DIGITAL DUE DILIGENCE FOR THE UPSTREAM TOOLBOX

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Abstract

As upstream services have become more sophisticated, so too has the technology that supports it. Simple, robust modems were developed to enable STB communications. Later, more sophisticated DOCSIS® modems complemented these for high-speed data services. Similarly, in the plant, return optics adequately supported the robust physical layer of STB communications using low-cost Fabry-Perot (FP) lasers. For DOCSIS®, laser technology advanced to meet the new challenges. This included higher power FP lasers, isolation techniques to mitigate noise, and the introduction of Distributed Feedback (DFB) lasers into the return transmitter portfolio.

DOCSIS®, of course, has continued to advance. Deployment of DOCSIS® 3.0 began in earnest in 2010 and will continue through 2011 and beyond. A key challenge is the demands that this places on the return channel – yet more sensitive modulation of wider bandwidth, the addition of new DOCSIS® channels, and potentially the addition of new spectrum. Together, it adds up to a much more aggressive use of available dynamic range. Nonetheless, the promise of DOCSIS® 3.0 must be met upstream for consumers whose speed and QoE expectations continue to rise. Next generation systems also may ultimately impose additional high performance requirements on the HFC upstream.

As the deployments of DOCSIS® 3.0 have increased, so too has new confusion over technology options to cost-effectively support this new DOCSIS® era. The new crossroads, replacing the debate over FP and DFB lasers, is around DFB technology options and Digital Return systems. Digital Return, developed now over ten years ago, offers an intriguing set of benefits that all MSOs should consider when planning future HFC migration. However, it also comes with some important constraints. This paper will take a comprehensive look at the use of DFBs and Digital Return technologies for supporting DOCSIS® and new potential upstream requirements in the context of anticipated traffic growth and expansion. We will delve into the comparable digital return parameters that will help operators compare these systems to the capabilities of their analog counterparts, as well as among the various incarnations of Digital Return systems themselves. Finally, we will weigh the pros and cons of each and provide recommendations.

UPSTREAM GROWTH MANAGEMENT

Quantifying Traffic Growth

DOCSIS service rates have continued to increase with time, as users find more bandwidth-consumptive ways to enhance their Internet experience. The applications driving the growth vary. Because of the futility in trying to pick the next "killer app," analysis of Internet traffic trends often rely on "Nielsen's Law" which quantifies consumer traffic demand as a function of time. Most importantly, the law recognizes that the unmistakable historical growth trend over the life of mass Internet access has a compounding nature to it. There was a day when the parallel to interest-bearing savings accounts resonated better than it does in 2011, but it is that same principle at work – a multiplication each year by a value we refer to as Compound Annual Growth Rate, or CAGR. While each year the actual growth rate varies, over a number of years the CAGR trend can be smoothed into an average which can be used to portend future requirements. Because of the sensitivity of long-term end results to the CAGR used, a strong sense of past behavior is valuable. For the same reason, a mindset that errs on the side of aggressive ensures being prepared with the proper network resources to handle growth and manage long-term capex spending levels. Or, conversely, to avoid not being able to meet the demands of new traffic growth.

Figure 1 shows a sample of growth projection using CAGR analysis. It shows three CAGR trends – 30%, 40%, 50% – and three thresholds of upstream throughput for 5-42 MHz systems – 60 Mbps, 100 Mbps, and 150 Mbps. The chart represents a serving group aggregate, so along the way service group splitting is factored in, effectively doubling the average bandwidth per subscriber. The latter two represent rough estimates of the maximum available in a 5-42 MHz system for A-TDMA (only) and A-TDMA + S-CDMA systems.

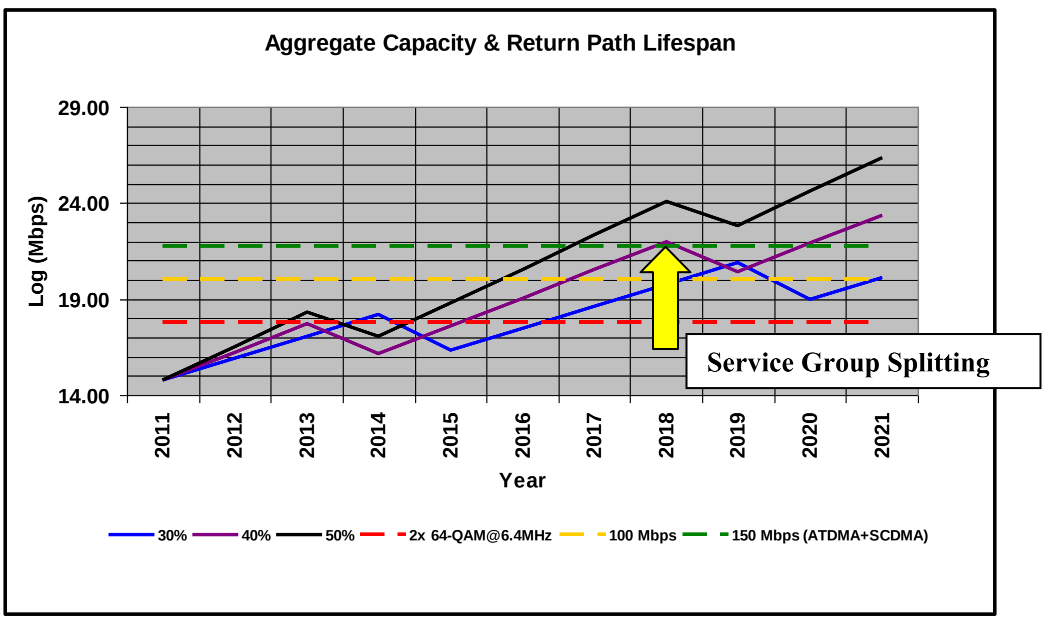

Figure 1 – Use of CAGR to Project Future Upstream Traffic Needs

A key point of Figure 1 is to recognize that it projects that next generation upstream technology will be required at some point in the near future lest available bandwidth be exhausted. The key question of "when" is a matter of CAGR, current level of service (starting point of plot), service group size, and efficiency of the use of the return bandwidth. For example, at 50% CAGR (black) using A-TDMA only (yellow), the upstream becomes fully consumed in 4.5 years with one service group split. At 30% CAGR – closer to actual for the past couple of years – it is exhausted in roughly seven years. For more details on traffic growth and considerations, please refer to [1], [2], and [3].

A few important comments should be made about use of Figure 1. First, it represents demand-based growth beginning with aggregate "demand" being what is offered today. Latent unused capacity of today's services – how far below alarm thresholds as a measure, for example – adds margin to the calculation. Second, and perhaps more important, is that demand is but one driver of new service rates. Other market forces also intervene. There may be a competitive need to offer higher peak rates and deliver averages that provide a competitive level of experience outside of mathematical demand. Limitations of today's available bandwidth come into play in both total capacity and peak rates long-term.

Finally, while upstream channel bonding (UCB) provides the key tool necessary to increase peak service rate offerings, it is important to recognize that bonding does nothing inherently to improve total upstream capacity. In implementation, UCB may involve lighting up new return spectrum that was not previously utilized. However, this is not new capacity enabled by UCB. It is merely latent capacity being exploited because there is available upstream spectrum – with or without UCB.

Where Do We Find the Bits?

Because of the potential to exhaust capacity and the upstream limitations on peak service rates, even with bonded channels, the next generation of upstream technology must consider the limitations of the current architecture and how to overcome them. Can they handle the inevitable traffic growth ahead? Can they support more sophisticated modulation profiles that create more bandwidth efficient use of upstream spectrum? Can they support the addition of new spectrum itself? These are the critical next generation system items that we look to address as we examine future upstream technologies and provide more bit-per-second

Theoretical capacity instructs us on where to go to find more bits. Capacity, C, of an additive Gaussian white noise-corrupted channel relies on two variables through a very simple equation. The variables are bandwidth available (BW) and Signal-to-Noise Ratio (SNR). The relationship is Shannon's well-known capacity theorem,

$$C = BW \bullet \text{Log}_2\,(1+SNR) \qquad (1)$$

Note SNR is in linear (not dB) format in (1). While we certainly have more than this type of noise to deal with on the return path, it is the starting point of any attempt to add new bits per second. Other receiver technologies are designed to manage additional impairments (equalizers, ingress cancellation, forward error correction, spreading).

The addition of upstream bandwidth has been part of industry discussion for many years. Once DOCSIS services grew to be widespread, it became clear that the bottleneck of 5-42 MHz could have long term implications to the traditional forward/return frequency domain duplex (FDD) architecture. What was once a "long-term" proposition is now winding down in quantifiable ways, as shown in Figure 1. Tools exist to further optimize 5-42 MHz, in particular 64-QAM and S-CDMA. While these will indeed buy some time, ultimately the limit itself is that it is only 37 MHz of spectrum, as equation (1) points out. The resulting industry discussion has been around the various split architectures used or specified elsewhere, such as the European split using 65 MHz of return, and the DOCSIS 3.0 identification of the N-Split of 85 MHz. There also has been industry discussion about an extended return split, foreseeing a goal to support a potential 1 Gbps of capacity and/or service rate. Some proposals suggest that this may be most easily done, and with the least disruption, by exploiting unused spectrum on the coax above the forward band in a triplex architecture. The bulk of our discussion will be return path growth and technologies associated with low/high diplex arrangements.

A way to use any bandwidth most effectively is to provide the highest SNR possible, per (1). More SNR means more bandwidth efficient modulation profiles can be used. When this is the case, the digital symbols can be more tightly packed within the same average transmit power because the risk of incorrect decision making due to noise has decreased. The DOCSIS specification sets a minimum for the upstream at 25 dB. Table 1 compares what this SNR means to theoretical capacity versus what the DOCSIS physical layer transport rate delivers assuming 64-QAM. 64-QAM itself represents an important step in modulation evolution of the return path, increasing by 50% what the return could do relative to the 16-QAM limitations of first generation DOCSIS. Table 1 also compiles theoretical rates as we consider variations to the diplex split for future growth.

Maximum Capacity for Each Bandwidth

Return Bandwidth	DOCSIS	Maximum Capacity
5-42 MHz	150 Mbps	300 Mbps
5-65 MHz	270 Mbps	500 Mbps
5-85 MHz	360 Mbps	650 Mbps
5-200 MHz	900 Mbps	1.6 Gbps

Table 1 – Bandwidth, DOCSIS, and Capacity Limitations

It is clear that there is room between the DOCSIS transport rate, lowered further by forward error correction (FEC) overhead, and theory. While reaching theoretical capacity is impractical, advances in communications and information theory in the 10+ years since DOCSIS emerged have continued to close the gap. What has become clear using modern DOCSIS and HFC technology is that another step closer towards channel capacity can be enabled with additional evolution of the modulation profile to higher density constellations such as 128-QAM and 256-QAM [4].

The relationship between SNR, offering the potential for new bits per second, and modulation efficiency is observed most readily in Figure 2.

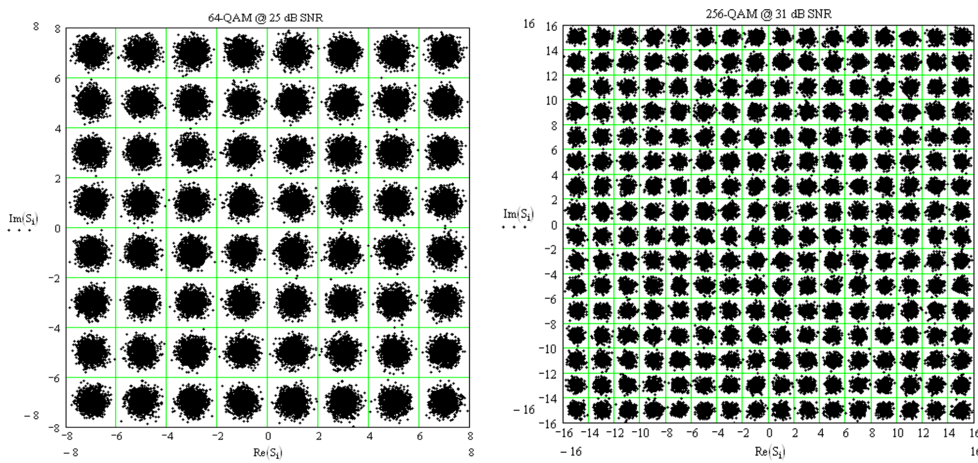

Figure 2 – 64-QAM @ 25 dB SNR and 256-QAM @ 31 dB SNR

The similarity of the relative relationship of the symbol "clouds" to the decision boundaries is readily apparent. Clearly, in absolute terms, the 256-QAM symbols could be misidentified with less noise power, and the amount less is precisely the 6 dB between these two constellations shown at SNRs of 25 dB and 31 dB. The actual receiver benefits from FEC and uses sequence detection algorithms, but Figure 2 properly identifies the obstacles to getting closer to capacity via increasing the modulation efficiency.

The evolution of the bandwidth allocated to return spectrum, and in the physical layer techniques such as advanced modulation are the tools by which new upstream capacity will be extracted, as capacity equation (1) easily instructs us. Given the inevitable growth of traffic, both of these variables become important elements for the evolution of any new upstream technologies. Each will be discussed, along with other practical and legacy hurdles, in the sections that follow.

UPSTREAM LINK COMPARISONS

Analog Return Solutions

Analog laser technology provides a low cost link connection that is expandable as bandwidth needs increase, and interoperable with a wide range of cable plant equipment. DFB lasers are widely available covering an array of optical output power levels and ITU grid CWDM plus DWDM wavelength options. DFB laser packaging and internal matching networks are typically capable of contiguous bandwidth exceeding 3 GHz. In practice, the usable bandwidth for upstream analog transmitters is usually determined by the RF drive amplification gain blocks and added filters used to reduce ingress noise or increase isolation between forward and return path signals. The RF driver hybrids and MMIC's in most legacy upstream transmitters have upper frequency capability of 150 to 200 MHz. The node diplex filter is used to establish the upper edge of the active return bandwidth split. In some cases changing the diplexer is all that is needed to expand the upstream capacity.

SNR for a DFB enabled upstream link is determined by a combination of the inherent laser noise or RIN (Relative Intensity Noise) caused by spontaneous non-coherent laser emissions, along with optical output launch level and the optical modulation index (OMI) of the RF drive signals. At the Head End / Hub side of the link the optical receiver noise performance also contributes to link SNR.

The reach limit for an analog link is determined by the optical link budget. This includes the laser output level, fiber loss, and passive losses due to muxing multiple upstream wavelengths onto a common fiber plus demuxing at the receiver. The upstream optical receiver sensitivity is a critical element in the link. Typical PIN diode detectors that are widely deployed in legacy Hub receiver platforms have a lower optical sensitivity limit of -16 to -18 dBm. Newer receiver designs have extended this threshold to > -26 dBm achieved by improving the detector EINC (equivalent input noise current) and limiting the total bandwidth of the receiver.

The different analog return solutions that are available represent a range of link reach capability. Table 2 illustrates a few common configuration examples and the link budget reach for each case. The reach capability of these options cover the characteristic maximum link distances needed for the majority of network serving area deployments by the major MSO's.

Band	Link Design	Reach
1310	P2P	50 km
1550	8λ CWDM	50 km
1550	8λ DWDM	80+ km*

* Reach extended with EDFA

Table 2 – Wavelength vs Reach

One of the main advantages of analog return systems is conversely identified as its biggest disadvantage. Analog transport allows the interoperable use of a broad assortment of equipment from different vendors since the RF upstream bandwidth is modulated onto the laser without manipulation. This allows cable operators to maintain existing, multiple source networks and acquired properties without the need to rework the Hub and node equipment. The downside of this flexibility is that laser transmitter gain and modulation level (OMI) varies from manufacturer to manufacturer. This requires the cable operator to verify and adjust, if necessary, the return path link gain during the initial node installation and alignment.

Digital Return Solutions

The advantages of digitizing data streams to provide improved signal to noise performance and extended reach are well known and certainly apply to Digital Return (DR) solutions for HFC upstream transport. Digital Return equipment has been successfully deployed for several years, enabling long link networks that are beyond the reach of analog lasers and without the need for expensive O-E-O regeneration.

The bandwidth capability of a digital return transmitter is determined by the system sampling rate and the data rate capability of the selected laser. Nyquist theorem dictates a minimum sampling rate of 2X the highest frequency or 2X the bandwidth for IF systems. This minimum number of samples is multiplied by the bit sample rate of the A/D chip set for each stream that will be transported.

Example: 5 to 42 MHz BW, 12 bit A/D, 2 channel transmitter (2 RF streams)

The minimum sample rate needed for this example is

$(2 * 42) * 12 * 2 = 2.016$ Gbps

In order to transport this data rate with some margin a digital laser with bandwidth capability of at least 2.5 Gbps is needed. Lasers with this and similar data rates are available in a wide range of form factors including pluggable SFP optics covering the full spectrum of ITU grid wavelengths.

SNR capability of a channel in all digital networks is best represented through use of Noise Power Ratio (NPR). This is basically a measurement of the noise floor rise of a vacant (RF) channel resulting from noise and distortion generated by the other channels of a fully loaded system. All digital return systems in use today are based on Time Division Multiplexing (TDM). As a result, the dynamic range performance of the selected A/D chip set as well as the bit sampling rate chosen for the design will determine the achievable NPR. Figure 3 shows the theoretical NPR peak and dynamic range differences corresponding to changes in the bit rate resolution of the A/D.

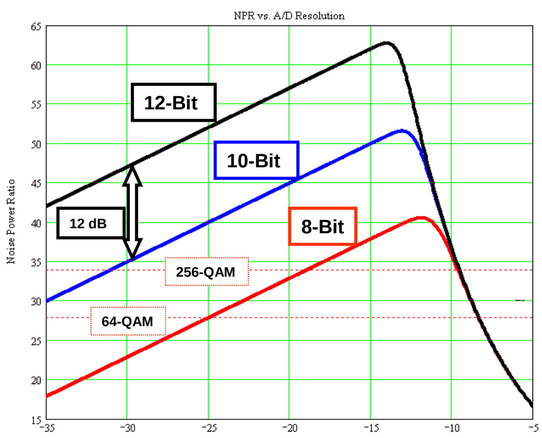

Figure 3 – NPR vs. A/D Resolution for Digital Returns

Digital return systems are not affected by optical noise from an NPR perspective for a properly functioning link. Digital transport is bit-error limited according to well-understood rules for the optical SNR of binary transport. Error correction makes the optical links themselves very robust. The result is digital return transmissions can be amplified over long link spans of 100 km or more with no impact on NPR performance.

A drawback for digital return systems is that the design implementation is different for every manufacturer. The consequence is that each vendors design becomes de-facto proprietary and not interoperable with other existing digital return equipment. This same disadvantage is conversely considered one of the main advantages of digital return by most cable operators. Since the DR transmitter and receiver at each end of the link are matched by design there is no uncertainty about the link gain parameters so digital return is considered to be a Plug-N-Play technology.

UPSTREAM CAPACITY PLANNING FOR THE FUTURE

Upstream data rate usage today is very asymmetrical when compared to downstream data rates. This is primarily due to the popularity of VOD content and services such as Netflix movie downloads. This trend is expected to continue for the foreseeable future. However, upstream rates are still increasing at a steady rate and with the deployment of DOCSIS® 3.0 the usable portion of the current 5 to 42 MHz return bandwidth will eventually be exhausted, and can be quantified by analysis such as shown in Figure 1. The earlier CAGR example predicted this could happen within five years, and perhaps sooner if a new smart CPE device or consumer application takes hold.

There are a number of options that the cable operator can choose to meet the potential data capacity requirements of their customers. As pointed out by equation (1), these boil down to two primary avenues – increasing RF bandwidth, or moving to a higher QAM modulation format can provide significant improvements in bandwidth efficiency. Options such as creating the new 1 Gbps symmetrical return band above the active downstream spectrum in a triplex architecture, or moving to a non-DOCSIS modulation format are still in the early study phase. In this segment we will explore the effect of the near term options on both analog and digital return systems.

Impact of Upstream Bandwidth Expansion

RF bandwidth expansion (mid split, high split) is a potential solution that is available today or in the near future. Table 1 (repeated below for convenience) quantified the maximum data rates for several of these RF bandwidth split cases comparing current DOCSIS 3.0 rates and the upper limit predicted by the Shannon capacity theorem.

Maximum Capacity for Each Bandwidth

Return Bandwidth	DOCSIS	Maximum Capacity
5-42 MHz	150 Mbps	300 Mbps
5-65 MHz	270 Mbps	500 Mbps
5-85 MHz	360 Mbps	650 Mbps
5-200 MHz	900 Mbps	1.6 Gbps

*DOCSIS Capacity @ 64-QAM. Assumes 25 dB minimum SNR limit

As described in the overview of analog systems, analog return lasers and RF driver stages already accommodate these bandwidth extension options with minimum if any changes needed to existing deployed transmitter modules or Hub receivers. For digital return the sampling rate and laser data rate requirements for a typical 2X RF stream transmitter become increasingly difficult and expensive as the bandwidth increases. Using the same back of the envelope calculation as shown previously, Table 3 shows the optical line rates resulting from various combinations of A/D resolution and RF upstream bandwidth.

Return BW (MHz)	10 bit A/D Sample Rate	12 bit A/D Sample Rate	Laser BW Requirement
5 - 42	1.90 Gbps	2.28 Gbps	2.5 Gbps
5 - 85	3.60 Gbps	4.32 Gbps	4.5 Gbps
5 - 125	5.20 Gbps	6.24 Gbps	8 Gbps
5 - 200	8.40 Gbps	10.08 Gbps	12 Gbps

Table 3 – Digital Return: A/D Resolution, Upstream BW, and Optical Link Bit Rate

The implication here is that each incremental increase in bandwidth will require a new design iteration replacement of the current DR transmitter / receiver pair. The A/D and laser cost also increases with each iteration, driven by the increasingly higher sampling speeds.

Another factor that must be considered when expanding the upstream bandwidth is the noise increase due to the larger bandwidth and the corresponding decrease in NPR / SNR. Figure 4 and Table 4 quantify the NPR reduction resulting from the expanded bandwidth for analog optical return paths. Figure 4 shows modeled NPR performance of DFB return links, using minimum specified laser and return path receiver (RPR) performance. Table 4 shows explicitly the loss in dB attributed to uniformly sharing the fixed laser drive power across a broader signal bandwidth of constant noise power density.

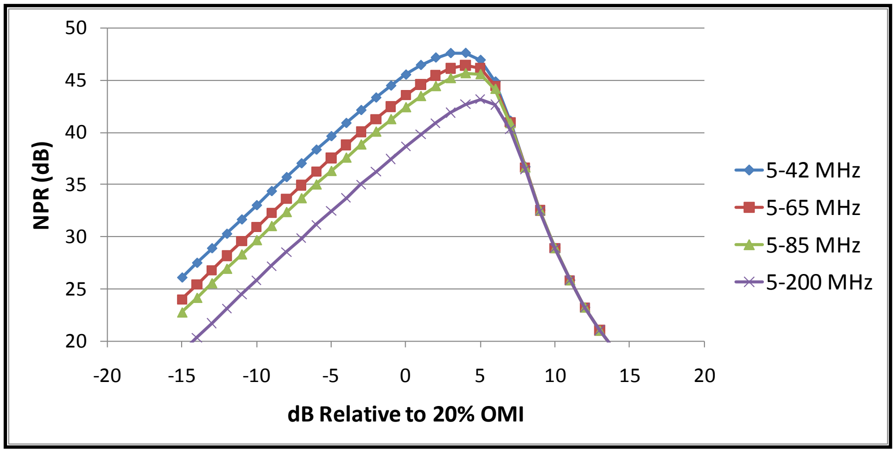

Figure 4 – Calculated NPR versus BW for Upstream DFB Links

Bandwidth Increase	NPR(SNR) Reduction
5-42 to 5-65	2.10 dB
5-42 to 5-85	3.35 dB
5-42 to 5-200	7.22 dB

Table 4 - NPR Loss vs BW

For Analog return systems the reduction in NPR due to expanded bandwidth could potentially be compensated with the substitution of a higher output power laser and/or by restricting the HFC cascade depth.

For digital returns, an increase in bandwidth often comes with a penalty to the A/D performance in terms of Effective Number of Bits (ENOB). This loss of NPR, combined with the desire to support more bandwidth efficient modulations, may dictate the use of a 12-bit A/D. In addition, any subsequent DSP operations outside the core function of the SerDes become more difficult and costly to implement in real time.

For a comparative perspective of current analog and digital technology, Figure 5 shows measured typical NPR performance of a 2 mw DFB-RPR return of nominal link length. A measured DR system using (post-processed) 10-bits of transport is shown overlaid, in each case using a 65 MHz (European) split. Note that there is link length dependence for the analog link, and the associated wavelength vs loss dependence. These variables are not drivers of NPR performance for optical fiber lengths within the digital optical link budget of the DR system, such as is commonly the case for HFC applications. Nonetheless, this data confirms the general equivalence of a digital return system achieving a full ten bits of performance to nominally performing higher power DFB returns over average HFC link lengths. It is apparent also how both technologies show comfortable margin to the higher order QAM thresholds shown.

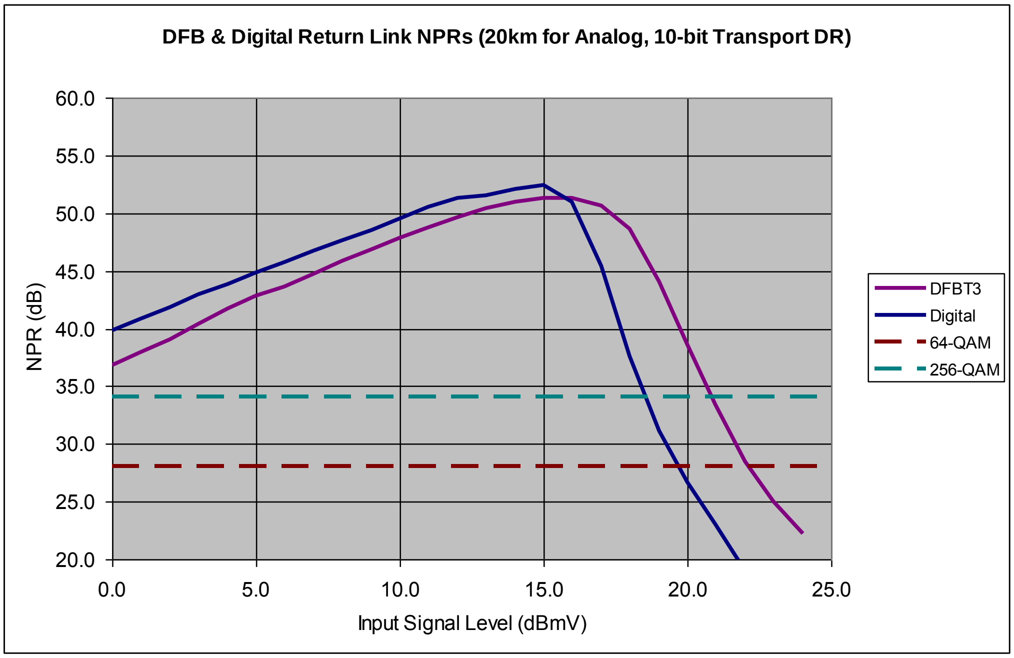

Figure 5 – Typical NPR Performance, Existing DFB and Digital Returns (65 MHz)

Impact of Higher Modulation Formats

The CableLabs DOCSIS 2.0® specification defined and expanded the approved modulation formats for downstream and upstream transport. In the upstream QPSK through 64-QAM are the accepted formats. For a single data channel 64-QAM provides roughly 28 Mbps data capacity (6.4 MHz channel). The DOCSIS 3.0 standard defined channel bonding to allow even higher data throughput rates. With four bonded 6.4 MHz channels of 64-QAM it is now possible to provide symmetric 100 Mbps data service to business and premium customers. However, as discussed, bonding does not add *new* capacity. In fact, use of bonding to create higher peak rates channels may also exhaust the available clean spectrum in many systems.

An alternative solution to RF bandwidth expansion for increasing data capacity is to move to yet higher order QAM modulations, as Table 1 indicates should be possible. While DOCSIS does not yet recognize modulation formats higher than 64-QAM for upstream transport, it is generally known in the industry that the most commonly used CMTS and cable modem DOCSIS chip sets already have these higher QAM formats built in. The benefit of 256-QAM modulation over 64-QAM is a 33% increase in data throughput for the same channel bandwidth. As described earlier and shown in Figure 2, the drawback of 256-QAM is the 6 dB higher SNR needed. Table 5 shows the 1e-8 BER-SNR relationships and the range of practical operating margins to compensate for HFC system variations for each of the higher order modulations we have discussed. The orders of M-QAM are necessary steps to delivering more bits per second on the return path, closer to full capacity, and support the associated traffic growth.

M-QAM	SNR (dB) Docsis Min	SNR (dB) Typ System
64	28	30 - 32
128	31	34 - 36
256	34	38 - 40

Table 5 – SNR Relationships for Higher Order M-QAM Formats

On the HFC plant side of the equation, the return transmitter laser peak power (NPR) and dynamic range is critical to providing the headroom needed for multi-channel loading and higher modulation rates. As discussed previously, the same DFB or DR solution enhancements suggested for expanded bandwidth would also apply in the case of providing the margin needed for higher order modulation. The higher SNR requirement for 256-QAM may also impose a limit to amplifier cascade depth, such as no more than N+3.

With high-performance HFC return paths in place, the noise performance of the CMTS upstream receiver becomes critical to making higher order modulation successful. A recent demonstration by Motorola and Cox Communications [4] used new generation CMTS receiver modules that provide significantly lower noise figure which increased usable dynamic range by greater than 10 dB. Taking advantage of this enhancement, the analog DFB, N+3 link was loaded with three 6.4 MHz, 256-QAM channels plus additional S-CDMA channels to fill the 5 to 42 MHz bandwidth, providing 141 Mbps of usable data capacity. A further test demonstrated the potential of 85 MHz bandwidth expansion by showing that with modified modems that support 85 MHz return and 256-QAM channel upstream loading a record breaking 400+ Mbps of upstream data capacity could be achieved.

Figure 6 shows the combined NPR performance of analog HFC optics and new CMTS receivers. Both legacy DOCSIS receivers and new generation cards are shown. Two important conclusions can be drawn from Figure 6. First, legacy DOCSIS equipment, while capable of 64-QAM when combined with high performance return optics, is not well-suited to supporting 256-QAM upstream, as expected. This is evident from the red trace in Figure 6 relative to the 256-QAM threshold (purple). The additional 6 dB required is simply not available with any reasonable operating margin. The second key point, conversely, is that the *new* generation of CMTS receivers, over the same high performance DFB, *can* support 256-QAM with plenty of operating margin to be practical. The newly considered 42-85 MHz spectrum tends to be considerably pure compared to the 5-42 MHz band, and in particular the 5-20 MHz band. This makes 256-QAM in this band yet more robust.

A final related point is that, theoretically, digital return optics should also be capable of supporting 256-QAM on 85 MHz return architectures. Figures 3 and 5 suggest this prospect. However, 85 MHz DR systems are still in development, so verification of this projection is not possible at this stage. This once again points to the issues of upgradability for DR systems. While analog returns can relatively easily be repurposed for extended bandwidth returns, DR systems typically require design iterations to do so due to A/D converter and sampling rate impacts of added RF bandwidth.

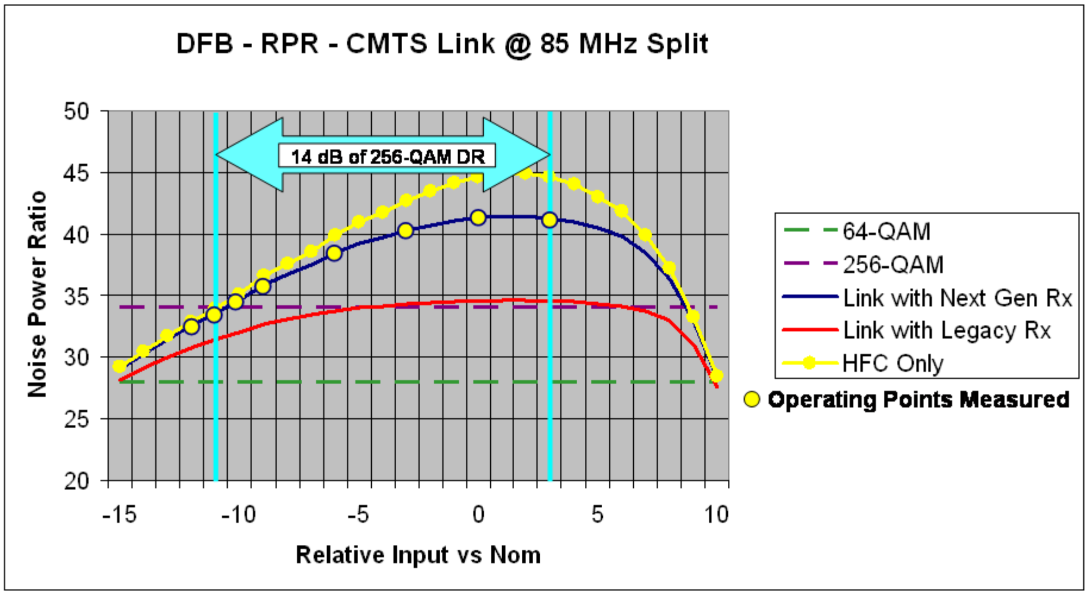

Figure 6 – HFC + CMTS NPR @ 85 MHz Split

Further testing of digital return systems is planned, although at this time only 5-42 MHz or 5-65 MHz digital return hardware is available. Actual deployments of 85 MHz mid-split systems are for the most part only planning exercises since many operators still maintain a basic analog tier of downstream video channels and commercially available cable modems supporting mid splits are not yet available. This is expected to change starting sometime in 2012.

Conclusions

Both analog and digital return laser transmitter technology are well suited to provide the wavelength option flexibility, bandwidth, and noise performance needed for the vast majority of current D3.0 deployments. This parity in operational performance and the closing gap in cost differential between the two technologies is expected to continue into the near future even as some cable operators take advantage of the mid-split upstream bandwidth option defined in the D3.0 specification.

As upstream bandwidth needs continue to grow the differences between analog and digital become more noticeable. DFB analog laser transmitters have considerable built in RF bandwidth expansion and dynamic range capability. Digital return transmitter designs, and in some cases, the matching digital receiver, must be replaced as a result of A/D chip set changes to meet sampling rate requirements. As bandwidth expands past the 85 MHz mid-split, the laser data rate requirements for digital return transmission could drive much higher costs compared to current designs and especially in comparison to analog DFB laser alternatives. Digital return solutions for 1 Gbps out of band proposals such as the above 1 GHz top split approach are not feasible due to both the A/D and laser requirements in the current designs.

Increasing data capacity by using a higher order modulation format while maintaining existing HFC upstream bandwidth allocations at 5–42 MHz to 5–85 MHz would appear to be the most cost effective potential solution for new and existing cable network deployments. New generation CMTS equipment and modems are becoming available that will make this option possible in the relatively near future. The experience gained deploying D3.0 today will allow cable operators to take advantage of 256-QAM upstream transmission if it becomes approved for use in the future. In this case the higher SNR requirements for 256-QAM may exceed the peak and dynamic range capability of lower cost 8 and 10 bit digital return solutions that are adequate for current HFC systems.

Except for extremely long reach links, DFB analog return path transmitters and receivers have the flexibility to meet a wide range of possible future data capacity enhancements in the upstream network. Technology to make analog return plug-n-play is possible but at the cost of making these systems completely proprietary and not interoperable with other deployed equipment.

Acknowledgements

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