Cisco Knowledge Network (CKN) Path to Higher Upstream Throughput

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Top of Mind: Cable Market

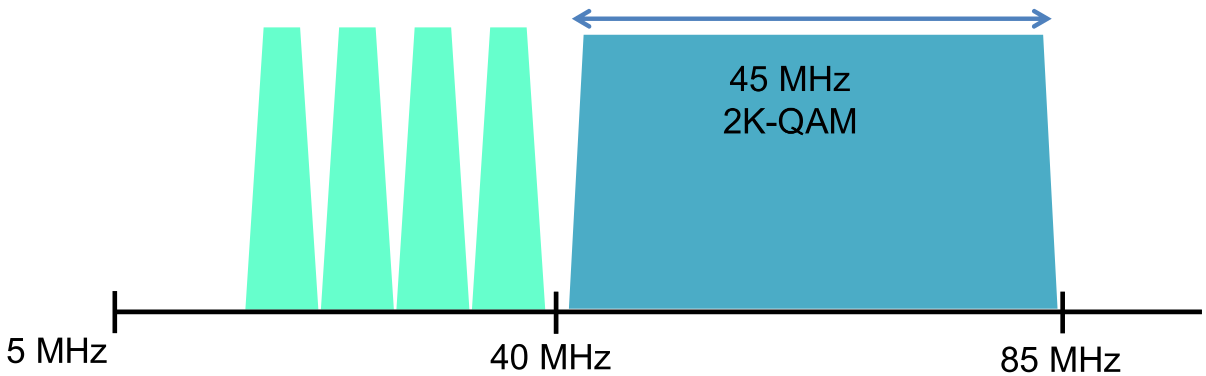
- Cable and the Pandemic
- Node splits for US congestion
- Global Cable will add 3.7M subs in 2021*
- Approx 4% sub growth over last two years*

- Market is fractured on the future
- HFC, RPHY, D4.0, FDX, FMA, PON
- 1Gb symmetrical speeds coming
- Mid and High splits + OFDMA required

**Source: GlobalData September 2021*

What Will an 85 MHz System Provide?

- Traditional 42 MHz systems limited to 100 Mbps ATDMA or 150 Mbps with OFDMA & ATDMA
- Mid-split (85 MHz) could achieve 500 Mbps (D3.0 using 8 SC-QAMs = ~ 200 Mbps)



4 SC-QAM & 45 MHz OFDMA
100+400 = 500 Mbps

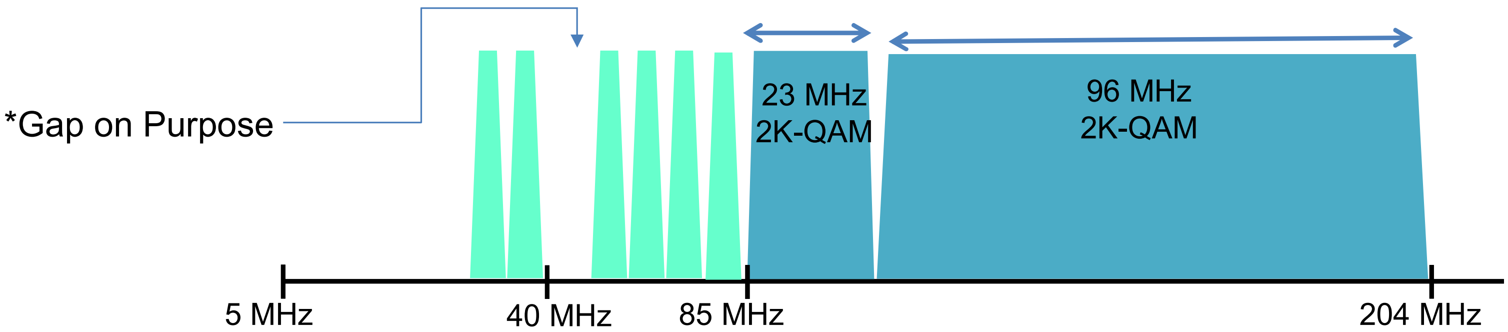
*Could also drop some ATDMA

- Ultimately, we want to offer 1 Gbps

D3.1 - 204 MHz US

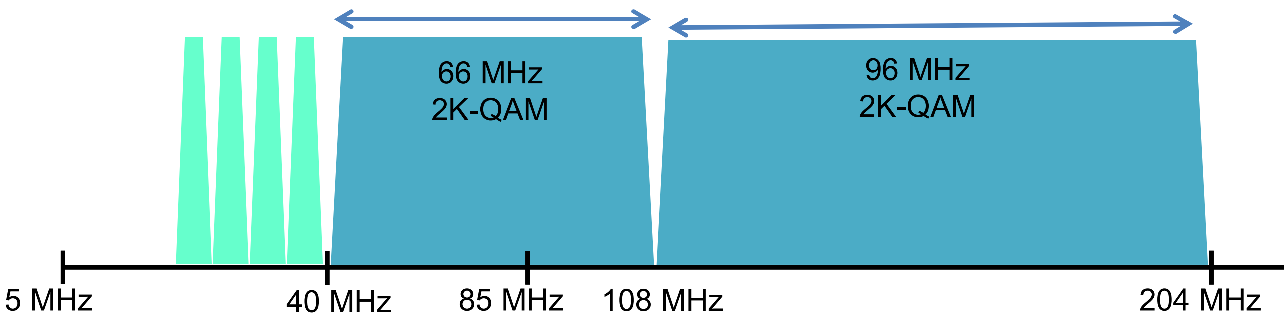
- Available Now
  - D3.1 CMs available today can support 204/258 MHz split
- Can achieve potentially 1.5 Gbps aggregate speed
- No special nodes with echo cancellation like FDX
- No need for N+0 or 1 like FDX
- DAA advantages along with no US laser clipping
  - EDR with analog link may be an option as well

D3.1 CMTS US Rx Examples for 204 MHz



Example 1: 23 MHz & 96 MHz OFDMA

50+100+200+875 = 1225 Mbps



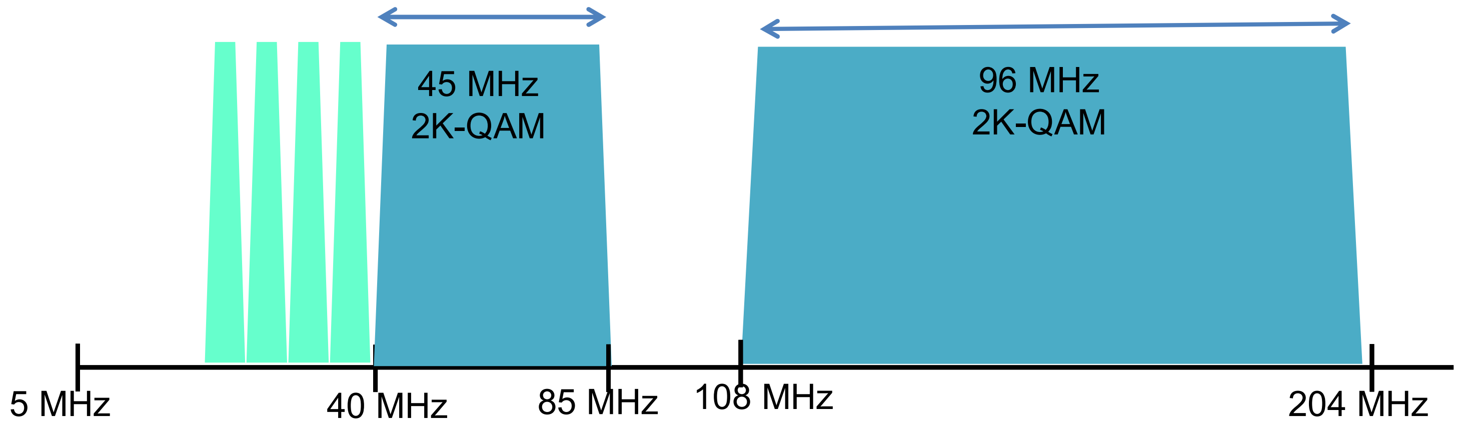
Example 2: 66 MHz & 96 MHz OFDMA

100+600+875 = 1575 Mbps

- **Note**: Need to address CMs that support 42, 85 and 204 MHz in same plant

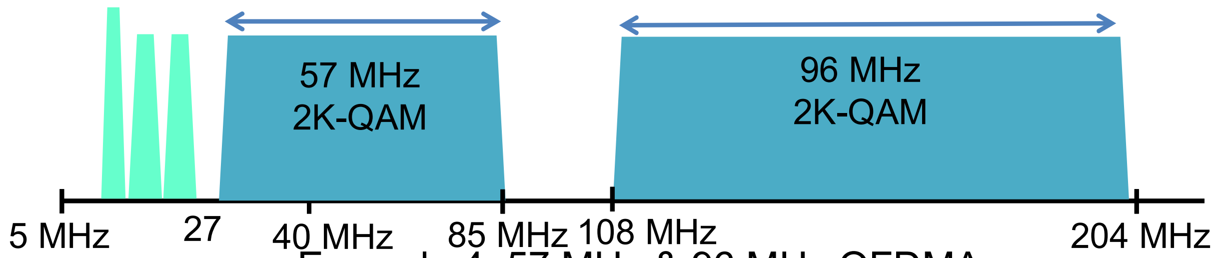
OFDMA Block Straddling 85 MHz Creates Issues

- CMs with 85 MHz filters exhibit issues locking on correct US BG
- **Fix** - Have smaller OFDMA block from 40 to 85 & another above 85 MHz
  - ➢ Avoid FM band altogether
- Working group looking at this and how to create partial mode scenario properly



Example 3: 66 MHz & 96 MHz OFDMA
100+400+875 = 1375 Mbps

Feedback on One Customer’s Ideas



Example 4: 57 MHz & 96 MHz OFDMA

50+500+875 = 1425 Mbps

The Good

- 1.4 Gbps aggregate could potentially provide 1 Gbps US service
- Avoids CB and FM band
- Also foresee need for SC-QAM for D2.0 & eMTAs, and 2-ch US bonding for D3.0 CMs
  - ➢ Cross-bonding also allows US partial mode, support of US scheduled flows like nRTPS and UGS, and a T4 multiplier of 3 for added resiliency 30*3 = 90 sec before a T4 timeout would occur
- Avoids issues with D3.1 CMs with 85 MHz filters

The Bad

- IRT leakage testing, not sure just avoiding those freqs will be acceptable in throughput lost or if FCC will even allow it
- Cablelabs working with test equipment vendors & D3.1 CMs OUDP test burst solution
- Testing on “house-by-house” basis is necessary for adjacent device interference (ADI) concerns and may require filters

The Ugly

- Still need to decide what to do about STBs
- Conditioned taps are desirable, but not if they have internal 42 MHz filters
  - ➢ Flexible solution taps have an EQ/CS from 5 or 10 MHz all the way to 1.2 or maybe even 1.8 GHz

D3.1 Upstream - Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA

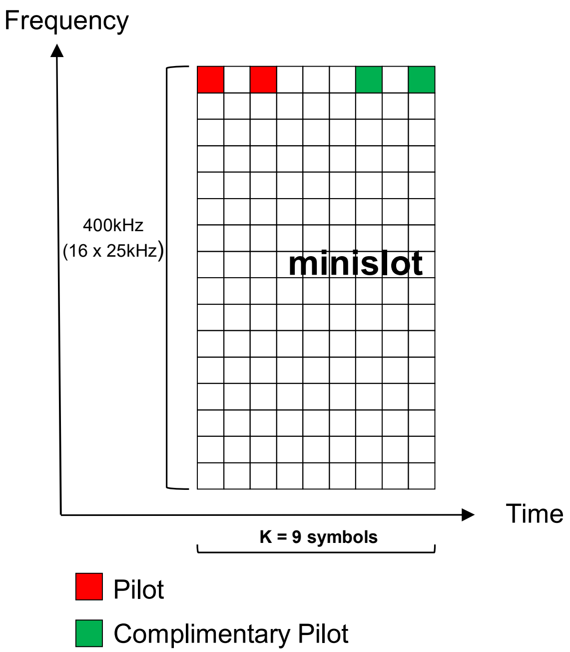
- OFDMA offers larger chs (up to 96 MHz) and higher order modulations compared to SC-QAM USs
- OFDMA is like the OFDM DS with many configuration options plus additional features to support multiple users
- Divide US ch into minislots which are assigned to CMs for transmission (or for contention slot)
- Minislot still defined in time as for SC-QAM but also now in frequency (400 kHz)
- Still rely on interval usage codes (IUCs) like in SC-QAM US to determine modulation order but now have options for up to 7 per OFDMA ch
- Can optionally override modulation per IUC for range of frequencies per OFDMA ch
- Adjust IUC per CM based on RxMER or CM codeword errors

OFDMA Configuration Recommendations

- 25 kHz subcarrier spacing recommended over 50 kHz (less overhead - although minimal with low cyclic prefix values)
- Cyclic prefix seems to have minimal impact on RxMER for OFDMA ch so run as low as possible to minimize overhead
- Pilot patterns with more overhead have been effective in reducing periodic codeword errors in frequencies below 42 MHz
- IUC 13 should be robust enough for all CMs to use error free (64-QAM or 16-QAM) – may need IUC override if in poor spectrum (< 10 MHz)
- Add multiple IUCs with higher modulation orders so CMs can transmit at higher speeds
- Avoid noisy spectrum below 10 MHz (minimal capacity gains)
- 50 kHz subcarrier spacing with large symbols per frame provides more time interleaving which may help with burst noise

OFDMA Configurations Recommendations

```
cable mod-profile-ofdma 428
  subcarrier-spacing 25KHz
  initial-rng-subcarrier 64
  fine-rng-subcarrier 128
  data-iuc 6 modulation 2048-QAM pilot-pattern 8
  data-iuc 9 modulation 1024-QAM pilot-pattern 8
  data-iuc 10 modulation 512-QAM pilot-pattern 8
  data-iuc 11 modulation 256-QAM pilot-pattern 8
  data-iuc 12 modulation 128-QAM pilot-pattern 8
  data-iuc 13 modulation 64-QAM pilot-pattern 8
 us-channel 12 docsis-mode ofdma
 us-channel 12 subcarrier-spacing 25KHz
 us-channel 12 modulation-profile 428
 us-channel 12 frequency-range 108000000 204000000
 us-channel 12 cyclic-prefix 96 roll-off-period 64
 us-channel 12 symbols-per-frame 9
 no us-channel 12 shutdown
```



- OFDMA channel speed ~ 875 Mbps (2048-QAM)
- Have been able to obtain 2048-QAM in production systems below 42 MHz without increased modem transmit power
- OFDMA channel speed ~ 800 Mbps (1024-QAM)
- OFDMA channel speed ~475 Mbps (64-QAM)

Higher Pilot Pattern Can Reduce Occasional Codeword Errors

```
cable mod-profile-ofdma 428
  subcarrier-spacing 25KHz
  initial-rng-subcarrier 64
  fine-rng-subcarrier 128
  data-iuc 6 modulation 2048-QAM pilot-pattern 11
  data-iuc 9 modulation 1024-QAM pilot-pattern 11
  data-iuc 10 modulation 512-QAM pilot-pattern 11
  data-iuc 11 modulation 256-QAM pilot-pattern 11
  data-iuc 12 modulation 128-QAM pilot-pattern 11
  data-iuc 13 modulation 64-QAM pilot-pattern 11
 us-channel 12 docsis-mode ofdma
 us-channel 12 subcarrier-spacing 25KHz
 us-channel 12 modulation-profile 428
 us-channel 12 frequency-range 108000000 204000000
 us-channel 12 cyclic-prefix 96 roll-off-period 64
 us-channel 12 symbols-per-frame 9
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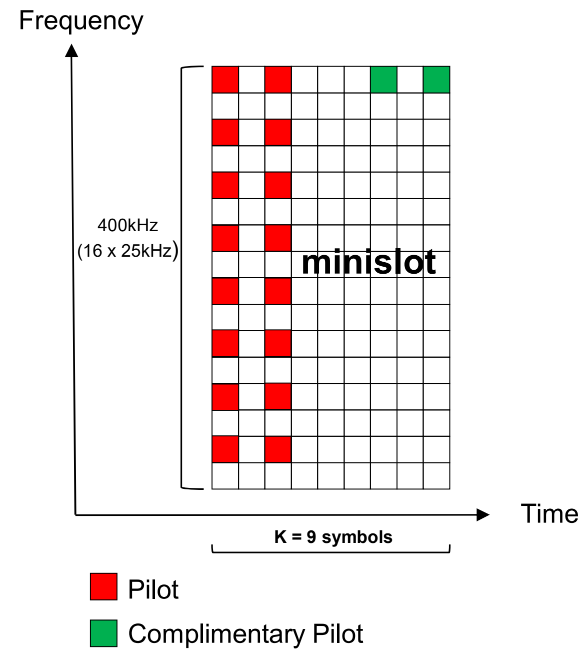

- OFDMA channel speed ~ 800 Mbps (2048-QAM)
- OFDMA channel speed ~ 725 Mbps (1024-QAM)
- OFDMA channel speed ~ 425 Mbps (64-QAM)

Can Override IUC Modulation And Pilot Pattern

```
cable mod-profile-ofdma 428
  subcarrier-spacing 25KHz
  initial-rng-subcarrier 64
  fine-rng-subcarrier 128
  data-iuc 6 modulation 2048-QAM pilot-pattern 8
  data-iuc 9 modulation 1024-QAM pilot-pattern 8
  data-iuc 10 modulation 512-QAM pilot-pattern 8
  data-iuc 11 modulation 256-QAM pilot-pattern 8
  data-iuc 12 modulation 128-QAM pilot-pattern 8
  data-iuc 13 modulation 64-QAM pilot-pattern 8
```

- Example below assumes some impairment at 175 – 180 MHz
- Uses 16-QAM with pilot pattern 11 for this part of spectrum for all IUCs
- Can support 4 override zone per IUC per OFDMA Channel (only showing a single override zone in example)

```
 us-channel 12 docsis-mode ofdma
 us-channel 12 subcarrier-spacing 25KHz
 us-channel 12 modulation-profile 428
 us-channel 12 frequency-range 108000000 204000000
 us-channel 12 cyclic-prefix 96 roll-off-period 64
 us-channel 12 symbols-per-frame 9
 us-channel 12 data-iuc 6 band 175000000 180000000 modulation 16-QAM pilot-pattern 11
 us-channel 12 data-iuc 9 band 175000000 180000000 modulation 16-QAM pilot-pattern 11
 us-channel 12 data-iuc 10 band 175000000 180000000 modulation 16-QAM pilot-pattern 11
 us-channel 12 data-iuc 11 band 175000000 180000000 modulation 16-QAM pilot-pattern 11
 us-channel 12 data-iuc 12 band 175000000 180000000 modulation 16-QAM pilot-pattern 11
 us-channel 12 data-iuc 13 band 175000000 180000000 modulation 16-QAM pilot-pattern 11
 no us-channel 12 shutdown
```

cBR-8 OFDMA Upstream Scheduling

- Recommend US bonding group with both SC-QAM and OFDMA for D3.1 CMs
- OFDMA currently only supports best effort flows on cBR-8 (no UGS)
- cBR-8 attempts to schedule D3.1 CM traffic on OFDMA first before using SC-QAM
- Real time nature of US scheduling may not fully load OFDMA before some traffic utilizes SC-QAM
- Minislot 0 starts at the lowest OFDMA frequency per the specs
- cBR-8 loads OFDMA starting with minislot 0 first
- CMs appear to prefer to use OFDMA for initial ranging (over SC-QAM)

IUC Selection Process From Probing

- Can assign each OFDMA ch up to seven IUCs (5, 6, 9 -13) and each can have different modulation order and pilot pattern
- Each D3.1 CM can only have up to 2 assigned OFDMA US Data Profile (OUDP) IUCs
- Interval Usage Code (IUC) 13 is default and intended to be most robust per the specification (will always be one of two OUDP)
- CM comes up on OFDMA and assigned IUC 13
- cBR-8 schedules probe time for CM but may not be immediate
- After probe, cBR-8 calculate RxMER for all active subcarriers from probing and then determines ***average*** value per minislot (400 kHz)
- cBR-8 determines best IUC based on exempt minislot / threshold settings
- Dynamic Bonding Change (DBC) used to alert CM to change IUC – will use IUC 13 during change if sending traffic
- One recommended IUC will be used across entire OFDMA ch

Use Same Bit Loading Recommendations As OFDM

Based on Table 7-41 in D3.1 PHY Specification

RxMER (in ¼ dB)	RxMER (dB)	QAM	Bit Loading
>60	>15	16	4
>84	>21	64	6
>96	>24	128	7
>108	>27	256	8
>122	>30.5	512	9
>136	>34	1024	10
>148	>37	2048	11
>164	>41	4096	12

- Recommend using the default thresholds as use **average** RxMER per minislot
- Normal to see quite a bit of RxMER variance in neighboring subcarriers

Enable IUC Downgrade Enhancements

- 16.12.1x - cBR-8 will downgrade to lower modulation IUC (if available) when uncorrectable codeword errors (cw errors) are higher than thresholds
- 16.12.1y – cBR-8 will place in partial service for OFDMA ch if CM is only using IUC 13 and cw errors are higher than thresholds
- 16.12.1z – cBR-8 will place CM in partial service for OFDMA ch if RxMER values from probe are below a selected IUC (normally most robust – IUC 13)
- IOS release 16.12.1z2 is popular release for OFMDA / 17.6.1w has a few more OFDMA bug fixes (some CMs occasionally getting stuck in IUC 13)

OFDMA Profile Management Recommendations

Optimal settings will tolerate occasional cw error but avoid constant trickle of cw errors – Settings should be adjusted to obtain desired outcomes

- Probe CMs every 10 minutes to measure RxMER
- Check for CM codeword errors on 10 second interval
- Downgrade if over 0.8 % cw errors with minimum of 500 codewords (>4 cw errors)
- Hold-down for 60 minutes after downgrade
- Enable partial service if RxMER below threshold to run on IUC 13

```
cable upstream ofdma-prof-mgmt rxmer-poll-interval 10
cable upstream ofdma-prof-mgmt prof-upgrade-auto
cable upstream ofdma-prof-mgmt downgrade enable
cable upstream ofdma-prof-mgmt downgrade interval 10
cable upstream ofdma-prof-mgmt downgrade threshold 80
cable upstream ofdma-prof-mgmt downgrade hold-down 60
cable upstream ofdma-prof-mgmt downgrade min-cws 500
cable upstream ofdma-prof-mgmt downgrade partial-threshold 80
cable upstream ofdma-prof-mgmt downgrade partial-hold-down 60
cable upstream ofdma-prof-mgmt downgrade rxmer-enable
```

OFDMA Deployments Thoughts

- OFDMA much more deployable today than 12 months ago but still learning
- Per CM IUC downgrade feature is a must for production deployments
- Current CM firmware much more stable on OFDMA
- Assure D3.1 CMs' firmware is upgraded *before* enabling OFDMA – CMs use OFDMA first, may not be able to download firmware if unstable
- Some CMs had issues with pre-equalization that caused subcarrier power to either drop very low (CM goes into partial service on OFDMA) or raise very high (US laser clipping drops all US chs)
- High and stable RxMER values lead to higher order modulations
- OFDMA does not fix bad plant

D3.1 US Spectrum Thoughts

- Increasing US spectrum = more coax loss & tilt from CM to CMTS
  - US max Tx level issues
  - DRW violations (12 dB)
- More USs may lead to laser clipping
  - OFDMA even in 42 MHz may cause issues with AM link
  - 85 MHz or higher may necessitate EDR (digital return) (A/D clipping?)
  - 204 MHz may necessitate DAA (Remote-PHY, FMA, …)
- No US ALC/AGC
  - Relying on CM/CMTS long-loop-level control and CM 12 dB DRW
  - Typical +/-2 dB swing @ 42 MHz (annual thermal fluctuations) w/ 4000' coax
  - CMTS US level settings and adjustable range

204 MHz US Concerns

- 204 MHz could be troublesome for N+3 or higher
- Need to replace line equalizers, subscriber drop pads/EQs (whether standalone or in tap), and house amps
- Legacy STB OOB at 104 MHz, DACs at 75 MHz
- Leakage testing at 138 MHz
- Adjacent device interference (ADI) affects STB AGC & analog TV IF
  - Filters in house where needed just like MoCA
  - Gateway architecture
- Home passives can generate passive device intermodulation (PDI) distortion when hit with high US Tx
- FM carriage in European markets (seems to be going away)
- Off-Air Broadcast potential interference

Potential Fixes for Higher Upstream Frequencies

- No Coax
- Conditioned taps - EQs & InvEQs for levels & DRW issues
  - ➢ Field Equalizers (FEQs) at least
  - ➢ EQ 5 MHz -1.2 GHz, no cutoff & grp delay or concern for diplex changes later
- Thermal issues
  - ➢ Underground cable
    - ✓ Passives still above ground
  - ➢ US thermal EQs to help stabilize negative fluctuations on cold days
    - ✓ Higher noise floor assuming aerial plant
  - ➢ Idea of US AGC driven by DS AGC circuitry or I-AMP especially for D4.0
- D3.0 CM with Extended Pwr ECN = 54 dBmV max for 4-ch bonding
- D3.1 CM has ~ 5 dB more power per equivalent 8-ch D3.0 CM
  - ➢ D3.1 = 65 dBmV total avg power

D3.1 - 204 MHz Implementation Today

- Surgically place at MDUs
- Compact shelf with modularity provides
  - Multiple RF outputs (SGs) for risers in bldgs
  - Easy powering
  - Rack and stack
- CMs placed where needed
- Older CMs still work fine
- If amp cascade, maybe DGA?

Closing Points

- Be aware of US temperature affects @ 204 MHz
  - ➢ Design 48 dBmV +/-3 dB for taps with < 25 dB of coax between RPD & tap, 46 +/-2 dB otherwise
- Conditioned taps alleviate US power & tilt issues
  - ➢ Disparate SC-QAM US ch widths exacerbate D3.1 CM DRW issues
    - ✓ Get rid of narrow SC-QAMs in TCS
- Fiber deep architectures with DAA will allow better performance and higher D3.1 modulation along with higher speeds
- Need to research ADI & PDI concerns
- OFDMA below 117 MHz may force 85 MHz filter to engage
- Legacy devices will go through attrition leading to more efficiency
  - ➢ Drop SC-QAMs, add more OFDM on DS, & allocate more OFDMA on US