifier determined by the tap design deployed. This method makes it easy to determine the optimal amplifier input or drive level required to achieve the best amplifier output signal quality. That peak MER point is also the clipping point, or the point past which any additional input power results in a degraded performance in the output signals of the amplifier. Refer to this point as the *Peak*.

This method is easily explainable to field personnel; however, it must be understood that these results are directly related to the total composite power or the number of active channels present in the lineup at the time of measurement.

It is important to note that the channels tested in an MER curve may reach their peak or clipping point at different power levels. A singular clipping point value would be the lower of the available values.

The data derived from developing an MER curve this way is fundamental to our hypothesis that new configurations and uses of PNM tools can identify amplifiers operating in a non-linear state.

3.1. Building the Curve

Having established a test system where there is a known and common channel plan, Channel Plan A, used to create an MER curve for a specific amplifier model, Amp 1, **Figure 3**, we can determine the maximum input level on our input and output reference channels at Amp 1 to achieve the peak MER figure in the transition region of the curve.

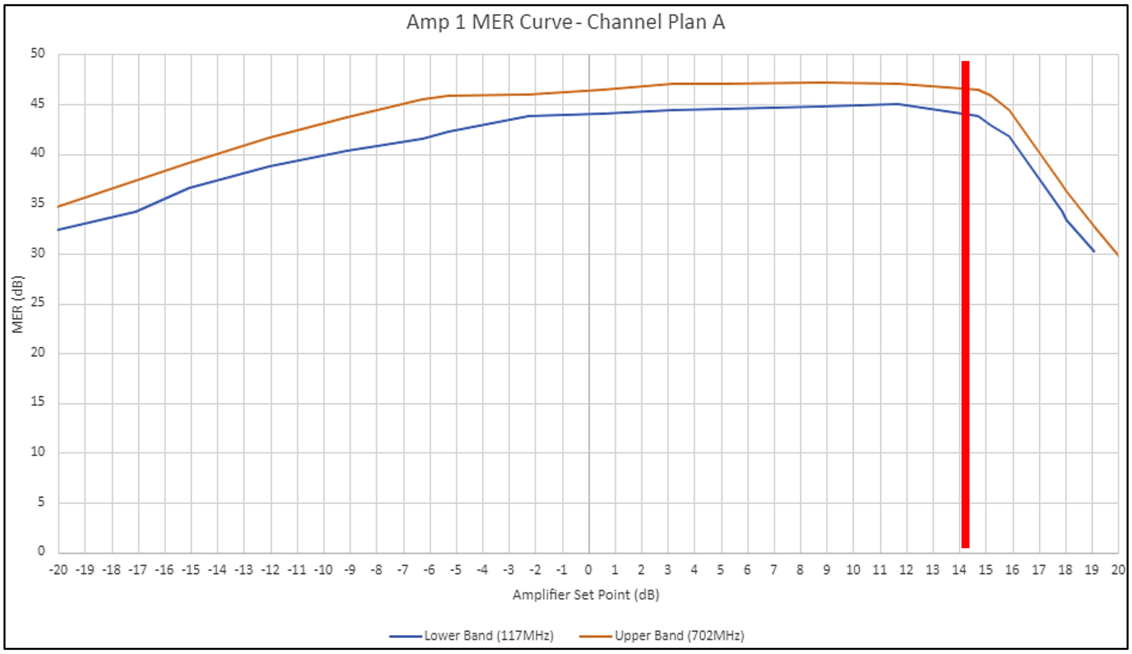

Figure 3- MER curve of Amp 1, using Channel Plan A

As the constant need for operational bandwidth dictates that operators continue to expand their downstream channel plans to add data capacity, it is reasonable to test the performance of the amplifier deployed into that system with a representative channel load. For this paper, we'll call this Channel Plan B. By measuring each channel plan's TCP at the input to the amplifier's first gain stage across the wide range of test values, we can calculate the TCP delta between the two plans. This additional power introduced during spectrum turnup (enablement) is useful in practical applications.

With the additional channels on Channel lineup B, the peak of this MER curve changes due to the additional composite power introduced into the input of the amplifier, **Figure 4**.

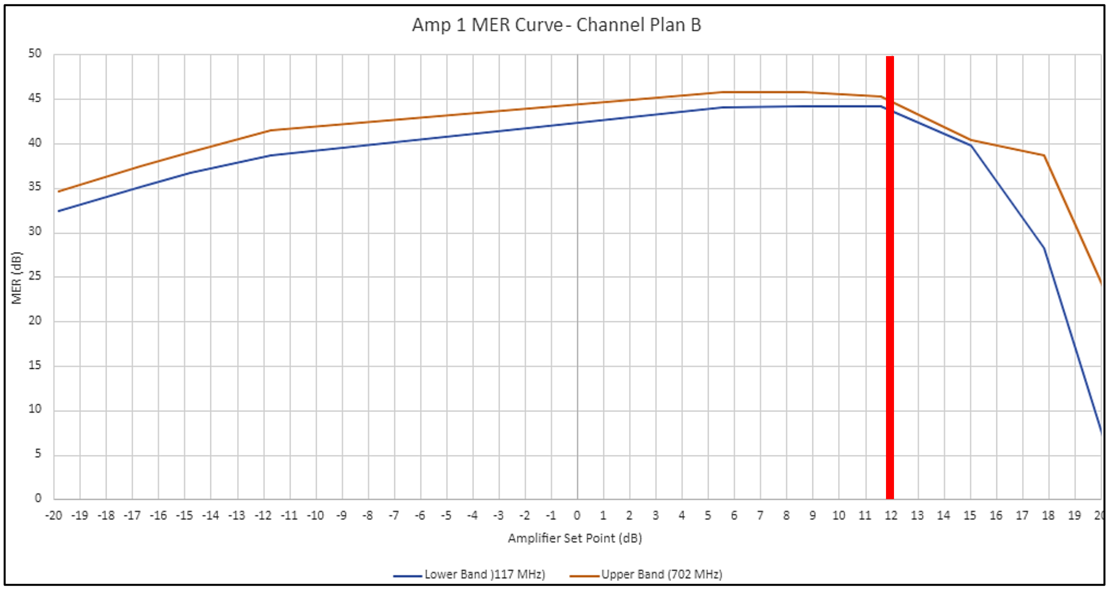

Figure 4- MER curve of Amp 1, using Channel Plan B

This delta would also indicate the amount of headroom necessary in the 750 MHz MER curve to deploy additional channels without introducing distortions into the system. In essence, how far left of the peak do we need to be to enable more spectrum successfully?

3.2. Symptoms of Amplifier Non-Linearity

Amplifiers in today's networks are of high quality and reliability. However, they require higher gain to support today's wider bandwidths and the frequency-specific loss figures inherent in coaxial cables at higher frequencies. Some amplifiers may have as many as four (4) distinct gain "stages" in the downstream amplification path. With this increased gain comes the risk of improper alignment. There are typically multiple points in the forward path to attenuate and equalize the input signals to ensure proper power or drive level at the various amplifier gain stages, **Figure 5**.

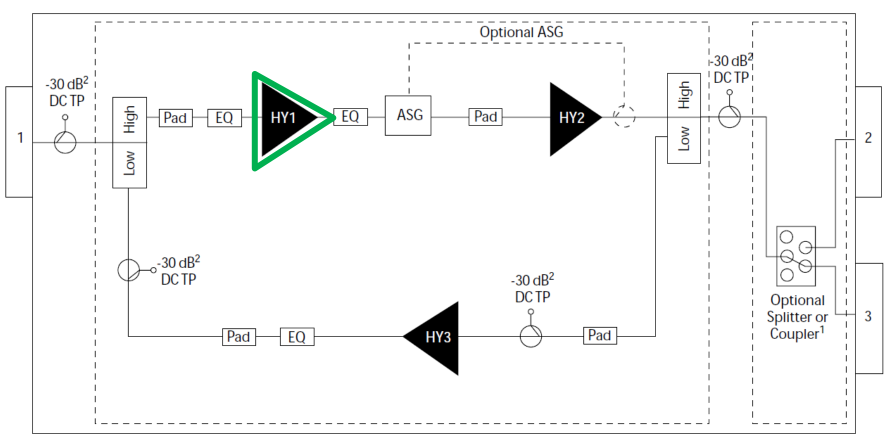

Figure 5- Typical Amplifier Schematic (Two Downstream Gain Stages Shown)

Arguably, the most important of these points in the amplification path is the drive level into the first gain stage of the amplifier, often located after the input attenuator and input equalizer locations in the amplifier station. Today's complex outside plant designs can result in an extensive range of signal levels into the input of an amplifier station. There are several common scenarios where an amplifier is aligned improperly, resulting in an input drive level in the noise region of the MER curve or the clipping region. Both extremes can result in poor overall system performance and generate symptoms in the signal and the noise. These symptoms can include poor MER and or RxMER, high BER, or indications of elevation in the noise floor. However, understanding the symptoms available from the Customer Premise Equipment (CPE) connected to these systems can provide some clues as to the precise cause of the poor performance.

In the following field example, customers in the network were experiencing poor service because of very low signal quality, although the RF levels were consistent with design specifications. An investigation by a network maintenance technician determined that the input attenuator in a high-gain amplifier was too low, resulting in a high drive level at the amplifier's first gain stage. This placed the first amplifier gain stage in the clipping region and created high intermodulation distortions in the amplifier station, **Figure 6**. As noticed in the channel scan taken by the technician with a field strength meter at the amplifier's output test point, not only was there low MER (31 dB), but the noise floor in the vacant portions of the spectrum was extremely elevated.

Figure 6- Misaligned Amplifier

When we observed the full band capture (FBC) data from CPE fed by this amplifier, **Figure 7**, we also observed the elevation in the vacant portions of the spectrum, similar to the example below. PNM tools' FBC clearly illustrates the apparent noise of the system created by the amplifier operating in a non-linear state.

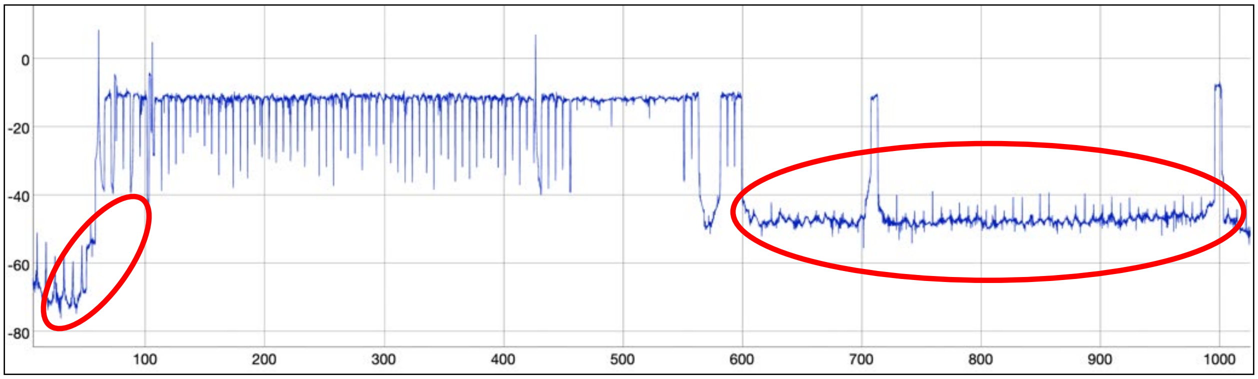

Figure 7- Full Band Capture from CPE Connected to a Non-Linear System

When the technician re-aligned the amplifier by moving 10 dB of attenuation from the output attenuator location to the input attenuator location, the drive level of the station moved from the clipping region of the MER curve into the more linear transition portion of the curve. This allowed the amplifier to operate at a much higher level of performance. While the total station attenuation remained the same, the 10 dB "shift" of the attenuation resulted in a 13 dB increase in MER, illustrating the non-linear impact of amplifiers operating in the clipping region. We also saw greater than 10 dB of reduction in the elevation of noise in the vacant portions of the channel plan. **Figure 8**.

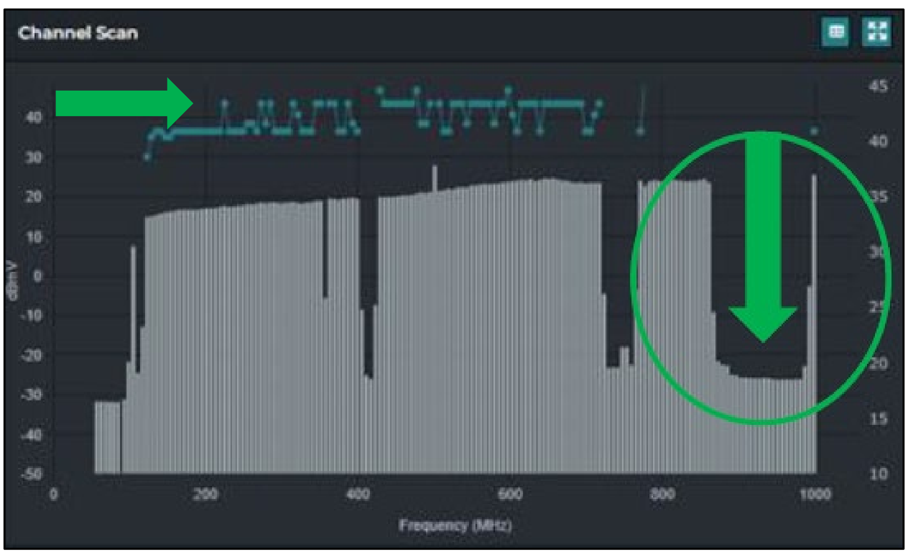

Figure 8- Same Amplifier When Properly Aligned

These were the initial indications that PNM tools could identify impairments caused by amplifier misalignment.

4. Lab Testing Setup

A critical part of this effort is constructing a testing environment that closely aligns with the architecture deployed into the network, has the flexibility to deploy various channel plans, and has access to highly precise test instruments to measure and record results. Comcast is fortunate to have such a facility, staffed with talented engineers, in its Downingtown, Pennsylvania facility.

The network created for this initiative, **Figure 9**, required access to a video core, Remote-Phy nodes, amplifiers, and lab-grade test equipment.

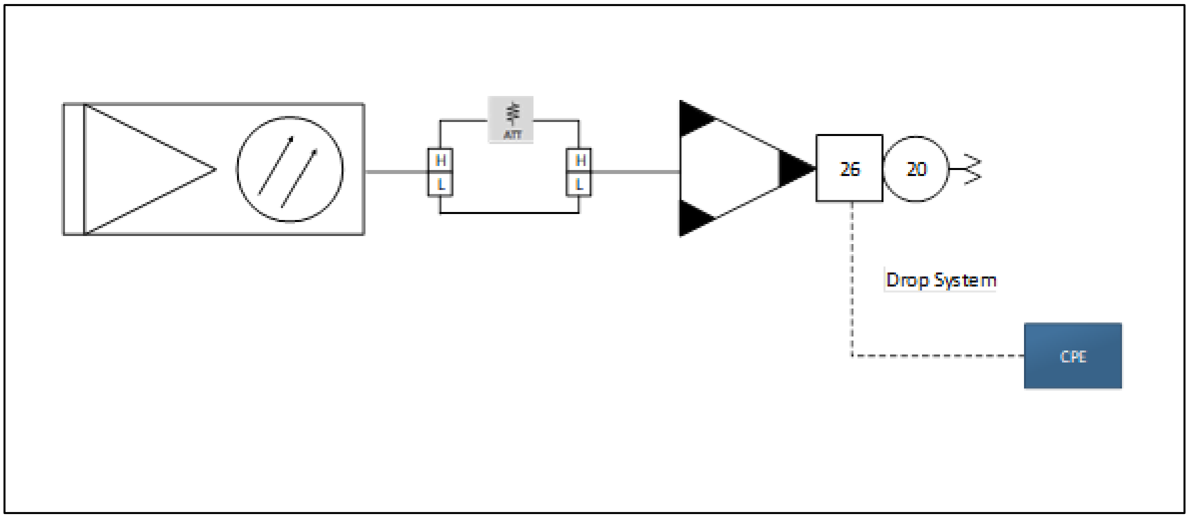

Figure 9- Diagram of Test System

A Remote-Phy node was activated and fed into a mid-split diplex filter. The filter allowed us to vary the input levels to the amplifier without impacting the upstream transmit levels of the CPE connected to the system. The high side of the diplex filter fed through a variable attenuator before being recombined with the upstream in a second diplex filter. The common port of the second diplexer connected to the input of a mid-split 1.2 GHz bridger amplifier. The main output of the bridger amplifier fed a series of tap ports that distributed a signal to the CPE used to collect the PNM data for the trial.

The drop system's design matched the upstream and downstream signals consistent with levels typical to our subscribers across the enterprise. The targets at the CPE were -5 dBmV downstream receive level on the DOCSIS channels and an upstream transmit value of 50 dBmV. The customer premise equipment chosen for the test is a cross-section of the equipment actively deployed throughout our network- a representative sample of video set-top boxes and a selection of DOCSIS gateways. All CPE had current production versions of firmware installed. In the test system, we accomplished SNMP polling by logging into the devices using the IPv6 address to acquire real-time full-band captures. Data files from the devices were polled, cataloged, and stored for visualization and analysis.

The test setup generated two distinct channel plans for the exercise, **Figure 10**.

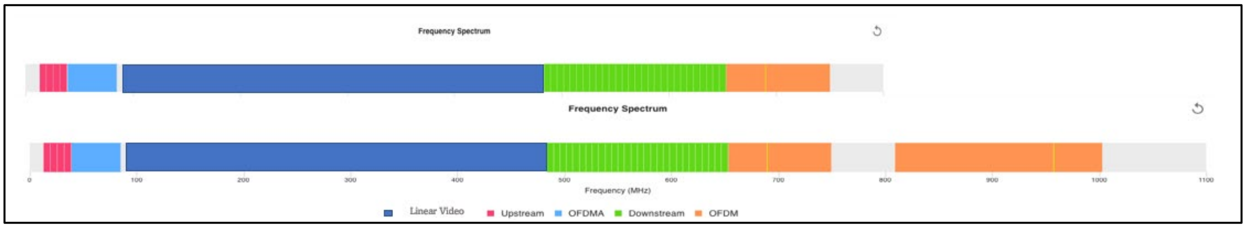

Figure 10- 750 MHz and 2G Channel Plans Used During Testing

The first plan is categorized as a 750 MHz channel plan consistent with what is currently deployed in production in our 750 MHz band limited systems. That plan is recreated for our Remote-Phy nodes' consistency before replacing all the sub-split amplifiers and passives in the network with mid-split capable amplifiers and passives. The second channel plan deployed in this test is consistent with production plans capable of delivering 2 Gbps and is loosely identified as the 2G downstream channel plan. The amplifier selected for this exercise is the default 1.2 GHz mid-split amplifier platform deployed across Comcast. The upstream and downstream levels of the amplifier are representative of a large number of systems across Comcast. Slight variations exist in production based on the tap designs used during the 750 MHz rebuilds, but the levels used are generally accepted as standard.

The test environment was provisioned and set to levels accepted as Comcast's optimal alignment and configuration using the 750 MHz channel plan. Levels and TCP were measured (**Figure 11**, **Figure 12**), validated, and recorded as a baseline configuration. CPE were queried for telemetry, cataloged, and stored at the baseline configuration.

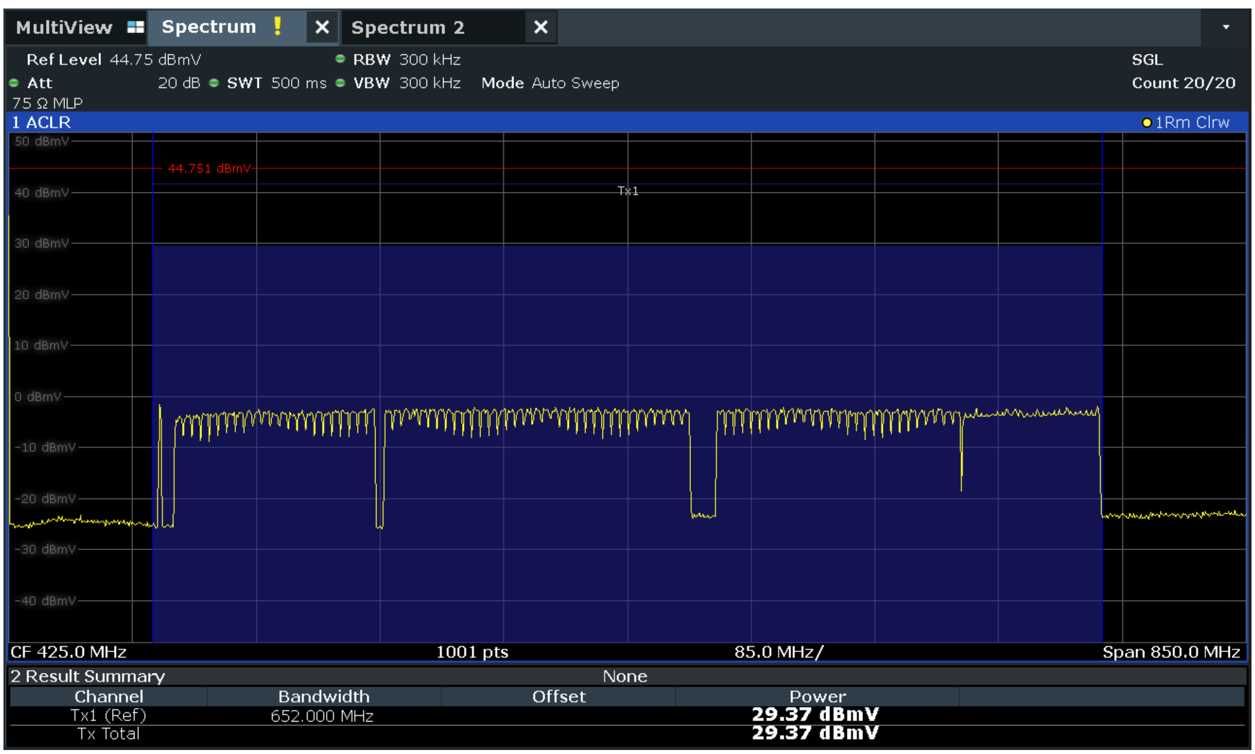

Figure 11- Total Composite Power Measurement of Channel Plan A

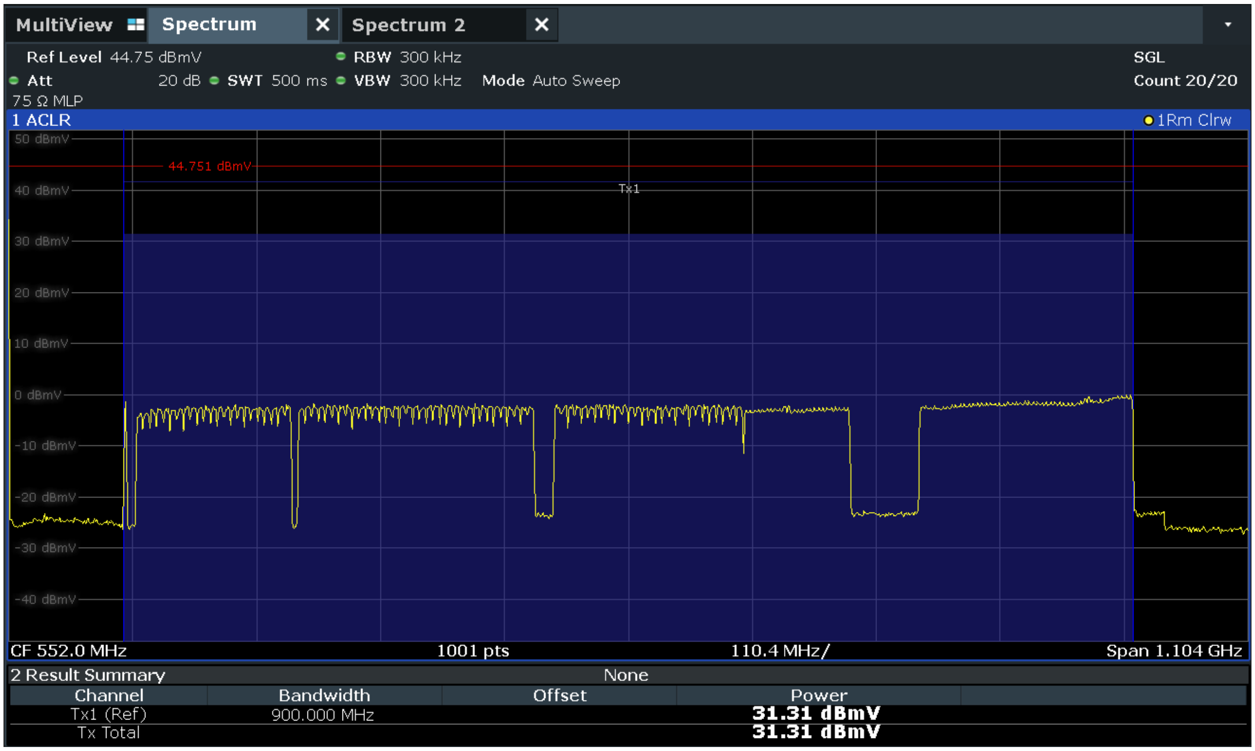

Figure 12- Total Composite Power Measurement of Channel Plan B

The forward input levels to the amplifier were then adjusted using the in-line variable attenuator described in the test setup description across a wide range of values. At each adjustment point, the output of the amplifier was adjusted to the design output level and tilt using the output attenuator locations. The dynamic gain value of the amplifier resulted in a wide range of test scenarios, ending when the amplifier output levels could no longer be achieved or the devices could not achieve a DOCSIS lock. In this fashion, the amplifier's output level and the CPE's upstream and downstream levels remained consistent across the entire range of test values. The variable in each instance was the input or drive level to the first gain stage of the amplifier station. Various data points and telemetry measurements were made, cataloged, and stored at each incremental adjustment level. When all plausible test scenarios were exhausted, the node was configured with the 2G channel plan, the equipment was re-baselined and verified, and the process was repeated. The stored data can then be used to populate tools to visualize the network's performance at various points in the architecture.

5. PNM Tooling

5.1. Tooling Considerations

Building a field tech-facing tooling system that helps alarm and identify distorted amplifiers starts with data. The crucial first step is collecting and storing PNM full band spectrum bin data, **Figure 13**. When collecting FBC data from CPE equipment, use on-chip averaging if possible; otherwise, collect multiple samples, choose a number between 4 and 16, and average the data server side before storing. When comparing samples and determining severity, capturing device MER and RxMER from DOCSIS SC-QAMs and OFDM channels is useful. Storing the data by node segment simplifies data storage and access. Consider storing metadata such as timestamp, mac address, node, CMTS, latitude, and longitude.

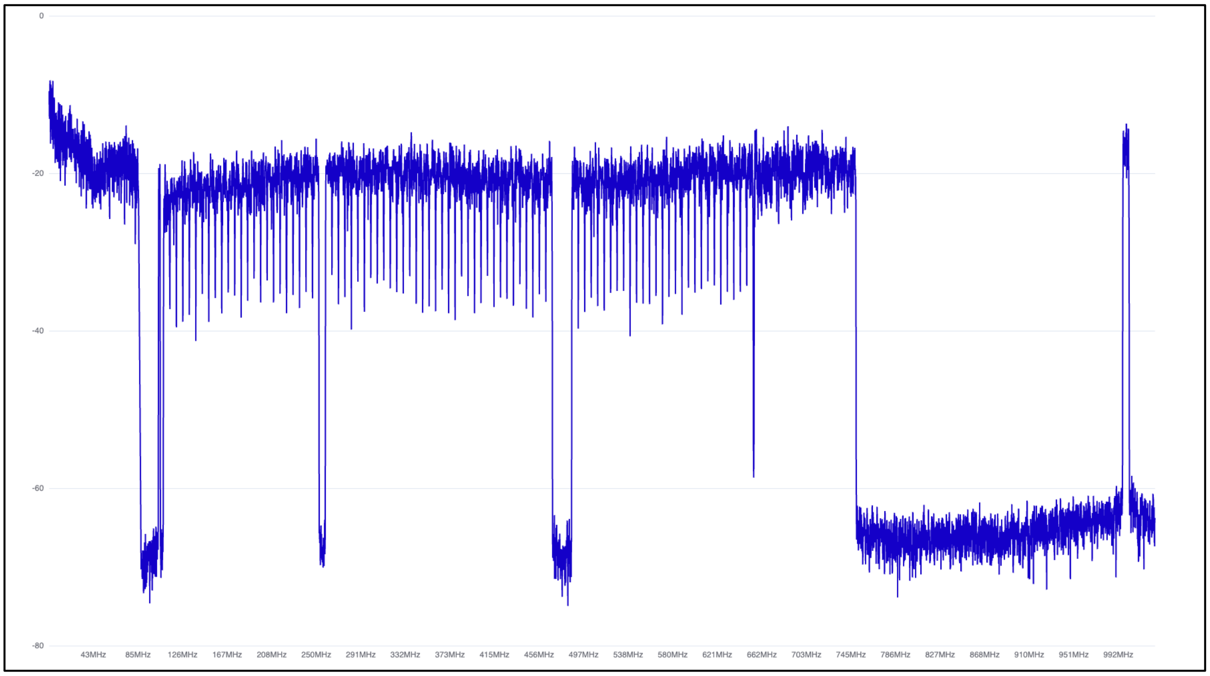

Figure 13- Sample Spectrum (FBC) Bin Data With Averaging

Mapping spectrum data with color-coordinated locations helps identify at which amplifier to start troubleshooting, **Figure 14**.

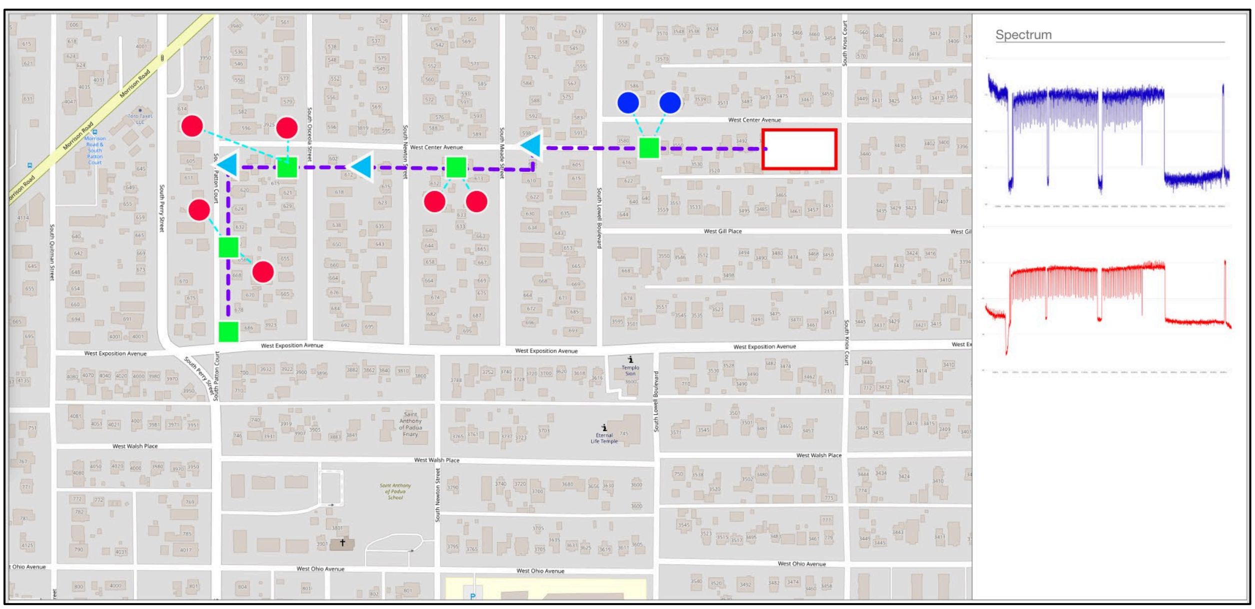

Figure 14- Identifying Locations (Red Devices) Experiencing Elevated Noise Floor

5.2. Visualizing the Data

Creating FBC images from bin data to represent the behavior of the signal is very common and well-understood. In this context, however, we are as interested in visualizing the noise *and* the signal. To that end, when we create the device representations, we must carefully consider the frequency bands of interest and the reference axes if we are to apply the data practically. In our test scenario, there is value in closely examining the spectrum between 87 MHz and 107 MHz. We consider this region to be the diplex filter transition region. Both of the channel plans tested were mid-split. As such, the first linear video channel began at 108 MHz, and the diplex filters of the DOCSIS 3.1 devices under test provided a low internal noise figure at these frequencies for us to analyze against. There is an Out-of-Band (OOB) data carrier at approximately 104 MHz; however, its width and the guard band spacing on either side didn't make it a useful reference point.

There is also great value in visualizing the entire catalog of available bin data to create a representation of the signals and the noise floor at both low and high frequencies. This is the more typical and accepted representation of FBC data.

5.3. Analyzing the Data

With the considerations described above in mind, the visualization of the test devices connected to an amplifier set to optimal input drive levels can be considered the baseline for good, or linear performance, at both the full spectrum representations and in the diplex filter transition region.

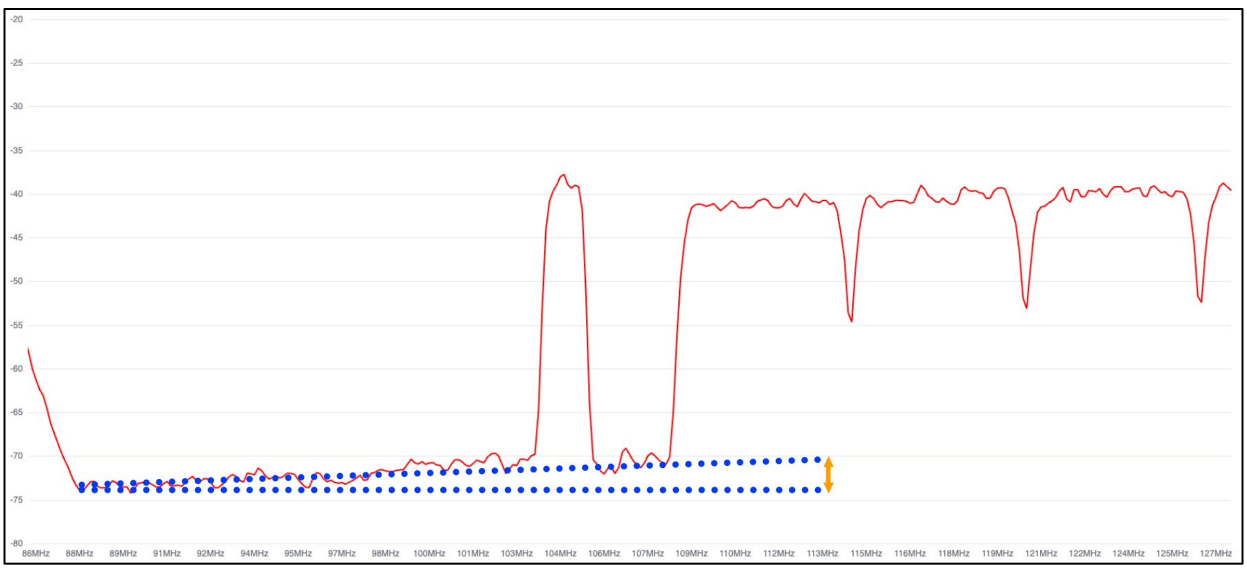

Figure 15- Diplex Filter Transition Region of a Device in Optimal Conditions

We added two lines to the bin visualization, beginning at a transition frequency of 87 MHz: one at a parallel amplitude to the noise figure at 87 MHz and another that intersects with the noise floor where the noise and the signal intersect at the leading edge of the linear video channel at 107 MHz, **Figure 15**. This created what we call a "noise angle." The diplex filter transition region exhibits an acute noise angle for devices connected to an amplifier operating in a linear or optimal fashion. The precise angle has not been calculated for this paper but is a consideration for future work on this topic.

Ingress can impact the low-frequency noise in an individual device within a premise, and some localization logic may have to be applied to discern the impact of the plant alignment, exclusive of premise wiring or ingress that may be present.

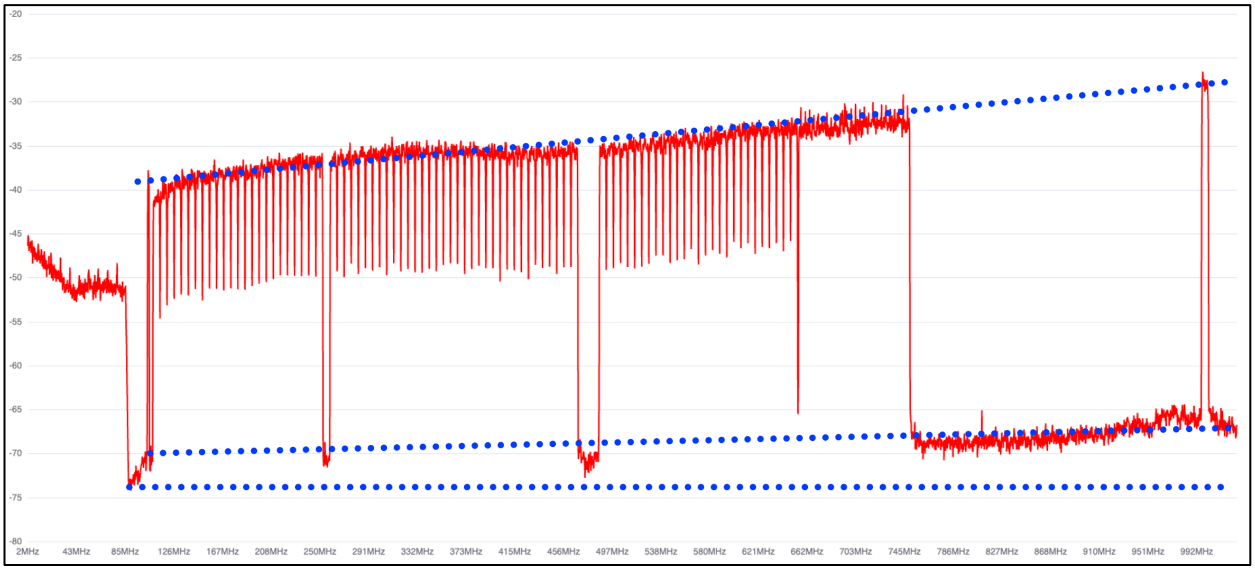

Figure 16- FBC Example of a Device With Optimal Amplifier Setup

We also observed other angles where the signal and noise relationship in the FBC representation of devices appear informative, **Figure 16**. A parallel line was constructed from the 87 MHz noise figure point extending to the highest frequency bin data point available from the device. This line indicates the noise figure of the measurement device. Creating another line that begins at the intersection of the noise floor, and the leading edge of our first video channel, in this instance 107 MHz, and extending that line to the highest frequency noise bin data point, we create another angle, which has a comparative amplitude at high frequency, which can be considered the noise delta (dn, **Figure 17**). The noise delta calculation can is expressed as: (dn) = high-frequency noise floor (hfnf) – low-frequency noise floor (lfnf). While this noise delta does not indicate the approximate position of the device under test (DUT) on the NPR or MER curves, it can be informative when combined with other pieces of information, like CPE receive level, MER, or RxMER. We also observed the relative relationship between the slope or tilt of the signal, with the slope or the tilt of the noise floor itself. These could be described as the signal slope and the noise slope.

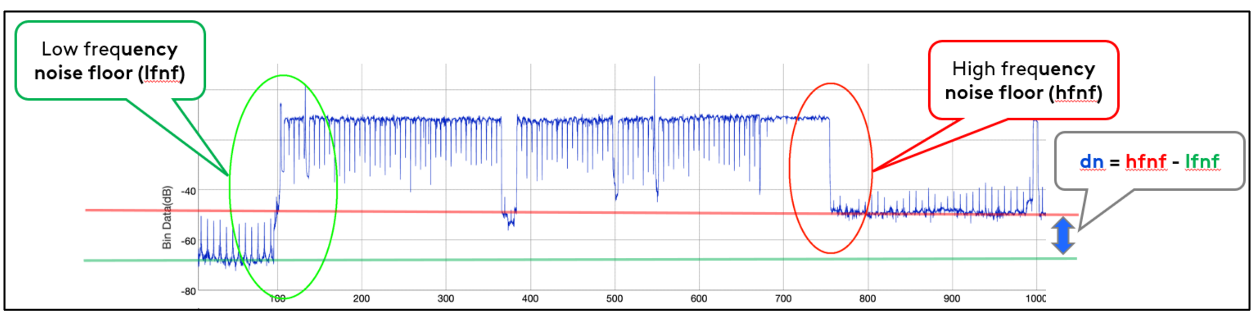

Figure 17- Example of Noise Delta (dn) Calculation

Using the data and visualizations from devices in ideal conditions, we compared data captured at other defined positions on the MER curve.

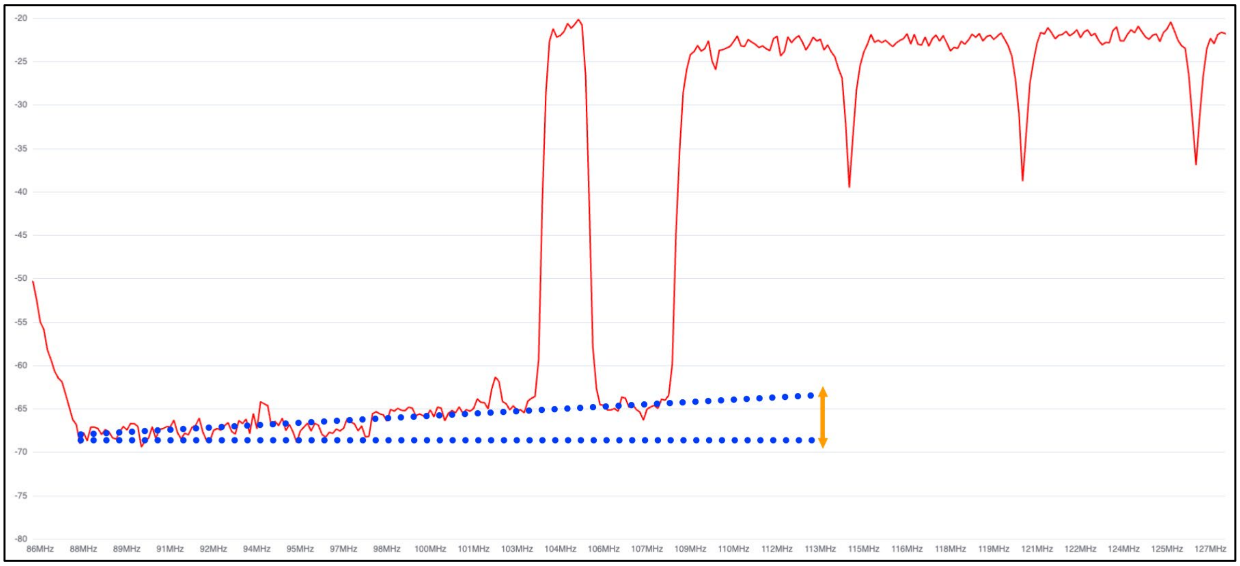

Figure 18- Diplex Filter Transition Region of a Device in the Noise Region of the MER Curve

Examining the noise angle, **Figure 18**, of a device connected to a system operating in the noise region of the MER curve, we found negligible difference in the noise angle when visually compared to a device operating in ideal conditions.

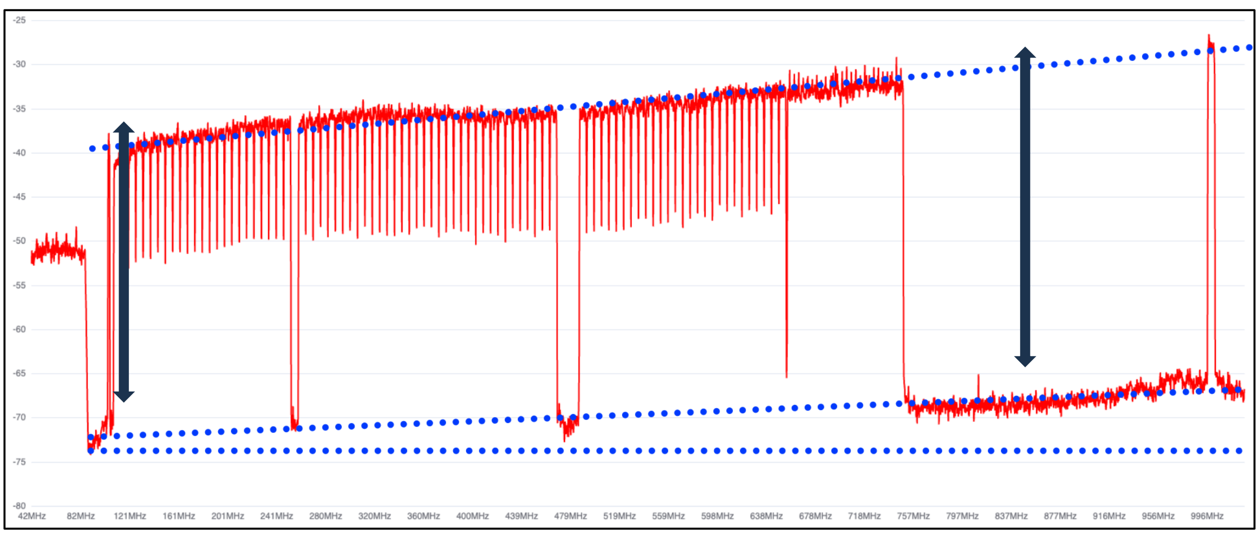

Figure 19- Example of a Misaligned Amplifier Operating in the Noise Region

When we observe the entire spectrum plot, some differences begin to emerge. Compared to the signal slope, the noise slope appears parallel, and the intercept point where the noise and signal converge at 107 MHz appears closer than the optimal setup condition, **Figure 19**. The noise delta calculated using the hfnf – lfnf equation is similar to optimal. However, the slope relationships are slightly different.

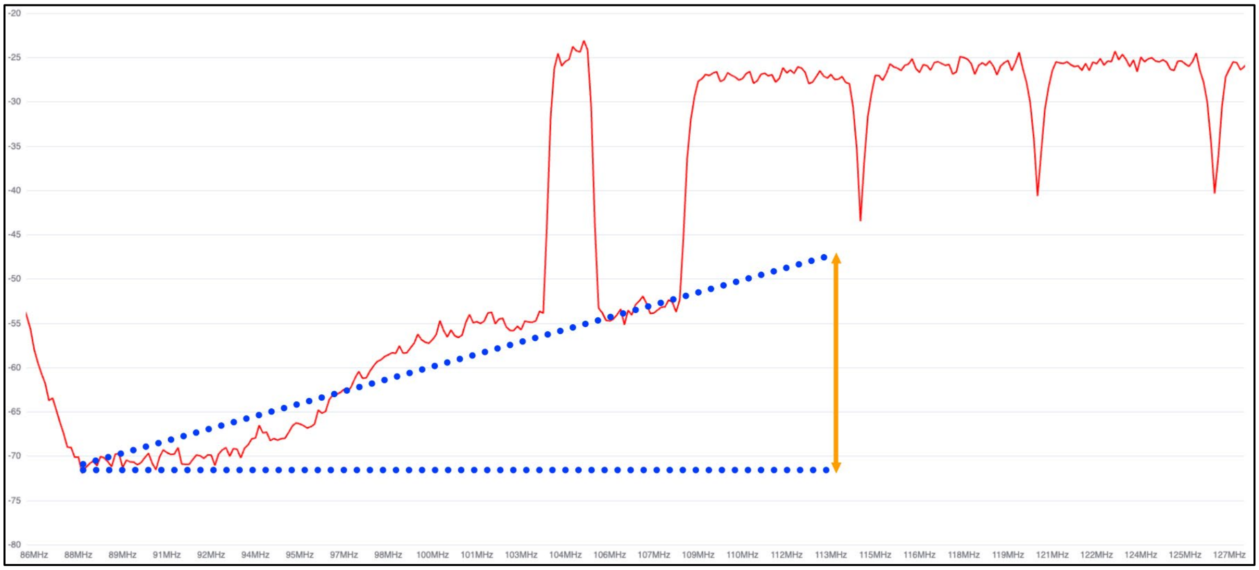

Figure 20- Diplex Filter Transition Region of a Device in the Clipping Region of the MER Curve

Moving to the device data from a system operating in the clipping portion of the MER curve, the impacts on the noise and signal relationship become immediately apparent. Examining the noise angle in the diplex filter transition region of a device connected to a system operating in a non-linear state shows significant impact using this noise angle method, **Figure 20**. This may also appear to be premise-related ingress or noise until we examine the entire spectrum plot and the impact of the noise floor at higher frequencies.

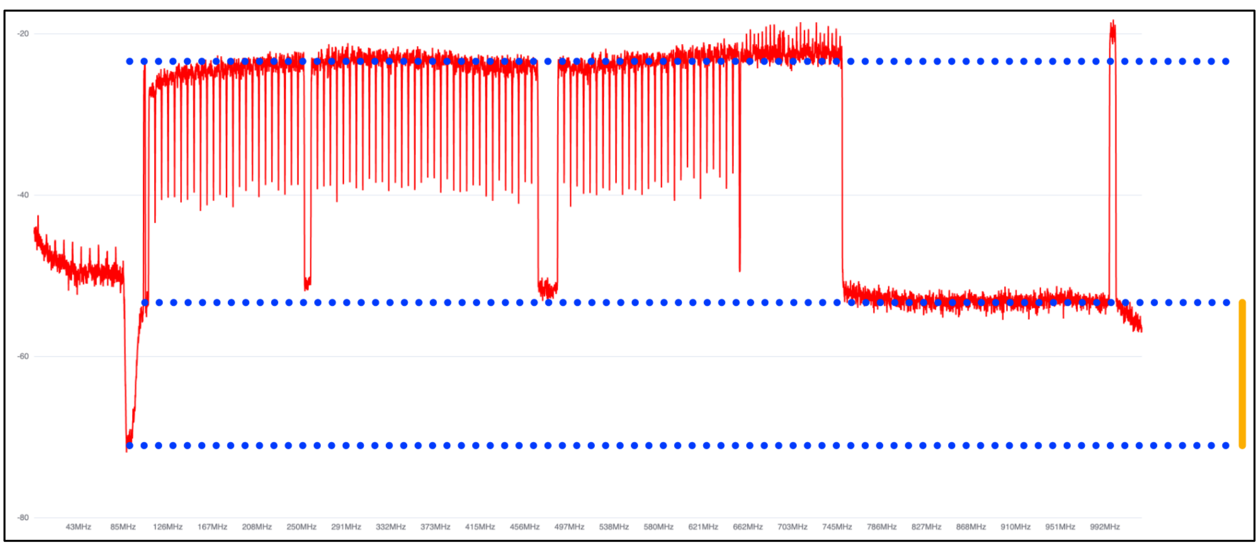

Figure 21- Example of a Misaligned Amplifier in Compression

Devices connected to this system were operating at a point 6 dB past the peak. The impact of non-linear performance becomes evident when evaluating the signal, noise amplitude and angle relationships. The amplitude and slope of the noise change with respect to the amplitude and slope of the signal, **Figure 21**. This appears to be the equalized response of the second and third-order (CSO and CTB) distortions of our digital channel plan generated by the amplifier.

Compared to the optimal condition, we are displaying the visual representations of the extreme cases at either end of the MER curve. The test data included many additional data points between the examples presented in this paper. Initial analysis of those other data sets supports the behaviors indicated by both NPR and MER curves. As devices transition through the curves, beginning in the noise region of the curve, as power is applied, there is a relatively linear relationship between the signals and the noise until you reach the clipping region, where the power-to-noise relationship is affected at a greater than 1:1 relationship.

Using the methods we describe for this test, it is possible to estimate the position of a system or amplifier on an MER curve and predict the impact of adding power to the system. Additionally, by understanding the amount of power added to the system, the predictions could include the severity of the impact if the system is in a non-linear state.

5.4. Practical Application

5.4.1. Pre-Enablement

The initial development for practical application of this effort was to predict the success of additional spectrum enablement. Using the data derived in our test environment directly informs this spectrum enablement process. A PNM-informed process could look something like this:

In the target node, acquire and store pre-enablement FBC bin data for the service group with the additional spectrum activated. Using PNM tooling and thresholds, evaluate the device pre-enablement telemetry for key indicators of non-linearity. Knowing that our spectrum enablement increases the system's TCP by 2 dB, any indications of non-linearity in any device in the node would predict that the system would deteriorate by a value greater than 2 dB, and enablement could end in catastrophic system failure.

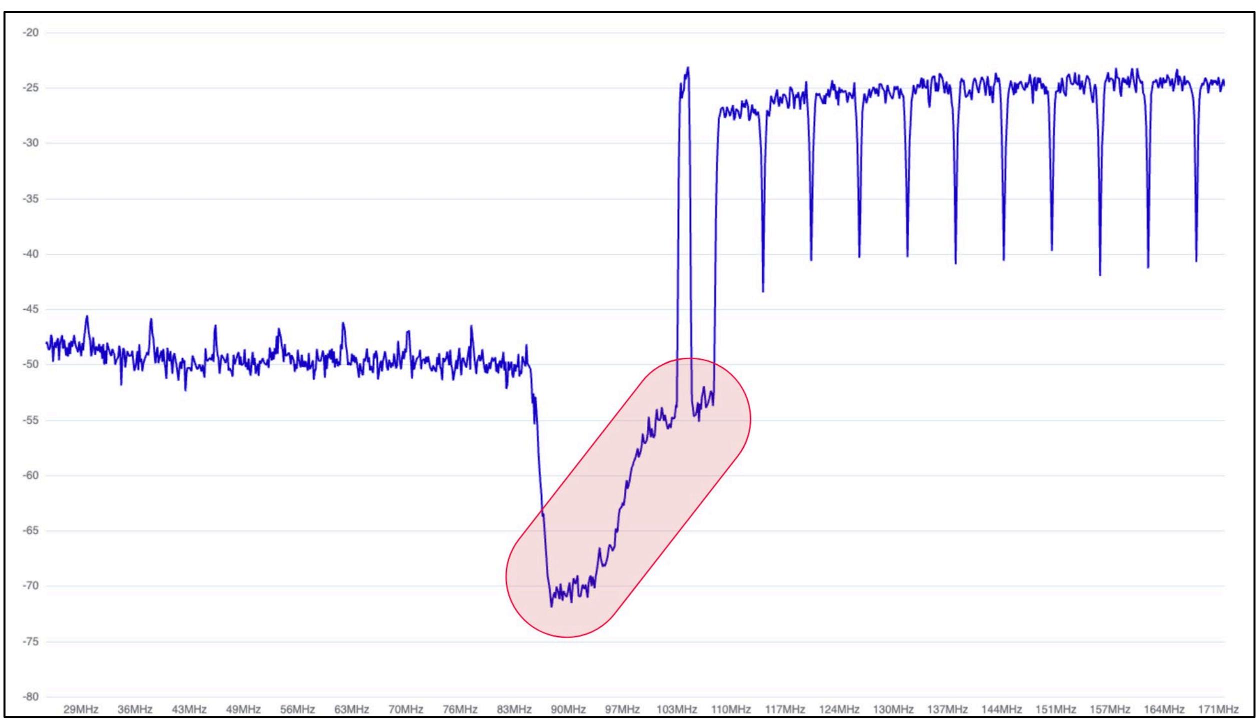

Figure 22- Example of Distortion Noise in the Diplex Filter Transition Region

If the target system does not detect impaired devices, the system could be considered a candidate for full deployment or a multi-phase approach to enablement. This multi-phase approach is the "canary" approach. This involves introducing a portion of the desired power into the system, 1 dB of TCP, for instance, and then requery devices for evidence of non-linear impairments, **Figure 22**. If the node devices show no or minimal indication of impairment, then the risk of degradation or failure due to the additional TCP can be considered negligible.

5.4.2. Post Enablement

Are there practical applications to this approach once your downstream payload is fully deployed? If we consider the dynamic conditions of the outside plant networks, and the inherent variability of weather, then this logic could have continued applications well beyond spectrum enablement. Instances of Automatic Level Control (ALC) failures in amplifiers, resulting in increased power into the successive amplifiers in cascade, are not uncommon. These changes in amplifier drive level could result in amplifiers becoming non-linear and would be in scope for tooling efforts such as this.

6. Conclusion

As outlined in this paper, there are many things to consider when evolving a CATV network, including the monitoring tools. PNM has become an indispensable platform for an operator to measure and qualify the network's performance. We believe the data collected, analyzed and shared in this paper support the position that amplifier alignment analysis using PNM tooling is one more tool that can be successfully developed and added to the toolbox. Operators desiring to enable additional spectrum into the downstream of their networks should be able to predict whether their system is operating in a condition that would allow them to do so successfully using PNM tools.

Abbreviations

ALC	Automatic Level Control
BER	Bit Error Rate
CATV	Community Antenna Television
CCN	Carrier-to-Composite Noise
CIN	Carrier-to-Intermodulation Noise
CMTS	Cable Modem Termination Systems
CNR	Carrier-to-Noise Ratio
CPE	Customer Pr
CSO	Composite Second Order
CTB	Composite Triple Beat
CTN	Carrier-to-Thermal Noise
DUT	Device Under Test
FBC	Full Band Capture
HFC	Hybrid Fiber Coax
MER	Modulation Error Ratio
MHz	Megahertz
NPR	Noise-to-Power Ratio
OOB	Out-of-Band
PNM	Proactive Network Maintenance
QAM	Quadrature Amplitude Modulation
RF	Radio Frequencies
RxMER	Receive MER
SNMP	Simple Network Management Protocol
TCP	Total Composite Power

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