Operating Legacy Cable Modems in an FDX Environment

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

The Full Duplex (FDX) capability of the DOCSIS® 4.0 specification allows significantly increasing the upstream capacity of the HFC network, without sacrificing the downstream capacity and without extending the upper band edge of the downstream band. This is achieved by means of echo cancelation on the remote PHY node, enabling it to transmit downstream signals and receive upstream signals simultaneously in the band that is assigned to downstream in a Legacy Frequency Division Duplex (FDD) partitioning scheme. The Legacy Cable Modems (CMs) that are connected to the same network will experience upstream transmissions from FDX capable modems in the frequency region intended only for downstream at the time when these CM were designed and manufactured. This can potentially cause service disruption if not handled properly, thus raising several questions. Can Legacy CMs function properly at all in an FDX environment? Should all CMs be replaced when even a single FDX capable modem is connected to the node? What are the methods to mitigate the impact? Are there methods to guarantee robust operation of Legacy CMs, perhaps even at the expense of downgrading their throughput capabilities or other attributes? What can be done with and without firmware upgrade to Legacy CM? All these questions must be addressed and understood before starting FDX CM deployment. In this paper we suggest a framework to address these questions. We first describe the different use cases of Legacy CMs in an FDX plant. Then, we address the interference and its impact on the CM's receiver for different receiver architectures. Lastly, we suggest several methods that can be employed to mitigate, monitor, and control the impact on Legacy CMs.

The analysis proposed in this paper allows understanding the considerations behind Legacy CM capabilities with respect to dealing with FDX interference, with the purpose of helping MSOs to focus on the necessary parameters that need attention and to enable estimating the expected performance. Eventually, a careful lab characterization and certification is required for each specific Cable Modem or set-top box model to characterize its specific behavior under the FDX interference.

Note that while FDX CMs will create an environment of signals on the plant which on some parameters may go beyond what the Legacy CMs were designed for originally (primarily the upstream interference power), other signal conditions of an FDX-ready plant (N+0 or N+1) are by design better. Due to a small number or a lack of amplifiers on the node, the network SNR is expected to be much better than what these CM were designed to. Other impairments, such as nonlinear distortion products associated with analog optical to electrical conversion are not present either. These and other differences enable the necessary wiggle room for making adjustments that enable the Legacy CM to operate in an FDX plant.

The considerations presented in the paper also apply to a more general case where not all CMs in the plant adhere to the same frequency split, thus creating a situation where some CMs may transmit upstream in the frequency range designed to be for downstream for other CMs. Such scenarios occur when there is an "ultra-high split", for example, when 10G CMs use all or part of the FDX band for a static upstream without actually employing FDX methods of operation.

2. Legacy Cable Modem Use Cases

An intended frequency plan for an FDX enabled node is depicted in Figure 1.

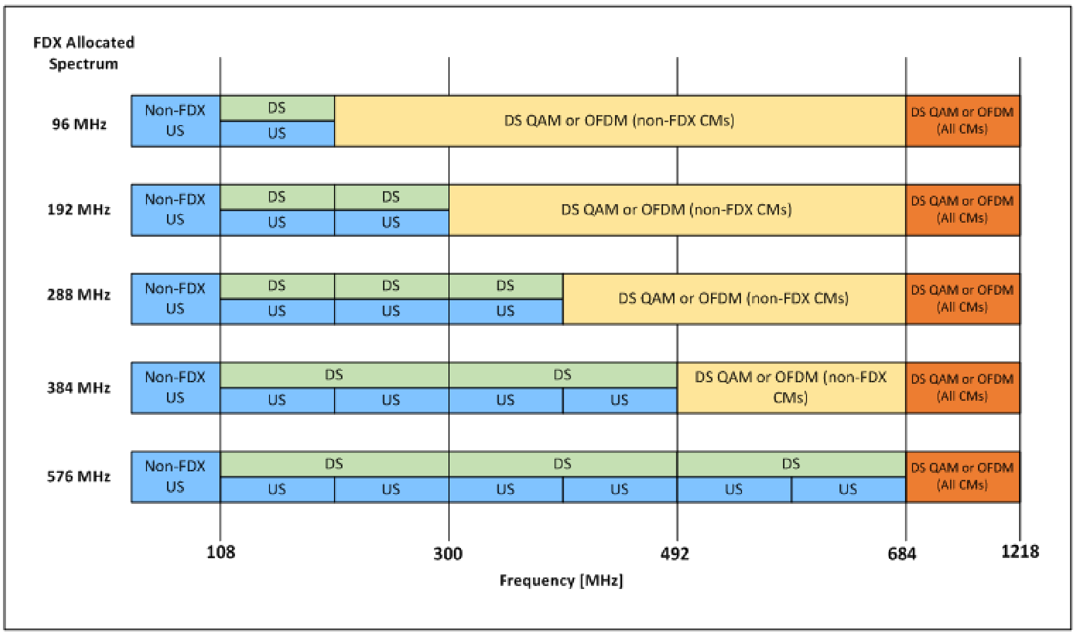

Figure 1 - Frequency Plan on an FDX enabled Node (Source: [1])

The use cases for deployment of Legacy CMs in an FDX enabled plant can be categorized into three types:

- Coexistence only
- Legacy DOCSIS 3.1 CMs that are able to receive in FDX region (namely, FDX-L)
- FDX capable modems used in a “soft split” FDD plant

We will address each type in more detail.

2.1. Coexistence Use Case

In this use case, DOCSIS 3.1, DOCSIS 3.0 or earlier CMs are expected to continue to operate, and perhaps share bonded channels with FDX enabled CM outside of the FDX frequency band. These CMs comply to test scenarios of a Legacy HFC plant.

2.2. FDX-L Use Case

The FDX-L CM is defined in DOCSIS 4.0 specifications as follows: A DOCSIS 3.1 CM with a software upgrade which can a) transmit in the 108 to 204 MHz Full Duplex upstream channels and receive in the 258 to 684 MHz Full Duplex downstream channels, in a high-split access network, or b) can receive in the 108 to 684 MHz Full Duplex downstream channels in a mid-split access network, with no access to Full Duplex upstream channels.

The FDX-L PHY receive performance requirements are not defined in the FDX specifications, but it is sensible to assume that these should not exceed the requirements for FDX CM.

2.3. “Soft Split” Use Case

One possible use case for the FDX technology is the elimination of the guard band between the upstream and downstream within the FDX band by means of echo cancelation. In such a scenario, the operator will be able to set the split frequency by setting the Resource Block Allocation (RBA) in a way that will effectively split between the upstream band and downstream band to any desired ratio with the granularity supported by the FDX frequency plan.

The signal conditions the Legacy CM has to deal with is identical to the coexistence and FDX-L use cases, with the exception of the properties of the upstream signals:

- The upstream band is smaller than 684 MHz.
- The upstream band is fixed to the lower part of the FDX band.

3. Characterization of the Interference (Aggressor)

The coexistence issue of the Legacy CMs in an FDX plant originates from the strong upstream signals the FDX CM transmits in a frequency range intended for downstream reception in all Legacy CMs. Before proceeding to understand the impact of these transmissions on the CM receiver, let’s establish the interference characteristics.

- Spectral shaping
- Power
- Time domain characteristics
- Topology dependence

The term used to describe such interference in the industry jargon is “non-self Adjacent Channel Interference (ACI)” or “external ACI”, as opposed to self-ACI which originates from the transmission of the same CM.

The dominant cause of interference is the DOCSIS 4.0 CM sharing a same tap with the “victim” CM. The contribution of CMs on other taps is significantly lower and can be ignored for the purpose of this analysis.

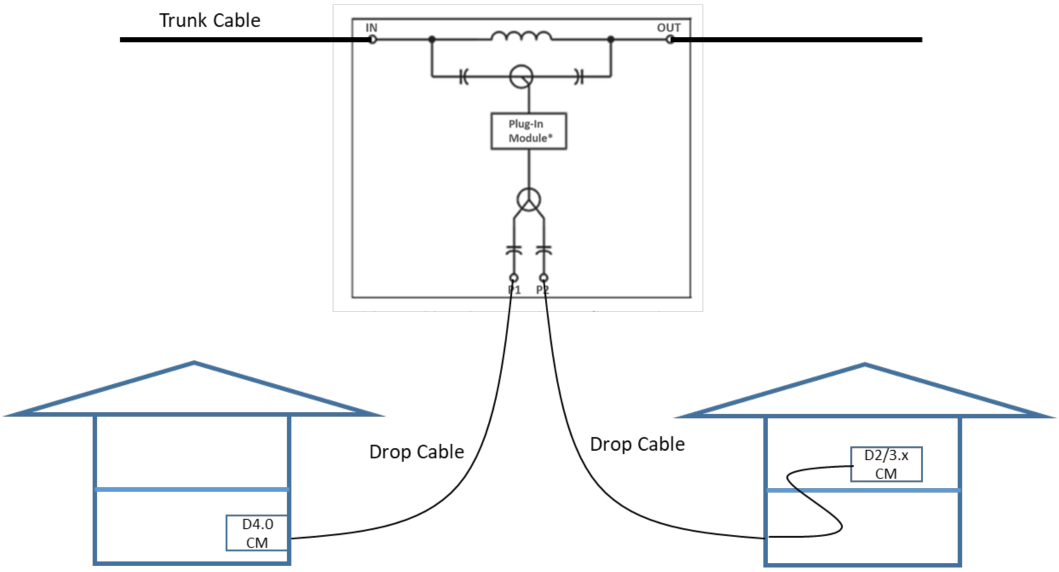

Figure 2 - A Typical 2-port Tap Configuration (Source for Tap Schematic: Arris FFT*-*Q Series Datasheet)

3.1. Power Spectral Density (PSD) Shape

The RG-6 drop cable loss down tilt is 4 dB between the edges of FDX band for 100 ft, while the upward tilt of the "reference PSD" (the specification required tilt of the transmission) of the CM is 10 dB. Consequently, the PSD of the non-self ACI is expected to have a 6 dB up tilt over the FDX frequency band for 50 ft drop and 2 dB up tilt for 100 ft drop, assuming a flat response of the coupler isolation in this band.

3.2. Power of non-self ACI

The power of non-self ACI depends on the following factors:

- The transmit power of the aggressor CM
- The coupling power ratio from the aggressor to the victim

The power of the aggressor CM depends on its ranging, i.e. on the link budget from a particular CM to the RPHY, and the desired receive level of the upstream signal at the input to the receiver of the RPHY.

Ideally, the CMTS would like the CM to transmit the highest power so that its upstream receiver signal level is optimal and would like the CM to be able to receive the signal at the lowest power possible so that the downstream transmission power could be the lowest. The same is true from the CM perspective, only with opposite considerations. When analyzing the relative level of the non-self ACI power to the received signal power, it is possible to take the following approaches:

- Assume a typical network model and "sensible" CMTS behavior for Tx and Rx levels.
- Use the minimum and maximum levels of Tx and Rx from the DOCSIS 4.0 specification.
- Use the non-self ACI levels "as is" from the Downstream BER test requirements of the DOCSIS 4.0 specification.

The latter describes an aggressor level at the victim CM of 4 dBmV/6 MHz at 108 MHz and a value of 10 dBmV/6 MHz at 684 MHz, while the downstream receiver values for the desired and rest of the channels is 0 dBmV. This means a non-self ACI level of 4 to 10 dB over the FDX frequency range.

A more stringent assumption is to use the maximum Tx of the DOCSIS 4.0 specification and the minimal Rx levels of the DOCSIS 3.1 specification independently to compute the interference. Assuming the CM to CM coupling of 30 dB, that would mean a non-self ACI level of 49 dBmV-30 dB – (-6 dBmV) = 25 dB (!) at the top edge of the FDX band. However, a more consistent assumption would be to use the receive levels of the DOCSIS 4.0 specification for outside of the FDX band. The ACI level then becomes 49 dBmV-30 dB – (+1 dBmV) = 18 dB.

The CM to CM coupling depends on the tap's port-to-port isolation and the drop cable loss, which depends on its quality and length. The port-to-port isolation is guaranteed by tap vendors to be better than 20 dB, and is usually at least several dBs better over the FDX frequency range. Measurements of typical taps show better than 30 dB isolation over most of the range. The RG-6 drop cable loss is about 6 dB for 100ft. This contributes 12 dB to the isolation for 100ft drop plants and 6 dB for 50ft.

Table 1 - Typical Drop Cable Attenuation (Source: CommScope 2275V WHRL RG6 Datasheet)

Frequency	Attenuation (dB/100 ft.)
100 MHz	2.01
200 MHz	2.86
400 MHz	4.23
700 MHz	5.96
900 MHz	6.96

So, while the datasheet-based CM to CM coupling on the same tap can be as bad as 26 dB for 50ft drop, the typical case is more than 40 dB for 100ft drop. Table 2 shows different ACI level scenarios.

Table 2 - Different ACI to Received Signal Level Scenario

Scenario	CM to CM Coupling [dB]	Interference Level (Top Edge of the FDX Band) Relative to +1dBmV/6MHz Input Level, Assuming Maximum CM Tx Power, [dB]	Interference Level (Top Edge of the FDX Band) Relative to +6 dBmV/6 MHz Input Level, Assuming Maximum CM Tx Power, [dB]
50ft drop, datasheet worst case scenario	26	22	17
100ft drop, datasheet worst case scenario	32	16	11
50ft drop, assuming 30 dB port to port isolation	>36	12	7
100ft drop, assuming 30 dB port to port isolation	>42	6	1
100ft drop, assuming 35 dB port to port isolation	>47	1	-4

Given all the considerations above, it is possible to conclude that for most of the cases the ACI interference will be close to the input signal level, and that assuming 10 dBc of ACI as worst case (as is assumed in the DOCSIS 4.0 BER test) is a reasonable working assumption.

3.3. Time Domain Characteristics

The time domain characteristics of the ACI interference follow the transmission pattern of the DOCSIS 4.0 upstream CM. Since there could be only one or a few dominant aggressors for a given Legacy CM (its tap “neighbors”), it is likely that most of the time the frequency/time resource of the interference will not be fully utilized. This greatly relieves the interference impact on the victim. However, to guarantee robust service of the Legacy, it is recommended to assume an extreme case where the aggressor is utilizing the maximum of its power and frequency resource, and also behaves in a bursty fashion.

4. Characterization of the Impact on the Cable Modem (Victim)

4.1. Overview of Legacy CM Analog Front End (AFE) Architectures

The severity and mechanism of the impact on a Legacy CM depends on its analog front-end architecture. In the past 15 years, the architectures used in CMs have gone through significant changes, primarily to accommodate for the growing number of bonded channels. To better understand the potential coexistence issues of Legacy CMs with an FDX interference, it is beneficial to understand the architectures of different generations of CMs.

4.1.1. Receiver types

All DOCSIS and set-top box receivers can be divided into the following three categories.

- Single channel receiver
- Wide band receiver
- Full band receiver

It is possible to identify the receiver type based on the DOCSIS standard support version and the number of supported downstream channels.

Table 3 - Receiver Types for CMs of Different DOCSIS Generations

DOCSIS Version	**Number of Supported Downstream Channels**	**Receiver Type**
DOCSIS 1.x – 2.0	1	Single channel receiver
DOCSIS 3.0	4-8	Wide band receiver
DOCSIS 3.0	16-32	Full band receiver
DOCSIS 3.1	2 OFDM, 32 SC-QAM	Full band receiver

All CMs use a diplex filter to separate upstream and downstream bands. The diplex filter consists of a low pass filter on the upstream transmission path, and a high pass filter on the downstream reception path. This ensures that the strong signal energy of the transmission in the upstream band and its harmonics in the downstream frequencies are filtered out by the combination of these two filters.

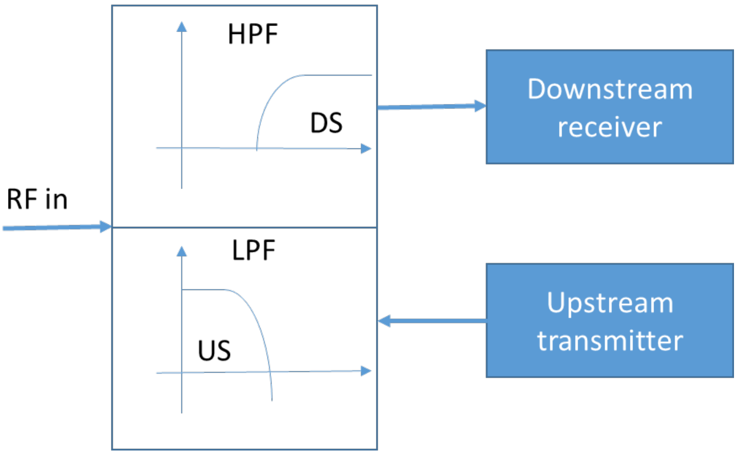

Figure 3 - Cable Modem Front End Band Separation

4.1.2. Single Channel Receiver Architecture

Single channel receivers are used for CMs compliant with the DOCSIS 2.0 specification or earlier. These receivers perform the tuning function and the channel selection function by analog means, using dual conversion, single conversion, low IF, or zero IF architectures. An oversimplified and generalized diagram of a single channel receiver is depicted in Figure 4. The RF gain is usually automatically controlled with no SW or FW intervention as the modem only “sees” the power in the single channel after it was “tuned” to IF or baseband and filtered out of the adjacent interference. The IF or baseband gain is controlled by the analog front end of the demodulator. The RF Automatic Gain Control (AGC) controls the gain of the low noise amplification stage of the receiver such that an optimal trade-off is made between the non-linear distortion and the thermal noise (noise figure). The IF AGC controls the signal level to optimize the input to the ADC. The total gain of the receiver, through both the RF and IF AGC, must present an almost continuous signal level to the demodulator to avoid performance degradation and packet loss. The AGC will not (and should not) be able to track significant and sudden changes in the total input power of the receiver. Such sudden changes in the total RF power at the input to the receiver, as in the case of FDX as an aggressor, may take the LNA out of its optimal point of trade-off between noise and interference, and cause degradation to the signal going out of the tuner to the demodulator. The level of impact and the frequencies affected may be somewhat unpredictable and dependent on the specific architecture of the tuner. The non-linear products that are created in the amplifier may fall on the frequency of the wanted channel. In this case, none of the filtering circuits further down the chain will be able to remove such an interference. The third order distortion, for example, produces not only harmonics of the signal at each threefold of the interferer frequency, but also intermodulation products of two or more signals. For example, intermodulation products of any pair of signals would fall on frequencies that are equal to the frequency of the interference plus and minus the gap between the interfering frequencies, as illustrated on Figure 5. The AGC at its converged state assuming a static downstream plant will damp the incoming interferer signal power to the level where those harmonics produce just as much distortion as designed by the CM vendor to pass the benchmark signal conditions during certification, testing, and typical plant operation. However, in case of a sudden rise of those interference signals beyond that level while the AGC is not yet able to converge, the level of interference will grow significantly. For third order distortions for example, the level of the distortion product grows by 3 dB for each 1dB of additional interference power.

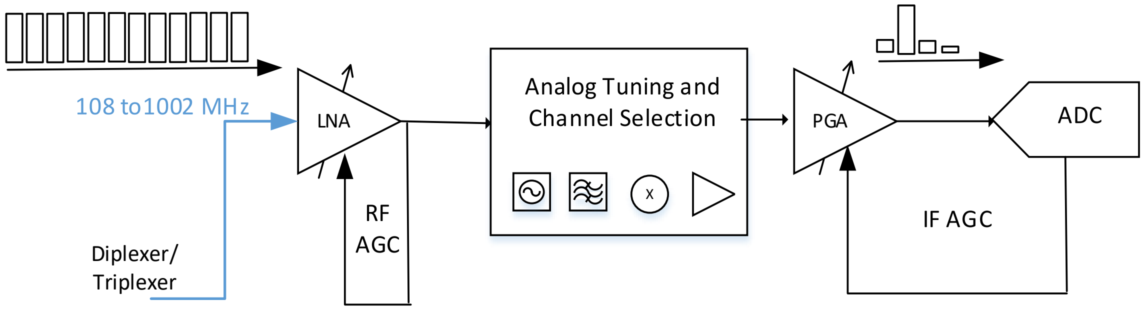

Figure 4 - Generalized and Simplified Diagram of a Single Channel Receiver

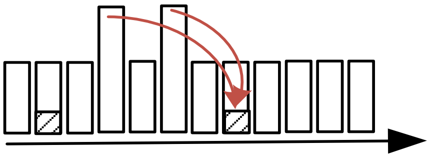

Figure 5 - Third Order Intermodulation Distortion

4.1.3. Wide Band Receiver Architectures

Wide band receivers are used for CMs compliant with DOCSIS 3.0 specifications and are employed in CMs that support either 4 or 8 bonded downstream channels. The DOCSIS 3.0 specification requires the CM to be able to receive at least 4 channels simultaneously, with a total band "captured" of at least 64 MHz. In practice, some of the wide band receivers on the market are for dual 32 MHz (e.g. [2]), 100 MHz (e.g. [8]), and dual 96 MHz band widths (e.g. [9]). The architecture of the wide band receiver is similar in concept to the one of the single channel receiver, and the considerations mentioned in 4.1.2 apply here as well. The difference is in the width of the band passed to the demodulator. Also, these receivers support the 1002 MHz band edge. An oversimplified and generalized diagram of a wide band receiver is depicted in Figure 6.

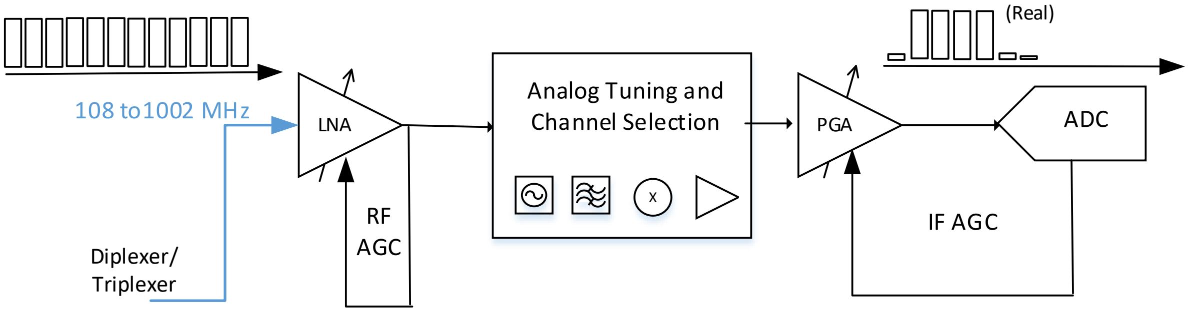

Figure 6 - Generalized and Simplified Diagram of a Wide Band Receiver

4.1.4. Full Band Receiver Architectures

Full band receivers were introduced for a second generation of DOCSIS 3.0 CMs which support a number of bonded downstream channels of 16 or higher. The major difference of this tuner architecture is that all signal selection and down conversion processing is done in a digital domain. Such a receiver requires a high bandwidth and a high dynamic range ADC. There is no analog IF AGC but there is an RF AGC, which can now be controlled by the modem (using digital power meter). The combined RF and digital AGC must ensure there is almost continuous signal channel power presented to the demodulator. It must adapt to changing signal conditions in the plant. The biggest challenge in designing such receivers is to ensure that the dynamic range of the ADC is high enough to enable sufficient SNR when the desired channel is surrounded by strong and numerous adjacent channels. The ADCs employed in these receivers stretch the bounds of feasibility for an integrated IC, and the performance of those is state of the art performance compared to publications (see [4] and the included references). To optimize the ADC dynamic range, the purpose of AGC scheme of the receiver is to bring the signal power to such level that would maximize the range of the ADC, while reducing clipping events to a level low enough statistically to not cause degradation. The downside of such headroom optimization is that any sudden total power change that the AGC is not tracking will cause ADC clipping. One mitigation to this problem is to add additional headroom, but that comes on the expense of the SNR of the ADC. This trade-off is further analyzed in section 5.1.

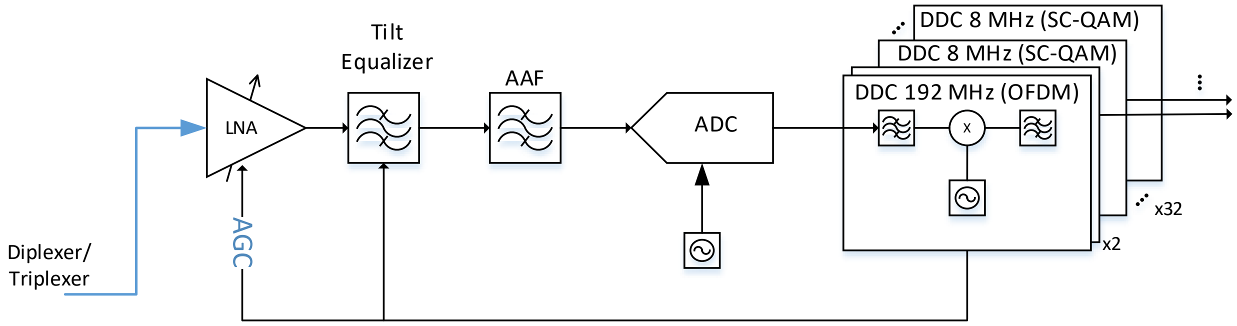

Figure 7 - Generalized and Simplified Diagram of Full Band Receiver

4.2. Adjacent Channel Leakage Interference (ALI)

Apart from the effects that are caused by the main lobe energy of the FDX signals, another contributor to interference is the leakage of the out-of-band emissions of the FDX signal to its neighbor. DOCSIS specifications guarantee a minimum 44 dBr rejection ratio between the Power Spectral Density (PSD) of the upstream signal and its out-of-band emissions. This is similar to the requirements from the downstream signal. DOCSIS 3.0 and earlier CMs are required to handle adjacent signals of at least 10 dB stronger and under stringent CNR conditions of 30 and 33 dB ([1]) which are not expected in N+0 plant. Therefore, it is likely that there should be no significant ALI impact on SC-QAM 256.

The case is different for FDX-L CMs. The DOCSIS 3.1 CMs are designed to deal with +3 dB adjacent. Any ACI level beyond that would mean some possible degradation to the signal reception capabilities of the FDX-L CM. This is generally true for all FDX CMs, not just for Legacy CMs.

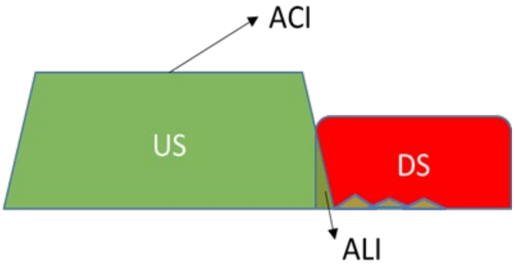

Figure 8 - Adjacent Channel Leakage Interference (ALI)

5. Mitigation Techniques

It is possible to mitigate the impact of the interference by utilizing one or a combination of the following methods.

- Tap port to port isolation improvement
- External filtering
- CM AGC settings adjustment through firmware upgrade
- FDX upstream TX power control
- Modulation and Coding Scheme (MCS) downgrading
- Partial FDX band utilization

5.1. AGC Settings Adjustment

The essence of this method is to change the AGC setting (through CM firmware upgrade) so that sufficient dynamic range headroom is present to contain any possible sudden energy change which could overflow the full scale range of the ADC and cause ADC clipping. Such clipping, as described previously, could have a disruptive effect on CM performance. However, adding additional headroom is equivalent to raising the ADC noise floor, and will cause degradation to the SNR seen by the demodulator. A CM that was originally designed to meet high dynamic range conditions would be able to maintain the required SNR despite the additional headroom. The following is an intentionally oversimplified analysis to illustrate this point and draw equivalence between the known use cases for which CMs are designed and the usage of increased headroom for the purpose of containing the FDX non-self ACI bursts.

Consider the following simplified model of a full band receiver depicted in Figure 9. It consists of a constant gain LNA and a linear scale (in dB) attenuator, an ADC, and a demodulator. We fix the parameters so that the SNR at the slicer meets the requirements for a given signal condition scenario. We then vary the external parameters, namely the input CNR and the BO, to observe which other scenario such a CM would be able to withstand and what would be the SNR degradation, if any. The AGC is assumed to keep the total power constant at the level that maximizes the dynamic range of the ADC. The fixed parameters include:

- LNA noise figure at max gain
- PAPR headroom
- ADC SNR
- ADC jitter
- Demodulator "implementation loss"
- Non-linear distortion

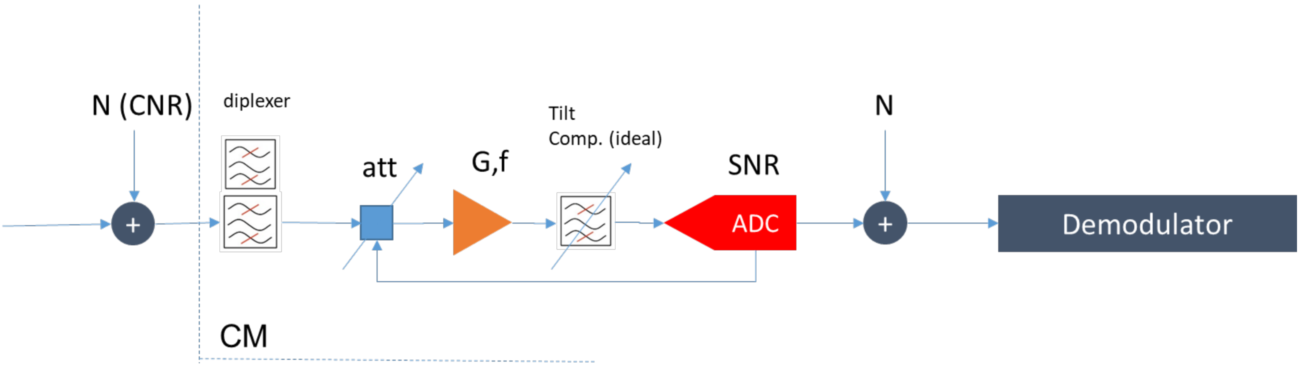

Figure 9 - Simplified Model of Full Band Receiver

Let's consider several input signal scenarios.

5.1.1. Scenario A: DOCSIS 3.0 Basic

In this scenario, the plant is full of signals with two adjacent channels of +10 dBc.

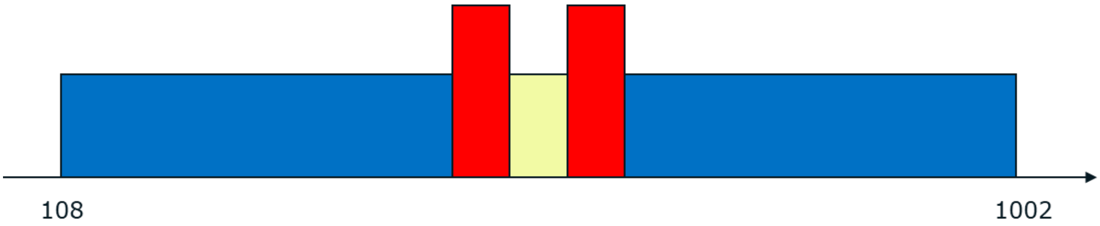

Figure 10 - Basic DOCSIS3.0 Input Signal Scenario

5.1.2. Scenario B: DOCSIS 3.0 Stringent

In this scenario, the entire plant is assumed to be +10 dBc.

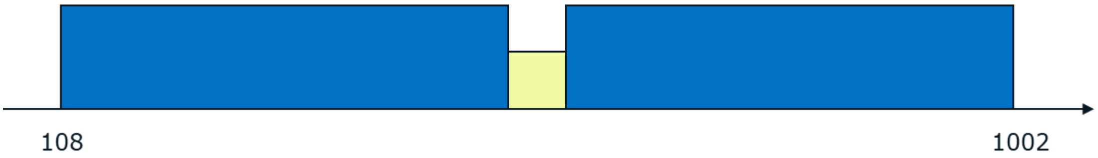

Figure 11 - Stringent DOCSIS3.0 Input Signal Scenario

5.1.3. Scenario C: SCTE-40 Based

This is a scenario that contains tilted spectrum with analog channels in the first half of the band and digital channels in the higher frequencies, two adjacents of 15 dB.

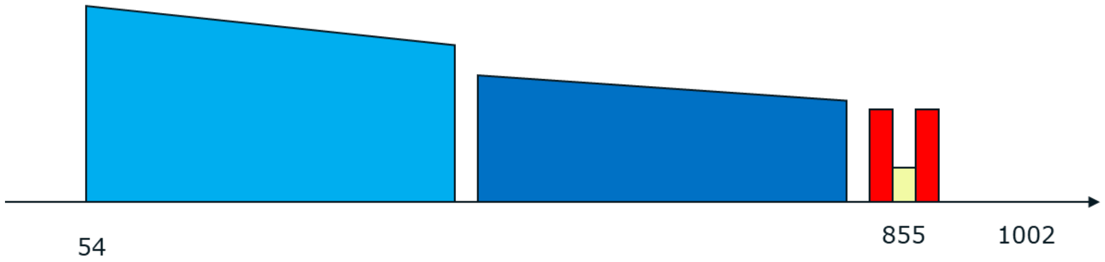

Figure 12 - SCTE-40 based Input Signal Scenario

5.1.4. *Scenario D: DOCSIS 3.1 Basic*

This scenario is assumed for BER performance tests of DOCSIS 3.1 CM

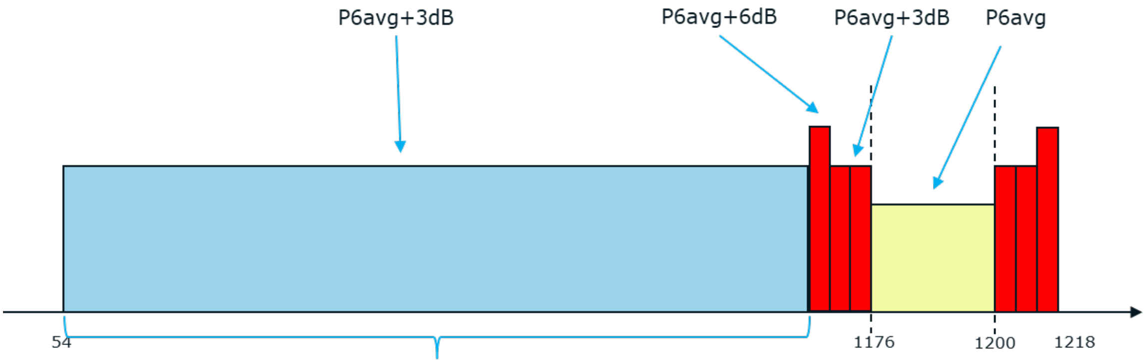

Figure 13 - DOCSIS 3.1 Input Signal Scenario

5.1.5. *Scenario E: DOCSIS 3.1 with FDX*

This is the assumed scenario in case of FDX transmission interference. The received signal is located anywhere in the yellow band.

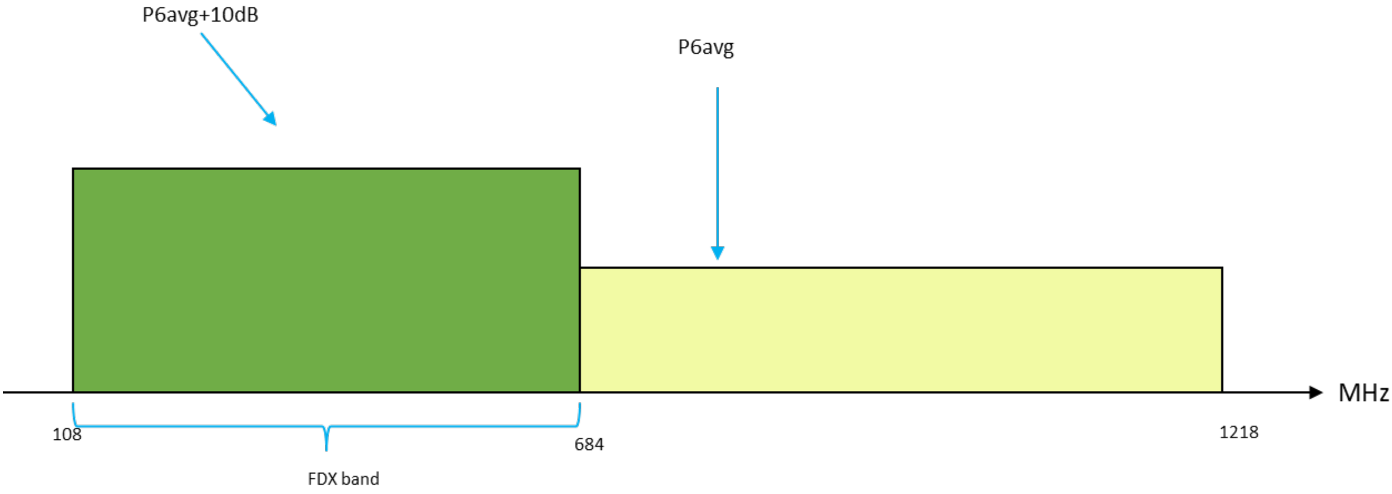

Figure 14 - DOCSIS 3.1 with FDX Interference Input Signal Scenario

5.1.6. Scenarios Summary

Table 4 summarizes the scenarios together with the back-off of the desired signal (defined as the ratio between the 6 MHz band power of the desired channel and the total signal power "seen" by the ADC) and the external CNR.

Table 4 - Possible CM Benchmark Input Signal Scenarios

Scenario	Name	MCS	Back Off/ 6MHz	CNR	"Desired" Channel Power
A	DOCSIS 3.0 Basic	256QAM-J83B	22	30	-6
B	DOCSIS 3.0 Stringent	256QAM-J83B	32	30	-6
C	SCTE-40 Based	256QAM-J83B	33	33	-12
D	DOCSIS 3.1 Basic	4K-8/9LDPC	26	41	-6
E	DOCSIS 3.1 with FDX	4K-8/9LDPC	30	41	-6

5.1.7. Expected performance with added AGC headroom to contain ACI (the simplified model example)

Figure 15 shows the result of the simplified model in Figure 9 assuming the CM was designed for the basic DOCSIS3.1 signal conditions. It shows that for CNR of 38 and higher, and back-off of 30 dB, the SNR is good enough for 2KQAM and about 2 dB short for 4KQAM.

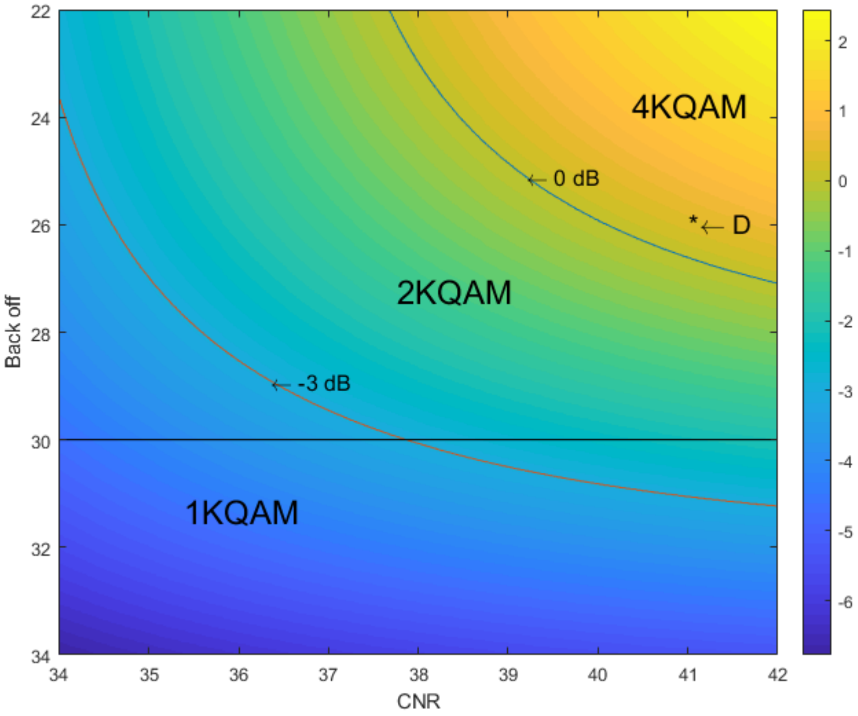

Figure 15 - SNR Margin for 4KQAM for a CM Designed for Scenario D

For the SC-QAM modulations, it is clear that a CM designed for scenario B and C has the additional dynamic range required, as the back-off of those scenarios exceed the assumed FDX ACI. A modem designed to only satisfy the basic scenario A, does not have this additional dynamic range, as shown in Figure 16. However, it has enough dynamic range for 64 QAM.

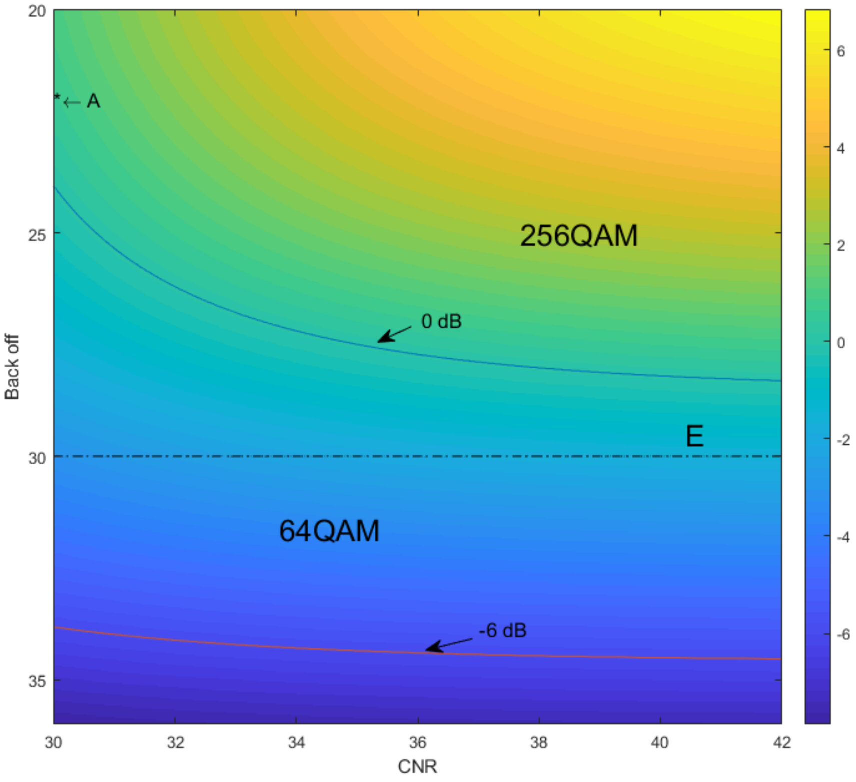

Figure 16 - SNR Margin for a CM Designed for Scenario A

5.2. Filtering

A fool proof method to prevent any disturbance of a Legacy CM reception would be placing a physical filter between the tap port and the CM. This would be a band-stop type of filter suppressing the FDX band. Placing it in the premises closest to the CM rather than on the tap would be better in terms of return loss in this frequency region, due to the additional attenuation of the drop cable. Alternatively, adding an attenuator produces the same effect. In an FDX plant, there should be enough margin for SC-QAM reception to allow reduction in the incoming signal power. The deployment of the filter can be limited to the tap that has the FDX CM on it, or even just the port that shares the final splitter stage with the FDX CM.

5.3. Reducing US Tx power

Another straightforward method of reducing the level of interference is reducing the Tx power of an FDX CM. It is possible to use “smart” and selective reduction of power only for those FDX CMs that actually interfere with Legacy CMs. Allocating these CM is possible by utilizing Proactive Network Maintenance (PNM) tools available to Legacy CMs as required by the DOCSIS 3.1 specification, and are common among DOCSIS 3.0 CMs as well.

5.4. Modulation and Coding Scheme (MCS) Downgrading

Together with reducing the Tx power mentioned in the previous section, MCS downgrading allows an agile compromise between the upstream and downstream throughput of the aggressor and victim CMs, respectively. DOCSIS 3.0 and earlier modulations allow dropping to 64 QAM from 256 QAM, while DOCSIS 3.1 allows practically continuous throughput reduction based on available SNRs. This is achieved using the bit loading as described in [7].

5.5. Partial FDX Band Deployment

While this is not an intentional mitigation method, it is worth mentioning that allocations smaller than the full FDX band reduce the level of potential interference. This is because according to the DOCSIS 4.0 specification the maximum transmit power is defined as a power spectral density (defined in the DOCSIS 4.0 specification as "reference PSD"), so that the total maximum power is achieved when the full FDX spectrum is modulated. Additionally, the reference PSD is up tilted so that higher frequency subbands have a higher contribution to the total TX power. The reduction in total power for different FDX spectrum allocation is depicted in Table 5.

Table 5 - Reduction in FDX Interference Power due to Partial FDX Band Allocation

FDX Spectrum Allocation Width	Maximum Interference Power within Partially Allocated Band versus Full FDX Band Power (Assuming 6 dB up tilt) [dB]
96 MHz	-10.7
192 MHz	-7.1
288 MHz	-4.8
384 MHz	-3
576 MHz	0

6. Conclusion

Backward compatibility and coexistence with earlier generations has historically been one of the strong points of DOCSIS technology. This allowed operators maximizing the return on investment by enabling longer life for deployed CPE, easier migration to new technologies, and avoiding disruption of existing services throughout the upgrades. What is different about FDX is that it does not provide such guarantee of coexistence by design due to the new frequency plan being incompatible with the old one. Therefore, it is important to carefully examine the potential disruption that FDX introduction may exhibit. In this paper, we characterized the interference and its potential impacts on different types of CMs, and proposed mitigation techniques. We believe that given the proper attention and careful examination of CM capabilities, together with the application of some of the methods mentioned in this paper, the coexistence issues of FDX and Legacy CMs could be greatly minimized if not eliminated altogether.

7. Abbreviations

ACI	Adjacent Channel Interference
ALI	Adjacent Leakage Interference
AWGN	Additive White Gaussian Noise
BER	1) Bit Error Ratio; 2) Bit Error Rate
BW	Bandwidth
CCI	Co-channel Interference
CM	Cable Modem
CMTS	Cable Modem Termination System

CNR	Carrier To Noise Ratio
CSO	Composite Second Order
CTB	Composite Triple Beat
dB	Decibel
dBc	Decibel Carrier
dBmV	Decibel Millivolt
dBr	Decibel Reference
DOCSIS	Data-Over-Cable Service Interface Specifications
DRFI	DOCSIS Downstream Radio Frequency Interface Specification
EC	Echo Cancellation or Echo Canceller
FDD	Frequency Division Duplexing
FDX	Full Duplex or Full Duplex DOCSIS
FEC	Forward Error Correction
GHz	Gigahertz
HFC	Hybrid Fiber/Coax
Hz	Hertz
IG	Interference Group
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak-To-Average Power Ratio
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
SC-QAM	Single Carrier Quadrature Amplitude Modulation
SCTE	Society of Cable Telecommunications Engineers
bps	bits per second
FEC	forward error correction
HFC	hybrid fiber-coax
HD	high definition
Hz	Hertz
ISBE	International Society of Broadband Experts
SCTE	Society of Cable Telecommunications Engineers

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