

Making Rational HFC Upstream Migration Decisions in the Midst of Chaos

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Abstract

It is estimated that approximately 1.5M miles of cable plant is now deployed in the United States. The majority of existing HFC networks have active 5-42 MHz reverse path in place. Much discussion has occurred during the past year relative to expanding reverse path network capacity on existing networks and how that expansion might proceed. Various ideas on the subject have included increasing the reverse pass band to 85 MHz, to 200 MHz, or even higher; adding a tri-split filter configuration with a second reverse path above 1GHz; relying upon node splitting and fiber deep migration to accomplish the goal; and incorporating a combination of solutions. Each approach has both technical and financial merits as well as disadvantages which need serious consideration.

To evaluate the costs of extending the upstream to 85 MHz or to 200 MHz (or greater) we will look at the issues involved in operating an HFC network upstream to those frequencies, including RF gain requirements, slope and AGC requirements and required laser performance. The cost of each of these components increases as the upstream bandwidth increases.

INTRODUCTION

Cable networks have been deployed universally with active reverse path since the inception of HFC in the 1980's. Essentially, the reverse coaxial path has been designed and operated for 5-42 MHz in North American networks and up to 5-65 MHz in some international regions. In HFC systems, due to the relatively small coaxial portion of

the network, performance parameters such as CNR and NPR are dominated by the optical network.

Coaxial plant in HFC generally uses up to three basic types of low cost amplifiers. These are the four port, high output level amplifier (Type A), the intermediate multi-port amplifier (also called a mini-bridger – Type B), and the single port, low cost line extender (Type C). The same single gain hybrid reverse amplifiers are used in each type of product; however, the amplifier station's operating gain is influenced by the degree of internal loss devices such as diplex filters and port combiners required. These losses plus equalizer losses and perhaps optional thermal circuitry for controlling minor level variations due to temperature changes result in different station operational gains for each type of amplifier used. A Type A amplifier may have 17.5 dB, a Type B amplifier may have 20 dB and a Type C amplifier may have 24 dB of station operating gain with all losses considered.

The coaxial network is a mini-tree/branch network where individual reverse signal paths funnel into common signal paths returning to the node. For this reason, each amplifier contains reverse path equalization and attenuation capabilities located on the output side of the reverse amplifier in order to be able to properly align and balance the reverse network having signals returning from different originations. A similar situation exists from the subscriber's customer premise equipment (CPE). Each home can have several devices such as cable modems and set top boxes. These reverse CPE signals all enter the HFC network through a series of cascaded passive tap devices. Operating levels for these terminal devices are remotely controlled by

the network's CMTS or other addressable control devices at the system's headend or hub location. CPEs do have maximum transmit power limitations which must be adhered to during the system design process. Issues such as excessive passive losses must be closely monitored in order to enable the reverse path to operate properly.

Today's existing networks with frequency limitations of 42 or 65 MHz generally have sufficient amplifier gain and CPE output power to insure proper reverse path operation provided the network was properly designed. In fact, it is estimated that 95% of reverse amplifiers contain attenuators due to an overabundance of reverse gain. In brownfield plant, such as is the majority of North American networks, and many international networks, upgrading the reverse path frequency limit needs to be reviewed in order to ensure proper products exist that are able to maintain the existing amplifier locations in the design. The last thing brownfield

operators want is to have to re-plumb their networks. Also, the degree of change to the existing amplifier components may be impacted due to the reverse path upper frequency limit desired.

UPSTREAM LEVELS

Overview

Before beginning to select proper signal levels, it is essential to first understand how the return path works. Figure 1 shows a typical HFC Network (note that only the return path components are shown in the headend and fiber node). Signals originate in the home (1) and flow through the plant towards the headend. The signal level in the plant is determined by the RF level produced by the transmitter at the house, which is most often a cable modem.

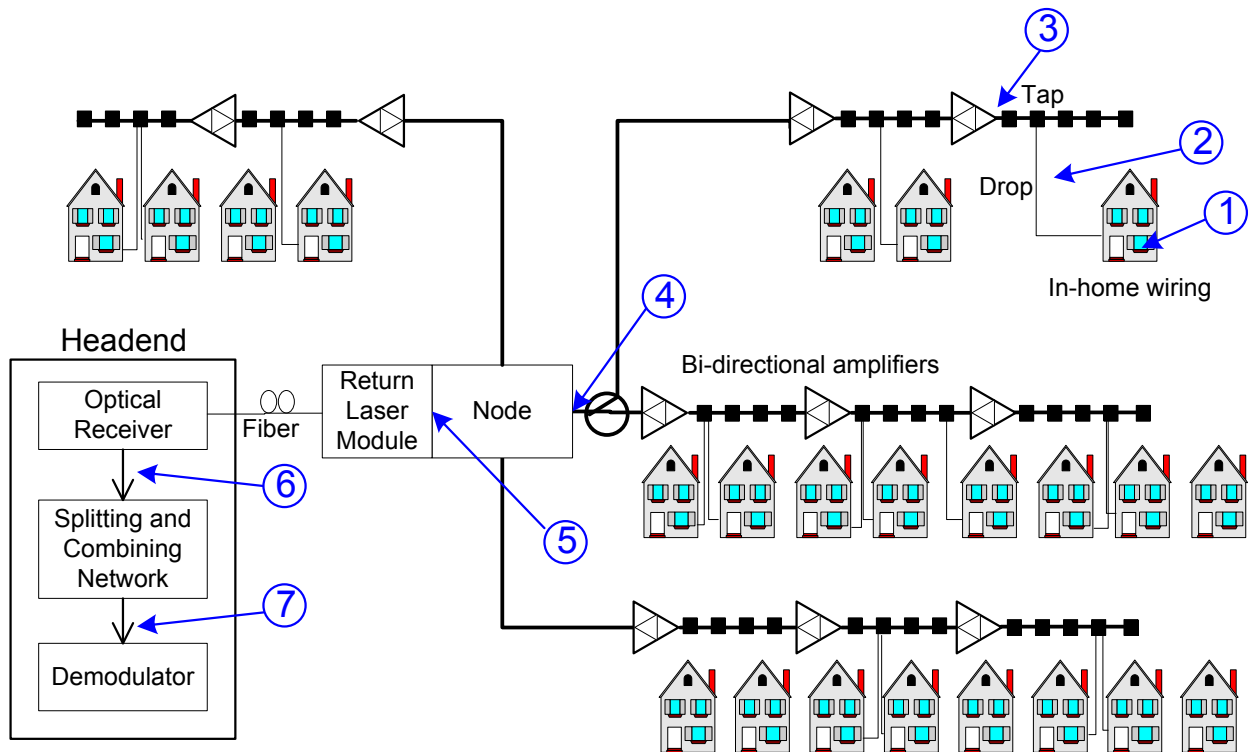


Figure 1: Upstream Levels in an HFC Network

After the signal leaves the cable modem, it goes through a variety of losses such as in-house cable, splitters, ground block, drop cable, tap port, and feeder cable before reaching the amplifier station port (3). All signals from the homes go through different amounts of loss, but all of these signals should arrive at the amplifier port (3) at the same level. This is a key premise of return path design. These variations require setting the transmitters in each cable modem to its own unique level – the level that produces the desired signal level at the amplifier.

Once the signals reach the amplifier, they continue on their way toward the headend. Every span of cable between two amplifier stations must be aligned to unity gain so that the return path gain of every amplifier station exactly matches the loss of the cable and passives following it (i.e., the cable span towards the headend). When the spans are all set to unity gain, the signal levels will be the same at every station. Ultimately, the signals reach the node station (4). Because the amplifiers have been aligned for unity gain, the signals at the node station port (4) are the same level as the signals at each amplifier station port (3). From the node station port, the signals continue on to the return path laser module (5). The relative levels between the node station port and the input to the laser are adjusted by selecting the proper gain or attenuation level in the node (see Figure 2).

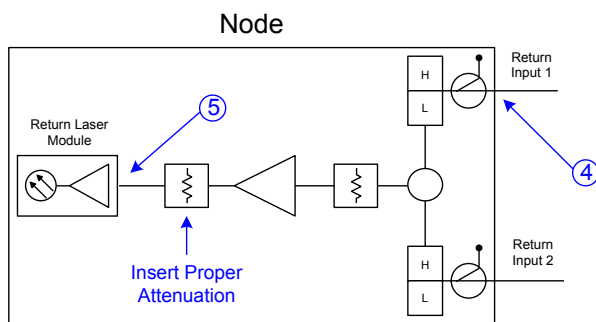


Figure 2: Adjusting Upstream Gain in the Node

After entering the return path laser module, the signals are then carried on fiber to the headend or hub location where they are converted back to RF by a fiberoptic receiver. This RF signal is then fed to the demodulator for that particular service. For DOCSIS services, the demodulator is the CMTS upstream input port.

Long Loop AGC

Many field technicians are already well-acquainted with aligning plants to unity gain, as described above. What is not immediately obvious, however, is how the real signals behave in a functioning plant. Long loop AGC refers to the process of adjusting the home signal levels via instructions from the demodulator in the headend. Most demodulators measure the level of the RF signal arriving at its input port (7). If this level is incorrect, a command is sent out via the forward path to the box in the house telling it to raise or lower its level accordingly. By making these adjustments, the demodulator assures that all signals from the plant arrive at the demodulator at the same level, within some accuracy limit.

“Long loop” refers to the fact that the commands are issued all the way from one end of the plant (the headend) to the other end of the plant (inside the home) to affect a signal originating inside the home and destined for the headend. Thus, a long loop is formed all the way across the plant and then back again. “Gain control” refers to the process of automatically adjusting gain. Strictly speaking, it is the level and not the gain that is controlled, but the term “long loop AGC” is widely used anyway.

Determining Ideal Upstream Levels

The following three different levels must be considered in every return plant:

- The level at the return path input port of every amplifier station (3) and (4)
- The level at the input to the return path laser module (5)
- The level at the input to the demodulator (7)

These three levels are based on independent criteria. The first step is to select the ideal level at the amplifiers based on the available transmitter power from the box in the home and the maximum loss through which that signal must travel on its way to the amplifier. Then, choose the ideal level at the return path laser module based on laser dynamic range and clipping versus carrier-to-noise (C/N) performance. Select the ideal level at the demodulator according to the manufacturer's specification. Once chosen, add gain or loss between each component so that all three simultaneously occur at the ideal level.

Levels in the plant are usually designed on a per-channel basis. The design begins with determining the available transmit power from the cable modem. Then the total loss between the cable modem and the amplifier station port is calculated. The transmit power minus the total loss is the available level at the amplifier station port. In most cases, some margin is added to that level to allow for loss variations over time and temperature.

The ideal level at the return path laser module (5) is a function of the type of laser and the module design. Several methods are available for determining the optimal input level to the module. In most cases, the manufacturer provides an optimal level. Generally, a trade-off exists between C/N and clipping distortion, which can best be identified by performing a Noise Power Ratio (NPR) test. In most cases, the ideal level determined for the laser is represented as composite total power.

Since the plant levels are generally calculated on a per-channel basis and the transmitter levels are calculated on a total power basis, a conversion must be performed. In most cases, operators desire that the upstream channels have a constant power spectral density, sometime referred to as constant power per Hz. Assuming all channels have the same bandwidth, one can convert from power per channel to total power by simply adding $10 \cdot \log(\text{number of channels})$.

Effect of Return Bandwidth on Upstream Levels

Since the total power at the laser transmitter is a function of power per channel and the number of channels, the total power will increase as the number of channels increases. Thus, wider return bandwidths, such as 85, 200 or 300 MHz will have larger total powers at the laser transmitter for the same individual channel levels.

Example of Upstream Levels

The first component to discuss is the output level available from cable modems. The DOCSIS spec for output level¹ is shown in Table 1. If the cable modem is only transmitting one upstream channel at a time, then it is capable of producing at least 57 dBmV. However, if it is a DOCSIS 3.0 modem and is transmitting multiple upstream channels, then guaranteed available maximum level per channel is reduced.

Number of Transmit Channels	Pmax (dBmV) TDMA
1	57
2	54
3-4	51

Table 1: Required Maximum Transmit Power for CMs for 64-QAM

The next component to analyze is the loss between the cable modem and the amplifier station port. Finally, the per-channel levels

must be converted to a total power in order to properly calculate the required upstream node gain between the node station port and the

upstream laser transmitter. An example is shown in Table 2.

	Levels	Power Increase Above 5-42 Power
CM Tx Level	52 dBmV	
Loss from CM to Tap Port	9 dB	
Largest Tap Value	23 dB	
Input to Amplifier and/or Node (per channel)	20 dBmV	
Total Power for 6 Channels (5-42 MHz)	27.8 dBmV	
Total Power for 12 Channels (5-85 MHz)	30.8 dBmV	3.0 dB
Total Power for 5-200 MHz	35.1 dBmV	7.3 dB
Total Power for 5-300 MHz	36.9 dBmV	9.1 dB

Table 2: Example of Upstream Levels and Conversion to Total Power

Table 2 assumes that the cable modem is able to transmit at 52 dBmV with some margin. Thus, this design does not allow for a DOCSIS 3.0 modem that is transmitting more than 2 channels at a time (see Table 1). Notice that the total power at the amplifier and node station ports will be 28 dBmV for a 5-42 MHz return bandwidth. This is a very common HFC design level. If the return bandwidth is increased to 85 MHz, the number of channels increases to 12 and the total power increases 3 dB to 31 dBmV. Similarly, if the return bandwidth increases to 200 MHz, the total power increases to 35 dBmV, which is 7.3 dB higher than it was for the 5-42 MHz return.

SELECTING THE OPTIMAL RETURN BANDWIDTH

Previous papers^{ii,iii} have included a detailed analysis of the options available for increasing upstream bandwidth. This paper will focus on the costs of upgrading from a 42 or 65 MHz return to a 85, 200 or 300 MHz return.

85 MHz Mid-Split

85 MHz was selected years ago as the next likely maximum frequency for return path

operation. The primary reason that 85 MHz was selected was so that the FM radio band, which operates from 88 to 108 MHz, would not be inside the return path operating band. Putting the FM band in the cross-over region reduces the likelihood that ingress from FM radio stations will be an issue.

Changing from 42 MHz or 65 MHz to mid-split is conceptually simple. All one needs to do is change the diplex filters in the nodes and amplifiers and realign the plant. In most cases, the amplifiers will have sufficient bandwidth and gain and the plant will not require any type of upstream AGC. When doing an upgrade, don't forget to change out any feederline equalizers that have diplex filters in them.

200 MHz High Split

Many people think that if 5-85 MHz is a good choice, then 5-200 MHz must be even better. However 5-200 MHz has some significant disadvantages.

Several of the disadvantages have nothing to do with the HFC network.

- A 5-200 MHz split means that downstream signals do not start until at least 250 MHz. Thus, a huge amount of deployed CPE cannot function and must be replaced. In particular millions of settop boxes have a downstream out-of-band receiver that cannot be tuned above 130 MHz.
- Loss of multiple VHF channels, some of which need to be carried on-channel.
- Reduction of downstream bandwidth

Other disadvantages related to the HFC network are:

- The entire FM band will now be in the return band. Thus, there is a the potential for large ingress.
- Return signals will exist in the aeronautical band. Leakage of return path signals becomes a concern.
- The change in gain of the coaxial network over temperature is no longer trivial.

Table 3 illustrates the gain and tilt change of 1000 feet of QR540 cable vs. temperature and frequency. One can see that the tilt from 5-42 MHz is less than 3 dB and that the change in gain and tilt across the full outdoor temperature range is less than 1 dB. Thus, amplifiers operating with a maximum upstream frequency of 42 MHz do not need gain and tilt correction to compensate for changes in temperature.

Conversely, the numbers for 5-200 MHz operation are not as optimistic. The tilt is almost 8 dB. This means that cable modems will need to transmit 8 dB higher if transmitting at 200 MHz than they would if transmitting at 5 MHz. This additional gain variance will be difficult to accommodate in the return path design. Perhaps even worse, the change in gain and tilt across the full temperature range is approaching 2 dB. Thus it is likely that some type of gain and tilt control will be required for 5-200 MHz operation through a cascade of amplifiers.

Loss of 1000' of QR540 Cable from 5 to 300 MHz
(Loss at 750 MHz = 18 dB, Loss at 1002 MHz = 21 dB)

Frequency (MHz)	25C		-40C		+60C		-40 to +60 Change	
	Loss (dB)	Tilt (dB)	Loss (dB)	Tilt (dB)	Loss (dB)	Tilt (dB)	Loss (dB)	Tilt (dB)
5	1.49		1.68		1.38		0.30	
42	4.31	2.82	4.87	3.19	4.01	2.62	0.86	0.56
65	5.36	3.87	6.06	4.38	4.99	3.60	1.07	0.77
85	6.13	4.64	6.93	5.25	5.70	4.32	1.23	0.93
200	9.40	7.92	10.63	8.95	8.75	7.36	1.88	1.58
300	11.10	9.61	12.54	10.86	10.26	8.88	2.28	1.98

Table 3: Comparison of Cable Gain and Tilt Change vs. Temperature and Frequency

Forward-Driven Return AGC

One potential solution to allow 200 MHz upstream RF cascades is to drive a return path

bode equalizer with the downstream bode equalizer control signal, as shown in Figure 3.

Although the control for such a system is relatively simple, there is minimal, if any,

equipment on the market today with this functionality.

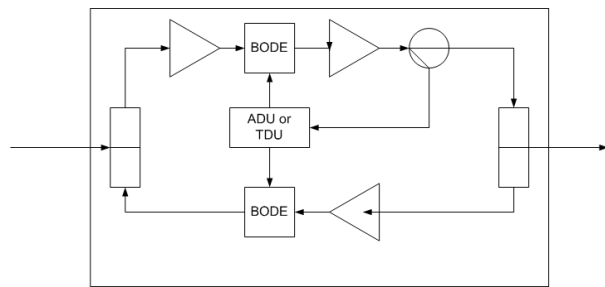


Figure 3: Forward-Driven Return AGC

Optical Link Performance

The most critical component in the upstream path in the HFC network is the laser transmitter. Receiver gain, output level capability, noise performance and distortion are also very important. All these components will have degraded performance when the upstream bandwidth is increased to 200 MHz. For instance, the noise power ratio (NPR) of an optical link for various bandwidths is shown in Figure 4 and summarized in Table 4.

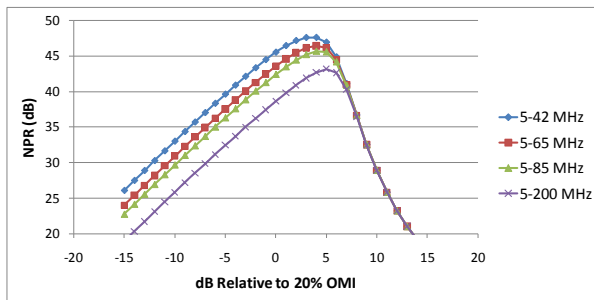


Figure 4: NPR of Upstream Link vs. Split

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 of Upstream Link vs. Split

ANALYSIS EXAMPLE

Theoretical Analysis

The reverse path network is comprised of a combination of cable loss and passive (flat) loss. Cable attenuation varies in accordance with the square root of the ratio of two frequencies. Passive loss does not follow that rule and is considered relatively flat across the reverse band frequencies under consideration in this paper. This means that the ratio of cable loss versus flat loss in the coaxial network impacts the amount of gain required in the reverse path. Table 5 illustrates a theoretical example of the reverse amplifier gain required based upon various combinations of cable versus flat loss – extending from 100% cable loss to 65% cable / 35% passive loss to 50% cable / 50% passive loss. It becomes quite evident that the more loss consumed by passive devices impacts the amount of reverse gain required in the amplifier. The bottom of Table 5 shows the total return path gain of typical amplifier stations. The gains are highlighted. The scenarios in the top portion of Table 5 for which that product has enough gain are also highlighted.

Table 5 indicates that under present conditions we would scarcely have enough reverse gain to accommodate an 85 MHz upgrade in applications where passive losses are present. As we all know, theory versus practice are often different and can produce two different outcomes. Theory does not factor in anomalies that exist in the real world such as short spaced amplifiers for placement optimization or the fact that most forward path amplifiers contain input pads (5dB on average) for example. Hence, we also reviewed three practical design applications to validate these data.

Frequency (MHz)			Forward			Reverse				
			1000	870	750	300	200	85	42	5
P3-625 loss/ft	@68deg. F.		0.0207	0.0193	0.0179	0.0113	0.0093	0.0060	0.0042	0.0015
Station Gain - dB (A/B)	100%	Cable	42	39.2	36.4	23.0	18.8	12.2	8.6	3.0
Station Gain - dB (C)	100%	Cable	34	31.7	29.4	18.6	15.2	9.9	7.0	2.4
Station Gain - dB (A/B)	65%	Cable vs. FL	42	40.2	38.3	29.7	26.9	22.7	20.3	16.6
Station Gain - dB (C)	65%	Cable vs. FL	34	32.5	31.0	24.0	21.8	18.3	16.4	13.5
Station Gain - dB(A/B)	50%	Cable vs. FL	42	40.6	39.2	32.5	30.4	27.1	25.3	22.5
Station Gain - dB (C)	50%	Cable vs. FL	34	32.9	31.7	26.3	24.6	22.0	20.5	18.2
Current Station Gains	A		42						17.5	
(Include 3dB average fwd. pad.)	B		42						20	
	C		34						24	

Table 5: Calculation of Required Return Amplifier Gain

Practical Analysis

The purpose of this section of this paper is to present some of the issues that arise at different reverse path frequencies in real world applications as well as to understand the cost implications.

Reverse path amplifiers generally have five basic elements that are impacted by a reverse path frequency upgrade. These are station gain, diplex filters, attenuators, equalizers, and thermal control. As previously stated, amplifiers used in current 42 and 65 MHz reverse plant have more than sufficient gain to operate properly. Some of those amplifier hybrids now in place are capable of 5-200 MHz operation so if they have sufficient gain at these upgrade frequencies, theoretically they may not need replacement. Other components such as diplex filters, attenuators, equalizers and thermal control units are

frequency dependent and would need to be replaced however. This leads to the analysis of identifying which elements need replacement depending upon desired reverse upgrade frequencies. Also, since this upgrade requires a truck roll, it may be important to consider what the desired end game is for reverse frequency versus the perceived life of the network. In an effort to answer these questions, we reviewed several network designs in order to determine the impact of upgrading existing 5-42 MHz reverse path to 5-85, 5-200 and 5-300 MHz reverse.

Prior to beginning this analysis, we first need to establish the design parameters followed in the reverse path designs at 5-42MHz. The output level available from cable modems was shown in Table 1. A complete list of design parameters is presented in Table 6.

Parameter	Common Existing Reverse Specifications	Comments
Cascade:	Up to N+5	
Amplifier Types:	Types A, B and C	

Parameter	Common Existing Reverse Specifications	Comments
Node Reverse Input:	Up to 20 dBmV/channel	This was a common level for DOCSIS 1 & 2 era designs. DOCSIS 3 presented a reduction in CPE output of 4 dB so this level was reduced by 4 dBmV/channel.
Amplifier Reverse Input:	Up to 20 dBmV/channel	Same as above.
Largest Tap Value Deployed:	23	Conditioning taps (with equalizers or cable simulators) may be used to correct excessive positive or negative slope.
Reverse Tap Port Minimum Input Level:	46 dBmV/channel	Level reduced to 42 dBmV in DOCSIS 3 designs.
Reverse Path Drop Loss CPE to Tap Port:	9dB	Combination of drop cable and passive loss.
CPE Maximum Output Per Channel:	55 dBmV/channel	Level reduced to 51 dBmV for DOCSIS 3 CPEs.

Table 6: Upstream Signal Level Assumptions for 5-42 MHz

Due to the reduction in CPE output level of DOCSIS 3.0 CPEs we began the exercise by adjusting the original design 5-42 MHz parameters as illustrated in the Comments section of Table 6 for the three sample designs. This resulted in negligible impact to the reverse designs.

DESIGN SCENARIOS

Three different sample design areas were reviewed along with three reverse design upgrade scenarios having an estimated cable to passive loss ratio average of 65%/35%.

Scenario 1, increased reverse bandwidth from 5-42 MHz to 5-85 MHz using the adjusted 5-42 MHz DOCSIS 3.0 design parameters. This resulted in minimal change to the reverse design.

- The amplifier to amplifier gains were sufficient to hold locations using existing hybrids.
- Amplifiers required change out of reverse equalizers, attenuators and diplex-filters.

- CPE to amplifier/node inputs held but approximately 12% of tap face plates needed to be changed. The alternative would be to either increase CPE output by 1 dB or reduce amplifier/node inputs by up to 1 dB. The latter would result in a reduction of reverse CNR and NPR.
- Additionally, if reduced input levels are under consideration, it is important to verify that the existing nodes in place contain sufficient reverse optical transmitter gain needed to drive reverse path optical links.
- Reverse thermal compensation modules continued to be used as the level variation over temperature was minimal.

Scenario 2 increased reverse bandwidth to 200 MHz. In this case, network revisions became more extensive.

- The amplifier to amplifier gains were sufficient to hold locations using existing amplifier stations.
- Amplifiers did require change out if reverse hybrids were not 200 MHz capable. Reverse equalizers, attenuators

and diplex filters also needed to be changed.

- CPE to amplifier/node inputs did not hold and up to 90% of tap face plates needed to be changed resulting in significant network redesign (and possible amplifier respacing). The alternative would be to either increase CPE output by 4 dBmV or reduce amplifier/node inputs by up to 4 dB. At this amount of input reduction, CNR and NPR performance in the reverse path can be reduced and the plant levels are getting closer to the level of ingress noise.
- Additionally, if reduced input levels are under consideration, it is important to verify that the existing nodes in place contain sufficient reverse optical transmitter gain needed to drive reverse path optical links. As shown in Table 2, the total power will increase as the bandwidth increases, thus less return gain will be required.
- Reverse thermal compensation modules would likely need replacement as well to accommodate increased level variations over temperature as Table 3 illustrated.

Scenario 3 increased reverse bandwidth to 300 MHz. In this case, network revisions became even more extensive.

- The amplifier to amplifier gains fell short by up to 5 dB using existing amplifier stations.

- Amplifiers did need to change out as well as reverse equalizers, attenuators and diplex filters.
- CPE to amplifier/node inputs did not hold and up to 90% of tap face plates needed to be changed resulting in severe network redesign. The alternative would be to either increase CPE output by 5 dBmV or reduce amplifier/node inputs by up to 5 dB. At this amount of input reduction, CNR and NPR performance in the reverse path can be reduced and the plant levels are getting closer to the level of ingress noise.
- Additionally, if reduced input levels are being considered, it is important to verify that the existing nodes in place contain sufficient reverse optical transmitter gain needed to drive reverse path optical links. As shown in Table 2, the total power will increase as the bandwidth increases, thus less return gain will be required.
- Reverse thermal compensation modules would likely need replacement possibly with automatic gain control depending upon the cascades in the network as Table 3 illustrated.

Table 7 summarizes these results a bit more concisely. The net result is that although a 5-85 MHz reverse upgrade can be achieved with minimal impact, moving to 5-200 MHz or 5-300 MHz results in far more network modification required.

Item	Scenario 1 85 MHz	Scenario 2 200 MHz	Scenario 3 300 MHz	Comments
Amp to Amp Gain	Held	Held	5 dB low	S2 may require amp replacement. S3 will require amplifier replacement.
CPE to Amp Inputs	Held	4 dB low	5 dB low	Requires increased output CPEs for S2 & 3.

Item	Scenario 1 85 MHz	Scenario 2 200 MHz	Scenario 3 300 MHz	Comments
% Tap Faceplate Change	12%	Up to 90%	Up to 90%	S2 & 3 cause significant rework and likely additional amplifiers. Increased CPE outputs would alleviate this.
Reverse Amp Reuse	Yes	Possibly if 200 MHz capable.	No	
Pad & EQ & Diplex Change	Yes	Yes	Yes	
Temperature Control	Thermal	Possibly AGC	AGC	
Truck Roll Required	Yes	Yes	Yes	

Table 7: Comparison of Upgrade Scenarios

Table 8 reviews the constructed cost implications of each scenario. It contains several assumptions made. Cost is based upon tap faceplate change out as opposed to replacing CPEs with higher output devices. The “Amp Accessories” line includes diplex filters, pads and EQs. In the 85 MHz case, the gain stages were assumed to be reusable. In

the 200 and 300 MHz cases, we assumed the gain stages needed to be upgraded.

We also observed that 5-200MHz and 5-300 MHz reverse upgrades with tap faceplate change out would likely cause significant network re-plumbing and create the need for new active device locations. This could then violate the network powering structure.

Item	Scenario 1 85 MHz	Scenario 2 200 MHz	Scenario 3 300 MHz
Total Reverse Upgrade Price/Mile	\$1203	\$4598	\$4598
Replace Reverse Hybrid	\$0	\$240	\$240
Add New Amplifier Location	\$0	\$600	\$600
Amp Accessories	\$264	\$385	\$385
Tap Face Plates	\$39	\$293	\$293
New P.S.	\$0	\$80	\$80
Labor	\$900	\$3000	\$3000
New CPE	\$0	\$0	\$0

Table 8: Cost Comparison of Upgrade Scenarios

TRI-SPLIT 1200MHZ REVERSE

The results portrayed in the 200 MHz and 300 MHz reverse upgrades demonstrated that higher gains and AGC are required to operate with high-bandwidth splits. It is evident that attempting to move to a tri-split filter with 5-42 MHz and 1100-1200 MHz return would be even more costly. Forward amplifier gain would experience additional loss due to triplex filter loss. Reverse amplifier gains would need to exceed the current 42dB maximum forward gains now deployed at 1000 MHz. Due to the increased reverse output level requirements, issues with crosstalk would be likely; therefore, a complete new e-pack and perhaps amplifier housing (depending upon existing housing capabilities) would be required. Cost of this model is deemed excessive.

AMPLIFIER UPGRADE METHODS

Most HFC networks deployed today use a 5-42 MHz or 5-65 MHz return. However, most operators are seriously considering moving to a 5-85 MHz or higher upstream bandwidth network in the near future. Operators want to deploy a product today that can serve their needs in the future. To do this, there are several options:

- Have multiple duplex frequencies in the initial product with some type of switching mechanism to select the desired frequency. The goal is to affect future change without visiting the amplifier.
- Have a pluggable sub-module that can be replaced in the future. The goal is to do the upgrade quickly without needing to discard or bench-upgrade existing product.
- Perform an electronics package (EPAC) swap in the future.

The following sections will consider each of these options.

Multiple Duplex Frequencies in Initial Product

Having multiple duplex frequencies in the initial product with some type of switching mechanism to select the desired frequency has several advantages, including:

- No need to visit amplifiers in the future
- Low down time
- Goal of no part changes or craft issues
- No bench upgrade

Unfortunately, there are several significant disadvantages with this approach:

- The “final” frequency is not known today. In particular, the selection of exactly “200 MHz” has not yet been decided by the industry.
- Highest initial product cost
- Increased product complexity
- Requires sweep and balance at 200 MHz during initial installation, which requires vacating all DS frequencies up to at least 200 MHz, then a revert back to 85, 65 or 42 MHz
- Risk that it “won’t work” when switched years from now
- Significant HFC plant changes may be required day 1 to accommodate highest upstream split increment incorporated

Pluggable Sub-Module

- Having a pluggable sub-module that can be replaced in the future, with a goal of doing the upgrade quickly without needing to discard or bench-upgrade existing product has several advantages, including:
 - Allows plant bandwidth changes to occur when needed
 - Low down time. Pre-configured modules plug in quickly.

Some disadvantages of this approach are:

- Need to visit the amplifier
- Higher initial cost with future incremental cost

- More challenging / higher risk design effort
- May still require powering down the feeder leg during the upgrade
- Will require sweep and alignment adjustments to the host EPAC
- Host EPAC design and maximum frequencies are locked down on day 1

EPAC Swap

Performing an electronics package (EPAC) swap in the future has many advantages including:

- Lowest initial cost
- Pay as you grow
- Lowest product complexity
- Option to either reconfigure or replace EPACs during the upgrade, depending on product age
- Don't need to make a bet today on the future configuration
- Very low down time. Pre-configured and tested EPAC modules are plugged in

There are a couple disadvantages to this method:

- Need to visit each amplifier during upgrade
- Could require bench top configuration and alignment and then bicycling of existing EPACs

The EPAC swap appears to be the best method for operators to upgrade their networks in the future. The other methods are more expensive, more intrusive during initial setup and include significant risk that the decisions made during initial deployment will not be the correct configurations in the future.

Plant Upgrade Procedure

When it is time to upgrade from one frequency split to another split, the following procedures should be followed.

“Cold swapping” is the preferred method. To perform a cold swap:

- Power down and cold swap modules
- Power up and sweep and balance each node segment

If the system down time cannot be tolerated and an “in cascade” module upgrade is chosen, care must be taken to avoid any possible loop gain oscillation as follows:

- The network should be void of any RF sources from the upper end of the original return band-pass split to the lower end of the new downstream band pass
- The operational gain in both directions should be equalized and padded with the design values prior to module power up
- Extra care should be taken on short spaced amplifiers to make sure the gains are not too high
- Each node segment should be committed to and completed timely
- N split modules should not be intermixed in plant of other splits

CONCLUSIONS

Operators should plan for an upgrade to 85 MHz. 5-85 MHz reverse upgrades in properly designed networks require little network modification to accomplish. Return path bandwidths beyond 85 MHz significantly add to the expense of the network.

There is no clear market driver that indicates return bandwidths beyond 85 MHz will be required any time in the next 10 to 15 years. There is no clear standard on what the next incremental return path frequency beyond 85 MHz will be.

200 MHz and 300 MHz reverse upgrades increase cost and complexity throughout the plant. 5-200 MHz and 5-300 MHz reverse upgrades are more involved, requiring higher gain return path amplifiers with higher output power capacity and potentially requiring

active upstream gain and tilt control. Amplifiers without these features may need to be replaced. Significant tap face plate change out is also required unless CPE output levels are increased or input levels to the amplifiers and nodes are decreased, which will impact carrier-to-noise and carrier-to-ingress performance. Perhaps most importantly, there are tens of millions of deployed CPE units that require a downstream communication channel at frequencies lower than 130 MHz^{iv}, preventing an upgrade to a 200 or 300 MHz upstream without replacing the CPE equipment.

CPE output levels are a key contributor to the overall cost of reverse upgrades.

Operators want to deploy a product today that can serve their needs in the future. The best method to plan for a future upgrade is to deploy a product that can be upgraded in the future.

ACKNOWLEDGEMENTS

The authors would like to thank Mike Aviles and Stuart Eastman for their calculations and design evaluation contributions to this paper.

ⁱ CM-SP-PHYv3.0-I10-111117, "Data Over Cable Service Interface Specifications DOCSIS® 3.0 Physical Layer Specification," available at <http://www.cablelabs.com/cablemodem/specifications/specifications30.html>

ⁱⁱ Rewriting the Book of Return – A New 10-yr Plan, Dean Stoneback, SCTE Cable-Tec Expo, October, 2010

ⁱⁱⁱ Characterizing and Aligning the HFC Return Path for Successful DOCSIS 3.0 Rollouts, Robert Howald, Phillip Chang, Rob Thompson, Dean Stoneback, Vipul Rathod, Charles Moore, SCTE Cable-Tec Expo, October, 2009

^{iv} ANSI/SCTE 55-1 and ANSI/SCTE 55-2, "Digital Broadband Delivery System: Out of Band Transport", available at <http://www.scte.org/>