SYSTEMS FOR OFDM BASED DIGITAL SIGNAL ASSESSMENTS FOR CATV NETWORKS

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Abstract

CableLabs has opened a new chapter in CATV digital communications with its latest installment of DOCSIS® 3.1. New DOCSIS® 3.1 capable products are expected to start showing up in 2015 time frame. Meanwhile, cable operators are looking into ways to start kicking the tires of OFDM-based PHY now by employing readily available simulation tools to produce DOCSIS® 3.1 PHY signals and subject them to a variety of simulated channel conditions.

Cable operators may also be aware of how some of these powerful simulation tools can be combined with signal generation and analysis equipment to produce DOCSIS® 3.1 signals that may be used to get an early look at how CATV systems will react to the new DOCSIS® 3.1 PHY. Simulation systems may be created to allow for deeper-dive into supported parameter sets, driving toward identification of optimal modulation profile settings, such as choosing appropriate cyclic prefix (CP) for expected channel conditions, or evaluating windowing parameter impacts to adjacent SC-QAM performance.

The authors wish to provide an initial reference point associated with porting DOCSIS® 3.1 PHY simulations into RF signal stimuli for more detailed analysis of how this new PHY performs across laboratory-based CATV systems. The authors expect to include both test topologies and new data resulting from these enhanced simulation capabilities, enabling others to contribute and add to this exciting new chapter in CATV digital communications.

BACKGROUND

This paper provides an introduction to software and equipment capable of testing DOCSIS®3.1 physical layer (PHY) performance. DOCSIS 3.1 is an essential component of a comprehensive network evolution strategy, delivering capacity increases through improvements in bandwidth efficiency and the addition of spectrum, and enabling the network to deliver long term capacity growth and best-in class data speeds [3].

Readers may be relieved to know that even though DOCSIS®3.1 certified products may not be available until sometime in 2015, there is opportunity now to start evaluating the specification by generating Orthogonal Frequency Division Multiplexed (OFDM) waveforms not just with software simulations, but also with hardware.

Many Arbitrary Waveform Generator (ARB) products are currently available, some of which are capable of generating the 192 MHz OFDM waveforms required by DOCSIS®3.1 downstream. Likewise, there are a variety of devices capable of digitizing large amounts of spectrum so that Vector Signal Analysis (VSA) software may demodulate and quantify fidelity via metrics including Error Vector Magnitude (EVM) or Modulation Error Ratio (MER).

The good news is that these are relatively mature products already being leveraged by the wireless industry for development activities associated with other standards bodies including Long Term Evolution (LTE) and IEEE 802.11ac (Wi-Fi®). Of course, mileage may vary given the many features included in the DOCSIS®3.1 specifications that may not get 100% coverage with custom OFDM waveform generation tools, like the unique upstream pilot patterns. Therefore, now is a good time to evaluate exactly what can be leveraged and what additional specification coverage can be made available going forward.

This paper provides insights of how adequate specification coverage is available to get up and running with some very basic PHY parameters including the following:

1. 4K, 8K IDFT size
2. Continuous Pilots
3. Up to 192 MHz Bandwidth
4. Downstream Cyclic Prefix
5. Downstream Roll-Off Prefix
6. Up to 4096-QAM Modulation

The authors would like to show how the above DOCSIS®3.1 test capability enables some preliminary evaluation of the DOCSIS®3.1 specifications to not only prove that this capability exists now, but hopefully inspire others to join the cause and leverage these benefits to help ensure DOCSIS®3.1 rollouts become the most successful in DOCSIS history.

The most obvious benefit is in verifying DOCSIS®3.1 requirements, not just when certifying DOCSIS®3.1 capable products, but in evaluating the requirements against channel model assumptions [4,5]. This is valuable work that could be done now to identify holes in the current requirement definitions so that issues may be resolved prior to a massive deployment. Many of the channel conditions can be simulated easily within a laboratory environment or field trials. DOCSIS®3.1 PHY can be exercised against the channel model conditions to ensure the PHY behaves as expected.

A less obvious benefit would be in identifying optimum PHY profiles. What is meant by optimum may vary among MSOs. It is the opinion of this paper's authors that the optimum profile is one that reliably provides the greatest capacity for the majority of users. To elaborate further, similar modulation profiles have already been created in DOCSIS®3.0 to reliably deliver optimum capacity of ATDMA channels in the upstream. There are many features available in DOCSIS®3.0 including pre-equalization, interleaving, Reed-Solomon (RS) coding, and preamble length. All these parameters can be tweaked against common channel conditions to reliably optimize capacity. DOCSIS®3.1 is a little different in that there are many more parameters available for tweaking and the opportunity is now to get a sense of which parameter profiles apply for the most relevant set of channel conditions.

Another less obvious benefit is in the identification of any potential operational challenges, ideally prior to mass deployment.

Fortunately, the authors will demonstrate how much of this due-diligence may commence now. This paper will highlight some prospective areas for investigation, like interoperation with legacy services. Specifically, how the various windowing parameters will impact adjacent DOCSIS®3.0 signals is something the authors will cover later in this paper.

The authors hope that this material will stimulate much-needed discussion on this topic and that many operational investigations and results will be brought forth so that our industry may support a quick convergence upon a sound DOCSIS®3.1 readiness strategy, an initiative already underway within the SCTE.

OFDM MEASUREMENTS

Windowing Power Spectral Density (PSD)

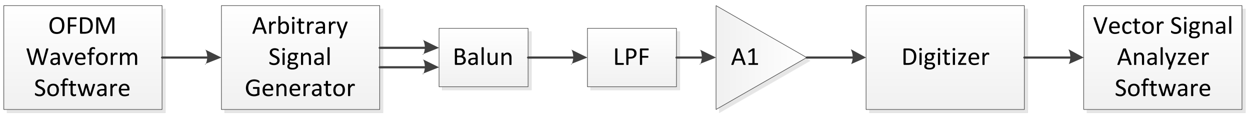

Figure 1 - Windowing Parameter Evaluation Test Topology

To evaluate the effects of windowing, Figure 1 test topology was used. OFDM waveform software is used to create the in-phase, (I) and quadrature (Q) data. This waveform is downloaded into the ARB for playback in the frequency domain. The digitizer bandpass samples the frequency domain content to recover the waveform and the results are aggregated into the vector signal analyzer software for a variety of measurements including MER, constellation plots, RF levels, etc.

There are five different Roll-Off Prefix (RP) settings available via DOCSIS®3.1 [1], which has been provided here in Figure 2 for reference. The test topology of Figure 1 was used to generate and analyze OFDM waveforms for the five different windowing settings from Figure 2. A 192 MHz, 4096-QAM modulated waveform was configured with a Cyclic Prefix (CP) setting of 2.5 µs. Both 4K, and 8K FFT waveforms were generated in this exercise. The maximum number of continuous pilots, M = 120, was used for all waveforms. M may vary between 48 and 120, which represents the number of continuous pilots that will occur at the same frequency location for all OFDM symbols. Their role is to assist in receiver synchronization.

Table 7–35 - Roll-Off Prefix (RP) Values

Roll-Off Period (µs)	Roll-Off Period Samples (N_{cp})
0	0
0.3125	64
0.625	128
0.9375	192
1.25	256

Figure 2 – DOCSIS®3.1 Downstream Windowing Specification

Amplitude traces were captured for all 10 waveforms and plotted onto a single chart for both the 4K, and 8K FFTs, illustrated in Figure 3 and Figure 4 respectively. The effects of windowing may be observed in these traces where the larger windowing settings provide a sharper edge in the frequency domain, resulting in more useful subcarriers. However, these settings come at the expense of reduced efficiency in the time domain. Finding the optimum windowing parameters will essentially be a trade-off between acceptable adjacent channel performance and DOCSIS® 3.1 capacity.

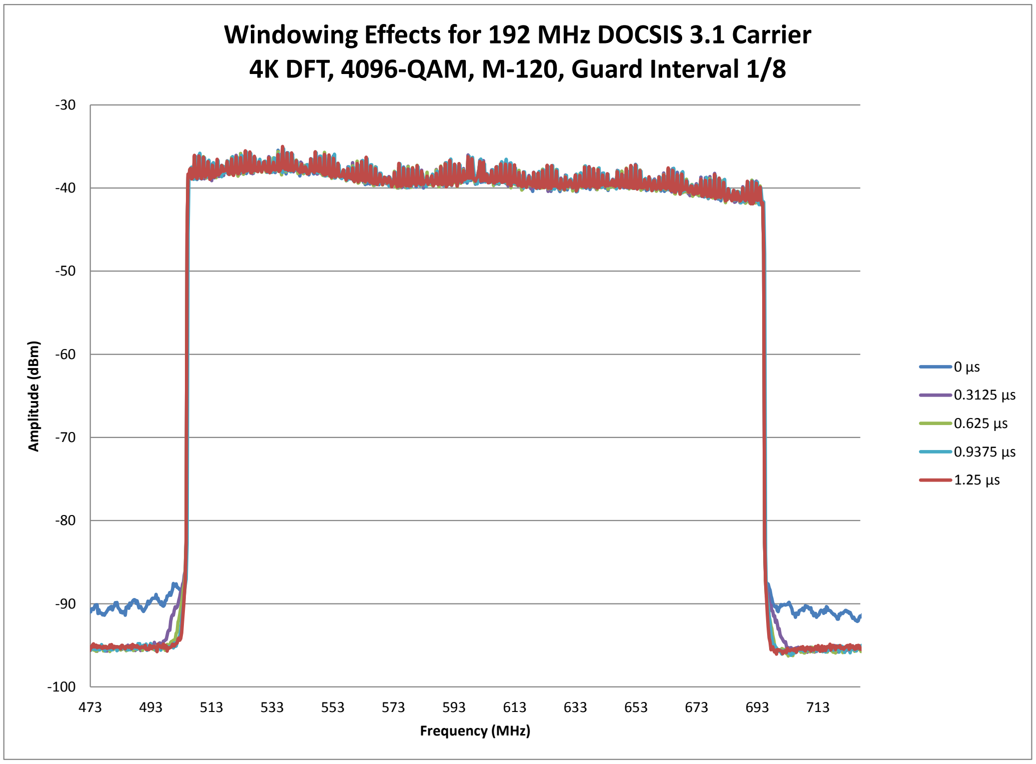

Figure 3 - Amplitude Traces, Using 4K FFT, for DOCSIS®3.1 Windowing

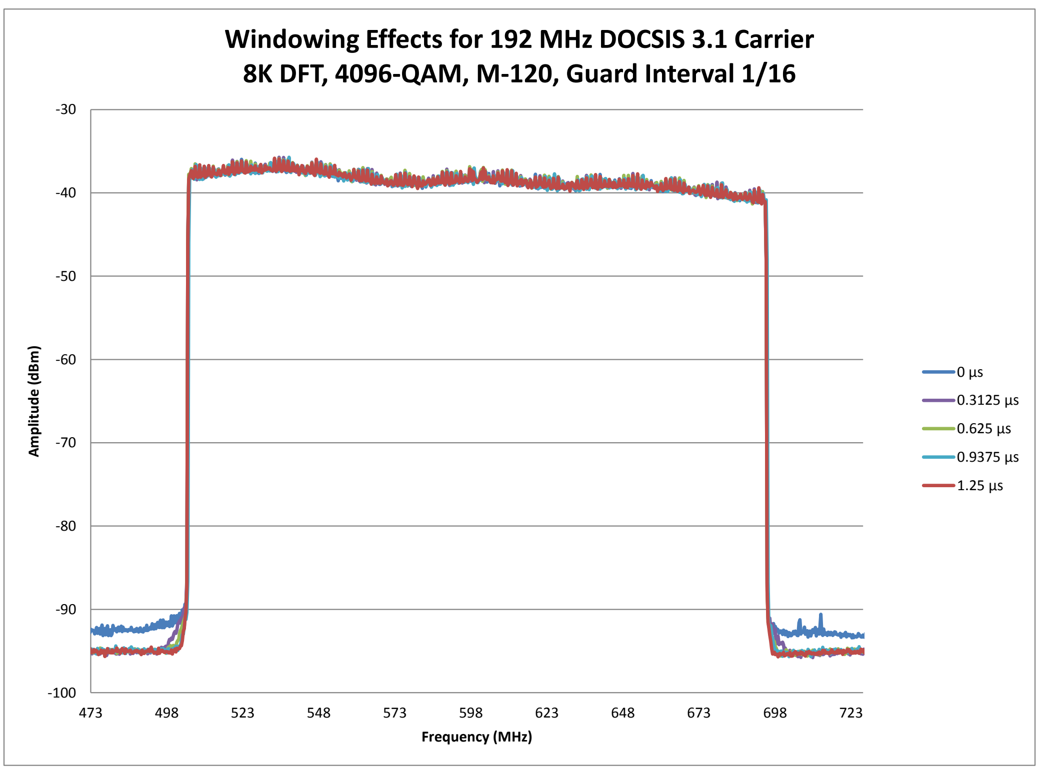

Figure 4 - Amplitude Traces, Using 8K FFT, for DOCSIS®3.1 Windowing

Adjacent Channel Performance

To assess adjacent channel performance, power measurements were made in both the DOCSIS®3.1 band, as well as six adjacent DOCSIS®3.0 bands for either side of the DOCSIS®3.1 signal. Many spectrum analyzers facilitate adjacent channel power (ACP) measurements similar to what has been illustrated in Figure 5.

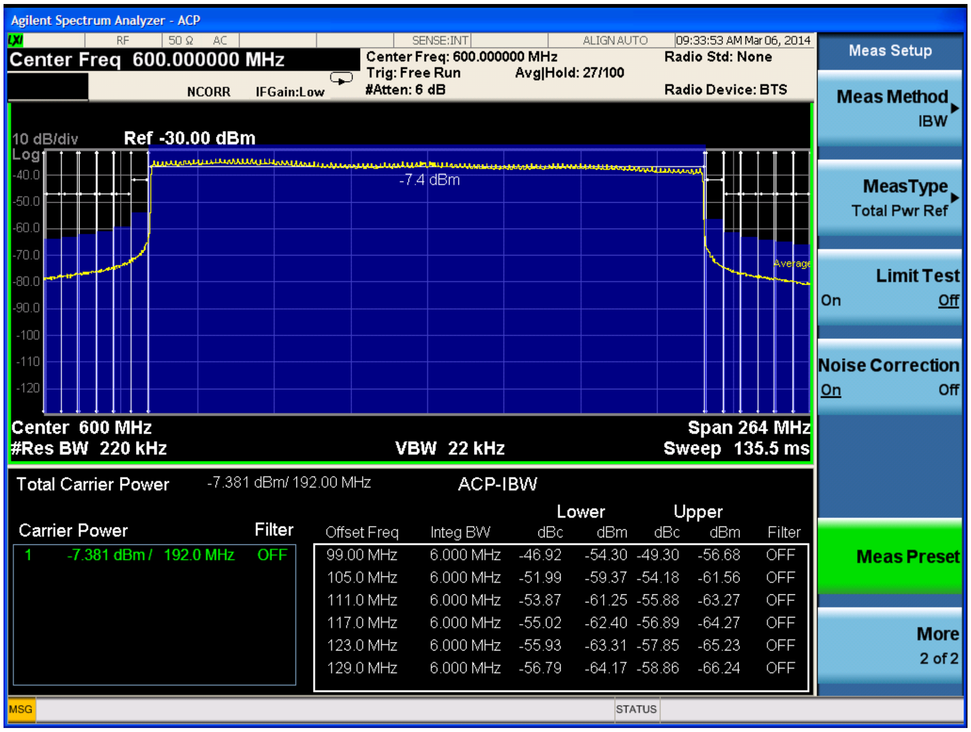

Figure 5 - ACP for 4K FFT, M = 120, CP = 2.5 µs, RP = 0 µs

Figure 6 summarizes the ACP for the 12 adjacent DOCSIS®3.0 carriers using 6 MHz bandwidth. The difference in power between 192 MHz DOCSIS®3.1 and a 6 MHz DOCSIS®3.0 bandwidths is $10*\log_{10}(192/6)$ = 15 dB. It can be seen how the ACP has the greatest impact to the next adjacent 6 MHz slot. There is also appreciably higher adjacent power when no windowing, RP = 0 µs, is used.

Windowing Effects via Relative Adjacent Channel Power - 6 MHz DOCSIS® 3.0 (dBc) Relative (dBmV) to 192 MHz DOCSIS® 3.1 Band Centered at F_c 4K FFT, 4096-QAM, M = 120, CP = 2.5 µs													
RP (µs)	F_c-129 MHz	F_c-123 MHz	F_c-117 MHz	F_c-111 MHz	F_c-105 MHz	F_c-99 MHz	F_c	F_c+99 MHz	F_c+105 MHz	F_c+111 MHz	F_c+117 MHz	F_c+123 MHz	F_c+129 MHz
0	-56.79	-55.93	-55.02	-53.87	-51.99	-46.92	39.61	-49.30	-54.18	-55.88	-56.89	-57.85	-58.86
0.3125	-73.22	-73.18	-73.10	-73.09	-72.22	-51.11	39.73	-53.83	-73.35	-73.83	-73.64	-73.61	-73.71
0.625	-73.01	-73.01	-72.98	-72.96	-72.91	-55.36	39.66	-58.56	-73.75	-73.50	-73.39	-73.31	-73.46
0.9375	-73.16	-73.17	-73.15	-73.09	-73.11	-59.30	39.71	-62.23	-74.08	-73.84	-73.75	-73.70	-73.71
1.25	-73.06	-73.01	-72.99	-73.05	-72.98	-62.96	39.69	-65.64	-73.82	-73.59	-73.49	-73.51	-73.49

Windowing Effects via Relative Adjacent Channel Power - 6 MHz DOCSIS® 3.0 (dBc) Relative (dBmV) to 192 MHz DOCSIS® 3.1 Band Centered at Fc 8K FFT, 4096-QAM, M = 120, CP = 2.5 µs													
RP (µs)	Fc-129 MHz	Fc-123 MHz	Fc-117 MHz	Fc-111 MHz	Fc-105 MHz	Fc-99 MHz	Fc	Fc+99 MHz	Fc+105 MHz	Fc+111 MHz	Fc+117 MHz	Fc+123 MHz	Fc+129 MHz
0	-58.24	-57.46	-56.42	-55.41	-53.37	-48.39	40.07	-51.80	-56.22	-57.88	-58.69	-59.73	-60.59
0.3125	-73.25	-73.25	-73.13	-73.07	-72.55	-53.68	40.18	-56.59	-73.63	-73.76	-73.58	-73.67	-73.68
0.625	-73.08	-72.97	-73.05	-72.98	-73.02	-58.54	40.20	-61.28	-73.82	-73.63	-73.54	-73.46	-73.48
0.9375	-72.78	-72.74	-72.69	-72.69	-72.69	-62.17	40.04	-64.78	-73.41	-73.17	-73.04	-73.02	-73.11
1.25	-73.17	-73.08	-72.94	-73.07	-73.01	-65.47	40.13	-68.23	-73.75	-73.53	-73.39	-73.43	-73.52

Figure 6 - ACP Summary Using Both 4K and 8K FFT DOCSIS®3.1

Legacy DOCSIS®3.0 channels were coupled into the test topology as shown in Figure 7. Minimum Loss Pads (MLPs) were used to combine legacy loading using 75 Ω impedance devices. A variable attenuator was used to adjust relative levels of legacy loading. An additional amplifier was used to compensate for the losses associated with the MLPs and passive devices.

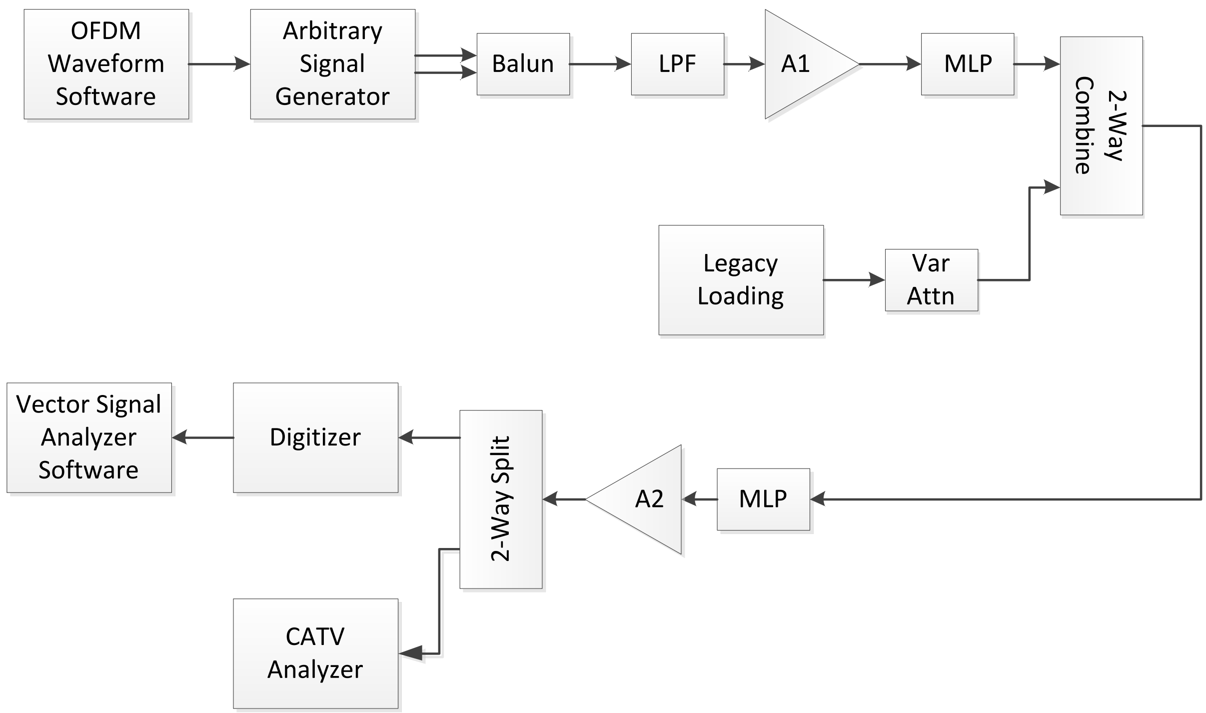

Figure 7 –DOCSIS®3.1 and DOCSIS®3.0 Coexistence Test Topology

Fidelity assessments, via Error Vector Magnitude (EVM) of the DOCSIS®3.1 signal, were made using Vector Signal Analysis software (VSA), shown in Figure 8, while a CATV Analyzer was used to measure Modulation Error Ratio (MER) impact on DOCSIS®3.0 signals using 256-QAM. The EVM of the DOCSIS®3.1 signals without the legacy loading was -53.9 dB for 4K FFT and -54.1 dB for 8K FFT.

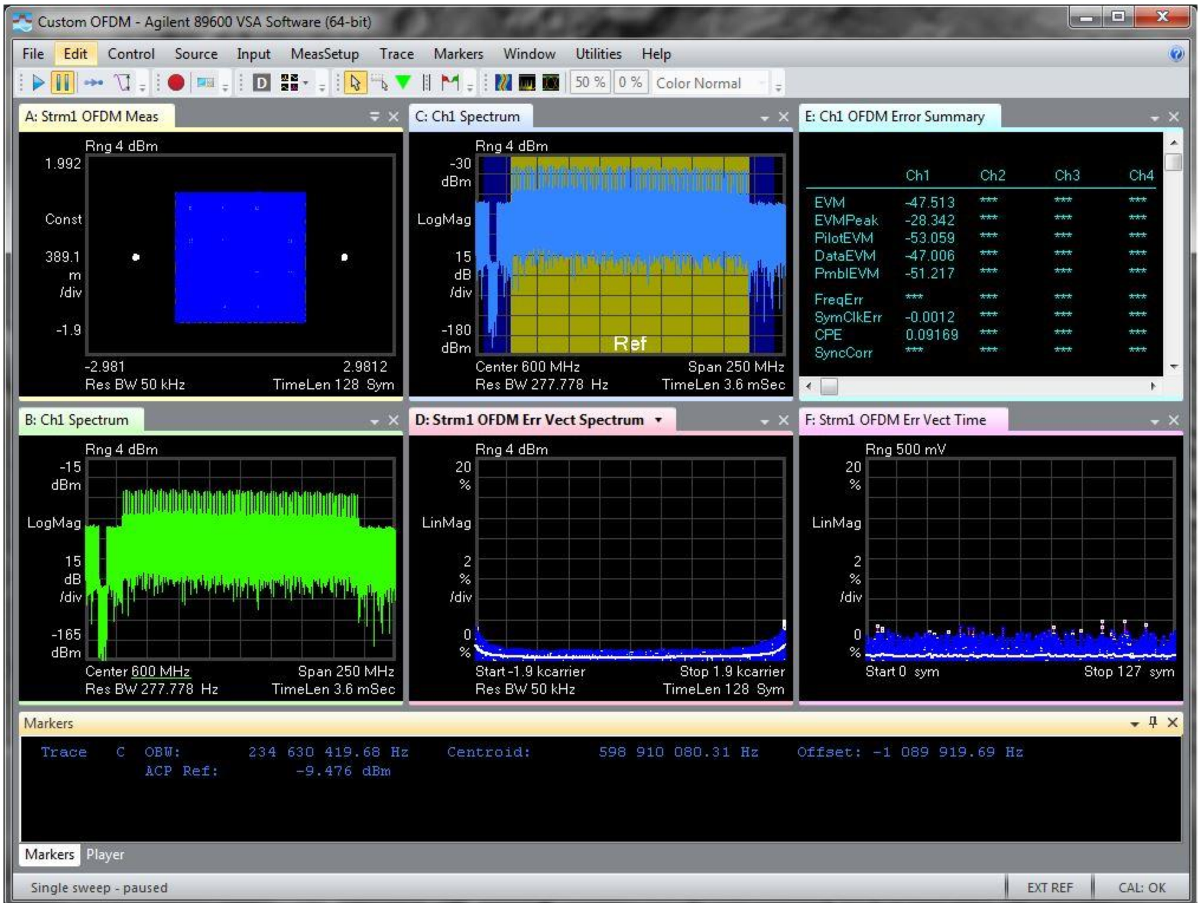

Figure 8 - VSA EVM Measurement of DOCSIS®3.1

The variable attenuator was used to adjust the relative levels of the DOCSIS®3.0 signals such that they were 0, -3, -6, and -9 dB with respect to the DOCSIS®3.1 signal. Previously, we had discussed that the DOCSIS®3.0 levels must be 15 dB lower than the DOCSIS®3.1 signal to ensure 0 dBc on a power-per-hertz basis. The resultant fidelity measurements are summarized for two different windowing settings, RP = 0.3125 and 1.25 µs in Figure 9. As expected, both DOCSIS®3.1 and 1st adjacent 3.0 signals are appreciably impacted, where the RP = 0.3125 µs has a more severe effect on adjacent DOCSIS®3.0 signals than the sharper edge produced by RP = 1.25 µs.

1st, 2nd Adjacent 6 MHz DOCSIS® 3.0 MER (dB) and 192 MHz DOCSIS® 3.1 EVM, Centered at F_c 4K FFT, 4096-QAM, M = 120, CP = 2.5 µs, RP = 0.3125 µs					
Legacy RF Level (dBc)	F_c-105 MHz	F_c-99 MHz	F_c	F_c+99 MHz	F_c+105 MHz
0	48.5	39.3	-42.0	40.8	48.0
-3	47.6	37.8	-43.4	39.0	47.3
-6	46.7	36.2	-45.5	37.4	46.4
-9	45.3	34.2	-47.5	35.3	45.0

1st, 2nd Adjacent 6 MHz DOCSIS® 3.0 MER (dB) and 192 MHz DOCSIS® 3.1 EVM, Centered at F_c 4K FFT, 4096-QAM, M = 120, CP = 2.5 µs, RP = 1.25 µs					
Legacy RF Level (dBc)	F_c-105 MHz	F_c-99 MHz	F_c	F_c+99 MHz	F_c+105 MHz
0	48.5	47.5	-41.6	47.7	48.0
-3	47.8	46.1	-43.4	46.7	47.5
-6	47.1	44.6	-45.3	45.3	46.6
-9	45.6	42.3	-47.2	43.4	45.3

1st, 2nd Adjacent 6 MHz DOCSIS® 3.0 MER (dB) and 192 MHz DOCSIS® 3.1 EVM, Centered at F_c 8K FFT, 4096-QAM, M = 120, CP = 2.5 µs, RP = 0.3125 µs					
Legacy RF Level (dBc)	F_c-105 MHz	F_c-99 MHz	F_c	F_c+99 MHz	F_c+105 MHz
0	48.4	41.4	-43.5	42.9	48.0
-3	47.8	40.0	-46.6	41.5	47.4
-6	46.1	37.2	-47.8	40.0	46.5
-9	45.0	36.1	-49.3	37.8	44.8

1st, 2nd Adjacent 6 MHz DOCSIS® 3.0 MER (dB) and 192 MHz DOCSIS® 3.1 EVM, Centered at F_c 8K FFT, 4096-QAM, M = 120, CP = 2.5 µs, RP = 1.25 µs					
Legacy RF Level (dBc)	F_c-105 MHz	F_c-99 MHz	F_c	F_c+99 MHz	F_c+105 MHz
0	47.7	46.9	-44.1	47.3	47.5
-3	46.8	45.3	-46.3	46.0	46.5
-6	45.6	43.5	-48.2	44.4	45.4
-9	43.4	41.1	-49.8	42.2	43.6

Figure 9 – DOCSIS®3.1 and DOCSIS®3.0 Coexistence Fidelity for 0, -3, -6, and -9 dBc (c = DOCSIS®3.1)

The majority of tests were performed with a CP = 2.5 µs, while all windowing settings were being evaluated. This may not make sense in a typical deployment scenario where a sharp windowing setting may negate the effectiveness of the CP to mitigate channel impairments, such as micro-reflections. A more typical configuration may leverage different CP settings for each windowing setting. In support of this anticipated flexibility, a single test reducing the CP = 1.25 µs for a given windowing setting, RP = 0.3125 µs had a negligible impact on adjacent channel performance, based on the 192 MHz, 4K FFT, 4096-QAM, and M=120 DOCSIS®3.1 signal. This makes sense given that CP does not play a role in shaping the DOCSIS®3.1 signal. Perhaps a more appropriate test may be to evaluate CP effectiveness under varying windowing settings while introducing a constant channel impairment in order to better understand optimal combinations of CP and RP relative to specific channel conditions.

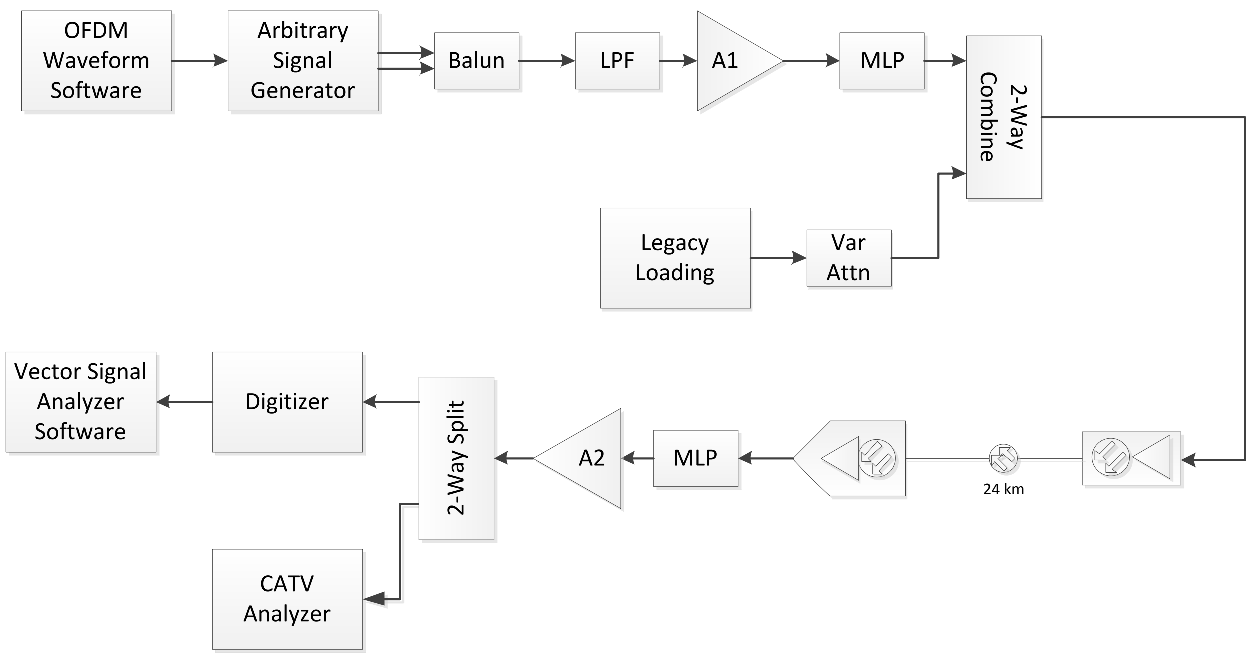

Figure 10 – Optical Link Test Topology

Optical Link Performance

A 1310 nm optical transmitter and node were added to the test topology in Figure 10, with 24 km of fiber in between. The node launch amplifier supported 1 GHz passband, but was only loaded to 700 MHz. The optical link performance was aligned for 696 MHz loading, which included 6 MHz DOCSIS®3.0 signals between 108 MHz and 504 MHz and a 192 MHz DOCSIS®3.1 signal at 600 MHz. Initially, the DOCSIS®3.0 and DOCSIS®3.1 signals were equivalent on a per-hertz basis. The DOCSIS®3.1 signal level was adjusted while fidelity measurements were made on all signals.

Adjacent 6 MHz DOCSIS® 3.0 MER (dB) and 192 MHz DOCSIS® 3.1 EVM 4K FFT, 4096-QAM, M = 120, CP = 2.5 µs, RP = 1.25 µs					
D3.1 RF Level (dBc)	F_c-117 MHz	F_c-111 MHz	F_c-105 MHz	F_c-99 MHz	F_c
0	41.7	41.9	42.0	42.0	-40.0
-3	45.3	45.3	45.3	45.5	-36.7
3	41.8	41.7	41.5	41.0	-41.5
6	35.0	34.6	34.3	33.8	-

Figure 11 - Optical Link Fidelity Summary

A performance summary of the optical link has been included in Figure 11. The 192 MHz DOCSIS®3.1 signal represents approximately 1/3 of the loading. The RF level adjustments reveal that the loading is already starting off too close to the peak performance of the optical link, where 3 dB increase in RF level does not yield a like increase in EVM, and 6 dB drives the optical link into compression. Furthermore, these higher fidelity measurements will require correction factors, specifically regarding the instrument contribution to the measurements provided. The average 4K FFT instrument performance was EVM = -53 dB, which means the instrument could contribute approximately 0.5 dB of measurement error associated with a measurement MER = 43 dB. The practical limitations of today's hardware is something to keep in mind when trying to validate DOCSIS®3.1 requirements.

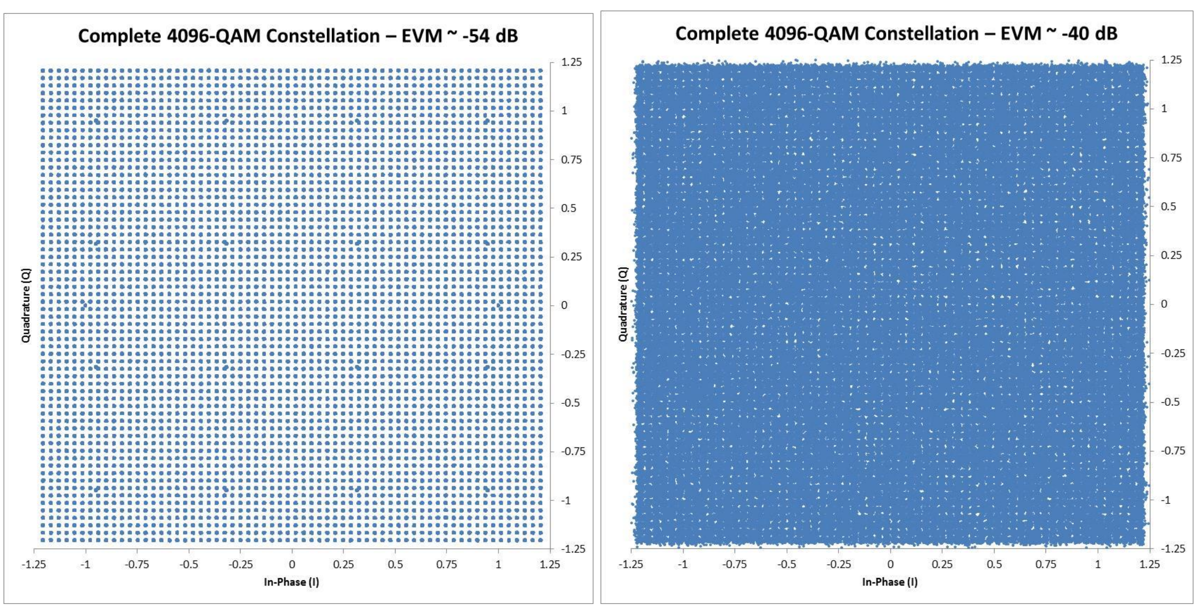

Figure 12 - Full 4096-QAM Constellation, Before and After Optical Link

The measured constellations, both before and after the optical link have been provided in Figure 12. The complete 4096-QAM constellation is difficult to view in its entirety, especially when performance is degraded. Analyzing constellations this large will require some modification of the display to facilitate easy impairment diagnosis traditionally used for lower order modulations.

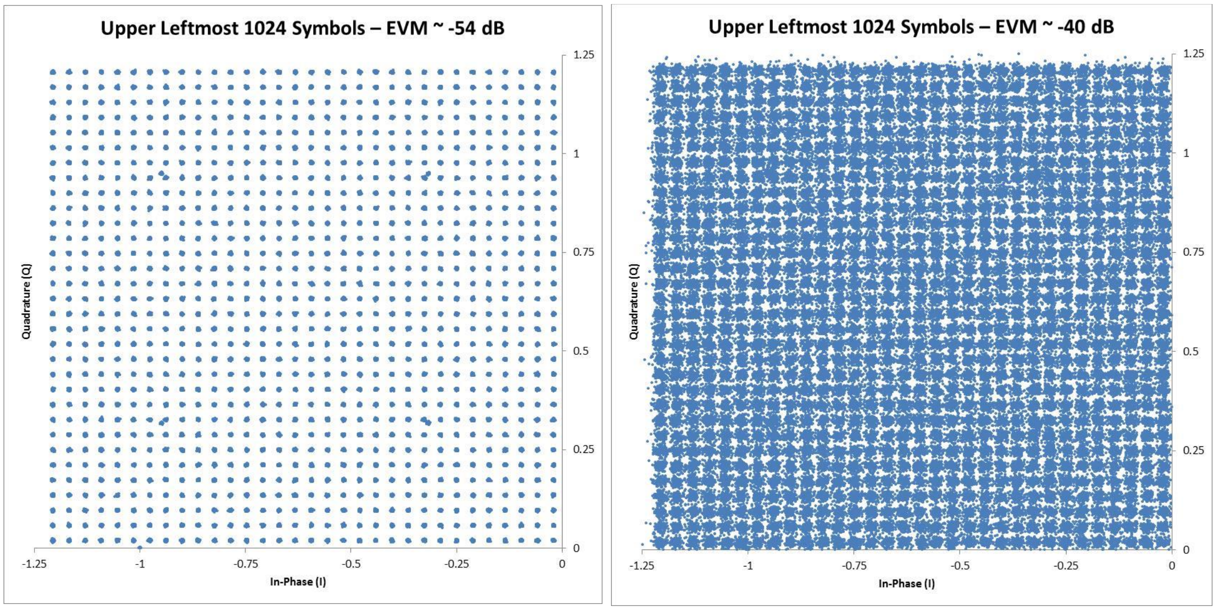

Figure 13 - Upper Leftmost 1024 Symbols of 4096-QAM Constellation, Before and After Optical Link

Zooming into the upper leftmost quadrant, shown in Figure 13, does provide a slightly improved perspective on performance, but still may be challenging for detecting unique impairment effects like phase noise.

Perhaps a better solution would be to color a group of symbols, such as 16 or 64 symbols, with a color associated with a specific value of MER, then repeating the process for the entire constellation assigning a color for each sub-group of symbols. The outcome would be a constellation heat map of sorts, where a single glance would easily distinguish the uniform effect of noise versus the non-uniform effect of phase noise or compression, where the outermost constellation points are impacted more severely than the any of the other symbols.

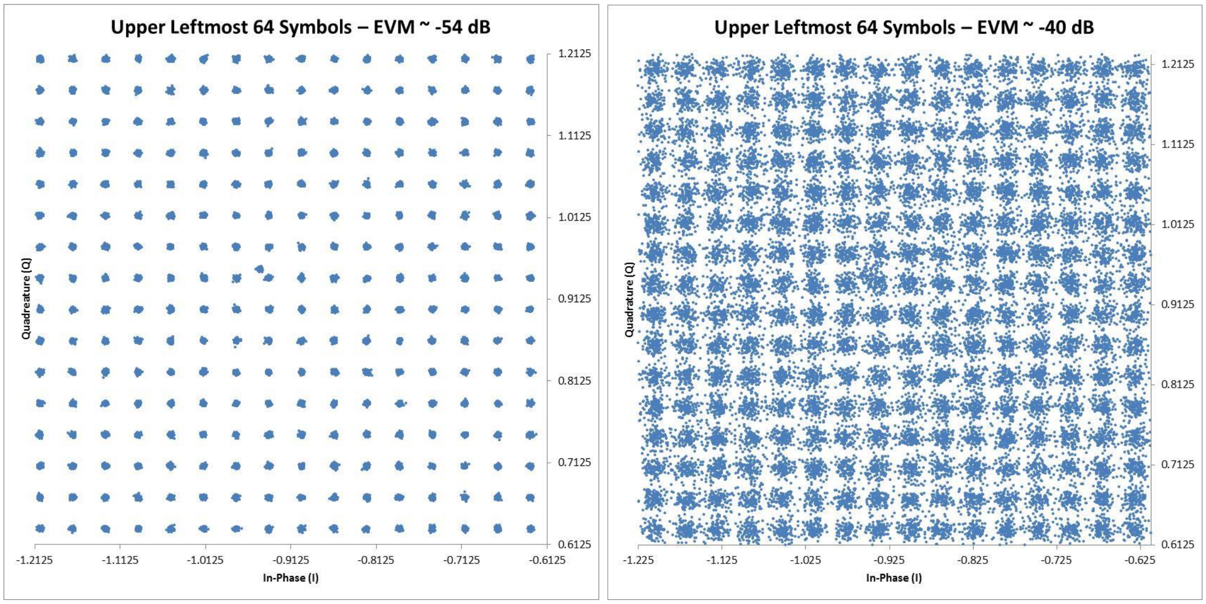

Figure 14 - Upper Leftmost 64 Symbols for 4096-QAM Constellation, Before and After Optical Link

Figure 14 shows only the upper leftmost 64 symbols. At this resolution the effects of the optical link are observed on the right constellation as uniformly impacting all symbols. As a check, the innermost 64 QAM symbols were also included in Figure 15 to verify similar conditions at the center of the constellation. At approximately EVM = -40 dB, uncoded BER = 1.12E-3 where appreciable LDPC error correction would be consumed.

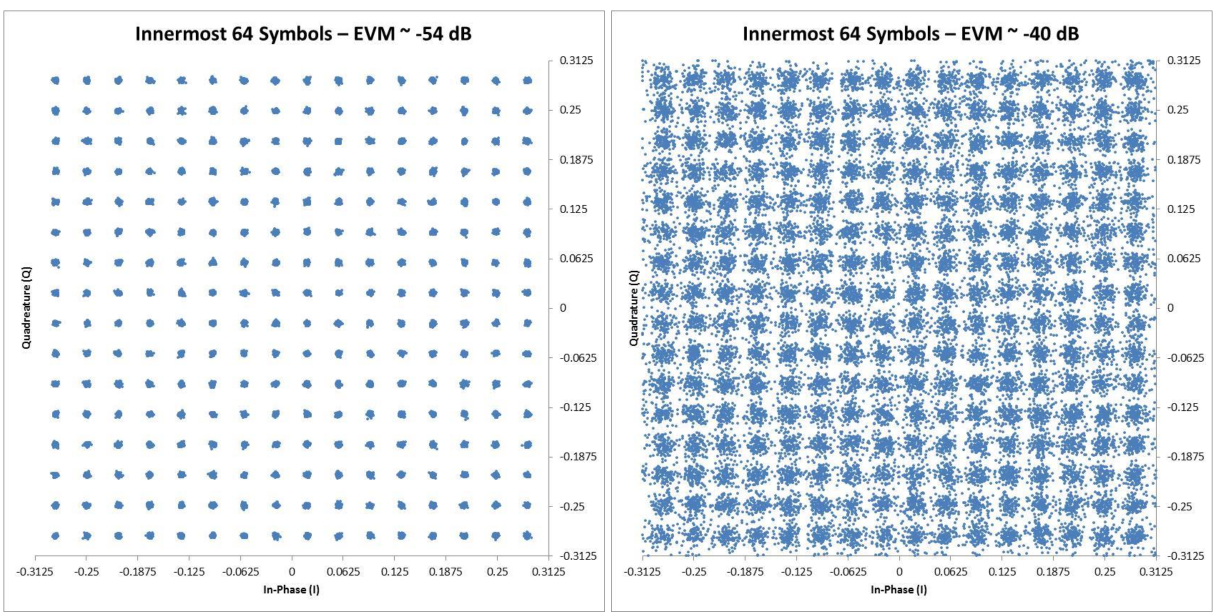

Figure 15 - Innermost 64 Symbols for 4096-QAM Constellation, Before and After Optical Link

Still, EVM = -40 dB does have promise for supporting 4096-QAM using LDPC coding. The DOCSIS 3.1 requirement for the cable modem is that it must meet low packet error criteria for a CNR of 41 dB as long as the input level is -6 dBmV. If we were to apply similar rules used for supporting nearly error-free 256-QAM via [2], where SNR = 34 dB, for BER = 1E-8, then 4096-QAM would require SNR = 46 dB to achieve similar fidelity. If it is possible to achieve the full 10 dB of coding gain predicted in AWGN with DOCSIS 3.1 LDPC, then the link may measure error free after decoding. However, 4096-QAM modulation may still pose challenges operationally; given there would be approximately 4 dB of margin available for the network performance to breathe, and the various non-AWGN impairments contribute more significantly as QAM order increases.

Table 1 - Experimental Setup Materials List

Device	Description	Vendor
M8190A	Arbitrary Waveform Generator	Agilent
M9703A	Digitizer	Agilent
89601B	Vector Signal Analyzer SW	Agilent
N9030A	PXA Spectrum Analyzer	Agilent
N6152A	Digital Cable TV X-series Application	Agilent
M9099	Waveform Creator Application SW	Agilent
5310A	Balun	Picosecond PulseLabs
ZX60-33LN	Amplifier (A1)	Minicircuits
ZX60-2514M	Amplifier (A2)	Minicircuits
SLP-1200	Low Pass Filter	Minicrcuits
GX2-LM1000B	Downstream Optical Transmitter	Motorola
SG4000 Node	Downstream Optical Receiver Node Launch Amplifier	Motorola
SMF-28	24 km Optical Fiber Spool	Corning
E6000	DOCSIS®3.0 Cable Modem Termination System (CMTS)	ARRIS

Test Equipment

Table 1 provides a list of the equipment used in the experimental setups described. An Agilent M8190A 14-bit, 8Gsa/s ARB was used to generate a 192 MHz BW DOCSIS3.1 signal in conjunction with the M9099 Waveform Creator Application Software. The IQ data is digitally up-converted in HW using the Digital Upconversion (DUC) mode, which gives the best signal quality in the desired frequency range.

An Agilent M9703A 12-bit digitizer was used to acquire the wide bandwidth signals with optimized dynamic range from the DUT at a sampling rate of 3.2GS/s.

Agilent's 89601B VSA SW was used to demodulate the DOCSIS 3.1 Signals. The Custom OFDM Modulation Analysis (Option BHF) mode provides the flexibility to perform time and frequency selective measurements over all subcarriers and symbols and report metrics such as EVM.

An Agilent N9030A PXA Spectrum Analyzer in conjunction with the Digital Cable TV X-series Application (N6152A) was used to measure MER of QAM carriers.

SUMMARY

The purpose of this paper was to provide an introduction to DOCSIS®3.1 test capability. This technology is available today and operators and solution providers could begin assessing a variety of DOCSIS®3.1 issues. Ideally this work would identify and resolve potential problems long before a massive deployment of DOCSIS®3.1 devices into customer homes.

Windowing settings will impact adjacent channel performance, in particular the 1st adjacent channel, and to a lesser extent the 2nd adjacent for non-zero windowing settings. How much impact will be dependent upon the window setting, and relative operating levels. Additional relief may come in the form of excluded subcarriers, lower order modulation on the data sub carriers located towards the edges (Mixed Modulation), or enhanced robustness of adjacent SC-QAMs. For example, only video signals with a longer interleaver depth may be used at the 1st adjacent carrier to a DOCSIS®3.1 signal.

Our testing suggests that an N+0 architecture can support 4096-QAM without any optimization of the signal profile or of the sample network, , when supported by LDPC coding. 4096-QAM, with its 12 bits per symbol, represents a significant gain in channel efficiency, it is 50% more efficient than 256-QAM. The question is, can the potential capacity be mined effectively by optimally leveraging DOCSIS®3.1 functionality. This needs to be explored more deeply so that operators can leverage the most optimal DOCSIS®3.1 PHY configurations possible for their specific network operating scenarios.

Our intent was merely to prove that the industry can be exploring optimal DOCSIS®3.1 deployment scenarios now. There are many tests, beyond what has been described in this paper that will help operators and solution providers in this regard. The following test case scenarios are a short-term to-do list for the authors to pursue after this paper has been written.

MoCA Coexistence

This testing examines issues with localizing DOCSIS®3.1 signaling adjacent to MoCA signaling within the home. Depending on the home network, MoCA signal levels may be running appreciably higher than DOCSIS®3.1. Identification of optimal center frequency placement of both would be provided.

CP Effectiveness

This testing examines the effectiveness of CP in the presence of varying linear distortion, as well capturing any impact of varying windowing settings. Identification of optimal CP, RP combinations would be provided.

Upstream Spectrum Allocation Implications

Examines any differences in PSD with equivalent legacy upstream DOCSIS®3.0 operating in 54-85 MHz. This energy may ingress into downstream receivers located within the home via poor isolation splitter and co-located DOCSIS®3.1 devices. If there is a higher expectation for ingress energy, then additional steps may need to be taken to protect legacy home devices, such as notch filters to block additional harmful RF. This work would identify any delta in ingress potential for a representative set of DOCSIS®3.1 configurations.

Mixed Modulation of Data Subcarriers

The testing explored in this paper exclusively uses uniform modulation on all data subcarriers. Mixed Modulation scenarios could be explored where data sub carriers situated near the adjacent SC-QAM carriers can be modulated at lower modulation rate to ensure error free performance.

Modulation Level Guidance

Optimal modulation level guidance for a diverse set of HFC optical and RF scenarios and channel conditions. Measured data support for theoretical expectations would be provided.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Neil Spence of Comcast. His assistance with many of the laboratory setups, configurations, and interconnections with legacy services and HFC equipment is very much appreciated.

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