Data-Over-Cable Service Interface Specifications Technical Reports

Midsplit Migration Implications on the HFC Network Technical Report

CM-TR-MID-SPLIT-V01-150223

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Executive Summary

This report summarizes the observations of field testing conducted in MSO networks analyzing the possible impacts of migrating the upstream channel of the HFC network from 5-42 MHz to 5-85 MHz.

Positive Outcomes

- Fiber node technology that we have measured across a variety of member field tests supports an 85 MHz split from a laser dynamic range point-of-view.
- House to house isolation within a tap and between taps was measured across a wide variety of tap values. The measurements indicate that house to house isolation is sufficient that a midsplit should not affect a neighbor's legacy set-top box or gateway which receives in the 54 to 85 MHz range.
- Existing networks should be capable of supporting 1024-QAM in the upstream, and many could support even higher modulation with a midsplit.

Challenges to Solve

- In-home wiring is of major concern due to the unpredictable quality of customer installed splitters and coax cabling. The RF isolation characteristics of currently installed splitters is poor, with insufficient isolation to protect legacy devices within the home from CM transmissions between 54-85 MHz.

Possible Solutions

- MSO provided high quality splitters with well matched termination on the common port in the home may provide sufficient isolation to prevent interference with older STBs.
- Inline filters could be installed on legacy devices to protect them from transmissions between 54-85 MHz.

Those solutions, although feasible, do have significant operational impact, in addition to making the self-install-kit approach quite problematic.

NOTE: The results included in this report are based on measurements conducted on the Bend Broadband and Shaw Communications networks. This report will undergo further updates based on additional field and lab testing activities.

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1 SCOPE

1.1 Introduction and Purpose

In this technical report, we focus on the midsplit migration of 5-42 MHz networks and the capability of the HFC network to support DOCSIS 3.0 and DOCSIS 3.1 technologies.

1.2 Background Information

Current Hybrid Fiber-Coax (HFC) networks have an upstream channel band of either 5-42 MHz (primarily in North America), 5-65 MHz (primarily in Europe), or 5-55 MHz (primarily in Japan), with the usable part of the spectrum actually starting at around 15 MHz, in practice limiting the available bandwidth to 27 MHz for 42 MHz networks and 50 MHz for 5-65 MHz networks. The current DOCSIS 3.0 specifications support an upper frequency edge for the upstream band of up to 85 MHz (also known as midsplit), while the newer DOCSIS 3.1 specifications support an upper frequency edge of up to 204 MHz (also known as highsplit). The DOCSIS 3.1 technology also enables increased resiliency to channel impairments through the use of strong forward error correction (FEC) and a variety of modulation orders, thus possibly enabling the use of the lower part of the spectrum (sub 15 MHz) and increasing available bandwidth.

1.3 Applicability

To meet the increased demand in upstream bandwidth and to enable larger upstream capacities, migrating the current upstream upper band edge to higher frequencies is a viable option. Midsplit migration from 5-65 MHz, although feasible, does not result in a significant increase in upstream capacities, as in the 5-42 MHz networks. It is expected that 5-65 MHz networks would migrate the upper band edge to 117 MHz or highsplit; in any case, the findings and analysis in this report are extendible to either 117 or 204 MHz splits.

2 INFORMATIVE REFERENCES

This technical report uses the following informative references. References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific. For a non-specific reference, the latest version applies.

[PHYv3.1] Data-Over-Cable Service Interface Specification, Physical Layer Specification DOCSIS 3.1, Cable Television Laboratories, Inc., http://www.cablelabs.com/specification/physical-layer-specification/

[PHYv3.0] Data-Over-Cable Service Interface Specification, Physical Layer Specification DOCSIS 3.0, Cable Television Laboratories, Inc., http://www.cablelabs.com/specification/docsis-3-0-physical-layer-interface-specification/

[SCTE 119] SCTE 119:2011 Measurement Procedure For Noise Power Ratio http://www.scte.org/documents/pdf/standards/ANSISCTE1192006.pdf

[Split] How to Increase the Upstream RF Spectrum: Challenges Facing Cable Operators When Expanding the Return Split Bandwidth From 42 to 85 MHz and Beyond to Leverage DOCSIS® 3.0 Extended Mode of Operation & DOCSIS® 3.1. Jack Moran, SCTE Tec Expo 2014.

[Clipping] Clipping Formulated as an Adding Signal Technique for OFDM Peak Power Reduction, D. Guel and J. Palicot. *Vehicular Technology Conference, 2009.* VTC Spring 2009.

2.1 Reference Acquisition

- Cable Television Laboratories, Inc., 858 Coal Creek Circle, Louisville, CO 80027; Phone +1-303-661-9100; Fax +1-303-661-9199; http://www.cablelabs.com
- SCTE - Society of Cable Telecommunications Engineers Inc., 140 Philips Road, Exton, PA 19341; Phone: 610-363-6888 / 800-542-5040; Fax: 610-363-5898; http://www.scte.org/

3 TERMS AND DEFINITIONS

This document uses the following terms:

Binary Phase Shift Keying (BPSK)	A form of digital modulation in which two phases separated by 180 degrees support the transmission of one bit per symbol.
Cable Modem (CM)	A modulator-demodulator at the subscriber premises intended for use in conveying data communications on a cable television system.
Cable Modem Termination System (CMTS)	A device located at the cable television system headend or distribution hub, which provides complementary functionality to the cable modems to enable data connectivity to a wide-area network.
Coefficient	Complex number that establishes the gain of each tap in an adaptive equalizer or adaptive pre-equalizer.
Distributed Feedback Laser (DFB)	A type of laser diode, quantum cascade laser or optical fiber laser where the active region of the device is periodically structured as a diffraction grating. The structure builds a one-dimensional interference grating (Bragg scattering) and the grating provides optical feedback for the laser.
Decibel (dB)	Ratio of two power levels expressed mathematically as $dB = 10\log_{10}(P_1/P_2)$.
DOCSIS	Data-Over-Cable Service Interface Specifications. A group of specifications that defines interoperability between cable modem termination systems and cable modems.
Frequency Division Multiple Access (FDMA)	A multiple access technology that accommodates multiple users by allocating each user's traffic to one or more discrete frequency bands, channels, or subcarriers.
Headroom	The difference between the laser MER and the MER required by the QAM order.
Hybrid Fiber/Coax (HFC)	A broadband bidirectional shared-media transmission system or network architecture using optical fibers between the headend and fiber nodes, and coaxial cable distribution from the fiber nodes to the subscriber locations.
Modulation Error Ratio (MER)	The ratio of average signal constellation power to average constellation error power – that is, digital complex baseband signal-to-noise ratio – expressed in decibels. In effect, MER is a measure of how spread out the symbol points in a constellation are. More specifically, MER is a measure of the cluster variance that exists in a transmitted or received waveform at the output of an ideal receive matched filter. MER includes the effects of all discrete spurious, noise, carrier leakage, clock lines, synthesizer products, linear and nonlinear distortions, other undesired transmitter and receiver products, ingress, and similar in-channel impairments.
Link Budget	An accounting of all of the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. The link budget accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains, feedline, and miscellaneous losses.
Node	An optical-to-electrical (RF) interface between a fiber optic cable and the coaxial cable distribution network. Also called fiber node.
OFDM Channel Bandwidth	Occupied bandwidth of a downstream OFDM channel.
OFDMA Channel Bandwidth	Occupied bandwidth of an upstream OFDMA channel.

Orthogonal Frequency Division Multiple Access (OFDMA)	An OFDM-based multiple-access scheme in which different subcarriers or groups of subcarriers are assigned to different users.
Orthogonal Frequency Division Multiplexing (OFDM)	A data transmission method in which a large number of closely-spaced or overlapping very-narrow-bandwidth orthogonal QAM signals are transmitted within a given channel. Each of the QAM signals, called a subcarrier, carries a small percentage of the total payload at a very low data rate.
Physical Layer (PHY)	Layer 1 in the Open System Interconnection architecture; the layer that provides services to transmit bits or groups of bits over a transmission link between open systems and which entails electrical, mechanical and handshaking procedures.
QAM Signal	Analog RF signal that uses quadrature amplitude modulation to convey information such as digital data.
Quadrature (Q)	The imaginary part of a vector that represents a signal, with 90 degrees phase angle relative to a reference carrier. See also *in-phase (I)*.
Quadrature Amplitude Modulation (QAM)	A modulation technique in which an analog signal's amplitude and phase vary to convey information, such as digital data. The name "quadrature" indicates that amplitude and phase can be represented in rectangular coordinates as in-phase (I) and quadrature (Q) components of a signal.
Quadrature Phase Shift Keying (QPSK)	A form of digital modulation in which four phase states separated by 90 degrees support the transmission of two bits per symbol. Also called 4-QAM.
Radio Frequency (RF)	That portion of the electromagnetic spectrum from a few kilohertz to just below the frequency of infrared light.
Root Mean Square (RMS)	A statistical measure of the magnitude of a varying quantity such as current or voltage, where the RMS value of a set of instantaneous values over, say, one cycle of alternating current is equal to the square root of the mean value of the squares of the original values.
Tap	In the feeder portion of a coaxial cable distribution network, a passive device that comprises a combination of a directional coupler and splitter to "tap" off some of the feeder cable RF signal for connection to the subscriber drop. So-called self-terminating taps used at feeder ends-of-line are splitters only and do not usually contain a directional coupler.
Upstream	1) The direction of RF signal transmission from subscriber to headend or hub site. Also called return or reverse. In most North American cable networks, the legacy upstream spectrum occupies frequencies from 5 MHz to as high as 42 MHz. 2) The DOCSIS 3.1 upstream is 5-204 MHz, with support for 5-42 MHz, 5-65 MHz, 5-85 MHz and 5-117 MHz.
Upstream Channel	A portion of the electromagnetic spectrum used to convey one or more RF signals from the subscriber premises to the headend or hub site. For example, a commonly used DOCSIS 3.0 upstream channel bandwidth is 6.4 MHz. A DOCSIS 3.1 upstream OFDMA channel bandwidth may be as much as 96 MHz.

4 ABBREVIATIONS AND ACRONYMS

This document uses the following abbreviations:

AWGN	additive white Gaussian noise
CCDF	complimentary cumulative distribution function
CM	cable modem
CMTS	cable modem termination system
CNR	carrier to noise ratio
dB	decibel
DFB	distributed feedback (laser)
HFC	hybrid fiber/coax
MER	modulation error ratio
MSO	multiple system operator
NPR	noise power ratio
OFDMA	orthogonal frequency division multiple access
PAPR	peak-to-average power ratio
PSD	power spectral density
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift keying
RF	radio frequency
RMS	root mean square
SNR	signal-to-noise ratio
STB	set-top box

5 UPSTREAM SIGNALING

The upstream channels for an 85 MHz split could be legacy DOCSIS 3.0 signals, DOCSIS 3.1 OFDMA signals or a combination of both. For DOCSIS 3.0 systems, a midsplit system can potentially fit up to 12 upstream channels occupying a total bandwidth of 76.8 MHz (even though commercially available DOCSIS 3.0 devices only support 8 upstream DOCSIS 3.0 channels). For a DOCSIS 3.1 system, it can be assumed that 80 MHz of spectrum is usable, with the lower portion of the spectrum operating at lower modulation orders.

Due to the expansion of the upstream bandwidth, the upstream signal characteristics differ from the signals in a 5-42 MHz plant; and thus need to be thoroughly characterized in order to identify the appropriate operating conditions for return path lasers.

5.1 Upstream Signal Average Input Power

The increase in upstream signal band from 5-42 MHz to 5-85 MHz will increase the average input signal power into return path lasers. The increase in upstream power, assuming that the power spectral density (PSD) remains constant, is given by:

$$\boldsymbol{Average\ Increase\ in\ Input\ Power} = \mathbf{10}.\log_{10}\frac{\boldsymbol{Bandwidth\ Occupied\ by\ Signals\ After\ Split}}{\boldsymbol{Bandwidth\ Occupied\ by\ Signals\ Before\ Split}} \quad \text{Eq. 1}$$

It is important to note that the actual bandwidth occupied by the DOCSIS channels needs to be accounted for and not the total available upstream channel bandwidth.

NOTE: The laser's characteristics define whether this increase in upstream power is achievable or not.

To maintain a constant average input power into the laser after the expansion to 85 MHz, then the power spectral density of the upstream signal needs to be reduced by:

$$\boldsymbol{Required\ PSD\ Decrease} = \mathbf{10}.\log_{10}\frac{\boldsymbol{Bandwidth\ Occupied\ by\ Signals\ After\ Split}}{\boldsymbol{Bandwidth\ Occupied\ by\ Signals\ Before\ Split}} \quad \text{Eq. 2}$$

For example, assuming a 5-42 MHz system originally supported 4 6.4 MHz channels, each operating at 12 dBmV per channel, has a total average power of 18.02 dBmV and a power spectral density of -56.06 dBmV / Hz.

Moving to midsplit, the system now supports 10 6.4 MHz channels, and thus to maintain the same average input signal power into the laser, the power spectral density needs to be reduced by:

$$\boldsymbol{Required\ PSD\ Decrease} = \mathbf{10}.\log_{10}\frac{\mathbf{10}\times\mathbf{5.12}}{\mathbf{4}\times\mathbf{5.12}} = \mathbf{3.98}\ \boldsymbol{dB} \quad \text{Eq. 3}$$

$$\boldsymbol{New\ PSD}\ (\mathbf{5}-\mathbf{85}\ \boldsymbol{MHz\ Split}) = -\mathbf{56.06}-\mathbf{3.98} = -\mathbf{60.04}\ \boldsymbol{dBmV\ per\ Hz} \quad \text{Eq. 4}$$

The 3.98 dB reduction in PSD will have an impact on the SNR per channel, thus potentially reducing capacity by approximately 1 Bit/Sec/Hz, or increasing packet loss rate.

5.2 Upstream Signal Peak to Average Power Ratio

Average input signal power defines the long term input power to the laser, and does not account for any sudden variations of the input power.

Attention must be given to the instantaneous power of the signal to minimize the probability that the instantaneous power of the signal will drive the laser into the nonlinear region temporarily. This is accounted for by the PAPR of the input signal, defined as:

$$\boldsymbol{PAPR} = \frac{\boldsymbol{Maximum\ Instantaneous\ Signal\ Power\ Level}}{\boldsymbol{Average\ Signal\ Power\ Level}} \quad \text{Eq. 5}$$

The PAPR of a signal is commonly given by Complimentary Cumulative Distribution function (CCDF) which estimates the probability that the instantaneous PAPR will exceed a certain threshold.

The measured CCDF for the PAPR of 12 upstream DOCSIS 3.0 signals and for an emulated OFDMA signal are shown in Figure 1.

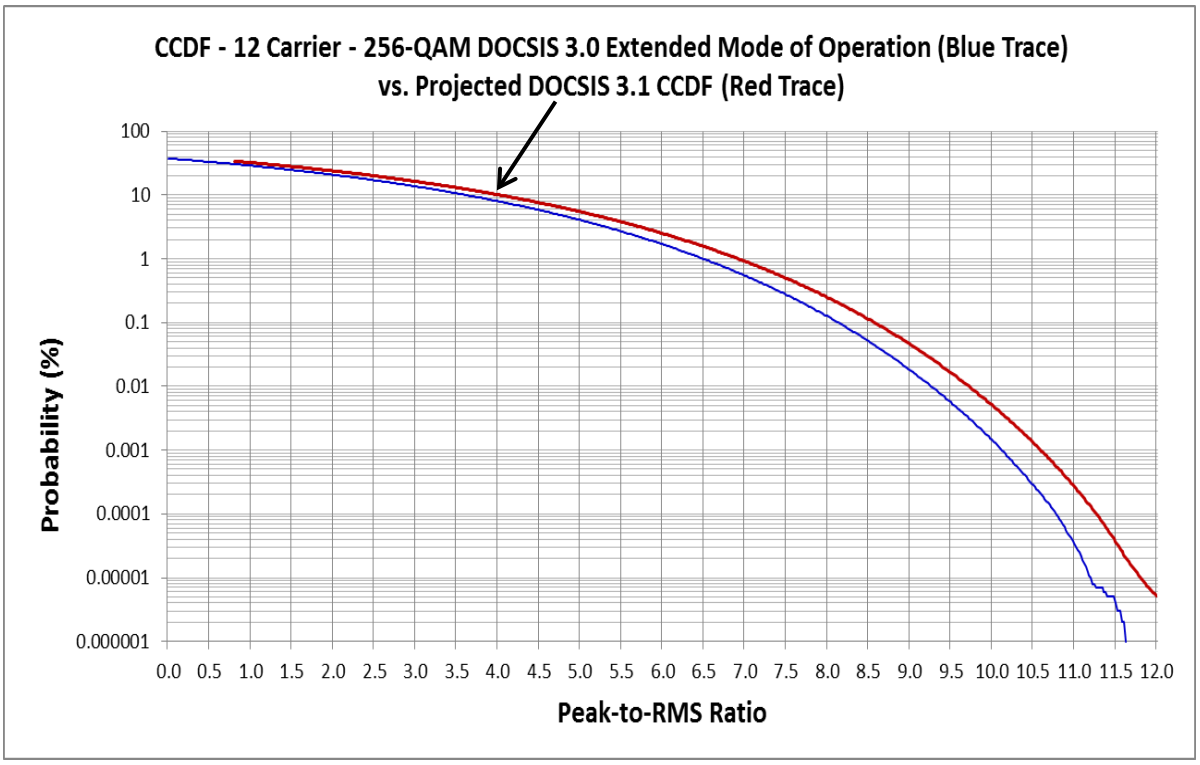

Figure 1 - PAPR CCDF for an Extended DOCSIS 3.0 Signal (Blue) and Simulated OFDMA Signal (Red)

To understand the peak-to-RMS curves above, assume we are operating an 80 MHz wide DOCSIS 3.1 upstream channel, with an average input power of 23 dBmV, thus if the instantaneous PAPR exceeds 4 dB, the laser will run in the nonlinear region, as shown in Figure 5, and the probability of the instantaneous PAPR exceeding 4 dB is approximately 8.36% as highlighted by the arrow on Figure 1.

Due to the large number of carriers in an upstream OFDMA channel, the PAPR CCDF curves remain fairly constant regardless of the mix of modulation orders being transmitted (by virtue of the central limit theorem). Figure 2 shows the PAPR CCDF curves for an 80 MHz OFDMA signal with 1024-QAMs, 256-QAMs, 64-QAMs and a mixture of modulation orders measured by lab test equipment.

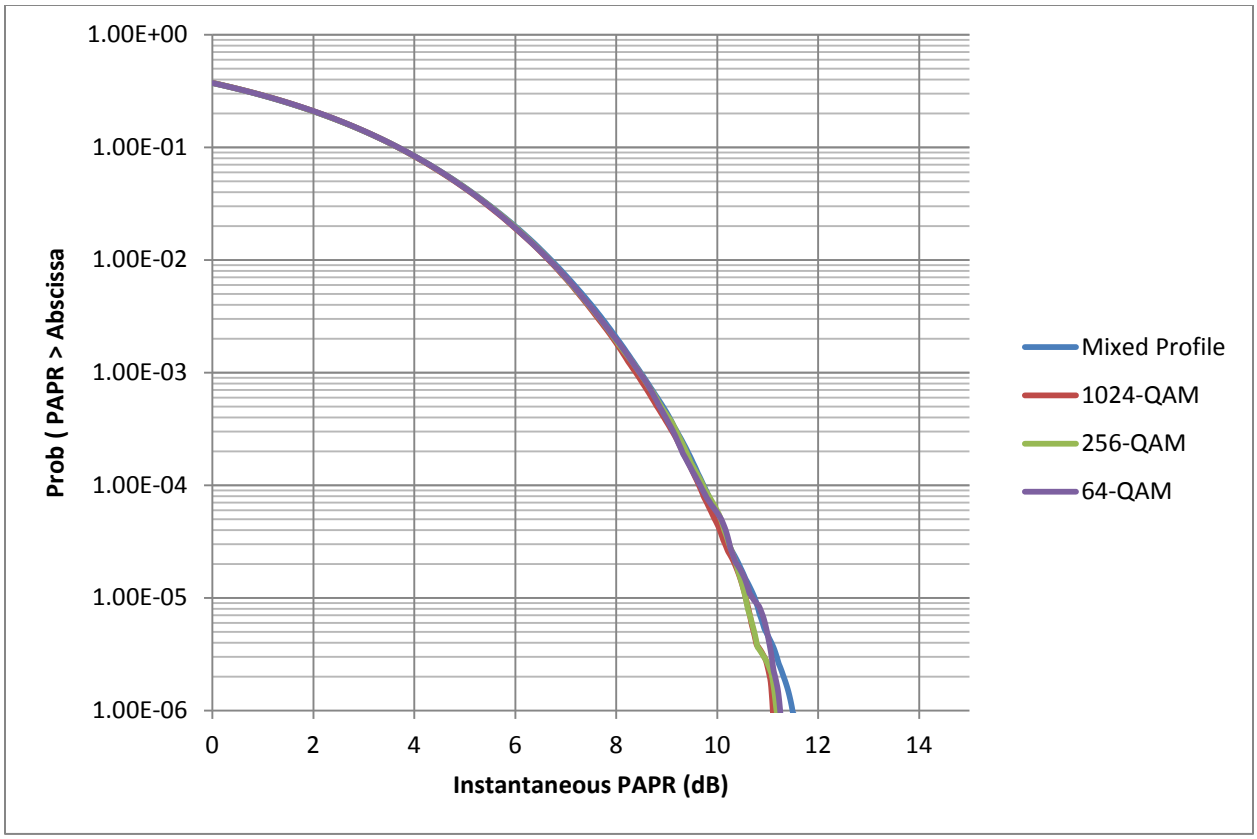

Figure 2 - PAPR CCDF for OFDMA Signals Using Various Modulation Orders

5.3 Impact of Laser Clipping on OFDM Performance

Given the PAPR characteristics of the OFDMA signal, it is important to quantify the impact of instantaneous operation of the laser in the nonlinear region on the output signal quality measured by SNR. To simplify the analysis, we assume that the laser non-linearity can be approximated by hard clipping. Using the adding signal system model for clipping technique, the resulting signal's SNDR (Signal to Noise and Distortion Ratio) for an OFDM signal can be approximated by:

$$SNDR = SNR\frac{[1-\Gamma(\rho)]^2}{1+SNR.(1-e^{-\rho^2}-[1-\Gamma(\rho)]^2)} \quad \textbf{Eq. 6}$$

where

$$\Gamma(x) = e^{-x^2} - x\sqrt{\pi}Q\left(x\sqrt{2}\right), \quad x \geq 0 \quad \textbf{Eq. 7}$$

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-\frac{r^2}{2}}.dr \quad \textbf{Eq. 8}$$

$$\rho = \frac{A}{\sqrt{P_x}} \quad \textbf{where A is the clipping threshold, and } P_x \textbf{ is the OFDM signal power} \quad \textbf{Eq. 9}$$

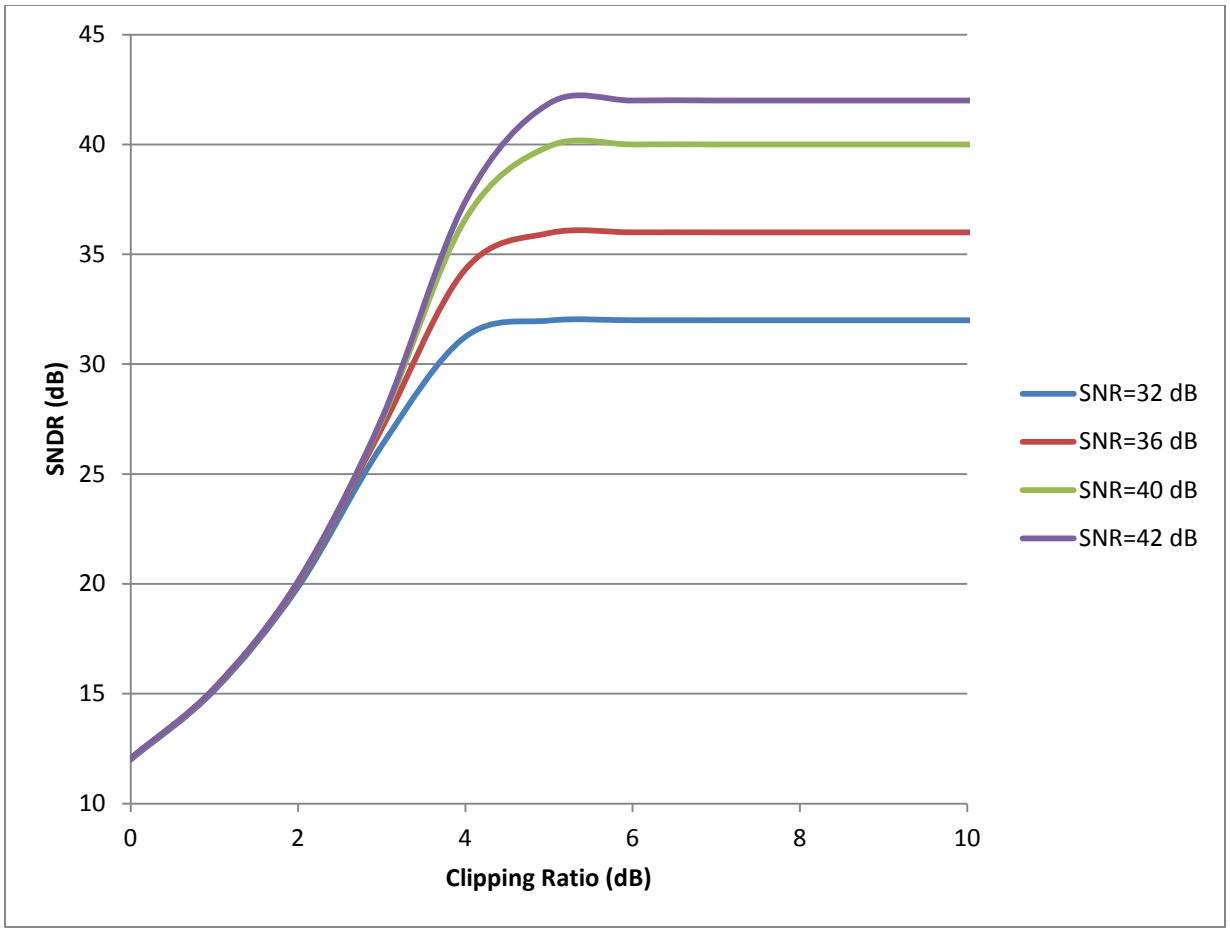

Figure 3 - Signal to Noise and Distortion Ratio (SNDR) as a Function of Clipping Ratio

To understand how the SNDR calculations relate to laser operation, let's revisit our previous example. The previous example assumes an upstream channel with an average input power of 23 dBmV and SNR of 40 dB, thus if the instantaneous PAPR exceeds 4 dB, the laser will operate in the nonlinear region. To evaluate the impact of nonlinear operation on the signal, we assume that once the laser goes into the nonlinear region, hard clipping occurs to the signal. Thus, in this case the clipping ratio is 4 dB, which when applied to an OFDMA signal with an SNR of 40 dB, results in an SNDR of 36.6 dB.

The result of these various calculations is that if we apply an OFDMA signal with an average input power of 23 dBmV and SNR of 40 dB, then the OFDMA signal will have an 8.35% chance of driving the laser into the nonlinear region, and the output OFDM signal will have an SNDR of 36.6 dB.

A more conservative approach is to assume that hard clipping occurs at 1-2 dB before the non-linear region limit is reached.

6 OPERATIONAL REQUIREMENTS

6.1 Laser Performance

A laser's operation is defined by its Noise Power Ratio (NPR) curves, which define the performance levels and regions as a function of the input power levels.

To select the operating region of the laser, two requirements need to be considered:

1. Return Path Laser Linearity: By expanding the upstream channel upper band edge from 42 MHz to 85 MHz, and operating either DOCSIS 3.0 channels in extended mode and/or DOCSIS 3.1 channels, the upstream laser loading is potentially increased which has a direct impact on laser linearity and system performance (or alternatively reducing the PSD resulting in a decrease in SNR). Depending on the laser's power handling capabilities, the power per channel (or equivalently, the power spectral density) might need to be reduced as described in Section 5.1.
2. Minimum Required Modulation Error Ratio (MER): Modulation Error Ratio is defined as the ratio of average signal constellation power to average constellation error power expressed in decibels. To support a certain QAM order, the laser must at a minimum support the MER required by the modulation order; this defines the minimum operating requirements for the laser. Practically, lasers are operated at MER levels higher than what is required by the QAM order. The difference between the laser MER and the MER required by the QAM order is known as the headroom. Typically, 3-6 dB of headroom is maintained in deployed networks to provide sufficient margin against other system impairments.

The DOCSIS 3.1 Physical Layer specification [PHYv3.1] defines the minimum required upstream CNR at the CMTS to achieve a maximum PER of $1x10^{-6}$ as shown in Table 1.

Table 1 - CMTS Minimum CNR Performance in AWGN Channel

Constellation	CNR (dB)
QPSK	11.0
8-QAM	14.0
16-QAM	17.0
32-QAM	20.0
64-QAM	23.0
128-QAM	26.0
256-QAM	29.0
512-QAM	32.5
1024-QAM	35.5
2048-QAM	39.0
4096-QAM	43.0

With a goal of achieving 1024-QAM on the upstream, a minimum received CNR at the CMTS of 35.5 dB is required; thus the laser is required to support a minimum MER of 38.5 dB (3 dB headroom) or preferably 41.5 dB (6 dB headroom). Here, headroom is defined as the difference (in dB) between the operating MER and the minimum required MER.

6.1.1 Laser NPR Characterization

6.1.1.1 Analog DFB Lasers

The measured Noise Power Ratio (NPR) curve for field-deployed analog DFB lasers is shown in Figure 4. The curve represents the average MER values as a function of the total input power to the laser, based on measurements performed across 16 lasers.[1]

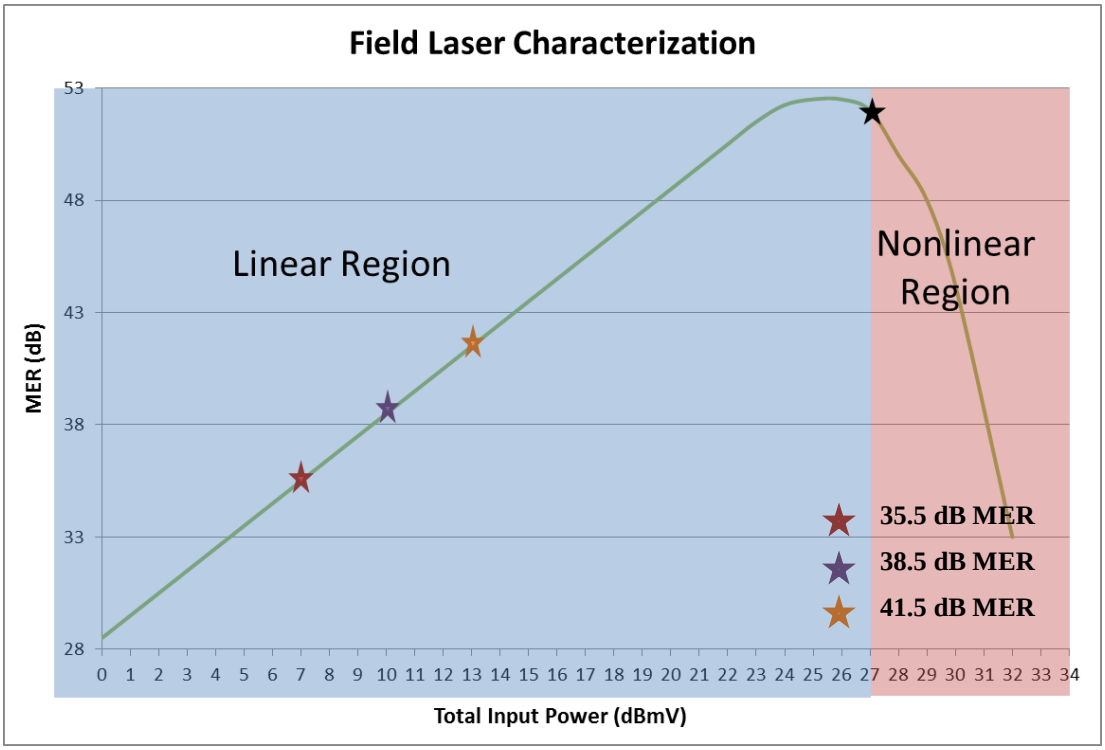

Figure 4 - NPR Curves for Analog DFB Lasers

As shown in Figure 4, the maximum input average power is limited to 27 dBmV before the laser starts operating in the nonlinear region. The minimum input power to the laser must be greater than 7 dBmV in order to support 1024-QAM, providing the largest dynamic range of 20 dB.

Table 2 below summarizes operating points of interest for the laser for supporting 1024-QAM.

Table 2 - Total Input Power versus MER Values for Analog DFB Lasers

Total Input Power (dBmV)	Modulation Error Rate (dB)	Headroom (dB)	Dynamic Range (dB)
7	35.5	0	20
10	38.5	3	17
13	41.5	6	14
26	52.5	17	1
27	52.0	16.5	0

As can be seen in Table 2, the minimum input power to the laser must be greater than 7 dBmV, and the maximum input power power to maintain linearlity must not exceed 27 dBmV, thus providing the largest dynamic range of 20

[1] See [Split].

dB. Dynamic range is defined here as the allowable signal power level variation while maintaining an MER greater than 35.5 dB and the laser operating in the linear region.

For 2048-QAM and 4096-QAM operation, the minimum required MER is 39 dB and 43 dB respectively, which would increase the minimum total input power into the laser by 4 and 7 dB, thus reducing the maximum available dynamic range to 16 dB and 13 dB, respectively. This 13 dB dynamic range also coincides with the ratio of 24 (13 dB) that exists when a single 3.2 MHz signal is transmitted compared to 12*6.4 MHz channels transmitted.

It is advisable however, not to fully populate the upstream with legacy DOCSIS 3.0 CMs across the entire 5-85 MHz, as the spurious emissions performance of that generation of CMs is lower than the DOCSIS 3.1 capable CMs. The DOCSIS 3.0 specification was defined based on noise generated per transmitted channel. The level for the 6.4 MHz channel case is -44 dBc.

By looking at Table 6-15 and Table 6-17 of the DOCSIS 3.0 PHY specification (see [PHYv3.0]), one can see that the aggregate adjacent spurious level increases with number of channels. Therefore, for 12 simultaneous channels channels being transmitted, the noise increases by approximately 11dB, for 8 simultaneous channels by 9 dB, and 6 dB for 4 simultaneous channels. This results in aggregate spurious levels of -33 dBc (12 channels), -35 dBc (8 channels), and -38 dBc (4 channels). Comparing these spurious levels with the QAM options in Table 1, indicates that the minimum CNR performance for 1024-QAM using DOCSIS 3.1 is not met. However, if a cable operator limits the channel occupancy of legacy CMs to 4 channels, 1024-QAM is feasible for coexisting with DOCSIS 3.1 CMs that share the 5-85 MHz spectrum. DOCSIS 3.1 CMs have been defined in a way that lowers spurious emissions. The CMTS scheduler can control the number of simultaneous transmissions to avoid these performance limiting scenarios.

6.1.1.2 Digital DFB Lasers

The measured Noise Power Ratio (NPR) curve for field-deployed digital return path lasers is shown in Figure 5. The curve represents the average MER values as a function of the total input power to the laser, based on measurements performed across 6 lasers.[2]

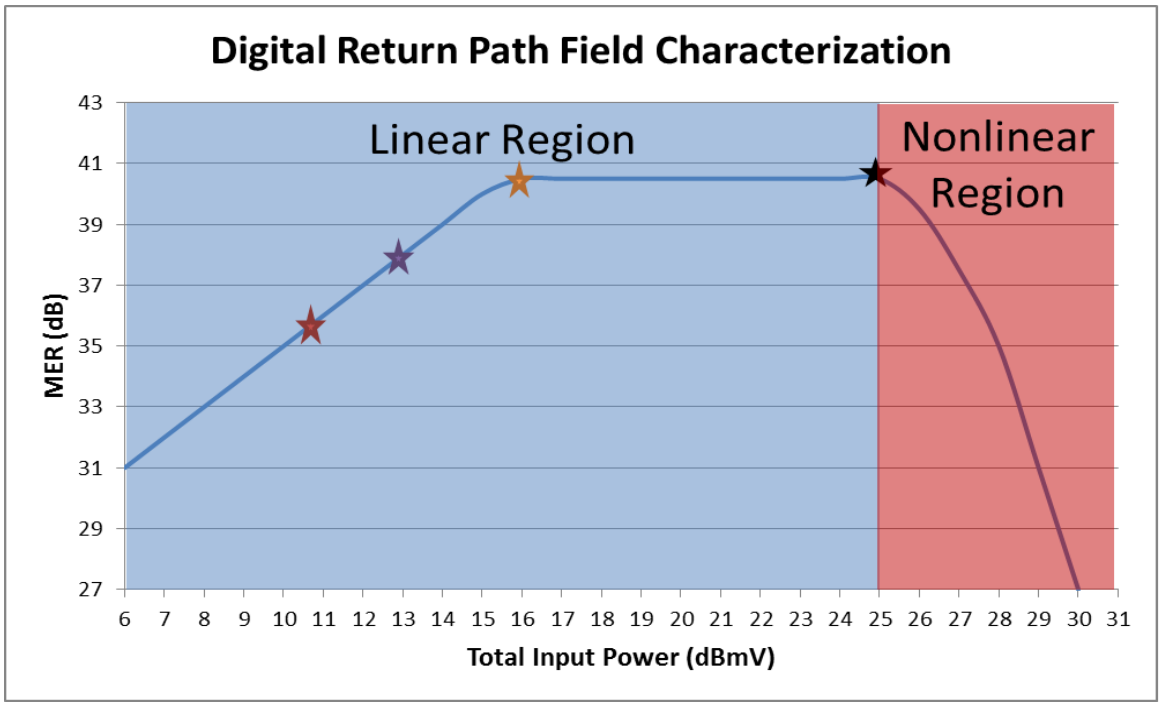

Figure 5 - NPR Curves for Digital Return Lasers

Figure Note: The flat region extending between 16 dBmV and 25 dBmV is attributed to the inability of the test equipment to measure an MER greater than 40.5 dB.

Table 3 below summarizes operating points of interest for the laser for supporting 1024-QAM.

Table 3 - Total Input Power versus MER Values for Digital Lasers

Total Input Power (dBmV)	Modulation Error Rate (dB)	Headroom (dB)	Dynamic Range (dB)
11	35.5	0	14
13	38.5	3	12
16	40.5	5	9
25	40.5	5	0

As shown in Figure 5, the maximum input power must be less than 25 dBmV, or the laser starts operating in the nonlinear region. The minimum input power to the laser must be greater than 11 dBmV in order to support 1024-QAM, thereby defining the dynamic range to be as much as 14 dB.

The dynamic range burden is different on digital optical returns than it is on analog optical links. In analog optical links, the ratio between a single narrow channel transmission and a fully populated channel could be high and meeting the dynamic range requirements rests predominantly on the return laser. In a digital optical return, the A/D converter used in digitization and the laser share the burden of carrying the RF signal. Even in the case when no RF transmission is present, the digital return is conveying the bits representing the digitized spectrum.

[2] See [Split].

The dynamic range on the digital return is mandated by the A/D converter characteristics. The bits/sample and the sampling rate characteristics of the A/D converter dictate the dynamic range and the bandwidth of the digitized return link. In digitized returns, the laser's role is to have enough bits to carry the necessary information. This means that in digital returns, one doesn't have to select high dynamic range lasers. Given specific CNR and dynamic range requirements of the RF signals, the A/D and laser are chosen based on capacity requirements rather than dynamic range requirements.

Figure 5 shows measurements related to specific digitized return systems for A/D converters with a sampling rate and number of bits per sample that support an 85 MHz upstream at 1024-QAM. Similarly, with a different combination of bits/sample and sampling rate, and an A/D converter of higher capacity installed on the baseband optical link, a 204 MHz upstream at 4096-QAM can be designed to be available when the plant is ready.

6.1.2 Upstream Average Input Signal Power Requirements

Setting the input signal power level for the return path laser depends on operating in the linear region and guaranteeing the minimum required MER. Within the linear region of operation, the average input power must be set so it meets the minimum MER requirements and at the same time provides sufficient buffer from excessive instantaneous operation in the nonlinear region due to high power spikes in the upstream signal.

In this section, we provide guidance on how to select the target average input power to the laser. Working backwards from the CMTS to the node, the impact of various elements contributing to signal degradation needs to be accounted for, as shown in Figure 6.

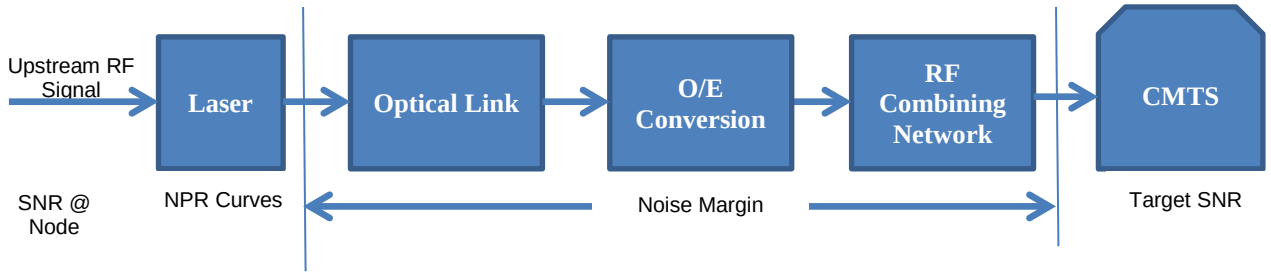

Figure 6 - Link Budget Considerations Between Node and CMTS

To calculate the operational limits of the laser to support the targeted upstream performance, the following properties need to be defined:

1. The highest order QAM targeted for operation at the CMTS needs to be defined, and the associated minimum SNR required by the CMTS to properly support the modulation order.
2. Noise margin accounting for signal degradation due to the channel impairments extending between the laser output and the CMTS.
3. Laser NPR curves.
4. Upstream SNR at the node.

The goal in setting the average input signal power level into the laser is to set it at a level that prevents the upstream signal from excessively driving the laser into the non-linear mode of operation, and thus degrading the SNR of the output signal.

The minimum required SNR at the CMTS + Noise Margin defines the target average SNR at the output of the laser. The difference between the SNR at the node, and the target SNR at the output of the laser, defines the maximum degradation allowed due to the laser operating in the non-linear region.

Using equation (7) to calculate the clipping ratio, the minimum required backoff for the laser is identified.

Example

The assumptions for the example are shown in Table 4:

Table 4 - CMTS Assumptions (Typical)

Requirement	Value
Target QAM order to be supported	1024-QAM
Minimum required SNR at CMTS	36 dB
Noise margin	1 dB
Target SNR at Laser Output	≥ 37 dB
SNR at Node	38 dB
CCDF (Max Allowed PAPR)	$1\text{-}10^{(3.7\text{-}3.8)} = .2056$

Using equation (7), a clipping ratio of 4.4 dB is calculated to give a SNDR of 37.28 dB. Meaning, that if the portions of the OFDMA signal that have a PAPR of 4.4 dB or more are subjected to hard clipping, then the resulting OFDMA signal will have a SNDR of 37.28 dB.

Taking a look at the NPR curves in Figure 4 and Figure 5, this translates to a maximum average input of 22.6 dBmV for the analog laser and 20.6 dBmV for the digital laser. Given that the upstream signal SNR at the node is 38 dB, this translates to a minimum average input power level of 10 dBmV for the analog laser, and 13 dBmV for the digital laser.

As can be shown from the field-measured NPR curves, and a separate calculation to evaluate the required backoff in the laser, currently deployed DFB lasers are able to support 1024-QAM.

6.2 Impact on Legacy Set-top Boxes and TVs

Tuners in legacy set-top boxes (STBs) and televisions (TVs) are designed to receive video channels operating in the range of 54-108 MHz. With the upstream operating range extended to 85 MHz, upstream energy in the 54-85 MHz range can potentially overload the STBs and TVs; the potential of overloading is determined by the RF isolation between the transmitting CMs and the legacy devices at various points in the network.

The following scenarios need be considered when evaluating the impact of CM transmissions on legacy devices:

- In home interference: Interference between a CM and a legacy device in the same home connected to the same coax network.
- Next door neighbor interference: Interference between a transmitting CM and a legacy device in a neighboring house connected to the same tap.
- Far-neighbor interference: Interference between a transmitting CM and a legacy device in a neighboring house connected to the next inline tap.

6.2.1 In-home Interference

Field testing of in-home wiring clearly shows that poor in-home wiring and choice of RF components within the home are a major concern in terms of the impact of interference from a DOCSIS CM to a legacy device.

RF isolation between the CM and the legacy devices can be described as poor at best, with isolation between the CM and legacy device ranging between 25 dB (best observation) to 9 dB (worst observation). Additionally, the various shielding and grounding methods cause us concern, and poor quality wiring is installed by some homeowners.

Figure 7 shows the range of isolation values found in homes visited by CableLabs. Based on the collected field measurements, in order for a CM to not impact a legacy device within the home, for the best case RF isolation scenario observed (25 dB), a DOCSIS 3.1 CM or DOCSIS 3.0 Extended Mode CM would be able to transmit up to 46 dBmV per 6.4 MHz carrier bandwidth and not impact the home STB. However, the more likely scenario is that the CM won't be able to transmit much more than 30 dBmV per 6.4 MHz carrier bandwidth.

Based on this, when installing an 85 MHz CM in a home, the MSO must take additional precautions to improve the quality of the in-home coaxial network to ensure sufficient isolation between the CM and the legacy devices within the home, as typical home wiring has poor RF isolation (due to poor quality customer installed coaxial cables and splitters).

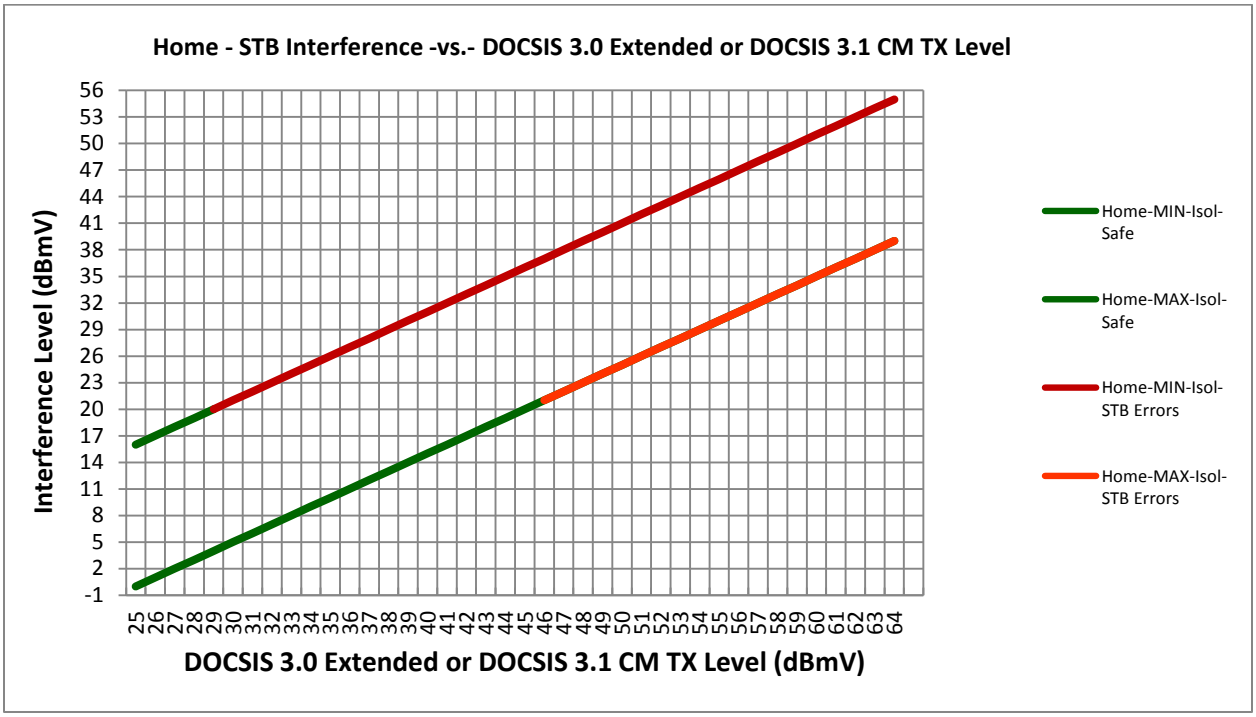

Figure 7 - Observed Interference Levels from Legacy Devices

6.2.2 Next Door Neighbor Interference

Another scenario that was evaluated was the impact of a new CM on legacy devices in a neighboring home connected to the same tap.

Port-to-port RF isolation measurements were conducted on a variety of taps and are summarized in Table 5.

Table 5 - Same-Tap Port-to-Port RF Isolation

Tap Model	Port to Port Isolation
14dB Two Port Tap	32 dB
11 dB End-of-Line 8 Port Tap	29.7 dB

Assuming a typical setup, with 2 way splitters deployed inside the household and drop cable loss of 1 dB; then in addition to the port to port isolation provided by the tap, a minimum of 8 dB additional RF loss between households connected to the same tap can be assumed, thus making the house-to-house isolation more than 38 dB.

In the event of a faulty tap impacting its port to port isolation, next door interference can occur. In that event, proactive network maintenance techniques can be used to localize the problem and resolve the issue.

Based on these measurements, next door neighbor interference would not be a concern when deploying an 85 MHz CM.

6.2.3 Far Neighbor Interference

The last consideration evaluated was the impact of a new CM on legacy devices in a home connected to the next inline tap. Tap-to-tap RF isolation measurements were conducted on a variety of taps and are summarized in Table 6.

Table 6 - Tap-to-Tap Isolation

Tap Model	Port to Port Isolation
14 dB 2 Port Tap 8 dB 4 Port Tap	51 dB

Using the same assumptions as in Section 6.2.2, and including the tap loss (14 dB and 8 dB), then a minimum of 30 dB additional RF loss between households connected to different taps can be assumed, thus making the house-to-house isolation more than 81 dB; thus alleviating any concerns of interference to legacy devices.

In the event of a faulty tap impacting its port-to-port isolation, the likelihood of far neighbor interference impacting legacy devices is low.

7 SUMMARY

This technical report summarized the observations based on field testing conducted by CableLabs, Inc., in a variety of networks, to analyze the possible implications on the HFC network when migrating the upstream split from 5-42 MHz to 5-85 MHz. Based on the findings of the testing, the optical return path of the HFC network is able to handle the additional power requirements of an 85 MHz network, while the MSOs will need to take additional precautions to address the realities of typical in-home wiring to minimize the impact of 85 MHz CMs on legacy devices that may be present within the home.

APPENDIX I ACKNOWLEDGEMENTS

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