Next Gen 10G Networks and 1.8 GHz HFC Design Challenges

The Design Path to 10G

A Technical Paper prepared for SCTE by

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1. Introduction

Operators worldwide are working through the 10G initiative and are in the process of developing and deploying scalable, cost-effective technology platforms to power future 10G wired networks. These efforts are coupled with physical network upgrades to leverage today's nearly ubiquitous Hybrid Fiber Networks (HFC) deployed throughout the world. The ultimate goal is to support delivery of 10G services and enable new immersive digital experiences over low-latency, reliable and secure connections at speeds of 10 Gbps. The introduction of DOCSIS 3.1 and DOCSIS 4.0 have given operators the ability to move towards the path to 10G.

This paper outlines Outside Plant (OSP) architectural, technical, and physical challenges that must be addressed when designing the next generation of HFC networks to achieve higher split orders, greater speeds and increased bandwidth capacities. The importance of leveraging the *existing HFC infrastructure and maintaining legacy RF levels below 1.8 GHz*, and why this is crucial during the design process, will be explained. In addition, we will focus on the importance of managing total composite power (TCP) and other performance indicators when operating higher powered 1.8 GHz hybrids and amplifiers. And the importance of full spectrum RF levels, tilts and step-downs, to ensure best performance while minimizing distortions, will also be discussed.

Through much research, extensive design specification creation and experimentation coupled with network modeling over more than 30 years, one thing stands out; the design process is one of the most important phases of proposed outside plant upgrades. It is true that HFC networks are thought of as forgiving. Meaning, even though the spacing of actives from past bandwidth expansions may have been pushed to or past the limits of their capability, somehow the networks continue to deliver. With 1.8 GHz upgrades, this tolerance to compromised networks is greatly reduced. Performance and distortion parameters are more critical. Insertion and attenuation losses at such high frequencies accumulate much more rapidly. Well tested design specifications and the adherence to them at 1.8 GHz becomes more crucial to ensure healthy, bi-directional 10G capable networks.

2. Leveraging the Existing OSP – What are the Objectives?

- Increase operational bandwidth for greater network capacity while maintaining a budget.
- Increase bi-directional speeds for faster data transfer.
- Achieve greater reliability through improved network stability.

How does an operator do this?

- Understand our current OSP infrastructure. This identifies the physical and technical challenges to overcome in the design process which directly affects OSP construction and splicing costs.
- Perform electronics product testing, evaluations, and network design modeling to see what is needed from an RF signal level viewpoint.
- Work through the R&D process with electronics manufacturers to be sure they are building what is needed.
- Test and evaluate product samples to be sure they meet or exceed our requirements.

3. Design Challenges – Legacy OSP vs 1.8 GHz Upgrades

Design challenges must be approached systematically to understand what needs to be overcome, met, or exceeded in creating effective 1.8 GHz design specifications. Once the specifications are created, 1.8 GHz design modeling of existing lower bandwidth networks will allow us to see what the physical and technical plant demands will be as part of the proposed upgrade.

Table 1 illustrates how the maximum cable spacing between RF actives decreases as operating bandwidth increases. Gain has increased with every new generation of actives. However, as we go higher in bandwidth, coaxial cable attenuations, in addition to passive device insertion losses, will increase. As a result, it can be more difficult to maintain physical legacy amplifier locations, which is especially evident when re-spacing a 750, 870, 1002 or even 1218 MHz outside plant to accommodate 1.8 GHz.

Table 1 - Gain, Cable Loss and Trunk / Express Spacing

Generational System Amps – Gain Max – dB in Cable at Frequency			
MHz	**Gain dB**	**.750 Cable Loss dB/100’**	**Cable Feet**
750	37	1.48	2500
870	40	1.61	2484
1002	43	1.74	2471
1218	48	1.94	2474
1794	49-50-51	2.45	2000+

Relocating actives can be expensive. If design specifications are not created to optimize greater distances and higher losses between current active locations, the network upgrade costs will increase exponentially due to added construction and splicing costs.

In Table 1, the differential between 750 MHz and 1794 MHz spacing with .750 cable is 500’. To turn the 500’ of .750 cable into dB we would do the following: 5-100’s (cable feet) X 2.45 (dB loss per 100’ @ 1794 MHz) = 12.25 dB. In theory this would mean we would be 12.25 dB short on our actives input to maintain the current location of the previously spaced 750 MHz active with a new 1.8 GHz active.

In an actual design, 1.8 GHz electronic equalizer (EEQ) losses at forward frequencies need to be considered when looking at Table 1. In addition, RF level input requirements of a manufacturer’s 1.8 GHz active, as well as legacy frequencies below 1794 MHz, must remain within specification.

In the example below in Figure 1, actives A and B are 1.2 GHz actives spaced at 1218 MHz, while the actives gain is 48 dB. The spacing realized due to equalizer losses <u>at all frequencies</u> and amplifier input requirements is 45.0 dB of .750 cable. The result is 2325’ of cable spacing.

Actives C and D are 1.8 GHz actives spaced at 1794 MHz, while the actives gain is 49 dB. The spacing realized due to EEQ losses <u>at all frequencies</u> and amplifier input requirements is 47.5 dB of .750 cable. The result is 1950’ of cable spacing. What is shown here is a 1.8 GHz active will fall 500’ or 12.25 dB short of making the spacing of the previous 1218 MHz active’s location. We now have the below choices in design to make.

- Relocate the 1.8 GHz active to a location (pole) where it is no greater than 1950’ of .750 cable spacing to satisfy the 1794 MHz input requirement.
- Upsize the .750 cable as necessary to a larger coaxial cable to reduce the amount of attenuation to satisfy the 1794 MHz input requirement maintaining 2325’ of cable footage.
- Add a booster type amplifier at a location along the 2325’ of .750 cable that increases the amplitude enough within the 2325’ of .750 cable spacing to satisfy the input requirement of the 1.8 GHz active.

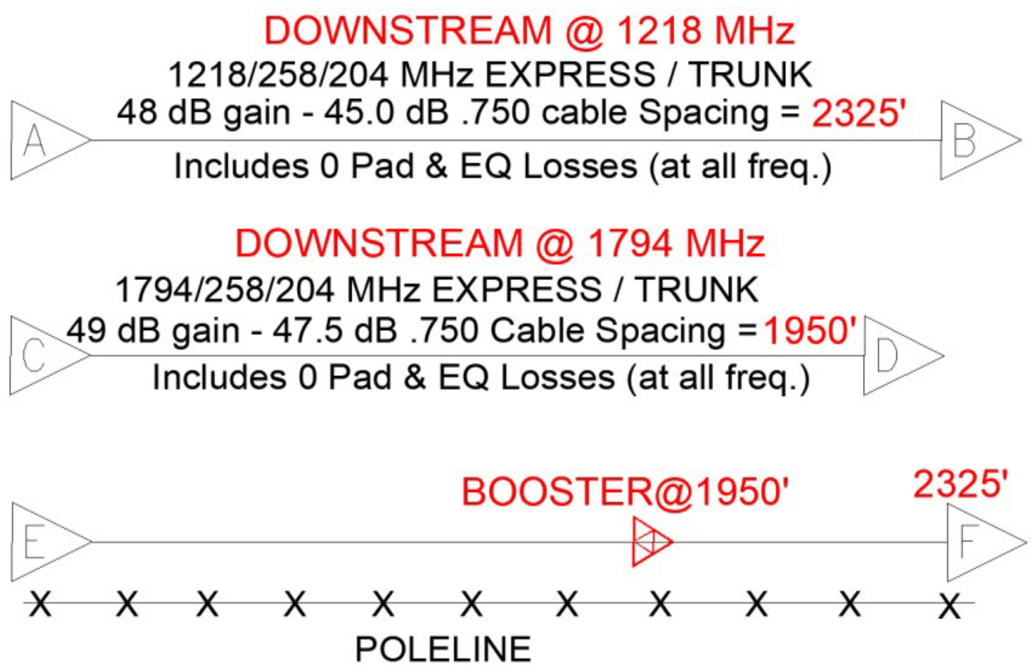

Figure 1 - Gain, Cable Loss and Trunk / Express Spacing

3.1. Gain, Cable Loss, and Distribution Spacing

Upgrading the distribution portion of the network can be especially challenging due to higher attenuation through smaller coaxial cabling and 1.8 GHz insertion losses through the frequent placement of taps and splitting devices. This is the section in the network where we must extract RF to serve our subscriber base. To that end, some points in the network will require certain levels of RF to be extracted or RF signals to be directed depending on the distribution requirements.

- Hot taps extraction of higher RF levels
- Directional couplers (DCs) or splitters delivering required input levels to additional downstream actives
- DCs or splitters feeding all passive legs (eliminating actives) requires higher RF levels
- Feeds and considerations for hardline-fed Wi-Fi transmitters
- Other dependencies upon an RF feed from the coaxial distribution (e.g., MDUs, hotels, etc.)

Figure 2 illustrates two things: 1218 MHz and 1794 MHz gain and spacing on P3.500 cable without any passive loss. Moreover, what happens when we introduce passive loss which is unavoidable in actual distribution. The higher losses at 1.8 GHz through the frequent placement of passives contributes to our depth of reach. In fact, adding passive devices can cut our total cable distance in half. The below examples would be significantly compounded if splitting were added to the passives shown.

It is imperative to know the gain of the chosen manufacturer's 1.8 GHz actives. Not all manufacturers' actives necessarily have the same gain. And not all manufacturers' actives have the same performance characteristics. Each of these considerations contribute heavily to defining network actives input and output RF design levels.

The below examples compare 1218 MHz and 1794 MHz. Even greater differences will occur between 1794 MHz and frequencies below 1218 MHz.

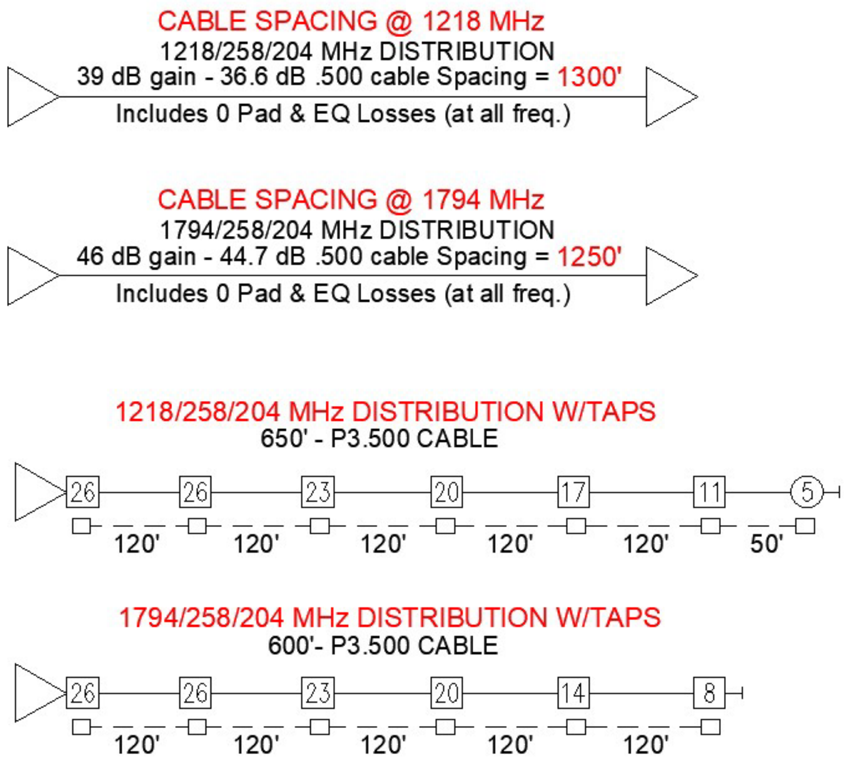

Figure 2 - Distribution Example with and without Passive Loss

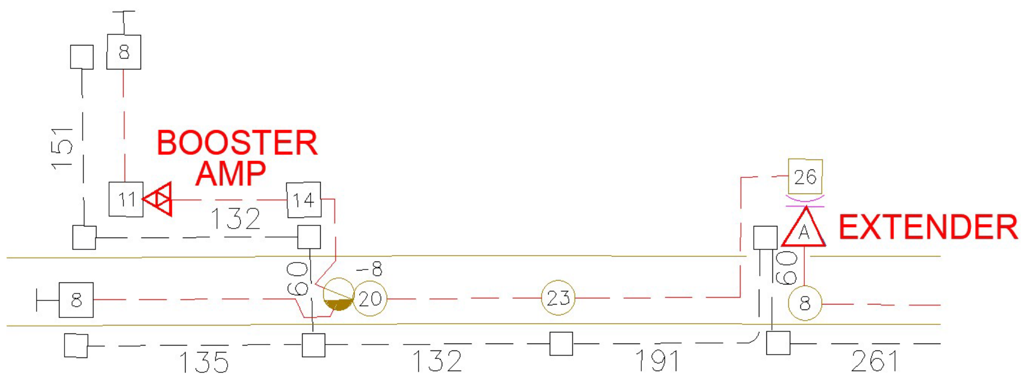

Figure 3 - Distribution Example with Booster

In Figure 3, there is not enough available RF for the design software to reach the last two taps. In 1.8 GHz design we may have a few choices to remedy the problem, but the most obvious choice would be to use a low gain booster type active. A line extender could also work, but that is much more gain and greater expense than necessary. We try not to knowingly waste gain.

Depending on the manufacturer, the gain in line extenders can sometimes be less than the gain in trunk or express type amplifiers. This means there is an additional challenge if standardization is utilized throughout the network with the intent for all actives to run at identical levels. The only way to achieve standardized levels would be to increase the input level requirement in the design software specifications for actives with lower gain in order to achieve the same output levels of actives with higher gain.

Example: A particular system type active might have 49 dB of operational gain at 1.8 GHz. A line extender might have 45 dB of gain at 1.8 GHz. The gain differential is 4.0 dB. To achieve the same output levels in both actives, the input level for the line extender would have to be 4.0 dB higher due to the lower gain. Having a higher input level requirement for any amplifier adds to the design challenges. These are the types of particulars that must be considered in design specifications.

4. Service Drop Engineering Profiles

We must understand distribution challenges in order to create design specifications that will meet or exceed the proper modem RX and TX RF levels at the premises or business.

Most networks have combinations of shorter and longer lengths of service drop line. Whatever these average distances are, as well as the service drop cable size, will help to define the RF levels needed from tap ports to adequately serve subscribers. Creating drop engineering profiles is integral in the development of design specifications to be sure we are maintaining proper modem RX and TX specifications.

Another component that merits further discussion in an operator's upgrade design specifications plan is the migration of DOCSIS modems, such as transitioning from legacy DOCSIS 3.0 or DOCSIS 3.1 modems to DOCSIS 4.0. It will be highly unlikely that an operator can swap all customers in a planned upgrade node or service area from earlier DOCSIS modems to a DOCSIS 4.0 modem immediately after the physical 1.8 GHz OSP upgrade. This may take weeks or months to accomplish.

In older existing plant below, 1.8 GHz splitters are common at the point-of-entry (POE) or even beyond that point located in the internal premises wiring. Sometimes splitters are in attics, walls or co-located with equipment. These splitters can be two-, three- or four-way splitters. Each addition of splitter ports constitutes additional RF signal loss. A two-way splitter will have about 3.5 dB of loss per port and a four-way splitter will have about 7.0 dB of loss per port.

The below bullets outline what is needed to create drop engineering profiles within your networks for legacy frequencies, as well as upcoming 1.8 GHz:

- Define average drop distance from tap port to premises POE or demark.
- Define average interior drop wiring distance to set-top box or modem located within the premises.
- Define average house type splitter number of ports at POE.
- Define average drop cable size RG-59, RG-6 or both.

Calculation example for premises (legacy modem) at 1.0 GHz:

RG6 drop cable loss / 100' = 6.55 dB

Two-way splitter loss @ POE = 3.5 dB

If the distance to the premises is 100' + 50' of interior wiring to the set-top or modem, that is a total of 150' of drop loss that must be accounted for in our drop engineering. 6.55 dB loss X 1.5 (150') = 9.82 dB. If we add a two-way house splitter (3.5 dB of loss), the total loss is (9.82 + 3.5) = 13.32 dB.

Calculation example for premises (D4 modem) at 1.8 GHz:

RG6 drop cable loss / 100' = 8.49 dB

If the distance to the premises is 100’ + 50’ of interior wiring to the set-top or modem, that is a total of 150’ of drop loss that must be accounted for in our drop engineering. 8.49 dB loss X 1.5 (150’) = 12.73 dB.

With 1.8 GHz upgrades, we focus on DOCSIS 4.0 modems, also known as D4 gateway. In theory, these gateways feature point-to-point wireless transmission of RF signals via Wi-Fi to internal premises devices. Internal premises wiring may still be used in our calculations only because we don’t know exactly where the gateway will be placed within a premises. They are often called point-of-entry (POE) devices. However, they may not always be placed right at the POE. They may be placed elsewhere in the premises. Splitters can be eliminated because they are no longer needed. If they continue to be used at the premises, the additional loss must also be accounted for.

An operator must know what the minimum and maximum modem receive (RX) levels are for certain DOCSIS generations of modems that reside in their networks or, at the very least, what modem RX design levels specifications have been used in the past as a guideline that need to be maintained in a 1.8 GHz upgrade. The idea is to prevent truck rolls and customer complaints during and after the 1.8 GHz upgrade.

Using the two drop calculation examples given above, we can show them below in Table 2:

Table 2 - Example of Service Drop Engineering

Service Drop Engineering		
MHz	1794	1002
RG6 Loss / 150’ (dB)	12.73	9.82
Loss 2/W Splitter (dB)	N/A	3.5
Total Drop Loss (dB)	12.73	13.32

The next items to define before we can build our tap output levels specifications are the legacy modem(s) RF levels input (RX) requirements that still need to be met in an upgrade and the proposed RX levels needed for the DOCSIS 4.0 gateway. At the time of writing this document, many operators are working diligently to define what these levels are. The sample levels shown below are not specific to any operator and are not final numbers. They are just placeholders to illustrate an example of the type of information that needs to be decided upon to build design specifications for tap output RF levels based on service drop engineering.

Table 3 - Example of Modem / Gateway RX & TX Levels

CPE / MODEM SPECIFICATIONS MIN/MAX FOR CALCULATED RX & TX									
MHz	1794	1794	396	396	1218/1002	1218/1002	204	204	RX
CPE / MODEM	Min RX dBmV	Max RX dBmV	Min RX dBmV	Max RX dBmV	Min RX dBmV	Max RX dBmV	Min RX dBmV	Max RX dBmV	Min RX dBmV
DOCSIS 3.1	N/A	N/A	N/A	N/A	-8.0	12.0	30.0	48.0	-8.0
DOCSIS 4.0	-6.0	15.0	30.0	49.0	N/A	N/A	N/A	N/A	-10.0
	21 dB Window		19 dB Window		20 dB Window		18 dB Window		

From these exercises we can now experiment with tap output levels needed to satisfy legacy DOCSIS modems as well as DOCSIS 4.0 gateways. It is simple: whatever min/max modem RX levels are decided upon for legacy modems, as well as DOCSIS 4.0, will determine the target tap output level range to maintain in our design to assure we are delivering within those tolerances.

Table 4 illustrates the math. As before, these are not levels or recommendations specific to any operator. They are just exemplary placeholders to show how the math works.

Table 4 - Example of Tap Output Levels and Modem / Gateway RX Levels

Defining Tap Output Levels		
MHz	1794	1002
RG6 Loss / 150' (dB)	12.73	9.82
Loss 2/W Splitter (dB)	N/A	3.5
Total Drop Loss (dB)	12.73	13.32
Tap Output dBmV	13.00	12.00
Minus Drop Loss = (Modem RX)	*0.27*	*-1.32*
Tap Output dBmV	10.00	9.00
Minus Drop Loss = (Modem RX)	*-2.73*	*-4.32*

The above modem RX examples would be typical numbers that should keep legacy, as well as upcoming DOCSIS 4.0 modems, within their desirable RX range.

For design purposes, *maximum* RX levels are generally in the +12.0 to +15.0 dBmV range. Taps immediately spliced to an active or hot tap with potentially higher than normal output levels should be monitored to be sure they are not causing excessive RX levels at the modem. The drop engineering we created is necessary for calculating tap output levels to be sure we will not exceed the maximum or drop below the minimum RX for particular modems.

Remedies for controlling excessive high tap output levels and modem RX vary across operators. One method of controlling excessively high tap spigot outputs is to increase the tap's value which will lower the drop port output dBmV. Using this method will also require the designer to be aware of upstream tap spigot input levels to be sure the higher tap face-plate value is not causing the modem to transmit out of its intended range. The higher the upstream loss in a network, the higher the modem will transmit to overcome the loss. Another method is to install internal plugin tap simulators which attenuate the tap spigot RF output levels on the downstream. These do not affect the downstream or upstream tap hardline (distribution cable) ports. They do however affect the upstream frequencies RF input from the modem through the tap drop spigots. As stated, care must be taken to ensure modems are not attempting to transmit out of their intended range.

5. Performance

With the increase in total bandwidth to 1.8 GHz, we now have a much wider spectrum to test and validate acceptable input and output RF signal levels in which to operate our amplifiers. As mentioned prior, in an OSP upgrade from previous legacy bandwidths out to 1.8 GHz, we must identify our network challenges. Those challenges can be summarized in a few words (e.g., **passive loss and coaxial cable attenuation at higher frequencies**). Amplifiers in a 1.8 GHz network upgrade will run at higher RF output levels than their previous counterparts. But we must be aware of the performance and TCP rules around establishing the new higher levels. The below checkmarks exemplify certain critical performance indicators to be mindful of.

	Reference
TCP – Total Composite Power	dBmV
NPR – Noise Power Ratio	dB
CCN – Carrier to Composite Noise	dB
CIN – Carrier to Intermodulation Noise	dB
CTN – Carrier to Thermal Noise	dB
CNR – Carrier to Noise Ratio	dB
MER – Modulated Error Ratio	dB
BER – Bit Error Ratio	dB

Figure 4 – Performance Indicators

6. Step-Down: TCP & Channel Power

The term "**step-down**" is in reference to an absolute decibel amount below the expected operational output of an active device at a specific frequency(s). Step-down is needed in high output 1.8 GHz modules to limit the TCP (Total Composite Power) of these modules and prevent the overdrive of RF amplifiers and unacceptable distortion levels. TCP is the combined amount of power of all signals within a specific frequency range (bandwidth).

It is vital in 1.8 GHz UHS (Ultra-high Split) design to maintain legacy cable modems as well as the new DOCSIS 4.0 gateway RX and TX specifications levels. The main thing to keep in mind is, yes, we are designing for greater total bandwidth and a higher split order in 1.8 GHz design, but we cannot ignore or cause out-of-spec situations for our legacy customers that still may be on DOCSIS 3.0 or 3.1 modems. When a node area is physically upgraded in the OSP it will take some time, possibly months or more, to transfer hundreds of customers in a given node area to DOCSIS 4.0 gateways. For this reason, the legacy customer premise equipment must continue to function. Receive (RX) and Transmit (TX) levels MUST be maintained and work for multiple generations of CPE.

1.8 GHz UHS actives have a significant increase in power over any previous generations of active devices. This increase brings with it challenges. While we need to harness the power, we really need to ***manage*** the power. This is done through step-down.

The goal is to utilize this higher power while maintaining distortion and performance acceptance levels. To exceed performance limits would mean introducing unwanted distortion into the network. Through a cascade of amplification, distortion only increases. It will never improve until the source or cause of the problem is changed. Without step-down, extending RF levels linearly out to 1.8 GHz could result in extremely high TCP levels exceeding 74 dBmV out of the RF hybrids. This is well beyond today's RF hybrid and amplifier technology.

DOCSIS 4.0 introduced the concept of RF level adjustments to manage TCP through signal level reductions to help improve amplifier performance. Operator "A" might use a single 6 dB step-down at 1.0 GHz OR 1.2 GHz. Operator "B" might use a 3 dB step-down at 1.0 GHz and a second 3 dB step-down at 1410 MHz, and so on.

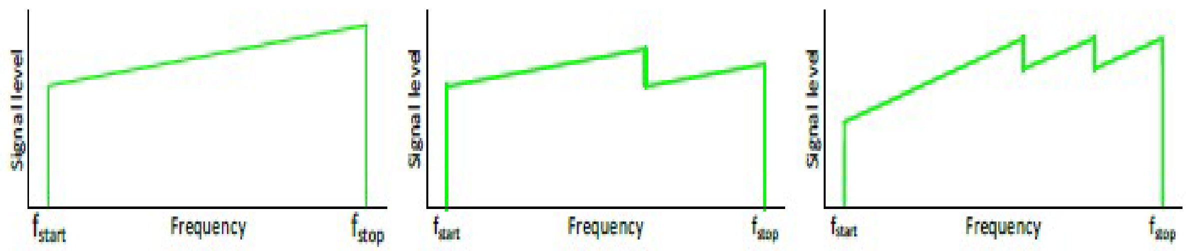

Figure 5 – Step-Down Frequency(s): Constant, Single, Multiple

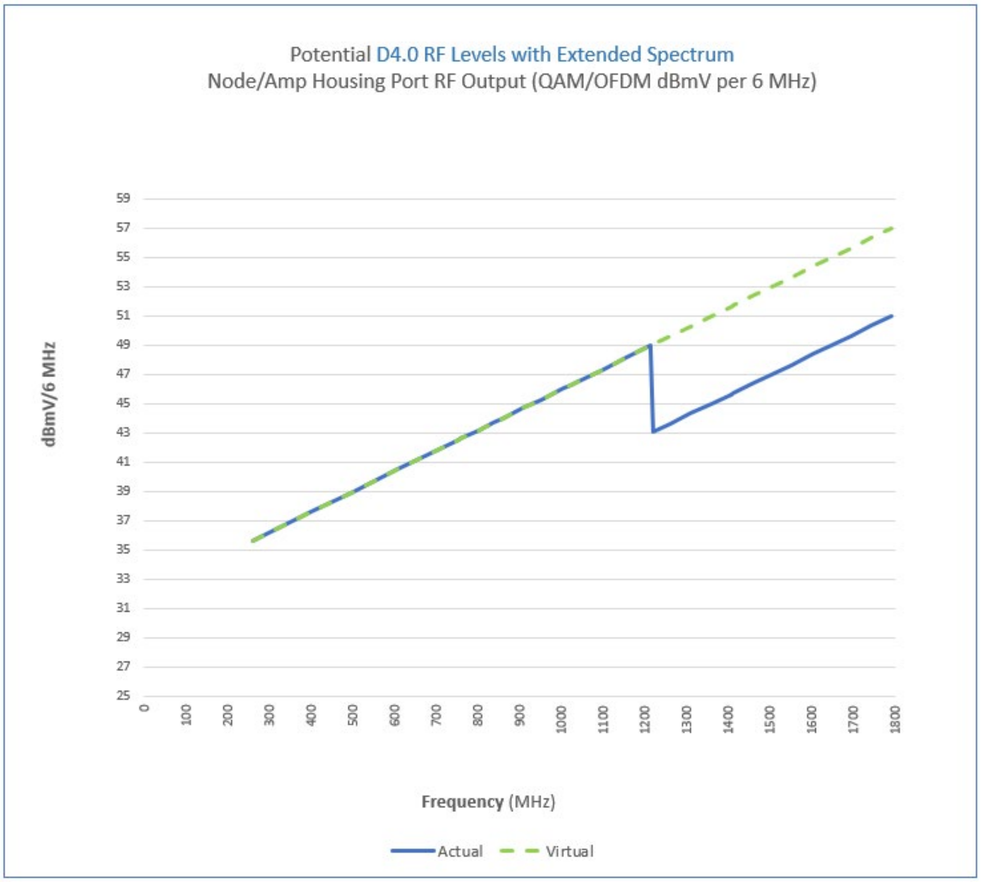

Figure 6 – Step-Down, Virtual- and Actual-Tilt, & Levels

Step-down occurs at the RF source right at the RPD (Node). It is already reduced as it travels downstream to the actives. In Figure 6, what we call "Virtual Tilt and Levels" is the dashed green line. "Actual Tilt and Levels" is the solid blue line. In this example there is a 6 dB step-down beginning at 1221 MHz and extending to 1800 MHz.

Virtual tilt (green line) is the RF power we would use in design software levels specification files. This is the amount of RF power the software will use to perform its calculations as we space and locate actives downstream in the network on trunk or express and extract tap values in our distribution.

In design, we don't subtract the step-down amount until we leave the tap. The RF power to 1.8 GHz is a straight, dashed, virtual line shown above in Figure 5. When we deduct the step-down amount, we begin at the lowest frequency where step-down is applied (actual). This deduction is subtracted from the tap output level from any frequency that is affected by the step-down.

Example: If we have a single 6 dB step-down starting at 1221 MHz, that means we have to deduct 6 dB starting at 1221 MHz and from all frequencies leading up to 1800 MHz. The same applies if we have multiple frequencies where step-down occurs. We would subtract the amount of step-down at the first lowest frequency where it is applied, then add that to the next highest frequency. This is now an accumulative amount of step-down all the way to 1800 MHz. So, two 3 dB step-downs would accumulate to 6 dB of total step-down at 1800 MHz.

At the operator level, calculating the exact frequency(s) and how much step-down to apply should be performed by those experienced in performance calculations. The step-down frequency(s) and step-down amount (dB) directly affect TCP dBmV, as shown in Table 5 and Table 6 below.

In addition, there is the TCP (dBmV) of the hybrid chips themselves, as well as the TCP at the active's housing port to be concerned with. Know that there is internal split loss from the internal power amp to the housing port. This usually ranges between 3 and 4 dB.

In Table 5, we are showing a 4 dB differential between the hybrid and the port. Note: Depending on variables, operators may have differing approaches and results when determining their TCP limits, forward tilt and operational levels.

Table 5 - Channel Power 61 dBmV and TCP Calculations

Channel Power @ 1791 MHz	Channel Power @ 1791 MHz	Channel Power @ 1791 MHz	Channel Power @ 1791 MHz
61 dBmV	61 dBmV	61 dBmV	61 dBmV
Tilt 57-1791 MHz	Tilt 57-1791 MHz	Tilt 57-1791 MHz	Tilt 57-1791 MHz
24.2 dB	24.2 dB	24.2 dB	24.2 dB
6 dB Step @ 1002 MHz	6 dB Step @ 1221 MHz	9 dB Step @ 1221 MHz	6 dB Step @ 1410 MHz
TCP @ Hybrid = 72.77 dBmV	TCP @ Hybrid = 73.46 dBmV	TCP @ Hybrid = 71.95 dBmV	TCP @ Hybrid = 74.53 dBmV
TCP @ Port = 68.77 dBmV	TCP @ Port = 69.46 dBmV	TCP @ Port = 67.95 dBmV	TCP @ Port = 70.53 dBmV

Looking at Table 5, the channel power at 1791 MHz is 61 dBmV. This is a virtual level out of the hybrid. This level will directly affect the virtual RF output levels we will be setting our 1.8 GHz actives output levels to operate in our design specifications files (actives' RF output levels are not the same as channel power). At the present time, manufacturers are indicating the amount of TCP that is tolerable at the port is between 68 and 70 dBmV.

Looking at Table 6, we have lowered the channel power by (1) dB to 60 dBmV. This also lowers our TCP. Our tilt of 24.2 dB remains the same. When we adjust channel power +/- we are raising or lowering the overall power levels, but not affecting the total tilt between the high and low forward frequencies. The ratio between them remains the same.

Table 6 - Channel Power 60 dBmV and TCP Calculations

Channel Power @ 1791 MHz	Channel Power @ 1791 MHz	Channel Power @ 1791 MHz	Channel Power @ 1791 MHz
60 dBmV	60 dBmV	60 dBmV	60 dBmV
Tilt 57-1791 MHz	Tilt 57-1791 MHz	Tilt 57-1791 MHz	Tilt 57-1791 MHz
24.2 dB	24.2 dB	24.2 dB	24.2 dB
6 dB Step @ 1002 MHz	6 dB Step @ 1221 MHz	9 dB Step @ 1221 MHz	6 dB Step @ 1410 MHz
TCP @ Hybrid = 71.77 dBmV	TCP @ Hybrid = 72.46 dBmV	TCP @ Hybrid = 70.95 dBmV	TCP @ Hybrid = 73.53 dBmV
TCP @ Port = 67.77 dBmV	TCP @ Port = 68.46 dBmV	TCP @ Port = 66.95 dBmV	TCP @ Port = 69.53 dBmV

7. Booster Type Actives for 1.8 GHz Design

The concept of booster type amplification is not new. Booster actives have been around since the 1970s. The use case for them was the same as it is today. They simply make up for a small amount of gain and cable footage allowing the next downstream active to realize its required RF input level and avoid relocation. In earlier years, cascades were longer and not as much of a concern as they are in today's modern networks where performance and distortion can add up rather quickly due to higher powered amplification and much greater channel loading.

Manufacturers of 1.8 GHz actives are still working through a plethora of ideas and concepts around what they perceive to be the best, most cost-effective booster product they can build given the obstacles it must overcome in 1.8 GHz networks. The devices must be:

- Cost effective (much less than a line extender)
- Smaller in size (not much larger than a typical line splitter or DC)
- Simple to install and set up (nowhere near the complexity of a conventional active)
- Small amount of gain, 11 to 15 dB (just enough to do the job)
- Good on performance (will contribute some, but minimal performance degradation)
- Power efficient (will not add significantly to current loads)
- Minimal bells and whistles (avoid complexity, keeping the price point as low as possible)
- Flexible in terms of where it can be placed in the network to deliver, but adds minimal noise contributions

Creating boosters in design software is much different than that of conventional actives. Conventional actives are completely predictable in terms of performance contributions along with their required RF input levels and fixed RF output levels. Boosters are none of these things. They are a complete moving target dependent upon where they are placed in the network and what the RF level inputs happen to be at that location. For this reason, the RF outputs will vary. Boosters are simply: RF input + Gain = RF output. This works the same on the downstream and upstream, subject to the gain in each direction. Boosters typically will have 2x to 4x the gain on the downstream as they do on the upstream. The gain is generally fixed. In some units there can be attenuation options. Some also have fixed or variable equalization. But in general, they are much simpler than a line extender.

Boosters will typically amplify the entire downstream and upstream spectrum, similar to conventional actives, but with much less gain. As stated, booster gain is typically between 11 and 15 dB at 1.8 GHz and dropping significantly as we go lower in frequency.

Design managers will have to train their designers on *how, when,* and *where* to deploy boosters. They cannot just be placed anywhere in a network with regard to maintaining performance. They are not intended to be used for every RF signal short-fall or design problem. A network can quickly get into trouble if too many boosters are used incorrectly, adding to cascade depth, performance degradation and power loads.

8. Design Modeling Legacy OSP With 1.8 GHz Proposed Upgrades

There must be careful coordination and synchronization between calculating TCP and performance measurements along with proposed RF network design levels and tilts. Depending upon current legacy plant conditions and previous design practices, proposed 1.8 GHz upgrades can go smoothly and stay within a projected budget, or be problematic and present significant cost-over-runs.

Once preliminary design specifications are created based on acceptable TCP and other performance indicators, network design modeling should be performed on actual legacy nodes or networks. This is a great way to test the design specifications for their effectiveness as well as present the opportunity to adjust them where needed.

The effectiveness of the design outcome in terms of making spacing of previous actives and providing service taps with minimal additional amplification are key to keeping construction, materials and equipment costs as low as possible.

Module drop in upgrades are the most common type of network expansion that has been the standard protocol for the past 25 or more years. These past drop in upgrades were somewhat simpler and easier to create design specifications for because the bandwidth expansions were generally 200 MHz or less.

Example Past Bandwidth Increases:
- 450 MHz to 550 MHz
- 550 MHz to 750 MHz
- 750 MHz to 870 MHz
- 870 MHz to 1002 MHz
- 1002 MHz to 1218 MHz

This coupled with the fact that electronics manufacturers increased the gain in the higher bandwidth amplifiers helped to ensure enough gain for an upgrade expansion, as shown previously in Table 1, to maintain existing actives spacing. As long as the legacy housings could accommodate the newer modules drop in, very little needed to change in the physical plant to facilitate this type of upgrade budget model. Construction and splicing costs could be kept to a minimum.

The proposed upgrade from a 1.0 GHz low- or mid-split system to a 1.8 GHz high-split or ultra-high-split system introduces certain facts that must be addressed as discussed herein. In this event, the downstream is an immediate 800 MHz increase in total bandwidth (1.0 GHz to 1.8 GHz). The upstream has its challenges as well, increasing from 42 MHz or 85 MHz to 204 MHz or 396 MHz. Again, higher bandwidth, greater RF losses.

Rebuilds generally happen when much of the existing coax needs to be replaced for various reasons. The outside plant may need significant plant extensions or additional coax added due to a newer architecture, such as going from an older Trunk and Bridger network to all Express architecture. Or from lengthy cascaded older networks to reduced Node + 0, Node + 2, Node + 4; or even going to N+6 would be a cascade reduction in some older networks.

Working through the gain and cable spacing examples shown previously will greatly help define successful and cost effective 1.8 GHz design and deployment. An operator must make decisions and budget accordingly regarding a complete rebuild or network upgrade. The differentials between these cost models are substantial.

9. Performing Network Due Diligence Ahead of Budgeting

No matter how much OSP due diligence is performed ahead of an upgrade or rebuild, something is bound to remain an unknown until it is known. Below are some of the more common items for consideration that can affect bandwidth expansions and costs:

- An operator must decide if their current design and plant mapping records are recent or accurate enough to perform a design upgrade to 1.8 GHz. Be mindful that if outside plant conditions have changed enough over time and have not been updated or reflected in the mapping records, it may be more difficult and costly to make certain 1.8 GHz design adjustments once construction is underway. A new field walkout or survey may be needed prior to beginning the design process.
- Limitations in 1.8 GHz active cascades. Can they meet the existing amplifier cascades? Is reducing lengthy cascades in older networks to Node + 0, Node + 2, Node + 4 or even N+6 part of the upgrade requirement? It is not recommended to exceed five to six 1.8 GHz actives in a cascade due to performance issues. This should be discussed with your chosen vendor(s).
- Prevent or limit node splitting as much as possible. In addition to the cost of the nodes themselves, node splitting generally means adding or extending new fiber optic cabling to feed them.
- Are high homes passed or service group counts in need of reductions or balancing to prevent future network bottlenecks or choke points?
- Avoid the relocation of current active locations. Moving active locations can be costly due to de-splicing and re-splicing. In addition, potential re-design at the new location(s), as well as the old, may now be needed and cause re-splicing and or equipment revisions of downstream legs.
- In many cases the chosen 1.8 GHz actives for the upgrade are duplicates of the current actives in terms of their type, configuration, and porting. Avoid re-splicing of current coaxial cabling configurations at actives locations to the greatest extent possible. Try to design by emulating the current cabling configurations while adhering to the new network design specifications.
- Adjust tap levels requirements using similar logic as illustrated in the drop engineering exercises shown previously. If it is discovered later that the modems are having RX or TX issues, costly design and construction revisions may become necessary.
- Leverage the existing outside plant coaxial cables to the greatest extent possible to avoid the placement of new or additional cabling.
- Be sure to use the manufacturer's powering specifications from their 1.8 GHz actives equipment specifications. Do not assume they are the same as previous generations of the same actives type. The newer 1.8 GHz actives in many cases use less power than previous generations of actives and may save the need to place additional power supplies.

- Create a set of design rules with respect to an upgrade. This will help prevent designers from making assumptions due to lack of guidance. The final designs will be much more consistent and cost effective if the rules are followed and assure best network performance.
- 1.8 GHz bandpass lab testing of legacy connectors, pin seizure mechanisms and splices has proven to be a factor. The manufacturers have addressed these issues within new amplifier and passive device housings, including backwards compatibility replacements in some older equipment.

If, however, you have certain types of splices, such as splice blocks, pin connectors or any equipment that is connected and intended to continue to use as is without revisiting them, to assure 1.8 GHz bandpass, you may find that they do not pass beyond 1.0 GHz. Or there can be a significant roll-off due to the connector. This can be a noteworthy cost increase if not considered or allocated for in budget planning.

10. Conclusion

This paper presents some of the more crucial and sometimes overlooked concerns regarding the creation of RF design specifications with respect to upcoming bandwidth expansions. It focuses on the approach from a pragmatic point of view using simple, real-world examples and calculations. Challenges and hurdles exist in any planned upgrade and there are a multitude of factors to consider. The greater the proposed bandwidth increase, the greater the challenges.

There are also numerous physical OSP challenges discussed herein that must be identified ahead of a planned upgrade and corresponding budgeting. The physical revisions needed depend on the design. Physical plant revisions or additions can contribute to the highest single budgetary costs.

In closing, the main message is this: we must do our due diligence. Leveraging the existing infrastructure and overall configuration of the OSP to be upgraded is to our biggest advantage and will help to ensure the least costly budget.

The creation of effective but accurate RF design specifications that honor performance is key to healthy bi-directional networks that can deliver the products and services intended.

Abbreviations

bps	bits per second
CPE	customer premises equipment
dB	decibel
dBmV	decibels relative to one millivolt
DC	directional coupler
DOCSIS	data over cable service interface specification
DS	downstream
EEQ	electronic equalizer
gbps	giga bits per second
GHz	gigahertz
HFC	hybrid fiber coax
MER	modulated error ratio
MHz	megahertz
NPR	noise power ratio
OFDM	orthogonal frequency division multiplexing
OSP	outside plant
POE	point of entry
QAM	quadrature amplitude modulation
R&D	research and development
RF	radio frequency
RX	receive
TCP	total composite power
TX	transmit
UHS	ultra-high split
US	upstream
W	watts

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