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Telecommunications
Engineers***

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SCTE STANDARD

SCTE 235 2017

**Operational Practice for the Coexistence of
DOCSIS 3.1 Signals and MoCA Signals
in the Home Environment**

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Table of Contents

Title	Page Number
NOTICE	2
1. Scope	6
1.1. Executive Summary	6
1.2. Scope	6
1.3. Benefits	6
1.4. Intended Audience	6
1.5. Areas for Further Investigation or to be Added in Future Versions	7
2. Normative References	7
2.1. SCTE References	7
2.2. Standards from Other Organizations	7
2.3. Published Materials	7
3. Informative References	7
3.1. SCTE References	7
3.2. Standards from Other Organizations	8
3.3. Published Materials	8
4. Compliance Notation	8
5. Abbreviations and Definitions	8
5.1. Abbreviations	8
5.2. Definitions	10
6. Coexistence of DOCSIS 3.1 Signals and MoCA Signals Overview	12
6.1. DOCSIS Physical Layer Characteristics	12
6.1.1. Overview of DOCSIS Technology and Specifications	12
6.1.2. DOCSIS 3.1 Technology and Specifications Overview	13
6.2. MoCA	14
7. Home Environment and Topology	16
7.1. Home-run	17
7.2. Loop-through	18
8. Frequency Selection Options	19
8.1. Overlapping	19
8.2. Adjacent	20
8.3. Non-Overlapping	21
8.4. Practical Filters	23
8.5. Single-port Scenarios	25
8.5.1. HFC to 1002 MHz with MoCA Using Full D-Band	25
8.5.2. HFC to 1194 MHz with MoCA Starting at 1275 MHz	26
8.6. Two-port	26
9. Fidelity Requirements	27
9.1. DOCSIS 3.1 Signal Characteristics	27
9.2. MoCA	28
10. RF Isolation Requirements for DOCSIS and MoCA Coexistence	29
10.1. RF Isolation from Adjacent Channel Interference Susceptibility	30
10.2. RF Isolation from Adjacent Channel Interference Noise and Spurious Emissions (0.1 dB Receiver Noise Floor Impact)	32
10.3. RF Isolation from Adjacent Channel Interference Noise and Spurious Emissions (DOCSIS 3.1 Carrier-to-Noise Ratio Impact)	35
10.4. MoCA 1.1 Transmitter to DOCSIS 3.1 Receiver RF Isolation	37
10.5. Summary of RF Isolation Requirements	40
11. Existence/Location of PoE and Protection Filters	41
11.1. Overview of How Filters Work	41
11.2. Example of Implementations	45
12. Two-port gateway	51
13. Guidelines	52

List of Figures

Title	Page Number
FIGURE 1 - DOCSIS 1.X EQUIPMENT FREQUENCY USAGE	12
FIGURE 2 - DOCSIS 2.0 EQUIPMENT FREQUENCY USAGE	13
FIGURE 3 - DOCSIS 3.0 EQUIPMENT FREQUENCY USAGE	13
FIGURE 4 – ALLOWABLE DOCSIS 3.1 DOWNSTREAM FREQUENCY USAGE	14
FIGURE 5 - DOCSIS 3.1 AND MOCA SIGNALS COULD SHARE THE SAME FREQUENCIES	14
FIGURE 6 - A TYPICAL IN-HOME MOCA NETWORK	15
FIGURE 7 - MOCA 2 TRANSMIT SPECTRAL MASK (FOR TPC SETTINGS OF -12 TO 20)	16
FIGURE 8 – MOCA 1.1 TRANSMIT SPECTRAL MASK	16
FIGURE 9 - LOOP-THROUGH (TOP) AND HOME-RUN (BOTTOM) SUBSCRIBER DROP ARCHITECTURES	17
FIGURE 10 - DETAILED HOME-RUN DEPLOYMENT	18
FIGURE 11 - DETAILED LOOP-THROUGH DEPLOYMENT	19
FIGURE 12 - OVERLAPPING DOCSIS 3.1 AND MOCA 1.1 SIGNALS	20
FIGURE 13 - ADJACENT DOCSIS 3.1 AND MOCA SIGNALS	21
FIGURE 14 - NON-OVERLAPPING DOCSIS 3.1 AND MOCA SIGNALS (A) ONE MOCA 1.1 CHANNEL (B) TWO BONDED MOCA 2.0 CHANNELS	22
FIGURE 15 - MOCA POE FILTER RESPONSE	23
FIGURE 16 - TRIPLEXER SIGNAL FLOW	24
FIGURE 17 - TRIPLEXER BLOCK DIAGRAM	25
FIGURE 18 - 2-PORT GATEWAY DEPLOYMENT SCENARIO	27
FIGURE 19 - DOCSIS 3.1 TRANSMITTER TO MOCA RECEIVER RF ISOLATION	31
FIGURE 20 - MOCA TRANSMITTER TO DOCSIS 3.1 RECEIVER RF ISOLATION	32
FIGURE 21 - DOCSIS 3.1 ACI NOISE AND SPURIOUS EMISSIONS INTO MOCA	33
FIGURE 22 - MOCA ACI NOISE AND SPURIOUS EMISSIONS INTO DOCSIS 3.1	34
FIGURE 23 - MAXIMUM TOLERABLE CNR DEGRADATION RELATIVE TO MAXIMUM EMISSIONS- TO-NOISE RATIO, ACI/N	36
FIGURE 24 - ADJACENT CHANNEL INTERFERENCE DEGRADATION OF CNR	36
FIGURE 25 - CNR IMPACT TO DOCSIS OPERATION USING MOCA 1.1 MODE	37
FIGURE 26 - CNR IMPACT TO DOCSIS OPERATION USING MOCA 2.0 OPERATING IN 1.1 MODE	39
FIGURE 27 - CNR IMPACT TO DOCSIS OPERATION USING MOCA 2.0 MODE	39
FIGURE 28 - LOWPASS FILTER	41
FIGURE 29 - HIGHPASS FILTER	41
FIGURE 30 - NOTCH FILTER	42

FIGURE 31 - BANDSTOP FILTER	42
FIGURE 32 - LOWPASS FILTER MEASUREMENT	43
FIGURE 33 - HIGHPASS FILTER MEASUREMENT	43
FIGURE 34 - BANDSTOP FILTER MEASUREMENT	44
FIGURE 35 - BANDPASS FILTER MEASUREMENT	44
FIGURE 36 - SUBSCRIBER PREMISES EXAMPLE	45
FIGURE 37 - TRIPLEXER BLOCK DIAGRAM	46
FIGURE 38 - TYPICAL DOCSIS TRIPLEXER RESPONSE	47
FIGURE 39 - MOCA POE FILTER REJECTING MOCA SIGNALS AND DOWNSTREAM SPURIOUS	48
FIGURE 40 - TYPICAL MOCA POE FILTER MASK	49
FIGURE 41 - TYPICAL MOCA POE FILTER RESPONSE	50
FIGURE 42 - FUNCTION OF HPF A-C	51

List of Tables

Title	Page Number
TABLE 1 - CABLE OPERATOR EXAMPLE FREQUENCY SCENARIOS	25
TABLE 2 - DOCSIS 3.1 DOWNSTREAM SIGNAL CHARACTERISTICS	28
TABLE 3 - MOCA SIGNAL CHARACTERISTICS	29
TABLE 4 - CM MINIMUM CNR PERFORMANCE IN AWGN CHANNEL	37
TABLE 5 - CM MINIMUM CNR, NOISE LEVEL, AND MAXIMUM EMISSIONS	38
TABLE 6 - ISOLATION SUMMARY FOR ALL MOCA, DOCSIS NON-OVERLAPPING INTERFERENCE SCENARIOS	40
TABLE 7 - TYPICAL DOCSIS TRIPLEXER ISOLATION REQUIREMENTS	47
TABLE 8 - TYPICAL MOCA POE FILTER REQUIREMENTS	49
TABLE 9 - ISOLATION SUMMARY FOR ALL MOCA, DOCSIS CO-CHANNEL INTERFERENCE SCENARIOS	52

1. Scope

1.1. Executive Summary

DOCSIS® 3.1 signals and MoCA® signals can both exist at frequencies above 1 GHz. This operational practice explains how operators can use frequencies above 1 GHz for both types of services. MoCA versions 1.1 and 2.0 are included in the analysis. The three cases of how these signals may coexist are:

- Overlapping
- Adjacent
- Non-overlapping

This document provides many recommendations for operational best practices for the coexistence between DOCSIS 3.1 signals and MoCA signals. Each recommendation is preceded with the text “**Guideline**” and is numbered. The guidelines are summarized in Section 12.

This document demonstrates that the hybrid fiber coax (HFC) network performance impacts the calculations. The initial conclusions are conservative in light of the ability of DOCSIS 3.1 technology to adapt to real-world environments. Final calculations are based on the selection of optimal DOCSIS 3.1 bit loading, which allows adequate performance with less isolation.

This document explains the need for sufficient isolation and suggests the proper location and required performance of filters. Filters are necessary in most architectures to:

- Prevent MoCA signals from one residence from bridging to a nearby residence
- Prevent overload of DOCSIS receivers and MoCA receivers

Filter locations can be at the consumer premises equipment (CPE) and/or at the point of entry (PoE).

Finally, home-run vs. loop-through architectures are explained, with the final recommendation that non-overlapping channels and home-run architectures be used whenever possible.

1.2. Scope

This operational practice applies to any network that contains DOCSIS downstream signals at frequencies greater than 1 GHz and has MoCA signals in the premises. The calculations are valid for DOCSIS 3.1 and for MoCA 1.1 and 2.0 single channel operation.

1.3. Benefits

The recommendations in this document are designed to assure that the DOCSIS networks and MoCA networks perform with minimal impact on each other. If these recommendations are not followed, significant performance degradation could occur to either network and, in some scenarios, one or both networks could completely fail to operate.

1.4. Intended Audience

This operational practice is intended to be used by network designers, cable industry technical personnel, equipment designers and others who have an interest in coexistence of DOCSIS 3.1 signals and MoCA signals above 1 GHz to assure that proper frequencies are selected and that proper filters are specified to be installed.

1.5. Areas for Further Investigation or to be Added in Future Versions

Additional documents could:

- Analyze MoCA 2.5 signals
- Provide recommendations for filters in mid-split systems
- Coexistence of DOCSIS 3.1 technology with other home networking technologies such as G.hn, HomePlug, etc.

2. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of the standard. At the time of Subcommittee approval, the editions indicated were valid. All standards are subject to revision; and while parties to any agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents may not be compatible with the referenced version.

2.1. SCTE References

- No normative references are applicable.

2.2. Standards from Other Organizations

- No normative references are applicable.

2.3. Published Materials

- [DOCSIS PHYv3.1] DOCSIS 3.1, Physical Layer Specification, CM-SP-PHYv3.1-I09-160602, June 2, 2016, Cable Television Laboratories, Inc.
- [MoCA 1.1] MoCA 1.1 Specification for Device RF Characteristics, MoCA_Specification_for_Device_RF_Characteristics, February 11, 2014, Multimedia over Coax Alliance, http://www.mocalliance.org/MoCA1/specification/MoCA_Specification_for_Device_RF_Characteristics.pdf
- [MoCA 2.0] MoCA 2.0 Specification for Device RF Characteristics, MoCA_2_Device_RF_Characteristics-150406d, February 11, 2014, Multimedia over Coax Alliance, http://www.mocalliance.org/MoCA2/specification/MoCA_2_Device_RF_Characteristics-150406d.pdf

3. Informative References

The following documents may provide valuable information to the reader but are not required when complying with this standard.

3.1. SCTE References

- [ANSI/SCTE 151] ANSI/SCTE 151 2015 Mechanical, Electrical, and Environmental Requirements for RF Traps and Filters (https://www.scte.org/documents/pdf/Standards/ANSI_SCTE%20151%202015.pdf).
- [ANSI/SCTE 79-1] ANSI SCTE 79-1 2009 DOCSIS 2.0 Part 1: Radio Frequency Interface

- [ANSI/SCTE 23-1] ANSI SCTE 23-1 2010 DOCSIS 1.1 Part 1: Radio Frequency Interface

3.2. Standards from Other Organizations

- No informative references are applicable.

3.3. Published Materials

- [CTA-542] CTA-542-D: CTA Standard, Cable Television Channel Identification Plan, June 2013. (Formerly CEA-542-D. Recently renamed CTA-542-D, but the contents have not changed.)
- [DOCSIS PHYv3.0] DOCSIS 3.0, Physical Layer Specification, CM-SP-PHYv3.0-I12-150305, March 5, 2015, Cable Television Laboratories, Inc. (<http://www.cablelabs.com/wp-content/uploads/specdocs/CM-SP-PHYv3.0-I12-150305.pdf>)
- [COUNTING] “Counting Channels,” <http://www.scte.org/TechnicalColumns/08-12-01%20counting%20channels.pdf>, December 2008 issue, *Communications Technology*

4. Compliance Notation

<i>shall</i>	This word or the adjective “ <i>required</i> ” means that the item is an absolute requirement of this specification.
<i>shall not</i>	This phrase means that the item is an absolute prohibition of this specification.
<i>forbidden</i>	This word means the value specified shall never be used.
<i>should</i>	This word or the adjective “ <i>recommended</i> ” means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighted before choosing a different course.
<i>should not</i>	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
<i>may</i>	This word or the adjective “ <i>optional</i> ” means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.
<i>deprecated</i>	Use is permissible for legacy purposes only. Deprecated features may be removed from future versions of the standard. Implementations should avoid use of deprecated features.

5. Abbreviations and Definitions

5.1. Abbreviations

ACI	adjacent channel interference
ACI/N	ACI emissions-to-noise ratio
AWGN	additive white Gaussian noise
BW	bandwidth

bps/Hz	bits per second per hertz
CEA	Consumer Electronics Association (now Consumer Technology Association)
CM	cable modem
CMTS	cable modem termination system
CNR	carrier-to-noise ratio
CNIR	carrier-to-noise-plus-interference ratio
CPE	customer premises equipment
CTA	Consumer Technology Association (formerly Consumer Electronics Association)
dB	decibel
dBm	decibel milliwatt
dBmV	decibel millivolt
dBr	decibel reference (or decibel relative)
DVR	digital video recorder
DOCSIS	Data-Over-Cable Service Interface Specifications
DTA	digital transport adapter (or digital terminal adapter)
eMTA	embedded multimedia terminal adapter
ETSI	European Telecommunications Standards Institute
ExD	extended band D
FEC	forward error correction
FTTP	fiber to the premises
GHz	gigahertz
GW	gateway
HPF	high-pass filter
Hz	hertz
i.e.	that is (<i>id est</i>)
kbps	kilobits per second
kHz	kilohertz
LAN	local area network
LDPC	low density parity check
log	logarithm
MAC	media access control (or medium access control)
MATV	master antenna television
Mbps	megabits per second
MDU	multiple dwelling unit
MHz	megahertz
MoCA	Multimedia over Coax Alliance
MULPI	MAC and upper layer protocols interface
NF	noise figure
ODU	outdoor unit
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
ONT	optical network terminal
OP2OP	output port-to-output port
OSP	outside plant
OSSI	operation(s) support system interface
PHY	physical layer
PoE	point of entry

QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase shift keying
RF	radio frequency
RX	receiver (or receive)
S-CDMA	synchronous code division multiple access
SC-QAM	single carrier quadrature amplitude modulation
SCTE	Society of Cable Telecommunications Engineers
SIK	self-installation kit
SMATV	satellite master antenna television
SNR	signal-to-noise ratio
STB	set-top box
TCM	trellis coded modulation
TPC	transmit power control
TV	television

5.2. Definitions

ACI susceptibility	The degree to which the performance of a desired signal is degraded by out-of-band or out-of-channel emissions from an adjacent signal. See also <i>adjacent channel interference</i> .
adjacent	An operating condition in which the bandwidth of the guard band between a DOCSIS 3.1 downstream signal and a MoCA 1.1 <i>Band D</i> signal is ≥ 5 MHz but ≤ 25 MHz, or the bandwidth of the guard band between a DOCSIS 3.1 downstream signal and a MoCA 2.0 <i>Band D</i> signal is ≥ 5 MHz but ≤ 75 MHz.
adjacent channel interference (ACI)	Out-of-band or out-of-channel emissions from one signal that degrade the performance of another signal occupying a channel or frequency next to the first signal.
diplexer	A passive device or circuit comprising a combination of low pass and high pass filters, used to combine or separate signals in two frequency ranges. Two of the device's ports or connections (e.g., low frequency or "L" and high frequency or "H") are multiplexed onto a third port or connection (e.g., common or "C").
downstream	1) The direction of RF signal transmission from headend or hub site to subscriber. Also called forward. In North American cable networks, the downstream or forward spectrum may occupy frequencies from just below 54 MHz to as high as 1002 MHz or more. 2) The DOCSIS 3.1 downstream spectrum is 258 MHz (optional 108 MHz) to 1218 MHz (optional 1794 MHz).
filter mask	A graph of a filter's desired magnitude (or other characteristic)-versus-frequency response limits, which may be overlaid on the filter's measured frequency response plot to provide a quick visual indication of whether the measured response meets specification. The graph can show minimum and/or maximum performance limits, typical performance limits, or other performance metrics of interest. See also <i>filter response</i> .
filter response	Magnitude-versus-frequency and phase-versus-frequency characteristics of a filter, including such parameters as half-power

	point(s), and pass-band and stop-band bandwidth, flatness, attenuation, and ripple.
isolation	1) The difference, in decibels, between the power of a desired signal or signal component and the power of an undesired signal or signal component. 2) The amount of attenuation or signal loss, in decibels, between two ports or connections of a passive or active device or circuit.
MoCA Band D	A frequency range above 1 GHz used for transmission of Multimedia over Coax Alliance signals. <i>Band D</i> comprises eight 50 MHz-wide channels in the 1125 MHz to 1525 MHz range. <i>Extended Band D</i> is 550 MHz wide and comprises 100 MHz-wide single channels, 225 MHz-wide bonded-pair channels, and two sub-bands (D-Low and D-High) in the 1125 MHz to 1675 MHz range.
noise figure (NF)	A measure, in decibels, of the difference between input and output SNR (or CNR) in a component, circuit, or device. Also an expression of a device's noise factor (F) in decibels. Both NF and F are often stated at a standard temperature of 290 K. Mathematically, $NF = SNR_{input(dB)} - SNR_{output(dB)}$ or $NF = 10\log_{10}(F)$ or where NF is noise figure in decibels, F is noise factor, $SNR_{input(dB)}$ is the input signal-to-noise ratio in decibels due to thermal (or Johnson-Nyquist) noise, and $SNR_{output(dB)}$ is the output signal-to-noise ratio in decibels
non-overlapping	An operating condition in which the bandwidth of the guard band between a DOCSIS 3.1 signal and a MoCA signal is > 25 MHz for MoCA 1.1 and > 75 MHz for MoCA 2.0.
overlapping	An operating condition in which a DOCSIS 3.1 downstream signal and a MoCA signal occupy some or all of the same range of frequencies.
S-parameter (S_{xy})	The ratio of the voltage appearing at port x of a device to the applied voltage at port y of a device. For example, if a device has two ports, 1 and 2, where port 1 is the input and port 2 is the output, the S-parameter, or scattering parameter, S_{21} is the ratio of the voltage appearing at port 2 to the applied voltage at port 1. In this example, S_{21} is equivalent to the voltage gain. Similarly, S_{11} is the ratio of any reflected voltage at port 1 to the applied voltage at port 1. S-parameters are in general complex values. However, it is often useful to deal with the magnitude of S-parameters, as indicated by the vertical bars on either side (i.e., $ S_{21} $). The magnitude of an S-parameter is typically expressed in decibels.
triplexer	A passive device or circuit comprising a combination of three filters, used to combine or separate signals in three frequency ranges. Three of the device's ports or connections (e.g., low frequency, mid-frequency, and high frequency) are multiplexed onto a common fourth port or connection.
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 spectrum is 5 MHz to 204 MHz, with support for 5 MHz to 42 MHz, 5 MHz to 65 MHz, 5 MHz to 85 MHz, and 5 MHz to 117 MHz.

6. Coexistence of DOCSIS 3.1 Signals and MoCA Signals Overview

In the Data-Over-Cable Service Interface Specifications (DOCSIS[®]) version 3.1, the radio frequency (RF) spectrum was expanded to beyond 1 gigahertz (GHz), either to 1.2 GHz or even to 1.8 GHz. Unfortunately, this means DOCSIS 3.1 signals and Multimedia over Coax Alliance (MoCA) signals now share common frequencies above 1 GHz. Plus, the vastly different signal levels expected in the home coax network for DOCSIS 3.1 signals and MoCA signals means achieving the required isolation between them will be challenging. In this document, operational practices for the coexistence of DOCSIS 3.1 signals and MoCA signals on the same coax network in the customer premises will be given, with the goal of ensuring the maximum performance of both networks when they must coexist on the same physical medium.

6.1. DOCSIS Physical Layer Characteristics

6.1.1. Overview of DOCSIS Technology and Specifications

The first version, DOCSIS 1.0, was introduced in the late 1990s, and gave the cable industry standards-based interoperability. The latter means “certified” cable modems from any vendor will work with a “qualified” cable modem termination systems (CMTS) from any vendor. The second version, DOCSIS 1.1, added a number of features, including quality of service (QoS), more robust scheduling, packet classification, and other enhancements that facilitated voice and non-best effort data services.

DOCSIS 1.0 and 1.1 technology and specifications – collectively known as DOCSIS 1.x – supported per-channel downstream raw data rates (includes forward error correction (FEC) coding and framing overhead) of 30.34 megabits per second (Mbps) using 64-QAM (64-state quadrature amplitude modulation) and 42.88 Mbps using 256-QAM in a 6 megahertz (MHz) channel bandwidth. DOCSIS 1.x technology and specifications supported several upstream raw data rates (includes FEC coding and framing overhead), ranging from a low of 320 kilobits per second (kbps) to a high of 10.24 Mbps. It also supported two upstream modulation formats – quadrature phase shift keying (QPSK) and 16-QAM – as well as five upstream radio frequency (RF) channel bandwidths from 200 kilohertz (kHz) to 3.2 MHz. DOCSIS 1.1 technology and specifications added some enhancement to upstream transmission robustness, using 8-tap adaptive pre-equalization. Figure 1 shows the frequency usage by DOCSIS 1.x equipment. The upstream was 5 MHz to 42 MHz, and the downstream 88 MHz to 860 MHz.¹

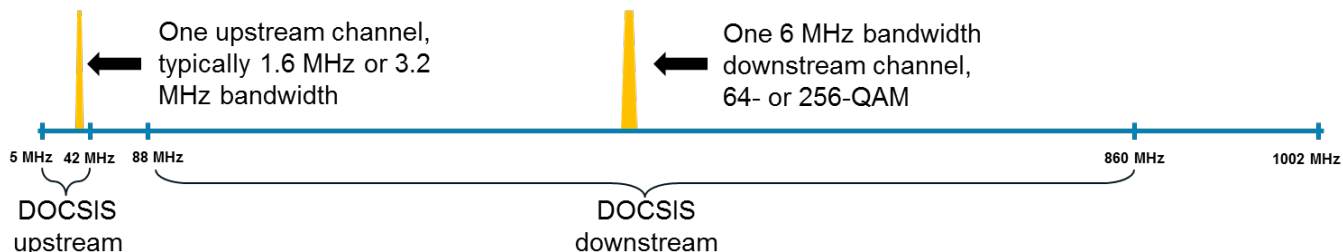


Figure 1 - DOCSIS 1.x Equipment Frequency Usage

Downstream data rates and the downstream channel bandwidth in the next version, DOCSIS 2.0, remained unchanged from DOCSIS 1.x, but supported higher upstream raw data rate per RF channel, up

¹ A downstream upper frequency limit of 860 MHz does not align with the upper channel boundary of any CTA cable channel as defined in [CTA-542]. Depending on channel capacity, the highest upper CTA channel boundary frequencies that match a nominal 860 MHz are 858 MHz, 864 MHz, or 870 MHz. For more on this, see [COUNTING].

to 30.72 Mbps in a 6.4 MHz channel bandwidth. DOCSIS 2.0 technology and specifications supported 8-QAM, 32-QAM, and 64-QAM – and optionally 128-QAM trellis coded modulation (TCM) encoded modulations for synchronous code division multiple access (S-CDMA) channels. To facilitate more robust upstream data transmission, DOCSIS 2.0 technology introduced advanced physical layer (PHY), including features such as a 24-tap pre-equalizer, improved upstream FEC and interleaving, ingress cancellation, and direct sampled RF in the CMTS’s upstream burst receiver. Figure 2 shows DOCSIS 2.0 frequency usage, which remained the same as DOCSIS 1.x. frequency usage

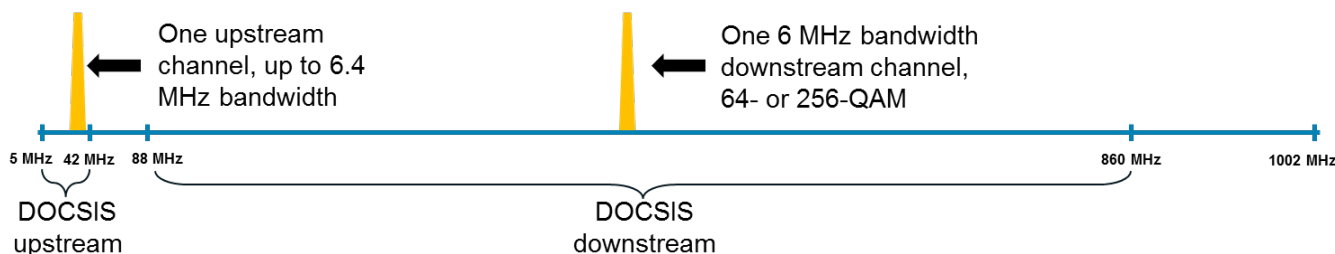


Figure 2 - DOCSIS 2.0 Equipment Frequency Usage

DOCSIS 3.0 technology and specifications retained a downstream channel bandwidth of 6 MHz, and upstream channel bandwidths up to 6.4 MHz. The DOCSIS 3.0 specification introduced channel bonding, in which logical bonding of multiple channels increases data throughput. For example, bonding four downstream 256-QAM 6 MHz-wide channels gives a raw data rate of 42.88 Mbps * 4 = 171.52 Mbps. The downstream lower frequency limit changed from DOCSIS 1.x and 2.0’s 88 MHz to 108 MHz, and the upper frequency limit increased from 860 MHz to 1002 MHz. The upstream upper frequency limit increased to as high as 85 MHz (optional); see Figure 3. DOCSIS 1.x / 2.0 cable modems can reside on same system as DOCSIS 3.0 modems.

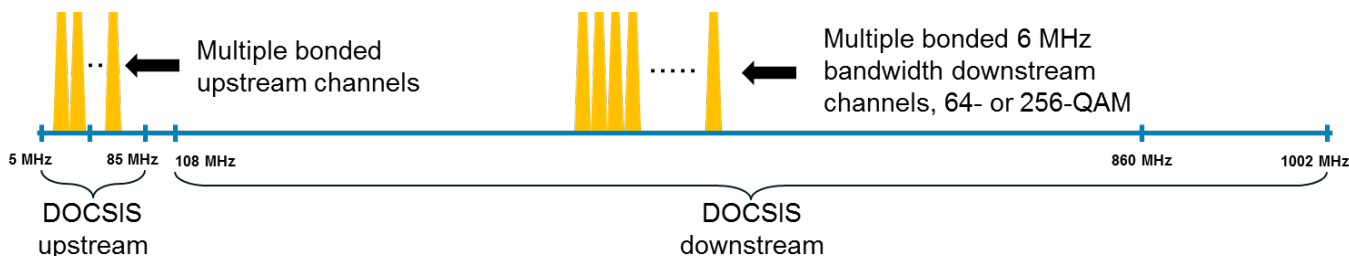


Figure 3 - DOCSIS 3.0 Equipment Frequency Usage

6.1.2. DOCSIS 3.1 Technology and Specifications Overview

DOCSIS 3.1 is the latest set of CableLabs’ DOCSIS Specifications. CableLabs® released version I01 of the new 3.1 spec in late October, 2013. The latest version is I09, released June, 2016. All DOCSIS 3.1 specifications including *MAC and Upper Layer Protocols Interface Specification (MULPI)*, *Cable Modem Operations Support System Interface Specification (OSS)*, *Physical Layer Specification (PHY)*, *CCAP™ Operations Support System Interface Specification*, and *Security Specification* have been publicly released. DOCSIS 3.1 specifications became an international standard in early December 2014 (ETSI TS 103 311).

Why not just continue with DOCSIS 3.0 technology? After all, DOCSIS 3.0 devices can scale to gigabit-class speeds. However, DOCSIS 3.1 technology will scale better, and is more spectrally efficient than single carrier quadrature amplitude modulation (SC-QAM) technology. Among the goals of the DOCSIS 3.1 specification are achieving 10+ gigabits per second (Gbps) in the downstream and 1+ Gbps in the

upstream; backwards compatibility with DOCSIS 3.0, 2.0, & 1.1 equipment; and the previously mentioned better spectral efficiency – that is, more bits per second per hertz (bps/Hz) through the use of higher modulation orders.

DOCSIS 3.1 operation takes advantage of technology that is new for the cable industry: orthogonal frequency division multiplexing (OFDM) in the downstream, orthogonal frequency division multiple access (OFDMA) in the upstream, and low density parity check (LDPC) FEC. Also supported are higher modulation orders than earlier versions of DOCSIS equipment: Up to 4096-QAM in the downstream and upstream, optional to 16384-QAM in the downstream.

Of interest to coexistence with MoCA, the DOCSIS 3.1 specification supports expanded downstream and upstream spectrum usage (see Figure 4). The mandatory supported downstream spectrum is 258 MHz to 1218 MHz, optional to 1794 MHz (and optionally starting at 108 MHz on the lower end of the downstream spectrum). The upstream spectrum is from 5 MHz to as high as 204 MHz. The maximum downstream OFDM channel bandwidth is 192 MHz, and the minimum is 24 MHz. The maximum upstream OFDMA channel bandwidth is 96 MHz, and the minimum occupied bandwidth (equal to the encompassed spectrum minus exclusions) is either 6.4 MHz (25 kHz subcarrier spacing) or 10 MHz (50 kHz subcarrier spacing).



Figure 4 – Allowable DOCSIS 3.1 Downstream Frequency Usage

Figure 5 shows that DOCSIS 3.1 signals and MoCA signals are both allowed to occupy frequencies between 1125 MHz and 1675 MHz



Figure 5 - DOCSIS 3.1 and MoCA Signals Could Share the Same Frequencies

6.2. MoCA

MoCA develops home networking media access control (MAC) and PHY specifications and certification programs for its members. MoCA has provided RF characteristics summaries for both MoCA 1.1 and MoCA 2.0 specifications to the public via its website. See [MoCA 1.1] and [MoCA 2.0] for details.

MoCA technology is capable of establishing communications links that have frequency nulls, large attenuation, and significant delay spread. MoCA has been designed to communicate over components where communication may not have been originally intended. Some examples of the RF challenges MoCA can overcome include:

- Communicating across home splitter or amplifier output ports
- Communicating through devices that may have spectral nulls above 1 GHz

- Communicating through high coaxial cable attenuation above 1 GHz

Figure 6 illustrates a typical in-home MoCA network from [MoCA 2.0], where communication between nodes could involve, at a minimum, communication across splitter output ports (sometimes called “splitter jumping”). Splitter jumping is illustrated in Figure 6 as the communication path between point A and point B. Many legacy splitters were designed with the intention to not allow signals to pass across their output ports, hence the specification output port-to-output port (OP2OP) isolation. A common value of OP2OP isolation is 25 decibels (dB) minimum up to 1 GHz. Also frequency nulls (high attenuation over a relatively narrow bandwidth) may exist above 1 GHz, a region of spectrum historically not specified on legacy splitters or home amplifiers. Since MoCA has been in use since 2010, it has been designed to coexist with these RF challenges. A detailed description of the advantages and usage of PoE filters is provided in section 11, “Existence/Location of PoE and Protection Filters.”

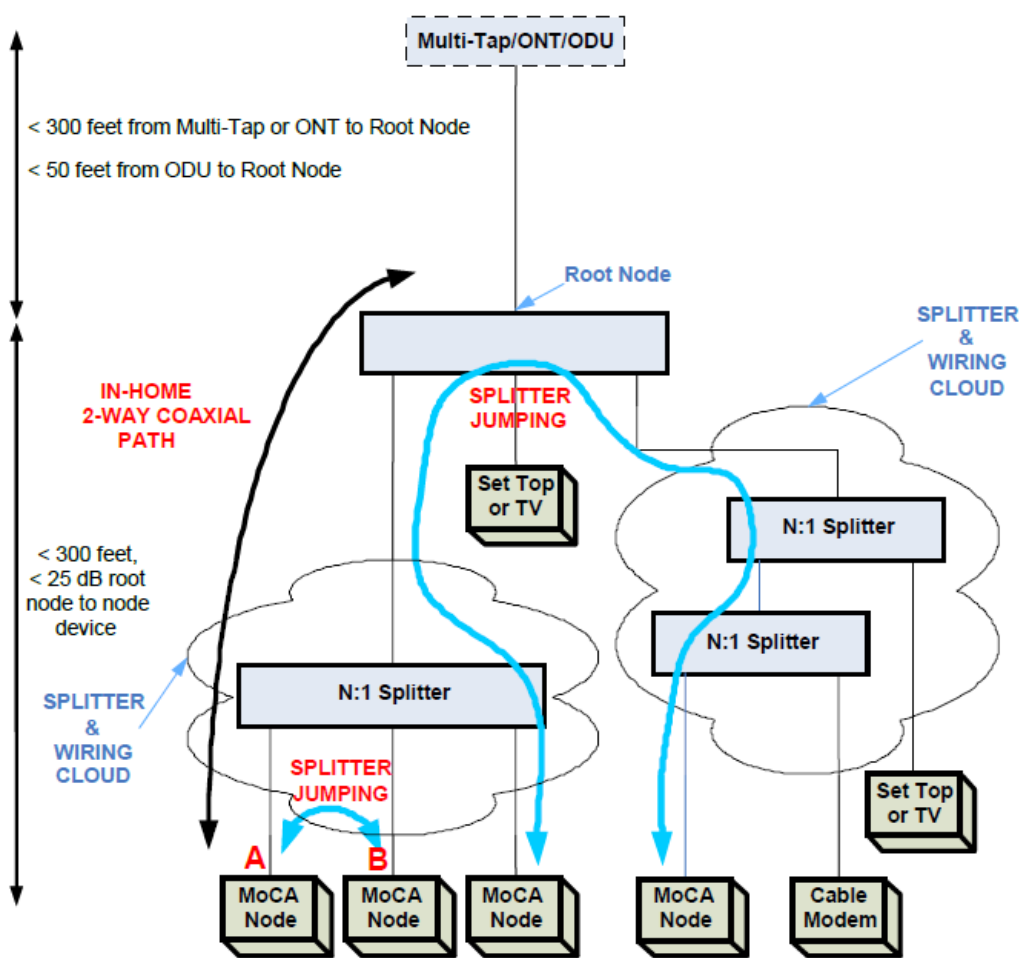


Figure 6 - A Typical In-home MoCA Network

MoCA band D has a frequency range above 1 GHz used for transmission of Multimedia over Coax Alliance signals. Band D comprises eight 50 MHz-wide channels in the 1125 MHz to 1525 MHz range. Extended Band D, introduced in MoCA 2.0, is 550 MHz wide and comprises 100 MHz-wide single channels, 225 MHz-wide bonded-pair channels, and two sub-bands (D-Low and D-High) in the 1125 MHz to 1675 MHz range.

MoCA 2.0 primary channels (100 MHz bandwidth (BW)) in ExD are centered on a 25 MHz grid and their maximum total output power can be between -1 decibel milliwatt (dBm) and +7 dBm per 100 MHz. The spectral mask for MoCA 2.0 has been provided in Figure 7 and is the basis for the MoCA 2.0 Out of channel emissions discussed in Section 9.2 Fidelity Requirements for MoCA.

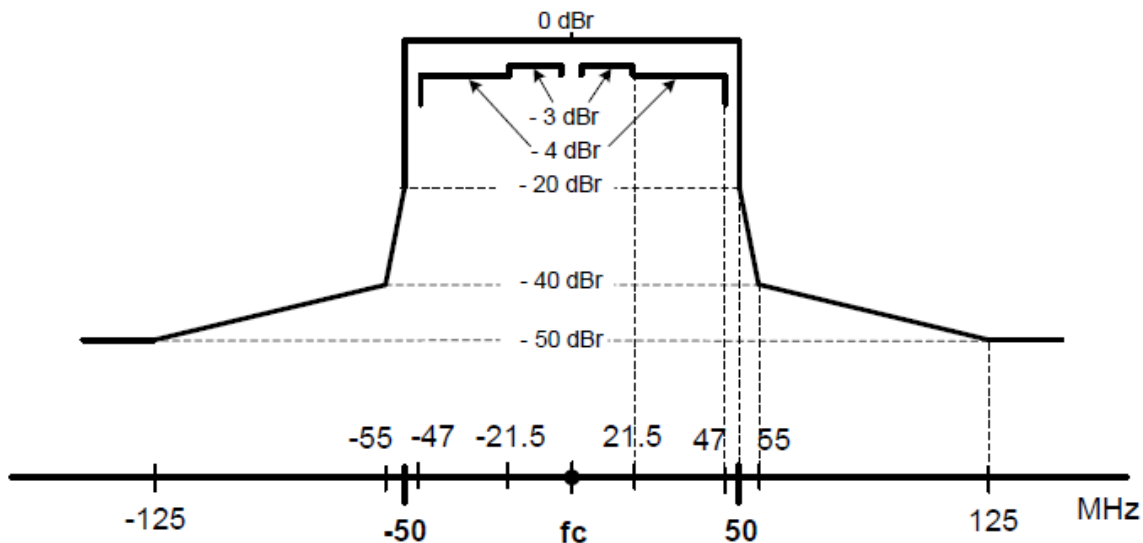


Figure 7 - MoCA 2 Transmit Spectral Mask (for TPC Settings of -12 to 20)

The spectral mask for MoCA 1.1 has been provided in Figure 8 and is the basis for MoCA 1.1 Out of channel emissions discussed in Section 9.2 Fidelity Requirements for MoCA. The spectral mask attributes of MoCA and DOCSIS signals are critical in understanding the isolation requirements for coexistence, which are described in more detail, later in this document.

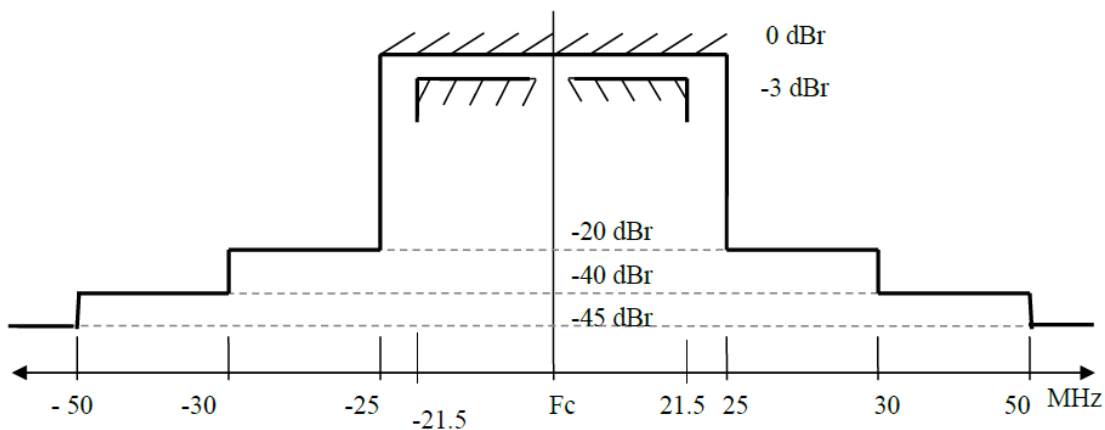


Figure 8 – MoCA 1.1 Transmit Spectral Mask

7. Home Environment and Topology

Cable operators have used two architectures for residential and multiple dwelling unit (MDU) installations. One is loop-through, and the other is home-run. Figure 9 illustrates a high-level view of the two architectures.

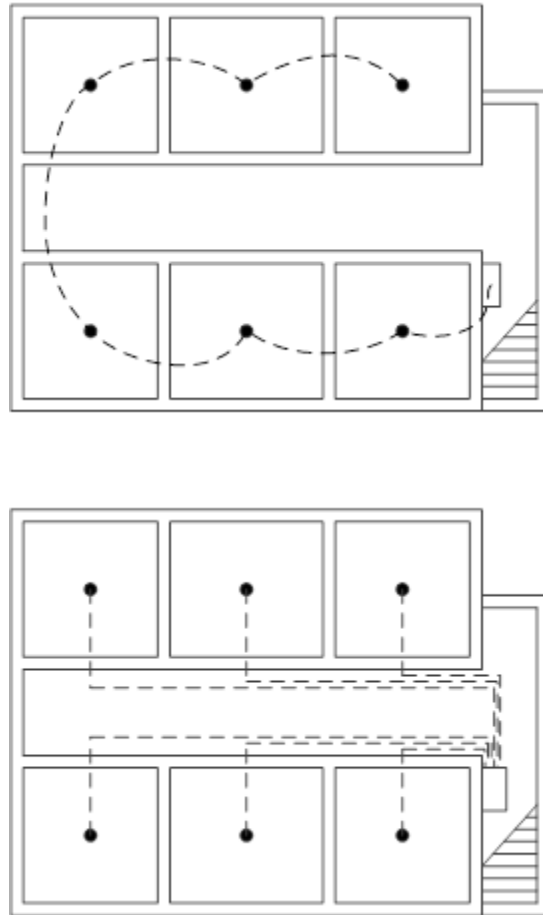


Figure 9 - Loop-through (top) and Home-run (bottom) Subscriber Drop Architectures

A home-run architecture is similar to a hub-and-spoke architecture, in which each room or unit is fed by a dedicated run of coaxial cable from the root device or signal distribution point. Home-run wiring is commonly used in residential installations, and in most MDUs.

A loop-through architecture is series-wired from a root device or signal distribution point to the rooms or units in the building (or floor). One port of a splitter or directional coupler in the first room taps off signal for that room, and the other port feeds subsequent rooms or units. Loop-through architectures were at one time widely used for master antenna television (MATV) and satellite master antenna television (SMATV) signal distribution in MDUs, and also were used for distribution of cable signals in MDUs and in some single-family residences. Though no longer in widespread use, some buildings still have loop-through cabling. Some single family residences have a hybrid of both home-run and loop-through topology.

7.1. Home-run

A detailed home-run topology is depicted in Figure 10. An important characteristic of a home-run topology is a single cable between a root device or distribution point and each customer premises equipment (CPE) location. In one variation, one output of a two-way splitter feeds the cable modem, and the other output is connected to a second splitter that in turn feeds the remaining CPE. In another variation (shown in Figure 10), splitters are not cascaded.

Guideline 1: A home-run topology should be used to control losses and RF levels more uniformly across the home CPE.

This latter approach also makes it easier for MoCA devices to communicate with one another, since MoCA has been designed to be robust enough to work in much more challenging environments, with multiple cascaded splitters.

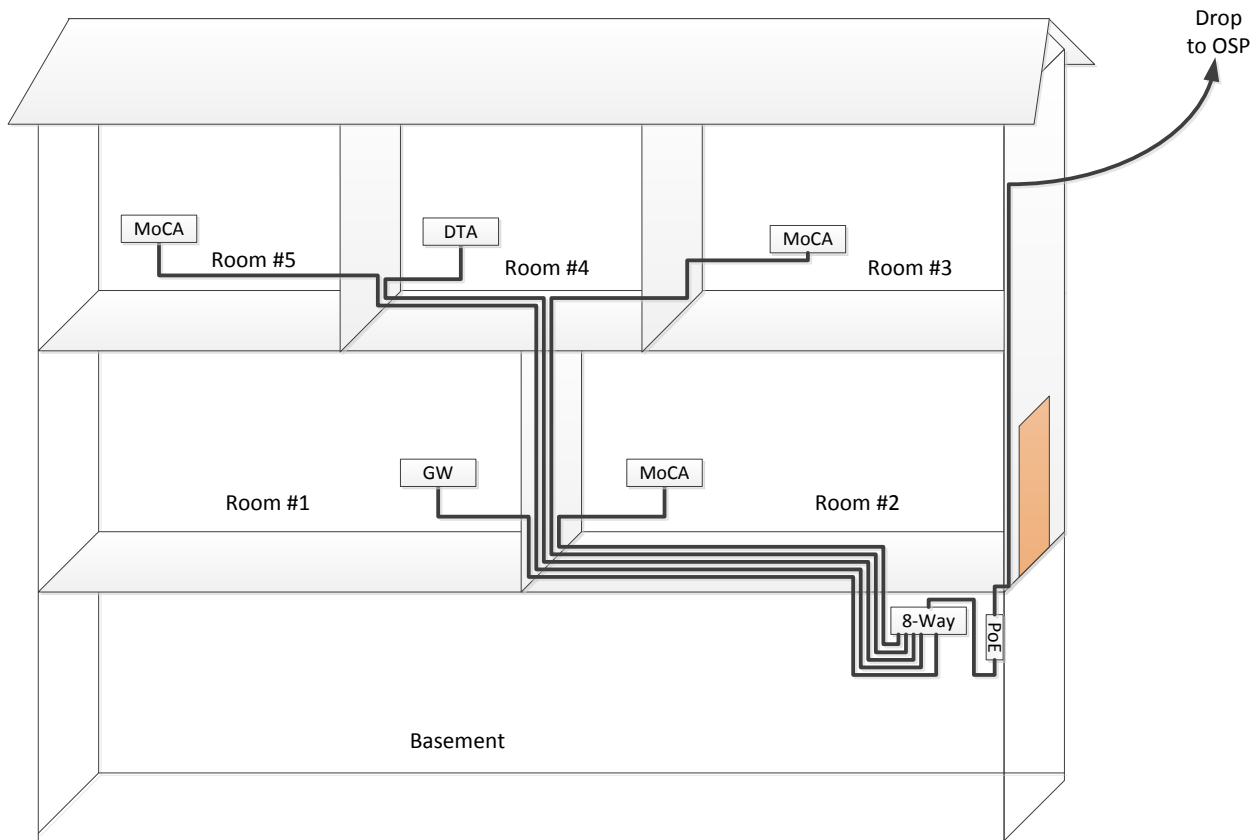


Figure 10 - Detailed Home-run Deployment

7.2. Loop-through

A detailed loop-through architecture is shown in Figure 11.

Guideline 2: The series-wired nature of a loop-through architecture should be avoided because it complicates the ability to control losses and achieve uniform RF levels across the home CPE.

For instance, downstream signal levels will be greater at the outlet closest to the beginning of the loop and lower at the end of the loop. Conversely, CPE upstream transmit levels will be higher at and near the end of the loop, since the signals must overcome greater losses than CPE at or near the beginning of the loop. MoCA is robust enough to work in a loop-through architecture and allow devices to communicate with one another. However, placement of the PoE filter must be at the root device or distribution point, since its placement in other locations may affect MoCA operation in other rooms or units.

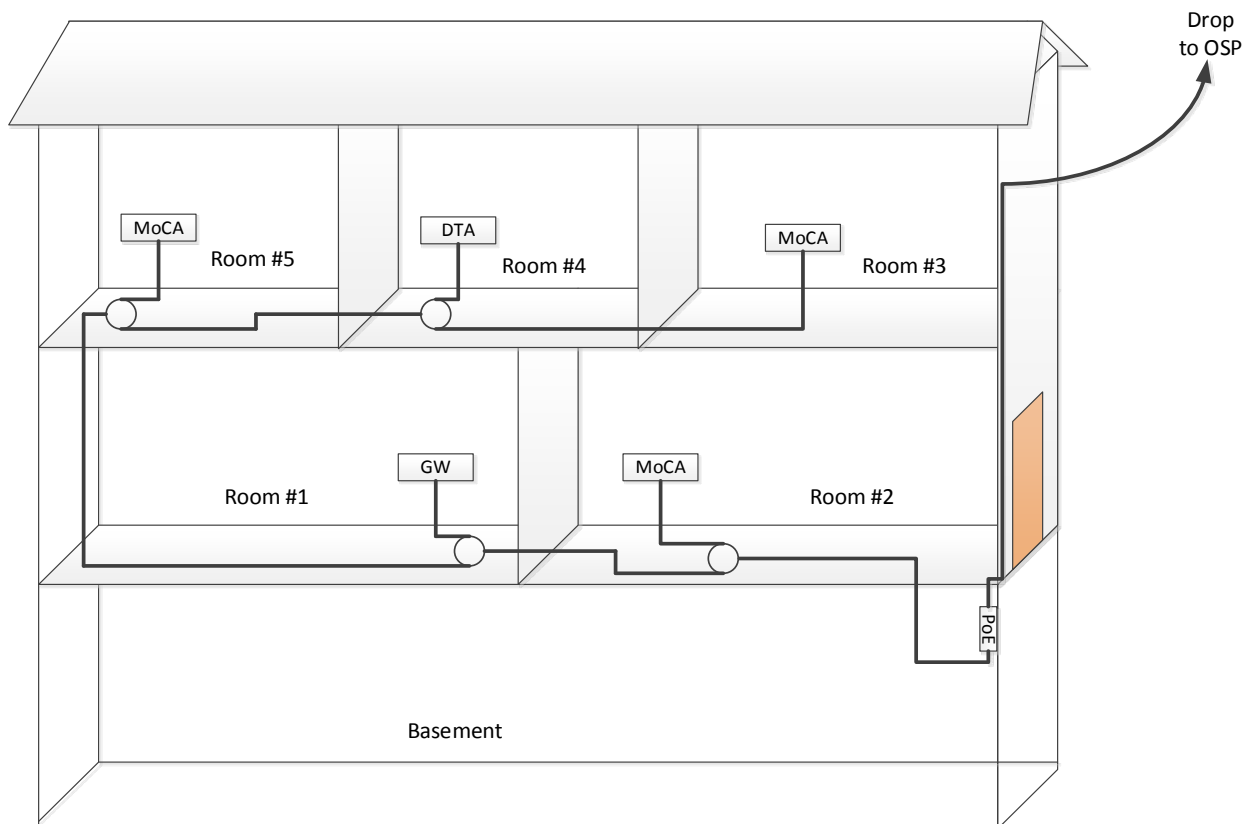


Figure 11 - Detailed Loop-through Deployment

8. Frequency Selection Options

The DOCSIS spectral occupancy and MoCA spectral occupancy mentioned in Section 6.1.2 are introduced in more detail here. The three cases considered are:

1. Overlapping
2. Adjacent
3. Non-overlapping

8.1. Overlapping

Overlapping DOCSIS 3.1 signals and MoCA signals will have the same frequencies for some or all of their RF bandwidths. Figure 12 illustrates overlapping MoCA 1.1 band D signals with DOCSIS 3.1 downstream signals. In Figure 12, the DOCSIS downstream signal has an upper edge of 1.194 GHz, while the MoCA band D signal has a lower edge of 1.125 GHz. The region between 1.125 and 1.194 GHz, requires the highest amount of isolation in order to reduce MoCA transmit signals at or below a level which would have a negligible impact to DOCSIS 3.1 receive signals. For example, let's estimate the RF isolation needed to attenuate a MoCA 1.1 transmit signal, 8 dBm/50 MHz to a level such that its impact on the DOCSIS 3.1 receive signal would be minimal, say 0.1 dB degradation total. The total isolation required would be the Maximum MoCA 1.1 Transmit Power minus the Receiver Noise Level, plus additional attenuation to ensure minimal impact. To use numbers from Figure 12, $8 \text{ dBm/50 MHz} - (-89 \text{ dBm/50 MHz}) + 16 \text{ dB} = 113 \text{ dB}$. We will also show later in Section 10, how 0.1 dB degradation equates to 16 dB more attenuation required.

Guideline 3: 113 dB of RF isolation is very difficult for filter designers to support, which is why overlapping DOCSIS 3.1 frequencies and MoCA frequencies are not recommended at this time.

If the use of overlapping frequencies cannot be avoided, then a two-port gateway or CM would be necessary to provide the required isolation.

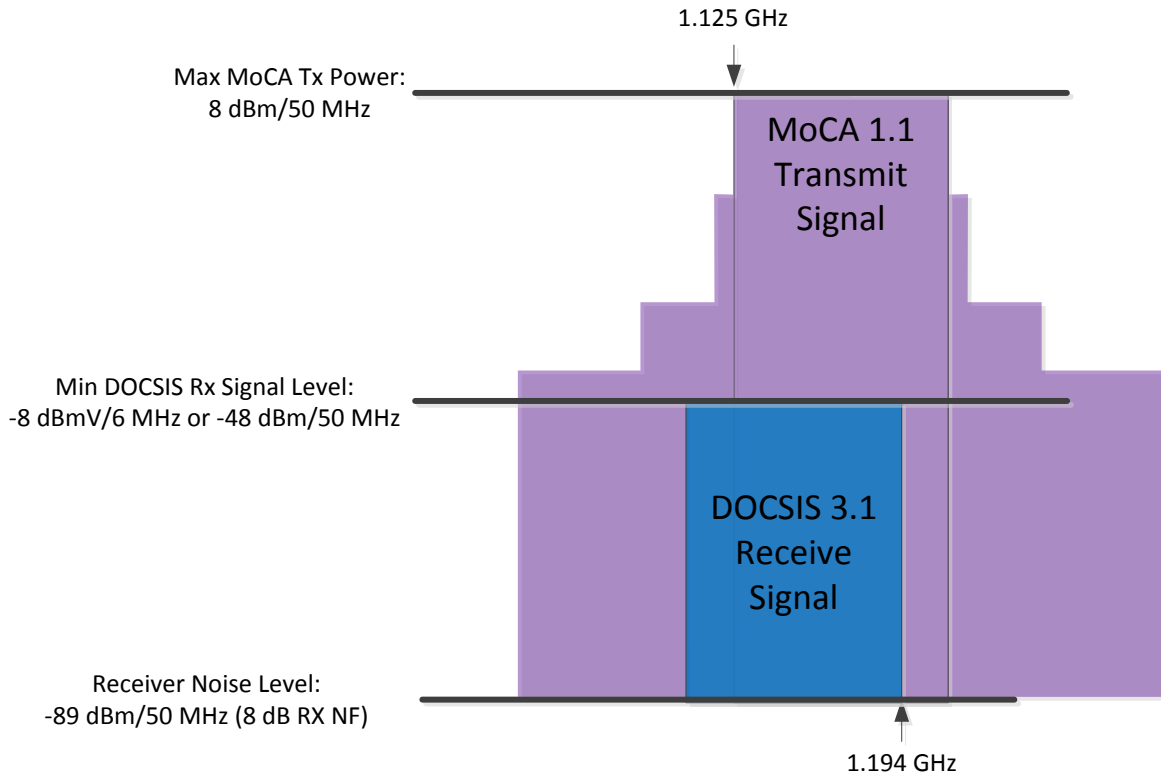


Figure 12 - Overlapping DOCSIS 3.1 and MoCA 1.1 Signals

8.2. Adjacent

Adjacent frequency separation will have very little guard band between the DOCSIS 3.1 downstream and the MoCA signals. The following conditions apply to adjacent separation between DOCSIS 3.1 signals and MoCA signals:

- ≥ 5 MHz guard band for both MoCA 1.1 and MoCA 2.
- ≤ 75 MHz for MoCA 2.0
- ≤ 25 MHz for MoCA 1.1

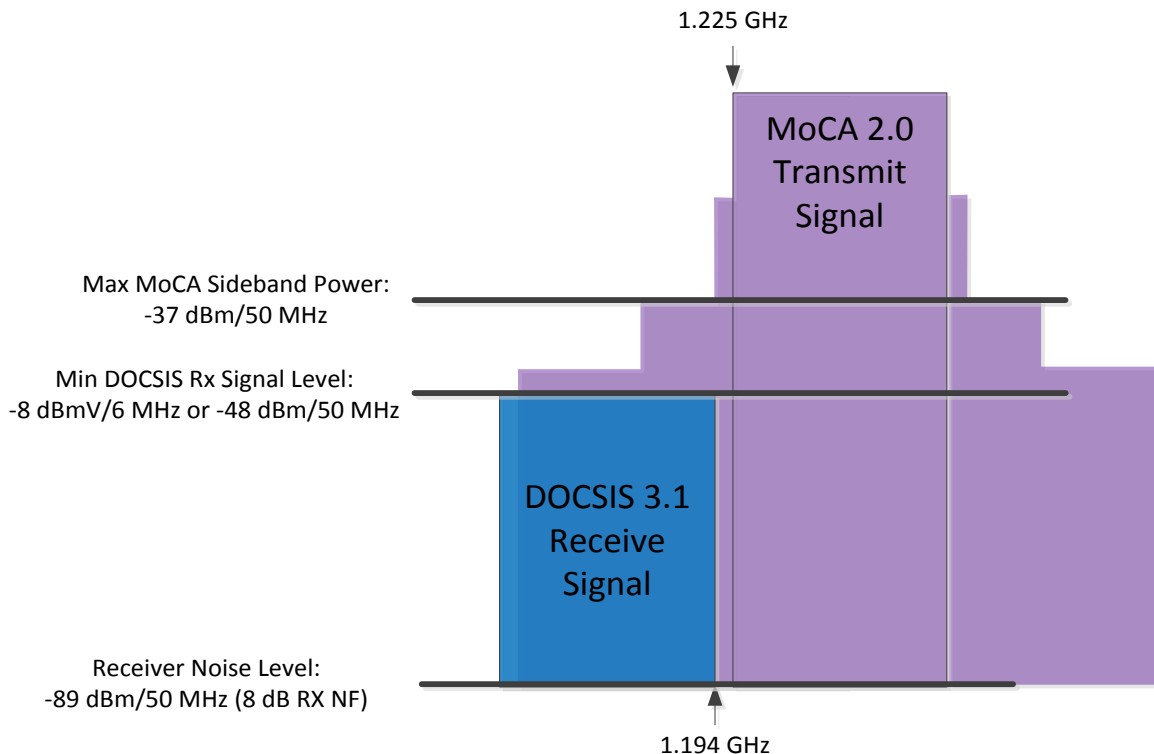


Figure 13 - Adjacent DOCSIS 3.1 and MoCA Signals

Figure 13 illustrates a scenario where MoCA band D is adjacent to DOCSIS 3.1 downstream signal. In Figure 13, the DOCSIS 3.1 downstream signaling has an upper edge of 1.194 GHz, while the MoCA 2.0 band D signaling has a lower edge of 1.225 GHz. Since this is a MoCA 2.0 signal, this scenario falls into the adjacent case since 31 MHz of separation falls between 5 and 75 MHz, a requirement of the MoCA 2.0 adjacent case, based on the conditions above. For MoCA 1.1 the overlap would have to be between 5 and 25 MHz in order to be considered an adjacent case. Therefore, this scenario would not be adjacent for MoCA 1.1. This scenario requires less isolation than the overlapping scenario previously discussed in order to reduce MoCA transmit signals since the DOCSIS 3.1 signal now overlaps with MoCA transmit signal sideband. However, the bigger challenge will be associated with designing filters to isolate these signals from one another, such as supporting a transition band between 5-75 MHz.

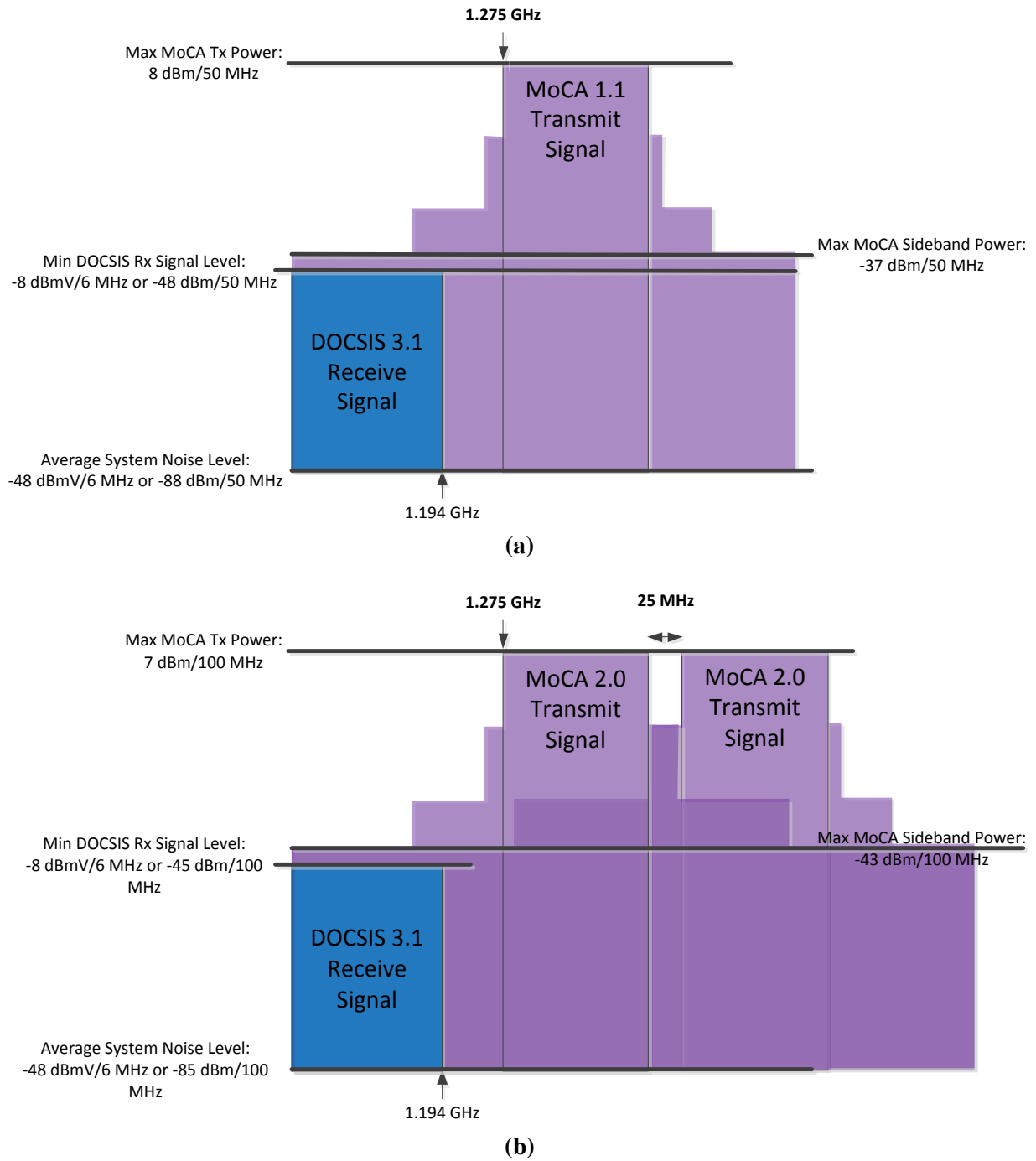
Guideline 4: The adjacent scenario is not a recommended practice.

If the use of adjacent frequencies cannot be avoided, then a two-port gateway or CM might be necessary to provide the required isolation.

8.3. Non-Overlapping

Non-Overlapping frequency bands will have more guard band than the adjacent scenario, greater than 75 MHz for MoCA 2.0 and greater than 25 MHz for MoCA 1.1. Figure 14 illustrates a non-overlapping scenario where MoCA band D is non-overlapping, relative to DOCSIS downstream signaling. In Figure 14, the DOCSIS signaling has an upper edge of 1.194 GHz, while the MoCA band D has a lower edge of 1.275 GHz. The DOCSIS signals below 1.194 GHz would require the least amount of isolation in order to minimize the impact from MoCA transmit signals, including the two-channel bonded case. This scenario is similar to some current deployment scenarios where DOCSIS receive signaling is ≤ 1 GHz and MoCA signaling is ≥ 1.125 GHz. This may remain an attractive scenario for cable operators wishing to support

higher capacity MoCA links. Such links could leverage more bandwidth. For example, MoCA 2.0 two-channel bonded mode leverages 225 MHz of bandwidth within band D to support a minimum of 800 Mbps in the home local area network (LAN). Essentially there may be compromises made between the DOCSIS passbands and home LAN passbands such that Gbps capacities are achievable in both. One such compromise could have the upper edge of DOCSIS downstream operation being 1.1 GHz, while the lower edge of MoCA is 1.175 GHz.



**Figure 14 - Non-overlapping DOCSIS 3.1 and MoCA Signals
 (a) one MoCA 1.1 channel (b) two bonded MoCA 2.0 channels**

Note that in MoCA 2.0 bonded mode, the farthest channel from the DOCSIS 3.1 channel will add the emissions greater than 75 MHz from the band edge of this second bonded channel (-50 dBr) to the nearest MoCA channel emissions (-50 dBr) for a total emissions interference level (-47 dBr) which requires 3 dB more isolation.

Guideline 5: The non-overlapping scenario is the best operational practice since it offers the largest guard band, and will have the lowest isolation requirement.

8.4. Practical Filters

Practical filters for current applications may include low-pass filters that have necessary characteristics to minimize impact to both the DOCSIS signals and MoCA signals will have on legacy set-top box (STB) and digital transport adapter (DTA); one filter response example is illustrated in Figure 15. Current PoE filters today roll-off around 1 GHz, and have a transition band that extends to about 1.125 GHz, while offering at least 40 dB stopband rejection.

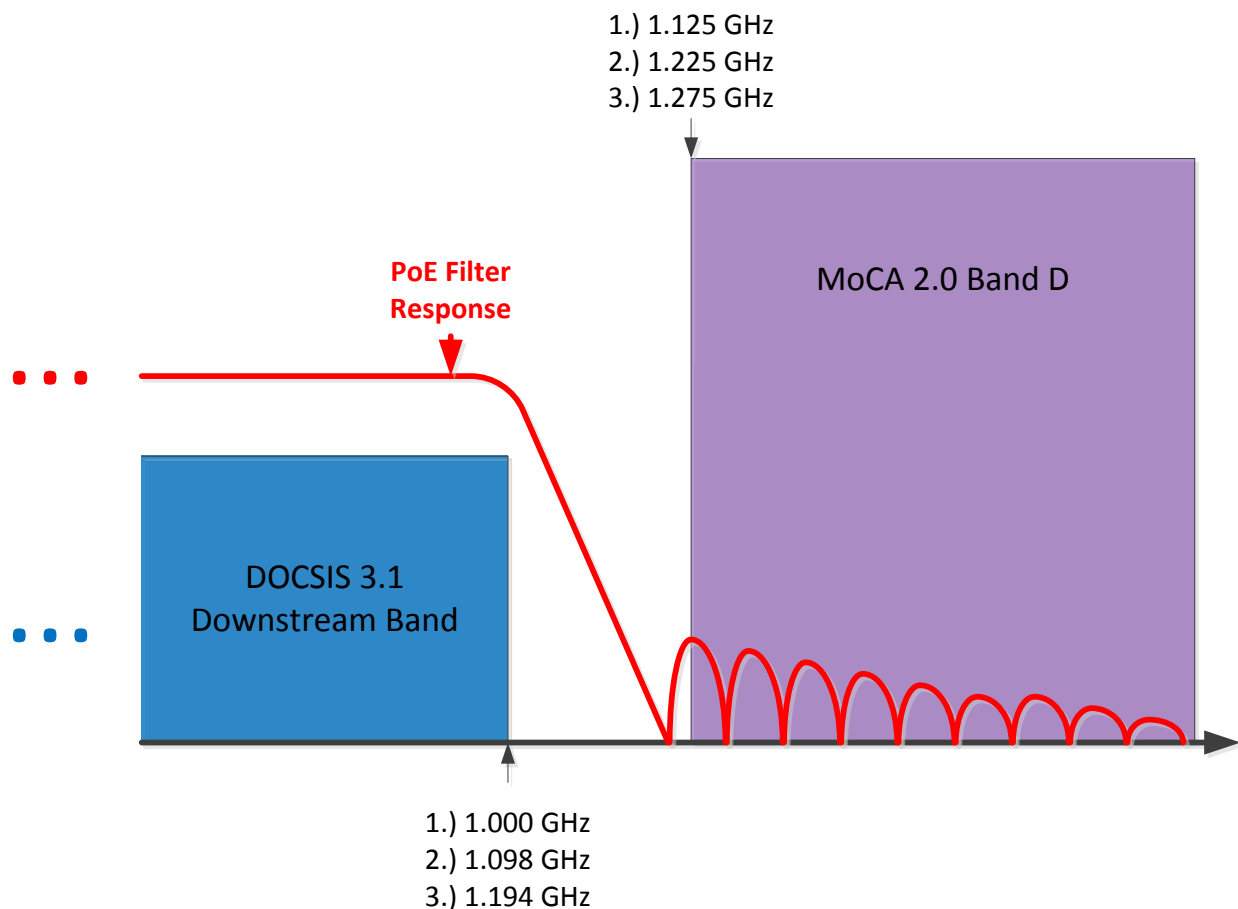


Figure 15 - MoCA PoE Filter Response

Guideline 6: The primary use-case for PoE filters is to RF isolate one MoCA home from another.

It's the combination of two of these filters, one for each home that will provide adequate isolation between two MoCA home networks. PoE filters may be installed at tap spigots, ground blocks, or at the input of a root distribution device, such as a splitter or home amplifier.

Guideline 7: A secondary use-case for PoEs is to prevent MoCA signals from overloading legacy STB, DTA, and other CPE tuners.

In the secondary use-case, PoEs are installed on legacy STB, DTA, and other CPE input ports.

Filtering can be used within a single-port gateway that passes both DOCSIS and MoCA signaling through its RF port. The single-port gateway will require a triplex filter (triplexer) to minimize the impact between DOCSIS downstream and MoCA, since a diplex is already required to isolate DOCSIS downstream and upstream signals. Figure 16 illustrates the signal flow through a gateway triplex filter and Figure 17 shows a block diagram of a triplex filter. Overlapping, adjacent, and non-overlapping signal requirements will have a significant impact on this triplex filter design and increases cable modem complexity.

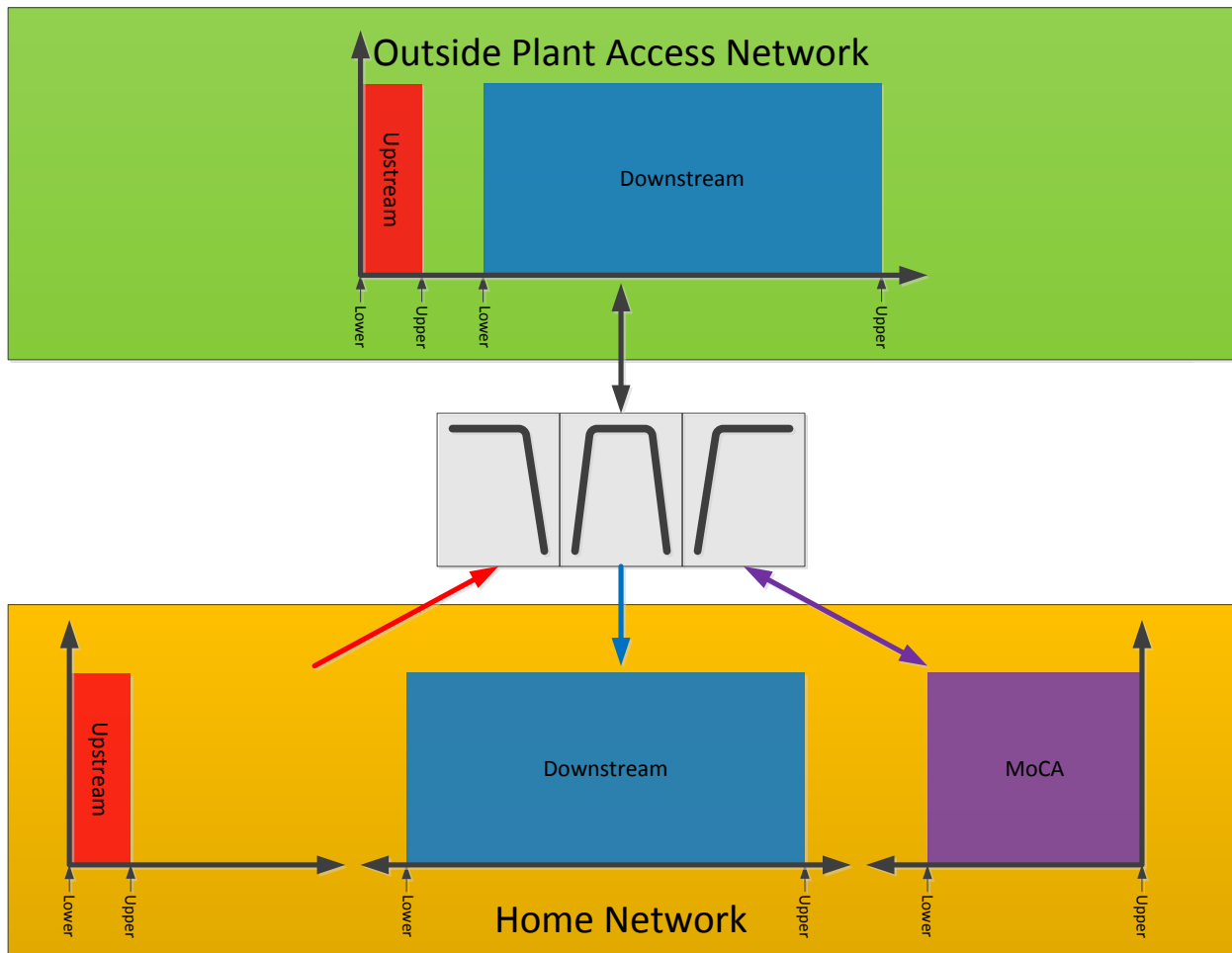


Figure 16 - Triplexer Signal Flow

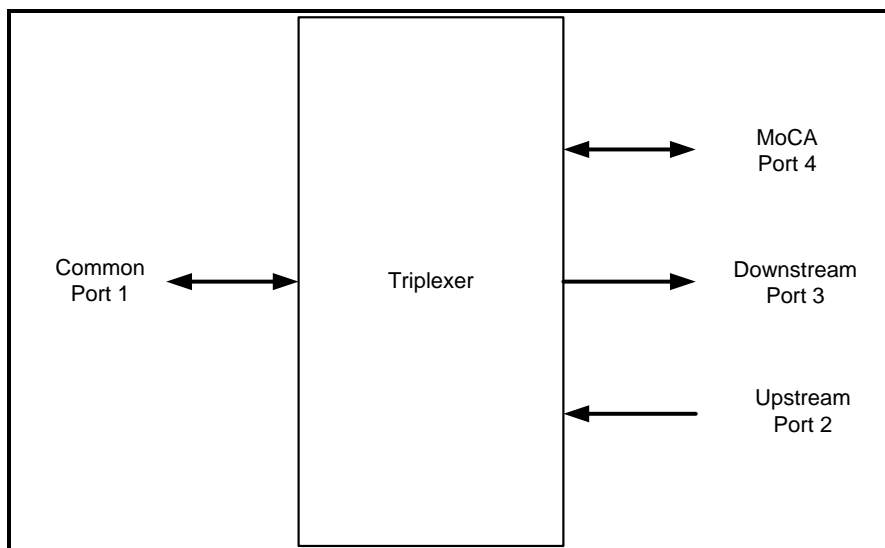


Figure 17 - Triplexer Block Diagram

Table 1 describes multiple frequency loading scenarios that could be leveraged by cable operators. The scenarios described here are not meant to be an exhaustive list of spectral loading use-cases, but rather an illustrative example demonstrating the need for filtering in the home to manage isolation between the outside plant (OSP) access network and the home LAN. The variations among these scenarios may be driven by varying needs to drive additional capacity in the OSP access network to support growth of services, including Gbps services. In cases where OSP downstream frequencies overlap with MoCA home LAN frequencies, band D will be constrained. Instead of 550 MHz originally allocated to band D, only 450 MHz would be available with a lower edge of 1225 MHz, and 400 MHz available using a lower edge of 1275 MHz.

Table 1 - Cable Operator Example Frequency Scenarios

Scenario #	OSP Upstream		OSP Downstream		MoCA Home LAN	
	Lower	Upper	Lower	Upper	Lower	Upper
#1	5 MHz	42 MHz	54 MHz	1002 MHz	1125 MHz	1675 MHz
#2	5 MHz	85 MHz	102 MHz	1002 MHz	1125 MHz	1675 MHz
#3	5 MHz	85 MHz	102 MHz	1098 MHz	1225 MHz	1675 MHz
#4	5 MHz	85 MHz	102 MHz	1194 MHz	1275 MHz	1675 MHz
#5	5 MHz	204 MHz	258 MHz	1002 MHz	1125 MHz	1675 MHz

MoCA only devices may band pass filter their RF ports in order to (1) suppress any MoCA signal energy that could overlap with DOCSIS signals, and (2) suppress any impact DOCSIS signals may have on the MoCA receiver.

8.5. Single-port Scenarios

8.5.1. HFC to 1002 MHz with MoCA Using Full D-Band

Single-port deployment scenarios have a home gateway device that uses a single RF port to provide DOCSIS- and MoCA-based services. This RF port will have both MoCA and DOCSIS signals passing through it simultaneously. DOCSIS operation may have an upper edge of 1.000 GHz, while MoCA band

D will have a lower edge of 1.125 GHz. The DOCSIS signals may be isolated using triplexers, that will attenuate both the MoCA transmit signals to levels that will have minimal impact to the DOCSIS signaling. Additionally, PoE filters previously discussed may be installed to prevent (1) bridging between two MoCA home networks on the same tap, and (2) prevent legacy STBs/DTAs from being overloaded with MoCA energy. Additionally, MoCA only devices may also have band pass filters to prevent interference from impacting either DOCSIS receivers or MoCA receivers. Figure 10 and Figure 11 illustrate single-port deployment scenarios, where the former is currently how many cable operators deploy DOCSIS and MoCA technology today.

8.5.2. HFC to 1194 MHz with MoCA Starting at 1275 MHz

The case where DOCSIS spectrum upper edge is 1.194 GHz and MoCA lower edge is 1.275 GHz is similar to the current deployment scenario using 1.000 GHz upper edge of DOCSIS downstream and MoCA band D starting at 1.125 GHz. These are both non-overlapping scenarios, where the difference is that the frequencies are shifted approximately 200 MHz higher and the transition band is a little tighter, previously 125 MHz and now 81 MHz. The isolation requirements remain the same since ≥ 75 MHz separation exists.

Guideline 8: The example values in Table 1 can be leveraged by cable operators for other non-overlapping frequency scenarios so long as the DOCSIS signals and MoCA signals are non-overlapping with one another, similar guard bands are maintained, and other cautions mentioned in Section 8.5 are observed.

Using a smaller guard band (< 75 MHz) between DOCSIS downstream and MoCA 2.0 has increasingly more difficult isolation requirements mainly because MoCA sideband spurious energy gets higher, closer in frequency to the MoCA transmit signal. The challenge becomes even greater when DOCSIS signals and MoCA signals directly overlap with one another. The following bullets are recommended for managing isolation between DOCSIS signals and MoCA signals using currently available filtering technology and are illustrated in the triplexer signal flow diagram, Figure 16:

- All OSP access network signaling, including DOCSIS signaling, uses lower frequencies
- All home LAN signaling, including MoCA, uses frequencies higher than the OSP signaling
- ≥ 75 MHz guard band required between OSP and home LAN signals

8.6. Two-port

Instead of using external filters to protect legacy STBs/DTAs or MoCA only devices in a single-port gateway environment previously illustrated, a two-port gateway may be used to manage isolation between the OSP and home LAN. All of the isolation challenges associated with the overlapping, adjacent, and non-overlapping scenarios would still apply. Figure 18 illustrates one possible deployment scenario for the two-port gateway. The following challenges exist with two-port gateway deployments, some of which are more operational in nature:

- Increased installation complexity, including self-installation kits (SIKs), over traditional deployment scenarios
- Wireless coverage challenges, requiring separate device(s) to support ubiquitous coverage

There are also many benefits to using a two-port gateway, with the most significant being the ability to isolate the home LAN from the OSP. This benefit may be fully realizable in the future when all legacy

STBs/DTAs have been aged out of the network entirely and there is no longer a need to pass OSP RF signals into the home. Some of the additional benefits are as follows:

- Eliminates PoE filters
- Aligns with fiber to the premises (FTTP)
- Minimized impairment funneling to OSP
- Manages RF coexistence issues with both higher upstream splits and MoCA

Guideline 9: The pros and cons of deploying one versus two-port gateways must be weighed carefully since they will likely vary among cable operators.

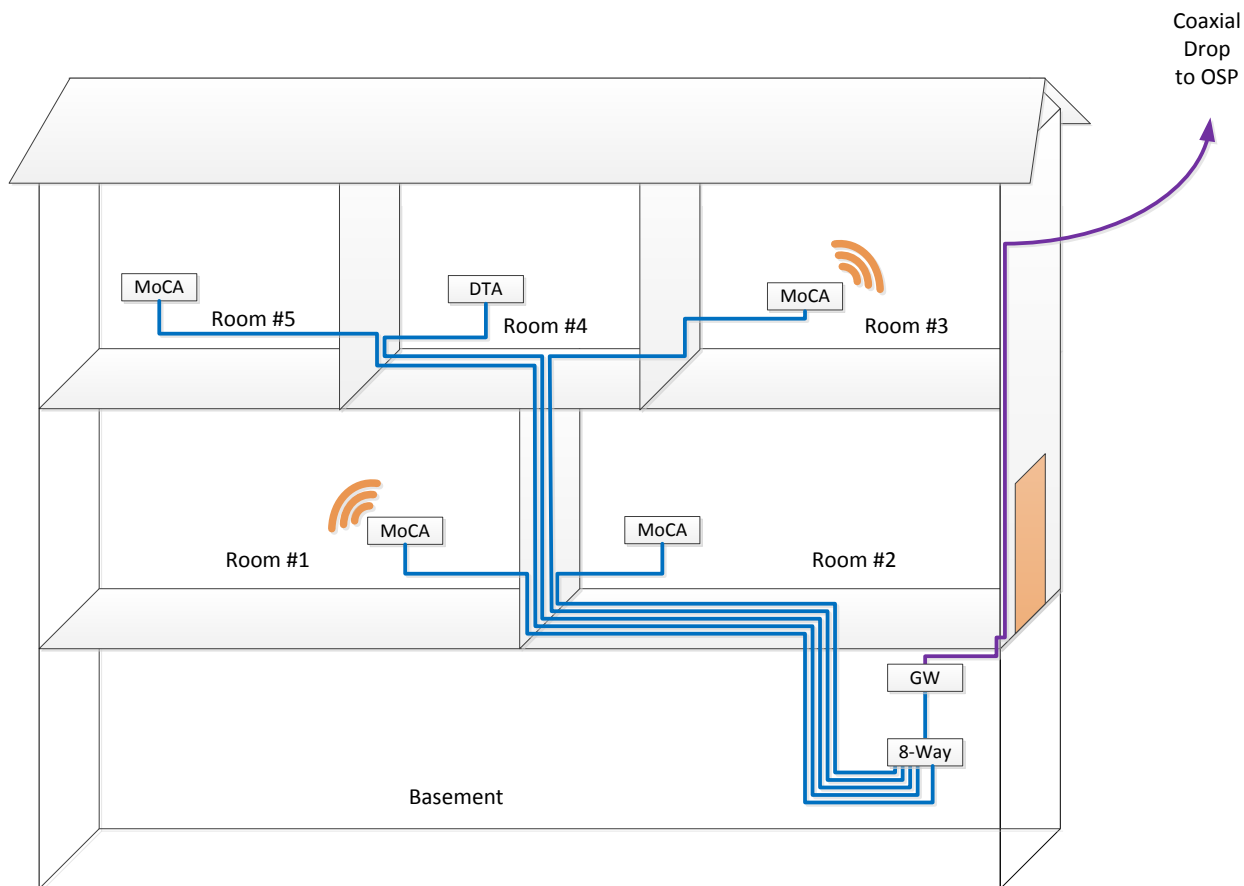


Figure 18 - 2-Port Gateway Deployment Scenario

9. Fidelity Requirements

9.1. DOCSIS 3.1 Signal Characteristics

Key DOCSIS 3.1 signal specifications and characteristics have been summarized in Table 2. These specifications shall be used in subsequent sections to estimate isolation requirements between DOCSIS signals and MoCA signals. The specifications come from the DOCSIS 3.1 Physical Layer Specification, [CM-SP-PHYv3.1-I05-150326, or later specification reference].

Table 2 - DOCSIS 3.1 Downstream Signal Characteristics

Parameter	Value
Lower Frequency Boundary	258 MHz Required 108 MHz Optional
Upper Frequency Boundary	One or more of: 1002 MHz 1218 MHz 1794 MHz
CM's Minimum Receive Power	-15 dBmV/6 MHz
CM's Maximum Receive Power	15 dBmV/6 MHz
Maximum average power per MHz input to the CM (dBmV/MHz)	Min [X – 10*log(24) + 10; 21 – 10*log(24)] where X = Average power of lowest power 24 MHz bandwidth for demodulation; X ≤ 11 dBmV.
Maximum out of Channel Emissions for DOCSIS 3.1 192 MHz Channel (from DOCSIS spec with N*=32):	
0 – 750 kHz from Channel Edge	-57.4 dBr
750 kHz – 6 MHz from Channel edge	-56.5 dBr
6 -12 MHz from Channel Edge	-57.3 dBr
12 -18 MHz from Channel Edge	-57.9 dBr
> 18 MHz from Channel Edge	-57.9 dBr
Note: dBr ≡ dB relative to the DOCSIS signal power in a 6 MHz bandwidth	
Maximum out of Channel Emissions for DOCSIS 3.1 192 MHz Channel into MoCA Channels (calculated from the values above for the maximum received signal level):	
5– 55 MHz from Channel Edge	-33.1 dBmV
5 – 105 MHz from Channel Edge	-30.4 dBmV
25 – 75 MHz from Channel Edge	-33.7 dBmV
75 – 175 MHz from Channel Edge	-30.7 dBmV

9.2. MoCA

Key MoCA signal characteristics have been summarized in Table 3. These specifications also shall be used in subsequent sections to estimate isolation requirements between DOCSIS signals and MoCA signals. MoCA RF Characteristics for Regulators document was the source for this information and is available publicly on the MoCA website, [“MoCA 2.0 Specification for Device RF Characteristics 20150406”, or later characteristics reference].

Table 3 - MoCA Signal Characteristics

Parameter	Value
MoCA 1.1 Channel Width	50 MHz
MoCA 1.1 Device Maximum Transmit Power	8 dBm/50 MHz
MoCA 2.0 Channel Width	100 MHz
MoCA 2.0 Device Maximum Transmit Power	7 dBm/100 MHz
	10 dBm/225 MHz (2 x 100 MHz channels separated by 25 MHz)
Band ExD Lower Frequency Boundary	1125 MHz
Band ExD Upper Frequency Boundary	1675 MHz
Out of Channel Emissions	Adjacent channels:
	MoCA1.1 channels: -40 dBr (5 MHz to 25 MHz)
	MoCA2.0 channels: -40 dBr (5 MHz to 75 MHz)
	Non overlapping frequencies:
	MoCA1.1 channels: -45 dBr (>25 MHz) MoCA2.0 channels: -50 dBr (>75 MHz)
Receiver ACI Susceptibility	First Adjacent Channel : Interference power < S - 6 dB
	Second Adjacent Channel: Interference power < MAX{ - 42 dBm, MIN[S+8, -2 dBm]}; Where S is the received MoCA signal level
Minimum Receive Level	MoCA 1.1 channels: ~ -67 dBm
	MoCA 2.0 channels: ~ -64 dBm

10. RF Isolation Requirements for DOCSIS and MoCA Coexistence

Introduced in Section 8 Frequency Selection Options, the three following major use-cases may occur when DOCSIS 3.1 signals and MoCA signals coexist on the same physical media:

1. Overlapping frequencies (highest isolation requirement)
2. Adjacent channels (less isolation than overlapping, but more than non-overlapping cases)
3. Non overlapping frequencies (lowest isolation requirement)

The two types of interference are thus:

1. **Adjacent channel interference (ACI) susceptibility**, which is the degree to which the performance of a desired signal is degraded by the receiver due to out-of-band or out-of-channel emissions from an adjacent signal. ACI susceptibility describes the maximum level of signals in adjacent channels that a receiver is not susceptible to degradation in performance.
2. **Adjacent channel interference (ACI)**, which is out-of-band or out-of-channel emissions from one signal that degrade the performance of another signal occupying a channel or frequency next to the first signal.

And the two directions of interference are:

1. MoCA signal to DOCSIS 3.1 receiver
2. DOCSIS 3.1 signal to MoCA receiver

Since the non-overlapping case aligns closely with current DOCSIS and MoCA deployment plans, it will be examined in this section.

The mutual signal placement assumptions of the non-overlapping frequency case are that MoCA and DOCSIS 3.1 channels operate with a gap between their adjacent band edges as follows:

- MoCA 1.1 channels with greater than 25 MHz
- MoCA 2.0 channels with greater than 75 MHz

The calculation of RF isolation requirements requires the evaluation of the isolation needed for two sources of ACI:

- ACI susceptibility (maximum power of signals adjacent to the desired signal)
- Noise and spurious emissions (out-of-band interference from signals adjacent to the desired signal)

The approach presented will also include alternative adjacent channel RF isolation required for noise and spurious emissions from MoCA devices into DOCSIS 3.1 signals that meet the DOCSIS 3.1 specifications for signal integrity with minimal degradation.

10.1. RF Isolation from Adjacent Channel Interference Susceptibility

Figure 19 examines the impact the DOCSIS signal's power will have on a MoCA device's receiver. Recall from the MoCA Signal Characteristics in Table 3, that interference power for First Adjacent Channel must be lower than the 6 dB below the MoCA received signal's power (Interference power < S – 6 dB). This interference limit is illustrated in Figure 19 as -73 dBm/50 MHz for MoCA 1.1 and -70 dBm/100 MHz for MoCA 2.0. The Interference power in this case, is the DOCSIS cable modem's (CM) Maximum Receive Power, which can be obtained from the DOCSIS 3.1 Downstream Signal Requirements Table 2 as 15 decibel millivolt (dBmV)/6 MHz (-24.5 dBm/50 MHz) and is also illustrated in Figure 19.

Converting 15 dBmV/6 MHz to -24.5 dBm/50 MHz involves following steps:

1. Convert dBmV to dBm by subtracting 48.75 dB
2. Calculate bandwidth correction via $10 \cdot \log_{10}(BW_{NEW} / BW_{OLD})$
3. Add bandwidth correction

The following bullets apply the above steps for 50, 100, and 192 MHz, some of which are shown in Figure 19.

- $15 \text{ dBmV}/6 \text{ MHz} - 48.75 \text{ dB} + 10 \cdot \log_{10}(50 \text{ MHz}/6 \text{ MHz}) = -24.5 \text{ dBm}/50 \text{ MHz}$
- $15 \text{ dBmV}/6 \text{ MHz} - 48.75 \text{ dB} + 10 \cdot \log_{10}(100 \text{ MHz}/6 \text{ MHz}) = -21.5 \text{ dBm}/100 \text{ MHz}$
- $15 \text{ dBmV}/6 \text{ MHz} - 48.75 \text{ dB} + 10 \cdot \log_{10}(192 \text{ MHz}/6 \text{ MHz}) = -18.7 \text{ dBm}/192 \text{ MHz}$

From the MoCA Signal Characteristics in Table 3, a MoCA device's Minimum Receive Level is -64 dBm/100 MHz for MoCA 2.0, and -67 dBm/50 MHz for MoCA 1.1 and is represented as the "S" value in the Receiver ACI Susceptibility equations.

Guideline 10: In order to meet the MoCA interference requirement for First Adjacent Channel, there should be at least 48.5 dB of isolation between DOCSIS 3.1 signals and MoCA signals (both 1.1 and 2.0).

This is calculated as follows:

- MoCA 1.1: $-24.5 \text{ dBm}/50 \text{ MHz} - (-67 \text{ dBm}/50 \text{ MHz} - 6 \text{ dB}) = 48.5 \text{ dB}$
- MoCA 2.0: $-21.5 \text{ dBm}/100 \text{ MHz} - (-64 \text{ dBm}/100 \text{ MHz} - 6 \text{ dB}) = 48.5 \text{ dB}$

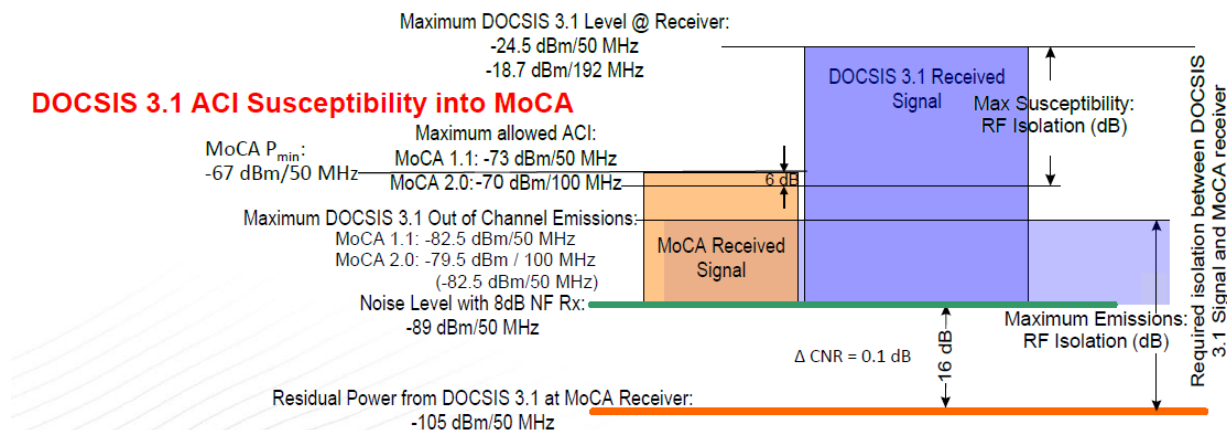


Figure 19 - DOCSIS 3.1 Transmitter to MoCA Receiver RF Isolation

Figure 20 examines the impact the MoCA transmit signal’s power will have on a DOCSIS device’s receiver. The maximum allowed ACI, in 1 MHz, must be no more than 10 dB above the DOCSIS minimum received signal power per MHz, per DOCSIS Signal Specifications of Table 2, row 5 (“Maximum average power per MHz input to the CM”). As indicated in the table, the reference level of DOCSIS signal power per 1 MHz is directed to be calculated using the power in the 24 MHz of DOCSIS modulated spectrum (24 MHz contiguous spectrum) which contains the lowest power within all the DOCSIS modulated spectrum, and this is referred to as “X dBmV” in the table; this power in 24 MHz is normalized to 1 MHz by subtracting “ $10 \cdot \log_{10}(24)$ ” from X dBmV. The 10 dB allowance above the DOCSIS signal power per 1 MHz is evidenced by the “10” in the expression “ $X - 10 \cdot \log_{10}(24) + 10$ ” in the “Min” function in row 5. The right hand argument of the “Min” function in row 5 of Table 2 caps the allowed ACI in 1 MHz at the absolute level of 7.2 dBmV, which equates to 15 dBmV evenly spread over 6 MHz. This interference limit is illustrated in Figure 20 as the maximum allowed ACI. The Interference power in this case is the MoCA Device’s Maximum Transmit Power illustrated in Figure 20, which can be obtained from the MoCA Signal Characteristics in Table 3. The calculation requires conversion from dBm to dBmV by adding 48.75 dB, and then applying a bandwidth correction for converting 50 MHz to 6 MHz. The calculations are summarized as follows:

- MoCA 1.1: $8.0 \text{ dBm}/50 \text{ MHz} + 48.75 \text{ dB} + 10 \cdot \log_{10}(6 \text{ MHz}/50 \text{ MHz}) = 47.5 \text{ dBmV}/6 \text{ MHz}$
- MoCA 2.0: $7.0 \text{ dBm}/100 \text{ MHz} + 48.75 \text{ dB} + 10 \cdot \log_{10}(6 \text{ MHz}/50 \text{ MHz}) = 43.5 \text{ dBmV}/6 \text{ MHz}$

10 dB above the minimum DOCSIS 3.1 Received Signal equals -5 dBmV/6 MHz and the Maximum Susceptibility RF Isolation is then calculated as follows:

- MoCA 1.1: $47.5 \text{ dBmV}/6 \text{ MHz} - -5 \text{ dBmV}/6 \text{ MHz} = 52.5 \text{ dB}$
- MoCA 2.0: $43.5 \text{ dBmV}/6 \text{ MHz} - -5 \text{ dBmV}/6 \text{ MHz} = 48.5 \text{ dB}$

Guideline 11: In order to meet the DOCSIS requirement for Maximum average power per MHz input to the CM, there should be at least 52.5 dB of isolation between MoCA 1.1 and DOCSIS 3.1 signals and 48.5 dB of isolation between MoCA 2.0 and DOCSIS 3.1 signals.

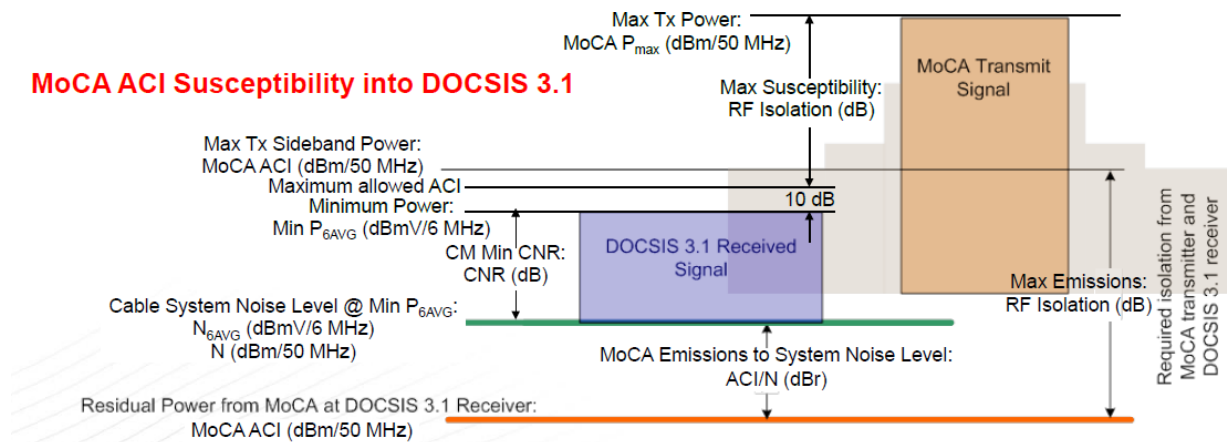


Figure 20 - MoCA Transmitter to DOCSIS 3.1 Receiver RF Isolation

10.2. RF Isolation from Adjacent Channel Interference Noise and Spurious Emissions (0.1 dB Receiver Noise Floor Impact)

Figure 21 summarizes the impact that DOCSIS Spurious Emissions will have on a MoCA received signal. DOCSIS 3.1 Spurious Emissions have been provided in DOCSIS 3.1 Downstream Signal Requirements of Table 2 and are repeated here:

- Maximum ACI 25-75 MHz: -33.7 dBmV/50 MHz
- Maximum ACI 75-175 MHz: -30.7 dBmV/100 MHz

In order to compare Spurious Emissions levels to MoCA, conversion to dBm will be required, and is calculated as follows and illustrated in Figure 21:

- -33.7 dBmV/50 MHz – 48.75 dB = -82.5 dBm/50 MHz
- -30.7 dBmV/100 MHz – 48.75 dB = -79.5 dBm/100 MHz

To estimate the residual power from the DOCSIS 3.1 signal at the MoCA Receiver, the following assumptions have been made:

- Emissions estimates are based on receiver noise floor impact, thereby avoiding any assumptions of carrier-to-noise ratio (CNR) at the RF receiver input port
- No HFC network noise contribution (0 dB noise figure (NF))
- MoCA receiver noise figure is 8 dB
- MoCA receiver’s CNR degradation from spurious emissions is limited to 0.1 dB

The rationale for choosing the metric of the receiver noise floor impact is as follows:

- MoCA only specifies PHY bit rate vs. receiver signal level
- The DOCSIS 3.1 specification states CNR vs. spectral efficiency above a minimum receiver signal level
- The reason for choosing receiver noise impact of mutual interference is that MoCA does not specify CNR vs. spectral efficiency
- This metric provides an equal but very conservative basis of comparing the effect of each signal interfering with the other

Since the noise measurement point is inside the receiver, the Johnson-Nyquist thermal noise floor, -174 dBm/Hz, and the receiver noise figure of 8 dB are used to calculate the receiver’s noise floor, represented as -89 dBm/50 MHz in Figure 21.

Guideline 12: In order to maintain a maximum of 0.1 dB CNR degradation in the MoCA receiver, the CNR associated with the DOCSIS 3.1 emissions must be 16 dB lower than the MoCA receiver’s noise floor. The required RF isolation is 22.5 dB for both MoCA 1.1 and 2.0.

The following bullets provide the calculations associated with the emissions limits for MoCA 1.1 and MoCA 2.0, based on the previous assumptions and are illustrated in Figure 21.

- MoCA 1.1: $-174 \text{ dBm/Hz} + 10 \cdot \log_{10}(50 \text{ MHz/Hz}) + 8 \text{ dB} - 16 \text{ dB} = -105.0 \text{ dBm/50 MHz}$
- MoCA 2.0: $-174 \text{ dBm/Hz} + 10 \cdot \log_{10}(100 \text{ MHz/Hz}) + 8 \text{ dB} - 16 \text{ dB} = -102.0 \text{ dBm/100 MHz}$

Therefore, the RF isolation required to meet the above assumptions is as follows:

- MoCA 1.1: $-105.0 \text{ dBm/50 MHz} - 82.5 \text{ dBm/50 MHz} = 22.5 \text{ dB}$
- MoCA 2.0: $-102.0 \text{ dBm/100 MHz} - 79.5 \text{ dBm/100 MHz} = 22.5 \text{ dB}$

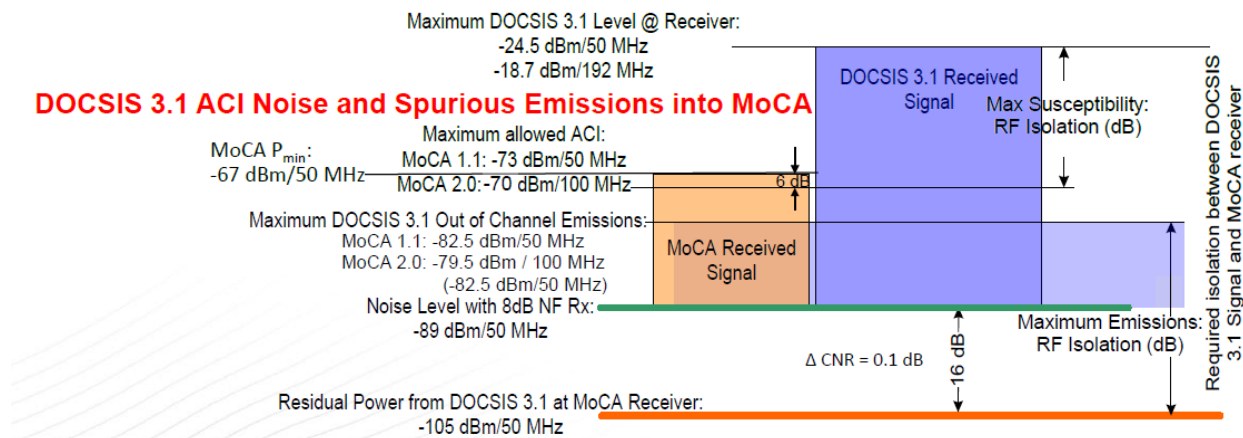


Figure 21 - DOCSIS 3.1 ACI Noise and Spurious Emissions into MoCA

Figure 22 summarizes the impact that MoCA Spurious Emissions will have on DOCSIS 3.1 received signal. MoCA Maximum Transmit Power has been provided in MoCA Signal Characteristics from Table 3, as follows:

- MoCA 1.1 P_{max} : 8.0 dBm/50 MHz
- MoCA 2.0 P_{max} : 7.0 dBm/100 MHz

Also, MoCA Out of Channel Emissions for Non overlapping frequencies are as follows:

- MoCA 1.1 ACI: -45 decibel reference (dBr)
- MoCA 2.0 ACI: -50 dBr

The following bullets convert MoCA ACI from dB relative to a reference level (dBr/50 MHz), to dBm/50 MHz or dBm/100 MHz:

- MoCA 1.1 ACI: 8 dBm/50 MHz + (-45 dBr) = -37.0 dBm/50 MHz
- MoCA 2.0 ACI in 1.1 Mode: 8 dBm/50 MHz + (-50 dBr) = -42.0 dBm/50 MHz
- MoCA 2.0 ACI: 7 dBm/100 MHz + 10*log₁₀(50 MHz/100 MHz) + (-50 dBr) = -46 dBm/50 MHz

Note that MoCA 2.0 ACI in 1.1 Mode has enhanced spurious performance of MoCA 2.0 while operating in MoCA 1.1 mode.

Applying the same assumptions described in the previous case of DOCSIS 3.1 ACI Noise and Spurious Emissions into MoCA, the following DOCSIS 3.1 emissions limit can be calculated for MoCA 1.1, MoCA 2.0 in 1.1 mode, and MoCA 2.0 as:

- -174 dBm/Hz + 10*log₁₀(50 MHz/Hz) + 8 dB – 16 dB = -105.0 dBm/50 MHz

Guideline 13: In order to maintain a maximum of 0.1 dB CNR degradation in the DOCSIS 3.1 receiver, the CNR associated with the MoCA emissions must be 16 dB lower than the DOCSIS 3.1 receiver’s noise floor. The required RF isolation is 68 dB for MoCA 1.1, 63 dB for MoCA 2.0 in 1.1 mode and 59 dB for MoCA 2.0 and 62 dB for MoCA 2.0 two-channel bonded.

The following bullets provide the calculations associated with the emissions limits for MoCA 1.1 and MoCA 2.0, based on the previous assumptions and are illustrated in Figure 22.

- MoCA 1.1: -37.0 dBm/50 MHz – -105.0 dBm/50 MHz = 68 dB
- MoCA 2.0 in 1.1 Mode: -42.0 dBm/50 MHz – -105.0 dBm/50 MHz = 63 dB
- MoCA 2.0: -46 dBm/50 MHz – -105.0 dBm/50 MHz = 59 dB
- MoCA 2.0 two-channel bonded: -46 dBm/50 MHz + 3 dB – -105.0 dBm/50 MHz = 62 dB

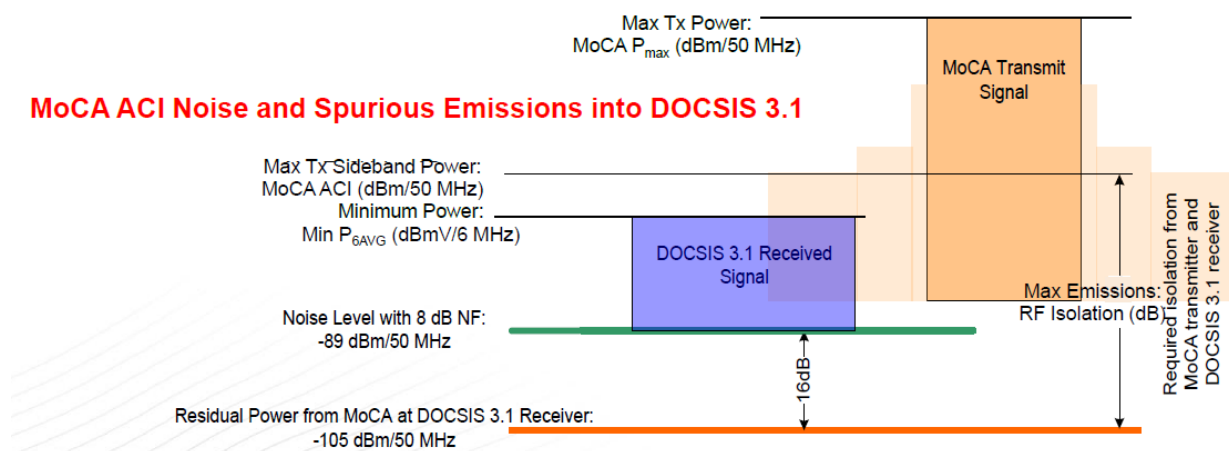


Figure 22 - MoCA ACI Noise and Spurious Emissions into DOCSIS 3.1

As stated earlier, the above analysis is one effective way to compare DOCSIS systems and MoCA systems without the complexities of accounting for the noise contribution of HFC distribution network. In

the analysis that follows, the HFC distribution network contributions will be accounted for as the cable system CNR at the thermal noise floor. The minimum signal level for 4096-QAM is -6 dBmV/6 MHz, while the thermal noise floor is at -174 dBm/Hz or -125.3 dBmV/Hz. Thus the cable system minimum CNR is $-6 - (-125.3 + 10\log_{10}(6 \text{ MHz})) = 51.5 \text{ dB}$. Therefore the RF isolation from MoCA 1.1 of 68 dB or MoCA 2.0 of 59 dB reduces the cable system CNR by 0.1 dB to a minimum CNR of 51.4 dB. A degradation of 0.1 dB in CNR is equivalent to a 0.03 bits/second/Hz (or bits/symbol), and the granularity of bit-loading in DOCSIS 3.1 technology is 1.5 dB (or 0.5 bits/second/Hz) with mixed modulation mode. **Note:** RF isolation required to support 0.1 dB CNR degradation is too conservative, even for this optimistic cable system CNR.

10.3. RF Isolation from Adjacent Channel Interference Noise and Spurious Emissions (DOCSIS 3.1 Carrier-to-Noise Ratio Impact)

The reasoning for choosing the metric of DOCSIS 3.1 CNR impact is that DOCSIS 3.1 specification states CNR vs. spectral efficiency above a minimum signal level. This metric provides a DOCSIS 3.1 specification basis for evaluating the effect of the MoCA signal interfering with the DOCSIS 3.1 CM receiver.

The approach here is different than what was previously presented in Section 10.2, where the common point of comparison was the receiver noise floor impact. The implications of using DOCSIS 3.1 CNR impact are thus:

- The noise measurement point is moved to the receiver input
- Receiver noise figure is not needed to evaluate CNR performance degradation
- This includes the CNR specification at the CM input
- This incorporates the actual HFC network CNR present at the cable modem

Note that MoCA does not have a similar specification for the home network to evaluate this metric in a similar manner.

The approach of using DOCSIS 3.1 CNR impact means that:

- A maximum tolerable level of degradation to the input CNR is chosen, which corresponds to a maximum ACI emissions-to-noise ratio (ACI/N), illustrated in Figure 23 where it can be seen that per the earlier example, a 0.1 dB Δ CNR corresponds to -16 dB ACI/N
- The input noise floor for any spectral efficiency (modulation order) at its minimum required DOCSIS 3.1 signal level is calculated
- Illustrated in Figure 24, the required RF isolation for at most this maximum input CNR degradation at the calculated ACI/N ratio and maximum MoCA ACI emissions level over all modulation orders is calculated
- The required RF isolation so calculated should be close to the highest RF isolation required for all other ACI susceptibility and emissions cases previously considered (i.e., 52.5 dB MoCA 1.1 ACI susceptibility into DOCSIS 3.1 receivers)

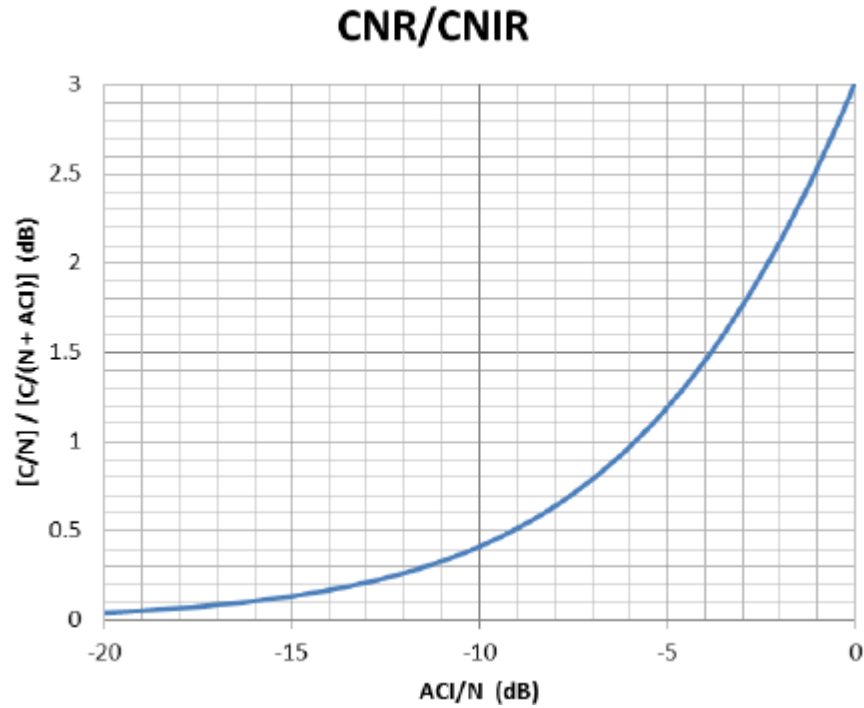


Figure 23 - Maximum Tolerable CNR Degradation Relative to Maximum Emissions-to-Noise Ratio, ACI/N

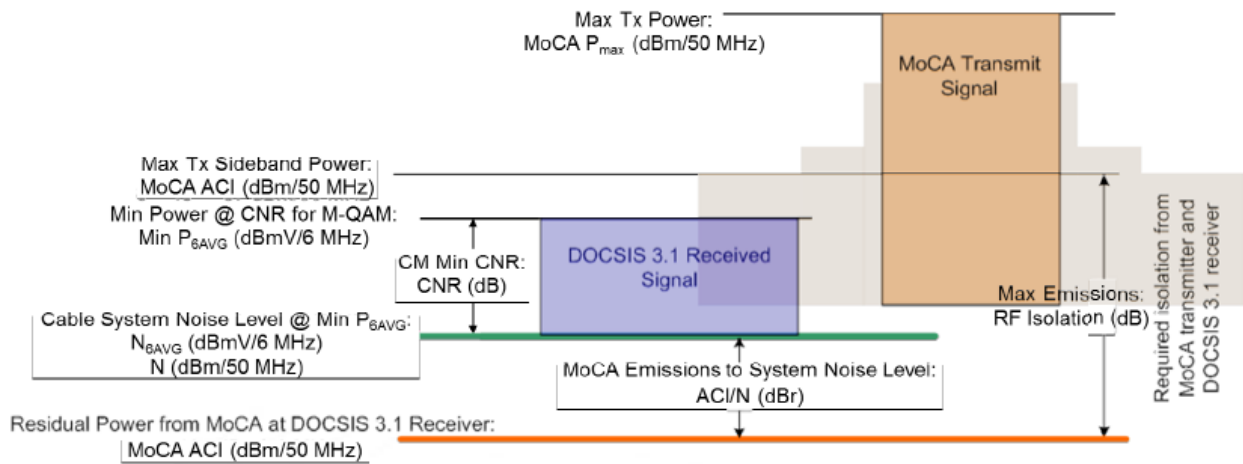


Figure 24 - Adjacent Channel Interference Degradation of CNR

10.4. MoCA 1.1 Transmitter to DOCSIS 3.1 Receiver RF Isolation

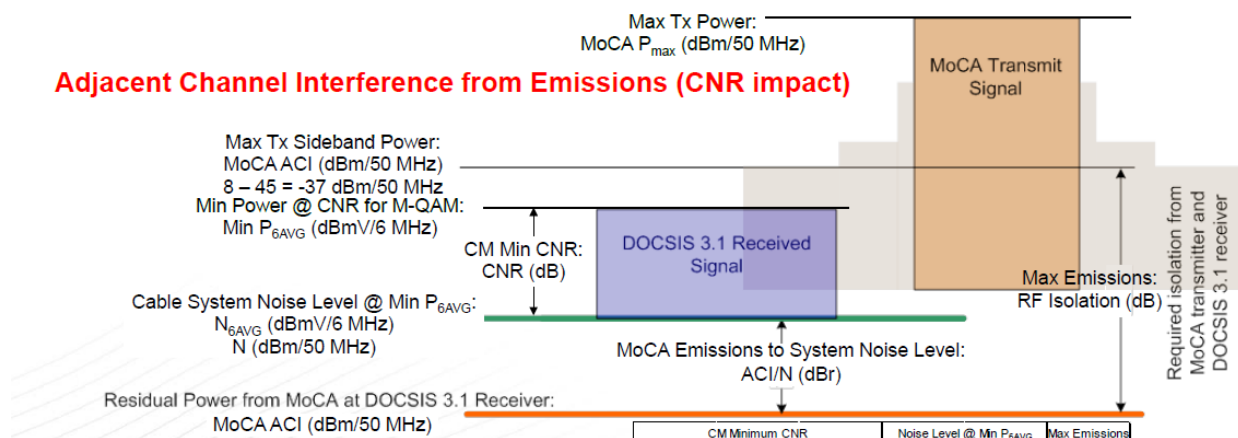


Figure 25 - CNR Impact to DOCSIS Operation using MoCA 1.1 Mode

Figure 25 summarizes the impact of MoCA 1.1 transmit signal spurious emissions on a DOCSIS 3.1 received signal. The two key parameters that differentiate this analysis approach from the previous approach are the CM’s minimum CNR requirements, and the maximum ACI emissions-to-noise ratio, ACI/N.

Table 4 from the DOCSIS 3.1 Physical Layer Specification, [CM-SP-PHYv3.1-I05-150326, or later specification reference] shows the required CNR for a variety of constellations. Also note the different CNR requirements for Up to 1 GHz and 1 GHz to 1.2 GHz. These CNR requirements, combined with Min P_{6AVG} will enable approximation of the noise floor at the DOCSIS receiver input. P_{6AVG} is the average receive power divided by the number of occupied Consumer Technology Association (CTA) channels (formerly known as Consumer Electronics Association, or CEA, channels).

Table 4 - CM Minimum CNR Performance in AWGN Channel

Constellation	CNR ^{1,2} (dB) Up to 1 GHz	CNR ^{1,2} (dB) 1 GHz to 1.2 GHz	Min P_{6AVG} dBmV
4096	41	41.5	-6
2048	37	37.5	-9
1024	34	34	-12
512	30.5	30.5	-12
256	27	27	-15
128	24	24	-15
64	21	21	-15
16	15	15	-15

Table Notes:

Note 1 CNR is defined here as total signal power in occupied bandwidth divided by total noise in occupied bandwidth

Note 2 Channel CNR is adjusted to the required level by measuring the source inband noise including phase noise component and adding the required delta noise from an external AWGN generator

Table 5 calculates the noise level at the Min P_{6AVG} by first subtracting the CNR from Min P_{6AVG} for each of the constellation levels. For example, the Noise Level for 4096 constellation is N_{6AVG} = -6 dBmV/6 MHz – 41 dB = -47 dBmV/6 MHz, and so on. The following calculation allows comparison of this noise level with MoCA noise level, which is expressed in dBm/50 MHz:

$$-47 \text{ dBmV/6 MHz} - 48.75 \text{ dB} + 10 \cdot \log_{10} (50 \text{ MHz/6 MHz}) = -86.5 \text{ dBm/50 MHz}$$

Table 5 - CM Minimum CNR, Noise Level, and Maximum Emissions

Constellation	CM Minimum CNR		Noise Level @ Min P _{6AVG}		Max Emissions
	CNR (dB) Up to 1 GHz	Min P _{6AVG} dBmV/6 MHz	Noise N _{6AVG} dBmV/6 MHz	Noise N dBm/50 MHz	RF Isolation (dB)
4096	41.0	-6.0	-47.0	-86.5	55.4
2048	37.0	-9.0	-46.0	-85.5	54.4
1024	34.0	-12.0	-46.0	-85.5	54.4
512	30.5	-12.0	-42.5	-82.0	50.9
256	27.0	-15.0	-42.0	-81.5	50.4
128	24.0	-15.0	-39.0	-78.5	47.4
64	21.0	-15.0	-36.0	-75.5	44.4
16	15.0	-15.0	-30.0	-69.5	38.4

Recall from earlier analysis in Section 10.2, the MoCA 1.1 signal’s maximum transmitter sideband power is -37 dBmV/50 MHz. Subtracting the CM’s noise level from the maximum transmitter sideband power, the isolation would be -37 dBmV/50 MHz – -86.4 dBm/50 MHz = 49.4 dB. However, the CM’s noise level and MoCA spurious being at equal levels would result in a 3 dB degradation in the CNR, 41 dB degrades to 38 dB. This may be an unacceptable degradation in performance. Earlier analysis allowed for 0.1 dB degradation in the noise floor by isolating the MoCA spurious 16 dB below the floor, which may be too conservative. Perhaps an ideal compromise is to have the flexibility to allow for something in between these two extremes.

If 1 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio (ACI/N) becomes -5.9 dB. Therefore 49.4 dB + 5.9 dB = 55.3 dB isolation results in 1 dB CNR degradation at the CM’s RF input. A 1 dB degradation in CNR results in 0.3333 bps/Hz capacity loss and aligns more closely with DOCSIS 3.1 bitloading of 0.5 bps/Hz. Capacity loss estimations can be made using the following famous Shannon-Hartley Theorem.

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

Where C is the channel capacity in bits/s, B is the bandwidth of the channel in Hz, and S/N is the signal-to-noise ratio, or CNR. CNR in this equation is expressed as a linear power ratio, not in dBs. Capacity loss can be approximated by examining its relationship with CNR degradation, ΔCNR, which can be a trended using a straight line with a slope of 1/3. Therefore, dividing ΔCNR, or 1 dB by 3 will result in a capacity loss of 0.333 bps/Hz.

Guideline 14: If 1 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio (ACI/N) becomes -5.9 dB and the resulting capacity loss is 0.333 bps/Hz.

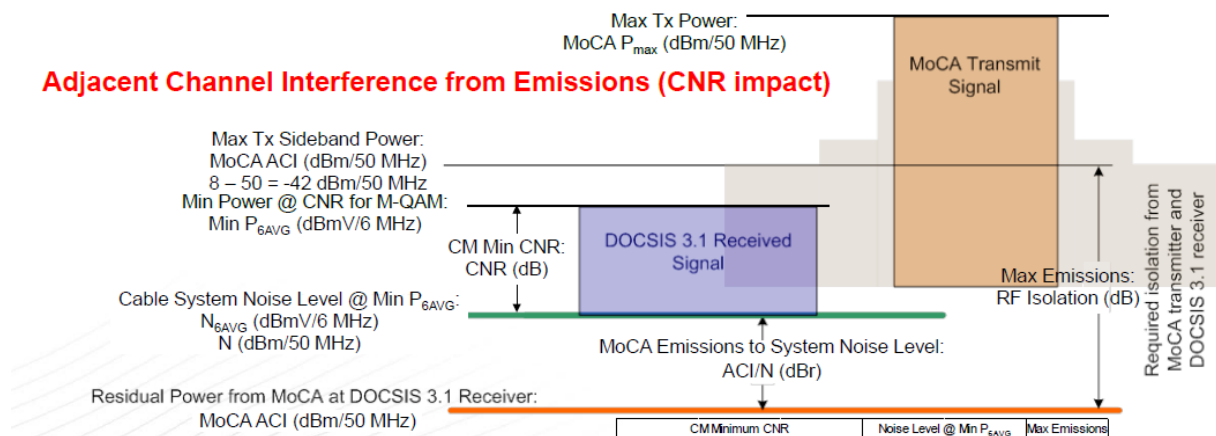


Figure 26 - CNR Impact to DOCSIS Operation using MoCA 2.0 Operating in 1.1 Mode

Figure 26 summarizes the impact of MoCA 2.0 operating in 1.1 mode transmit signal spurious emissions on a DOCSIS 3.1 received signal. Recall from earlier analysis in Section 6.2, when a MoCA 2.0 device is operating in 1.1 mode, its maximum transmitter sideband power is -42 dBmV/50 MHz, which is lower than the MoCA 1.1 case because of the improved MoCA 2.0 spurious emissions performance. Subtracting the CM’s noise level from the maximum transmitter sideband power, the isolation would be -42 dBmV/50 MHz – -86.4 dBm/50 MHz = 44.4 dB. Thus, the improved MoCA spurious emission performance can allow for both reduced noise degradation to the CM’s RF input and reduced isolation requirements.

If 0.6 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio (ACI/N) becomes -8.3 dB. Therefore 44.4 dB + 8.3 dB = 52.7 dB isolation results in 0.6 dB CNR degradation at the CM’s RF input. A 0.6 dB degradation in CNR results in 0.2 bps/Hz capacity loss.

Guideline 15: If 0.6 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio (ACI/N) becomes -8.3 dB and the resulting capacity loss is 0.2 bps/Hz.

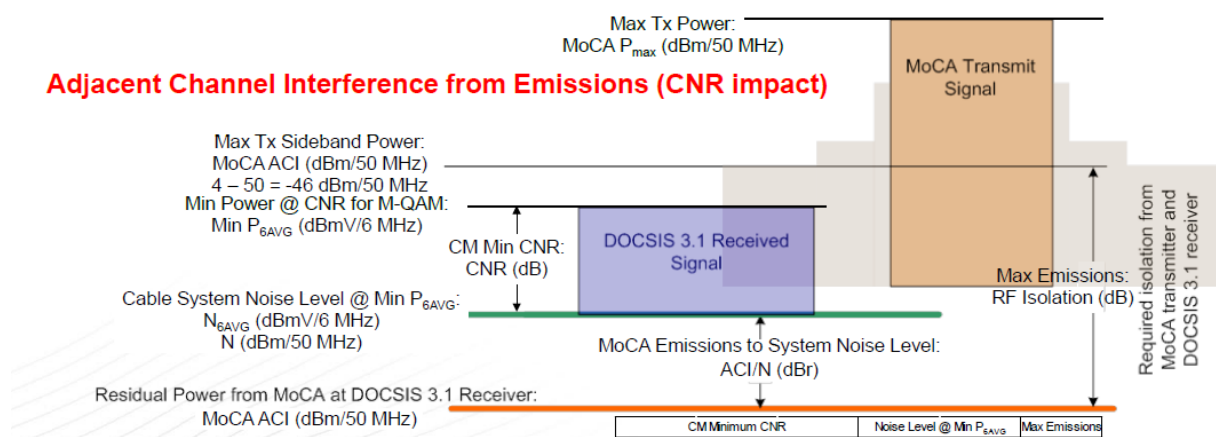


Figure 27 - CNR Impact to DOCSIS Operation using MoCA 2.0 Mode

Figure 27 summarizes the impact of MoCA 2.0 transmit signal spurious emissions on a DOCSIS 3.1 received signal. Recall from earlier analysis in Section 6.2, when a MoCA device is operating in MoCA 2.0 mode, its maximum transmitter sideband power is -46 dBmV/50 MHz. Subtracting the CM’s noise level from the maximum transmitter sideband power, the isolation would be -46 dBmV/50 MHz – -86.4

dBm/50 MHz = 40.4 dB. Thus, the improved MoCA spurious emission performance can allow for reduced noise degradation to the CM’s RF input with a similar isolation requirement.

If 0.25 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio ACI/N becomes -12.3 dB. Therefore 44.4 dB + 12.3 dB = 52.7 dB isolation results in 0.25 dB CNR degradation at the CM’s RF input. A 0.25 dB degradation in CNR results in 0.0833 bps/Hz capacity loss.

Guideline 16: If 0.25 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio ACI/N becomes -12.3 dB and the resulting capacity loss is 0.0833 bps/Hz.

Note that as shown in section 8.3, MoCA 2.0 two-channel bonded mode increases MoCA emissions by 3 dB requiring 3 dB more isolation for the same CNR degradation of the DOCSIS 3.1 signal.

10.5. Summary of RF Isolation Requirements

Guideline 17: The isolation summary for all the MoCA ↔ DOCSIS interference scenarios analyzed is listed in Table 6.

Table 6 - Isolation Summary for all MoCA, DOCSIS Non-overlapping Interference Scenarios

Non-overlapping Interference Case	MoCA Signal to DOCSIS 3.1 Receiver Isolation	DOCSIS 3.1 Signal to MoCA Receiver Isolation
Susceptibility	MoCA 1.1: 52.5 dB MoCA 2.0: 48.5 dB	MoCA 1.1: 48.5 dB MoCA 2.0: 48.5 dB
Emissions – Receiver Noise Floor Impact (Interference level 16 dB below Johnson-Nyquist thermal noise limit + 8 dB receiver noise figure for ΔCNR = 0.1 dB in all cases)	MoCA 1.1: 68 dB MoCA 2.0 in 1.1 mode: 63 dB MoCA 2.0: 59 dB (-105 dBm/50 MHz) MoCA 2.0 two-channel bonded: 62 dB	MoCA 1.1: 22.5 dB MoCA 2.0: 22.5 dB (-105 dBm/50 MHz)
Emissions – CNR Impact (CNR degradation below DOCSIS 3.1 minimum CNR at minimum 4096-QAM OFDM input level)*	MoCA 1.1: 55.4 dB (ΔCNR = 1.0 dB); MoCA 2.0 in 1.1 mode: 52.8 dB (ΔCNR = 0.6 dB); MoCA 2.0: 52.8 dB MoCA 2.0 two-channel bonded: 55.8 dB (ΔCNR = 0.25 dB)	N/A

*Note: Lower CNR impact can be achieved with higher isolation required (the spreadsheet evaluates this trade-off in Emissions-D3.1 CNR).

MoCA ACI Noise and Spurious Emissions into DOCSIS 3.1 devices impacting the assumed receiver noise floor by 0.1 dB will require significantly higher RF isolation of all other mutual interference cases. Replacing the ΔCNR = 0.1 dB case with MoCA ACI Noise and Spurious Emissions into DOCSIS 3.1 devices for minimally impacting the required CNR at the minimum signal level of the highest spectral efficiency (modulation order) in the DOCSIS 3.1 specification requires comparable RF isolation to the highest of all other mutual interference cases (52.7 to 55.3 dB isolation). Incorporating the CNR requirements for DOCSIS 3.1 operation provides a significant reduction (12.7 dB to 15.3 dB reduction) in

the required RF isolation between a MoCA transmitter and a DOCSIS 3.1 receiver resulting in a practical isolation filter design with minimal loss in CNR margin (ΔCNR).

11. Existence/Location of PoE and Protection Filters

11.1. Overview of How Filters Work

A filter is a circuit or device that is used to selectively pass a signal or signals within a range or ranges of frequencies called the filter’s passband(s), while selectively attenuating a signal or signals within other frequency ranges called the filter’s stopband(s). The transition between the passband(s) and stopband(s) is called the cutoff frequency, usually defined as the transition’s half-power or -3 dB point. The following figures (see Figure 28 through Figure 31 from [ANSI/SCTE 151]) illustrate examples of some of the more common filter types. In the figures, the vertical axis is amplitude or magnitude, and the horizontal axis is frequency.

A *lowpass filter* passes signals up to a specified cutoff frequency, while attenuating or rejecting signals above the cutoff frequency.

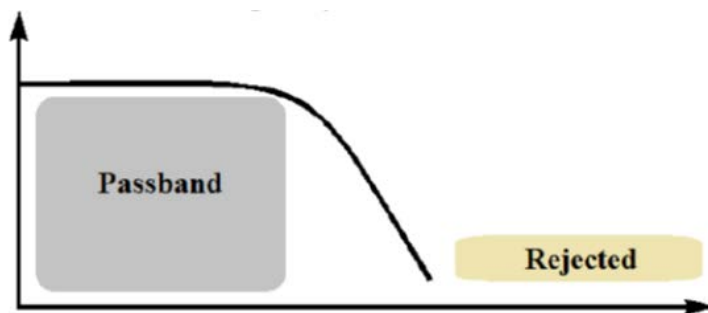


Figure 28 - Lowpass Filter

A *highpass filter* passes signals above a specified cutoff frequency while attenuating or rejecting signals below the cutoff frequency.

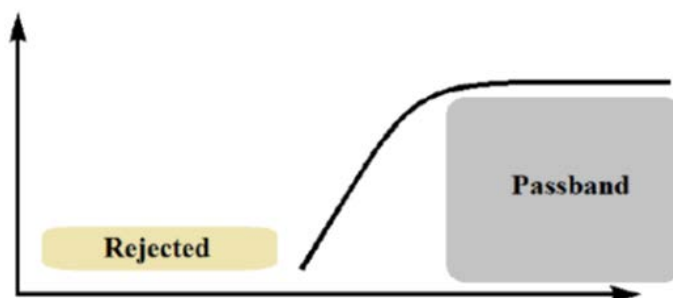


Figure 29 - Highpass Filter

A *notch filter* is a type of *bandstop filter* that attenuates or rejects signals within a relatively narrow range of frequencies, while passing signals in the frequency ranges below and above the stopband.

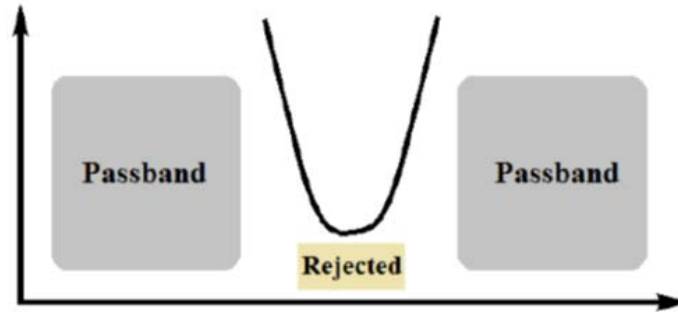


Figure 30 - Notch Filter

A *bandstop filter* attenuates or rejects signals in a relatively wide range of frequencies (compared to a notch filter) and passes frequencies above and below the stopband.

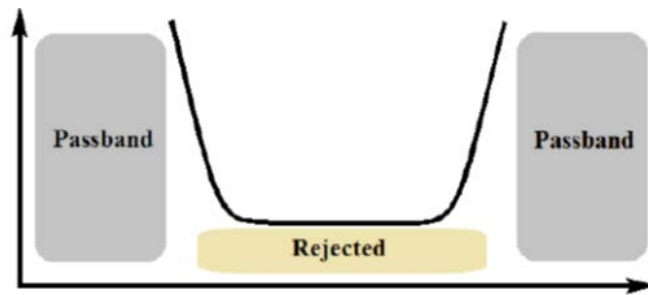


Figure 31 - Bandstop Filter

The following test equipment plots show examples of real-world filter measurements. The vertical axis is amplitude or magnitude in dB, and the horizontal axis is frequency.

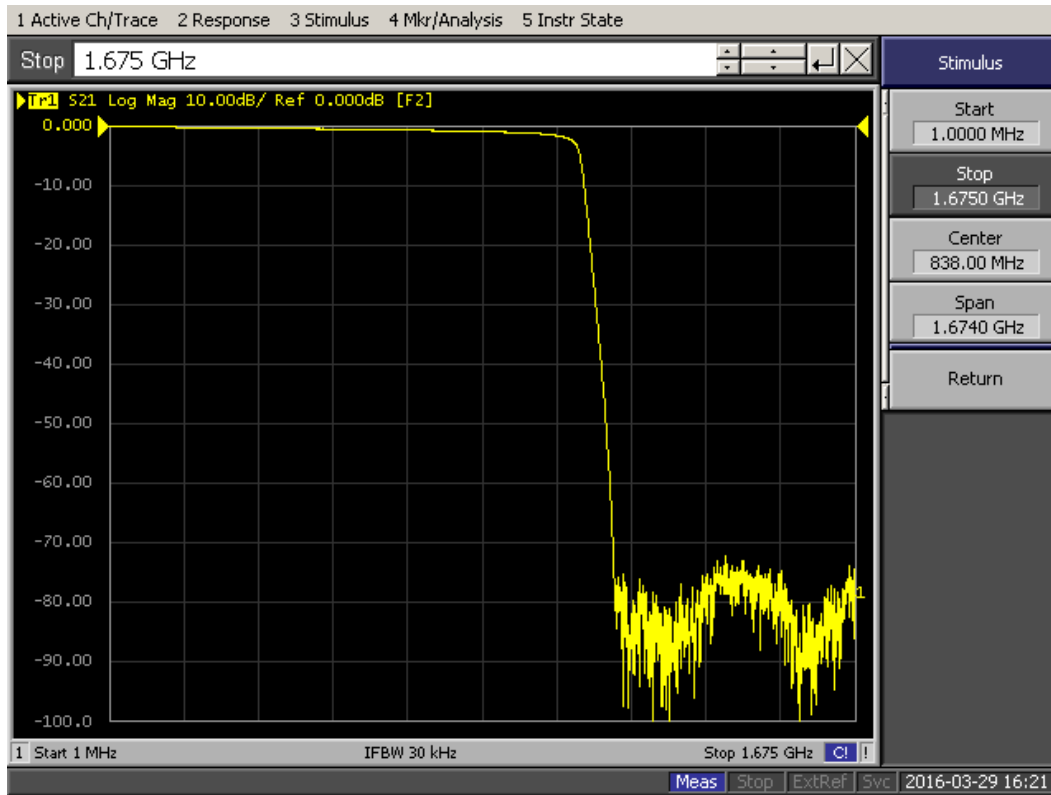


Figure 32 - Lowpass Filter Measurement

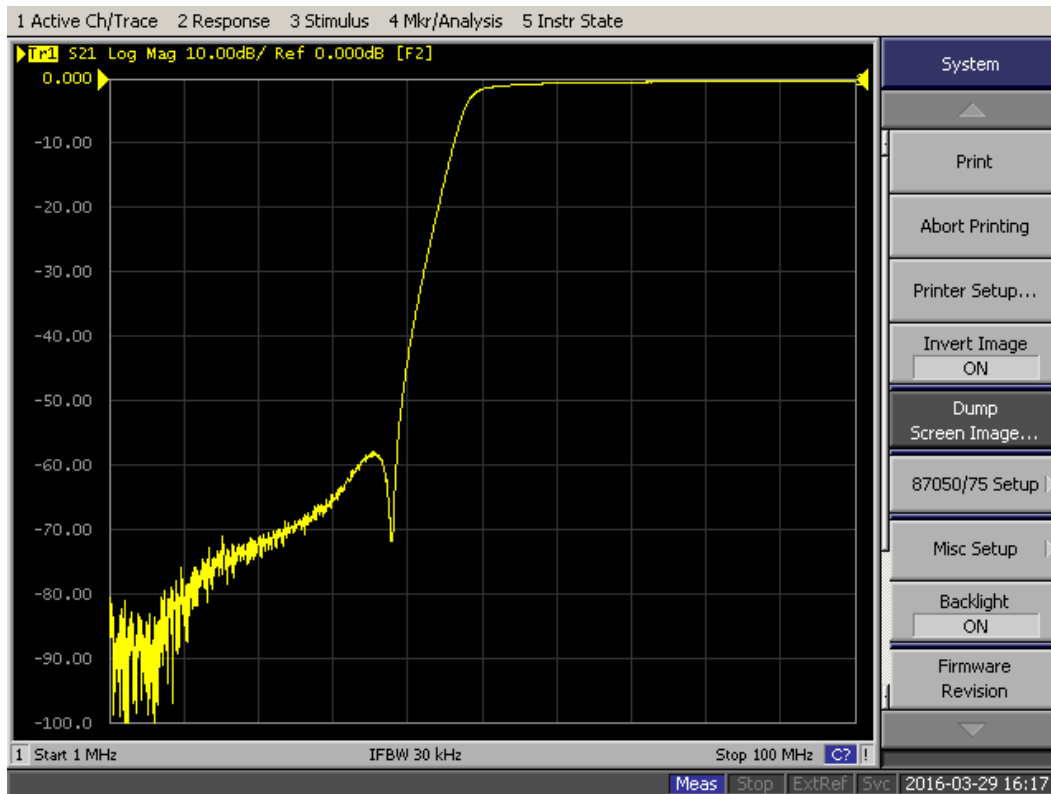


Figure 33 - Highpass Filter Measurement

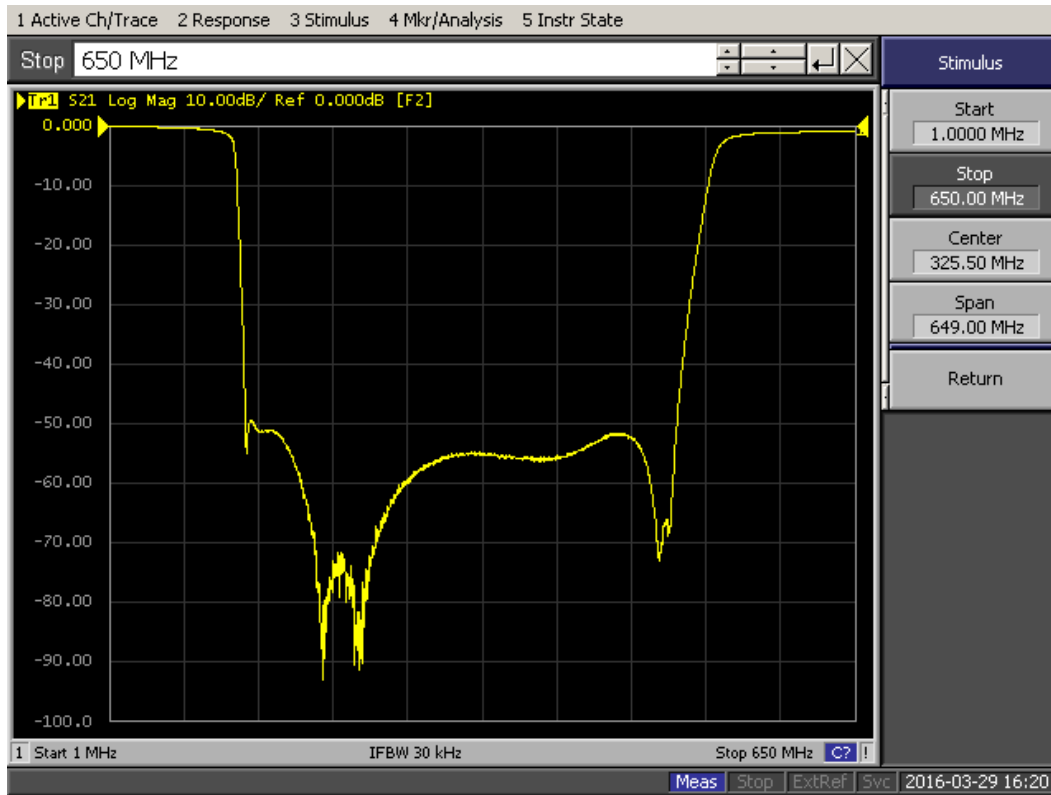


Figure 34 - Bandstop Filter Measurement

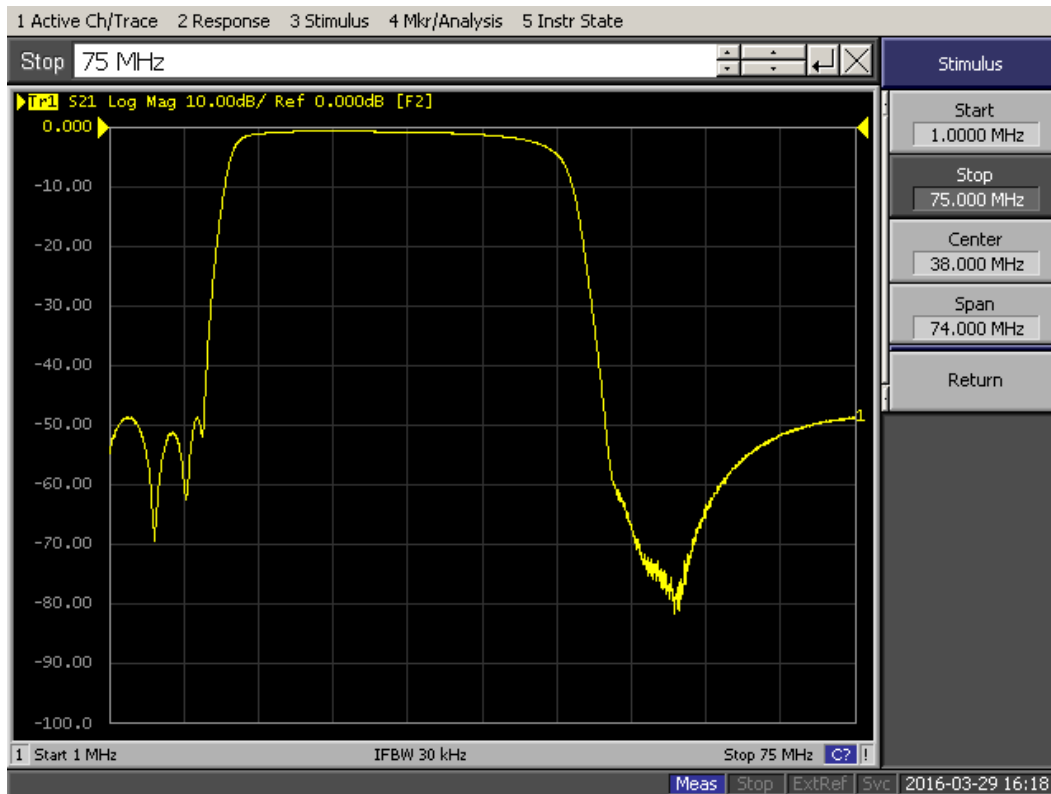


Figure 35 - Bandpass Filter Measurement

A PoE filter is a lowpass filter designed to pass signals below about 1 GHz, while attenuating or blocking MoCA signals above 1 GHz. PoE and other filters are installed in the subscriber drop as discussed in Section 11.2.

11.2. Example of Implementations

As mentioned earlier, there are several subscriber hardware and wiring scenarios that might result in signals from one device creating undesirable effects in another device. In this section we will consider an example that illustrates this issue. The reader should be aware that there are numerous scenarios in which interconnects may be accomplished in the drop and subscriber premises. The example contained herein is not meant to be an exhaustive examination of all of these scenarios. Rather, the purpose is to identify a few key issues and methodologies to address the issues. It should be apparent how to use these same techniques in other scenarios.

Let us begin by examining the first subscriber example as illustrated in Figure 36.

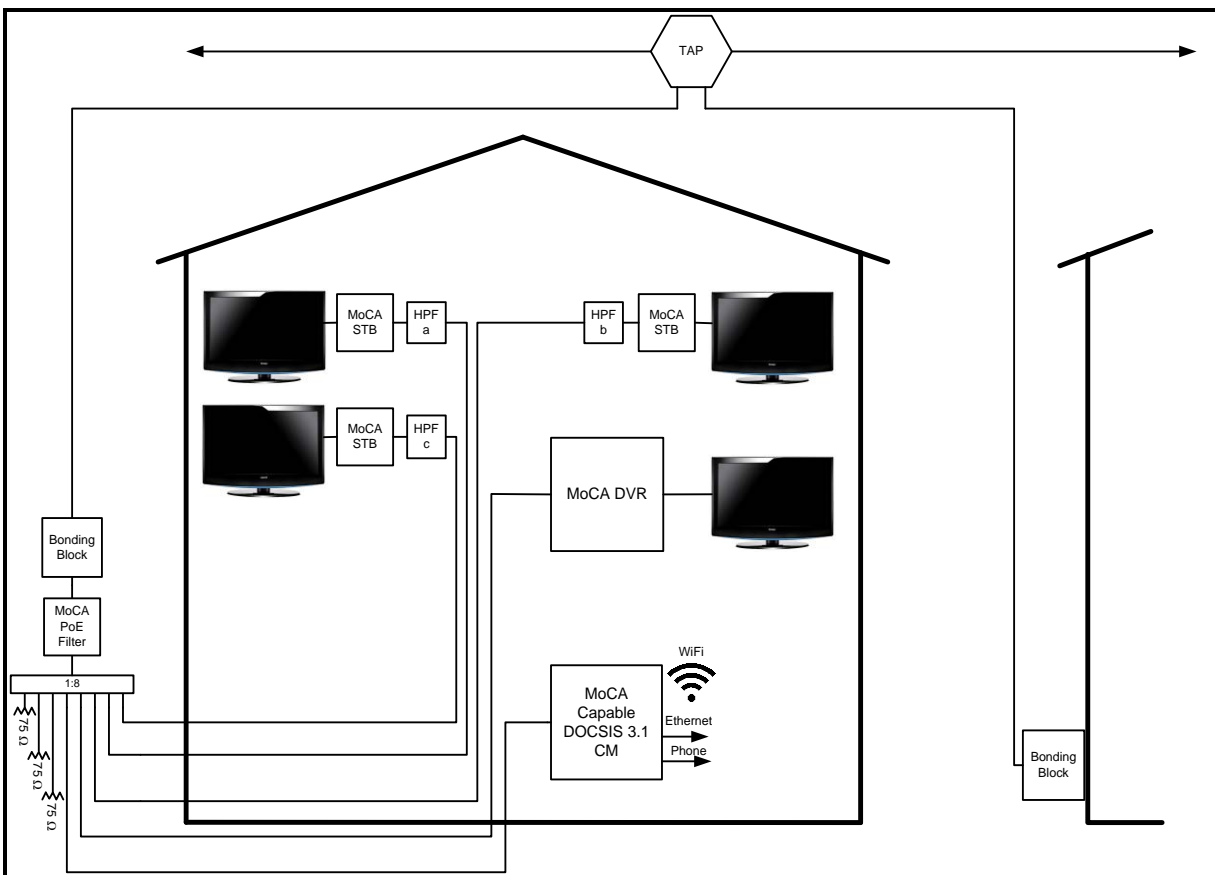


Figure 36 - Subscriber Premises Example

There are several pieces of CPE in this example. At the lower right of the subscriber premise is a DOCSIS 3.1 capable cable modem. Since this device contains interfaces for telephony it may also be referred to as an embedded multimedia terminal adapter (eMTA). Also in the home is a MoCA master digital video recorder (DVR) with three satellite MoCA STBs.

In this example the overall network is designed to operate in the sub-split band plan. The downstream frequency range is 54 MHz to 1002 MHz and the upstream frequency range is 5 MHz to 42 MHz. The

MoCA DVR and MoCA capable DOCSIS 3.1 cable modem are each capable of operation in three frequency bands; 5 MHz to 42 MHz upstream, 54 MHz to 1002 MHz downstream and the MoCA 2.0 ExD band at 1125 MHz to 1675 MHz.

Guideline 18: CPE devices intended to operate on DOCSIS upstream, DOCSIS downstream, and MoCA frequencies simultaneously must have internal triplex filters (triplexers) that provide adequate isolation between these three bands.

For reference a typical triplexer block diagram, frequency response and isolation requirements are shown in Figure 37, Figure 38, and Table 7 respectively. Filter response and isolation are typically described in terms of scattering parameters or S-parameters. An S-parameter, S_{xy} , is defined as the ratio of the voltage appearing at port x of a device to the applied voltage at port y of a device. For example, if a device has two ports, 1 and 2, where port 1 is the input and port 2 is the output, S_{21} is the ratio of the voltage appearing at port 2 to the applied voltage at port 1. In this example, S_{21} is equivalent to the voltage gain. Similarly, S_{11} would be the ratio of any reflected voltage at port 1 to the applied voltage at port 1. S-parameters are in general complex values. However, it is often useful to deal with the magnitude of S-parameters, as indicated by the vertical bars on either side (i.e. $|S_{21}|$). The magnitude of S-parameters are typically expressed in decibels as shown the figures contained herein.

S_{34} is the ratio of the voltage appearing at port 3 to the applied voltage at port 4.

Guideline 19: Triplexer isolation requirements are summarized in Table 7. They are based on the values in Table 6, with calculations based on the amount of acceptable CNR degradation, 1 dB to 0.1 dB respectively.

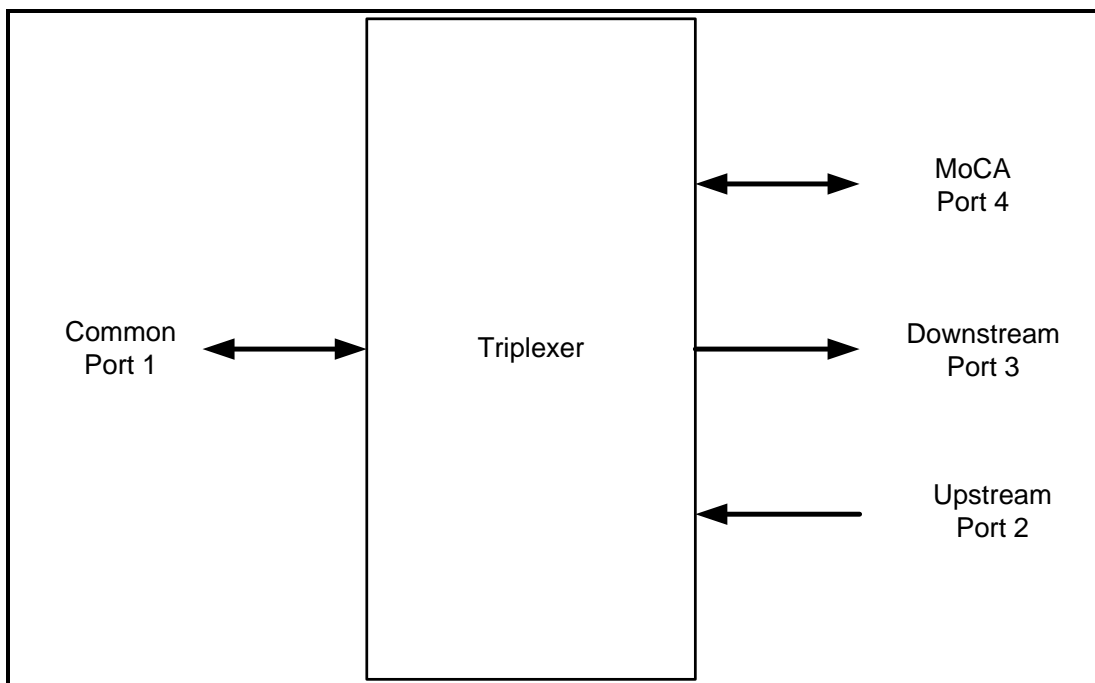


Figure 37 - Triplexer Block Diagram

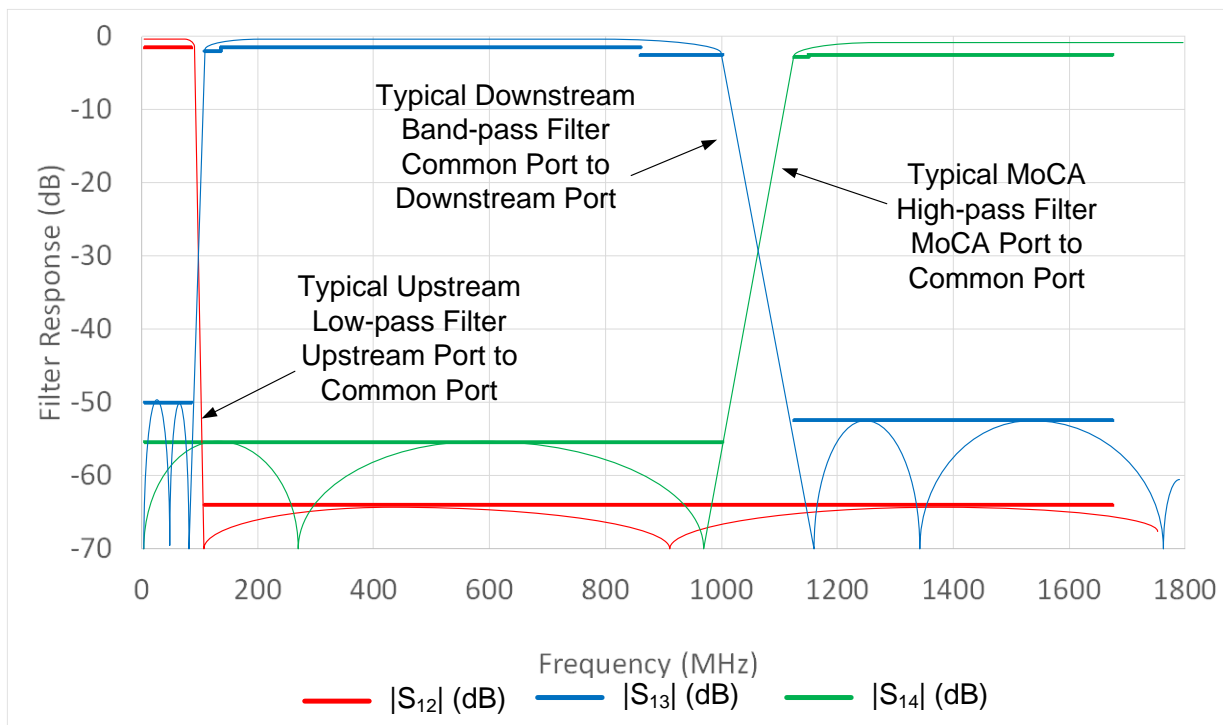


Figure 38 - Typical DOCSIS Triplexer Response

Table 7 - Typical DOCSIS Triplexer Isolation Requirements

F1	F2	$ S_{12} $	$ S_{31} $	$ S_{41} $	$ S_{32} $	$ S_{34} $
5 MHz	85 MHz	> -2 dB	< -50 dB	< -55 dB	< -50 dB	
108 MHz	136 MHz	< -64 dB	> -2 dB	< -55 dB	< -64 dB	< -52.7 to -68 dB
136 MHz	860 MHz	< -64 dB	> -2 dB	< -55 dB	< -64 dB	< -52.7 to -68 dB
860 MHz	1002 MHz	< -64 dB	> -3 dB	< -55 dB	< -64 dB	< -52.7 to -68 dB
1125 MHz	1150 MHz	< -64 dB	< -52 dB	> -3 dB	< -64 dB	< -52.7 to -68 dB
1150 MHz	1675 MHz	< -64 dB	< -52 dB	> -3 dB	< -64 dB	< -52.7 to -68 dB

The in-home RF cabling in this scenario is referred to as a “home-run.” The home-run has one main RF splitter, in this example an 8-way splitter, typically located near to the bonding block. A dedicated coaxial run is pulled from the splitter to each CPE inside the customer premises.

The MoCA PoE filter is located at the bonding block (see Figure 39). This is a low pass filter designed to pass both the system upstream (5 MHz to 42 MHz) and the system downstream (5 MHz to 1002 MHz) while rejecting the MoCA band (1125 MHz to 1625 MHz) and above.

The MoCA PoE filter serves several purposes:

- It must prevent high level MoCA transmissions within the subscriber premises from traveling back up the drop and affecting other subscriber drops.
- It must prevent out-of-band spurious signals in the band above 1125 MHz from the downstream signals sources coming down the drop cable, such as downstream CMTS QAM or OFDM modulators or edge-QAM modulators, from affecting the MoCA signal quality in the home. This is illustrated in Figure 39.
- It provides a reflection point for MoCA signals to bounce against so they reflect back to other MoCA devices in the home.

Guideline 20: The MoCA PoE filter serves several purposes: prevent bridging to other premises, maintain coexistence of DOCSIS signals and MoCA signals, and reflect MoCA back into the home

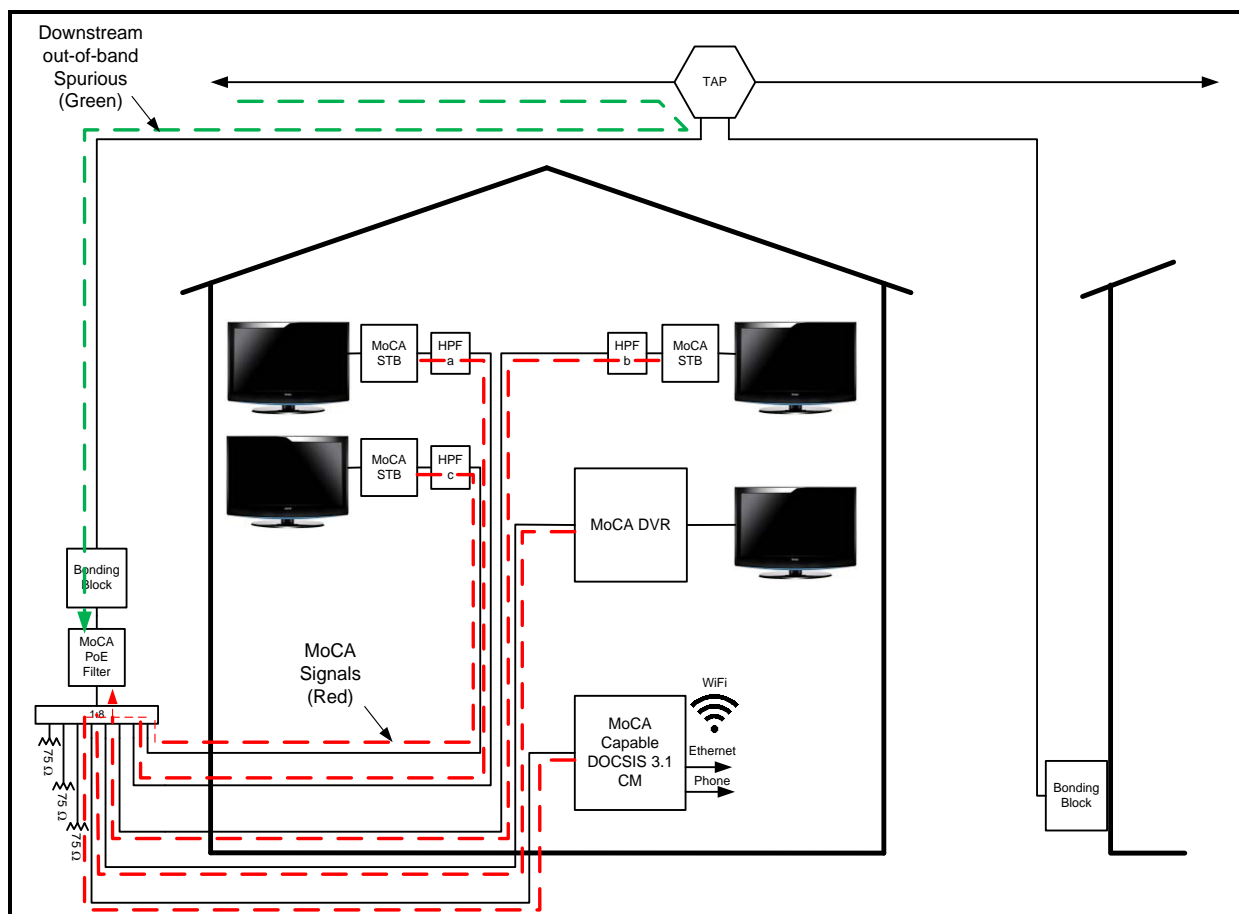


Figure 39 - MoCA PoE Filter Rejecting MoCA Signals and Downstream Spurious

Typical MoCA PoE filter requirements are given in Table 8. A typical MoCA PoE filter mask and filter response are shown in Figure 40 and Figure 41 respectively. Ideally the losses should be as small as possible to have as little impact as possible to avoid affecting any marginal CM installations and their connectivity with the CMTS after a PoE filter is added.

Table 8 - Typical MoCA PoE Filter Requirements

F1	F2	 S12 (indoor)	 S12 (outdoor)
5 MHz	870 MHz	> -0.8 dB	>-1.0 dB
870 MHz	1002 MHz	> -1.6	>-1.8 dB
1125 MHz	1675 MHz	< -55 dB	<-50 dB

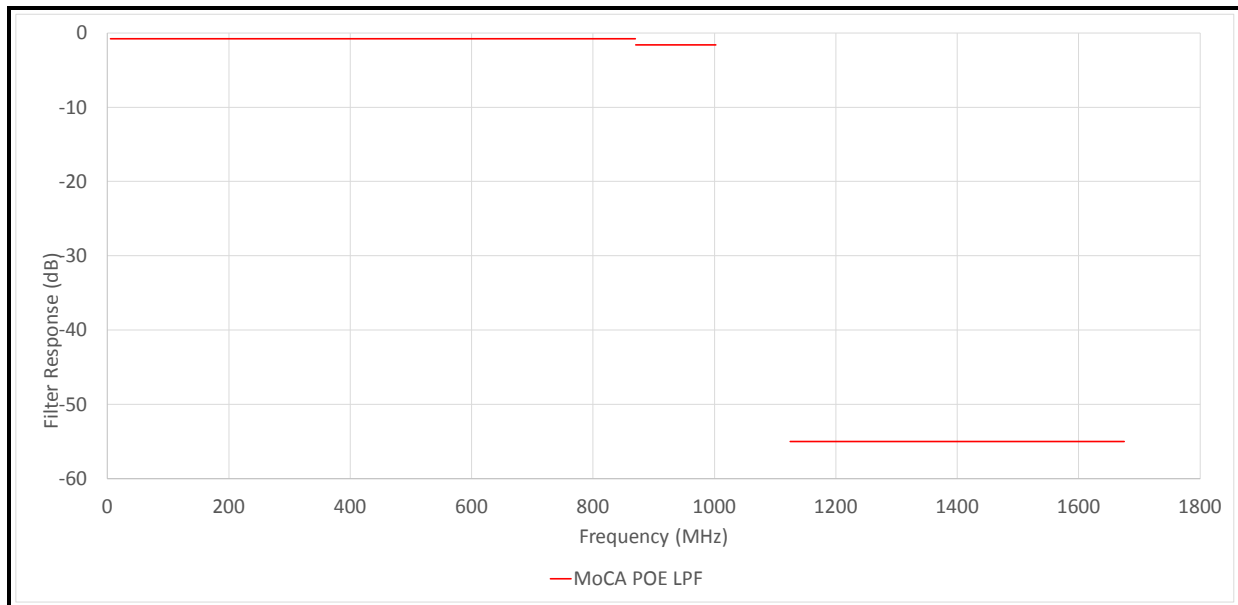


Figure 40 - Typical MoCA PoE Filter Mask

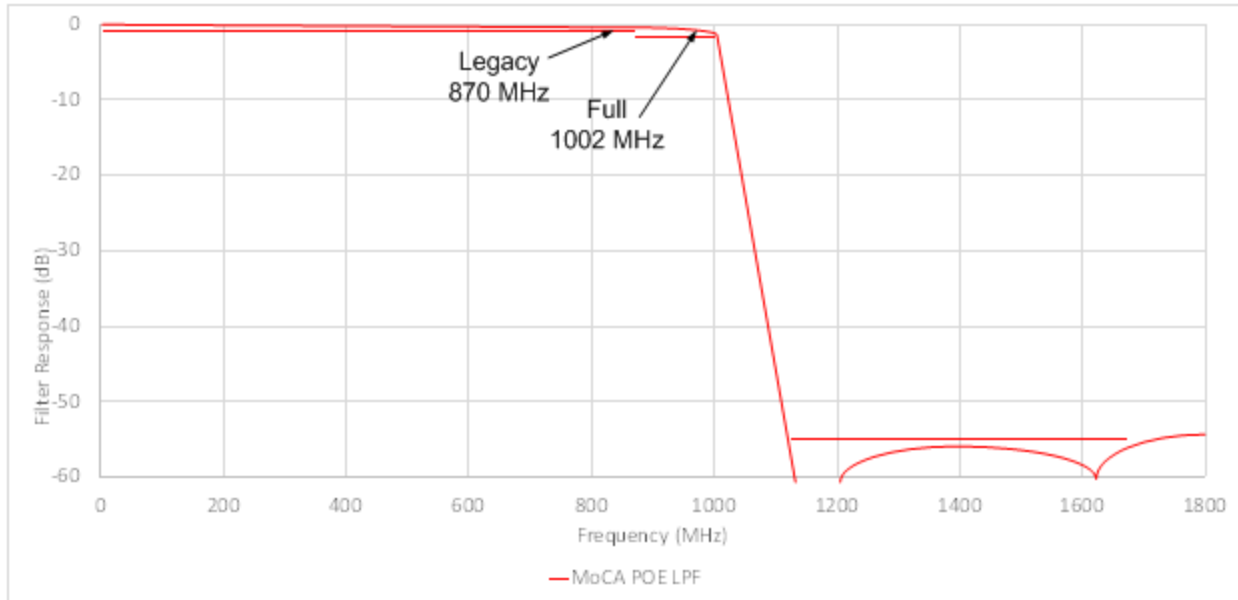


Figure 41 - Typical MoCA PoE Filter Response

A second set of filters is required in this first example. These are labeled high-pass filter (HPF) a, b and c in Figure 42.

Guideline 21: MoCA-only filters have a dual function. First, they prevent network signals in the 5 MHz to 1002 MHz range from affecting the MoCA receiver in the MoCA devices. Second, they prevent MoCA spurious signals in the frequency range below 1002 MHz from the any of the MoCA STB transmitters from affecting the DOCSIS signals used by the MoCA capable DVR and DOCSIS 3.1 CM.

This is illustrated in Figure 42. Note that the high-pass sections in the triplexers in the MoCA DVR and MoCA enabled DOCSIS 3.1 CM provide this function in those devices.

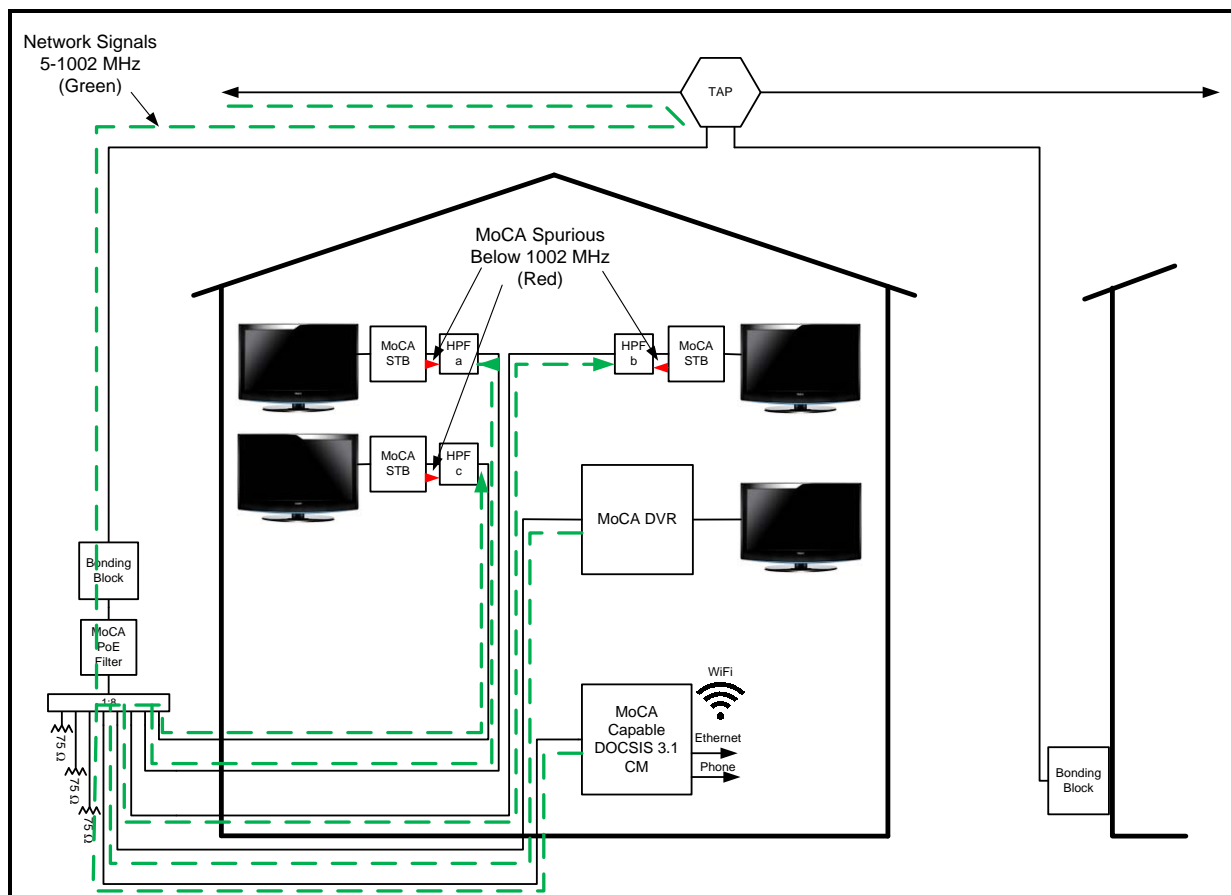


Figure 42 - Function of HPF a-c

HPF a-c should be labeled with text similar to one of the following examples:

- “Do not remove – Required for multi-room DVR operation”
- “Do not remove – Required for whole-home DVR operation”
- “Do not remove – Required for any-room DVR operation”.

Guideline 22: Any MoCA-only filters deployed in the home should be clearly labeled so that consumers do not remove them.

12. Two-port gateway

The two-port gateway was introduced in Section 8.6 as a way to separate the home network signals from the OSP signals. The home network signals are MoCA based, whereas the OSP can include a variety of signals such as DOCSIS signals. The analysis of the two-port gateway filtering requirements between MoCA and DOCSIS signals can be similar to what has already been provided in this document for the one-port gateway. The main benefit of the two-port gateway is that some or all the filtering needed for the home could be localized within the two-port gateway.

If no outside plant signals were passing into the home network, filtering could be applied by the two-port gateway, enabling the home and outside plant signaling to coexist with one another. One benefit of tasking the two-port gateway with the coexistence filtering is that it could eliminate the need for additional filtering within the home to protect CPE, since no outside plant signals are passing into the

home. Further, if outside plant and home network signals were to overlap with one another in frequency, as described in Section 8.1, then the isolation for each port in Table 9 would need to be provided by the two-port gateway.

The two-port gateway could also integrate the PoE filter and thus negate the need for installing standalone filters, like groundblock PoE filters. The two-port gateway will then prevent adjacent home MoCA networks from bridging with one another, as well as provide a mechanism to bounce MoCA signals back into the home.

Lastly, if some non-overlapping outside plant signals were allowed to pass through the two-port gateway, then additional filters will be needed and the deployment model will be similar to what has been described in Section 11.

Table 9 - Isolation Summary for all MoCA, DOCSIS Co-Channel Interference Scenarios

Co-Channel (Overlapping) Interference Case	MoCA Signal to DOCSIS 3.1 Receiver Isolation	DOCSIS 3.1 Signal to MoCA Receiver Isolation
Emissions – Receiver Noise Floor Impact (Interference level 16 dB below Johnson-Nyquist thermal noise limit + 8 dB receiver noise figure for ΔCNR = 0.1 dB in all cases)	MoCA 1.1: 113 dB MoCA 2.0: 109 dB (-105 dBm/50 MHz)	MoCA 1.1: 80.5 dB MoCA 2.0: 80.5 dB (-105 dBm/50 MHz)
Emissions – CNR Impact (CNR degradation below DOCSIS 3.1 minimum CNR at minimum 4096-QAM OFDM input level)*	MoCA 1.1: 100.4 dB (ΔCNR = 1.0 dB); MoCA 2.0 in 1.1 mode: 102.8 dB (ΔCNR = 0.6 dB); MoCA 2.0: 102.8 dB (ΔCNR = 0.25 dB)	N/A

*Note: Lower CNR impact can be achieved with higher isolation required (the spreadsheet evaluates this trade-off in CCI-D3.1 CNR).

13. Guidelines

The guidelines from this document are summarized in this section. To assure proper implementation For additional information about each guideline please consult the section in which the guideline was first mentioned.

Guideline 1: A home-run topology should be used to control losses and RF levels more uniformly across the home CPE.

Guideline 2: The series-wired nature of a loop-through architecture should be avoided because it complicates the ability to control losses and achieve uniform RF levels across the home CPE.

Guideline 3: 113 dB of RF isolation is very difficult for filter designers to support, which is why overlapping DOCSIS 3.1 frequencies and MoCA frequencies are not recommended at this time.

Guideline 4: The adjacent scenario is not a recommended practice.

Guideline 5: The non-overlapping scenario is the best operational practice since it offers the largest guard band, and will have the lowest isolation requirement.

Guideline 6: The primary use-case for PoE filters is to RF isolate one MoCA home from another.

Guideline 7: A secondary use-case for PoEs is to prevent MoCA signals from overloading legacy STB, DTA, and other CPE tuners.

Guideline 8: The example values in Table 1 can be leveraged by cable operators for other non-overlapping frequency scenarios so long as the DOCSIS signals and MoCA signals are non-overlapping with one another, similar guard bands are maintained, and other cautions mentioned in Section 8.5 are observed.

Guideline 9: The pros and cons of deploying one versus two-port gateways must be weighed carefully since they will likely vary among cable operators.

Guideline 10: In order to meet the MoCA interference requirement for First Adjacent Channel, there should be at least 48.5 dB of isolation between DOCSIS 3.1 signals and MoCA signals (both 1.1 and 2.0).

Guideline 11: In order to meet the DOCSIS requirement for Maximum average power per MHz input to the CM, there should be at least 52.5 dB of isolation between MoCA 1.1 and DOCSIS 3.1 signals and 48.5 dB of isolation between MoCA 2.0 and DOCSIS 3.1 signals.

Guideline 12: In order to maintain a maximum of 0.1 dB CNR degradation in the MoCA receiver, the CNR associated with the DOCSIS 3.1 emissions must be 16 dB lower than the MoCA receiver's noise floor. The required RF isolation is 22.5 dB for both MoCA 1.1 and 2.0.

Guideline 13: In order to maintain a maximum of 0.1 dB CNR degradation in the DOCSIS 3.1 receiver, the CNR associated with the MoCA emissions must be 16 dB lower than the DOCSIS 3.1 receiver's noise floor. The required RF isolation is 68 dB for MoCA 1.1, 63 dB for MoCA 2.0 in 1.1 mode and 59 dB for MoCA 2.0 and 62 dB for MoCA 2.0 two-channel bonded.

Guideline 14: If 1 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio (ACI/N) becomes -5.9 dB and the resulting capacity loss is 0.333 bps/Hz.

Guideline 15: If 0.6 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio (ACI/N) becomes -8.3 dB and the resulting capacity loss is 0.2 bps/Hz.

Guideline 16: If 0.25 dB of CNR degradation is preferred, then the appropriate ACI emissions-to-noise ratio ACI/N becomes -12.3 dB and the resulting capacity loss is 0.0833 bps/Hz.

Guideline 17: The isolation summary for all the MoCA ↔ DOCSIS interference scenarios analyzed is listed in Table 6.

Guideline 18: CPE devices intended to operate on DOCSIS upstream, DOCSIS downstream, and MoCA frequencies simultaneously must have internal triplex filters (triplexers) that provide adequate isolation between these three bands.

Guideline 19: Triplexer isolation requirements are summarized in Table 7. They are based on the values in Table 6, with calculations based on the amount of acceptable CNR degradation, 1 dB to 0.1 dB respectively.

Guideline 20: The MoCA PoE filter serves several purposes: prevent bridging to other premises, maintain coexistence of DOCSIS signals and MoCA signals, and reflect MoCA back into the home

Guideline 21: MoCA-only filters have a dual function. First, they prevent network signals in the 5 MHz to 1002 MHz range from affecting the MoCA receiver in the MoCA devices. Second, they prevent MoCA spurious signals in the frequency range below 1002 MHz from the any of the MoCA STB transmitters from affecting the DOCSIS signals used by the MoCA capable DVR and DOCSIS 3.1 CM.

Guideline 22: Any MoCA-only filters deployed in the home should be clearly labeled so that consumers do not remove them.

14. Conclusions

Recommendations enabling DOCSIS and MoCA coexistence have been provided. These recommendations cover filter design, home network topology, and filter placement.

Non-overlapping DOCSIS and MoCA frequencies will result in the most attractive filter characteristics. In particular, non-overlapping frequencies permit the lowest isolation requirements. The amount of isolation required can be calculated based on the service performance degradation that the cable operator is willing to allow. The assumptions and methods for calculating isolation requirements have been provided so that cable operators may investigate proper isolation requirements specific to their own deployment models.

Home-run and loop-through home network topologies have been presented as two possible networks DOCSIS and MoCA products may be used in. It has been shown how the home-run topology can help cable operators control path loss, resulting in more uniform RF levels across CPE, whereas loop-through networks may make it more difficult to control path loss and RF levels.

Many factors unique to each cable operator's deployment model will impact filter design and ultimately the placement of those filters within the home. This document provided recommendations for proper placement of filters and discussed the impact a one-port gateway versus a two-port gateway has on filtering requirements in the home.

It is hoped that these recommendations will help cable operators define optimal DOCSIS and MoCA coexistence strategies