# Next Generation Neighbor Interference Prediction Tools

## From iHAT to nHAT

A Technical Paper prepared for SCTE by


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## 1. Introduction

During the planning for activation of the mid-split spectrum on the cable plant, adjacent channel interference (ACI) between the mid-split upstream spectrum and legacy devices on the network that use the same spectrum on the downstream was anticipated. Extensive testing was conducted on DOCSIS® and set-top devices to understand the impact on the performance of these devices and the customer-impacting thresholds. Based on this testing, tools have been developed to identify this interference and prevent negative customer experiences when the mid-split spectrum is activated.

With millions of mid-split activations in the field, we have been able to see how well the tools that look for interference perform. We also have gained better insight into how ACI impacts the RF front end and performance of the CPE devices and how in-home wiring can have a large impact on ACI.

As the industry moves to DOCSIS 4.0 technology, ACI involves not just co-located in-home devices but also neighboring devices. In this paper, we will review our current prediction tools for ACI, field and lab test results of CPE devices in the presence of ACI, and improvements which have been made to the prediction tools. Most important will be how these tools and lessons learned can be adapted to understand and predict neighbor interference to ensure an optimal customer experience as the upstream spectrum is expanded further in DOCSIS 4.0 technology.

## 2. Mid-Split Adjacent Channel Interference Background

As the industry moves to increase bandwidth with the full capabilities of DOCSIS 3.1 and 4.0 devices, these devices will be deployed simultaneously with older, less capable devices: cable modems, gateways, and set-top boxes. Different revisions of these devices have different RF filtering and front ends, and it is important to ensure interoperability with differing upstream channel loads and RF bandwidths.

In mid-split systems, set-top boxes are more susceptible to adjacent channel interference (ACI). The front end of the set-top boxes typically has a lower downstream band edge of 54 MHz, which overlaps with the mid-split upstream frequency band of 5-85 MHz. With the activation of the mid-split spectrum, energy from the Mid-Split cable modem/gateway at 54-85 MHz can make its way across the in-home splitting network and impact the operation of the set-top boxes. This is shown in Figure 1. Another contribution to the interference problem is that the upstream transmission from the cable modem is at a much higher power level compared to the downstream receive level at the CPE devices.

Typically, a high transmit level is the result of high upstream path loss; these conditions can also lead to low downstream receive levels. A change in path loss results in a 2-to-1 relationship between the interfering signal level at the set-top box vs. the downstream receive level at the set-top box. As an example, if a cable modem is transmitting at its maximum power of 65 dBmV, with 25 dB splitter isolation, the total composite power of the interfering signal level at the set-top box is 40 dBmV. With a nominal input level of -10 dBmV/6 MHz into the set-top box, which equates to a total power of 11.7 dBmV, the ACI is 29.3 dB higher than the downstream total power. This is shown in Figure 2. This level difference, plus the bursty time domain nature of this interfering signal, can impact the AGC of the set-top box along with overdriving the front end, causing distortion.

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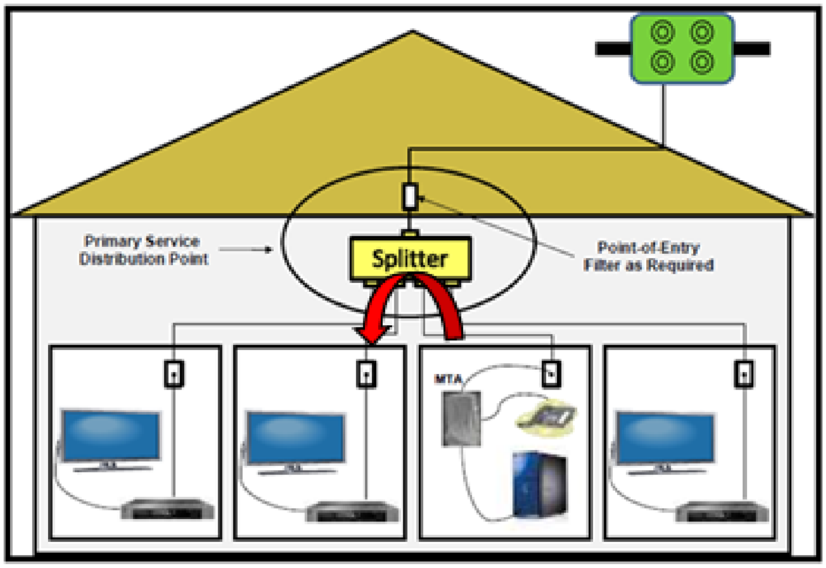


**Figure 1 - ACI In-Home Interference**

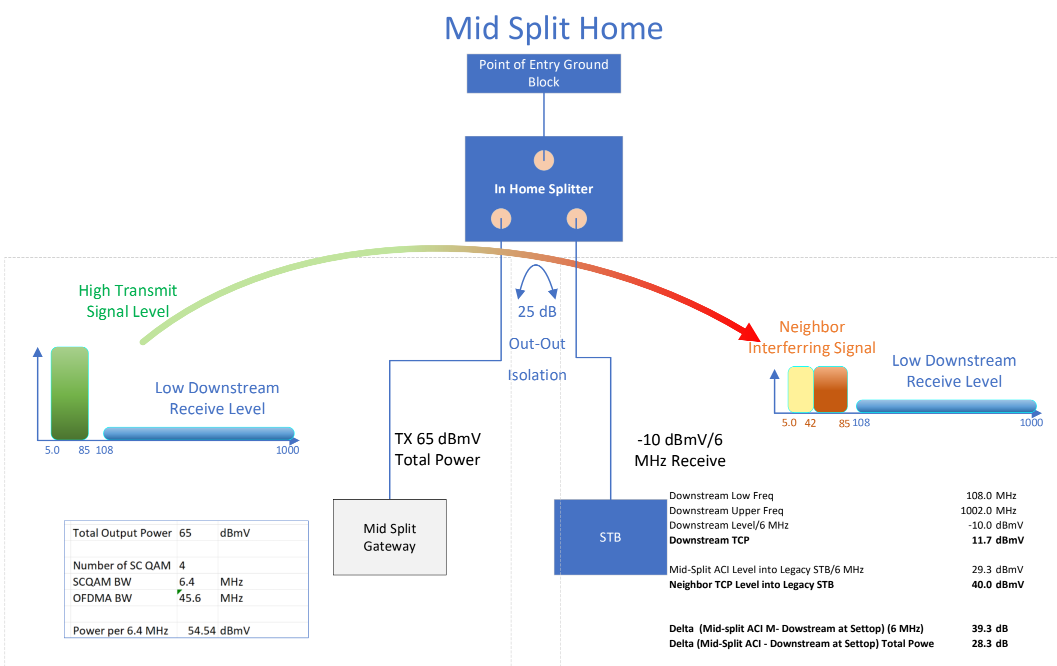


**Figure 2 - ACI Example Power Calculation**

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## 3. iHAT Background

To be proactive and minimize any negative customer experience during mid-split upgrades and activation, Comcast developed an In-Home Assessment Test tool called iHAT. This tool has two main functions. The first is to check and validate that a mid-split device can use the mid-split spectrum and OFDMA channel on the upstream. Second is an ACI video interference test for any set-top boxes in the same home as the mid-split cable modem or gateway.

The test to validate the OFDMA channel is straightforward, with a check if the OFDMA channel is bonded. The test to check for video interference is more involved. The original concept for iHAT video interference was a brute force test, which consisted of running a speed test and simultaneously monitoring the SNR of the adjacent set-top box. This had several issues. First, the speed test needed to use the entire upstream spectrum. Second, the speed test had to be long enough to affect the set-top box SNR. Third, in order to run a speed test and use the entire upstream spectrum, a specific boot file had to be loaded onto the cable modem and then reverted to the customer boot file after the test. Fourth, the STB had to be tuned to a specific channel to monitor the SNR. This was customer-impacting in many ways. Loading the boot files required a cable modem reboot. Using the entire upstream spectrum to check for interference had the possibility of impacting high-speed data customers, and changing the STB tuner to a specific channel can impact a customer's viewing experience.

A better way to measure video interference had to be developed. DOCSIS 3.1 technology has an OFDMA Upstream Data Profile (OUDP) functionality which allows the CMTS to schedule an upstream OFDMA burst which can be used for measurements. Comcast had developed and used OUDP signaling to facilitate upstream leakage measurements for high-split applications. OUDP signaling coupled with downstream spectrum capture on the set-top boxes allows adjacent interference measurements without impacting the customer’s experience. The OUDP burst originally was 1.6 MHz wide at 80 MHz. The narrow bandwidth was chosen to minimize adjacent interference and minimize unwanted power at the set-top box. 80 MHz was chosen to correspond to the lowest isolation point in the spectrum. RF splitters typically have lower isolation as frequency is increased, and 80 MHz is near the worst isolation point of the splitter in the mid-split band. Figure 3 and Figure 4 illustrate the upstream spectrum with the OUDP burst and typical in-home splitter isolation.

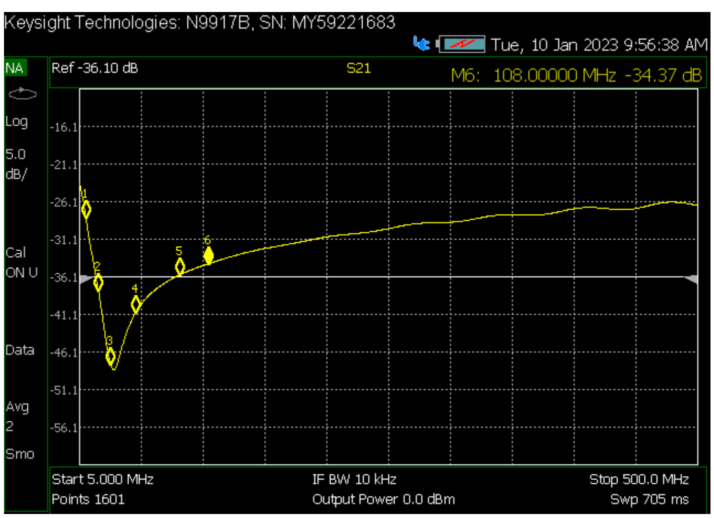


**Figure 3 - Typical Splitter Isolation Lab Measurement**


**Figure 4 - Upstream Capture Showing OUDP Burst**

Figure 4 - Upstream Capture Showing OUDP Burst shows the upstream band with 4-SC QAM channels, OFDMA and OUDP burst. Through extensive testing measuring interference thresholds on set-top boxes in the lab, we have established a threshold set for pass/fail for interference, which the customer sees as video tiling. From the set-top box full band capture, the delta between the OUDP burst, and downstream spectrum is measured and compared against the pre-determined threshold. If the delta exceeds the threshold, the device is steered to the 4 SC-QAM sub-split bonding group via a DBC command, and the OFDMA channel is not used. If the delta is lower than the threshold, the device remains with the OFDMA channel active. In the example in Figure 5 - Set-top Box Downstream FBC with OUDP and Downstream Video, the ACI delta is ~ 25 dB, which is very high and would trigger the device to be steered to sub-split.

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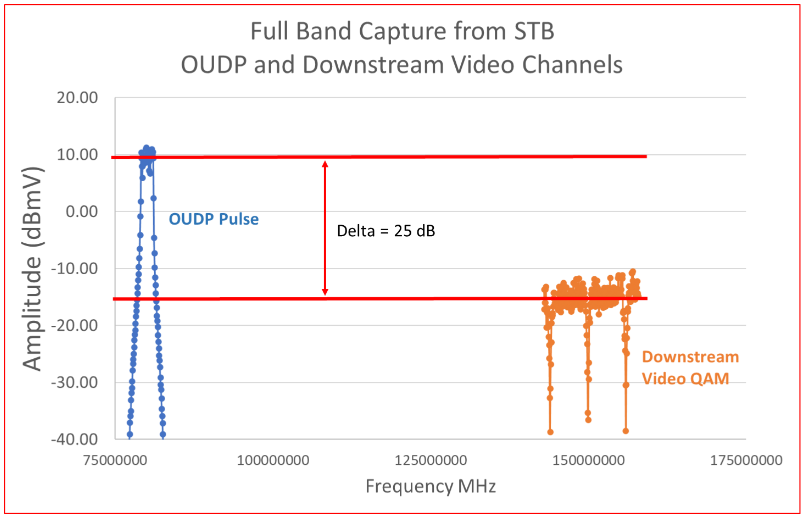


**Figure 5 - Set-top Box Downstream FBC with OUDP and Downstream Video**

## 3.1. Summary of Comcast Mid-Split Deployments and iHAT Results

Comcast has a well-defined automated process for activating mid-split. Over the past year, Comcast has tested over 2.4 million mid-split devices, and iHAT is run for every mid-split RPD activation with results available in several dashboards.

The iHAT summary dashboard for all these tests is shown in Figure 6 - iHAT Summary Dashboard. We see:

- 77.4% Pass
- 15.5% OFDMA blocked, (typically in-home drop amps blocking the OFDMA)
- 1.7% Video failures, (based on the OUDP test measurements)
- 3.9% Could not be tested

We also look at CM high transmit power to ensure the devices that do not have enough power to support the extra mid-split spectrum are not forced to use OFDMA.

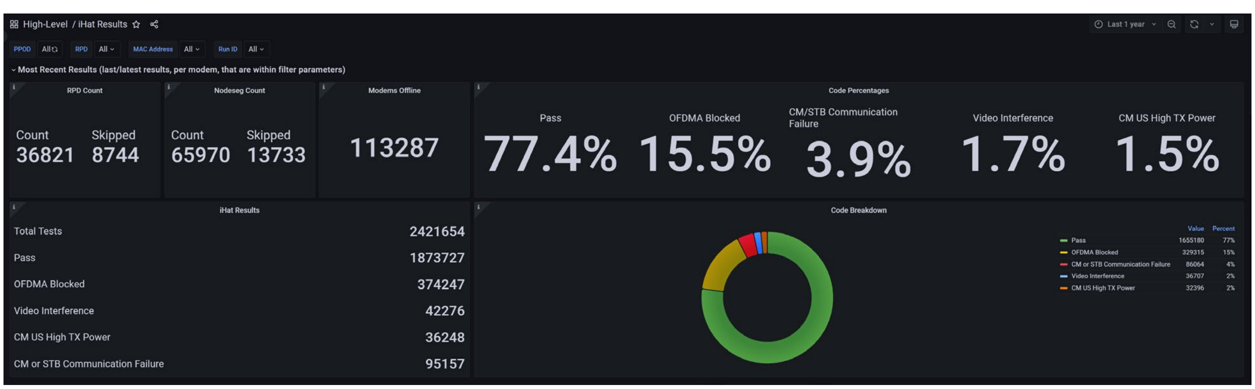


**Figure 6 - iHAT Summary Dashboard**

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# 4. iHAT Improvements and Optimization

## 4.1. Field Test Results

Over the course of these 2.4 million deployments, observations, updates, and optimizations have been made to the functionality of iHAT. After reviewing the data and feedback from customers and field technicians, we investigated instances where iHAT was not as accurate as we needed on the video interference test. After evaluating many customer accounts, we identified two main areas for improvement to accuracy.

## 4.2. STB Front End Concerns

Our original test data for video interference was based on understanding that the burstiness and duty cycle of the interfering signal affected the AGC of the set-top box, which would affect the entire downstream band, and all video channels would be impacted. The data used to determine the thresholds for video interference was taken in the middle of the downstream video band.

Table 1 shows test data from 4 customer accounts that experienced video interference. Three of these accounts used RDK set-top boxes, and one account had a 3rd party video device, which also experienced video interference.

**Table 1 – Setop Field Video Tiling vs ACI Frequency**

| Customer | CM | STB | DS RX dBmV | US TX dBMV | 111 MHz | 129 MHz | 291 MHz | 333 MHz |
|---|---|---|---|---|---|---|---|---|
| 1 | RDK D31 modem A | STB model A | -4 | 45 | Y | Y | N | N |
| 2 | Retail modem A | Cable Card based video device | 0-6 | 44 | Y | Y | N | N |
| 3 | RDK D31 modem A | STB model B | -6.5 | 47.8 | Y | Y | Y | Y |
| 4 | RDK D31 modem AB | STB model B | -9 | 50 | Y | Y | Y | Y |

As can be seen from this data, two accounts showed video interference at lower video channels, and two accounts showed video interference across the video spectrum; this result implied there was more to the interference than just AGC impact on the set-top box. Additional testing was completed in the lab, which confirmed that the interference from the adjacent mid-split spectrum caused a 2nd harmonic distortion, affecting video channels 2X the frequency from the narrow OUDP interfering signal as shown in Figure 4 and Figure 5.

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### 4.3. 2nd Harmonic Distortion

Figure 7 - MER Degradation with 4 MHz OUDP Pulse shows the degradation of MER and codeword error rate on the video channels in a STB vs. the input frequency of the interference. In a lab home network configuration, a 4 MHz wide OUDP pulse was generated at different frequencies in a cable modem, and corresponding frequencies of an adjacent set-top box were measured. A 4 MHz pulse was used to validate that only frequencies 2X the OUDP pulse in the video spectrum were impacted.

With an OUDP pulse with a 58.5 MHz center frequency, the entire spectrum is affected somewhat, but 2X the OUDP pulse frequency, 117 MHz, is most impacted. This second order distortion component of the interference continues as the OUDP pulse is cycled from 67.5 through 73.5 MHz. In each instance, the video channel 2X the video frequency is the most impacted. A similar correlation to the affected frequency is measured when looking at the codeword errors. Video frequencies 2X the OUDP pulse frequency were most impacted.

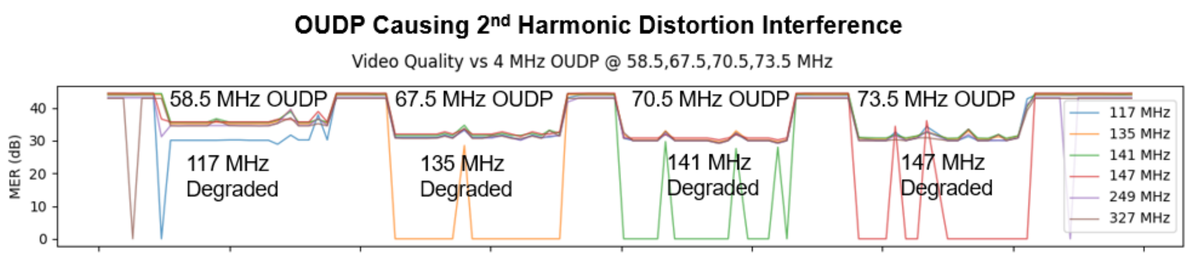


**Figure 7 - MER Degradation with 4 MHz OUDP Pulse**

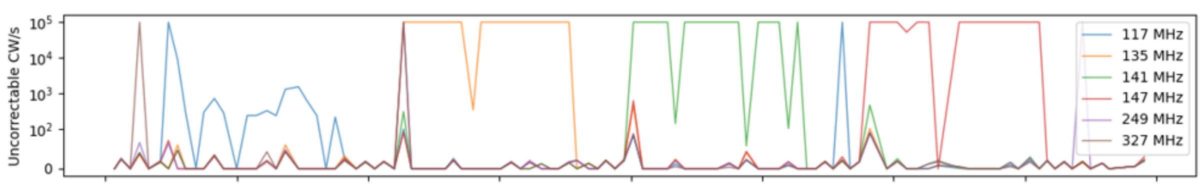


**Figure 8 - Codeword Error with 4 MHz OUDP Pulse**

In addition to measuring MER and codeword errors, testing was also performed for correlation to actual video tiling. A group of set-top boxes were set up, and the video was monitored, with adjacent channel interference applied at various frequencies. Video tiling was present on channels that were 2X the adjacent channel interference, correlating to the MER and uncorrectable codeword errors seen. This data is detailed in Table 2.

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**Table 2 – Setop Lab Video Tiling vs ACI Frequency**

| Channel Number | Channel Frequency (MHz) | US OFDMA Freq (MHz) | OFDMA Power (dBmV) | STB/TV1 Video Status | STB/TV2 Video Status |
|---|---|---|---|---|---|
| 800 | 141 | 60 | 59 | No Tiling | No Tiling |
| 800 | 141 | 70 | 52 | Video Tiling | Video Tiling |
| 800 | 141 | 80 | 59 | No Tiling | No Tiling |
| 306 | 159 | 60 | 59 | No Tiling | No Tiling |
| 306 | 159 | 70 | 59 | No Tiling | No Tiling |
| 306 | 159 | 80 | 50 | No Tiling | Video Tiling |
| 306 | 159 | 80 | 54 | Video Tiling | Video Tiling |

### 4.4. OUDP Pulse

One of the early updates to iHAT and the video interference test was to ensure that running the test itself caused minimal to no impact on the customer experience. The OUDP pulse used to measure the amount of interference at the adjacent set-top box was narrow in width, with a duration of the minimal amount of time needed to complete an accurate full band capture and measurement at the set-top box. As mentioned previously, the frequency chosen for the interference measurement was chosen for worst-case in-home splitter isolation, which is typically at higher frequencies. In investigating field-related video tiling, emphasis was placed on field measurements of the OUDP pulse and set-top box full band capture. During the field investigation, speed tests were performed with set-top full band captures recorded. Where the isolation of a splitter when measured with a network analyzer is typically at higher frequencies, looking at the full band capture of a speed test in the field, which utilizes the full upstream band, the isolation, and the measured spectrum can be significantly different from a splitter 2-port measurement in the lab. Figure 3 - Typical Splitter Isolation Lab Measurements shows the splitter isolation measurement in the lab. Figure 9 - Set-top Box Field Full Band Capture Measurement shows a full band capture measurement from the field, which in essence, shows the isolation of the in-home network. The red marker is at 80 MHz, and with an OUDP pulse generated at 80 MHz, the level measured on the full band capture is 7 dB lower than the maximum peak of the interfering signal at the setup box.

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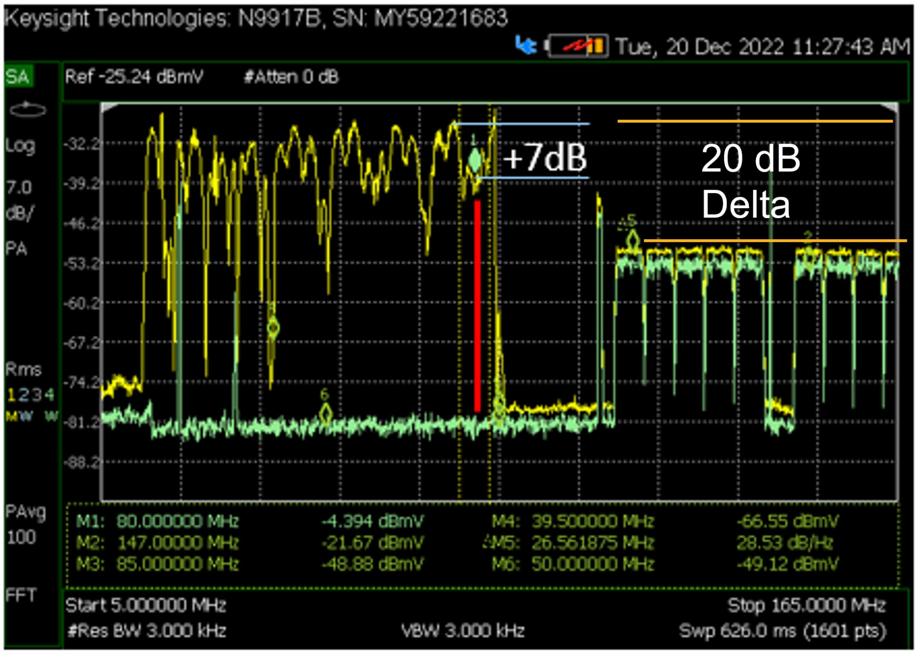


**Figure 9 - Set-top Box Field Full Band Capture Measurement**

Measurements were made in the lab with various in-home network topologies, with ports both terminated and unterminated, which validated the field results.

To improve the measurement accuracy of the isolation and interfering signal at the set-top box, a wider OUDP pulse is necessary to encompass the variation in amplitude seen with frequency. With an OFDMA bandwidth of 39.4-85 MHz, using this entire spectrum for the OUDP pulse and corresponding set-top box full-band capture would be the most accurate and provide the exact total interference level. This could be capacity and customer-impacting and also require a longer time to do an accurate full-band capture. Out of several measurements, a 20 MHz pulse was chosen and encompassed most of the variation in amplitude seen in Figure 9 - Set-top Box Field Full Band Capture Measurement while still minimizing the energy at the front end of the setup box during the measurement.

With a 20 MHz wide OUDP measurement, a different methodology to measure the interfering signal and energy at the set-top and corresponding ACI delta is needed. One method is to calculate the total power of the interfering signal. Another method is to measure the peak across the 20 MHz band. Due to the possibility of an interfering signal at a specific frequency causing 2$^{nd}$ Harmonic distortion, measuring the peak across the 20 MHz OUDP interference measurement was chosen. The full band capture of the 20 MHz OUDP band is broken down into ten 2 MHz segments, and then the segment with the highest power is used for the ACI delta measurement. An example of this is shown in Figure 10, the original 20 MHz wide pulse centered at 80 MHz is shown in gray, and the 20 MHz pulse is split into 2 MHz increments. In this example, the peak of the 20 MHz pulse and worst interference is below 80 MHz. When comparing the two methods, the original pulse at 80 MHz vs peak across the 20 MHz pulse from 60-80 MHz, the maximum power across the 20 MHz is ~ 2 dB higher than the original OUDP pulse, improving the accuracy of the ACI measurement.

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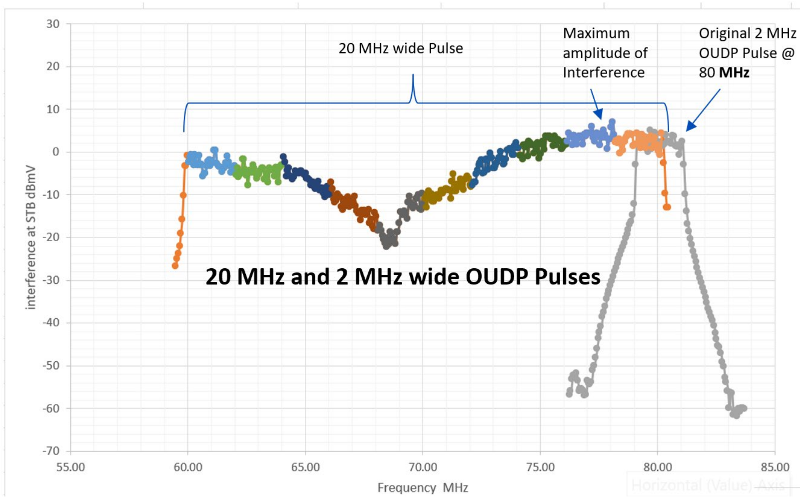


**Figure 10 - 20 MHz OUDP Pulse Measurement Example**

## 5. Summing up the iHAT Improvements

Using the above field and lab test data, the iHAT methodology was updated, and the field measurements improved.

1) The OUDP pulse was updated to be 20 MHz wide instead of the original 1.6 MHz pulse, and the peak across a 2 MHz band is used for the ACI measurement.
2) When using the lab set-top box data to calculate the interference thresholds, frequencies at 2X the upstream frequency is now used for threshold measurements.
3) When measuring the full band capture and interference, similarly, frequencies within 2X the OUDP pulse of 60-80 MHz are used to calculate the interference delta.

## 6. Moving to FDX

Full Duplex DOCSIS (FDX) technology poses additional challenges with adjacent channel interference. With Mid-Split systems, interference is confined to each individual mid-split customer's in-home network. The total power addition of the mid-split spectrum is high enough to cause interference on the mid-split customer's set-top box, but the total power of the mid-split spectrum is not enough to cause interference on neighbor home set-top boxes.

With a mid-split system consisting of four 6.4 MHz wide SC-QAMs and a single OFDMA channel 45.5 MHz wide, the power added by the OFDMA channels is 4.4 dB. With six 96 MHz wide FDX channels added, the additional power is 9.6 dB, or a total of 14 dB additional power with both the OFDMA and FDX channels. Figure 11 shows power addition for the OFDMA and FDX channels in the upstream.

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| | BW(MHz) | Power level per 6.4 MHz bandwidth | | |
|---|---|---|---|---|
| SCQAM1 | 6.4 | 45.00 | dBmV | |
| SCQAM2 | 6.4 | 45.00 | dBmV | |
| SCQAM3 | 6.4 | 45.00 | dBmV | |
| SCQAM4 | 6.4 | 45.00 | dBmV | |
| | | | | |
| | | SC QAM TOTAL POWER (dbmV) | 51.02 | dBmV |
| | | | | |
| MS OFDMA | 45.6 | Total Power SC + MS OFDMA = | 55.46 | dBmV |
| FDX1 | 96 | Total Power SC +MS OFDMA + FDX1 = | 59.17 | dBmV |
| FDX2 | 96 | Total Power SC +MS OFDMA + FDX1+FDX2 = | 61.14 | dBmV |
| FDX3 | 96 | Total Power SC +MS OFDMA + FDX1+FDX2+FDX3 = | 62.49 | dBmV |
| FDX4 | 96 | Total Power SC +MS OFDMA + FDX1+FDX2+FDX3+FDX4 = | 63.52 | dBmV |
| FDX5 | 96 | Total Power SC +MS OFDMA + FDX1+FDX2+FDX3+FDX4+FDX5 = | 64.35 | dBmV |
| FDX6 | 96 | Total Power SC +MS OFDMA + FDX1+FDX2+FDX3+FDX4+FDX5+FDX6 = | 65.05 | dBmV |
| | | | | dBmV |
| | | Total Power addition of FDX Channels | 9.59 | dBmV |
| | | Total power additoin of FDX and OFDMA | 14.03 | dBmV |

**Figure 11 - ACI Power Addition vs. OFDMA and FDX Channels**

In an FDX system, the FDX customer will be an all-IP customer with no additional gateways or set-top boxes. The FDX customer will have no DOCSIS devices that will be affected by the upstream FDX spectrum generated by their FDX cable modem. Instead, neighbor homes may be affected. Figure 12 - FDX Neighbor Interference Paths shows this potential interference path to neighboring homes.

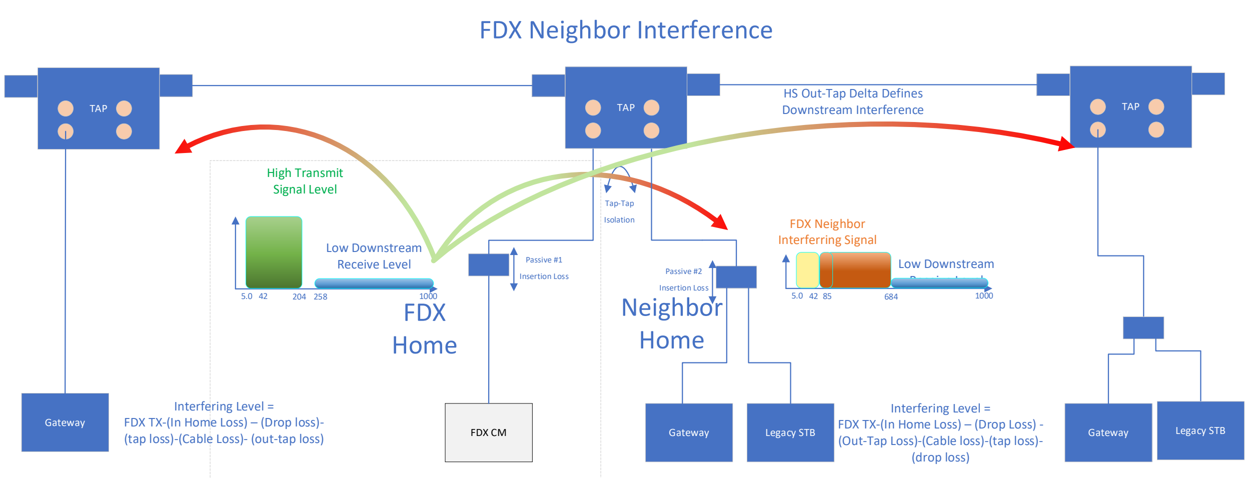


**Figure 12 - FDX Neighbor Interference Paths**

As can be seen, the neighboring homes contain set-tops with a sub-split front end, and DOCSIS 3.0 and 3.1 technology gateways can be susceptible to ACI from FDX signals from a nearby FDX device. To fully characterize the impact on these neighboring homes, Comcast labs in Downingtown and Dry Creek tested both gateways and set-top boxes to determine the thresholds for ACI interference. These results are presented in section 7 of this report.

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# 7. Determining Interference Thresholds

## 7.1. STB

### *7.1.1. Test Setup and Parameters*

Five different STB models from different vendors were selected based on ranking in terms of the total quantity deployed in the Comcast network. As discussed previously, both impact from the AGC and the distortion of the STB front end are part of this study. Since composite distortions will have frequency dependency due to the channel line-up and also due to the order (second, third, etc.), video is monitored at multiple channels corresponding to different analog frequencies.

Downstream video signals are generated from an RPD node. Upstream interfering carriers are generated using a DOCSIS cable load generator (CLGD), while a second CLGD is used to generate downstream FDX signals (Figure 13).

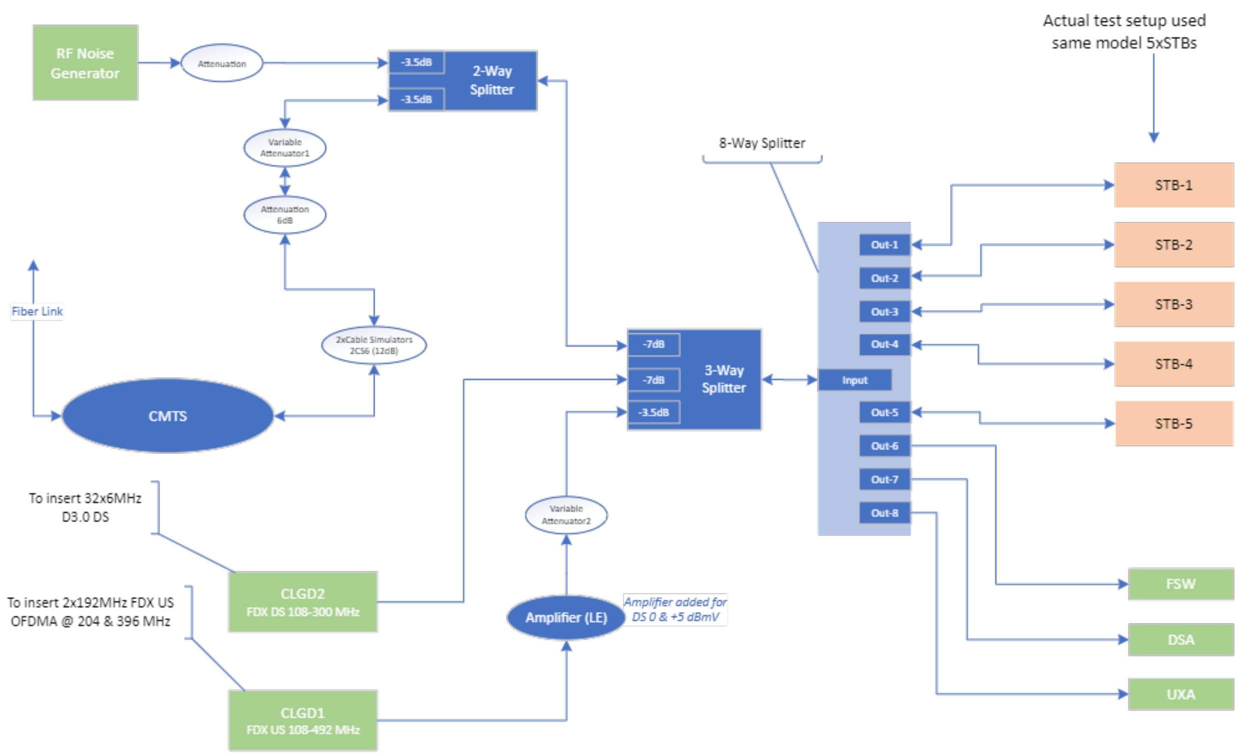


**Figure 13 - Test Setup for Adjacent Channel Interference on STBs**

The downstream signal levels are kept constant while the upstream carrier levels are increased until video tiling is observed. Upstream carriers utilize a burst profile as specified in the CableLabs PHY specifications, as shown below in Table 3 for waveforms with periods of 10, 70, and 200 milliseconds. Furthermore, a period with four milliseconds was added to the test parameters as real-time measurements of prototype FDX cable modems show that transmissions with periods as low as four milliseconds are possible.

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**Table 3 - Period and Duty Cycle for Upstream Burst Signals**

| US FDX Period (ms) | US FDX On Time (ms) | US FDX Duty Cycle (%) |
|---|---|---|
| 10 | 1 | 10 |
| 10 | 5 | 50 |
| 10 | 9 | 90 |
| 70 | 7 | 10 |
| 70 | 35 | 50 |
| 70 | 63 | 90 |
| 200 | 20 | 10 |
| 200 | 100 | 50 |
| 200 | 180 | 90 |
| 4 | 0.4 | 10 |
| 4 | 2 | 50 |
| 4 | 3.6 | 90 |

Waveforms generated by the CLGD for each period and duty cycle are verified on a real-time analyzer. Initially, due to RAM limitations, the CLGD was not able to generate upstream FDX signals with the correct timing, and a firmware upgrade was necessary to implement a new algorithm for generating the waveforms. Figure 14 is an example of the time domain measurement of a waveform with a duty cycle of 50% and a period of 10 milliseconds.

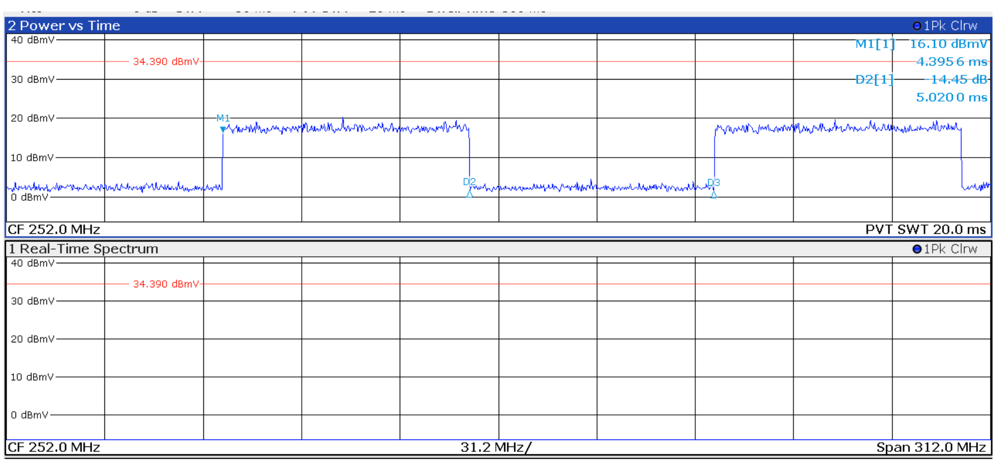


**Figure 14 - Power vs Time Capture of Waveform with 10 ms Period and 50% Duty Cycle**

Five different channel line-up scenarios were used in the test, shown in Figure 15 below. While these may not be the actual channel line-ups that will be deployed, they represent various amounts of upstream spectrum utilization to ensure that all cases are considered in the design.

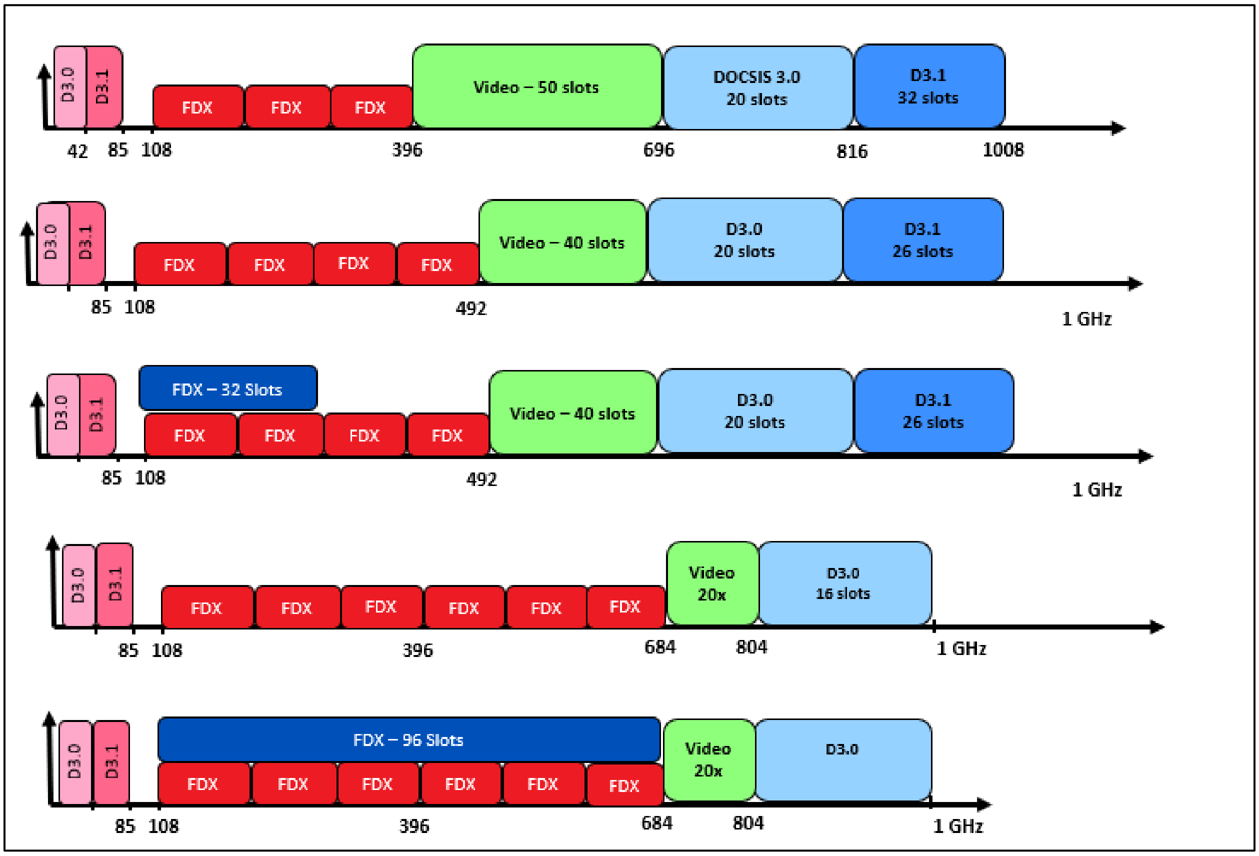


**Figure 15 - FDX Upstream and Downstream Channel Lineup scenarios for testing neighbor interference scenarios**

### *7.1.2. Test Results*

All measurements are in terms of total composite power (TCP) to provide for a consistent way to compare signal levels where interference to video quality is visible . TCP is measured for the upstream signal present at the STB front end and also measured for the downstream spectrum at the STB front end. The delta for these two TCP values is defined as the threshold value at which ACI impacts the STB and is the value that the neighbor Health Assessment Test (nHAT) uses as reference in its detection algorithm.

Thousands of measurements were taken for different channel maps, RF levels, downstream video frequencies, waveform periods, and duty cycles. This was set up using a Design of Experiment (DOE) approach, and the data was tabulated so that it could be analyzed using tools such as pivot tables and queries. It is not practical to include all the data in one report, so subsets of the data were selected and presented below to highlight factors that impact the TCP threshold for ACI interference.

The susceptibility of the STB to video tiling varies for each STB model. This is likely due to different chipsets and RF front-end designs. These performance differences are significant and can be in excess of 10 dB for different STB models, as shown in Table 4.

Furthermore, Table 4 also shows that both the period and duty cycle impact the TCP threshold. In the case of the STB with the lowest TCP threshold, the lower duty cycle of 10% and shorter period results in the lowest threshold.

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**Table 4 - TCP Delta Threshold for Map 2 and DS Video at 495 MHz**

| Period | 10 ms | | | 70 ms | | | 200 ms | | |
|---|---|---|---|---|---|---|---|---|---|
| Model / Duty Cycle | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| 1_Model A | 14.9 | 14.1 | 13.2 | 9.5 | 10.1 | 8.4 | 10.3 | 9.7 | 11 |
| 2_Modle B | 14.9 | 14.1 | 13.2 | 6.6 | 8.2 | 8.4 | 8.3 | 10.7 | 11 |
| 3_Model C | 15.7 | 14.1 | 14.1 | 8.3 | 14.1 | 14.3 | 8.3 | 8.6 | 12 |
| 4_Model D | 13.5 | 13 | 13.2 | 4.5 | 5.2 | 8.4 | 5.4 | 5.9 | 6.1 |
| 5_Model E | 4.4 | 7.1 | 12 | 4.5 | 5.2 | 12.5 | 5.4 | 5.9 | 8.1 |

Multiple video channels at analog frequencies ranging from closest to the FDX upstream signals to farthest away were measured. Table 5 shows the relationship of frequency to TCP delta. For the particular channel map (Map 2), the worst-case performance is not always at the lowest frequency (closest to the ACI signals) and is an indication that, in addition to the AGC, distortion from the STB front end is also a contributor to ACI.

**Table 5 - TCP Delta for Map 2 for Various Video Channels**

| Video Ch Freq | 495 MHz | 549 MHz | 651 MHz | 729 MHz |
|---|---|---|---|---|
| 1_Model A | 9.5 | 7.4 | 9.8 | 9.6 |
| 2_Modle B | 6.6 | 7.4 | 8.7 | 8.4 |
| 3_Model C | 8.3 | 8.3 | 10.8 | 10.9 |
| 4_Model D | 4.5 | 5 | 5.7 | 6.4 |
| 5_Model E | 4.5 | 4.3 | 5.9 | 5.5 |

As shown in Figure 15, Map 2 and Map 3 have the same upstream FDX spectrum. Map 3, however shows that a portion of the FDX upstream spectrum is also utilized for downstream FDX signals. Table 6 shows the TCP threshold measurements for the downstream video channel at 495 MHz. For the STB with the lowest TCP threshold, Map 3 resulted in an improvement to the TCP threshold of the STB.

**Table 6 - TCP Threshold Comparison for Map 2 and Map 3 (DS Video 495 MHz)**

| Map | 2 | | | 3 | | |
|---|---|---|---|---|---|---|
| Duty Cycle | **10** | **50** | **90** | **10** | **50** | **90** |
| 1_Model A | 14.9 | 14.1 | 13.2 | 13.4 | 13 | 12.8 |
| 2_Modle B | 14.9 | 14.1 | 13.2 | 13.4 | 13 | 12 |
| 3_Model C | 15.7 | 14.1 | 14.1 | 14.2 | 13.6 | 13.8 |
| 4_Model D | 13.5 | 13 | 13.2 | 12 | 13 | 12 |
| 5_Model E | 4.4 | 7.1 | 12 | 10.3 | 11.9 | 12 |

In conclusion, TCP threshold data was captured for all five maps, tested with different periods and duty cycles, at different RF input levels to the STB, and with video monitored at different frequencies. This

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data is then implemented as thresholds for the new nHat tool used to support FDX activations and to allow for proactive remediation of potential ACI issues.

## 7.2. Cable Modems

When the FDX CMs utilize OFDMA channels, the total composite power of the spectrum can fluctuate frequently to affect the neighboring pre-DOCSIS 4.0 CMs' downstream performance. This is because frequent total composite power fluctuations on legacy devices can cause analog-to-digital converter (ADC) saturations and result in uncorrectable codeword errors. Several factors, such as the tuners and AGC algorithms used by the pre-DOCSIS 4.0 cable modems, can result in variations in devices' tolerance levels to the neighbor interference bursts. To understand different CM models' performance under neighbor interference, we performed extensive tests to collect data for determining their thresholds.

### *7.2.1. Test Setup and Automation*

We designed test procedures for searching CM tolerance thresholds under different test setups and conditions. As the test procedures are highly repetitive and time-consuming if performed manually, we successfully developed test automation software to reduce the workload and testing time.

The lab setup created for neighbor interference testing for pre-DOCSIS 4.0 cable modems consists of a mid-split RPD, a set of cable modems under test, a traffic generator, and an upstream burst signal generator to simulate FDX upstream OFDMA bursts. The test automation software communicates with the test devices and equipment through various interfaces to control the traffic generation life cycles, power level, attenuation, cycle period, and duty cycle of the burst signal, and arbitrary waveforms for each interference band. For configuration changes and subscriber management, the test automation software utilizes our virtual cable modem termination system (vCMTS) application programming interfaces (APIs) to perform downstream OFDM modulation profile changes and dynamic bonding changes (DBCs). It also communicates with a network power switch's APIs to perform automated power cycling to reset CM states completely when necessary. The high-level illustration of the test setup is shown in Figure 16 - FDX Neighbor Interference CM Test Setup.

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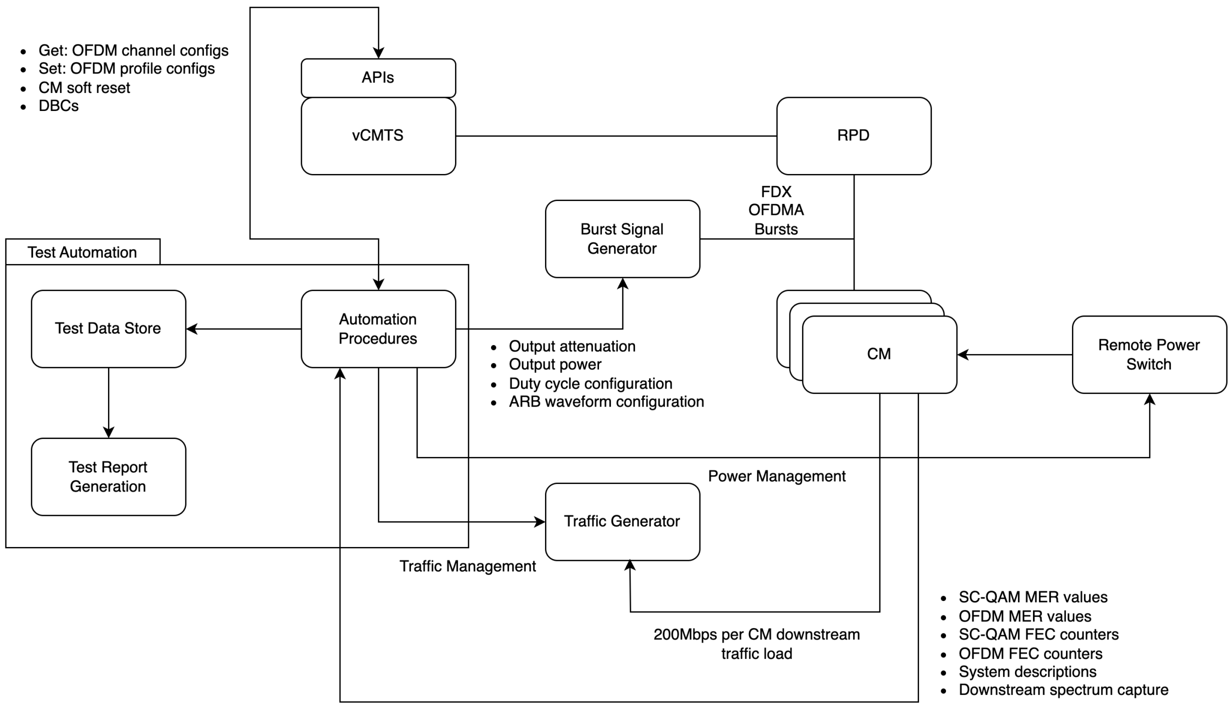


**Figure 16 - FDX Neighbor Interference CM Test Setup**

In order to collect increasing forward error-correction (FEC) codeword counters and calculate statistically meaningful codeword error ratio (CER) values, the traffic generator is configured by the test automation software to send 200 Mbps downstream user datagram protocol (UDP) traffic on each test device for 10 minutes during each round of the tests. This contributes to the majority of testing time.

The test automation software integrates with all required equipment controls and error handling that allow it to continuously run tests 24 hours a day, seven days a week, without human intervention. Once the tests are complete and the data is collected, interactive test reports are generated by the test automation software to include summarized test results and detailed CM performance metrics.

The test parameters in Table 7 are used to cover spectrum and interference characteristics variations while searching for devices' neighbor interference tolerance thresholds. Currently, the test automation is configured to search linearly through incremental interference output power levels; this provides a complete view of the CMs' performance while the interference characteristics change and provides valuable insights for determining the thresholds. Alternatively, when there is a need to identify the CMs' failing points quickly, binary search can be used while changing the interference's power level to reduce the test time.

**Table 7 - CM Neighbor Interference Test Parameters**

| Parameter | Value |
|---|---|
| Interference power spectral density difference range | 20 dB (1 dB steps) |
| Interference spectrum | 192 MHz, 288 MHz, 384 MHz, 576 MHz |
| Burst cycle periods | 4 ms, 10 ms, 70 ms |
| Duty cycle | 10%, 50%, 90% |

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For each spectrum configuration, 162 rounds of tests are run to cover all test parameter combinations. Given that each round of tests performs a 10-minute downstream traffic session, it can be estimated that the test automation covers all test parameter combinations within 30 hours, considering configuration and wait times on the test equipment.

In addition to the procedure designed to test with periodic neighbor interference bursts, we designed another test procedure to explore how the legacy devices tolerate sudden total composite power changes after they are adapted to quiet FDX bands. This test procedure is performed by turning the signal generator on after being muted for 4 minutes. It examines the maximum CM front-end tolerance under extreme changes and provides reference data points of bottom-line CM thresholds. Both described test procedures are run for DOCSIS 3.1 CMs and DOCSIS 3.0 CMs.

### 7.2.2. Initial Test Results

In this section, we discuss selected results from testing 288 MHz and 384 MHz of FDX upstream neighbor interference with DOCSIS 3.1 CMs, respectively. These two spectrum configurations are the candidates to be implemented in the initial FDX deployment phase. We also focused on researching the CMs' tolerance levels with simple interference characteristics as a starting point. This was done by injecting the neighbor interference signals in the downstream direction to affect the CMs' AGC immediately. Alternatively, as planned for future tests, the interference source can be combined to form port-to-port isolation to simulate a more realistic scenario in terms of echoes and harmonics or replaced by real FDX devices that are configured to utilize upstream FDX OFDMA bands at different levels.

The performance metrics collected from the CMs are downstream SC-QAM and OFDM FEC counters and MER values. These metrics are collected by the test automation software using simple network management protocol (SNMP) version 3 and are included in the test reports for passing/failing a test and providing detailed CM performance data. The FEC codeword counters of the downstream channels are used to calculate the CER values, which indicate the user impact from the traffic-loss probability perspective. The downstream MER values are expected to decrease as the power of the neighbor interference increases; this is because the AGC on the CMs adds attenuation to adapt to the increased total composite power. Degraded MER values can potentially affect the codeword errors on the SC-QAM channels as they approach the MER threshold for 256-QAM modulation order and can reduce the spectral efficiency of the OFDM channels as their modulation orders are downgraded by our profile management application (PMA) to ensure optimal robustness while maximizing the total capacity.

For each round of tests run for a certain combination of test parameters, the test failing criteria are defined as:

- Showing greater than or equal to $9e^{-7}$ CER on either SC-QAM or OFDM channels
- Significantly impaired SNMP (Simple Network Management Protocol) reporting capabilities

The passing/failing conditions are aggregated in the top-level test summaries, shown in Table 9, Table 10, and Table 11, by PSD differences between the interference and the rest of the legacy downstream spectrum; this means that failing one of the duty cycle tests also fails other tests conducted under the same PSD difference.

#### 7.2.2.1. 288 MHz FDX Neighbor Interference Test Results

In this test, the signal generator was configured to simulate 288 MHz (3 OFDMA bands) worth of FDX upstream bursts. The arbitrary waveforms were generated for combinations of 4 ms, 10 ms, and 70 ms burst cycle periods and 10%, 50%, and 90% duty cycles. A static, 1024-QAM flat modulation profile was

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assigned to the OFDM channel during the test. The CM downstream receive-power level was configured to -2 dBmV to accommodate the signal generator's maximum output power while staying in the receive-power range required by the DOCSIS PHY layer specifications. The spectrum configuration is shown in Table 8. The test results are listed in Table 9, Table 10, and Table 11.

**Table 8 - 288 MHz FDX: Downstream Spectrum Configuration**

| Type | Start Frequency (Lower Bound) | End Frequency (Upper Bound) | Width |
|---|---|---|---|
| Reserved for FDX | 108 MHz | 396 MHz | 288 MHz |
| Video QAM channels | 396 MHz | 696 MHz | 300 MHz |
| Downstream SC-QAM channels | 696 MHz | 816 MHz | 120 MHz |
| Downstream OFDM channel | 816 MHz | 1002 MHz | 186 MHz |

**Table 9 - 288 MHz FDX: 4 ms Cycle Period Test Results**

| Reference PSD Diff. (per 6 MHz) | Calculated FDX TCP (dBmV) | Calculated Legacy TCP (dBmV) | TCP Diff. (dB) | CM 1 | CM 2 | CM3 | CM 4 | CM 5 | CM 6 | CM 7 | CM 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +7 dB | 21.81 | 18.04 | 3.77 | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL |
| +6 dB | 20.81 | 18.04 | 2.77 | FAIL | FAIL | FAIL | FAIL | FAIL | PASS | PASS | FAIL |
| +5 dB | 19.81 | 18.04 | 1.77 | PASS | FAIL | PASS | PASS | FAIL | PASS | PASS | PASS |
| +4 dB | 18.81 | 18.04 | 0.77 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| +3 dB | 17.81 | 18.04 | -0.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| +2 dB | 16.81 | 18.04 | -1.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| +1 dB | 15.81 | 18.04 | -2.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |

**Table 10 - 288 MHz FDX: 10 ms Cycle Period Test Results**

| Reference PSD Diff. (per 6 MHz) | Calculated FDX TCP (dBmV) | Calculated Legacy TCP (dBmV) | TCP Diff. (dB) | CM 1 | CM 2 | CM 3 | CM 4 | CM 5 | CM 6 | CM 7 | CM 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +9 dB | 23.81 | 18.04 | 5.77 | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL |

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| Reference PSD Diff. (per 6 MHz) | Calculated FDX TCP (dBmV) | Calculated Legacy TCP (dBmV) | TCP Diff. (dB) | CM 1 | CM 2 | CM 3 | CM 4 | CM 5 | CM 6 | CM 7 | CM 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +8 dB | 22.81 | 18.04 | 4.77 | FAIL | FAIL | FAIL | FAIL | FAIL | PASS | FAIL | FAIL |
| +7 dB | 21.81 | 18.04 | 3.77 | FAIL | FAIL | FAIL | FAIL | FAIL | PASS | FAIL | FAIL |
| +6 dB | 20.81 | 18.04 | 2.77 | FAIL | FAIL | FAIL | FAIL | FAIL | PASS | FAIL | FAIL |
| +5 dB | 19.81 | 18.04 | 1.77 | FAIL | FAIL | PASS | FAIL | FAIL | PASS | FAIL | PASS |
| +4 dB | 18.81 | 18.04 | 0.77 | FAIL | FAIL | PASS | PASS | FAIL | PASS | FAIL | PASS |
| +3 dB | 17.81 | 18.04 | -0.23 | FAIL | FAIL | PASS | PASS | FAIL | PASS | FAIL | PASS |
| +2 dB | 16.81 | 18.04 | -1.23 | PASS | PASS | PASS | PASS | FAIL | PASS | PASS | PASS |
| +1 | 15.81 | 18.04 | -2.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| 0 dB | 14.81 | 18.04 | -3.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |

**Table 11 - 288 MHz FDX: 70 ms Cycle Period Test Results**

| Reference PSD Diff. (per 6 MHz) | Calculated FDX TCP (dBmV) | Calculated Legacy TCP (dBmV) | TCP Diff. (dB) | CM 1 | CM 2 | CM 3 | CM 4 | CM 5 | CM 6 | CM 7 | CM 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +6 dB | 20.81 | 18.04 | 2.77 | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL |
| +5 dB | 19.81 | 18.04 | 1.77 | FAIL | FAIL | FAIL | FAIL | FAIL | PASS | FAIL | FAIL |
| +4 dB | 18.81 | 18.04 | 0.77 | FAIL | FAIL | PASS | PASS | PASS | PASS | FAIL | PASS |
| +3 dB | 17.81 | 18.04 | -0.23 | FAIL | PASS | PASS | PASS | PASS | PASS | FAIL | PASS |
| +2 dB | 16.81 | 18.04 | -1.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| +1 | 15.81 | 18.04 | -2.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| 0 dB | 14.81 | 18.04 | -3.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |

It was observed that in the test results, different CMs can have significant tolerance thresholds to the neighbor interference, which can be as large as 7 dB worth of total composite power difference (between CM 5 and CM 6).

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Diving into the detailed test data, as a reference, the average MER value of the SC-QAM channels on CM 2 dropped approximately 3 dB as the neighbor interference power increased by 8 dB, such changes are shown in Figure 17 - 288 MHz FDX: CM-2 SC-QAM Average MER changes (4 ms cycle period). We also observed that the 10% duty cycle created more impact than the 50% and 90% duty cycles. An example from CM 2's test results is shown in Table 12.

**Table 12 - 288 MHz FDX: 10% Duty Cycle Created the Most Impact (CM 2 Example, 4 ms)**

| Reference PSD Diff. (per 6 MHz) | Duty Cycle | OFDM Avg. MER | SC-QAM Avg. MER | SC-QAM Corrected | SC-QAM Uncorrectable | OFDM Corrected | OFDM Uncorrectable |
|---|---|---|---|---|---|---|---|
| +5 dB | 90% | 42.36 dB | 40.58 dB | 0.000e+00 | 0.000e+00 | 5.149e-01 | 0.000e+00 |
| +5 dB | 50% | 42.12 dB | 40.55 dB | 0.000e+00 | 0.000e+00 | 5.387e-01 | 0.000e+00 |
| +5 dB | 10% | 42.25 dB | 40.54 dB | 1.901e-04 | **1.293e-03** | 5.555e-01 | **5.193e-06** |

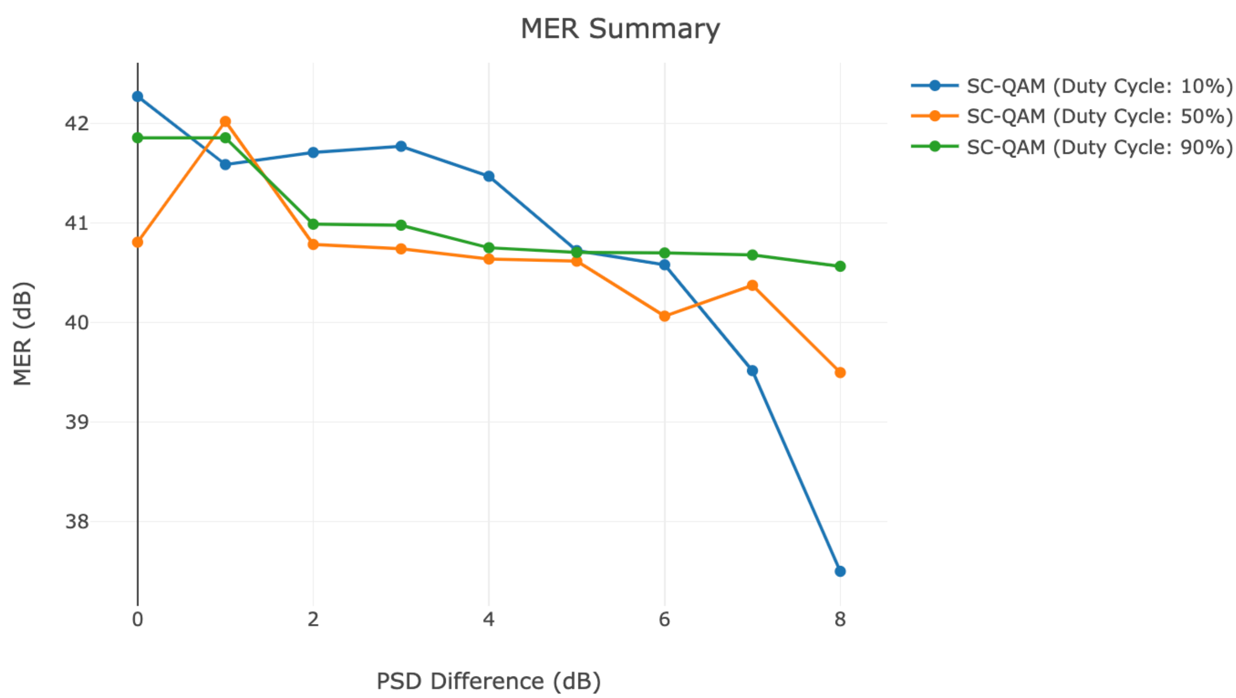


**Figure 17 - 288 MHz FDX: CM-2 SC-QAM Average MER changes (4 ms cycle period)**

In the per-CM test report generated for 4 ms cycle period, 10% duty cycle, and +5 dB PSD difference for CM 2, it can be observed that all downstream channels produced uncorrectable codeword errors in the selected time window, as shown in Figure 18 - 288 MHz FDX: CM-2 CER Over Time (4 ms cycle period, 10% duty cycle, 5 dB PSD Difference):

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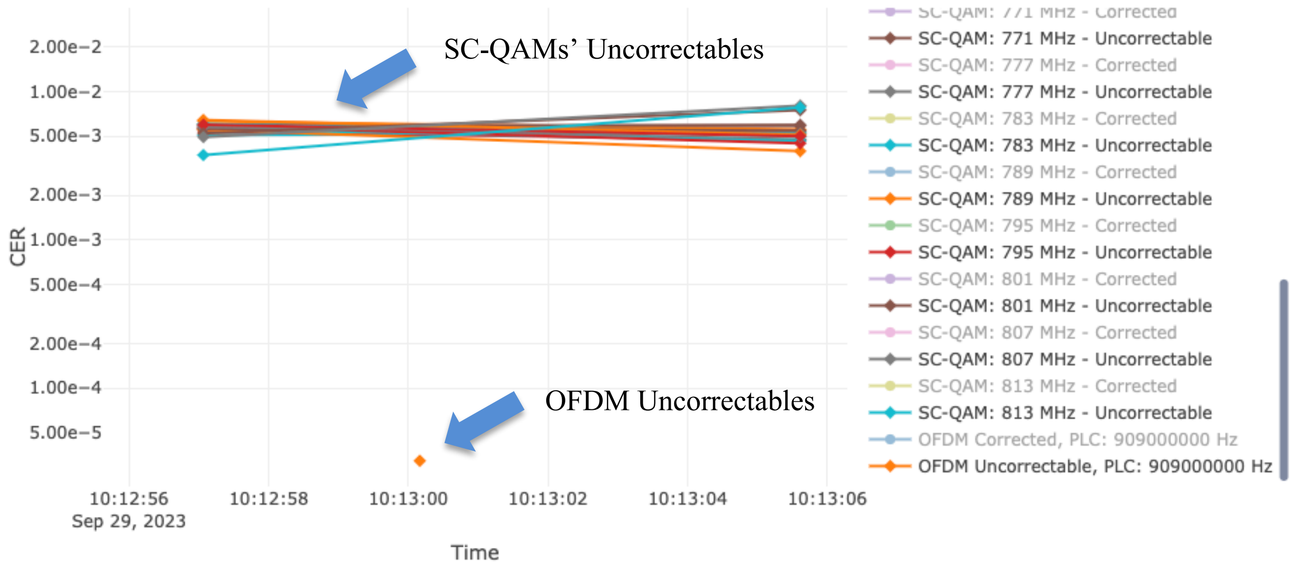


**Figure 18 - 288 MHz FDX: CM-2 CER Over Time (4 ms cycle period, 10% duty cycle, 5 dB PSD Difference)**

#### *7.2.2.2. 384 MHz FDX Neighbor Interference Test Results*

In this test, the signal generator was configured to simulate 384 MHz (4 OFDMA bands) worth of FDX upstream bursts. The same arbitrary waveforms, cycle periods, and duty cycles were used. The spectrum configuration is shown in

**Table 13. The test results are listed in**

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**Table 14, Table 15, and**

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Table 16.

**Table 13 - 384 MHz FDX: Downstream Spectrum Configuration**

| Type | Start Frequency (Lower Bound) | End Frequency (Upper Bound) | Width |
|---|---|---|---|
| Reserved for FDX | 108 MHz | 492 MHz | 384 MHz |
| Video QAM channels | 492 MHz | 732 MHz | 240 MHz |
| Downstream SC-QAM channels | 732 MHz | 852 MHz | 120 MHz |
| Downstream OFDM channel | 852 MHz | 1002 MHz | 150 MHz |

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Table 14 - 384 MHz FDX: 4 ms Cycle Period Test Results

| Reference PSD Diff. (per 6 MHz) | Calculated FDX TCP (dBmV) | Calculated Legacy TCP (dBmV) | TCP Diff. (dB) | CM 1 | CM 2 | CM 3 | CM 4 | CM 5 | CM 6 | CM 7 | CM 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +6 dB | 22.06 | 17.29 | 4.77 | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL |
| +5 dB | 21.06 | 17.29 | 3.77 | FAIL | FAIL | PASS | FAIL | FAIL | PASS | PASS | PASS |
| +4 dB | 20.06 | 17.29 | 2.77 | FAIL | FAIL | PASS | PASS | PASS | PASS | PASS | PASS |
| +3 dB | 19.06 | 17.29 | 1.77 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| +2 dB | 18.06 | 17.29 | 0.77 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |
| +1 dB | 17.06 | 17.29 | -0.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |

Table 15 - 384 MHz FDX: 10 ms Cycle Period Test Results

| Reference PSD Diff. (per 6 MHz) | Calculated FDX TCP (dBmV) | Calculated Legacy TCP (dBmV) | TCP Diff. (dB) | CM 1 | CM 2 | CM 3 | CM 4 | CM 5 | CM 6 | CM 7 | CM 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +6 dB | 22.06 | 17.29 | 4.77 | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL |
| +5 dB | 21.06 | 17.29 | 3.77 | FAIL | FAIL | FAIL | FAIL | FAIL | PASS | FAIL | FAIL |
| +4 dB | 20.06 | 17.29 | 2.77 | FAIL | FAIL | PASS | PASS | FAIL | PASS | FAIL | PASS |
| +3 dB | 19.06 | 17.29 | 1.77 | FAIL | FAIL | PASS | PASS | PASS | PASS | FAIL | PASS |
| +2 dB | 18.06 | 17.29 | 0.77 | FAIL | FAIL | PASS | PASS | PASS | PASS | PASS | PASS |
| +1 dB | 17.06 | 17.29 | -0.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |

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**Table 16 - 384 MHz FDX: 70 ms Cycle Period Test Results**

| Reference PSD Diff. (per 6 MHz) | Calculated FDX TCP (dBmV) | Calculated Legacy TCP (dBmV) | TCP Diff. (dB) | CM 1 | CM 2 | CM 3 | CM 4 | CM 5 | CM 6 | CM 7 | CM 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +5 dB | 21.06 | 17.29 | 3.77 | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL | FAIL |
| +4 dB | 20.06 | 17.29 | 2.77 | FAIL | FAIL | PASS | FAIL | FAIL | PASS | FAIL | PASS |
| +3 dB | 19.06 | 17.29 | 1.77 | FAIL | FAIL | PASS | PASS | PASS | PASS | FAIL | PASS |
| +2 dB | 18.06 | 17.29 | 0.77 | PASS | FAIL | PASS | PASS | PASS | PASS | FAIL | PASS |
| +1 dB | 17.06 | 17.29 | -0.23 | PASS | FAIL | PASS | PASS | PASS | PASS | PASS | PASS |
| 0 dB | 16.06 | 17.29 | -1.23 | PASS | PASS | PASS | PASS | PASS | PASS | PASS | PASS |

In the 384 MHz FDX testing results, the total composite power difference increased by 2 dB at the same PSD difference levels compared to the spectrum configuration used for 288 MHz FDX interference tests, as the interference spectrum increased from 288 MHz to 384 MHz and the legacy downstream spectrum decreased from 606 MHz to 510 MHz. This caused a subset of CMs to show a 2 dB lowered threshold in the normalized PSD differences under certain cycle period settings. However, this effect is not consistently reflected by all test CMs across all test conditions at the same degree. Because multiple factors can result in variations in CMs' performance, their different responses to different neighbor interference characteristics can cause non-linear effects in the results.

Leveraging the automation software that we developed for this testing initiative minimizes the effort of building a rich dataset of interference tolerance thresholds for different CM models under various test conditions. And the CM thresholds for nHAT can potentially be determined automatically based on this dataset and associated policy configurations.

## 8. FDX Neighbor Interference Implementation and nHAT

Comcast's terminology for validating the neighbor accounts and devices for interference with implementing FDX is nHAT (neighbor Health Assessment Test). This testing will be similar to that completed for iHAT with a few differences.

Different thresholds will be needed for the set-top boxes, and thresholds will also need to be determined for pre-DOCSIS 4.0 Devices.

OUDP signaling will be used to measure neighbor interference. Where in the updated iHAT test, a 20 MHz wide OUDP measurement is used, for nHAT, three 2 MHz OUDP pulses across the FDX spectrum from 108-684 MHz will be utilized to determine the level of interference at the neighboring devices; this will allow for variation across frequency and also minimize the amount of time needed for the full band capture.

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With FDX neighbor interference having the potential to impact many neighboring devices, minimizing and optimizing the number of neighbors to test is needed. Comcast uses a mapping graph database called ROCI (Routing of Cable Infrastructure), which will be used to determine the neighbor devices which are susceptible to ACI and which neighboring devices to be tested. If ROCI is not available for a specific node or segment, the entire node segment will be evaluated.

Figure 19 - nHAT Flow Diagram shows the nHAT flow, which includes determining which devices to test using ROCI, running the test, pass/fail actions, remediation, and activation.

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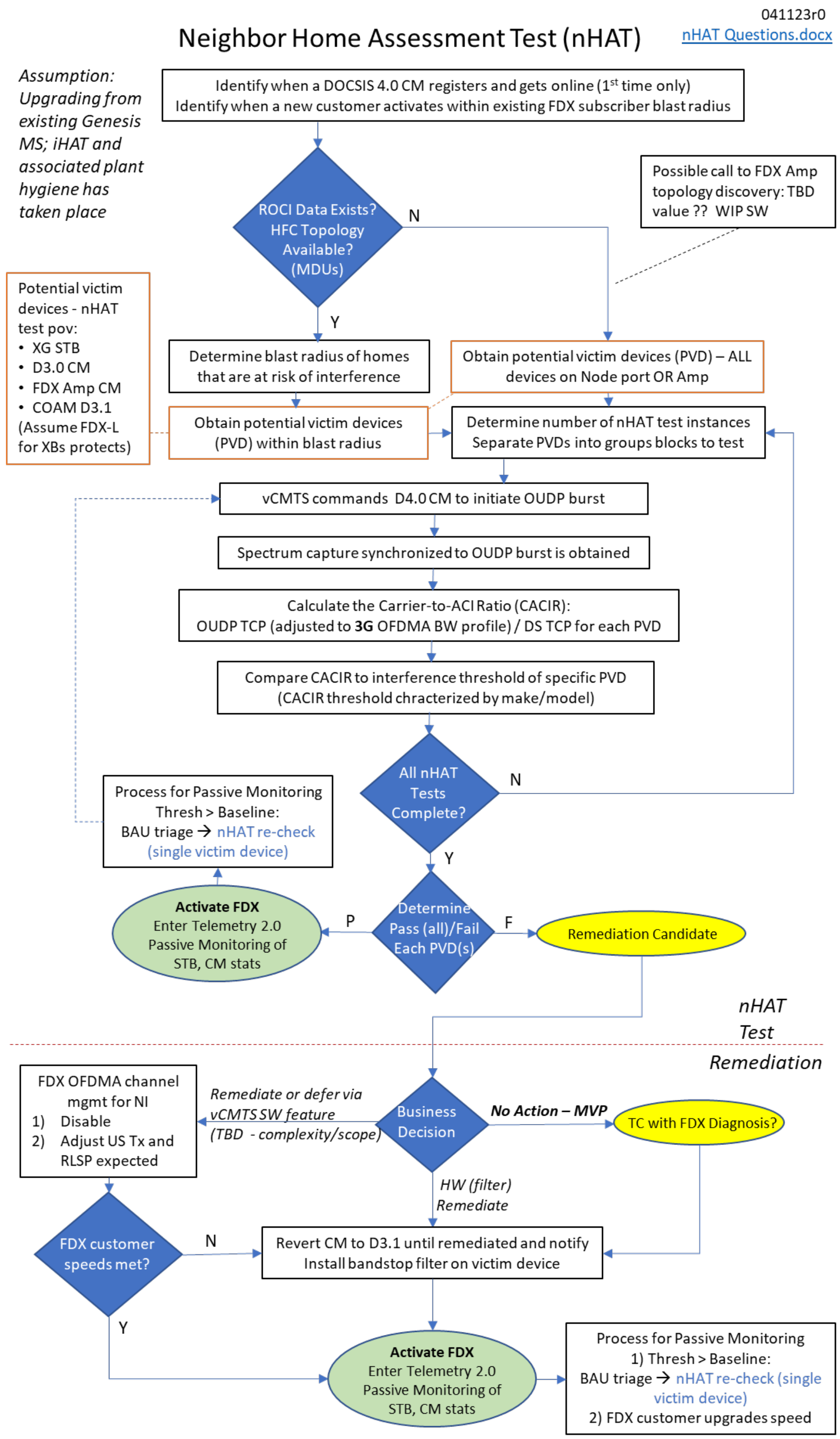


**Figure 19 - nHAT Flow Diagram**

Pre-analyzing the network is beneficial to help determine the potential for neighbor interference. Using the plant topology and devices which are in ROCI, an estimate of interference can be determined. Figure 20 - Example ROCI Topology with FDX Customers shows an example plant topology with two FDX customers. The red dot is the node, purple are actives, green are taps and light blue are customers. ROCI

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contains plant information including cable types and lengths and device model types. In this example, customer one has three neighbors off the same tap and customer two is the only customer on their tap.

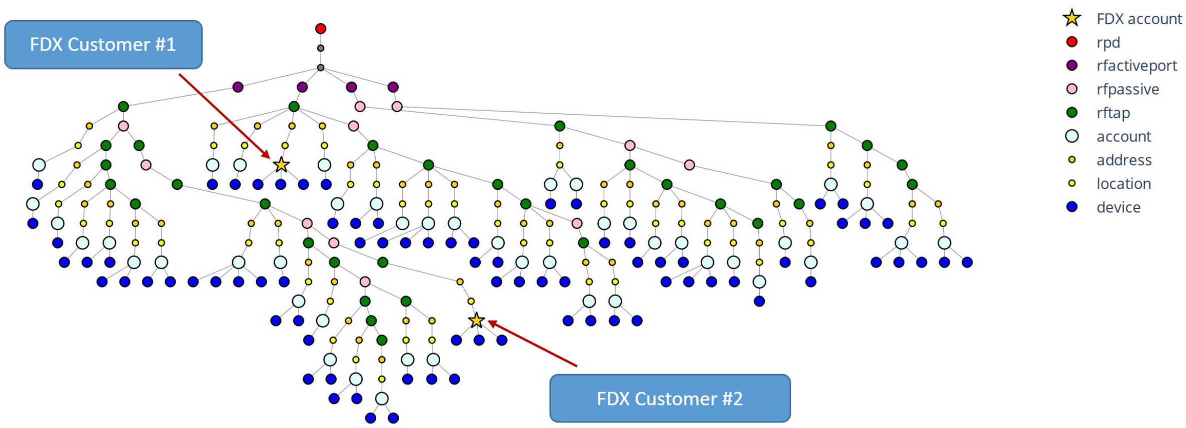
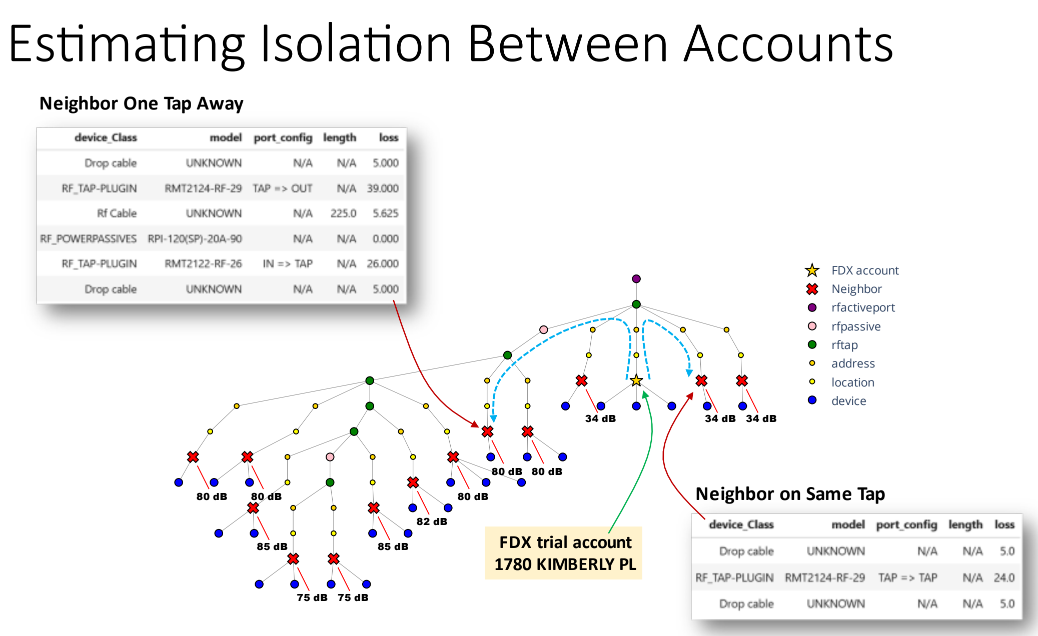



**Figure 20 - Example ROCI Topology with FDX Customers**

Drilling down further, the plant details can be seen. See Figure 21 - ROCI Analysis of Neighbor Interference Levels. Cable spans and tap values are used to determine the amount of isolation between the FDX customer and neighbors. In this example, the drop loss is unknown and a nominal value of 5 dB is used.




Neighbor One Tap Away

| device_Class | model | port_config | length | loss |
|---|---|---|---|---|
| Drop cable | UNKNOWN | N/A | N/A | 5.000 |
| RF_TAP-PLUGIN | RMT2124-RF-29 | TAP => OUT | N/A | 39.000 |
| Rf Cable | UNKNOWN | N/A | 225.0 | 5.625 |
| RF_POWERPASSIVES | RPI-120(SP)-20A-90 | N/A | N/A | 0.000 |
| RF_TAP-PLUGIN | RMT2122-RF-26 | IN => TAP | N/A | 26.000 |
| Drop cable | UNKNOWN | N/A | N/A | 5.000 |

Neighbor on Same Tap

| device_Class | model | port_config | length | loss |
|---|---|---|---|---|
| Drop cable | UNKNOWN | N/A | N/A | 5.0 |
| RF_TAP-PLUGIN | RMT2124-RF-29 | TAP => TAP | N/A | 24.0 |
| Drop cable | UNKNOWN | N/A | N/A | 5.0 |

**Figure 21 - ROCI Analysis of Neighbor Interference Levels**

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Using the measured transmit levels for the FDX customer and receive levels for the neighbor accounts, the level of interference can be estimated.

For neighbors on the same tap see Figure 22 - nHAT ROCI Analysis ACI Delta Same Tap:

- FDX transmit PSD = -28 dBmV/Hz
- Neighbor-to-neighbor isolation = 34 dB
- Received interference level = -62 dBmV/Hz
- Downstream mean at legacy device = -69 dBmV/Hz
- FDX/DS PSD delta = 7 dBmV/Hz
- FDX/DS Power delta = 3 dBmV

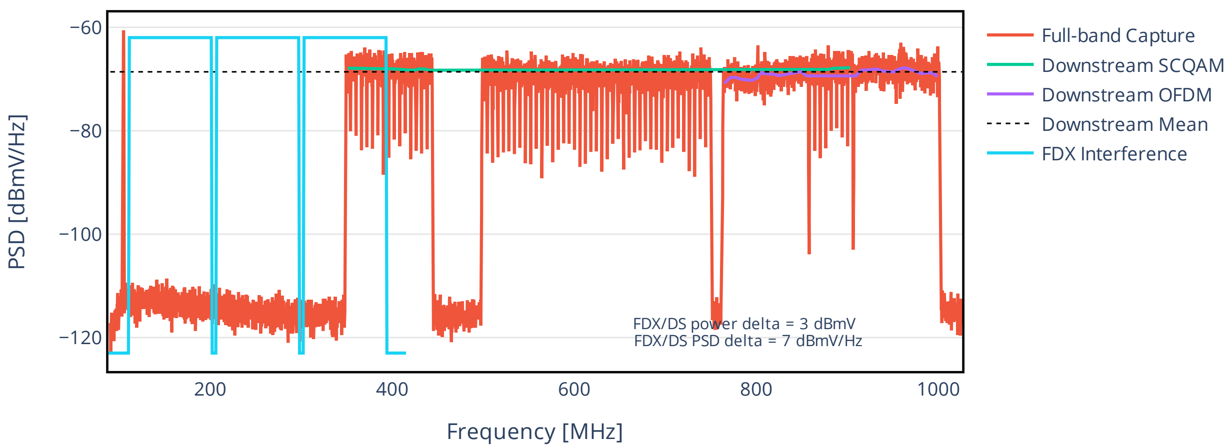


**Figure 22 - nHAT ROCI Analysis ACI Delta Same Tap**

Thresholds are still being determined for FDX neighbor interefence. Initial data shows a power spectral density delta of 7 dBmV and total power delta of 3 dBmV between the interfering signal and the neigbor, which is below the thresholds being measured in the lab for interference for both the set-top box and cable modems.

For neighbors on the downstream adjacent tap see Figure 23 – nHAT ROCI Analysis ACI Delta Adjacent Tap:

- FDX transmit PSD = -28 dBmV/Hz
- Neighbor-to-neighbor isolation = 80 dB
- Received interference level = -109 dBmV/Hz
- Downstream mean at legacy device = -69 dBmV/Hz
- FDX/DS PSD delta = -46 dBmV/Hz
- FDX/DS Power delta = -40 dBmV

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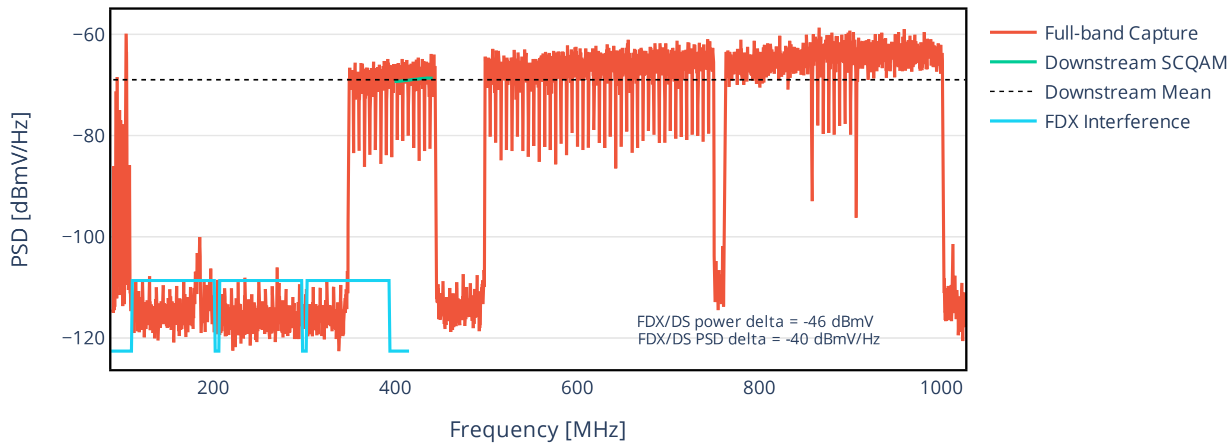


**Figure 23 – nHAT ROCI Analysis ACI Delta Adjacent Tap**

Both the power spectral density and total power delta are well below the threshold of interference and testing is not required on this device.

## 9. Conclusion

Understanding, calculating, detecting, and remediating adjacent channel interference are all needed as the industry advances and implements newer revisions of DOCSIS which re-use existing spectrum while the cable plant has a large number of older DOCSIS and video devices co-existing on the systems. With over 2.4 million mid-split activations, Comcast has developed a very good understanding of how to detect and monitor ACI in mid-split applications. This knowledge and experience are being used to be proactive in the modeling, calculations, and detection of interference in FDX systems. The interference in FDX systems may be significantly more impactful as it has the potential to affect both neighboring set-top devices and cable modems and not just devices in a single home as in the mid-split systems.

Comcast pioneered the use of OUDP signaling first for leakage applications in high-split systems and then again in the iHAT tool to evaluate the health of mid-split homes and accounts. The continued use of OUDP signaling in nHAT for FDX systems is key to ensuring ACI is detected before there is any negative customer impact.

The discussion in this paper touched on many of the improvements which are being made to iHAT and the additional complexities of measuring interference in FDX systems. The development of tools and processes in bringing mid-split to scale was an excellent learning experience for interoperability with different DOCSIS capabilities and also to bring this technology to scale across the network. For FDX, work continues on determining the interference thresholds for both the cable modems and set-top boxes. Work also continues on developing the processes and tools needed to bring FDX to scale. FDX has been deployed on a small scale to date and full-scale deployments are planned for Q4 2023 and 2024.

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## 10. Abbreviations

| | |
|---|---|
| ACI | adjacent channel interference |
| AGC | analog-to-digital converter |
| AGC | automatic gain control |
| ARB | Arbitrary |
| BW | bandwidth |
| CACIR | carrier to ACI ratio |
| CER | codeword error rate |
| CM | cable modem |
| CMTS | cable modem termination system |
| COAM | customer owned and maintained |
| CPE | customer premises equipment |
| CW | continuous wave |
| CW | codeword |
| dB | decibel |
| dBc | decibel from Carrier |
| DBC | dynamic bonding change |
| dBmV | decibel Millivolt |
| DOCSIS | data over cable service interface specification |
| DS | downstream |
| HFC | hybrid fiber-coax |
| HS | High-Split |
| FBC | full band capture |
| FEC | forward error correction |
| FDX | full duplex DOCSIS |
| Hz | hertz |
| iHAT | In Home Health Assessment Test |
| MER | modulation error ratio |
| MHz | megahertz |
| ms | millisecond |
| MS | mid split |
| MVP | minimum viable product |
| nHAT | neighbor home health assessment test |
| OFDM | orthogonal frequency division multiplexing |
| OFDMA | orthogonal frequency division multiple access |
| OUDP | OFDMA upstream data profile |
| PMA | profile management application |
| PSD | power spectral eensity |
| PVD | potential victim device |
| QAM | quadrature amplitude modulation |
| RDK | reference design kit |
| RF | radio frequency |
| RLSP | return level setpoint |
| ROCI | routing of cable infrastructure |
| RPD | remote physical device |
| R-PHY | remote physical layer |
| RX | receive |

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| | |
|---|---|
| s | second |
| SC | single carrier |
| SC-QAM | single carrier quadrature amplitude modulation |
| SCTE | Society of Cable Telecommunications Engineers |
| SNMP | simple network management protocol |
| STB | set-top box |
| SW | software |
| TBD | to be determined |
| TC | Trouble call |
| TCP | total composite power |
| TX | transmit |
| UDP | user datagram protocol |
| uV/m | microvolt per meter |
| US | upstream |
| vCMTS | Virtual cable modem termination system |
| WIP | work in progress |

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