Access Network Evolution for the Next Decade

SCTE – Goldengate
August, 2019

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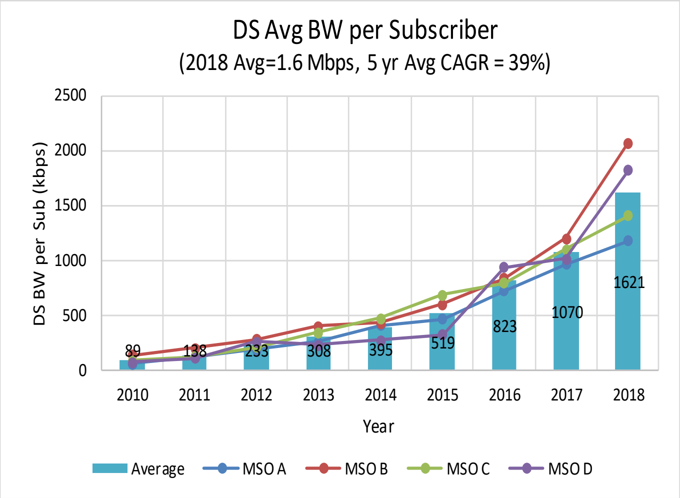
AGENDA

- **Traffic Engineering Trends**
- FDX
- Soft FDD
- XSD DS
- High-Split for Symmetrical Gigabit Services
- Active Taps
- HFC Network Migration & Recommendations
- Conclusions

Data Analytics on Real-World Cable Traffic

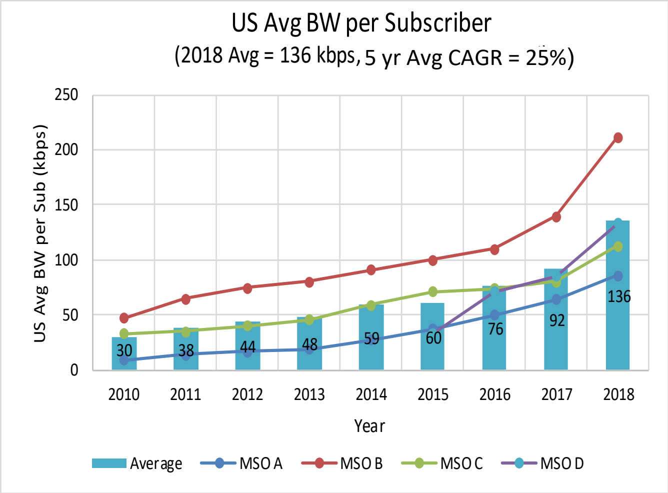
Downstream Tavg @ Peak Busy Hour



Observations:

- 2018 Highest DS Tavg (for reporting MSOs) = 2.07 Mbps
- **DS Tavg 5-yr CAGR dropped from 50% to 39%**

Upstream Tavg @ Peak Busy Hour

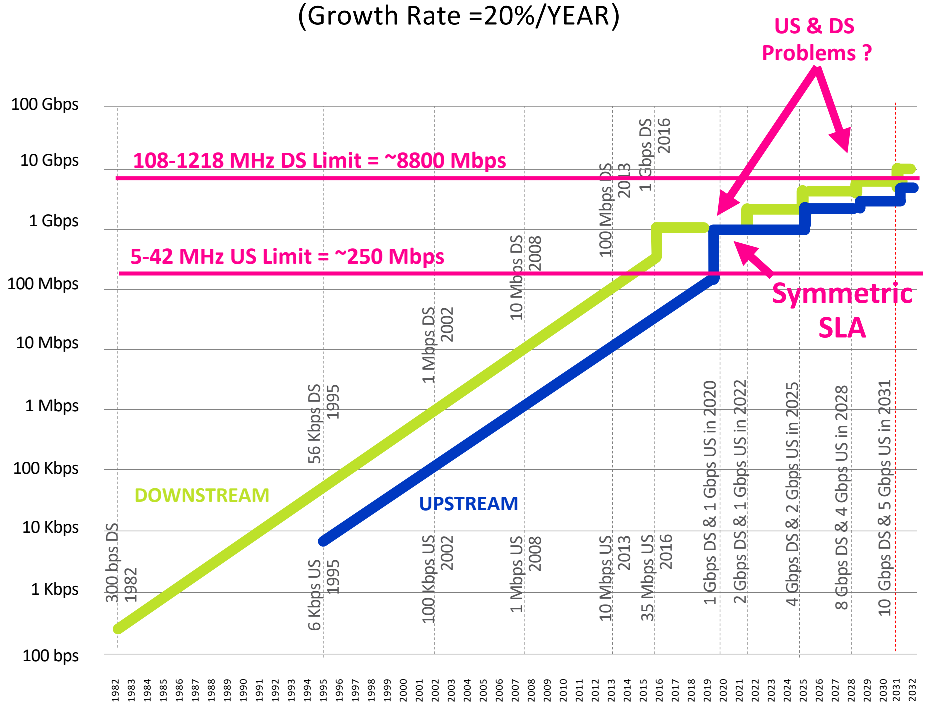


Observations:

- 2018 Highest US Tavg (for reporting MSOs) = 0.21 Mbps
- **US Tavg 5-yr CAGR increased from 20% to 25%**

Downstream & Upstream Tmax

NIELSEN'S "SLOWED" LAW OF INTERNET BANDWIDTH GROWTH
(Growth Rate =20%/YEAR)



Guesses:

- **CAGR slows to 20% this year?**
- **1Gx1G Symmetrical Service in 2020 ?**
- **Semi-Symmetrical Service w/ US Tmax = 5-50% of DS Tmax thereafter ?**

AGENDA

Traffic Engineering Trends

▶ **FDX**

Soft FDD

XSD DS

High-Split for Symmetrical Gigabit Services

Active Taps

HFC Network Migration & Recommendations

Conclusions

Why Full Duplex DOCSIS (FDX)? Isn't it too early to create a new spec soon after DOCSIS 3.1?

- FDX is a response to the Telco offering of symmetrical speeds!
- The focus is on the US here…. Speeds more than 1 Gbps are needed (without continuously changing the split in the network)

Full Duplex DOCSIS (FDX) Objectives

A flexible solution that:

- Offers more US BW (both Average BW & Peak BW)
- Permits Symmetrical Services to be offered by DOCSIS
- Does NOT reduce the DS BW "very much" within the proposed solution

Specifications Timeline: CableLabs has already issued the ECRs for the FDX PHY specifications and the MULPI/OSSI specifications.

- Now being migrated to the DOCSIS 4.0 spec

Deployment Timeline: Possible MSO deployments of **FDX** are expected to occur by **2019/2020**.

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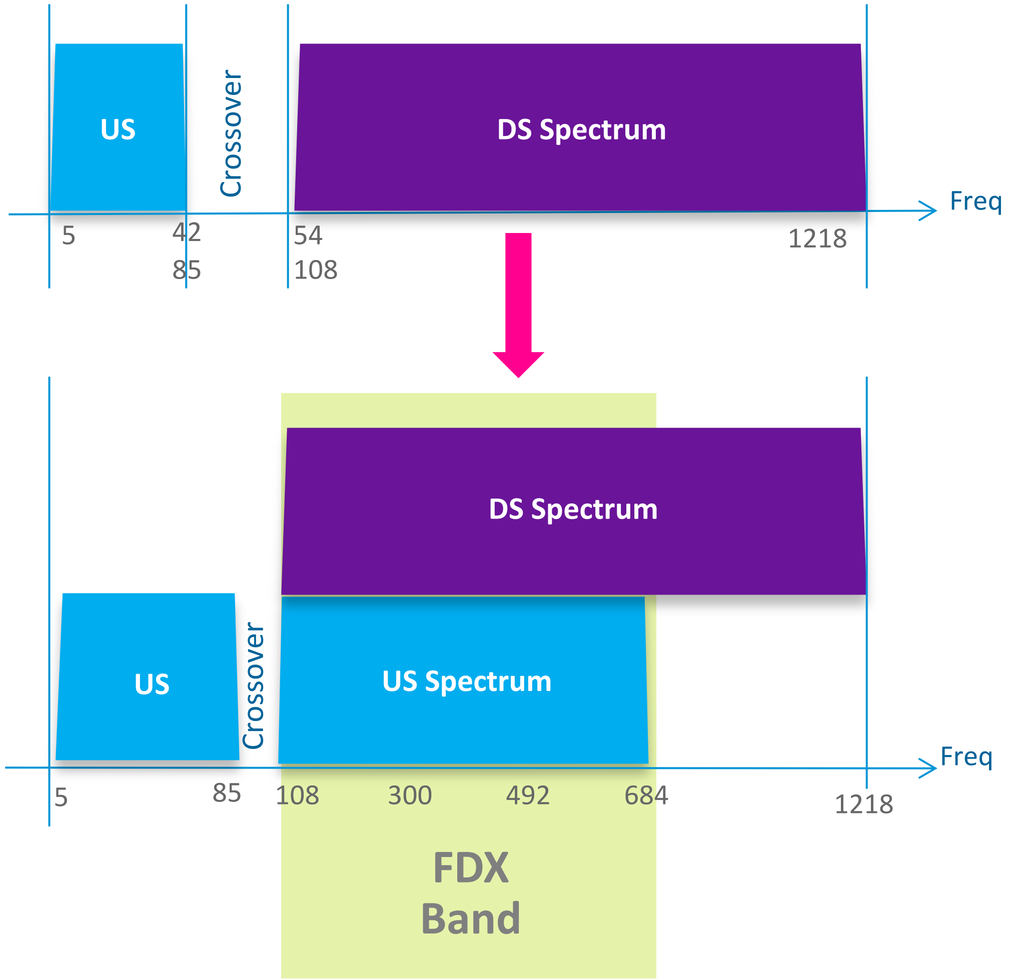
Full Duplex DOCSIS (FDX) in a Nutshell – Augmenting the Upstream for Symmetrical DOCSIS Service

- Target BW: 10+ Gbps DS and 5+ Gbps US
- US spectrum… 684 MHz US versus 42Expanded MHz today… 16x increase in US spectrum
- Optimized for **Fiber Deep (Node+0) with DOCSIS Remote PHY Nodes**
- Complicated design addition to the FDX RPD Nodes & CCAP Cores & the CMs… Requires Echo Cancellers in both the FDX RPD and the FDX CMt



Available in ~ 2019

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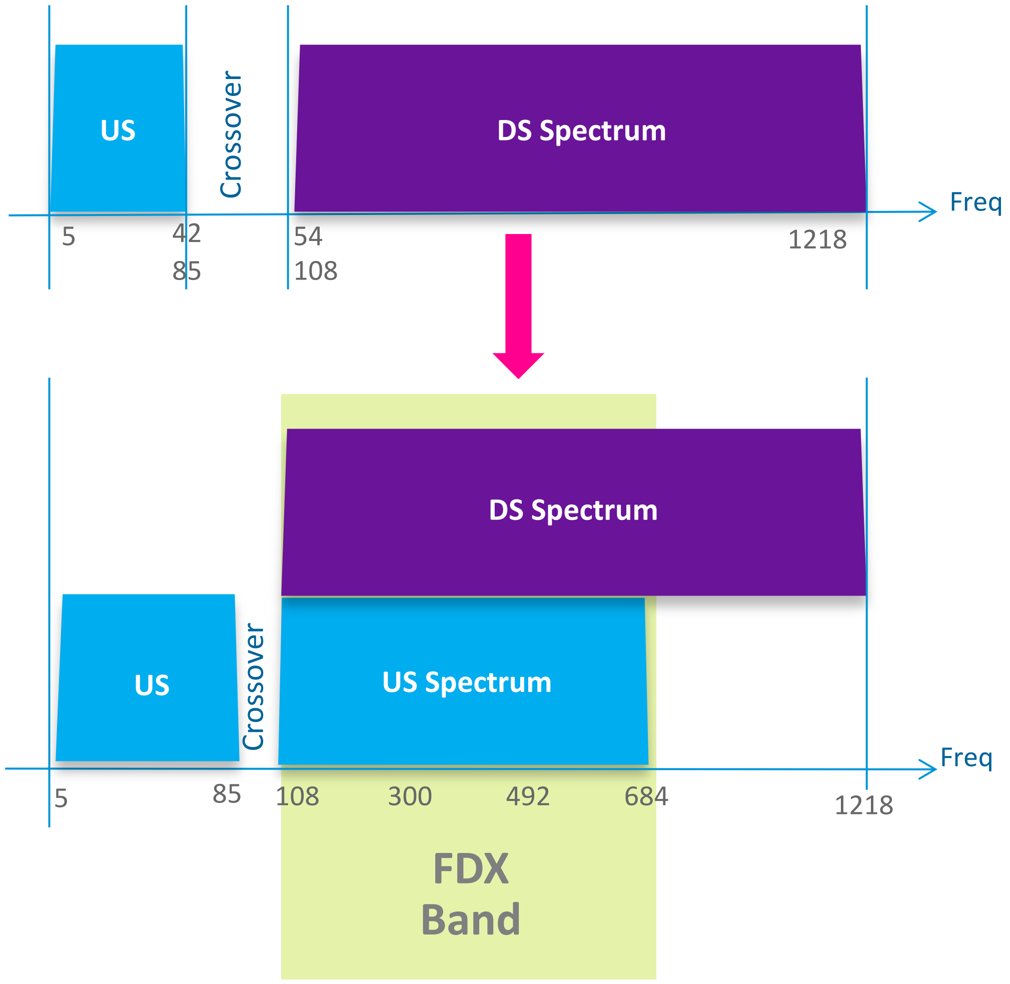
FDX-
What Is Required To Do It?

At least three things:

- DAA (probably RPHY at first)
- Node+0 HFC Plant
- Echo Cancellation for Noise Mitigation



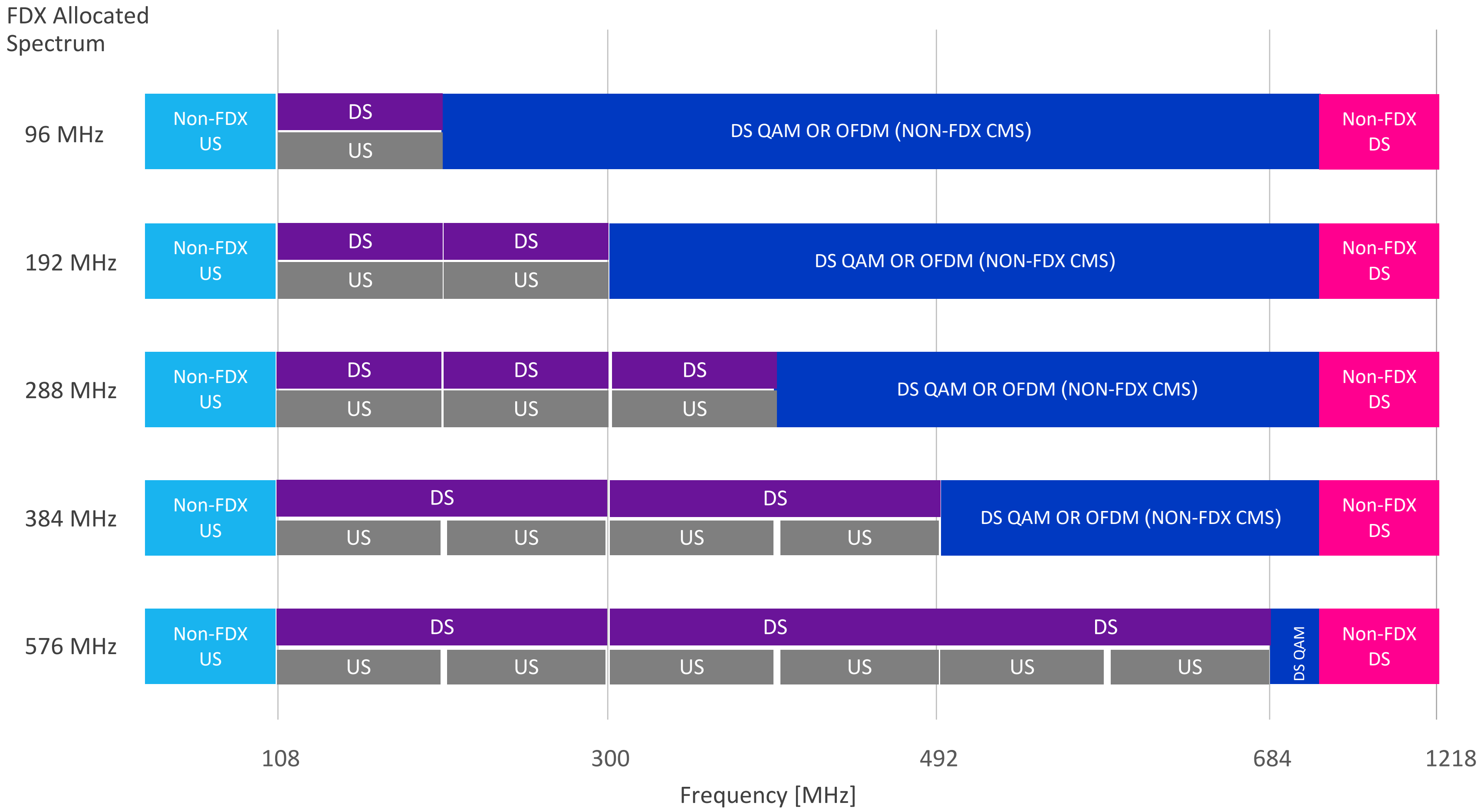
Available in ~ 2019

FDX Allocated Spectrum

FDX Allocated Spectrum Grid options:

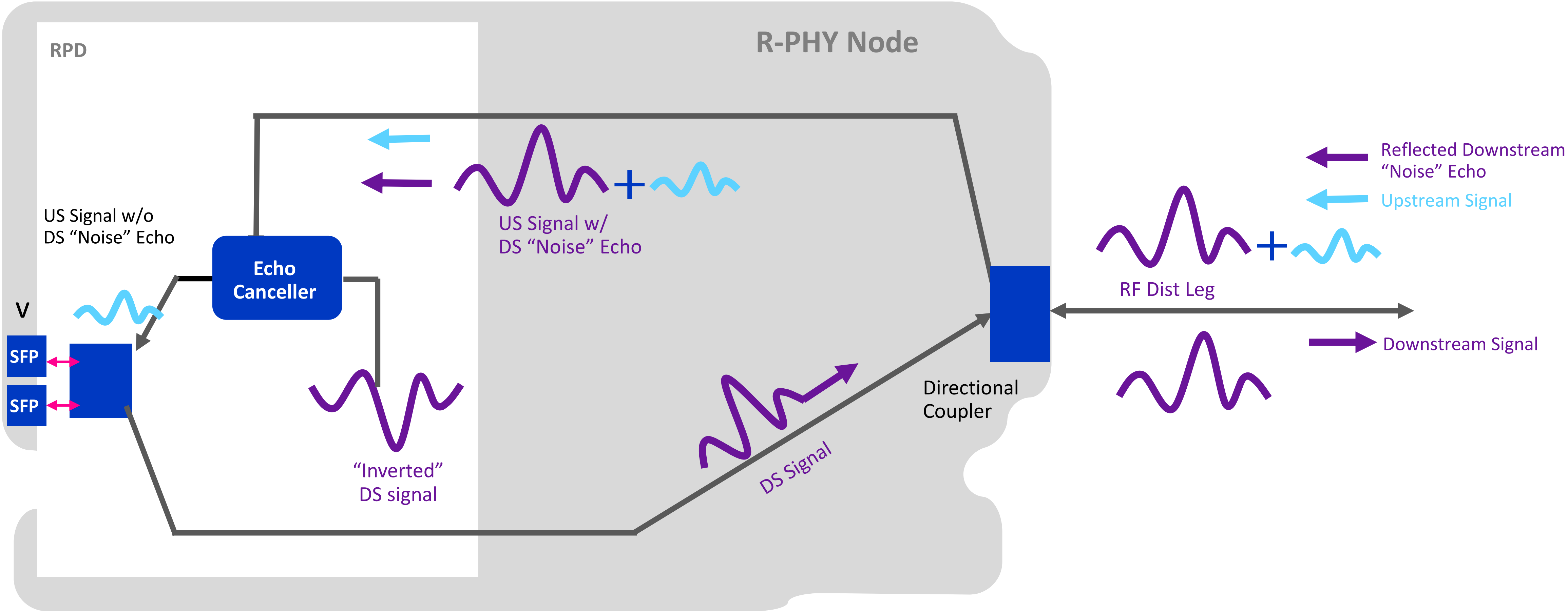
- 96 MHz: Occupying 108 MHz to 204 MHz; 1 sub-band
- 192 MHz: Occupying 108 MHz to 300 MHz; 2 sub-bands
- 288 MHz: Occupying 108 MHz to 396 MHz; 3 sub-bands
- 384 MHz: Occupying 108 MHz to 492 MHz; 2 sub-bands
- 576 MHz: Occupying 108 MHz to 684 MHz; 3 sub-bands

DOCSIS FDX – Spectrum Plans



FDX Node Echo Cancellation Overview

(greatly simplified)



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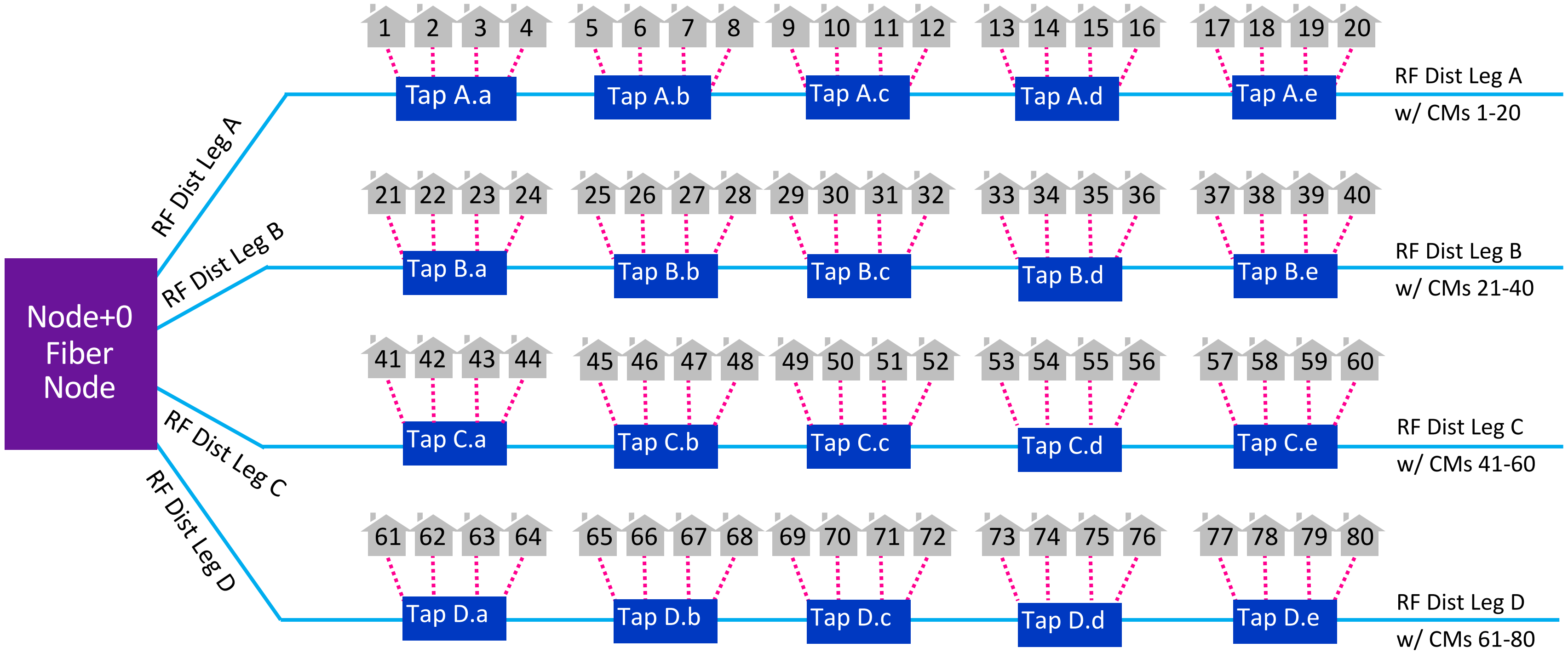
Interference Groups & Transmission Groups

Why Is FDX Hard When Early Experiments Showed It Is Doable?

Original FDX Experiment… No Noisy Neighbors

Real-world Cable Example of a Node+0 SG… Lots Of Noisy Neighbors = Problems

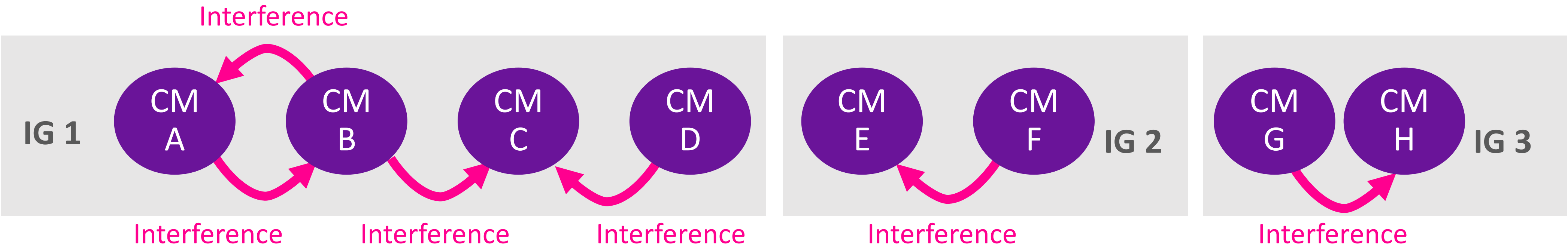
81 transceivers on the coax



Interference Groups & Transmission Groups

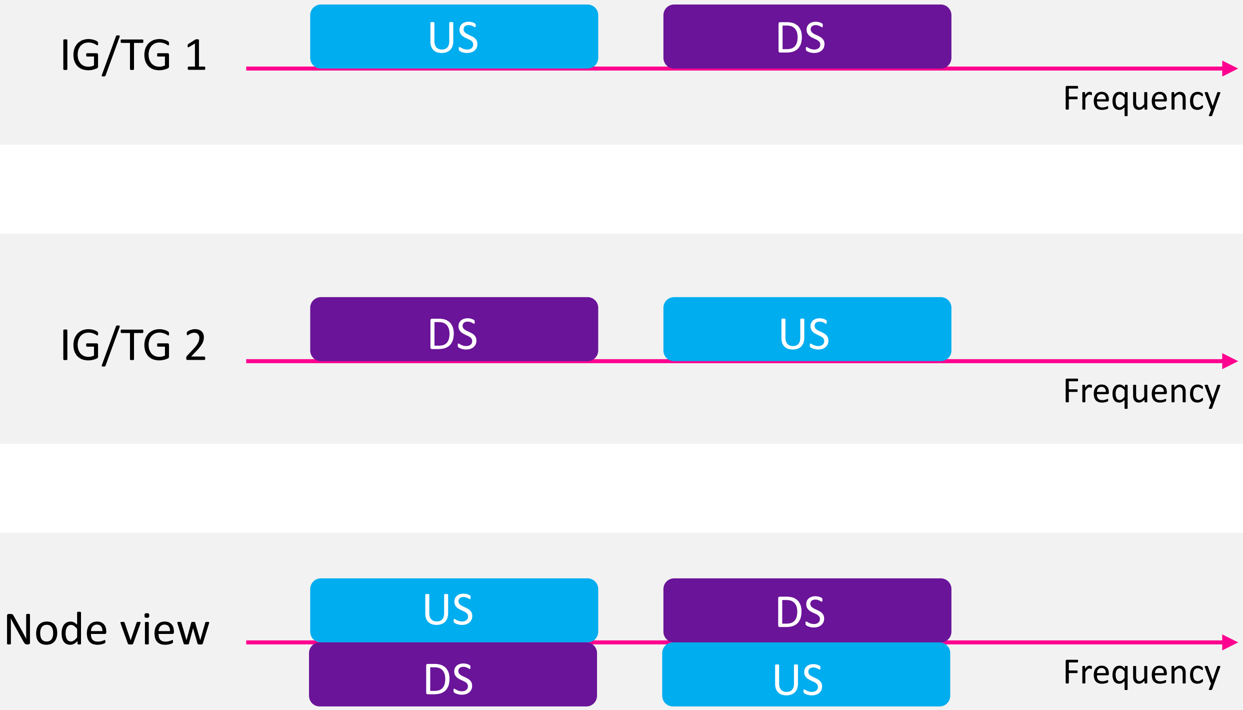
The Interference Group (IG) is a PHY-level concept…. If US transmissions of one modem affect the DS reception of another CM, those modems are declared to be members of the same interference group

Sounding is used to determine the groups of modems that interfere with each other (when the DS signal & US signal are in the same frequency band)…



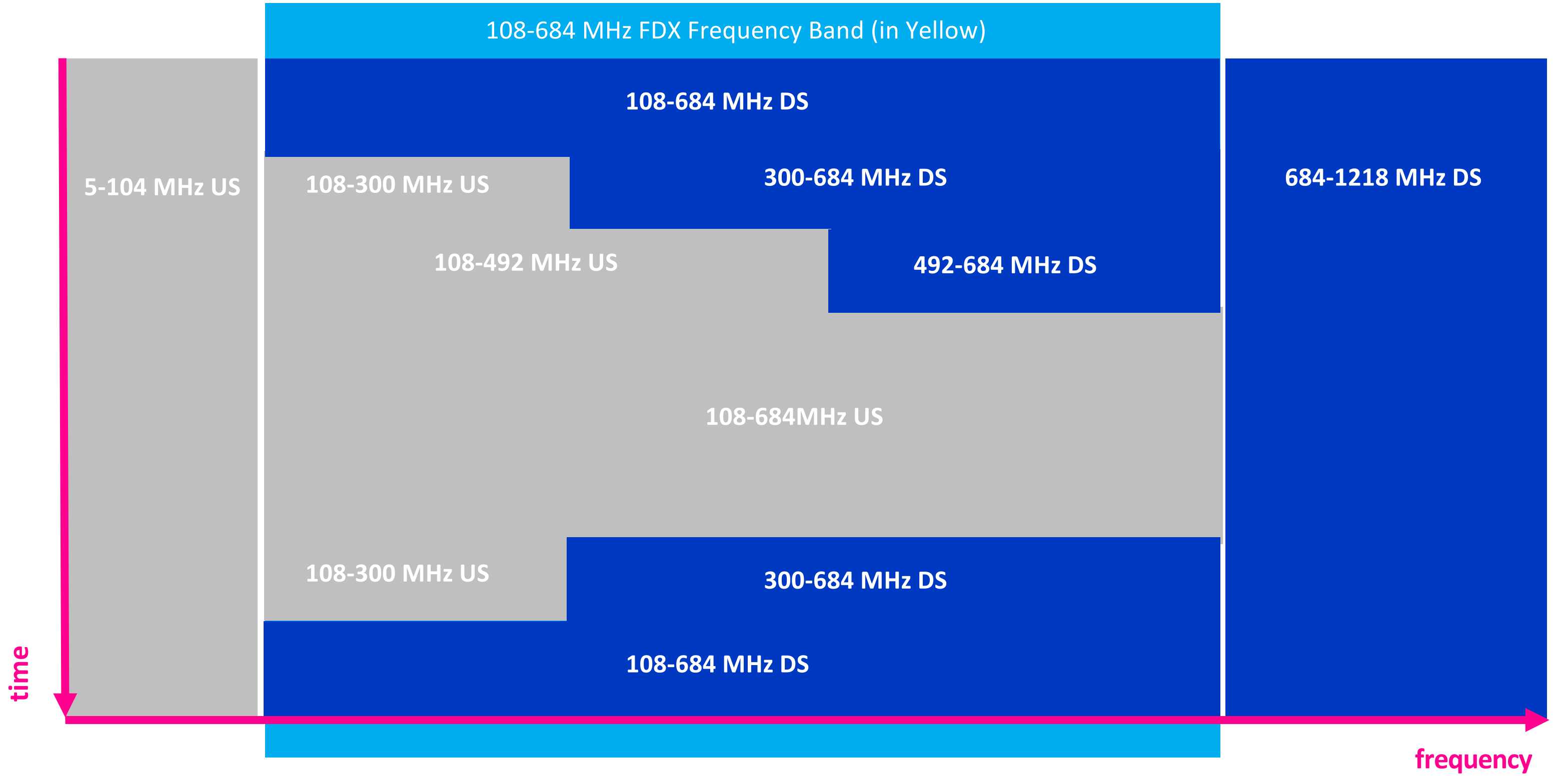
The Transmission Group (TG) is a MAC-level concept… It is the logical merging of one or more Interference Groups to create a larger group of modems that can be treated as a single managed entity on the HFC plant

Example of Frequency Allocation (& RBAs) to Two IGs on one RF Leg



- FDD Approach for TG1
- FDD Approach for TG2
- FDX Operation at the node

Dynamic-FDD In a Single Full-Duplex (FDX) DOCSIS Modem



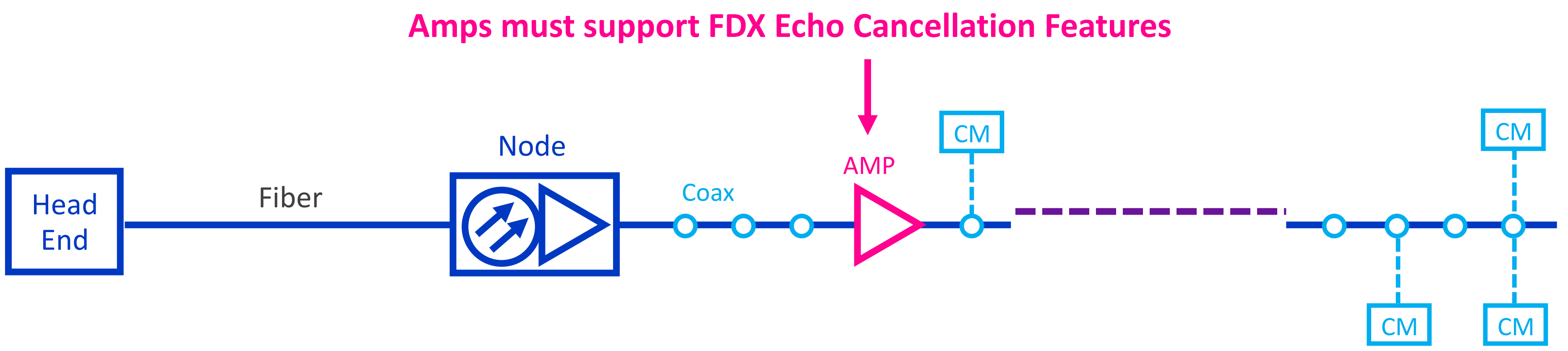
ARRIS has been involved in the FDX committees from the beginning… and contributed many ideas like many details on this Dynamic FDD Proposal!

We can stair-step US BW up and down as a function of US Traffic Load

Depending on HFC plant characteristic, MSOs should be able to offer up to 10 Gbps Downstream and ~6 Gbps Upstream with FDX

FDX Amplifiers

FDX for the Masses… Creating New FDX Amplifiers Will Help Support FDX in a Node+X Environment



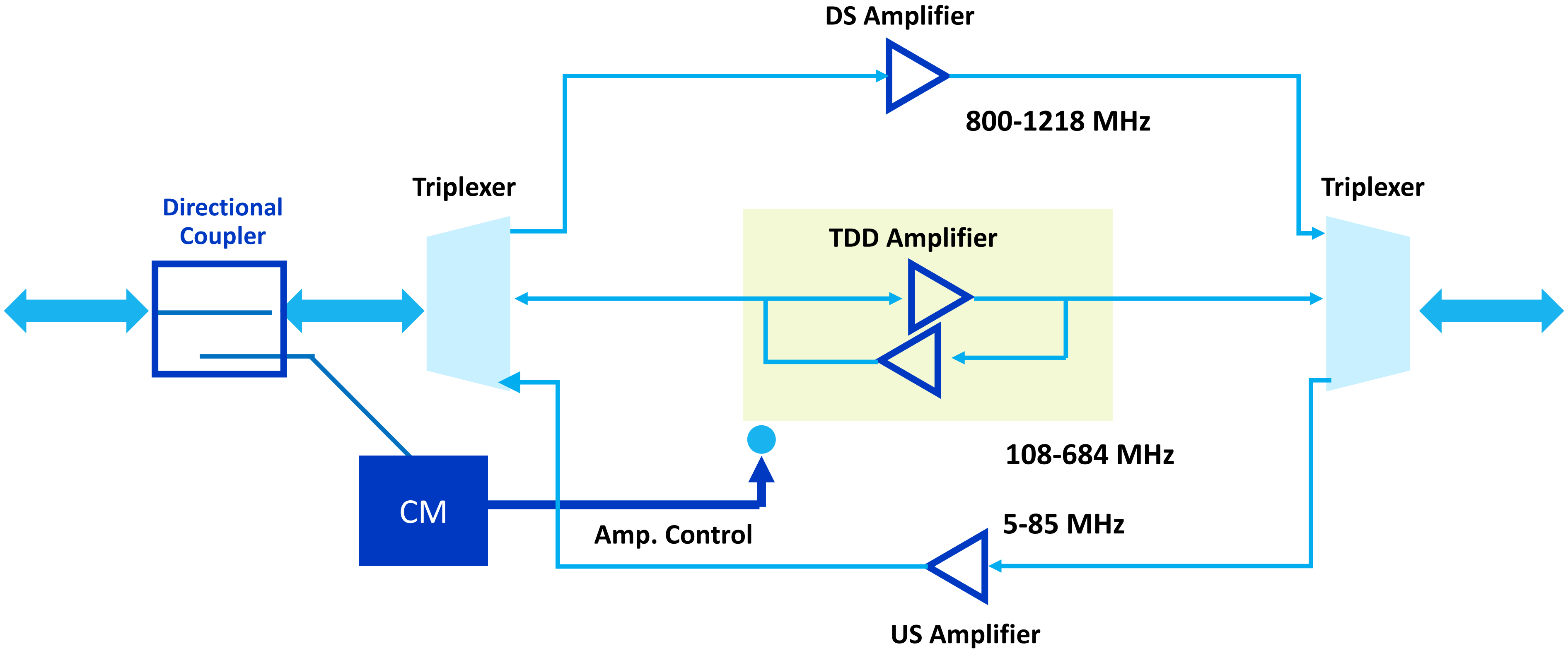
Permit the number of subscribers to be increased since more subscribers can share the FDX functions of the single Node

Can help decrease the Cost/Sub

Cost & power of the FDX Amplifier must be kept low

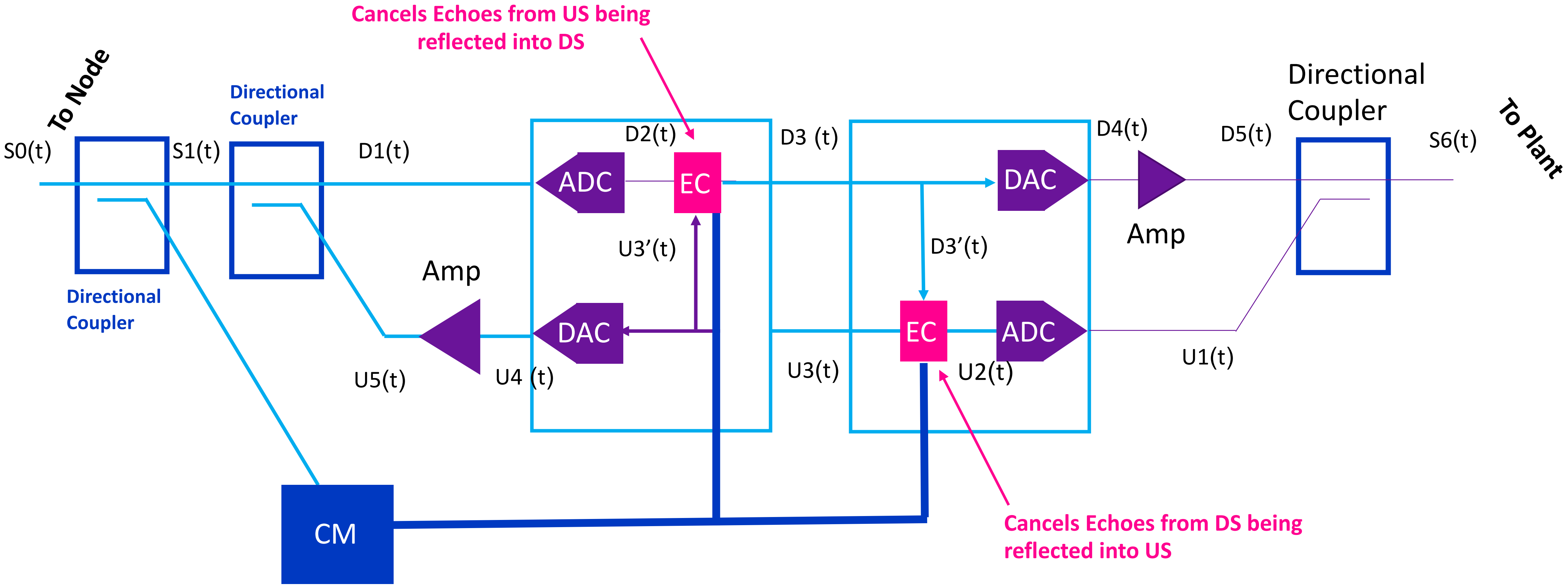
2 Approaches are being proposed

“TDD” FDX Amplifier Proposal – Currently Called “Gen-1 FDX Amplifier” within the Cablelabs FDX Amplifier committee



- Amplifier will be controlled via IP messaging
- Scheduler relays to the amplifier the DS/US RB assignments
- CM embedded into amplifier for IP messaging
- It actually operates in a half-duplex mode of operation for each RF Distribution Leg

Full-Duplex FDX Amplifier Proposal “Gen-2” Proposal



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FDX Amplifier Questions that Still Need to be Resolved

The maximum FDX Amplifier cascade length

The increased amplifier power levels needed to overcome the cascade of directional couplers in the upstream

The increased heat generated by the increased amplifier powers… can it be cooled in normal Amp enclosures

The feedback issues resulting from having 2 echo cancellers sitting in a loop (must have loop gain <1)

The Traffic Eng. Impact if an RF leg of the node becomes a single Interference Group/Transmission Group and therefore no FDX operation can occur on the leg that is being amplified (but no different than Half-Duplex FDX Amp)

The required real estate in the amplifier may force larger amp housings

The costs of FDX Amplifiers… will it cost too much?

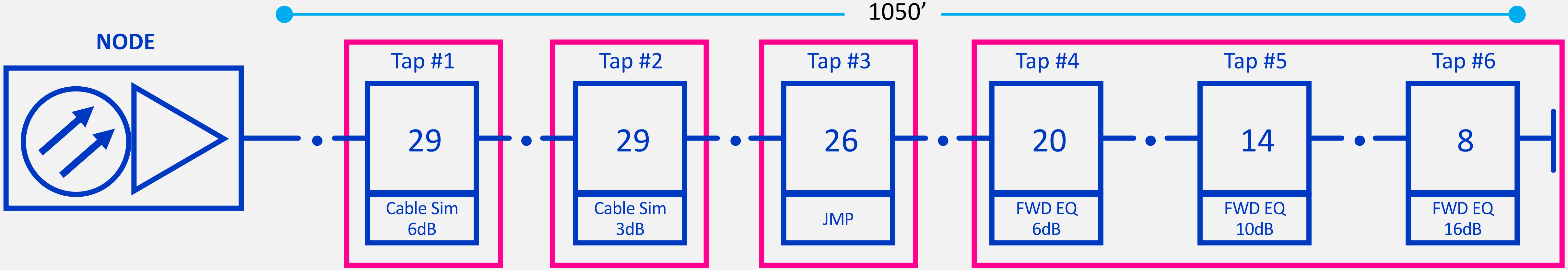
The power of FDX Amplifiers… will it consume too much?

The performance of a cascade of FDX Amplifiers… will it be good enough?

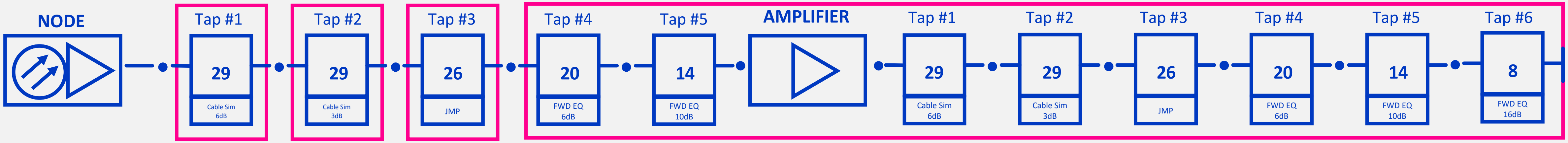
TBD

Interference Group Combining Due to FDX Amplifiers

N+0 System:

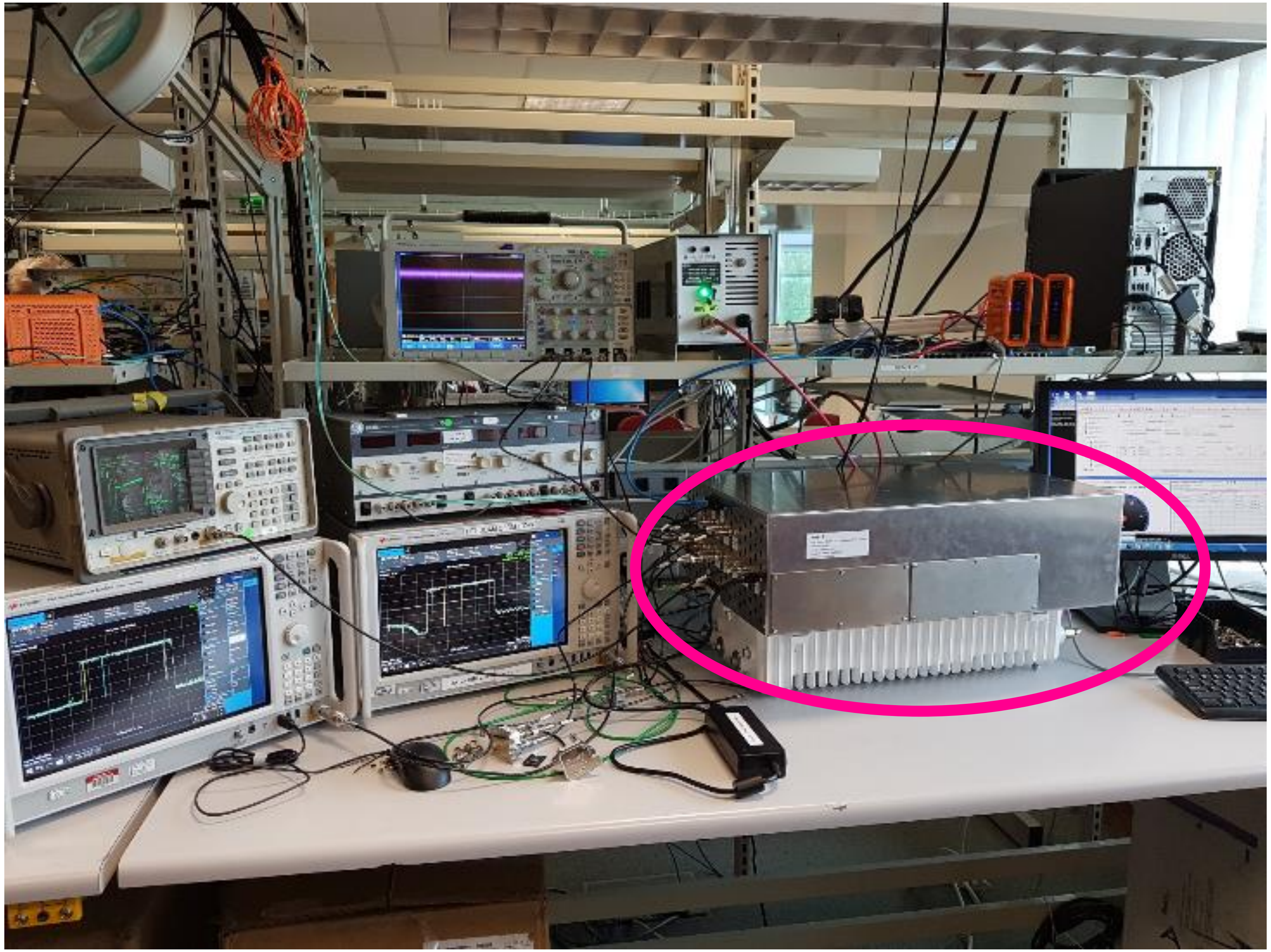


N+1 System:



FDX Field Trials Update

ARRIS FDX Test System (with the Franken Node)



FDX Upconverter Modules

Field Trial Logistic Details

ARRIS equipment was delivered to and tested at a greenfield/overbuild Coaxial Plant in Waterford, Connecticut

Plant Type: Aerial Plant (similar to Model 1)… ~1000 ft. using .875" & .625" hardline, 5 taps & 1 coupler

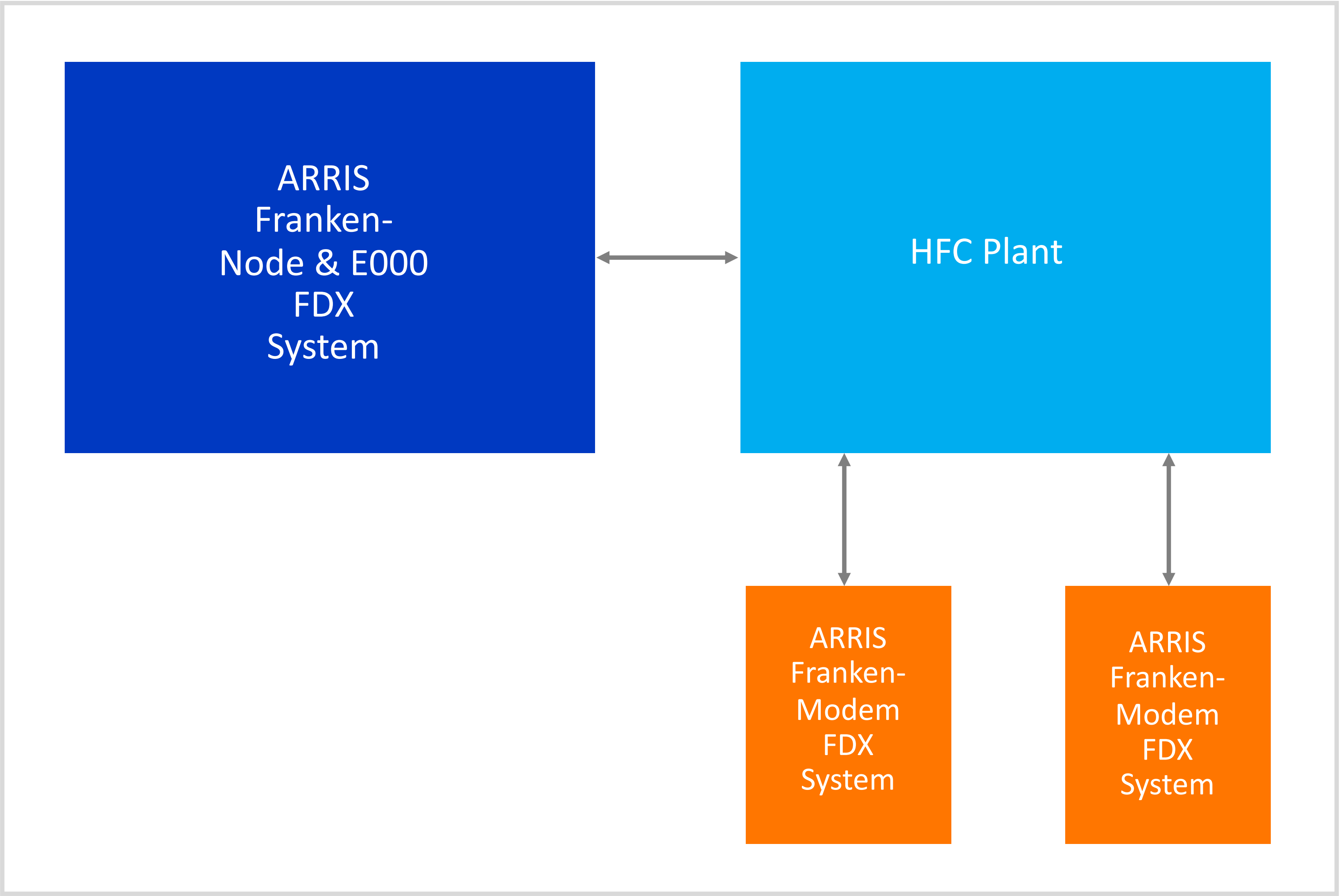
Period of Testing: November 2018

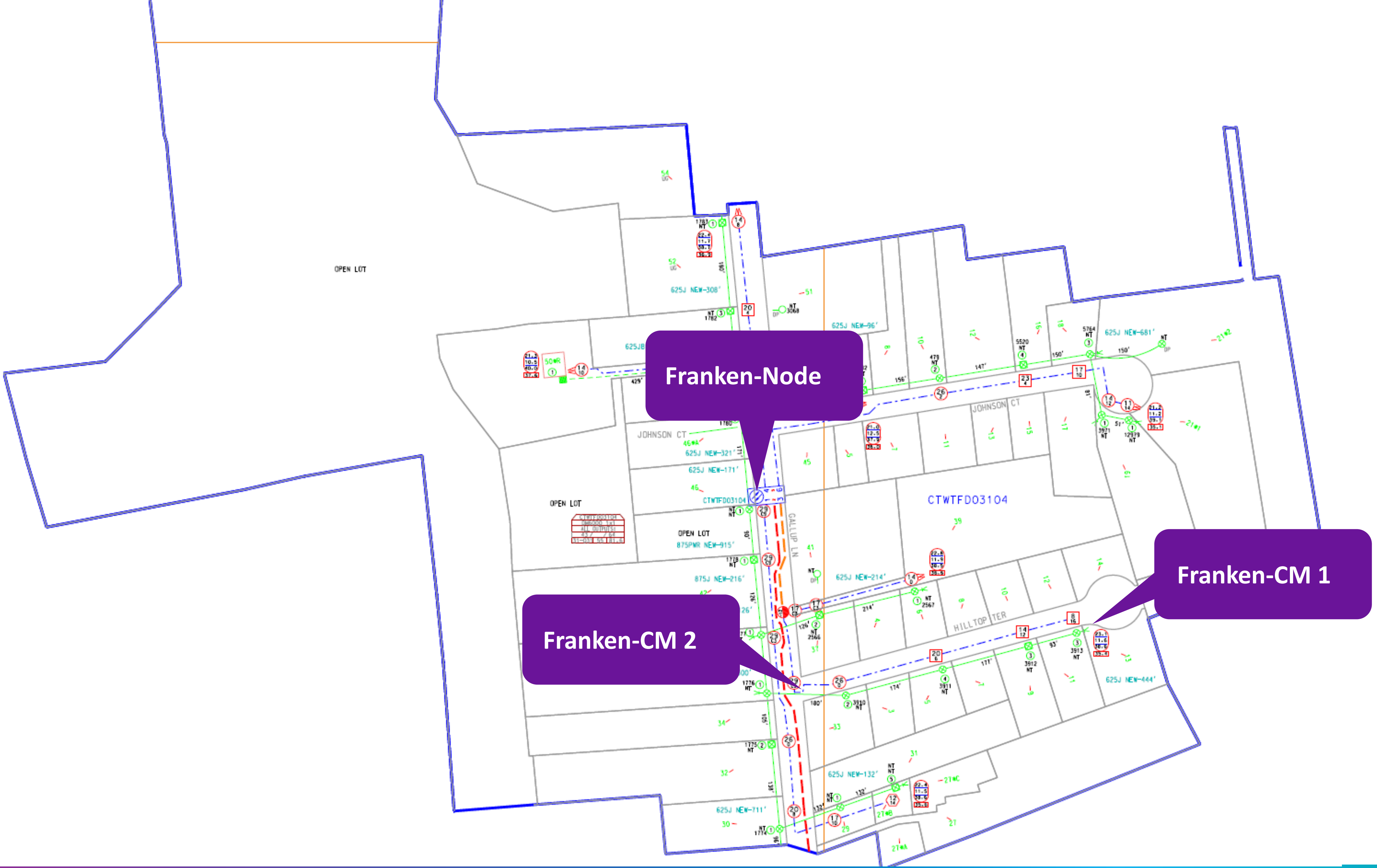
Testing Duration: ~1 week

Conditions:

- Typical late autumn weather
- Temperatures ranging from 64 degrees F to 39 degrees F
- Rain for 2 of the days
- Moderately gusty winds up to 14 mph

Block Diagram of the System Under Test in the Field Trial



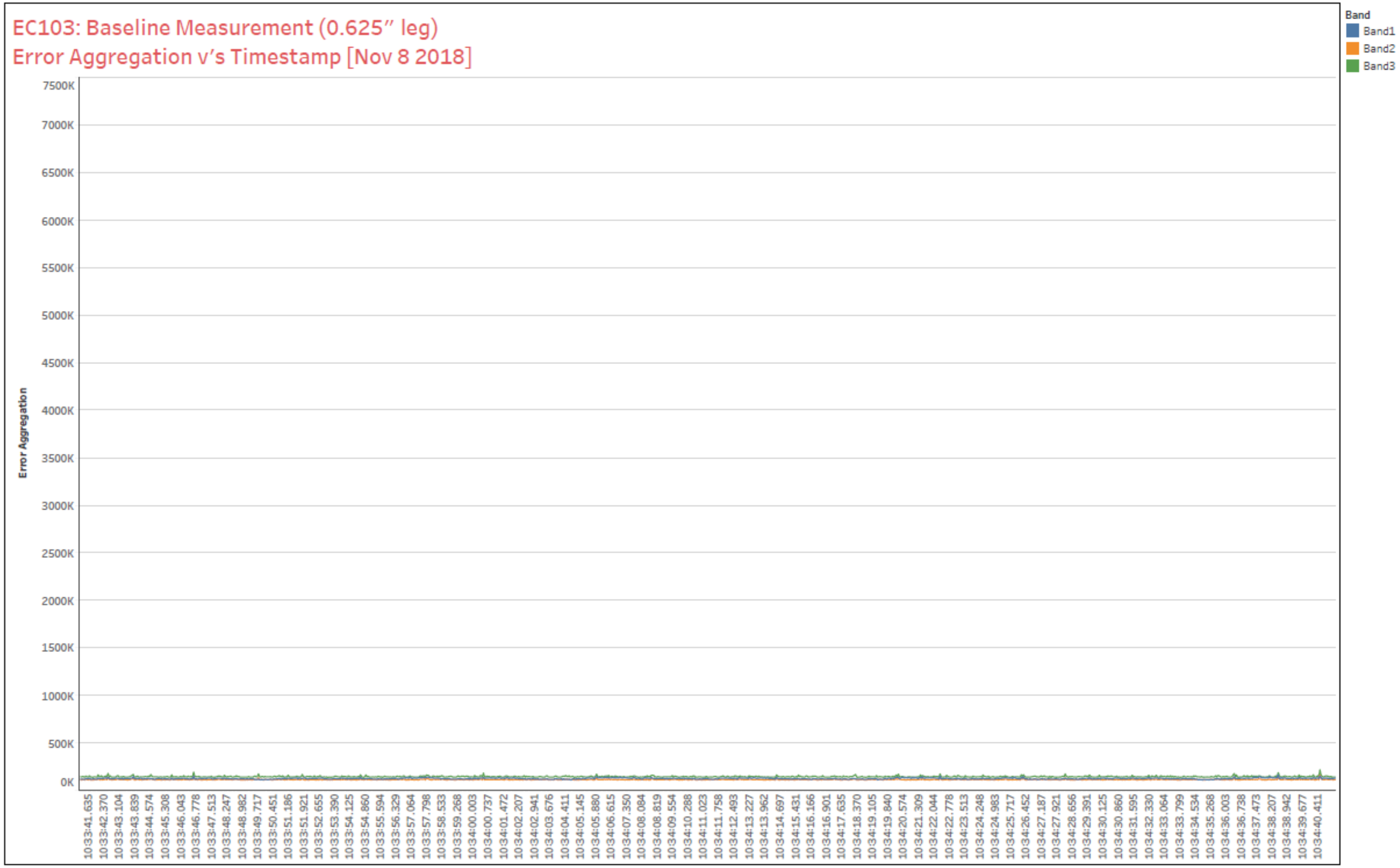

Franken-Node
Franken-CM 1
Franken-CM 2
OPEN LOT
JOHNSON CT
GALLUP LN
HILLTOP TER
CTWTFD03104


The Location Where
Franken-Node Was Connected

FDX Field Testing Adventures ☺… Node & Headend side

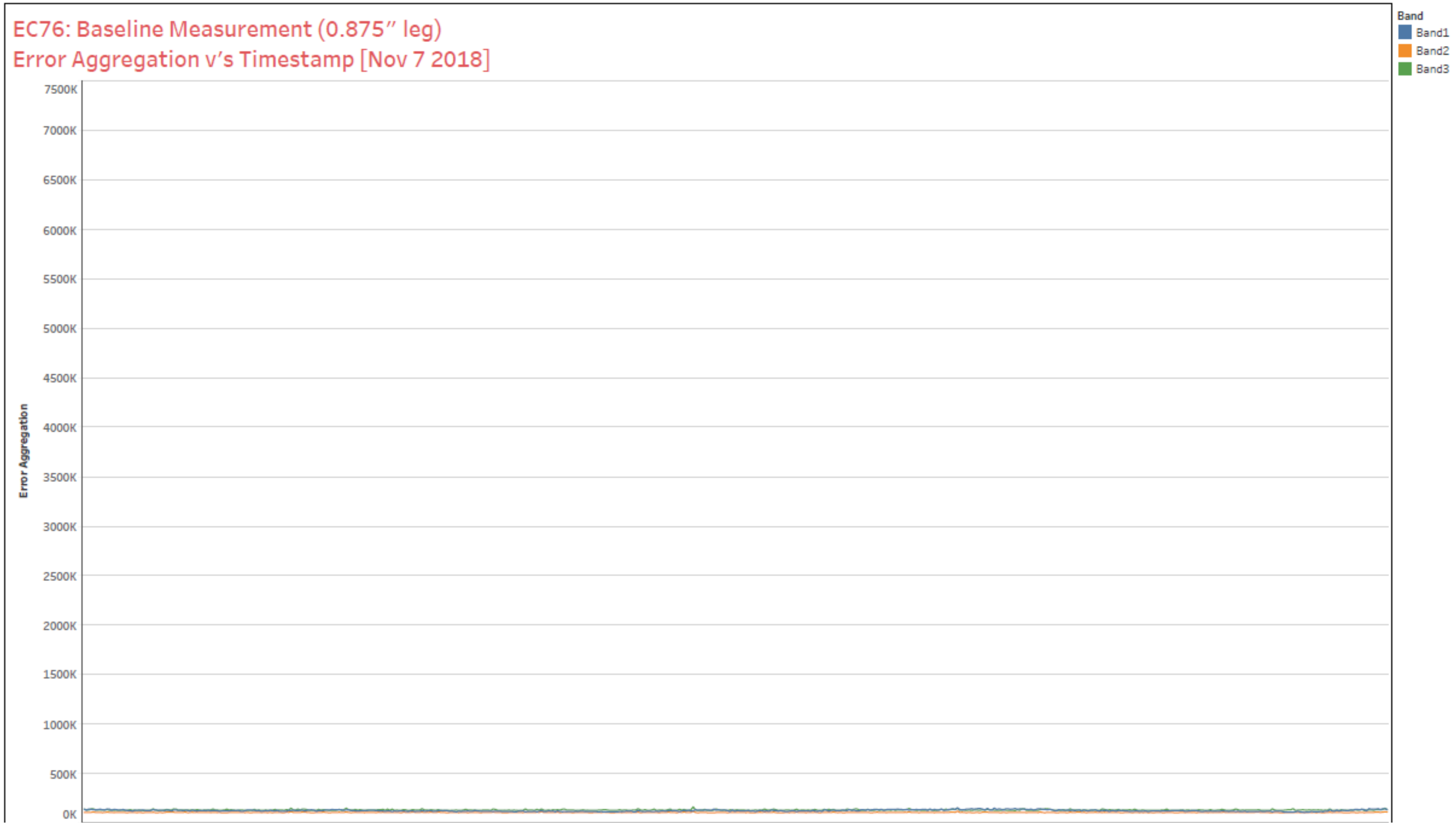
FDX Field Testing Adventures ☺… Modem side

General Operation Without Any Major Events



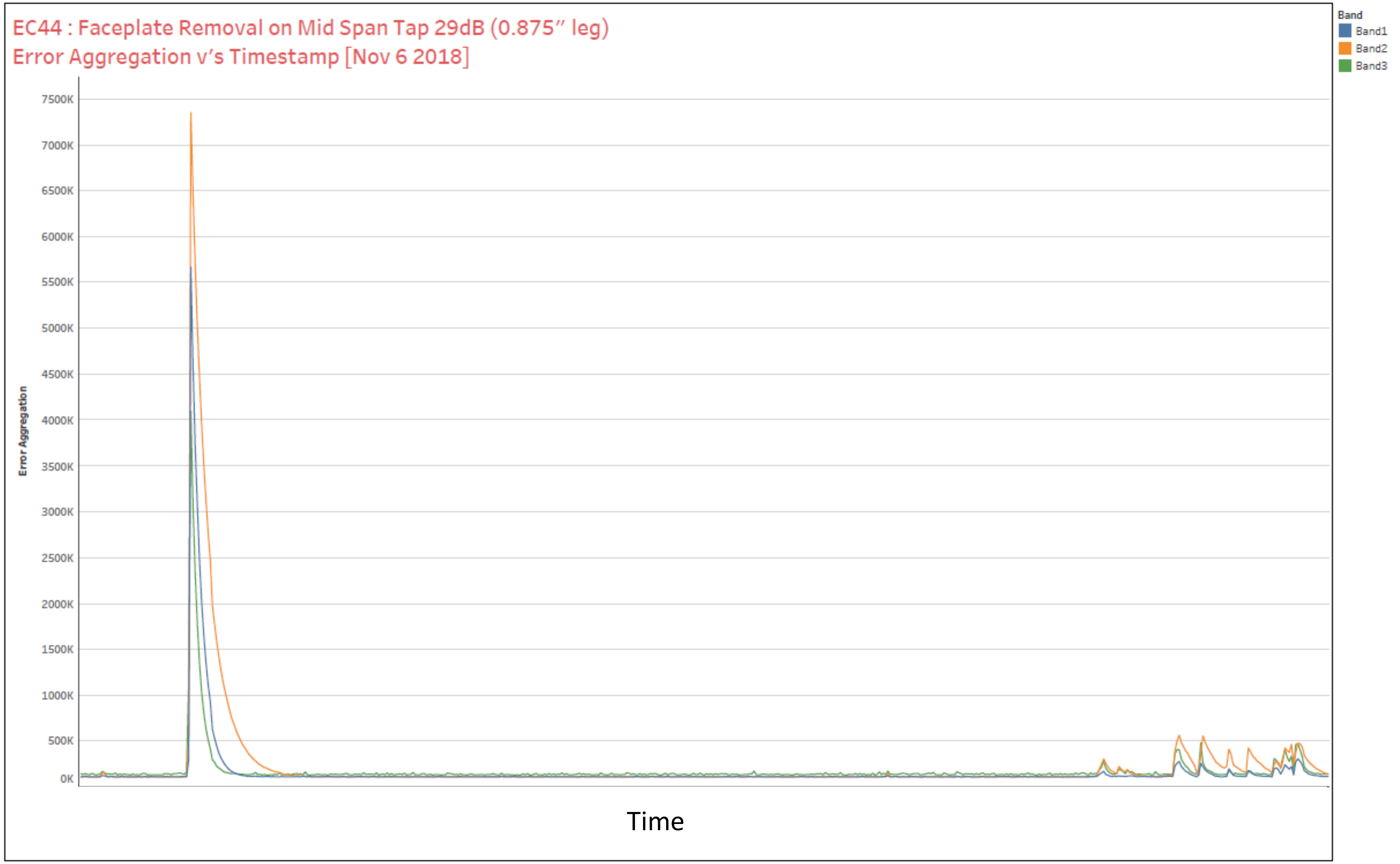
Time

Operation With Wind Gusts

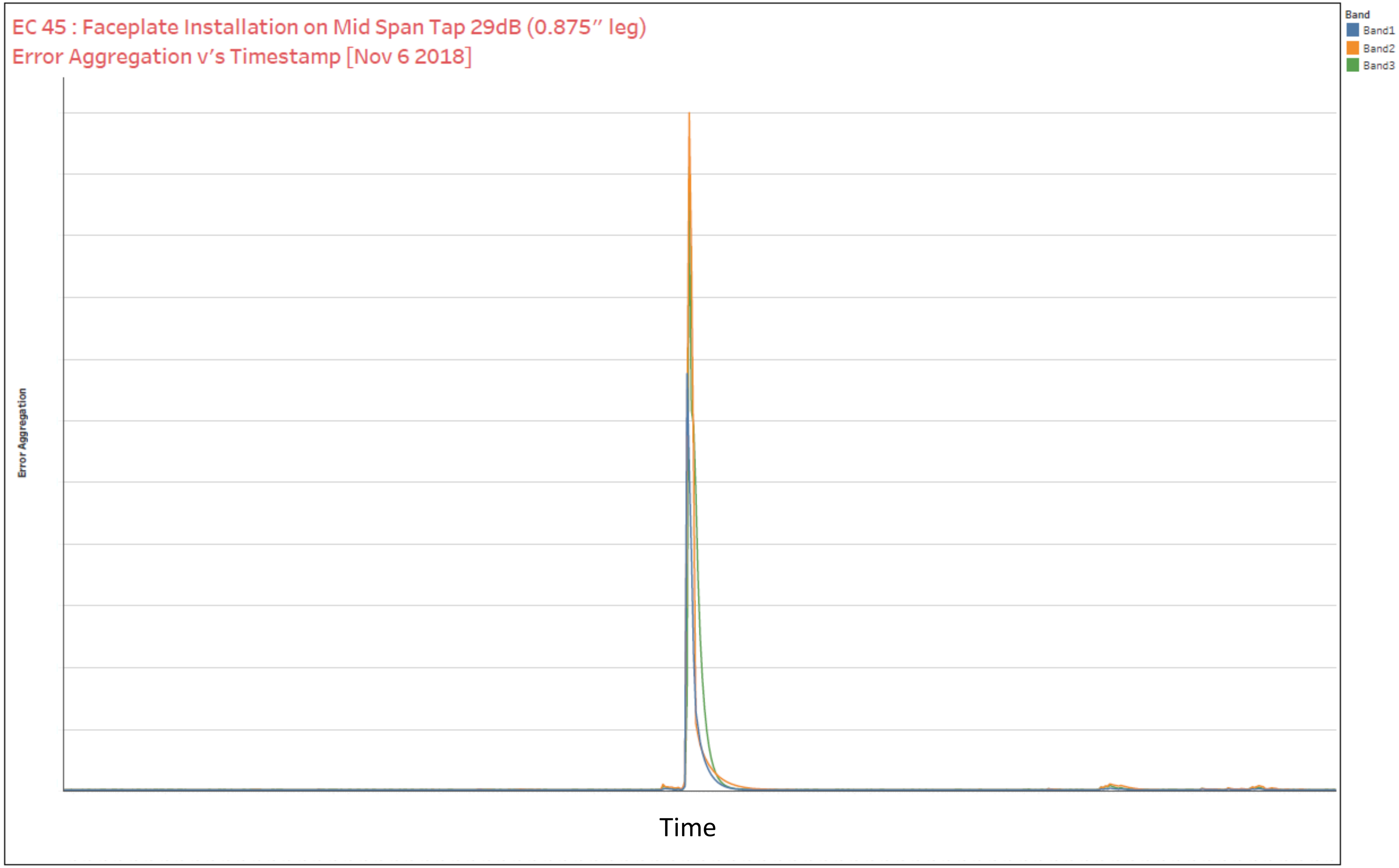


Time

Operation With Faceplate Removal



Operation With Faceplate Installation



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ARRIS Performed Intensive amount of FDX Testing

Several gigabytes of data captured over the duration of the CT field trial (25+ GB)

Captured modem performance & EC data for each of the 6 FDX bands from 108-684 MHz

- ~1Gbps DS traffic and ~570Mbps US traffic of real data per modem via the iPerf tool
- Repeated this at multiple tap locations on two different node legs

Modem/ EC Data also captured during several Maintenance Events including:

- Faceplate removal & insertion
- Seizure screw tap adjustments
- Addition and removal of terminations on drop cables
- Addition and removal of terminations on tap drops (without drop cables)

Learnings & Conclusions

- We have high confidence in the ability of FDX to work on real-live plant
- Tap changes a long distance down the line still impacted the cancellation coefficients
- Wind did not have much of an effect… there were strong wind gusts in a storm with overhead cable & little to no degradation was observed
- QAM4K in the Downstream and QAM1K in the Upstream seemed to work very well in a real-world environment
- Overall, the system was very stable

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Traffic Engineering Trends

FDX

▶ **Soft FDD**

XSD DS

High-Split for Symmetrical Gigabit Services

Active Taps

HFC Network Migration & Recommendations

Conclusions

What is Soft FDD? [Frequency Division Duplex]

- Soft FDD: Soft Frequency Division Duplex
- FDD is running non-overlapping US & DS spectra…. Just like today!
- Soft FDD is the ability to change the US/DS “split” location easily
  - Split today in the US is 42/54 MHz
- Soft FDD is focused on increasing the US spectrum
  - Soft = Can we have the ability to change that to, say, 204/258, 492/578, 684/804 MHz easily (potentially via software?)
  - Yes, use the FDX node and modem technology and run them in static FDX mode to achieve this. Static FDX mode = fixed RBA assignment
- Soft FDD may converge the cable industry again
  - This is helpful for MSOs with cascaded networks (N+x) to be able to continue using their N+x networks (no need for N+0) and they can change the split dynamically
  - This is helpful for MSOs with N+0 that want to use FDX. Soft FDD will increase the volume of the FDX chipsets which leads to cheaper FDX products

How does Soft FDD work?

How to use Static FDX Mode to Obtain **5-204 MHz/258-1218 MHz FDD** Network

Assumptions:

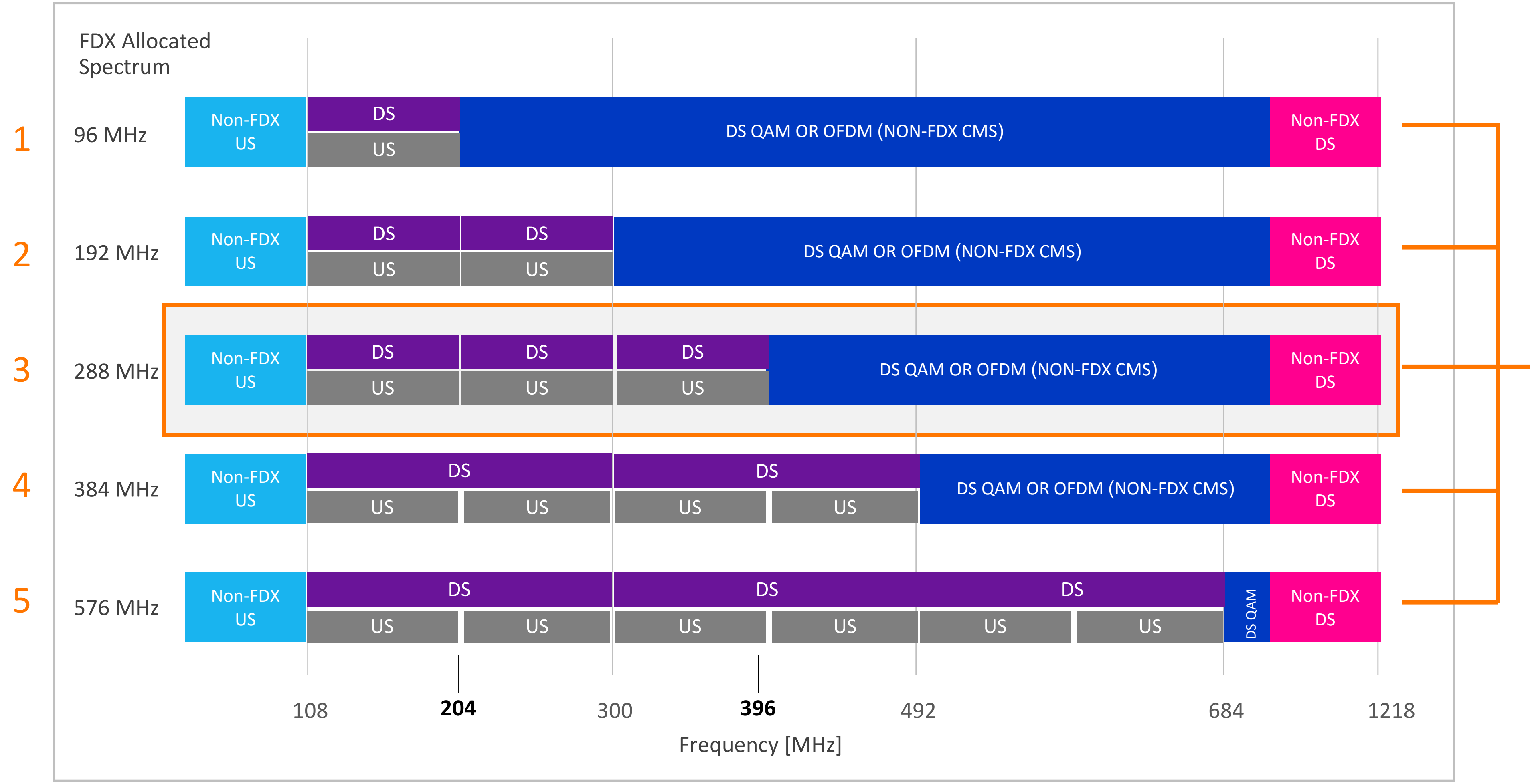
- FDX node
- FDX CM (Gen 1)
- N+x Network with 5-204 MHz High-split
- DS starts at 258 MHz

Questions

- How to configure the FDX node to operate on the network above?
- What is the behavior of the FDX modem?
- What is the behavior of a legacy D3.1 modem?

FDX & XSD are complementary…. How to Run an FDX Node & FDX CM in Static FDX/Extended Spectrum Mode (i.e., FDD model) for N+x Networks? 5-204 MHz US Network

Configure the node to work in FDX mode



Can use any of these grids depending on desired:

- # video channels*
- # SC-QAM channels*
- Usable BW for FDX CM*

* If more video/SC-QAM channels are needed, use low-numbered grids (and vice versa). If low usable DS BW is needed for FDX, use low-numbered grids and vice versa.

Let's assume that the FDX CM requires DS BW beyond what is offered in the non-FDX DS spectrum. Let's use grid 3 as an example

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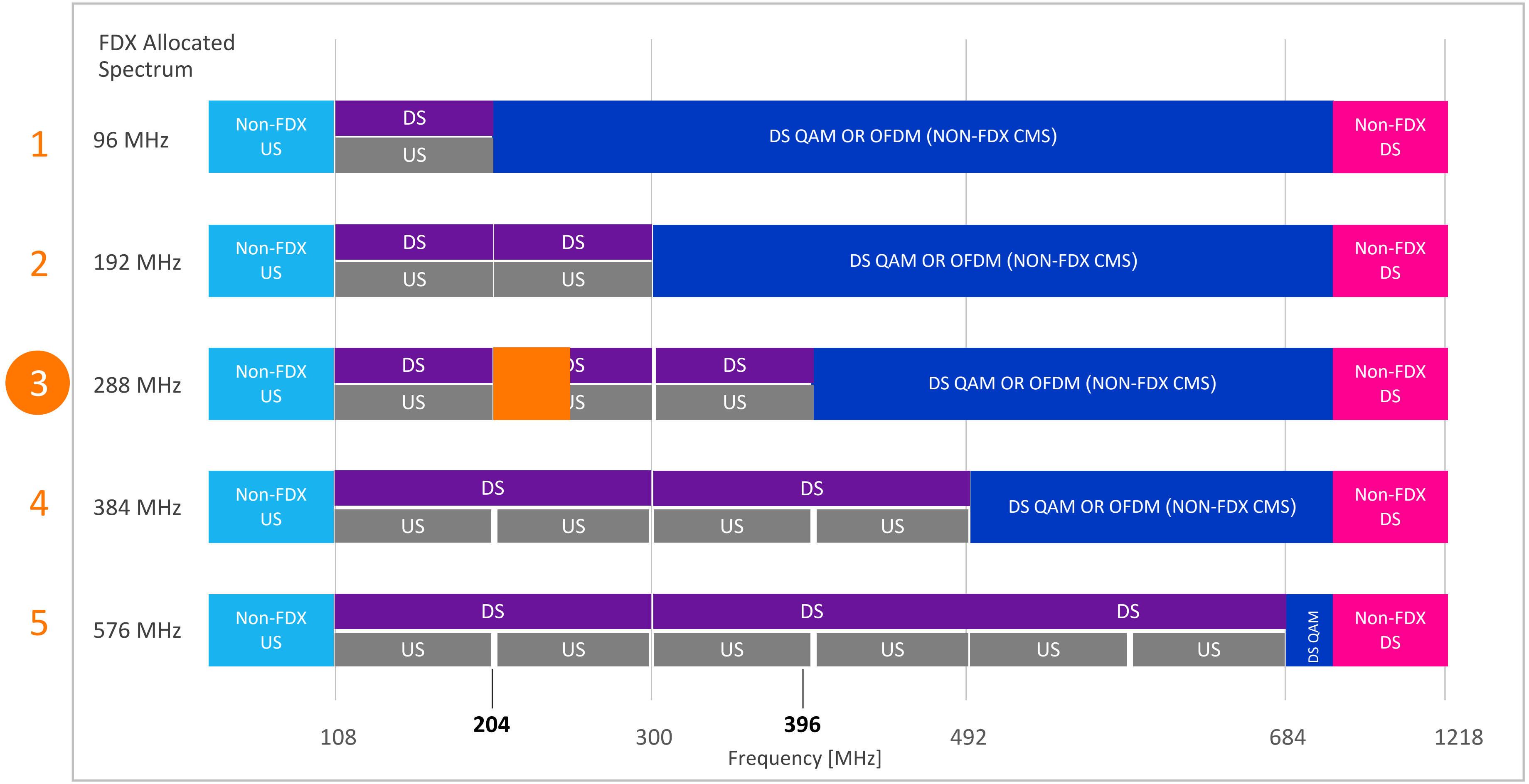
FDX & XSD are complementary…. How to Run an FDX Node & FDX CM in Static FDX/Extended Spectrum Mode (i.e., FDD model) for N+x Networks? 5-204 MHz US Network

Configure the node to work in FDX mode



- Configure the node to 'know' that the plant has 204/258 MHz diplexer
- Configure an exclusion zone in 204-258 MHz
- All D4.0/FDX modems are assigned to the same IG/TG
- Node configures RBA such that
  - 108-204 MHz always US
  - 300-396 MHz always DS (accessible by FDX CMs)
- Decide on what to do with 258-300 MHz
  - Always DS - Accessible to FDX CMs
  - Exclude it & Use video and/or data SC-QAM
- Configure video and/or data SC-QAMs in 396-804 MHz

Notes

- **FDX CM cannot use 396-804 MHz in this scenario**
- **D3.1 high-split CM will work just fine. US ends at 204 MHz & DS starts at 258 MHz**

AGENDA

Traffic Engineering Trends

FDX

Soft FDD

▶ **XSD DS**

High-Split for Symmetrical Gigabit Services

Active Taps

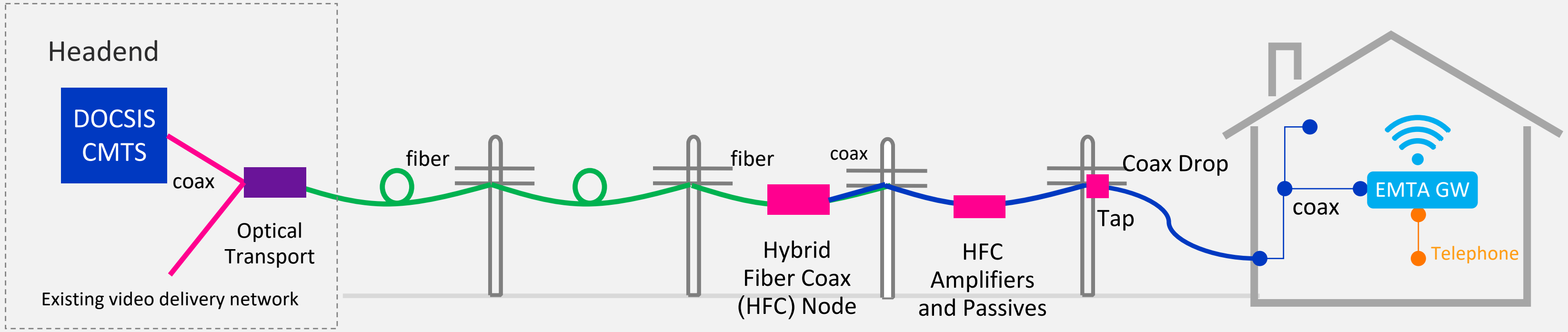
HFC Network Migration & Recommendations

Conclusions

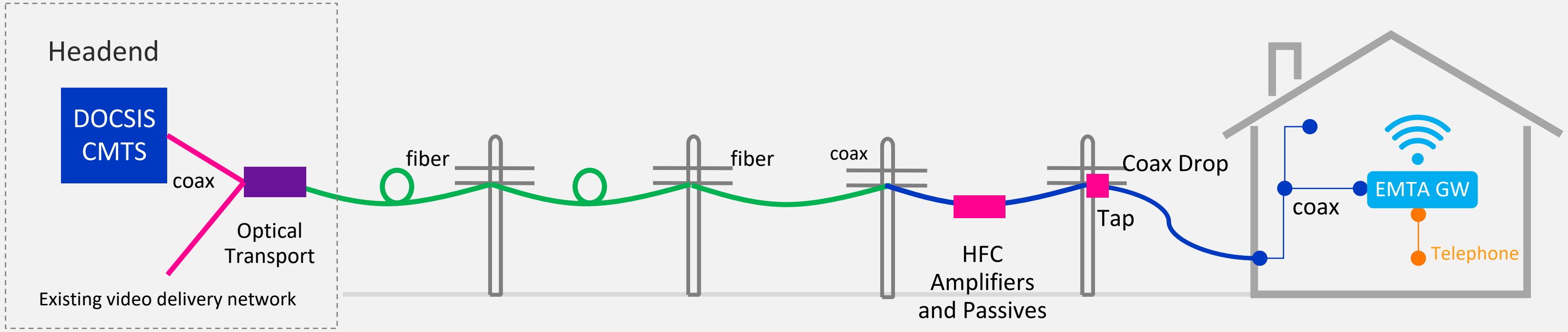
FTTx Topologies

	Facility	Outside Plant	Subscriber

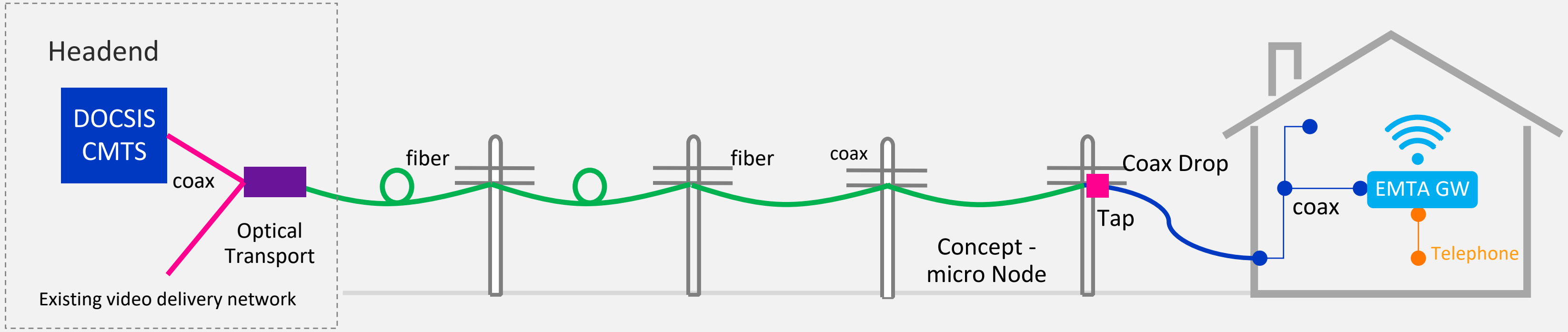
Fiber to The Node
N+1



Fiber to The Last Active
FTTLA

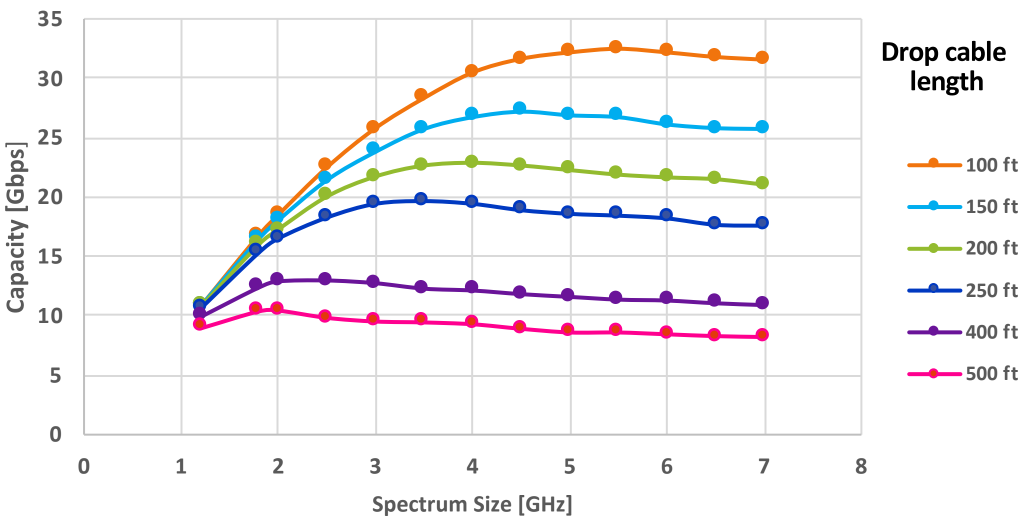


Fiber to The Tap
FTTT



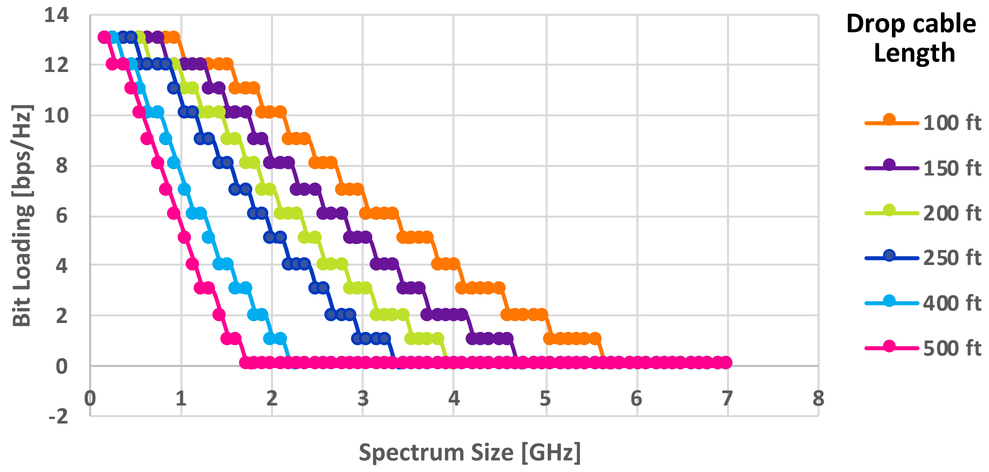
Extended Spectrum DOCSIS (XSD) - Permitted Capacities Depend on Fiber Depth & Cable Length

Capacity in an FTTLA system

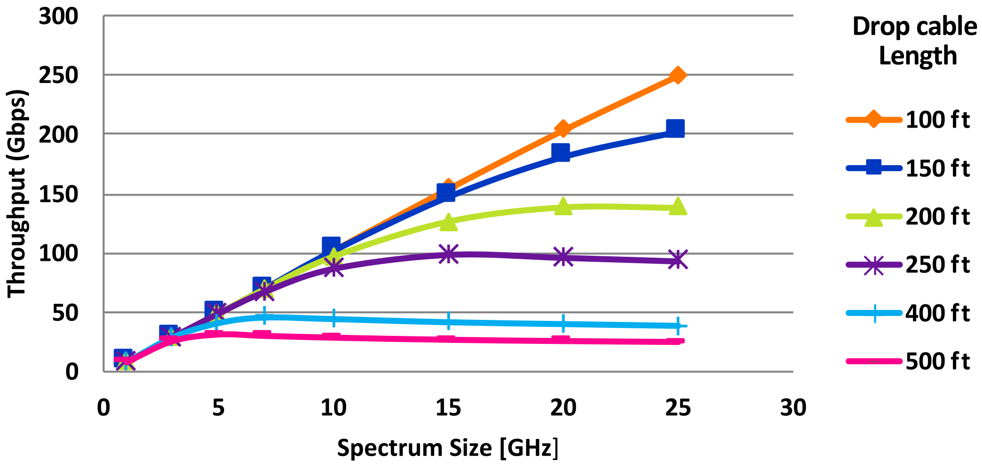


Bits/symbol

Bit Loading in an FTTLA system

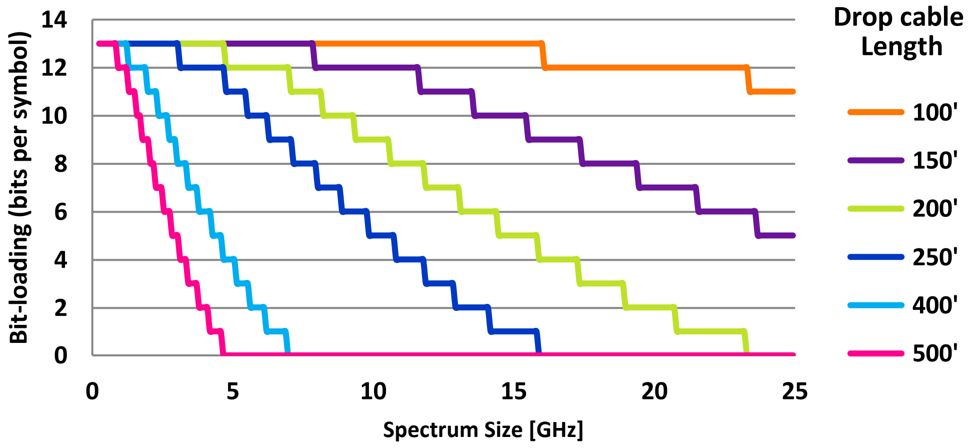


Capacity in an FTTT System



Bits/symbol

Bit Loading in an FTTT system



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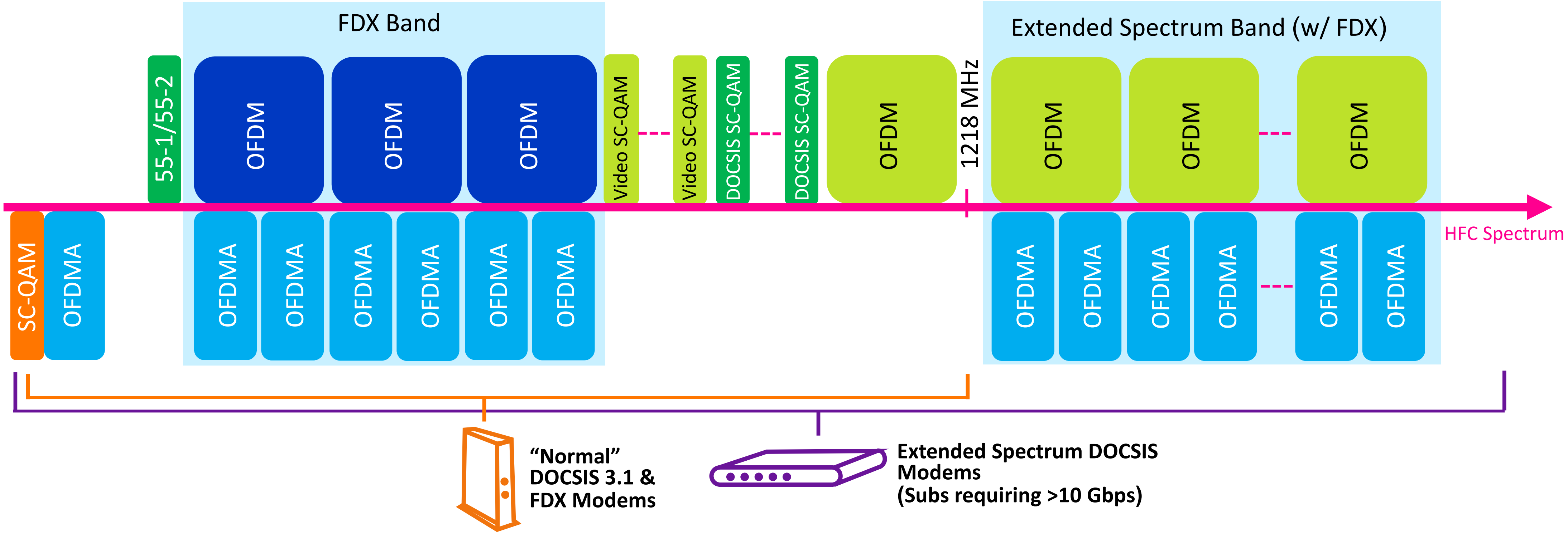
Extended Spectrum DOCSIS as Envisioned in 2015

- Simple idea was initially proposed by ARRIS in the 2015 CableLabs Summer Conference
- Just extend the spectrum of DOCSIS OFDM & OFDMA channels to use more of the available spectrum on the coax…
- Could be 1.8 GHz, 3 GHz, 6 GHz, 12 GHz, 25 GHz? (the shorter the coax, the higher the permissible spectrum)
- Use OFDM's Bit-Loading feature permitting lower Modulation Orders in higher frequencies with higher attenuation
- You do NOT need to increase Total Composite Power levels
- Use flat Power Spectral Densities for OFDM signals
- Backwards compatible with traditional DOCSIS & FDX



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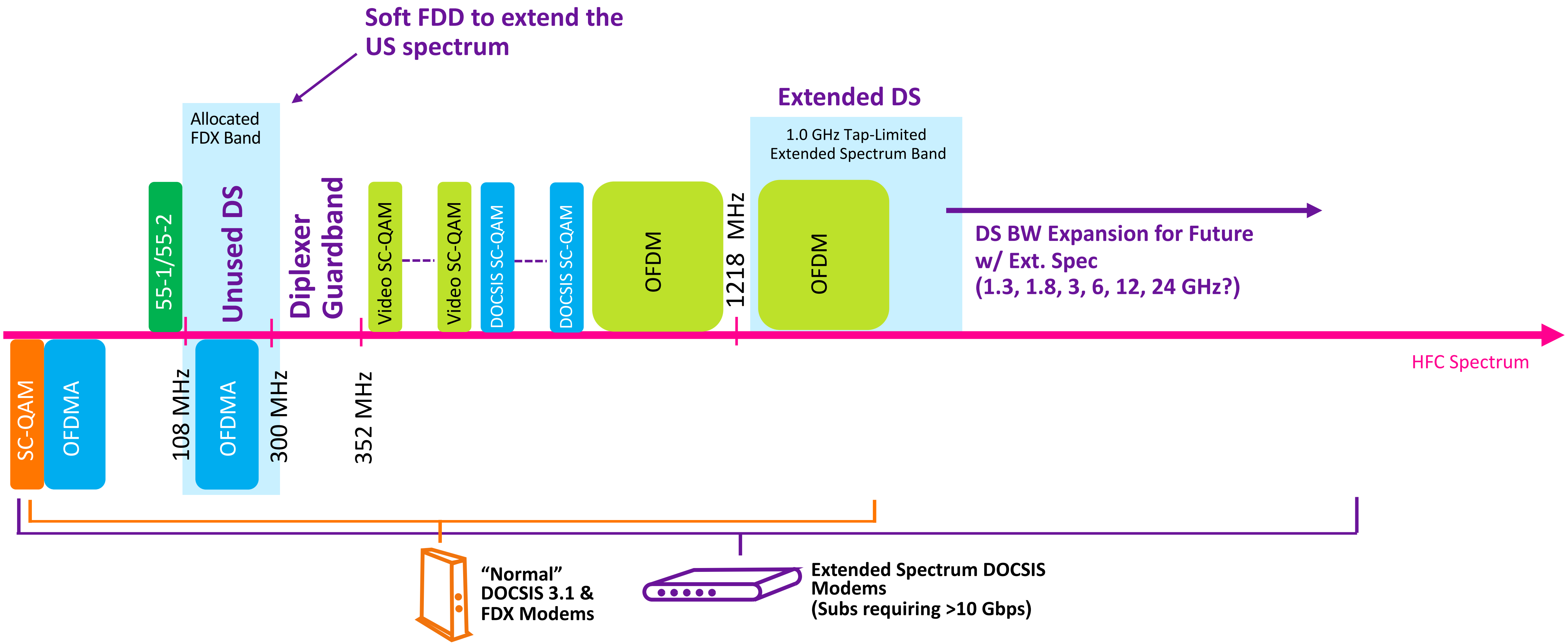
The New Vision of Extended Spectrum DOCSIS (Simplified)

Extending the DS spectrum to 1.2 GHz, 1.8 GHz, 3 GHz, 6 GHz, 25 GHz?



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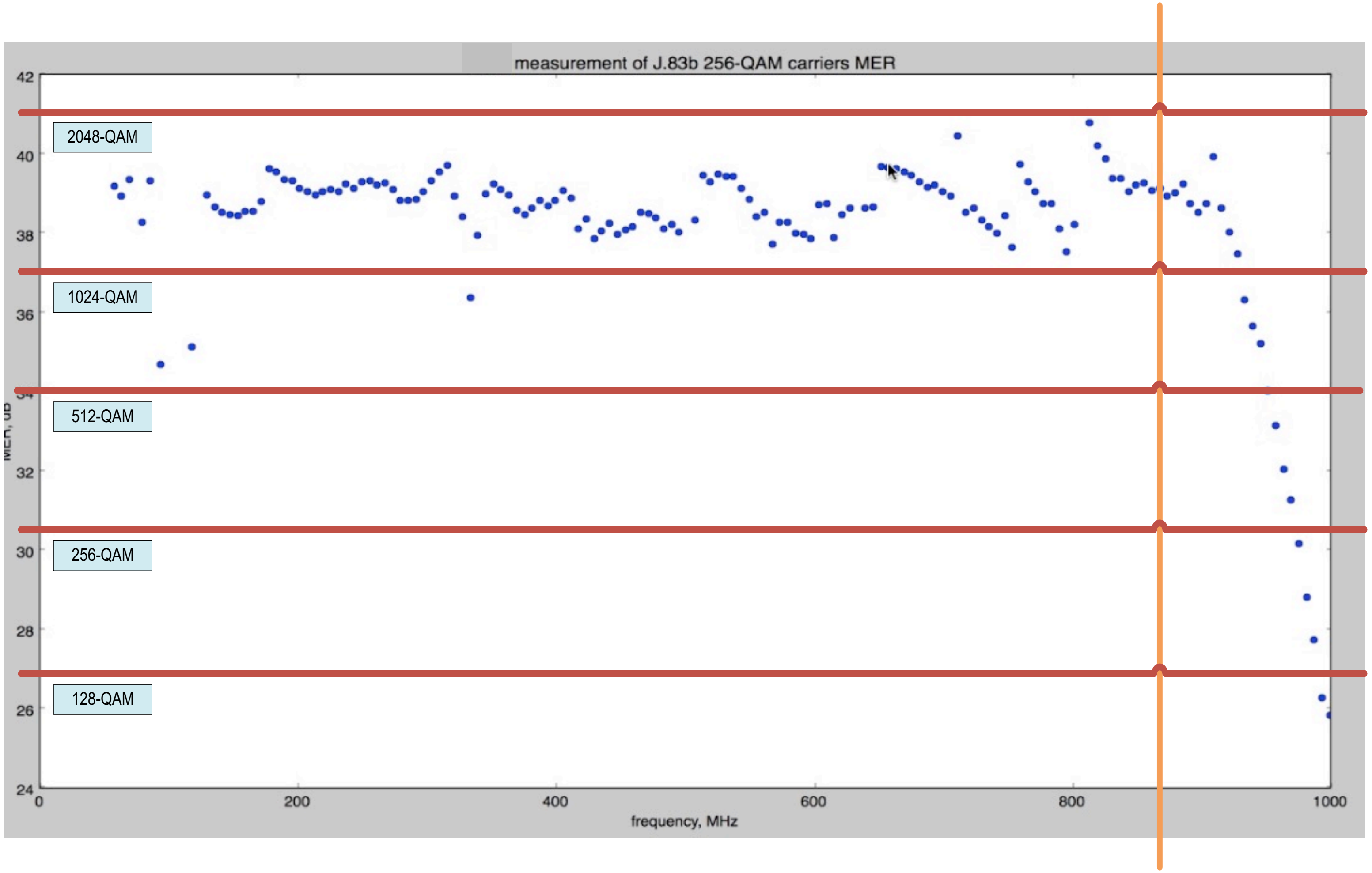
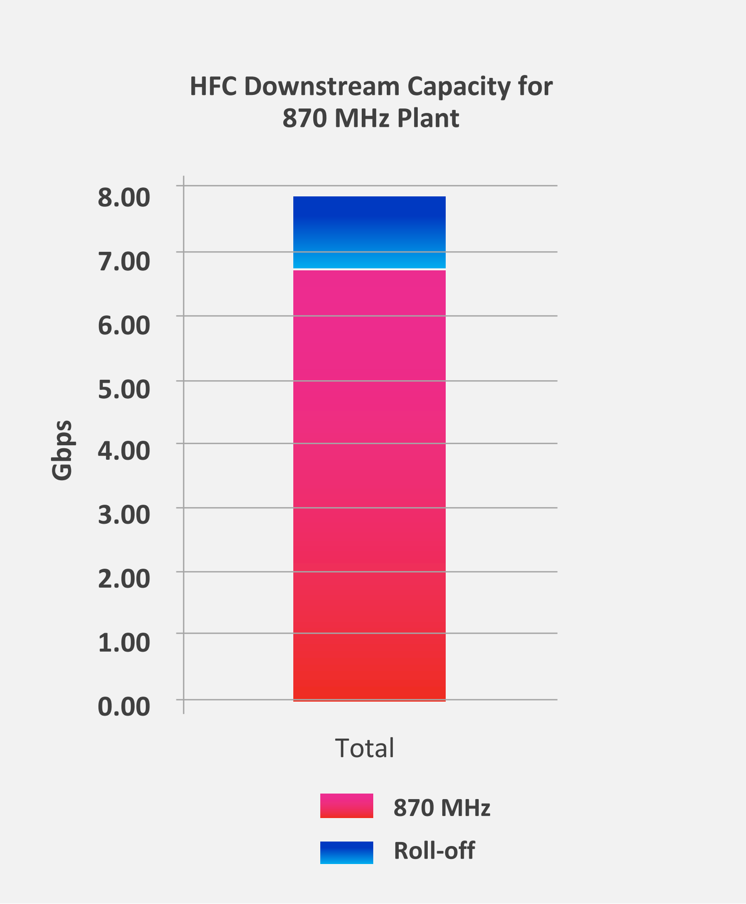
Possible RF Issues & Fixes for the Extending the DS Spectrum

- **Total Composite Power**… we keep it roughly fixed at an equivalent TCP used in normal HFC operation today…
- **Tilt**… use normal tilt and normal PSD levels for SC-QAM DOCSIS channel & SC-QAM Video channels, but use flat tilt for DS OFDM channels above the SC-QAM channels… as SC-QAM channels for Video or DOCSIS are retired, OFDM channels are added, and the flat region of the spectrum will expand and can have higher Power Spectral Densities (and higher SNRs and higher QAM orders and higher throughputs)
- **Re-spacing of Amps**… none is needed- we tilt the SC-QAMs as they are today… all works as it does today for the SC-QAMs… OFDM channels use bit-loading to compensate for attenuation and lower SNRs at higher frequencies
- **# of Amps in Cascade**… since we are building “normal” amps with ultra-high-split, we should be able to cascade many Amps after the Node
- **MOCA in the home**… place the CM as a portal GW with 2 isolated RF ports… this creates isolation between the OSP Network and the Home Network (just like FDX proposes to do)
- **Legacy Video**… could use IP Video over DOCSIS or could create filters to let QAM video pass through into Home Network or could receive QAM video and re-generate as IP Video for subtending IP STBs or could receive QAM video and re-generate QAM video in home network
- **Ease of Upgrades on existing HFC Actives and Taps**… TBD

Spectrum Roll-off in DS Offers Additional Capacity

Example based on Real Plant MER Samples





Sample MER Measurements on 870 MHz HFC Plant

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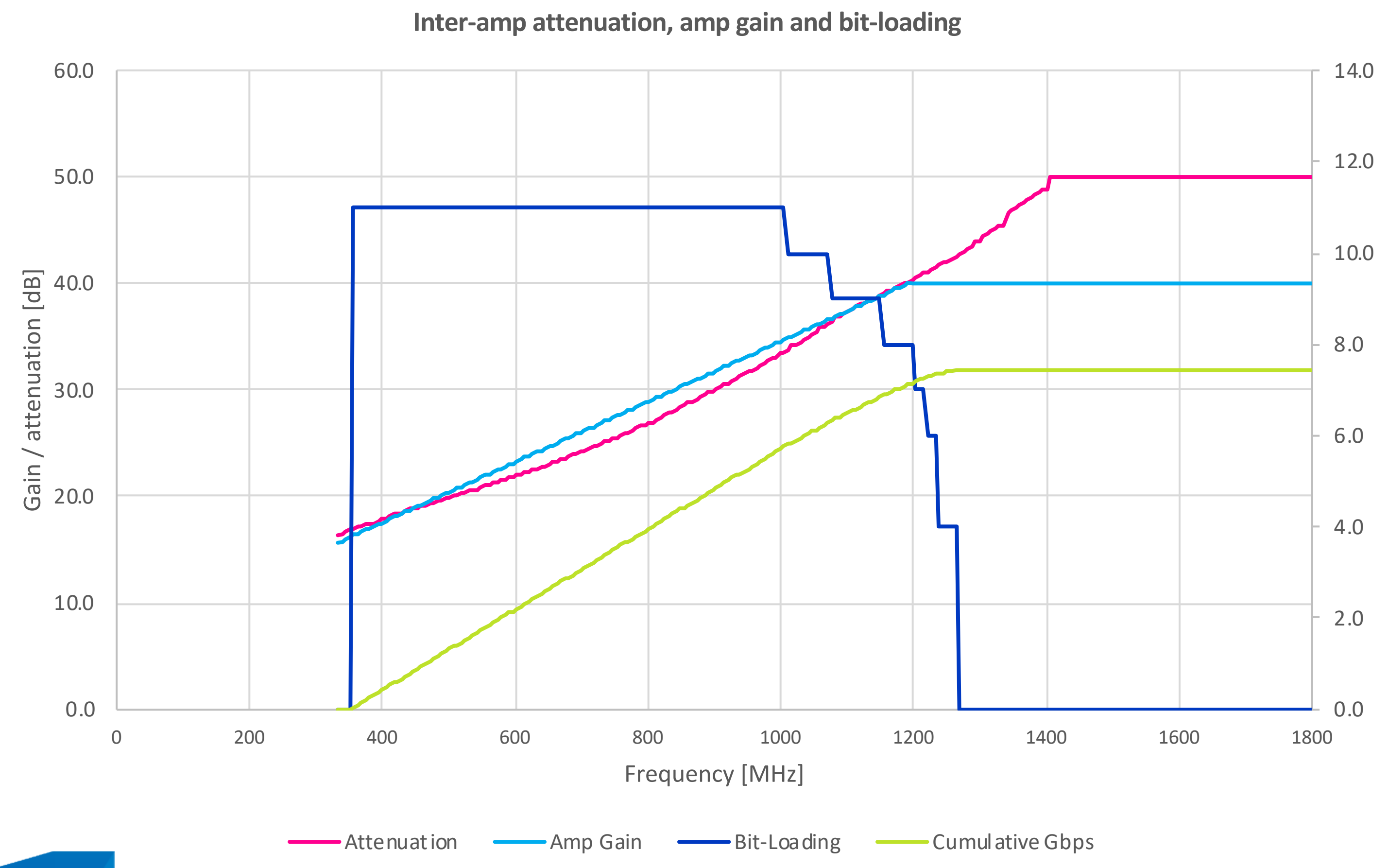
Throughput & Bit-Loading of a Real-World 1.0 GHz Tap (in Node+3 Architecture)

Key Take-Away:

- 1.0 GHz Taps permit operation in the roll-off region that permits variable bit-loading to operate between 358 & 1400 MHz, providing a Cumulative DS BW of ~8 Gbps
- The Upstream supports a Cumulative US BW of ~2.2 Gbps within a 300 MHz Upstream Spectrum
- This works even in a Node+3 Architecture
- Key Take-Away: Already-deployed 1.0 GHz Taps in the field today can provide additional BW Capacity using Extended Spectrum DOCSIS in the roll-off region



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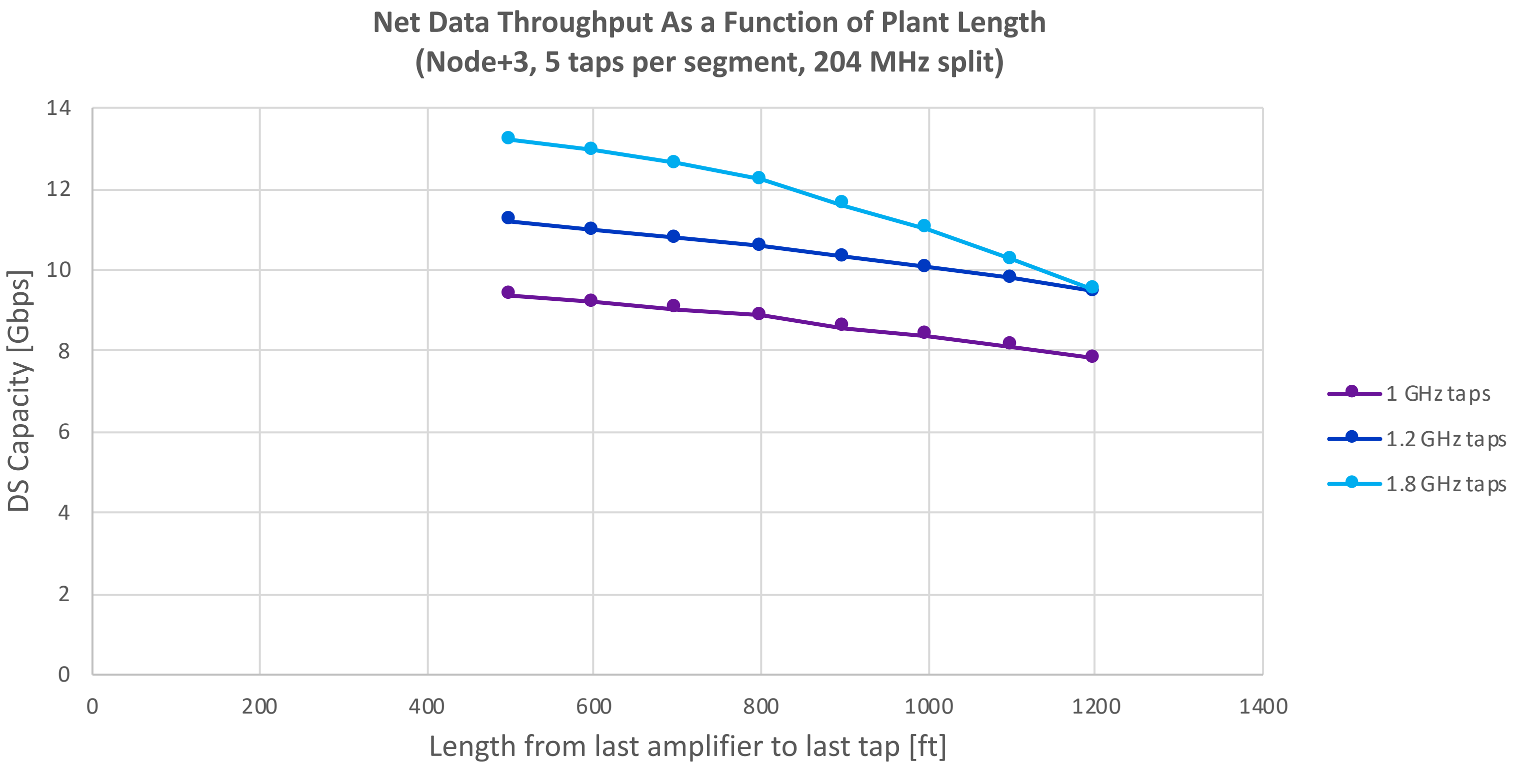
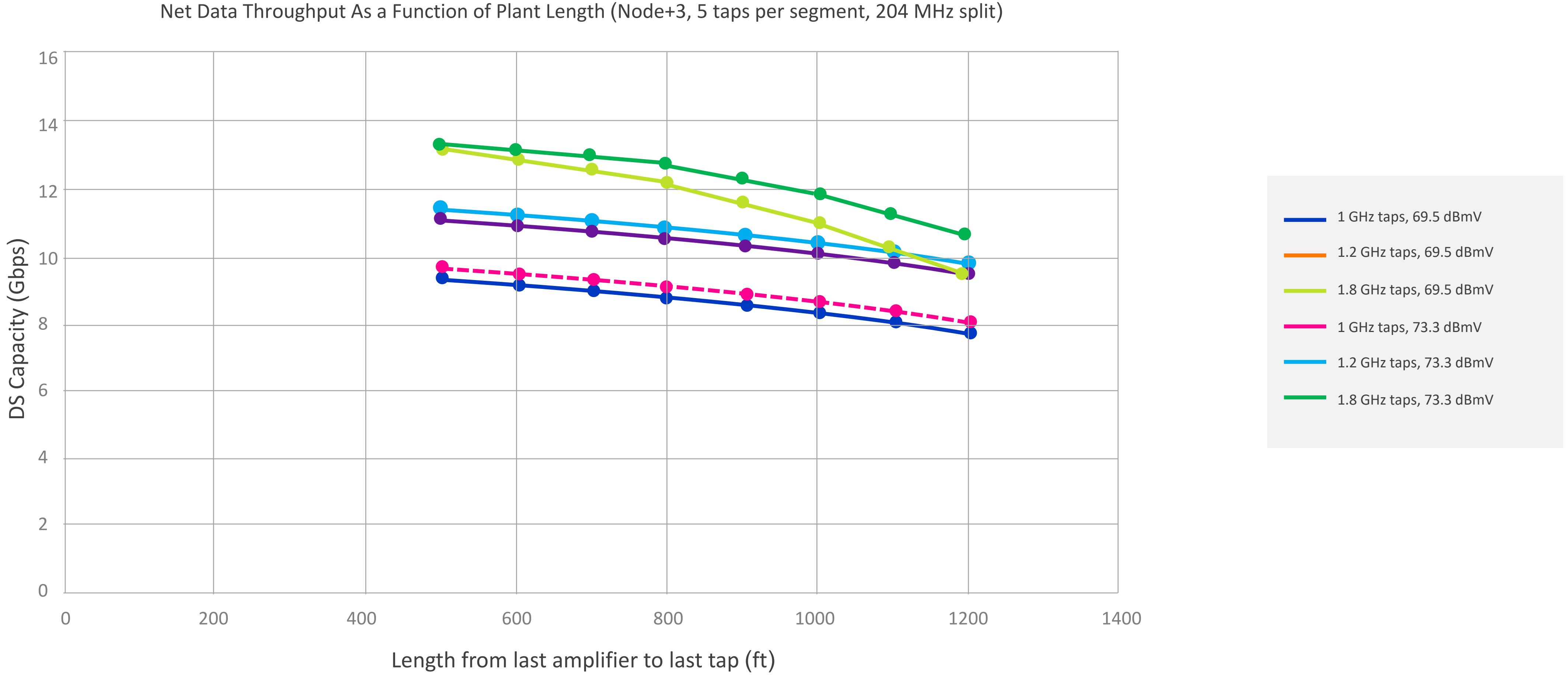
XSD DS 1.8 GHz Enables 10 Gbps Service EoL Performance

- Assumptions: TCP of 69.5 dBmV. Uptilt for SC-QAM is up to 400 MHz. 100 ft drop cable for all scenarios.

- 1.0 GHz & 1.2 GHz scenarios are using the roll-off regions. 1.8 GHz is not due to lack of 1.8 GHz tap data in the roll-off region.



Increased AMP Power from 69.5 dBmV to 73.3 dBmV does not Increase the Capacity significantly with the Current Plant Cable Lengths



2015 ARRIS Demo @ CableLabs Summer Conference…
XSD Experimental Setup (SNR @ Tap = 45 dB)

ARRIS E6000
w/ DOCSIS 3.1 96 MHz QAM4K OFDM
Output signal at frequency
below 1.0 GHz

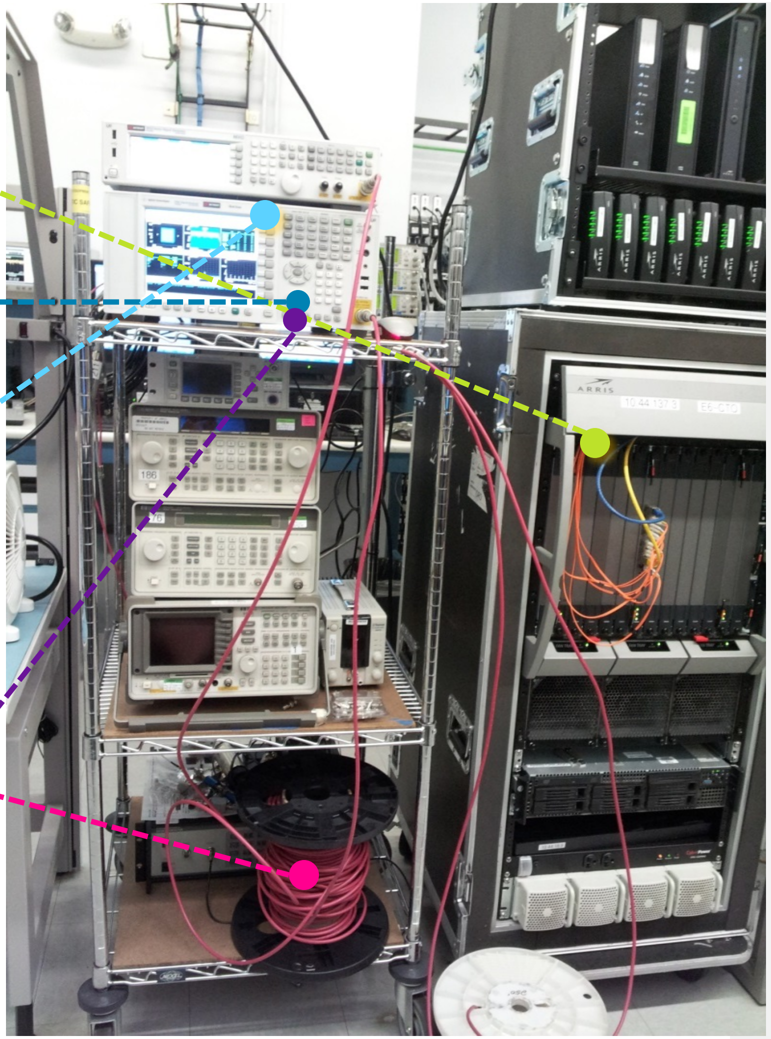
Signal recorded using Keysight
PXA N9030A VSA

Keysight MXG N5182B Signal Gen
Up-converting the recorded Signal
to a carrier frequency of ~6 GHz

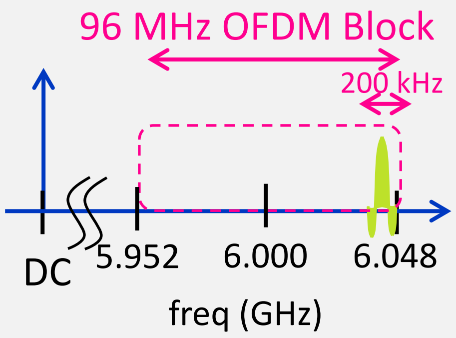
Standard RG-6 Coax (150’)
Transmission Line

Keysight PXA N9030A VSA
demodulating the DOCSIS 3.1 signal

In Demo today

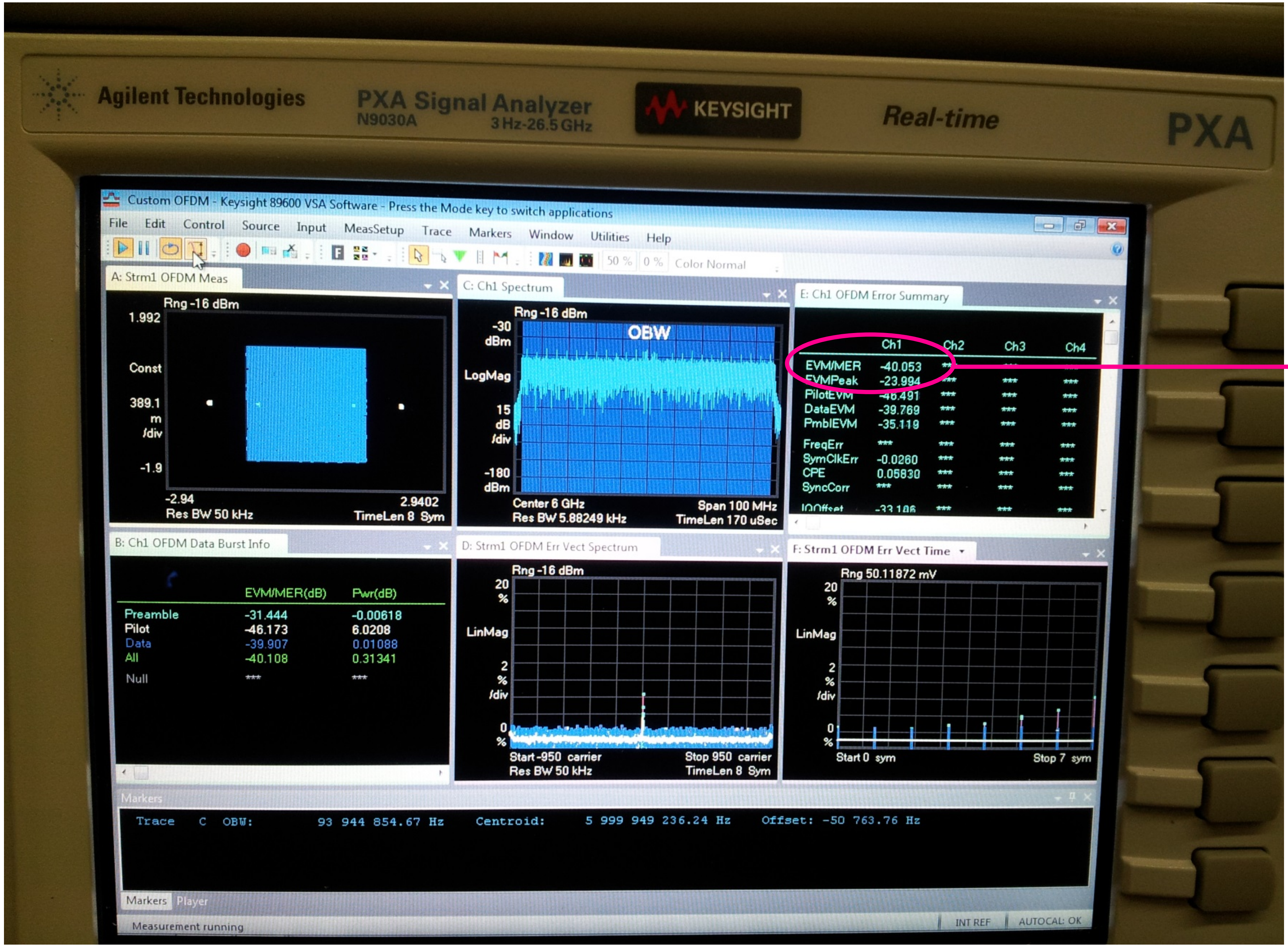


Amplitude Spectrum in Coax



Let’s take a look at the experimental results of sending a 96 MHz OFDM signal centered @ 6 GHz through 150’ of coax

Live Outputs from the Experiment



MER = 40.05 dB

(Very Good!!! Good enough to support DS~4096QAM!!!)

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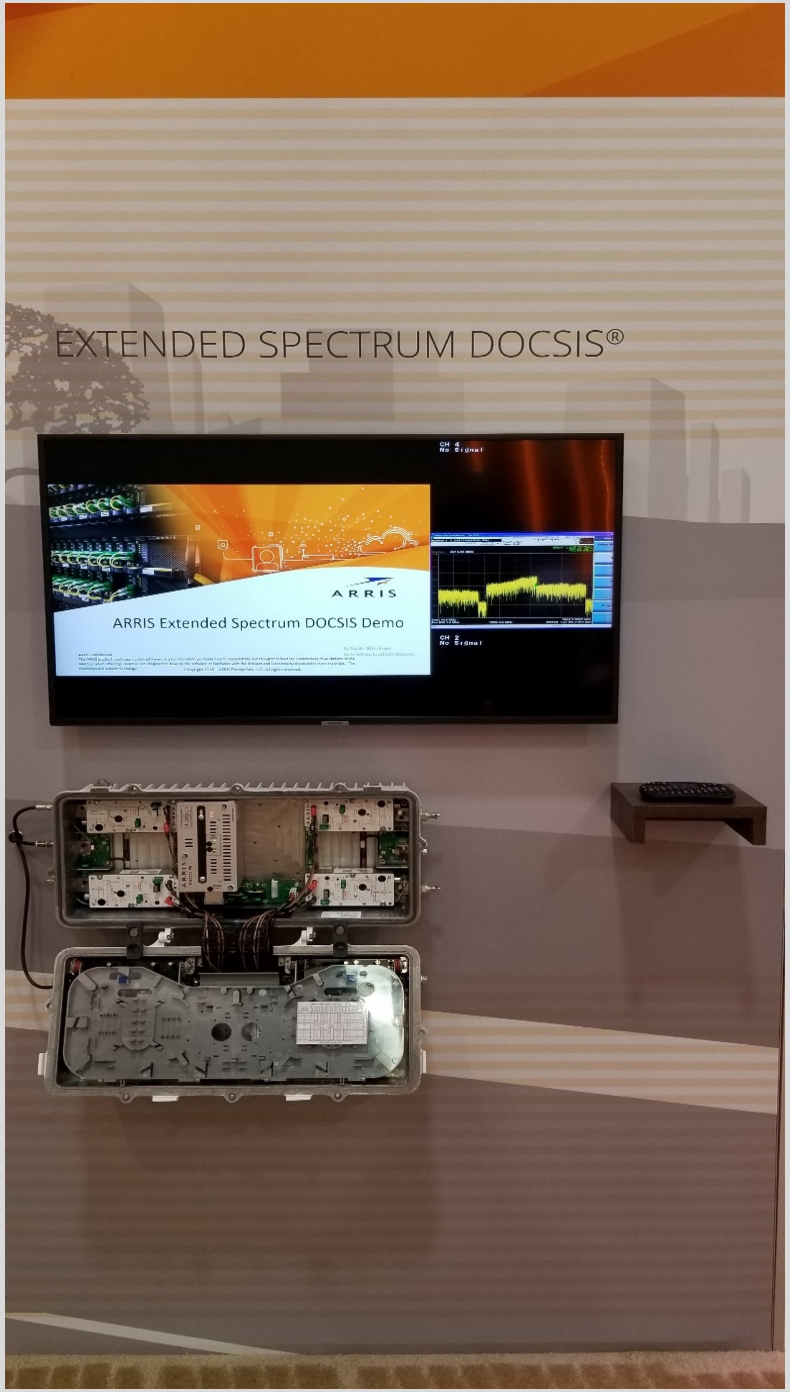
ARRIS 1.8 GHz XSD Demo at SCTE 2018



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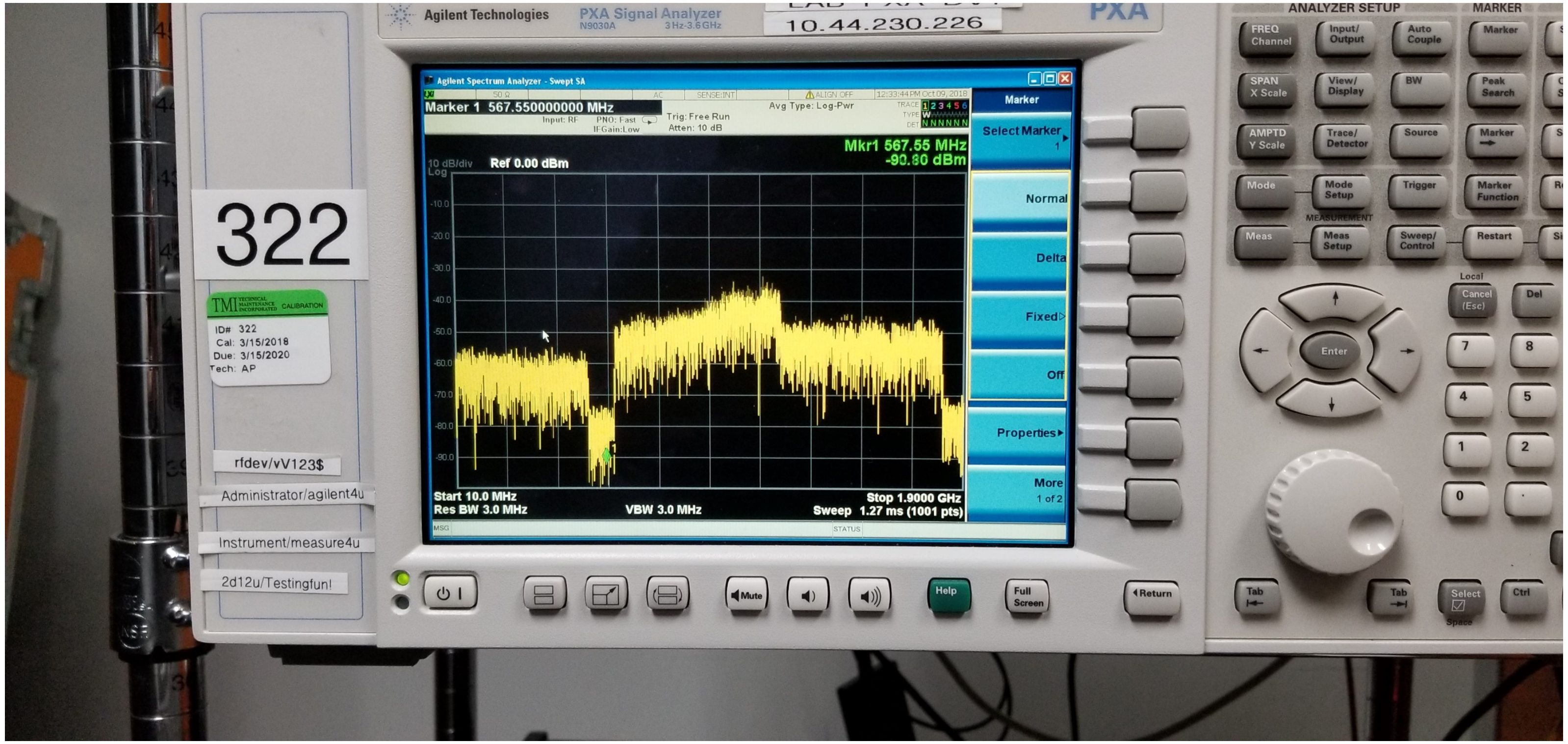
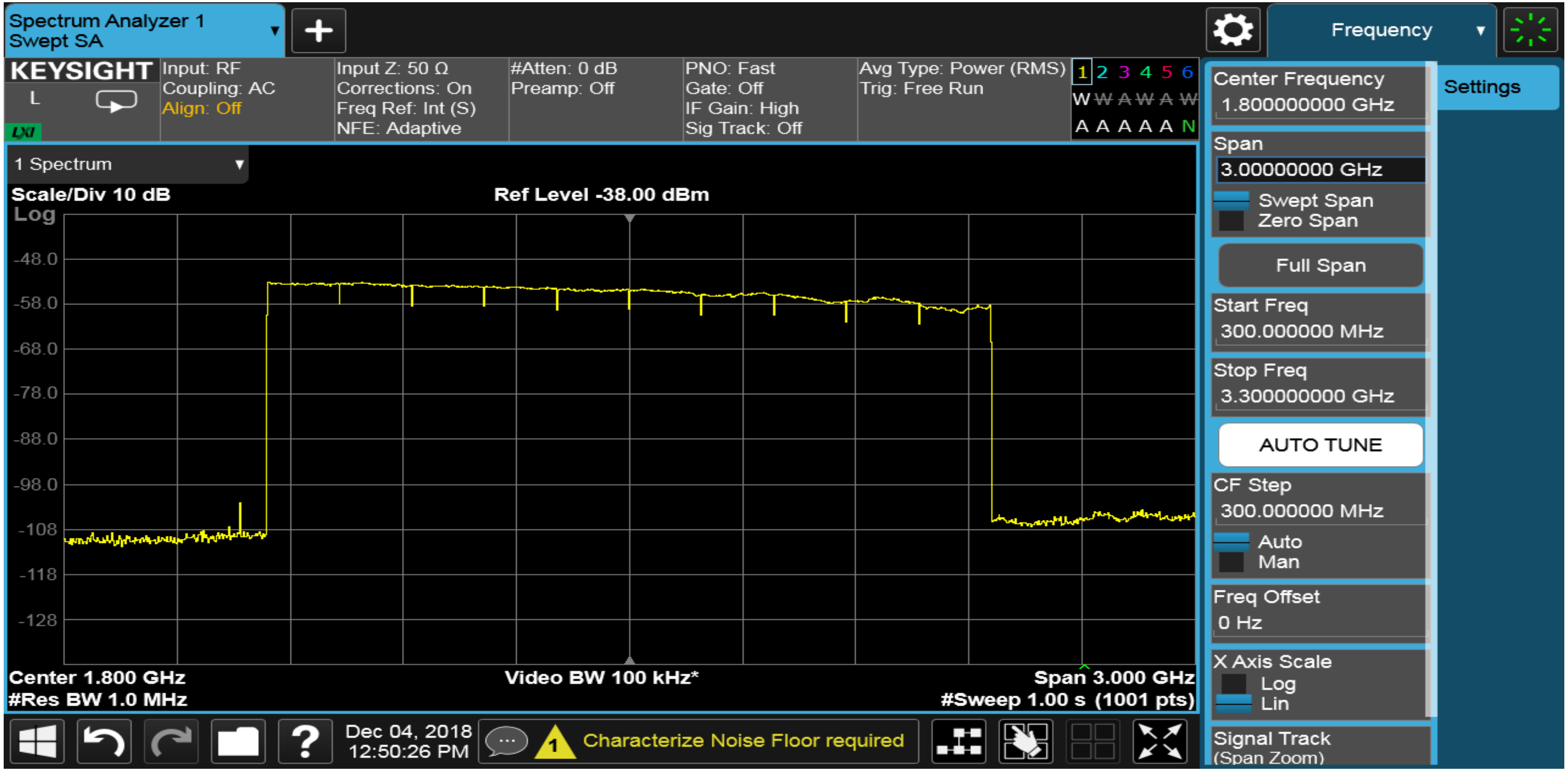
ARRIS 1.8 GHz XSD Demo at SCTE 2018



- Key Take-Away: 1.0 GHz Taps permit operation in the roll-off region that permits bit-loading to operate between 358 & 1400 MHz, providing a Cumulative DS BW of ~8 Gbps while also supporting Cumulative US BW of ~2.2 Gbps
- This works even in a Node+3 Architecture
- Key Take-Away: Already-deployed 1.0 GHz Taps in the field today can provide additional BW Capacity using Extended Spectrum DOCSIS in the roll-off region

ARRIS 2.8 GHz Ext. Spec. DOCSIS RPD Node Research in Jan. 2019



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AGENDA

- Traffic Engineering Trends
- FDX
- Soft FDD
- XSD DS
- ▶ **High-Split for Symmetrical Gigabit Services**
- Active Taps
- HFC Network Migration & Recommendations
- Conclusions

DOCSIS 3.1 Spectral Efficiency of US SC-QAM Channels

Assumptions

- Roll-off is 25% with QAM 64
- Long grants
- FEC block is (255, 223) [common IUC 10]
- 104-bit preamble

The above yields 26.6 Mbps per 6.4 MHz

This is equivalent to 4.15 bps/Hz (at QAM 64)

- QAM-independent spectral efficiency is 0.692 sps/Hz

DOCSIS 3.1 US Spectral Efficiency of OFDMA Channels

Assumptions (mostly using D3.1 US R6.0 feature parameters):

- 96 MHz
- 2K FFT
- CP = 1.875 µsec
- Frame size = 16 OFDMA symbols
- Pilot pattern 2
- Large CW size

QAM-independent spectral efficiency is 0.77 sps/Hz

When QAM1K modulation is assumed, the spectral efficiency is 7.7 bps/Hz

- Note: The estimates shown here are based on theoretical analyses. Real-world gains may be less. Results will change from one MSO to another. The results shown here represent statistical averages and the gain for different nodes on the same MSO's network may be different. The results here assume AWGN only and other noise types are not considered. Less efficient assumptions and noise conditions may affect/reduce the potential gain.

US Capacity Analyses

Analysis Assumptions

- Legacy US spectrum: 5-85 MHz (usable spectrum 20-85 MHz): 10 SC-QAM 6.4 MHz QAM64 channels
  - Spectral efficiency is 4.15 bps/Hz (see previous slide)
- FDX band phase 1: 108-204 OFDMA (1 OFDMA channel)
  - Spectral efficiency is 7.7 bps/Hz (see previous slide)
- FDX band phase 2: 108-300 OFDMA (2 OFDMA channels)
  - Spectral efficiency is 7.7 bps/Hz (see previous slide)

US capacity

- Legacy throughput = 10*6.4MHz*4.15bps/Hz ~ 265 Mbps
- FDX band capacity (phase 1)= 1*96MHz*7.7bps/Hz = 739 Mbps
- FDX band capacity (phase 2)= 2*96MHz*7.7bps/Hz = 1.48 Gbps

- Total available US capacity ~ 1.00 Gbps in Phase 1
- Total available US capacity ~ 1.74 Gbps in Phase 2

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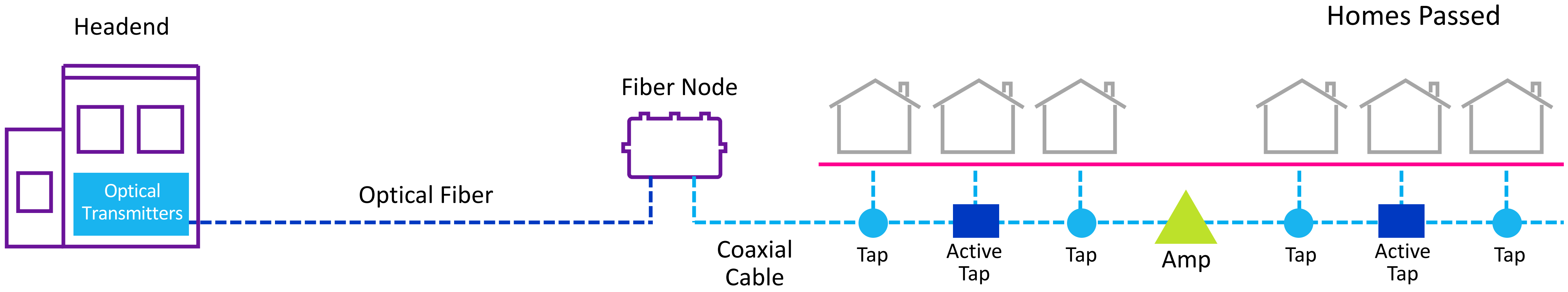
Active Taps Can Help Increase Signal to Noise Ratio & Increase BW Capacity… Especially for Extended Spectrum DOCSIS



Active Taps would have Amplifiers integrated to boost signal strength… Especially at high frequencies

AGENDA

Traffic Engineering Trends

FDX

Soft FDD

XSD DS

High-Split for Symmetrical Gigabit Services

Active Taps

▶ **HFC Network Migration & Recommendations**

Conclusions

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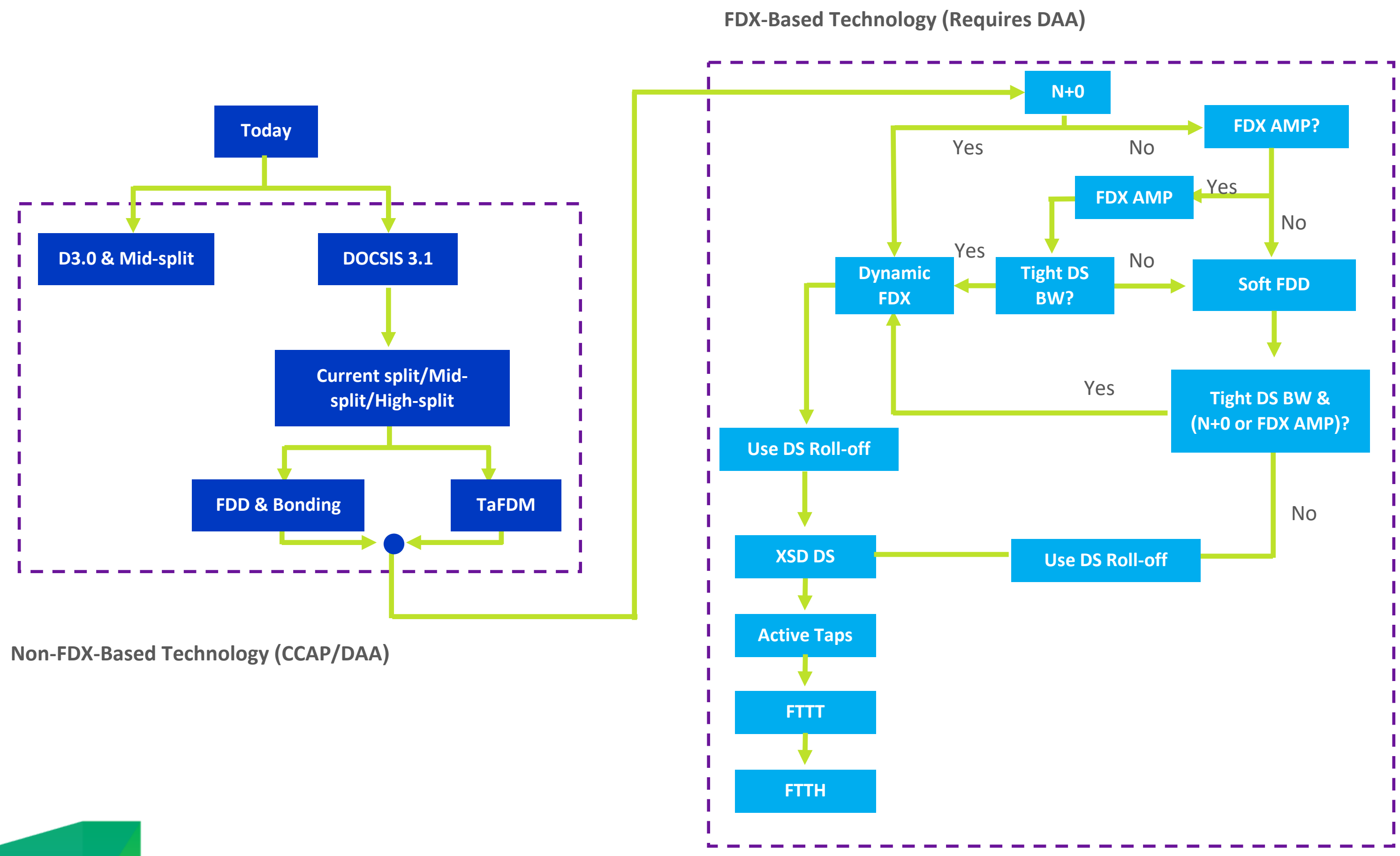
Network Migration Strategies to Offer Higher US & DS Peak Rates

- XSD specifications can also include expanded FDX Band (above 684 MHz)
- There are enough tools in the DOCSIS/HFC toolkit to enable multi-Gigabit US service offering via a smooth & gradual network migration over the next two decades!



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Conclusions

Supporting the traffic & marketing demands will require new technologies

MANY new technologies are becoming available

- Denser I-CCAP, RPHY, RMACPHY, RMC, Virtualization, DOCSIS 3.1, Full Duplex DOCSIS, Soft FDD, Extended Spectrum DOCSIS, Remote OLT
- FDX, Soft FDD, & XSD DS are complementary technologies

High-split will be required to support symmetrical Gigabit services.

1.8 GHz is required to support 10 Gbps DS services. Going deeper fiber and/or using Active taps can boost the 1.8 GHz performance

The above tools will extend the life of HFC plants into the 2020-2030 decade

Thanks!

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