ATLANTA, GA
OCTOBER 11-14

2021 Fall Technical Forum
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The Road to 10G

Migrating Today's HFC network to meet Tomorrow's Demand

A Technical Paper prepared for SCTE by

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1. Introduction

The hybrid fiber coaxial (HFC) network has served as both a reliable and flexible architecture which has enabled cable operators to continue to migrate their networks to meet the exponential growth in bandwidth demanded by both commercial and residential customers. This architecture has supported cost effective capacity increases with minimal disruptions to the network and end-users. While more recent efforts have focused on building fiber-to-the-home (FTTH) networks, they are generally quite expensive with cost estimates often nearing $1000 per household passed (HHP) or greater. Given the long-term capacity of an all-fiber network, it may be considered the obvious choice for green field deployments. However, for brown field areas, the cost of a FTTH network upgrade drives the continued evolution of the existing HFC architecture as a better choice.

The introduction of extended spectrum Frequency Division Duplex (FDD) Data Over Cable Service Interface Specification (DOCSIS) within the DOCSIS 4.0 specifications enable that continued evolution by defining standards that for Cox would support capacities as high as 12 Gbps on the downstream and 3 Gbps on the upstream across the legacy HFC node and amplifier (N+X) architecture.[CM-SP-PHYv4.0] The strategy for operational implementation of this upgrade will be a critical component to the success of multi-Gig deployments over HFC.

This paper will explore several considerations for upgrading the HFC network to 1.8 GHz FDD DOCSIS 4.0 including a drop-in amplifier approach, intermediate upgrade steps, amplifier gains/tilts, and other operational aspects.[1]

2. Requirements and Constraints

A key challenge for cable system operators is the ability to transform the HFC network to meet the growing bandwidth demands while simultaneously continuing to provide reliable services to a large existing customer base. In fact, many of these customers have service level agreements (SLAs) in place which prohibit significant down time in the network. As a result, it is almost always the case that an operator cannot upgrade an entire market or, in some situations, even a single node within a maintenance window of a few hours. The ability to execute an upgrade to a network in incremental steps while continuing to support legacy devices and services is critical to the success of the operator, and the evolution to 1.8 GHz extended spectrum DOCSIS will be no exception to this requirement.

2.1. Tap Output Radio Frequency (RF) Levels

The DOCSIS 4.0 specification was developed with an assumption that extended spectrum DOCSIS 4.0 FDD signals operating up to 1.8 GHz would be communicating with a single point of entry (POE) device in the home. That is, there would be no splitters, drop amplifiers, or pass-through devices between the tap output and the DOCSIS 4.0 customer premise equipment (CPE) device. For extended spectrum FDD, this assumption was based upon the need to provide adequate forward signal levels at the CPE to support up to 1.8 GHz in spectrum with higher order quadrature amplification modulation (QAM) levels. Historically, operators have modeled drops with 2 or 4-way splitters and a 100-150 ft of cabling. With a POE device, at a minimum, the 2 or 4-way splitters are no longer necessary providing an additional 4 to 8 dB of signal level to a DOCSIS 4.0 device. However, that signal level increase does not carry-over to

[1] The authors wish to acknowledge and express their appreciation to others in the Cox Outside Plant Engineering team who also contributed to the technical work presented in this paper

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legacy devices in other homes. It will take significant time for operators to migrate their in-home CPE to DOCSIS 4.0, and, as a result, the network will be required to support both single DOCSIS 4.0 POE device homes and legacy homes with multiple CPE devices including legacy video.

2.1.1. *Legacy Levels*

Video service offerings were the driver for the birth and growth of the cable industry during the 70's, 80's and 90's. The incorporation of data services (DOCSIS) was first introduced in the late 90's long after video services provided in the form of set tops were prolific within the network. While many operators, including Cox, are developing roadmaps to replace proprietary video CPE devices with Internet Protocol Television (IPTV), it is both cost prohibitive and infeasible to do a wholesale replacement of millions of these legacy devices within a short time. As a result, operators are required to continue to support both legacy video and data services to set tops and cable modems at their current location within the home as they migrate the network. This requirement constrains the architecture as tap output power levels in the legacy spectrum must be kept close to what they had been prior to the upgrade. When tap levels change, legacy CPE devices within the home are at risk of no longer receiving the minimum signal level required, driving the potential for a poor customer experience and truck rolls.

During Cox's initial experimentation with node plus 0 amplifier (N+0) architectures in 2017, early attempts were made at minor reductions in tap output levels to increase the reach or HHP per node. (See Figure 1) Early trials revealed a more than 20% increase in truck rolls and while there are a number of factors which can contribute to truck rolls when migrating from a N+X to a N+0 architecture, subsequent trials with restoration of design tap output level targets to more closely match legacy levels brought the number of truck rolls back in line with historical levels.

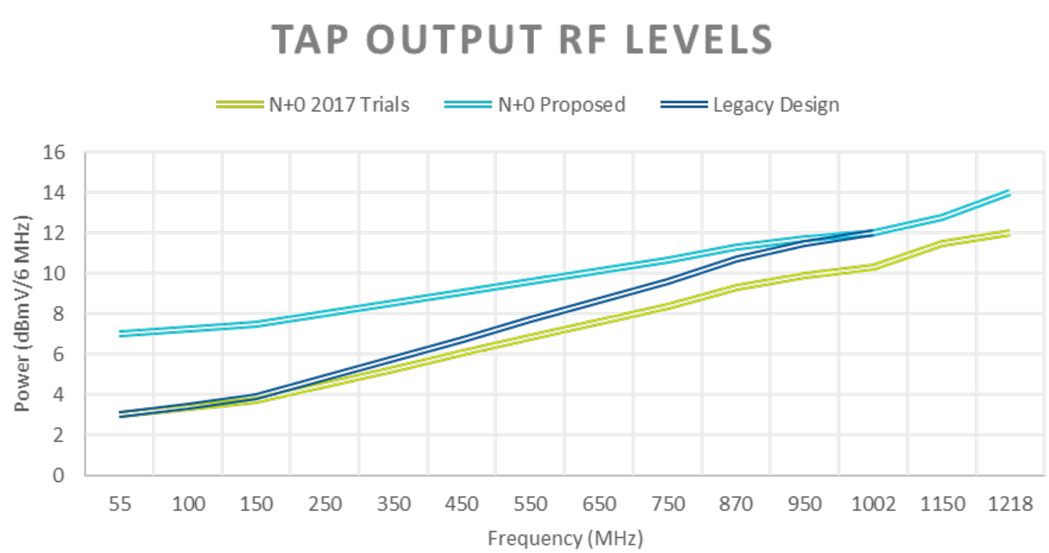

Figure 1. Previous Cox Trials Revealed the Importance of Maintaining Legacy Levels

2.1.2. *In-House Conditioning*

In addition, a more subtle dependency in tap output levels also exists. While HFC plant design constraints dictate a minimum tap output level, fielded implementations generally yield levels that are

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above that minimum. See Figure 2 for an example of output levels for a series of 5 consecutive taps on a cable run between amplifiers. Actual output levels are provided in blue and minimum design requirements are provided in red. If a future change or upgrade to the plant results in the output levels changing, for example, if any of the actual output levels are reduced and brought closer to the design minimum levels, then any homes/devices connected to taps whose output levels were reduced might be at risk of no longer functioning properly.

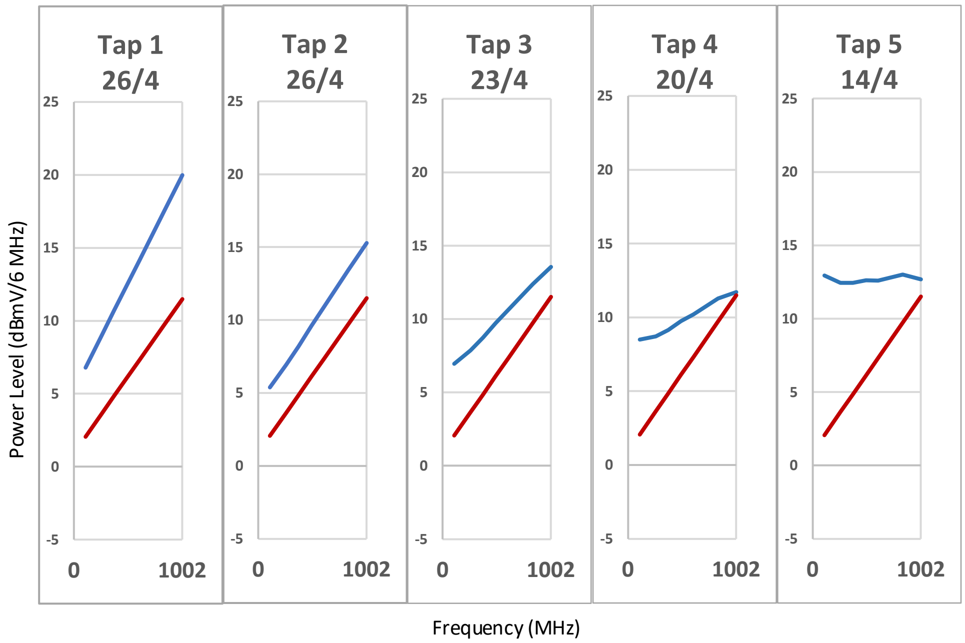

Figure 2. Example Tap Cascade Output Levels (Blue) versus Minimum Design Spec (Red)

While the red curve meets minimum design constraints, there is a risk that in-house wiring may have leveraged the additional power previously provided at that tap to deliver adequate levels perhaps deeper into the home. That is, either the operator or the homeowner may have placed devices within the home that leveraged this additional power. Alternatively, technicians may have installed in-home attenuators to force levels closer to what they considered to be optimum. If the levels are subsequently lowered (but still at or above spec), adequate signal level may not be present for those devices, driving the need for possible in-house amplification, splitter reconfigurations, or attenuator removals that were not required before. From the homeowner's perspective, his service was working before the upgrade but no longer functions properly afterward. This situation can be referred to as in-house conditioning and is quite common.

2.2. Mainline Amplifier Considerations

During most prior HFC downstream bandwidth upgrades, a "drop-in" approach was used. The drop-in term was meant to convey that legacy amplifier locations were maintained and that new amplifier modules/stations with increased downstream bandwidth were dropped in as replacements at those locations. Mainline passives (taps, splitters, and directional couplers) also maintained their legacy locations and were only replaced if needed to support the increased downstream bandwidth. The drop-in approach minimized the need for extensive plant construction/redesign that would have been required if amplifier locations were moved, which in turn helped minimize downtime during the upgrade.

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When considering a 1.8 GHz upgrade, the drop-in approach continues to be attractive in that upgrades to passives (which far outnumber actives) could be accomplished regardless of whether the amplifiers in the area have been upgraded or not. This increases the flexibility to efficiently deploy resources for that part of the upgrade and enables small sections of plant (down to individual feeder legs) to be upgraded without the long duration outages inherent in upgrades where actives move locations, requiring the passives to be changed along with the actives.

Historically, both downstream amplifier gains and downstream amplifier RF output levels were increased to help facilitate drop-in upgrades while maintaining amplifier and tap RF output levels in the existing legacy band. Each are discussed next in more detail.

2.2.1. Downstream Amplifier Gain

To facilitate a drop-in bandwidth upgrade, the downstream gains of the mainline amplifiers were increased to offset increased cable losses at the higher frequencies. Table 1 below shows the downstream amplifier gains for many of the amplifiers commonly used in North America, and how they increased as downstream bandwidths increased.

Note that downstream amplifier gain generally refers to the gain at the downstream upper band edge (highest rated frequency). It is important to keep in mind that sufficient gain is required to offset the coaxial and passive losses between amplifiers (to achieve unity gain) and that gain requirements are not directly linked to amplifier RF output levels.

Table 1 – Amplifier Gains for 750, 870, 1000, and 1218 MHz Amps

Manufacturer	Amplifier Type	Operational Gain at Rated Frequency (dB)			
	Amplifier Rated Frequency (MHz):	750	862/870	1000	1218
Commscope - Motorola	MB-AGC	36	38	42	47
	4 Port BT–AGC	40	40	42	-
	BLE–AGC/Therm/Man	28	30	34	38
Commscope – C-COR	FMB–AGC	37	40	43	47
	FMT–AGC–Trunk Port	28	30	33	36
	FMT–AGC–Bridger Ports	37	39	43	47
	FM LE–AGC/Therm	30	32	35	38
	FM LE-Manual	33	35	38	42
Cisco - SA	HGBT–AGC/Therm		38	41	46
	HGD–AGC	35	40	43	48
	HGD-Therm	39	40	43	48
	UBT–AGC–Main Port	28	31	34	-
	UBT–AGC–Bridger Ports	37	40	43	-
	LE-AGC	24.5	31	33	38
	LE-Thermal	29	32	34	38
	LE-Manual	34.5	37	39.5	-

For a full drop-in type of upgrade to 1.8 GHz to be supported, the downstream gains for the amplifiers would need to increase even higher.

Figure 3 shows the historical gains for Line Extenders plotted against cable loss increases. The frequency axis was extended to show the associated gains that would be required for drop-in upgrades to 1.8 GHz. A cable length and type (1360 ft of PIII .500 cable) whose loss matches the legacy gains at various lower

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frequency points was selected to graphically show the increased gain versus increased cable loss relationship. This shows the gains required if the span loss preceding the amplifiers were all coax, and if the amplifiers were at maximum spacing.

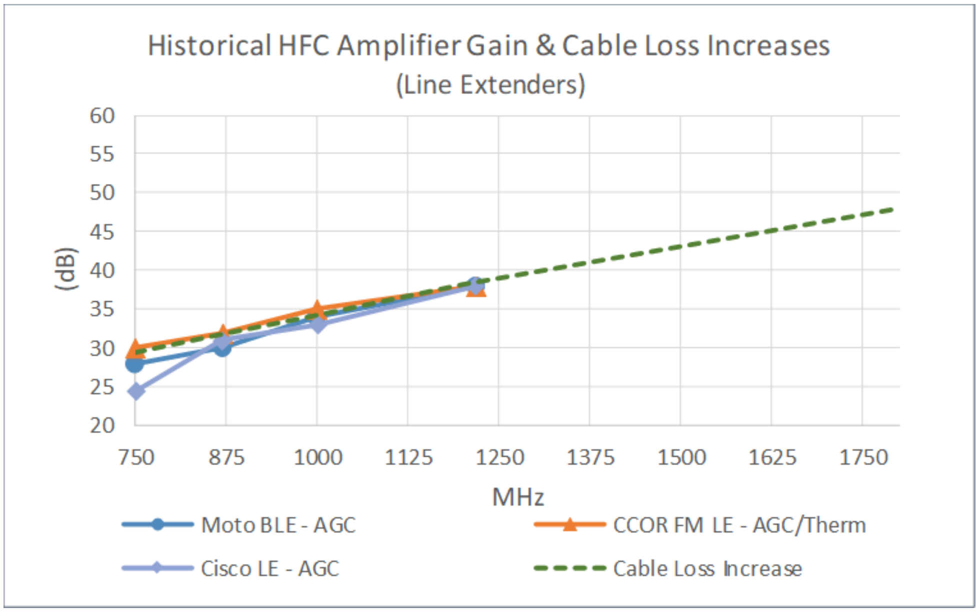

Figure 3. Line Extender Gain & Cable Loss Increase

For Line Extenders, the gains shown are for automatic gain control (AGC)/Thermal types. Based upon this information, gains at 1.8 GHz of approximately 48-49 dB may be required for full drop-in capability for these type amplifiers. There appears to be some consensus in the industry that this amount of gain is feasible for 1.8 GHz Line Extenders.

An internal Cox study was also performed to estimate what Cox's actual 1.8 GHz spacings would be for AGC/Thermal Line Extenders. Information from Cox's design data base was used to determine the existing 1 GHz coax and passive losses preceding each Line Extender. Based upon vendor data sheets, coax losses were increased by 40 percent and passive losses by 20 percent and summed to estimate the expected total loss at 1.8 GHz. The results are shown in histogram format in Figure 4.

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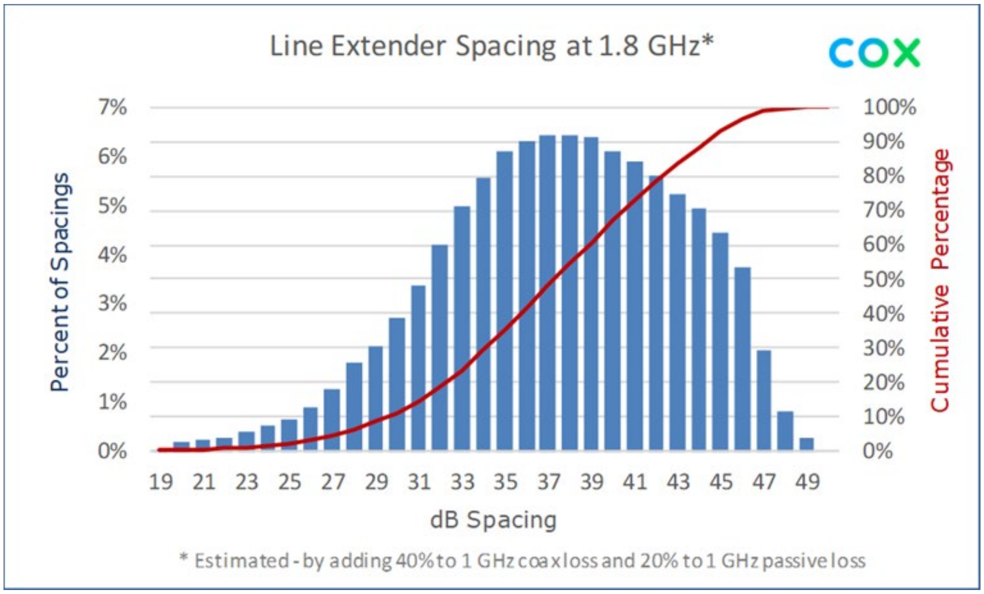

Figure 4. Estimated 1.8 GHz Line Extender Spacing for Existing Cox Spans

The histogram correlates the above assumption that AGC/Thermal Line Extenders with 48-49 dB of gain at 1.8 GHz should cover the vast majority of spacings for these type amplifiers using a drop-in upgrade approach.

Figure 5 shows the historical gains for high gain Multiport Bridger amplifiers plotted against cable loss. The frequency axis was extended to show the associated gains that would be required for drop-in upgrades to 1.8 GHz. A cable length and type (2450 ft of PIII .750 cable) whose loss matched the legacy gains at various lower frequency points was selected to graphically show the increased gain versus increased cable loss relationship. This show the gains required if the span loss preceding the amplifiers were all coax, and if the amplifiers were at maximum spacing.

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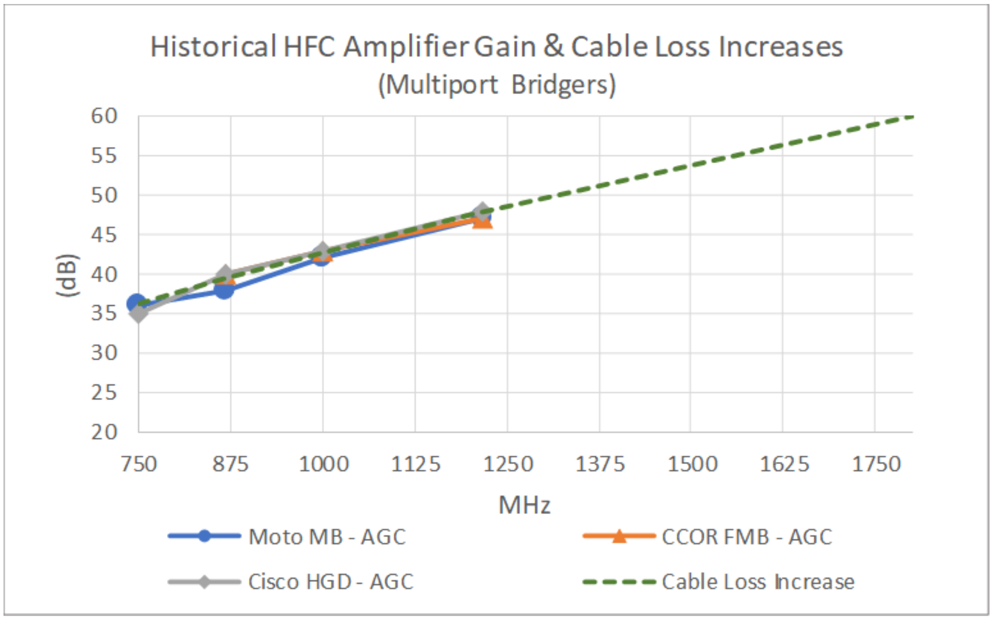

Figure 5. Multiport Bridger Amplifier Gain & Cable Loss Increase

For Multiport Bridgers, the gains shown are for AGC types. Based upon this information, gains at 1.8 GHz of 59-60 dB may be required for full drop-in capability for these type amplifiers. There appears to be consensus that this amount of gain would not be feasible for these types of amplifiers. For one, Carrier to Noise Ratio (CNR) would suffer due to the extremely low input levels that would need to accompany amplifiers with such high gains. Additionally, it would be very difficult to achieve sufficient closed loop isolation in a station with so much downstream gain combined with an increased upstream gain. There appears to be some consensus in the industry that 48-50 dB gain would be feasible for these types of amplifiers, but in systems that had made use of maximum spaced amplifiers with high coax losses in their legacy plant that would not be enough gain to overcome losses at 1.8 GHz. This led to the consideration of ways to address this concern.

The Booster Amplifier concept was conceived based upon the realization that there could be a 10 to 12 dB gain shortage in some cases where high gain Multiport Bridgers had been deployed at or near full spacing where most of the loss was coaxial. At Cox, this is called an express application, where the RF from the node was fed deeper into the network to efficiently reach tapped feeder areas by using lower loss express cable in conjunction with high gain amplifiers. In scenarios where the 1.8 GHz drop-in amplifier would not have enough gain to cover the high express losses, Cox initially considered adding a Line Extender, but realized a preference to use a smaller, lower gain, lower cost amplifier placed in the express cable route to supplement the drop-in amplifier's gain. Currently several amplifier manufacturers are planning to make such amplifiers which have come to be known as Booster Amplifiers. Cox recognizes that installing these type amplifiers will be much easier in aerial plant than in underground, but even in underground there are often locations along long express runs where the cable run is interrupted to accommodate a splitter, coupler, or splice block.

An internal Cox study was also performed to estimate what Cox's actual 1.8 GHz spacings would be for AGC Multiport Bridger amplifiers, to determine what percentage of those amplifiers might need Booster Amps added. Information from Cox's design data base was used to determine the existing 1 GHz coax and passive losses preceding each amplifier. Based upon vendor data sheets, Cox increased those coax

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losses by 40 percent and passive losses by 20 percent and summed them to estimate the expected total loss at 1.8 GHz. The results are shown in histogram format in Figure 6.

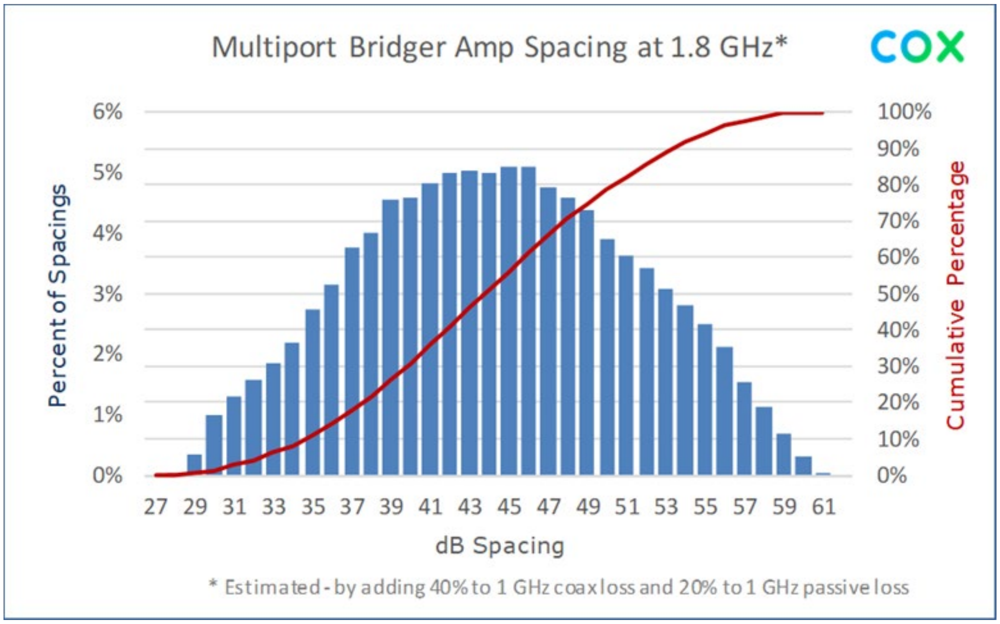

Figure 6. Estimated 1.8 GHz Multiport Bridger Spacing for Existing Cox Spans

The histogram shows that Multiport Bridgers with 48-50 dB of gain at 1.8 GHz should cover roughly 75 to 80% of Cox's spacings for these type amplifiers using a drop-in upgrade approach. The remaining 20 to 25% would require the addition of a Booster Amplifier. With Multiport Bridger amplifiers representing about 32% of the network, Cox's expects to need booster amplifiers for approximately 8% of the network spans.

2.2.2. Downstream Amplifier RF Output Levels

When considering downstream amplifier RF output levels for plant upgrades to 1.8 GHz, two important aspects must be considered. One is how closely the tap RF output levels after the upgrade should match the current tap RF output levels in the legacy band, and the other is the total composite power (TCP) constraints that exist when operating amplifiers with significantly greater channel loading at high output levels. When considering a drop-in upgrade approach these two factors are inherently linked.

The expectation that both legacy CPE and the new extended spectrum D4.0 CPE will need to co-exist in the same network for years to come should be well understood. With that comes a requirement to consider both the downstream RF levels that will feed the legacy CPE and the new extended spectrum CPE. As was mentioned prior, Cox learned that in order to minimize the potential for service complaints and associated truck rolls when performing a plant upgrade, it is best to keep the downstream RF levels feeding legacy CPE very close to what they were.

If the assumption is to leave the downstream RF output levels of the taps nearly unchanged in the legacy band, and to replace the existing taps with 1.8 GHz taps using the same tap values (which looks possible based upon 1.8 GHz tap insertion losses), then it follows that the downstream RF output levels of the replacement amplifiers should remain nearly unchanged in the legacy band. At Cox, the legacy band is 54 or 108 MHz to 1002 MHz for most of the network. Existing typical node/amplifier RF output levels in

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that band are shown in Figure 7. Note that actual signal level per 6 MHz is shown (not analog equivalent).

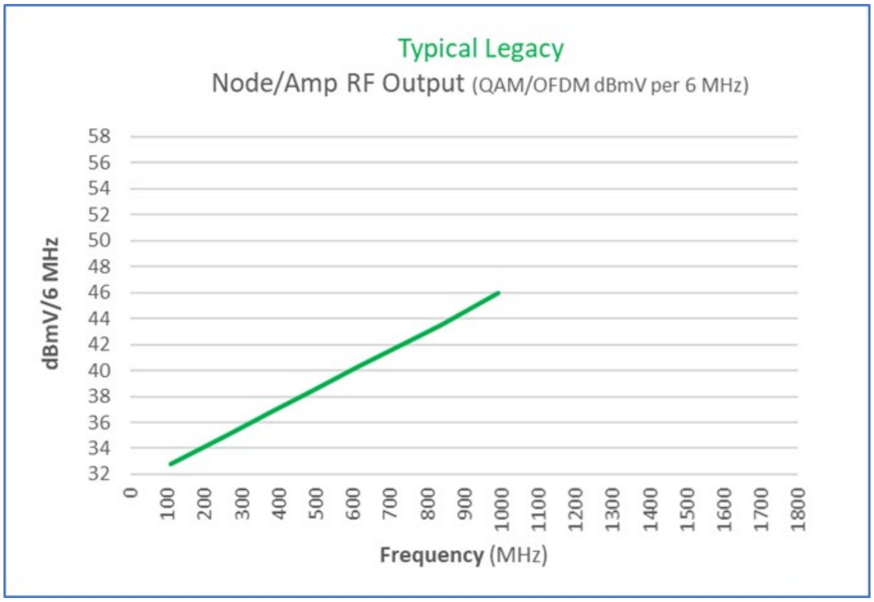

Figure 7. Typical Node/Amp RF Output Levels

In drop-in plant upgrades from 750 or 870 MHz to 1002 MHz, traditionally the amplifier RF output levels were increased along a common output tilt line. This trend also applied to some earlier plant upgrades that started at 550 MHz and has recently been incorporated for upgrades to 1218 MHz. Evidence of this approach is shown in Table 2 and Figure 8. Table 2 shows the reference output levels on the published data sheets for two major manufacturer's amplifiers. Figure 9 shows the same information in graphical format. While not all operators ran the exact reference RF output levels that were specified on published data sheets, most did tend to use similar RF output tilts as those shown.

Table 2 – Amplifier Data Sheet Reference Output Levels/Tilts (dBmV/Channel – analog equivalent)

Mfr	Rated Frequency (MHz)	Amp Type	54 MHz	750 MHz	870 MHz	1002 MHz	1218 MHz
S-A	750	LE, HGD, HGBT	36	46			
S-A	870	LE, HGD, HGBT	35	45.7	47.5		
S-A	1002	LE, HGD, HGBT	35	45.7	47.5	49.5	
Moto	750	BLE, MB, BT	37	47			
Moto	870	BLE, MB, BT	37	47	49		
Moto	1002	BLE, MB, BT	37	47	49	51	
Moto	1218	BLE, MB	38	48.2	49.9	51.8	55

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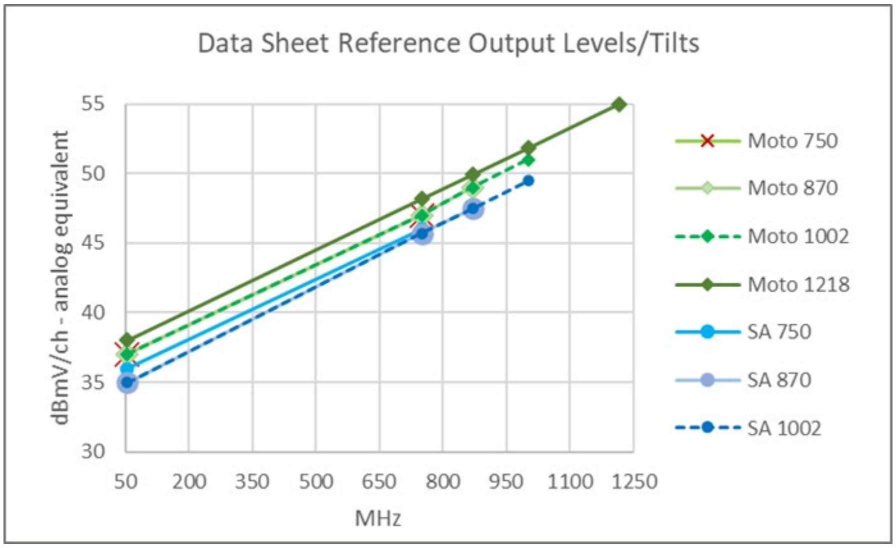

Figure 8. Amplifier Data Sheet Reference Output Levels/Tilts

Cox followed the trend of increasing the RF output levels along a common tilt line during upgrades to 1002 MHz; however, using a similar approach for upgrades to 1.8 GHz introduces a problem. Figure 9 shows what that would look like.

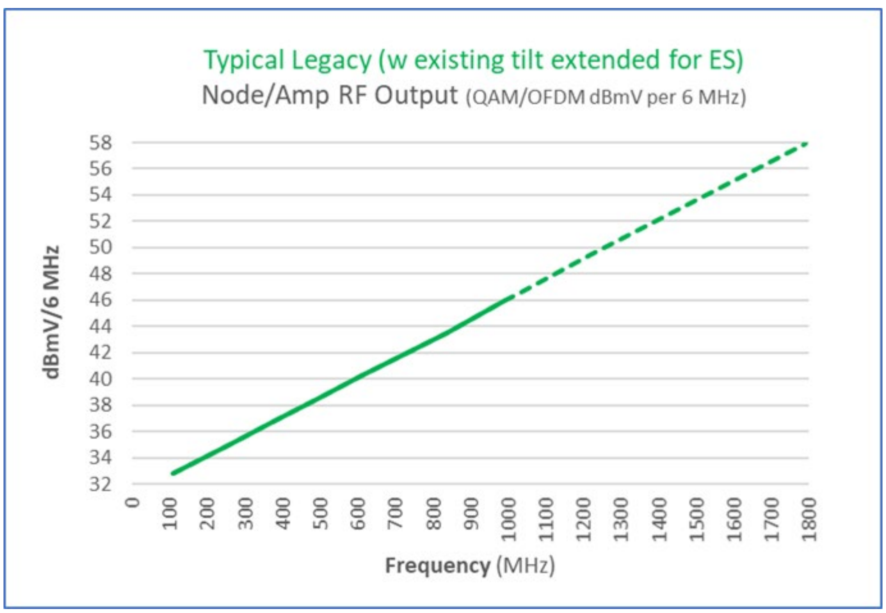

Figure 9. Typical Node/Amp RF Output Levels - if extended to 1.8 GHz

If the tilt line representing Cox's typical amplifier RF output levels in the legacy spectrum was extended out to 1.8 GHz and the band was fully loaded at those levels, the total composite power (TCP) at the amplifier output would be excessively high reaching 74.8 decibels relative to one millivolt (dBmV). It is worth noting that the associated TCP for the legacy band in this case is only 62.7 dBmV. If you consider that there may be roughly 4 dB of loss from the output of the final amplifier gain stage (commonly referred to as the power amplifier) to the station RF output port, 74.8 dBmV TCP at the port would equate

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to ≈ 78.8 dBmV TCP at the power amplifier output. That is much higher than any power amplifier can currently support while outputting usable signals.

The TCP limitations of state-of-the art broadband power amplifiers were recognized early on during the extended spectrum discussions, as similar discussions had gone on previously in association with the very high RF output powers required for N+0 architectures. All broadband amplifiers have limitations on how high they can run before distortion becomes excessive. The question of how high the new amplifiers will be able to run with extended spectrum loading is under investigation but gain block manufacturers are diligently working to optimize and characterize their output power capabilities. While beyond the scope of this paper, it is worth mentioning that there's more than one aspect to consider, as in some cases better performance may come at the cost of higher power consumption.

For reference, amplifier output TCP can be calculated by converting the output signal level (in dBmV per 6 MHz for each 6 MHz of bandwidth that will be occupied) to power (typically expressed in milliwatts), summing those powers, and converting the summed power to dBmV.

When the limitations due to TCP were discussed in conjunction with the desire to keep RF amplifier output levels near to what they have been in the legacy band, the idea of reducing or stepping down the RF power in the extended spectrum became a widely discussed topic. Various output power profiles for the extended spectrum were suggested, such as making use of multiple step downs; up to one per 192 MHz orthogonal frequency division multiplexing (OFDM) channel (referred to as zig-zag or lightning bolt), or shaping the amplifier RF output power in the extended spectrum to be flat while keeping the legacy spectrum tilted (referred to as tilt-flat).

After much discussion, most operators coalesced around the idea of having one or possibly two step downs in the extended spectrum, with all output power levels referenced to a virtual linear tilt line from lowest to highest frequency (referred to as tilt-tilt). This concept was not new, as prior to conversions to "all-digital" signal carriage, cable operators ran amplifier RF outputs referenced to what was called an "analog equivalent" tilt line - with analog video carriers ran at the levels shown on the tilt line and digital (SC-QAM256) signals typically ran 6 dB lower relative to the tilt line.

The ability for the DOCSIS 4.0 remote PHY device (RPD) / remote MACPHY device (RMD) in a distributed access architecture (DAA) node to make use of a step down (or multiple step downs) in the extended spectrum was written into the D.4.0 PHY specification. Up to 10 dB of step-down capability was mandated. The step-downs, once created at the RPD/RMD module, would pass through amplification and tilt stages in the node so that the tilted RF output with associated extended spectrum step-downs would be outputted at the node RF output ports. With this approach, the broadband amplifiers following the node in N+X architectures would not have any part in producing the RF profile with the step downs, and would just need to make use of equalization, amplification, and internal tilt to allow the duplication of the tilted RF output with associated extended spectrum step downs at their RF output ports.

With the extended spectrum step-down capability, operators will need to work to optimize a variety of factors. If it is desired to maintain legacy band amplifier RF output levels near to what they have been, the amount of step down for the extended spectrum can be adjusted to align the output TCP of the amplifier to a place that the operator deems to be optimum. That will require interaction with amplifier station manufacturers familiar with the output level capabilities of the amplifiers.

Some of the trade-offs to consider are that increasing the amount of extended spectrum step down lowers the TCP and increases the RF power margin between design operating levels and the point where significant ill effects from amplifier overdrive occur – such as 4-5 dB reduction in modulation error ratio

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(MER) with only 1 dB increase in levels, or the onset of significant bit errors. That margin needs to be considered because real world amplifiers and networks will have some inherent factors that could cause amplifier output levels to be higher than targeted. Those factors include the accuracy of the actual RF output levels versus the programmed RF output levels, the AGC's ability to hold output levels over temperature, and the fact that frequency response build-up in the network can increase the TCP even when high and low frequency output levels are held tightly at target levels. On the flip side, increasing the amount of extended spectrum step down reduces the RF input levels to amplifiers and the DOCSIS 4.0 modems in that spectrum, which can reduce overall carrier to noise and potentially reduce the order of modulation that the extended spectrum OFDM signals can support.

At Cox, based upon vendor feedback concerning power amplifier performance and on Cox's plant performance modeling, Cox identified two potential initial target profiles for amplifier RF output levels, shown in Figure 10 below. The green trace represents holding Cox's RF output levels in the legacy spectrum where they are now, extending that virtual tilt line, and using a 6 dB step down in the extended spectrum from 1 to 1.8 GHz. This represents a total virtual tilt of 25.1 dB from 111-1791 MHz. The blue trace shows what is Cox's preferred option, where the legacy RF output level at 1 GHz is held, but the overall virtual tilt is reduced and again a 6 dB step down is used in the extended spectrum. This represents a total virtual tilt of 21 dB from 111-1791 MHz.

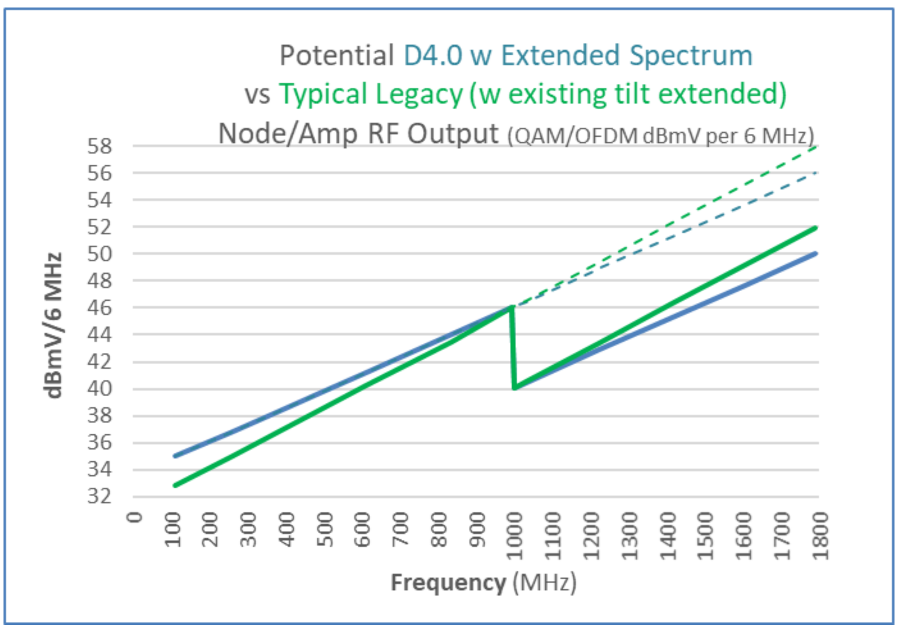

Figure 10. Potential Amplifier RF Output Profiles for 1.8 GHz

There are three potential advantages to the reduced tilt option:

1. Cox learned from amplifier gain block manufacturers that not all TCP is created equal. While it is true that conceptually, amplifiers with lower TCP also produce lower distortion, it has been found that the RF power at the highest frequencies has a disproportionate effect on distortion that is not captured via TCP differences alone. The RF energy at those very high frequencies can cause significant effects on the overall distortion, and it appears that keeping the RF energy lower at those frequencies is beneficial. In the blue reduced tilt trace the RF output power per 6 MHz at 1791 MHz is 2 dB lower than in the green trace.

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2. There is also an improvement in TCP for the blue reduced tilt trace (68.6 dBmV) compared to the green higher tilt trace (69.5 dBmV).

3. The first incarnations of 1.8 GHz taps available on the market have "flatter" insertion losses than legacy taps, i.e., less tilt from low to high frequency across the band. Since the losses at 1 GHz are no greater than the losses of the legacy taps they will replace, and they are flatter, that means that the losses at the lower frequencies for the new taps end up being somewhat higher. With the blue reduced tilt profile, the higher outputs from the amplifiers in the lower frequency range help to offset the effect of a tap cascade having higher insertion losses in that band.

Based upon modeling, the slight reduction in RF power per channel at the higher frequencies with the detilted blue trace profile does not appear to be enough to alter the supported order of OFDM modulation in that region; however, Cox will continue to work with amplifier manufacturers to monitor measured performance attributes and further adjustments to the extended spectrum step down may be needed.

One final input on this topic. Since Cox's initial efforts to develop a target amplifier RF output profile, a new wrinkle came up, which was the need to plan to support 1.2 GHz high-split in portions of the network. Understanding that RF output levels in the new 1 to 1.2 GHz spectrum will become a legacy condition to deal with on the road to 1.8 GHz, Cox put careful thought into what should be done in that spectrum. Many of today's DOCSIS 3.1 RPD's and the software applications used to configure them do not currently support the 6 dB step down shown above while continuing to provide quality overall performance. Cox also realized that if that spectrum was deployed with no step down, it would be painful to later reduce those levels significantly to match the 6 dB step down with the migration to 1.8 GHz. After careful consideration, Cox's current plan is to introduce a 3 dB step down, which is more readily available in RPD products today, in the new 1 to 1.2 GHz spectrum. With respect to how that will play into the eventual migration to 1.8 GHz, the target RF output profile (with the new double step approach), is shown in Figure 11 below. This did increase TCP slightly (by 0.3 dB to 68.9 dBmV) relative to the initial target shown above. There is a benefit in that OFDM signal in the ≈ 1 to 1.2 GHz spectrum is now expected to have better MER than anticipated in the original single stepdown profile. The virtual tilt from 111-1791 MHz remains unchanged at 21 dB.

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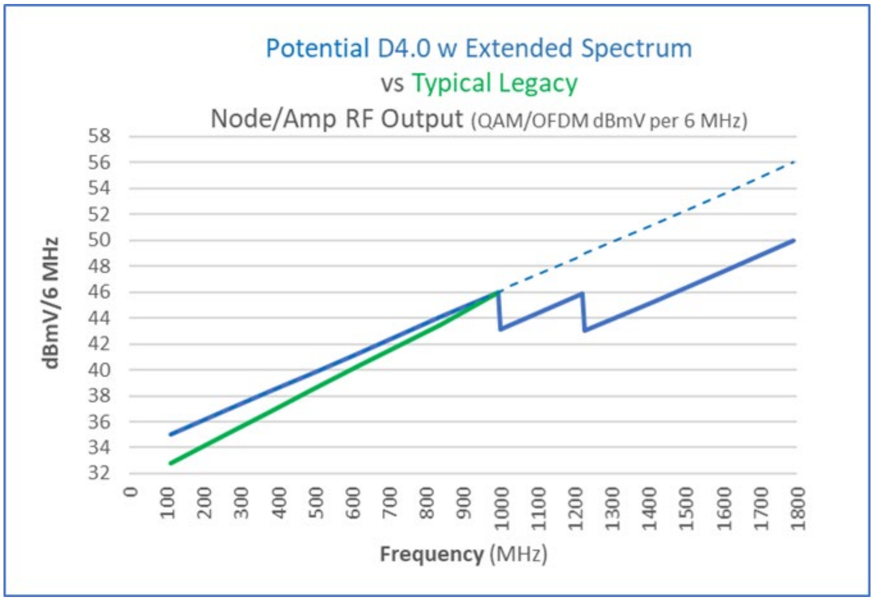

Figure 11. Current Potential Amplifier RF Output Profile for 1.8 GHz

2.3. Impacts of Spectrum Changes

Cable operators have a great deal of experience over the years with frequency expansion upgrades, i.e., increasing the top end frequency of the network (e.g., 550, 750, 870, 1000 MHz); however, these upgrades have always targeted increasing the downstream bandwidth and have rarely modified the upstream/downstream frequency split until recently. The transition from sub-split (42/54 MHz) to mid-split (85/108 MHz) represents one of the first times that operators are moving that upstream/downstream frequency split. Movement to mid-split is a minimal impact upgrade as most services that are locked into a particular frequency do not fall in the affected range or, if they do, the services were agile enough to allow movement beyond the band of change. With the transition to a high-split configuration (204/258 MHz), operators can no longer expect minimal impact as several downstream services are fixed in the spectrum below 204 MHz which will transition to upstream.

2.3.1. Service Impacts

One cannot say that DOCSIS has not been a resounding success. Cable was once a video only service that is now a majority data service. The compounded annual growth rate (CAGR) of data services continues to be in the 30% range, putting pressure on the need for more and more bandwidth devoted to data. This has led to an unprecedented number of node splits annually and the move to mid-split to relieve upstream congestion. Mid-split and the move to high-split and eventually ultra-high-split reduces the available downstream bandwidth below 1 GHz. While the higher spectral efficiency of DOCSIS 3.1 has helped significantly, it is not enough by itself.

2.3.1.1. QAM Video

To compensate for the reduced downstream bandwidth, Cox has converted QAM based video from MPEG2 to MPEG4, reducing the number of QAM video channels from approximately 70 to 42. Cox has already made extensive use of switched digital video (SDV) to reduce the number of QAM channels devoted to video. The MPEG4 conversion allowed the move to mid-split and the addition of another 96 MHz DOCSIS 3.1 OFDM block with no reduction of video services. Eventually, over a several year

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period, Cox plans to eliminate QAM based video services in favor of IPTV. Approximately 10% of our video base is already IPTV only. Based on current utilization, an all IPTV 250 HHP node would consume approximately 450 Mbps of IPTV traffic at peak busy hour. That is equivalent to ¼ of a DOCSIS 3.1 OFDM block, or 48 MHz (8 QAM video channels). However, the conversion to all IPTV comes at a significant price, the retirement of QAM only STB's and a much larger population of DTA's. The newest generation of QAM enabled STB's include bonded DOCSIS 3.0 modems and can be converted to IPTV.

There is also significant interest in being able to offer a symmetric gigabit service prior to the availability of DOCSIS 4.0. There are two paths using DOCSIS 3.1 to achieve this. The first is to move to high-split and increase the upper end of the downstream spectrum to 1.2 GHz to recover the lost downstream bandwidth. This requires that not only actives in the plant be upgraded, but passives will have to be upgraded beyond their current 1 GHz limitation. A second approach would be to accelerate the move to IPTV, removing QAM video from the network and devote that bandwidth to DOCSIS. This would require retiring all QAM-only CPE including the millions of DTA's in the network. The plant upgrade would then touch only actives and would be similar in cost to a mid-split upgrade. The tradeoff is then the cost of the passive upgrade vs. the cost of retiring CPE. Both must be done eventually to meet the final DOCSIS 4.0 ultra-high split (UHS) end state. A "halfway" solution is also possible; Cox dedicates 16 of the QAM channels to SDV/VOD. Retiring the QAM only CPE would allow removing the SDV/VOD QAMs from the network, keeping the broadcast QAMs and DTAs. This would allow high-split on 1 GHz plant with only a slight limitation in DOCSIS capacity while minimizing the amount of retired CPE.

2.3.1.2. Legacy OOB STBs

The upstream move to high split or ultra-high split introduces several issues. The first is the legacy out-of-band (OOB) downstream for STB's. Downstream OOB is limited to a highest frequency, by specification, of 130 MHz, which now falls in the upstream spectrum. Cox has retired all legacy OOB STB's in favor of DOCSIS Set top Gateway (DSG) STB's, however customer owned UDCP devices, such as TiVo, that use CableCards are required by regulation to be supported using legacy OOB. Several approaches to a solution have been proposed, such as moving the OOB to a higher frequency in the downstream and providing an in-home down converter for devices needing legacy OOB. Cox has chosen another approach, along with other operators, in developing a DSG to legacy OOB converter to be placed in the homes of UDCP customers. This eliminates the need for OOB support within the coaxial network.

2.3.1.3. Impacts of HS and UHS Devices

Large numbers of sub-split and mid-split STB's and modems will continue to be in the network, potentially for years, after high-split or ultra-high-split (UHS) networks are enabled. A high-split DOCSIS 3.1 modem or an UHS DOCSIS 4.0 modem could be transmitting upstream with levels bursting as high as 65 dBmV, with a significant portion of that energy falling within the downstream passband of the sub-split or mid-split devices. For a STB or modem, the total composite power (TCP) received from the network may be on the order of 20 dBmV. The automatic gain control (AGC) on the front end of those devices reacts relatively slowly, and the bursting upstream from the high-split or UHS modem, even through the isolation of a splitter, may overload the front end of the older device causing dropped packets or macro blocking. For this reason, Cox is recommending that all homes that are high-split or UHS enabled, should be single point-of-entry, and any video services should be IPTV only using wired or WiFi connectivity to the gateway. A potential similar problem exists for adjacent homes off the same tap of a high-split or UHS home. However due to drop cable loss and better isolation in the tap, analysis

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estimates this to be a problem in less than 5% of adjacent homes. Remediation could be through conversion of that home to HS/UHS or the installation of upstream blocking filters in that home.

2.3.1.4. MoCA Networks

Cox, along with other operators, has a significant footprint of Multimedia over Coax Alliance (MoCA) enabled homes used for multi-room DVR or in some cases WiFi extensions. Nominally, MoCA point-of-entry (POE) filters are used to isolate MoCA signals from the network and from interfering with adjacent MoCA networks. Once the downstream spectrum is extended above 1 GHz, to 1.2 or 1.8 GHz, MoCA will be incompatible with the network. Homes that have only 1 GHz CPE and MoCA, can continue as is if the MoCA POE filter provides adequate isolation. Homes using spectrum above 1 GHz cannot use MoCA, and any existing POE filters will have to be removed and the MoCA network replaced with WiFi or other compatible network technology within the home.

2.3.2. The Downstream Bandwidth Squeeze

In order to execute the migration process of increasing both the upstream and downstream frequency spectrum, two options are available as illustrated in Figure 12 and Figure 13. Figure 12 illustrates one option which provides for the lowest cost and lowest network downtime, as it benefits from completing the construction process (upgrading the node, and amplifiers for both upstream and downstream with the desired upstream/downstream frequency split) as a single step. However, by executing the entire construction change as a single step, the network maybe temporarily forced to operate with reduced downstream bandwidth, referred to here as the “squeeze”. The operator can avoid the squeeze by deploying an adequate number of CPE supporting the higher downstream frequency prior to the upgrade to absorb the lost bandwidth incurred by raising the split. Some limited modeling has indicated upgrading 20% of the CPE deployment should provide adequate congestion relief. However, the fact that these devices will need to be single point of entry (and drive the need to swap other sub-split and mid-split in-home devices) may limit early customer acceptance and thusly, the ability for an operator to deploy CPE early.

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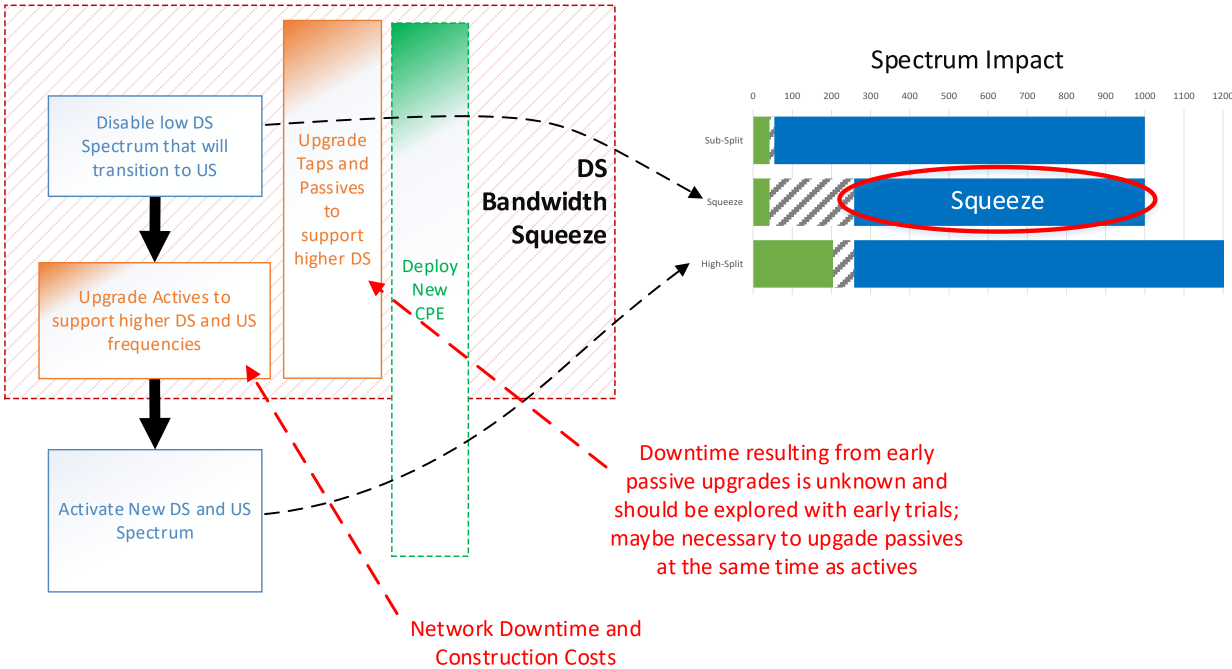

Figure 12. Migration Option to Support both DS and US Frequency Expansion with Minimal downtime but possibly incurring a Bandwidth Squeeze

Figure 13 illustrates a second option which eliminates the downstream bandwidth squeeze by executing the construction process as two steps. First the operator replaces the active and passive components to handle the higher downstream frequencies and activating that new downstream prior to changing the upstream/downstream frequency split in the actives. In parallel, the operator would be upgrading the CPE population to accommodate the increased downstream spectrum until an adequate number of high frequencies devices are deployed to eliminate the possibility of congestion when lower downstream spectrum is disabled to make room for upstream. Once an adequate number of new CPE were deployed, the operator would execute a second step to upgrade the active components a second time with the desired upstream/downstream frequency split and activating the new expanded upstream bandwidth.

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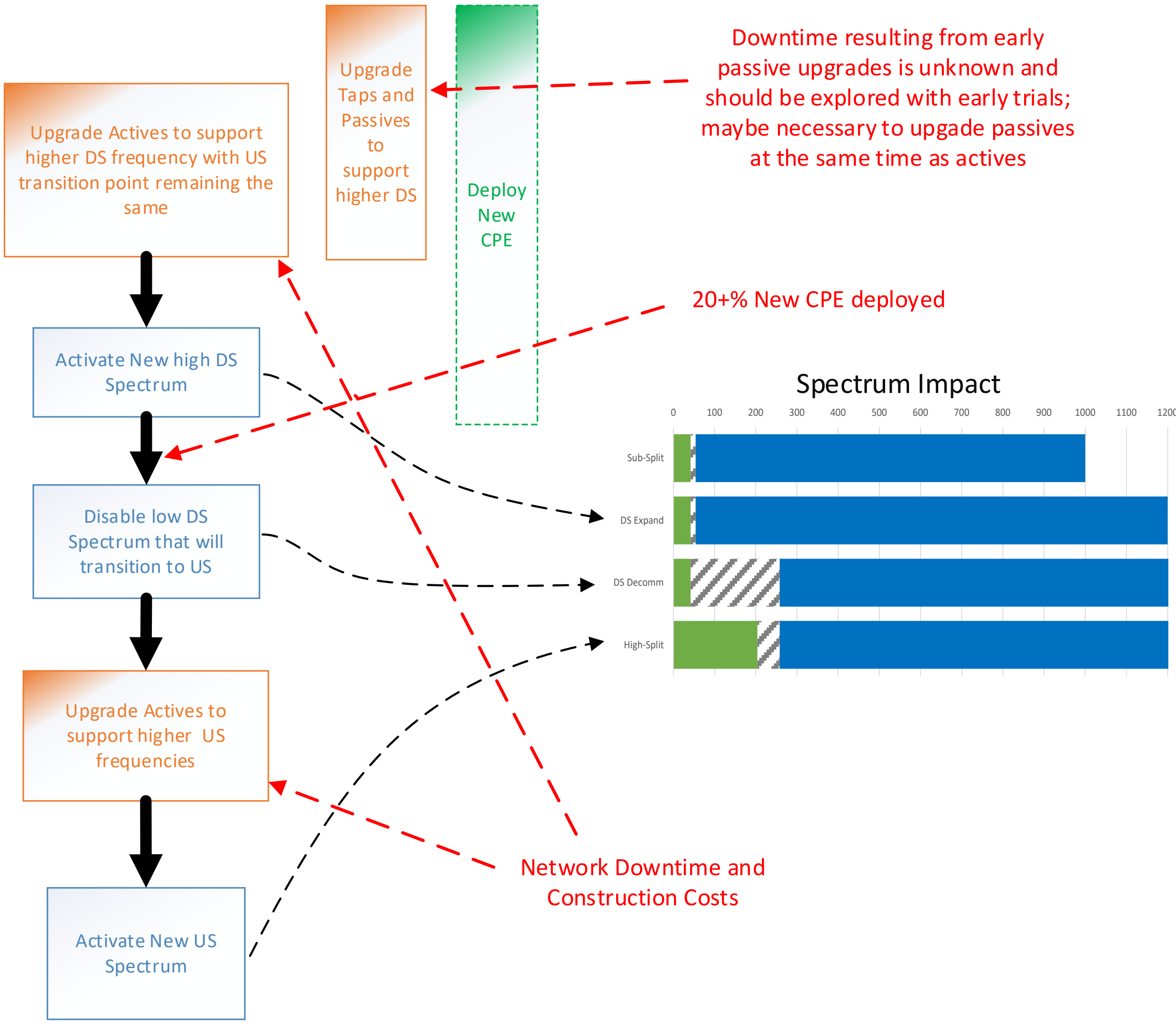

Figure 13. Migration Option to Support both DS and US Frequency Expansion with Increased Costs and Downtime but without a Bandwidth Squeeze

The increased costs and extended customer impacts in network down time, make the second option an undesirable choice. As a result, cable operators are strongly incentivized to identify ways to temporarily absorb the lost downstream bandwidth during the migration process. In the case of Cox, efforts are currently underway to look at accelerating the retirement of legacy video spectrum and replacement with IPTV which will provide some downstream spectrum relief during this transition period. Alternatively, operators may want to investigate accelerating their high-split upgrades prior to downstream congestion problems to also enable some absorption of this spectrum squeeze.

2.3.3. FCC Requirements for Leakage

Signal leakage is another factor which introduces significant challenges for operators as they move to DOCSIS 4.0 FDD, and, in particular, increased upstream spectrum. In the United States, the Federal Communications Commission (FCC) mandates that operators actively monitor their networks for signal leakage to assure that HFC network signals don't interfere with wireless services. While the FCC's requirement extends to many wireless services and frequencies, aircraft navigational signals (ranging

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from 108 to 137 MHz) are of particular concern and as such, operators are required to provide documentation annually to the FCC to assure compliance.

Historically, this frequency band overlapped with what is the downstream spectrum on the cable plant (sub-split or mid-split spectrum plans). (See Figure 14) As such, vendor solutions relied on reference leakage test signals either generated by specialized equipment feeding the combining network in a headend or by RPDs in the case of DAA. With the consideration of high-split and ultra-high-split spectrum configurations, the lower edge of the downstream moves to 258 MHz or higher. The leakage reporting region of the aeronautical band is then clearly in the middle of the upstream frequency spectrum.

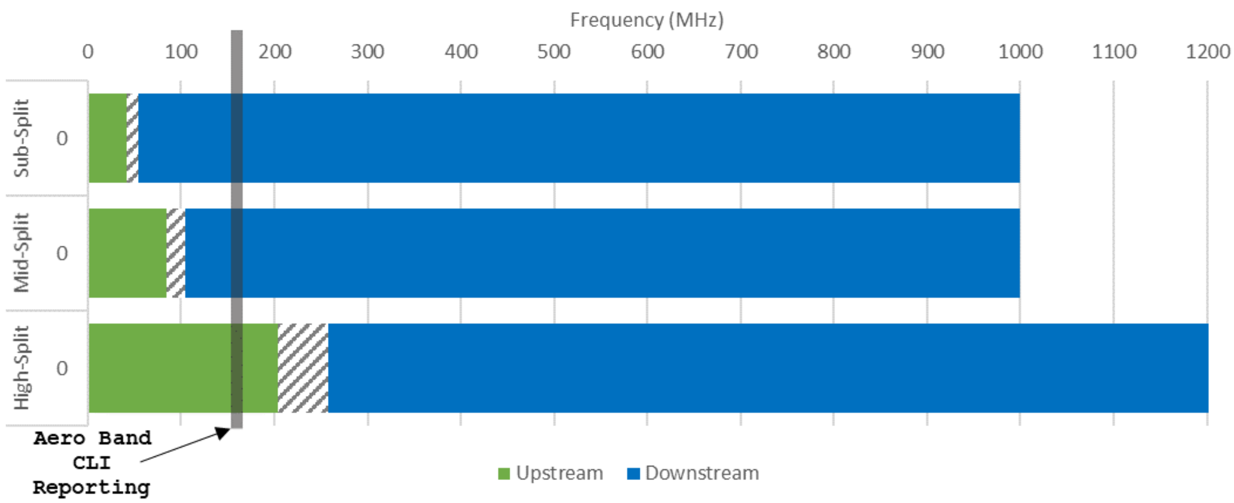

Figure 14. Leakage Reporting Spectrum Relative to Upstream/Downstream Split Configurations

This is a fairly dramatic paradigm shift for the leakage problem in that historically downstream signals are at their peak at the outputs of nodes and amplifiers in the network and are weaker as they progress through the tap outputs and onto the drop and in-house wiring. Conversely, upstream signals are near their peak at the cable modem output (on the order of 40 dB stronger than the downstream signals at the same point in the network). As a result, the signals in the aeronautical band are stronger in the house and on the drop, which is also the most common location of leaks.

High-split leakage solutions require a reference signal sourced from within the home to manifest these leaks within the network. An upstream signaling protocol called OUDP, that was part of the initial DOCSIS 3.1 standard, was leveraged to generate this reference signal. With some minor enhancements to the DOCSIS specifications, the industry enabled any DOCSIS 3.1 or 4.0 CPE device to function as a leakage reference signal source.[MULPIv3.1][CCAP-OSSIv3.1][MULPIv4.0][CCAP-OSSIv4.0] While requiring only firmware updates to CPE and CMTS devices, this solution does require hardware upgrades to leakage meters in order to detect this new signal. As a result, operators will need to lead their network upgrades with leakage meter upgrades to their truck fleet prior to enabling high and ultra-high-split configurations. It is generally expected that leakage meter vendors will provide solutions that function in both high-split and mid/sub-split networks enabling operators to continue to meet FCC reporting requirements during the transition period of upgrading from sub/mid-split to high/ultra-high-split on their network.

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3. DOCSIS 4.0 Migration Strategy

The optimal strategy for upgrading a cable operator's network depends upon several factors including initial architectural state, network congestion conditions, competitive positions, as well as planned future product offerings. In addition, standardization of an architecture is highly desirable providing an operator with economies of scale in all aspects of business operations including volume pricing, flexibility in supply chain management, market product offerings, organizational knowledge, network maintenance, and technical expertise. However, the diverse set of factors affecting the strategy means that operators must plan the execution at a global level while realizing that they will often need to respond in a local market to unique competitive situations.

With Cox's EON (Extended Optical Network) program which began in 2007, Cox became one of the first cable operators to migrate their network to a 1 GHz design; however, Cox chose to remain at a sub-split configuration (42/54 MHz upstream/downstream frequency split) during that upgrade primarily due to its large base of legacy video CPE requiring significant amounts of downstream QAM video spectrum. As time progressed, due to other efficiency upgrades such as MPEG4, Cox remained fairly well positioned relative to downstream capacity; however, in more recent years, Cox has begun to experience the pressure of upstream bandwidth demand with more and more nodes encroaching upon upstream congestion.

The most common tool readily available to operators to address congestion problems is a node split. (See Table 3) Node splits are a rather coarse tool that divides the serving area in half providing the same capacity to both serving areas, each with half as many users. It effectively provides a doubling of capacity for both the downstream and upstream. However, node splits are a congestion relief tool only as they cannot provide for an increase in individual maximum customer rates since the total spectrum allocation remains the same.

Table 3 – Relief Levers Available to Operators to Address Bandwidth Challenges

Bandwidth Challenge	Target Issue	Relief Action
Congestion Relief	Upstream and Downstream	Node Split
Congestion Relief	Upstream	Mid-Split
Product Competition	1 Gbps Symmetric	High-Split
Product Competition	2 Gbps Symmetric	Ultra-High-split

In recent years, Cox has experienced an enormous growth in necessary node actions with more than 90% of those driven to address upstream congestion issues. Initially, Cox leveraged node splits, however, beginning in 2020, Cox turned toward mid-split plant upgrades as the preferred course of action. Mid-split upgrades provide an additional 150% of upstream spectrum (from 30 MHz of usable upstream spectrum to nearly 75 MHz) providing greater upstream congestion relief while also providing for a greater maximum sustained data rate.

3.1. Capacity Milestones

While a mid-split configuration provides for significant runway for operators dealing with the tactical problem of upstream node congestion, it fails to address some of the key upstream data through-put milestones such as 1 Gbps upstream which may be desired due to competitive threats. Table 4 provides the expected maximum sustained data rates for various split configurations under consideration by Cox. Similarly, Figure 15 provides for possible Cox frequency allocations for these split configurations. Table 4 illustrates that the capacities provided by DOCSIS 4.0 enable HFC to remain competitive with all-fiber networks. High-split and ultra-high-split configurations enable operators to offer 1 Gbps and 2 Gbps

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symmetric speeds respectively through their networks. As such, it is the DOCSIS 4.0 1.8 GHz ultra-high-split configuration that is the end game for this plan.

Table 4 - Split Configuration Maximum Sustained Data Rates

Split Config	Upstream	Downstream
Sub-Split (42/1002 MHz)	0.1 Gbps	5 Gbps[1]
Mid-Split (85/1002 MHz)	0.5 Gbps	5 Gbps[1]
High-Split (204/1002 MHz)	1.5 Gbps	6.5 Gbps[2]
High-Split (204/1218 MHz)	1.5 Gbps	9 Gbps[2]
Ultra-High-Split (396/1794 MHz)	2.5 Gbps	12 Gbps

1 Assumes D3.1 limit of 2 4k-OFDM blocks and 48 D3.0 channels DS
2 Assumes all DOCSIS 4.0 4k-OFDM DS

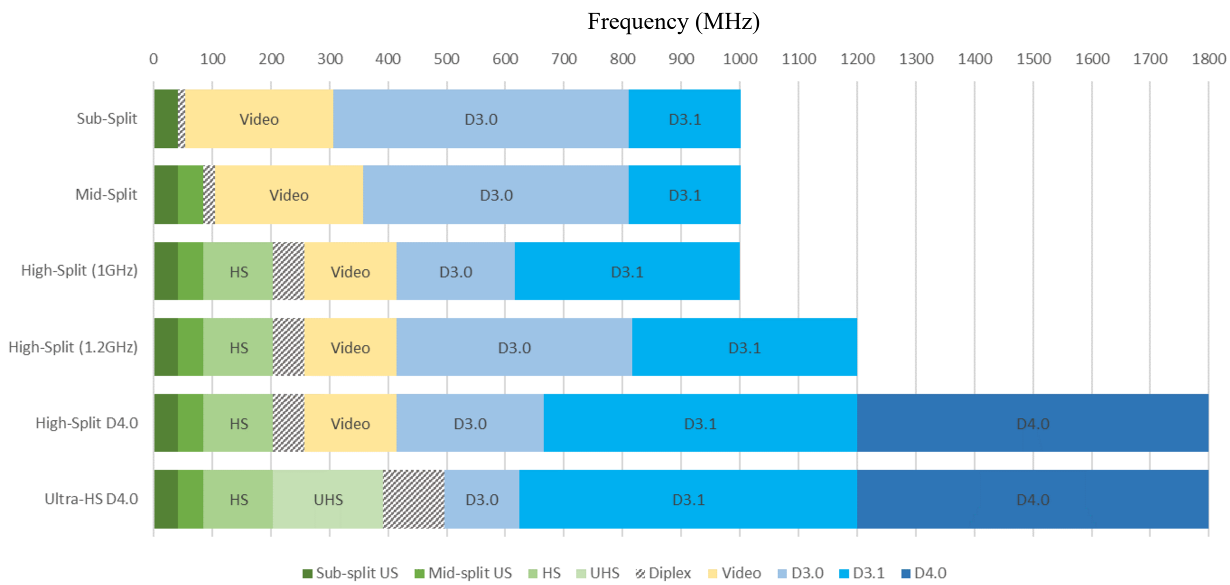

Figure 15. Possible Cox Spectrum Allocations for Various Split Configurations

3.2. Cost Implications

One important element to consider when evaluating migration paths is cost, and for the purposes of this analysis, Cox considered 8 alternatives for reaching a 1.8 GHz ultra-high-split target. (Figure 16). Each colored column in Figure 16 represents a network capacity as identified in Table 4. The circles in Figure 16 represent the network state of the plant where the letters represent the upstream/downstream frequency split (SS is sub-split, MS is mid-split, HS is high-split, and UHS is ultra-high-split) and the numbers represent the highest frequency supported by the actives and passives respectively. For example, the orange circles represent a network state with a high-split configuration and with nodes/amplifiers supporting 1.2 GHz, and taps/passives supporting 1.0 GHz (referred to as 1.2/1.0). Such a network would only run signals up to 1 GHz. While such a combination may seem odd to the reader, such states are incorporated into the plan to represent transition milestones that also minimize regrettable spend. Cox's network is primarily a sub-split 1.0/1.0 plant; however, as mentioned above, Cox is in a multi-year process of upgrading the network to mid-split 1.2/1.0. With Mid-split representing approximately 12% of the Cox network, starting points of both sub-split and mid-split were used as migration path options. In addition, remaining states were selected based upon vendor guidance concerning likely future product offerings and timelines.

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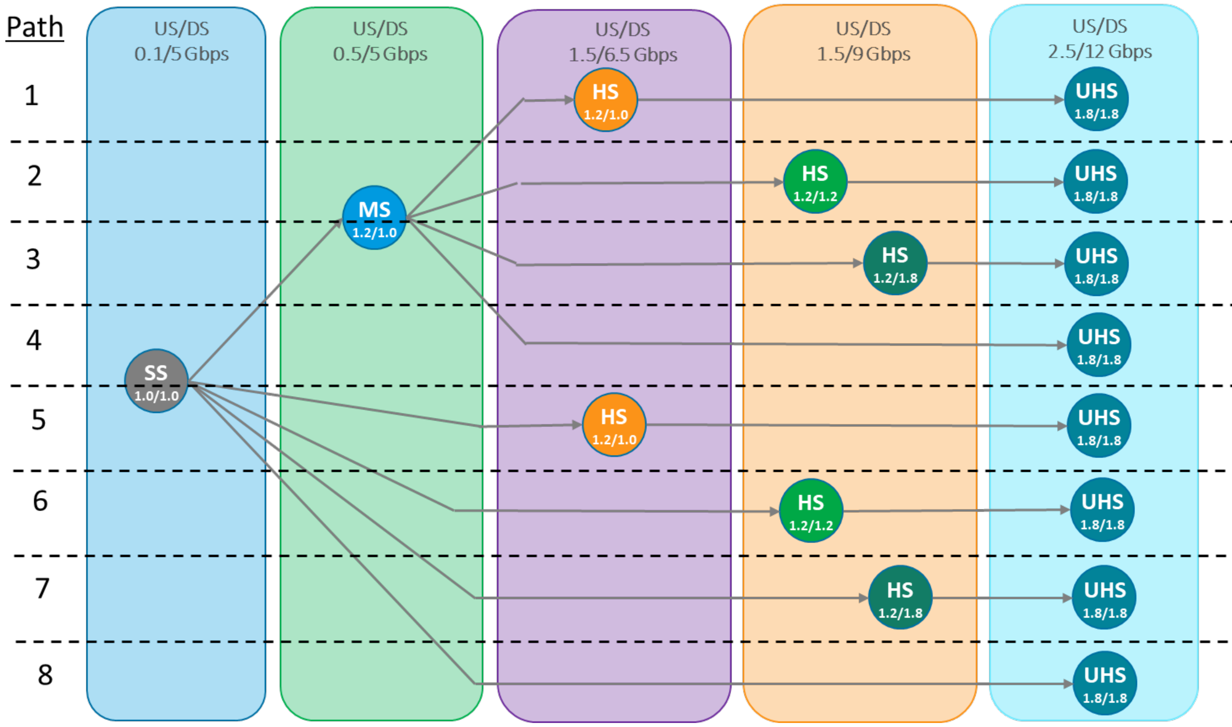

Figure 16. Cox Progression Path Options to Achieve 1.8 GHz UHS

Cox then developed an outside plant cost model for each of the transitions between states in Figure 16. It was then possible to sum those transitions to estimate total cost for each of the path options. (In order to remove proprietary cost data within this paper, all cost numbers were scaled relative to the cost of the transition of Sub-split 1.0/1.0 to Mid-split 1.2/1.0. The expectation is that other operators, equipped with their own unique costs for a mid-split upgrade, may then leverage the cost model results for their own unique circumstances.) Figure 17 provides the estimated total cost relationships for each of the 8 migration paths. In addition, the primary driver for high cost is provided for the more expensive paths.

As shown in Figure 17, paths 2 and 6 are significantly more expensive driven by the need to revisit all passive elements in the network twice for upgrades; first to 1.2 GHz and subsequently to 1.8 GHz. In addition, path 3 is quite expensive primarily because of the need to revisit the actives three times for bandwidth changes and twice for sweep and rebalancing to accomplish the upgrades; however, depending upon competitive circumstances, path 3 may still be necessary in some competitive market situations.

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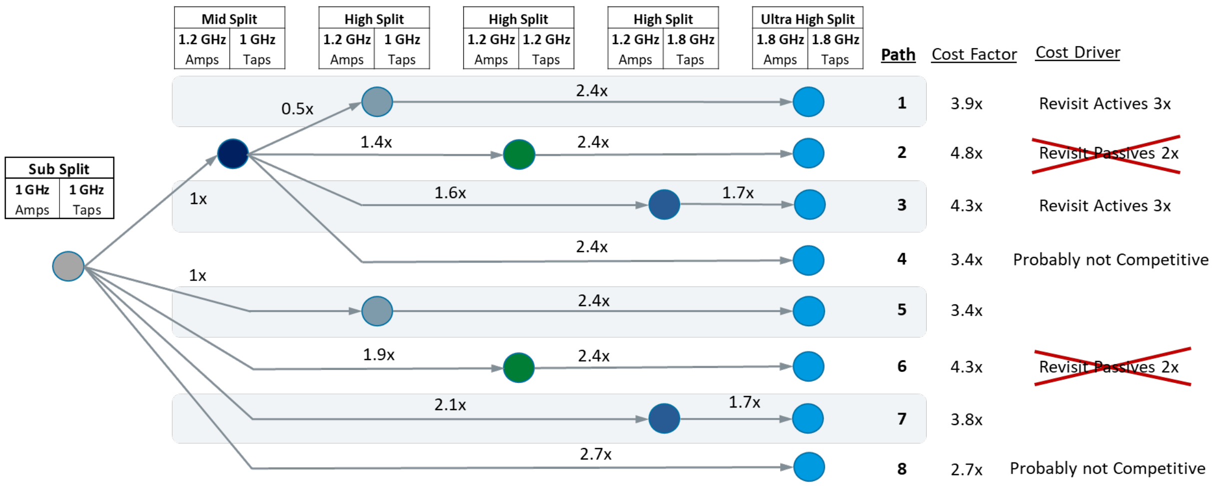

Figure 17. Estimated Cox Cost to reach DOCSIS 4.0 UHS for Eight Migration Paths

3.3. Product Availability and Path Implications

In addition to cost, commercial availability of products within the timeline demanded by competitive situations is also an important factor. As of the release of this paper, mid-split 1.2 GHz nodes, amplifiers, and passives are readily available. High-split 1.2 GHz nodes and amplifiers are expected to be readily available in 2022. However, as described above in sections 2.3.1 and 2.3.3, legacy video services and leakage monitoring need to be addressed in order to field a high-split network. Each operator must estimate their unique time implications to swap CPE to address service impacts; however, at a minimum, leakage aspects are likely to slow any large scale high-split deployments until at least late 2022 or early 2023 in order to deal with hardware upgrades of leakage meters and cumulative leakage index (CLI) reporting applications as well as CMTS modifications required in the enhanced DOCSIS specifications. 1.8 GHz nodes and amplifiers will likely not be available much earlier than late 2023 and more than likely middle of 2024 driving deployments into late 2024 to early 2025.

Relative to 1.8 GHz taps and passives, these are commercially available today with a cost premium over existing 1.2 GHz taps. However, this cost premium is more than offset by the high labor costs associated with revisiting passives twice in migration paths 2 and 6, driving a preference for a strategy where passives are only updated once in any timeline. In addition, based upon vendor feedback, 1.8 GHz passives are expected to require new housings. As such, there is some debate within Cox as to how disruptive a 1.8 GHz passive upgrade will be on network downtime, especially when considering the effects of power passing on other portions of the network. Given the raw number of passives within a node (Cox averages ~150 passives/node), it seems desirable for operators to begin passive upgrades significantly earlier than the rest of the plant upgrade; however, excessive network downtime might drive operators to a single cutover time for all actives and passives for a given node. Cox will need to pursue early trials using both a precursor and a concurrent upgrade process to better understand this impact and drive the scaled approach.

Migration paths 4 and 8, which basically capture jumping straight to a fully ultra-high-split 1.8 GHz configuration, are likely not competitively viable as it is quite likely that significant deployment penetration of symmetric 1 Gbps products beyond trials might be required earlier than 2025.

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As a result, 4 recommended paths (1, 3, 5, and 7) (Figure 18) are left for consideration, costing between 3.4x and 4.3x the cost of a mid-split upgrade.[2] Cox is continuing to investigate the possibility of accelerating the replacement of legacy video CPE with an IPTV-based solution which may be required for paths 1 and 5, both of which provide substantial cost savings. Depending upon the competitive urgency to move to high-split, there may not be adequate time to replace CPE, and as a result, Cox would need to pursue paths 3 and 7. However, paths 3 and 7 drive the need for accelerating and targeting 1.8 GHz passive upgrades as activating a high-split for these paths requires these new taps and passives. Selection between the options 1 and 5 or 3 and 7 is driven by whether the node faces more immediate upstream congestion in which case a mid-split upgrade would be needed and paths 1 or 3 would be taken.

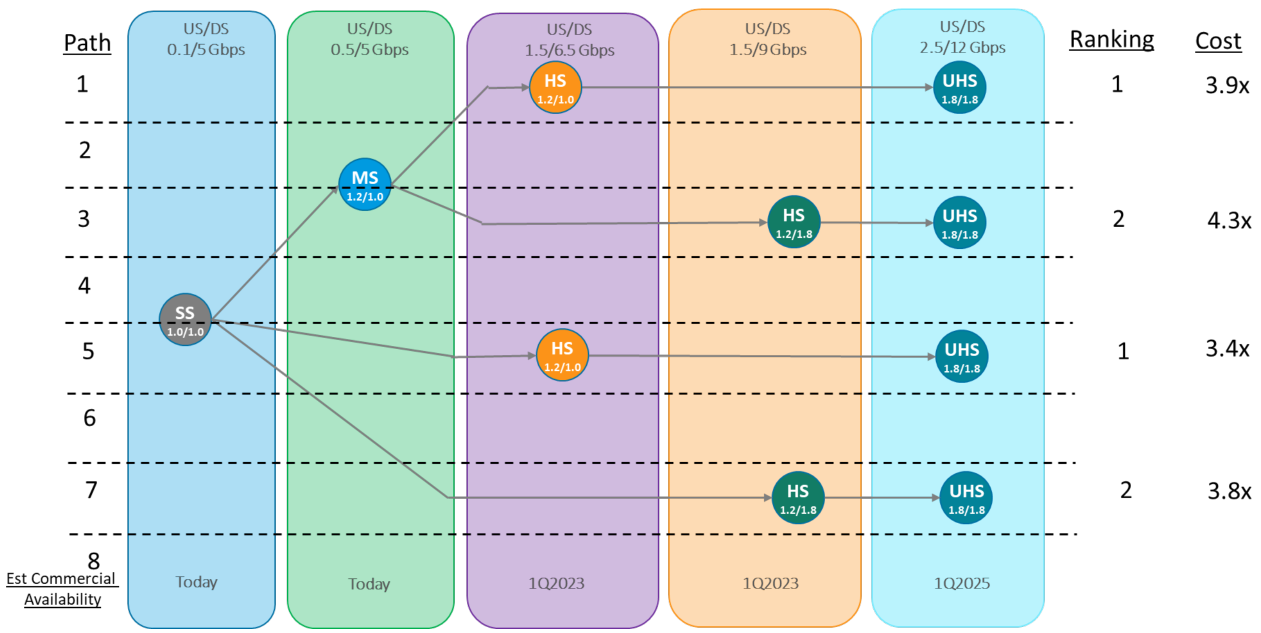

Figure 18. Recommended Migration Path Options to 1.8 GHz UHS

Figure 19 provides a possible timeline for paths 1 and 5. Key highlights of this process include the need to retire SDV/VOD or execute an IPTV upgrade to provide adequate downstream spectrum to achieve a high-split on a 1 GHz network as well as the need to upgrade homes with high-split service to a POE CPE device to eliminate in home interference with legacy devices. As mentioned earlier, there are some questions that will need to be resolved during trials as to the impact of earlier passive deployments on network downtime.

Figure 20 provides a possible timeline for paths 3 and 7. One key requirement in this process is the need to upgrade to 1.8 GHz passives much earlier in the process during the actual 1.2 GHz upgrade step; whereas that was a flexible option in Figure 19 assuming it didn't contribute to significant downtime.

[2] A key parameter in estimating the overall upgrade cost is cable replacement. The multipliers provided represent a 2% cable replacement assumption; however, Cox is currently performing tests in various markets to attempt to better refine that estimate. Any change in that percentage will impact the overall cost multiplier for each path but the relative differences will remain the same as the total cable replacement cost would be constant for all eight paths.

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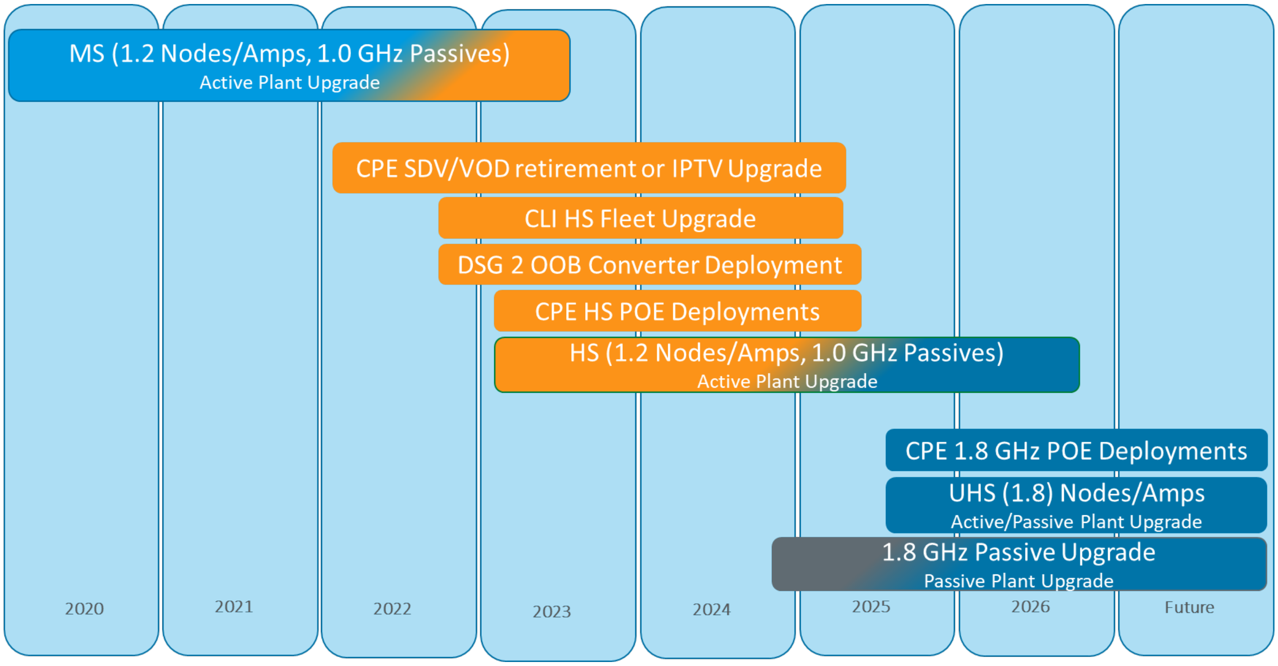

Figure 19. Possible Cox Migration Roadmap (Paths 1 and 5) with a 1.0 GHz Intermediate Spectrum Limit

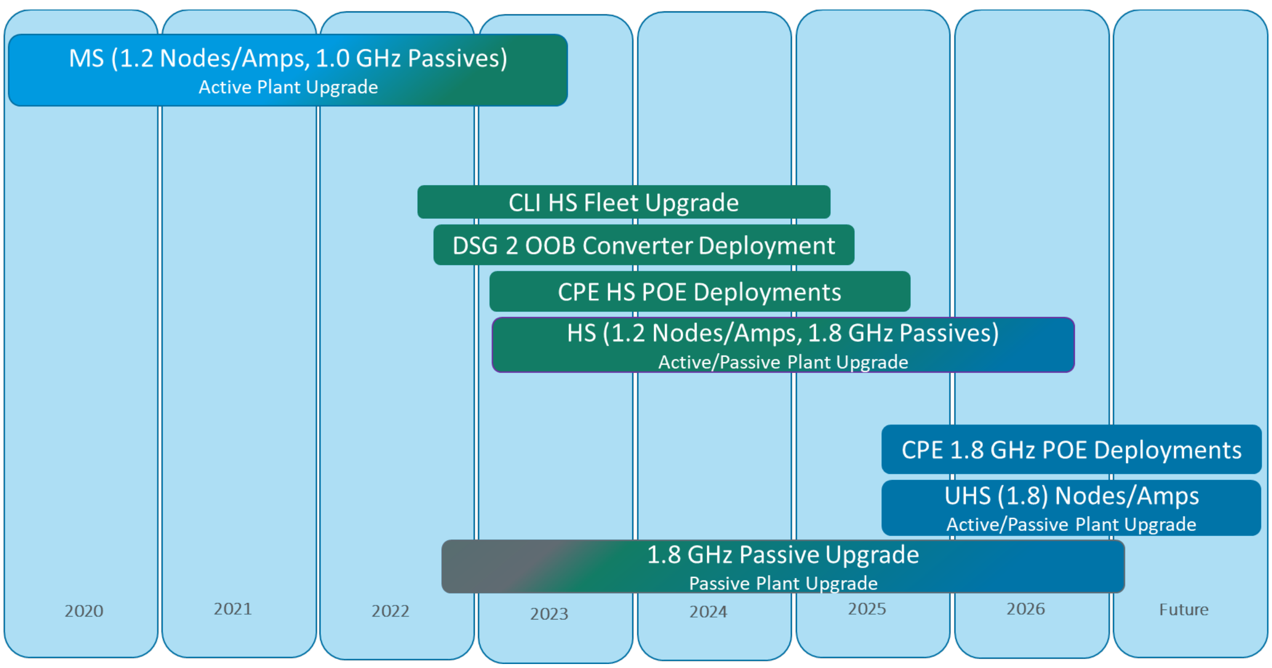

Figure 20. Possible Cox Migration Roadmap (Paths 3 and 7) with a 1.2 GHz Intermediate Spectrum Limit

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4. Conclusion

In summary, there are many important aspects to consider in association with potential bandwidth upgrades made possible by FDD DOCSIS 4.0. In the paper we explored many of those aspects and:

- Pointed out the rationale for maintaining legacy band tap RF output levels during plant upgrades.
- Described the historically used drop-in approach to plant bandwidth upgrades, and its benefits.
- Explained likely 1.8 GHz amplifier downstream gain requirements for drop-in upgrades and why Booster Amps may be needed.
- Provided for consideration, proposals for amplifier RF output profiles with associated rationale.
- Described some of the major items to consider associated with spectrum changes, with potential methods for handling them, including:
    - Reducing QAM Video
    - Meeting CableCard Regulations and Addressing Legacy OOB (55-1, 55-2)
    - Requiring POE for HS and UHS homes
    - Retiring MoCA
    - Meeting FCC Leakage Regulations
- Pointed out the potential requirements for a downstream spectrum "squeeze" associated with the plant upgrades and offered alternative mitigation approaches to consider.
- Shown a variety of potential approaches making use of progressive steps leading up to ultra-high-split 1.8 GHz and presented associated rationales and cost factors.

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Abbreviations

AGC	automatic gain control
Amp(s)	amplifier(s)
BAU	business as usual
BLE	Motorola line extender
bps	bits per second
BT	Broadband Telecommunications
CLI	cumulative leakage index
CMTS	cable modem termination system
CNR	carrier to noise ratio
CPE	customer premises equipment
DAA	distributed access architecture
dB	decibels
DOCSIS	data over cable system interface specification
DS	downstream
DSG	DOCSIS set top gateway
ES	extended spectrum
FCC	Federal Communications Commission
FDD	frequency division duplex
FEC	forward error correction
FM	CCOR FlexMax line extender
FMB	CCOR FlexMax bridger
FMT	CCOR FlexMax trunk/bridger
FTTH	fiber to the home
Gbps	Gigabits per second
GHz	Gigahertz
HFC	hybrid fiber coax
HGBT	high gain balanced triple
HGD	high gain dual
HHP	households passed
HS	high-split (204/258 MHz split)
Hz	Hertz
IPTV	internet protocol television
ISBE	International Society of Broadband Experts
LE	line extender
Man	manual
MB	minibridger
Mfr	manufacturer
MHz	Megahertz
MoCA	Multimedia over Coax Alliance
Moto	Motorola
MS	Mid-split (85/108 MHz slit)
N+0	node plus 0 amplifier architecture
N+X	node plus X amplifier architecture
NCTA	National Cable Television Association

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OFDM	orthogonal frequency-division multiplexing
OFDMA	orthogonal frequency-division multiple access
OOB	out of band
OSP	outside plant
OUDP	OFDM Upstream Data Profile
POE	point of entry
RF	radio frequency
RPD	remote phy (physical layer) device
RMD	remote mac device
SA	Scientific Atlanta
SCTE	Society of Cable Telecommunications Engineers
SLA	service level agreements
SS	sub-split (42/54 MHz or 40/52 MHz splits)
STP	set top gateway
TiVo	television input video output
TCP	total composite power
Therm	thermal
UBT	Scientific Atlanta unbalanced triple
UDCP	Uni-directional cable product
UHS	ultra-high-split (Cox tentative target 396/500 MHz split)
US	upstream
WiFi	wireless fidelity

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