SCTE LiveLEARNING WEBINARS™

DOCSIS 3.1:

WHAT IS IT, HOW DOES IT WORK, AND HOW CAN YOU PREPARE FOR IT?

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VIDEO

PART 1: OFDM BUSINESS DRIVERS

- **MAIN OBJECTIVES:** As we go through Part 1 of today's lecture, you should be able to answer the following questions:
  - ***What are the options in multiplexing today's data signals to the customer?***
  - ***What are the business, market and technology drivers for OFDM in cable?***
  - ***Why move beyond QAM 256?***
  - ***What are the options for higher order modulation?***
  - ***How will DOCSIS 3.1 with OFDM enable operators to deliver higher speed data services and increase the capacity of their HFC access networks?***
  - ***What makes OFDM especially well suited to deliver wider effective channels?***

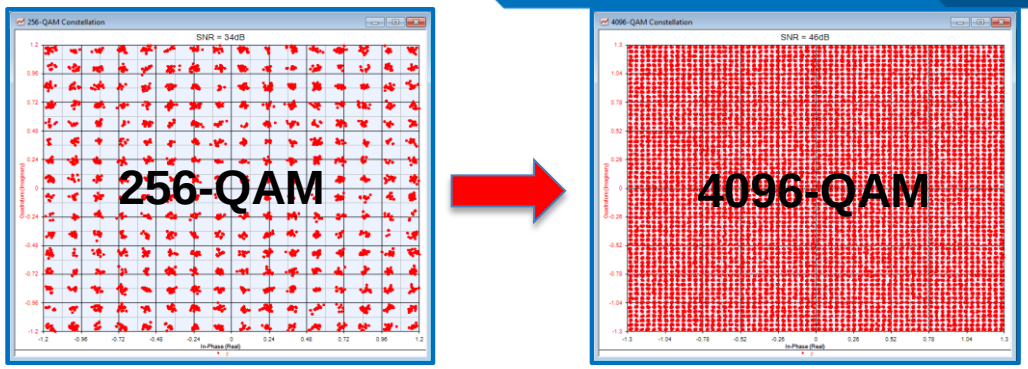
BUSINESS DRIVERS FOR OFDM ON HFC

In a phrase: MORE HFC CAPACITY IS NEEDED!

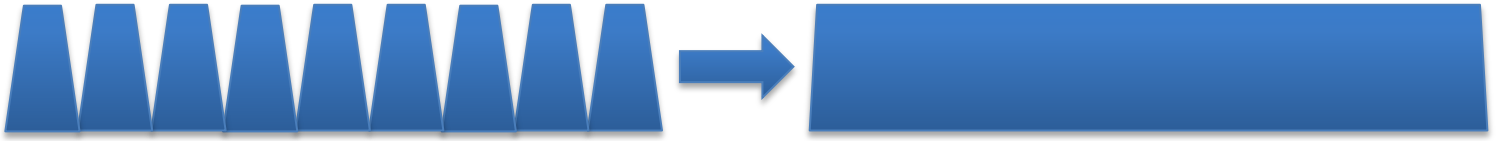
- **Market drivers:** Business services, Over The Top (OTT) video, 4K video, 3DTV, etc.
- **Economic drivers:** Decrease cost per bit transmitted
- **How much capacity do we need?**
  - 10 Gb/s downstream or greater
  - 1 Gb/s upstream or greater
- **Flexibility requirement:** Need easy adaptation to different amounts of spectrum and plant conditions

HOW TO GET MORE CAPACITY?

- Higher orders of modulation (HOM)



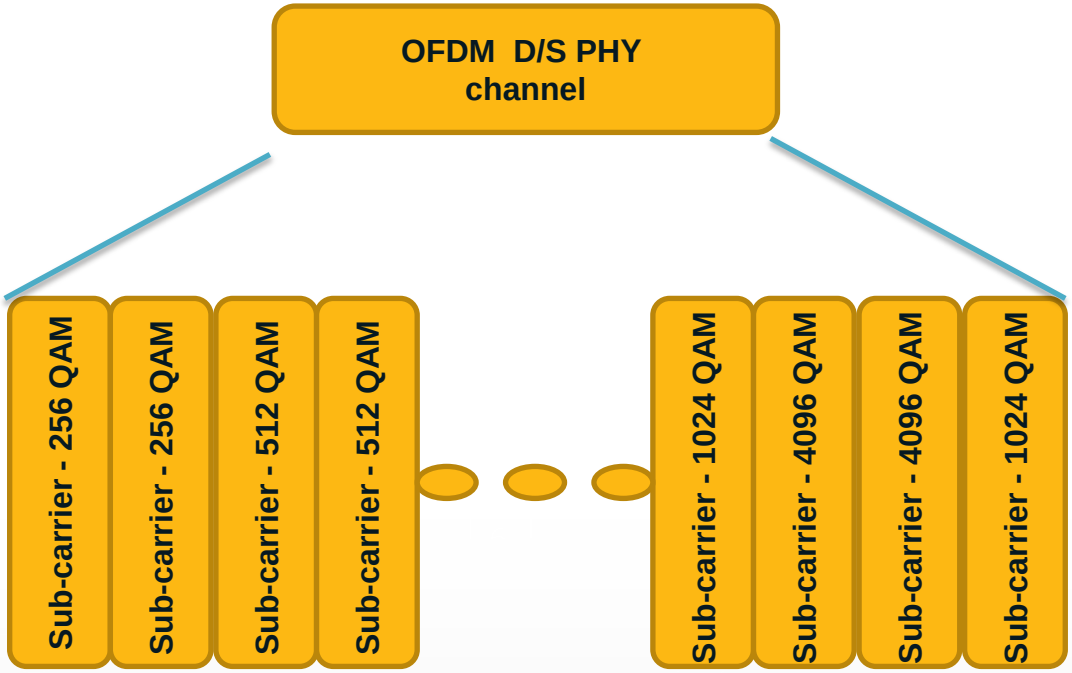
- Elimination/reduction of RF guard bands



- Greater capacity achieved primarily through LDPC (HOM in clean channel) and OFDM (elimination of guard bands and HOM in impaired channels)

- Close to 2x improvement over DOCSIS 3.0

NO WASTED CAPACITY: OFDM ADAPTIVE BIT LOADING



HIGHER ORDER MODULATION OPTIONS

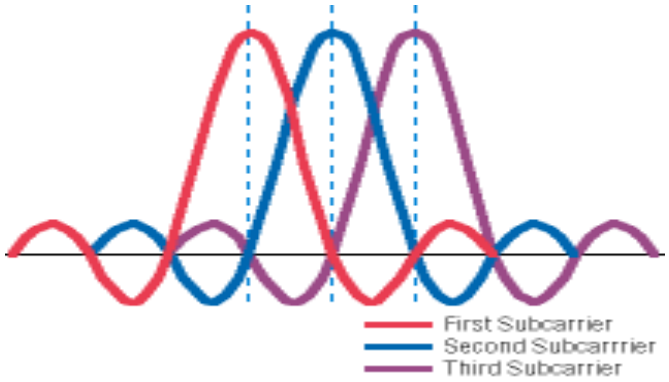
- *Why not just add LDPC to Single Carrier (SC) QAM to get higher order modulation? Guardbands and robustness!*
- Other reasons for going to OFDM:
  - Easier channel synthesis
  - Less complex than MAC layer bonding
  - Channel equalization (EQ) is simpler
  - Incremental capacity addition
  - Better economies of scale
  - Attract new chipset and system vendors to cable market

PART 2: ENGINEERING DETAILS

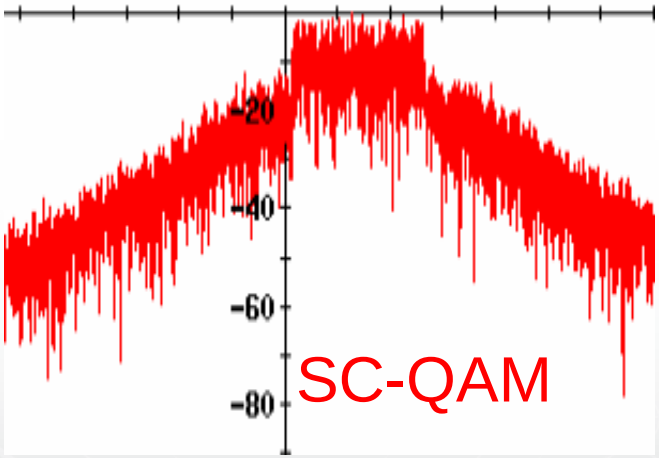
- **MAIN OBJECTIVES:** As we go through Part 2 of today's lecture, you will be able to answer the following questions:
  - ***How does OFDM differ from conventional FDM, ATDMA, and S-CDMA?***
  - ***How are the subcarriers orthogonal to each other in OFDM?***
  - ***How and why is the IFFT used in defining the OFDM waveform?***
  - ***How are pilot tones and the cyclic prefix used in OFDM?***
  - ***How does OFDM optimize the modulation order used in RF spectrum?***
  - ***Why makes OFDM better than S-CDMA and ATDMA in general?***
- **GLOSSARY:**
  - ***FDM: Frequency Division Multiplexing***
  - ***IFFT: Inverse Fast Fourier Transform***
  - ***OFDM: Orthogonal Frequency Division Multiplexing***
  - ***ATDMA: Advanced Time Division Multiple Access***
  - ***S-CDMA: Synchronous Code Division Multiple Access***

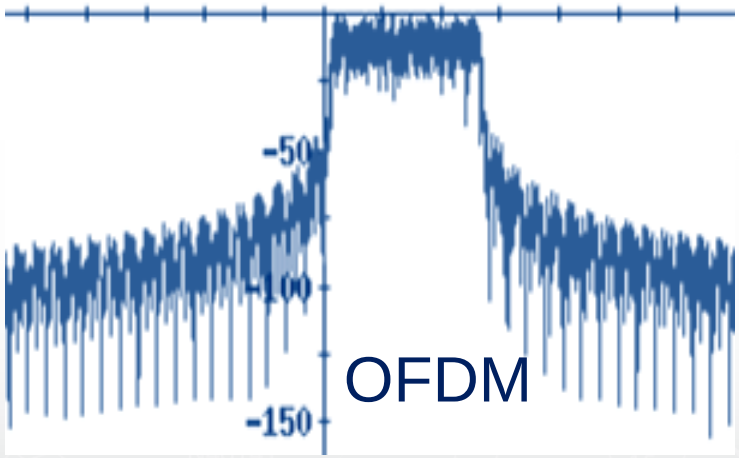
THE OFDM CONCEPT

- OFDM sub-carriers can be packed tightly without interfering with each other



- And they fall off faster at band edges





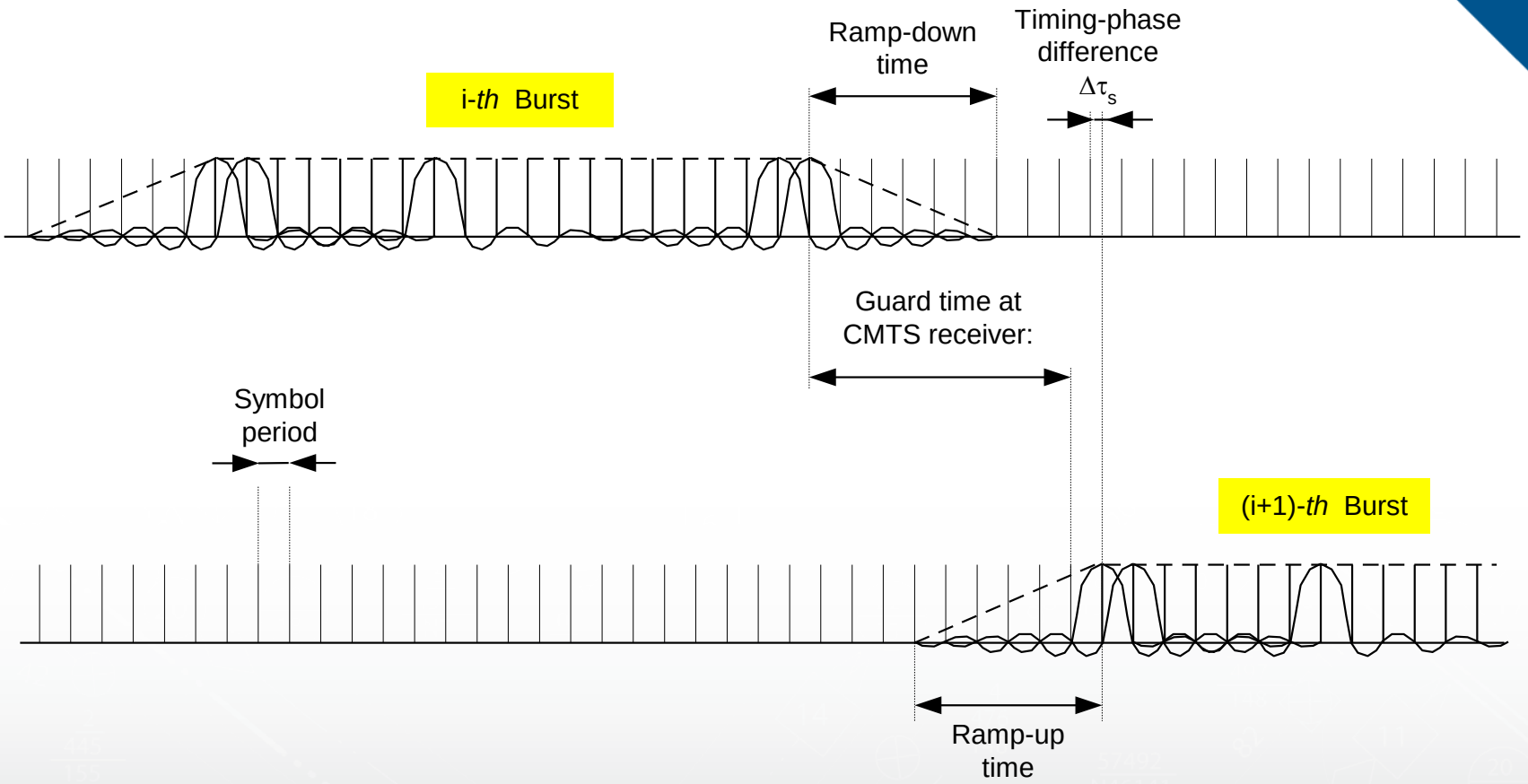
ORTHOGONALITY DEFINED

- Mathematical orthogonality: $\langle f, g \rangle = \int_a^b f(x)g(x)dx = 0$

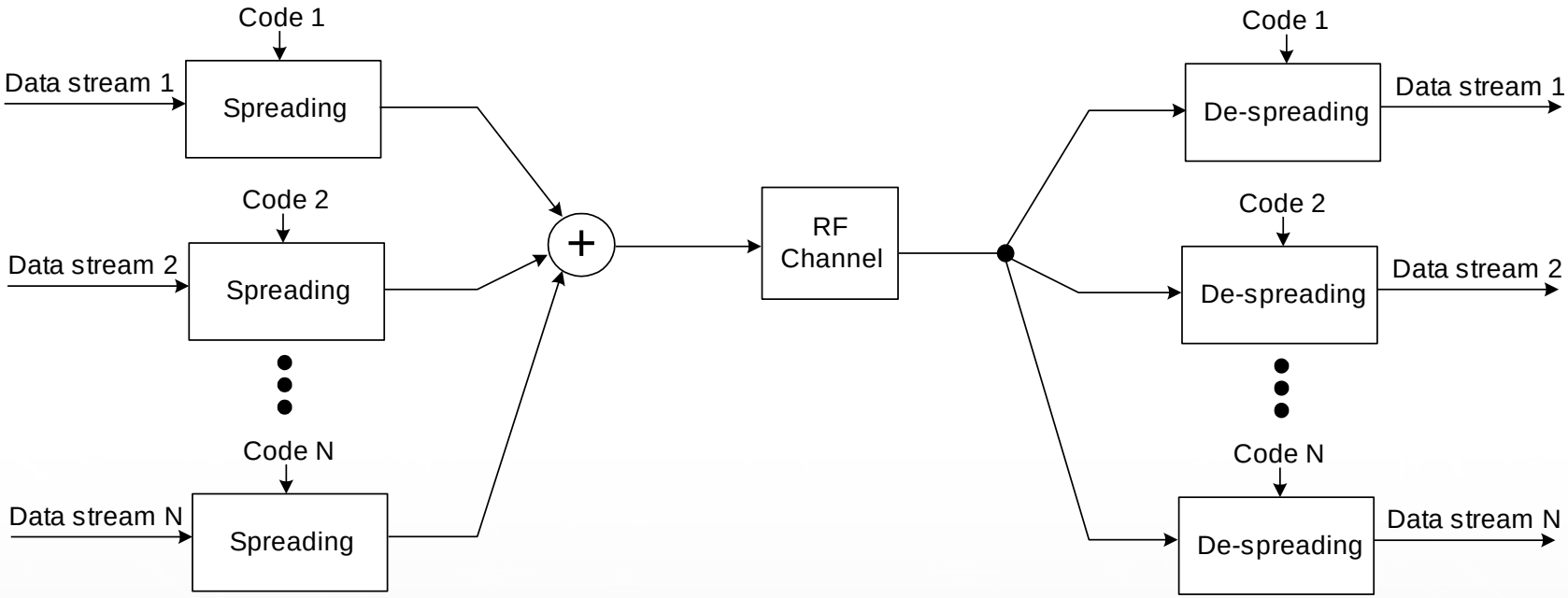
- In communications, orthogonality means zero interference with each other ***at the receiver sampling instant***

- Orthogonality in communications is typically in one of these domains: temporal, frequency, code, or spatial

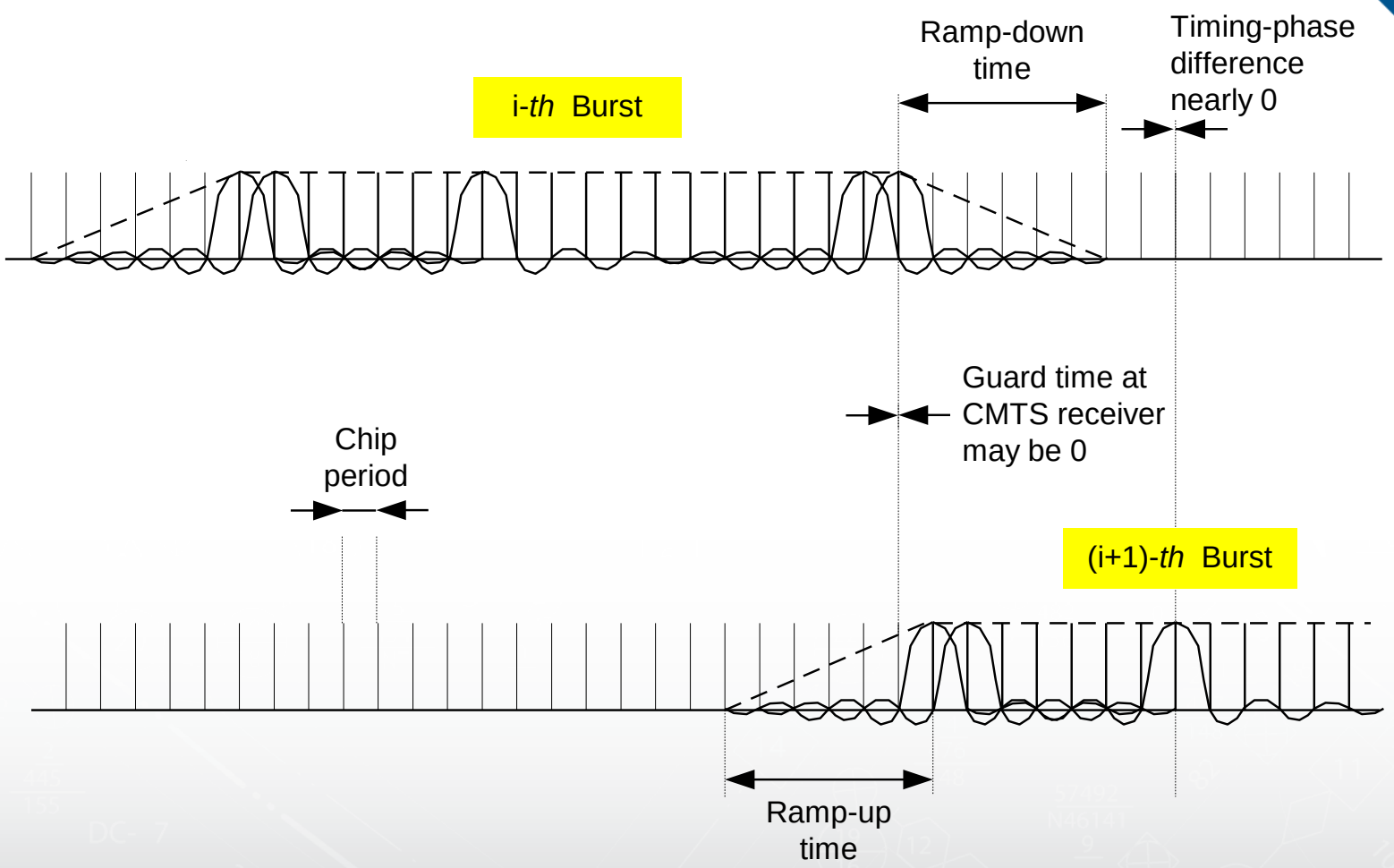
ORTHOGONALITY EXAMPLES: TDMA



ORTHOGONALITY EXAMPLES: S-CDMA CODE DOMAIN

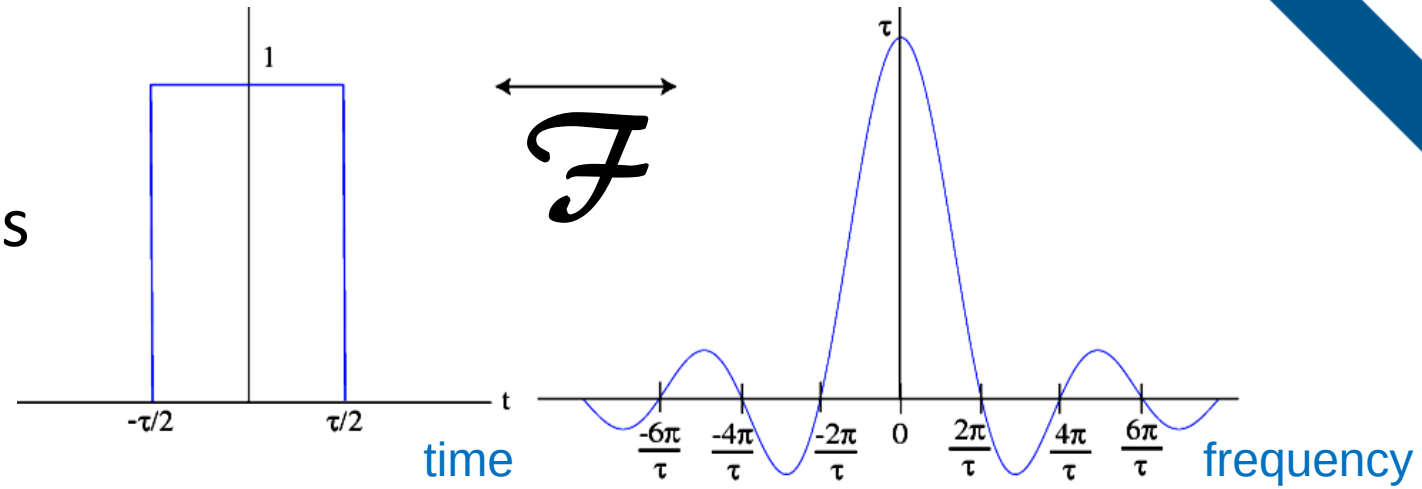


ORTHOGONALITY EXAMPLES: S-CDMA TIMING SYNCH

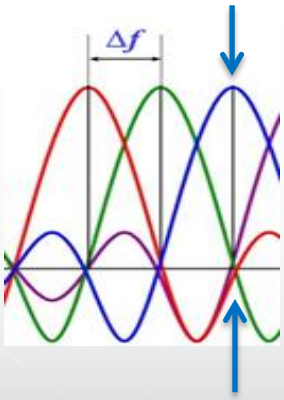


OFDM ORTHOGONALITY

- rect(t) transforms to sin(f)/f or sinc(f)



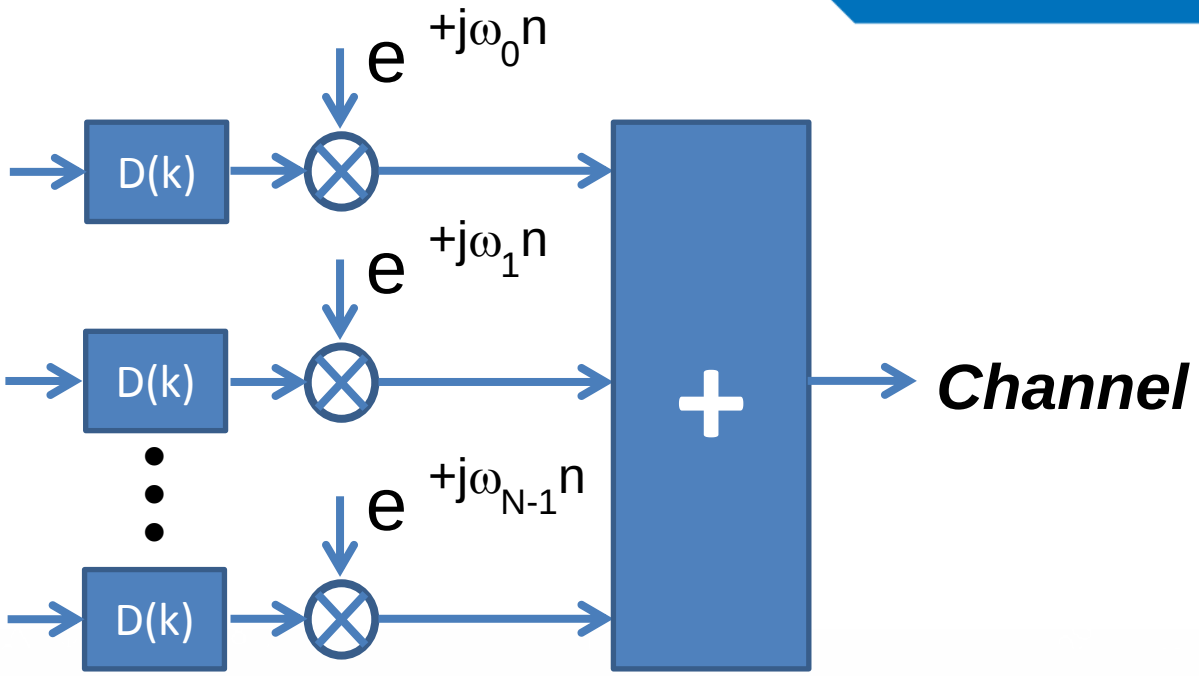
- Precise frequency spacing



$$\Delta f = \frac{k}{\tau}\text{ , k = 1 typically}$$

HOW OFDM DATA IS TRANSMITTED VIA IFFT

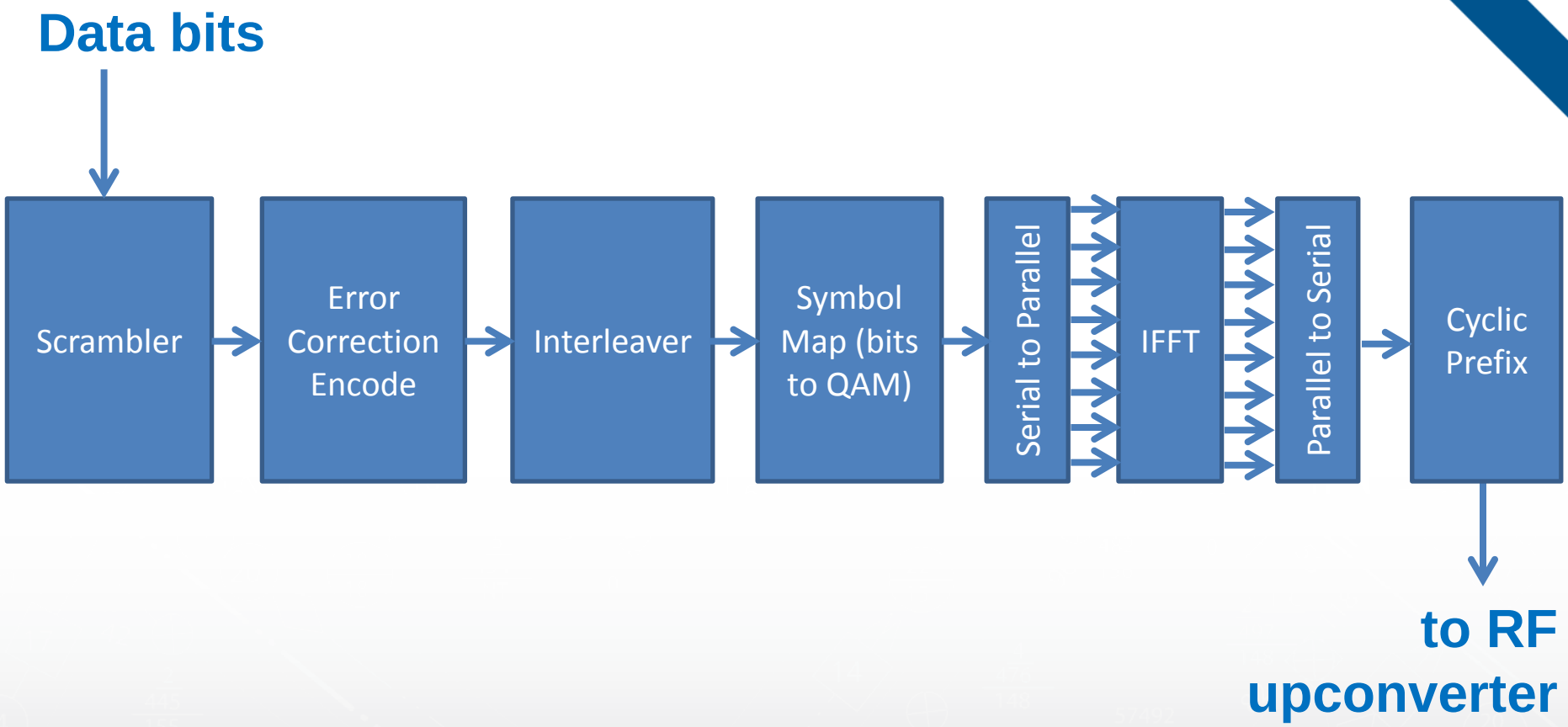
This…



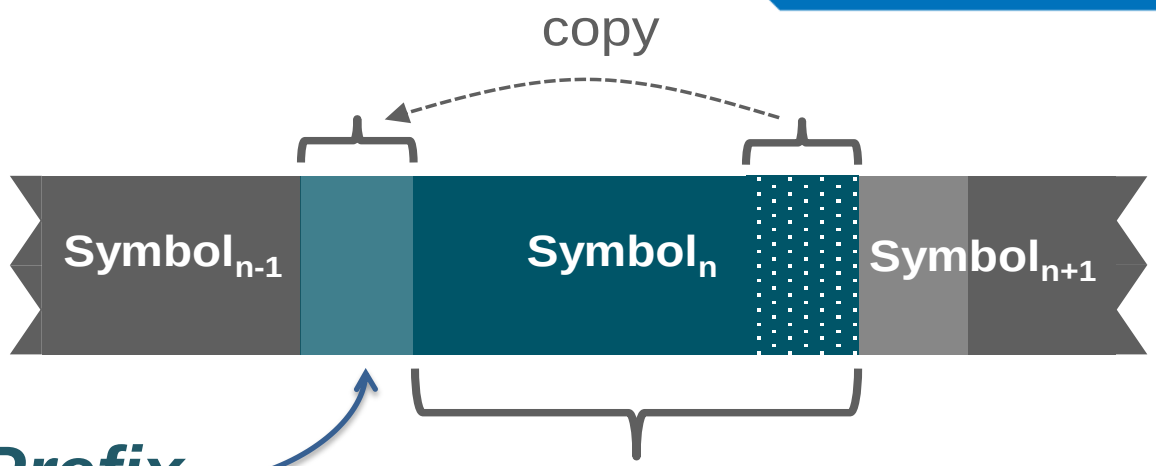
…is mathematically equivalent to this:

$$\sum_{k=0}^{N-1} D(k)e^{+j2\pi nk/N} = IFFT_N(n, D)$$

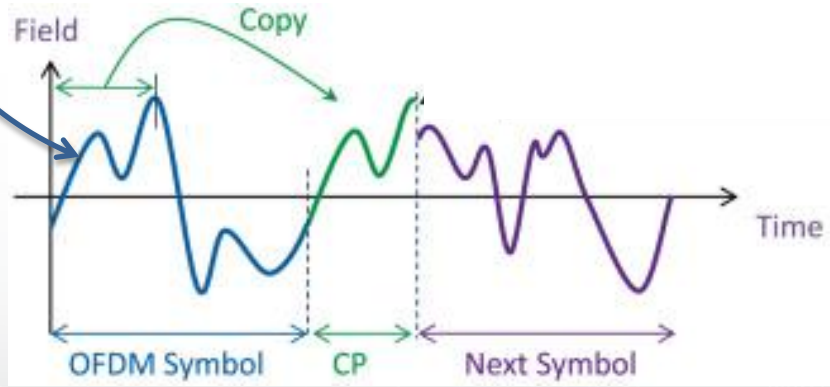
OFDM TX BLOCK DIAGRAM



OFDM CYCLIC PREFIX

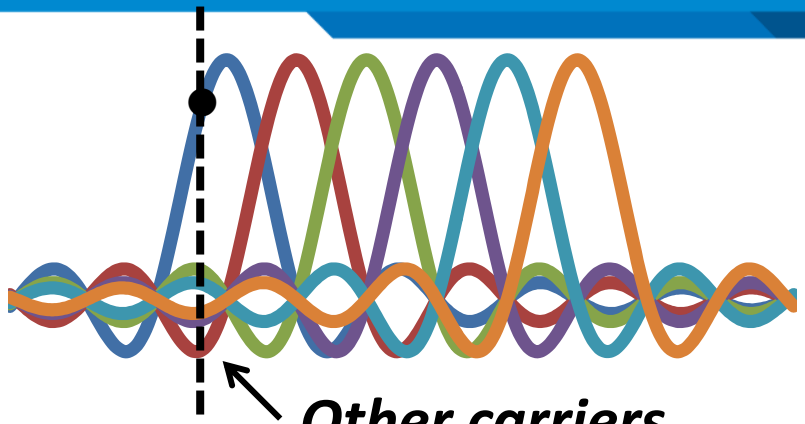


Cyclic Prefix

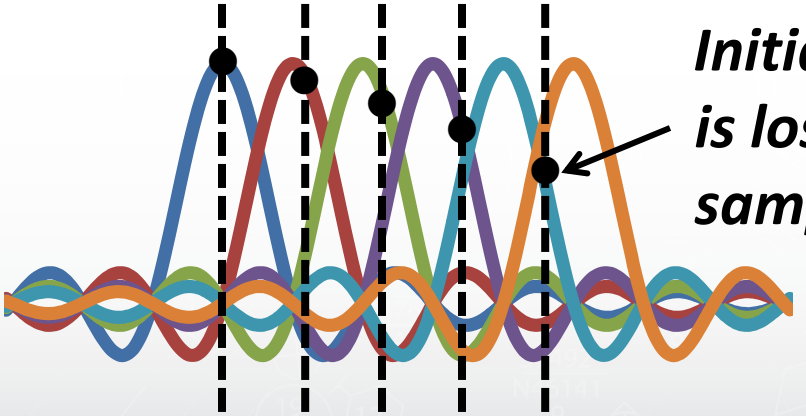


OFDM SYNCHRONIZATION

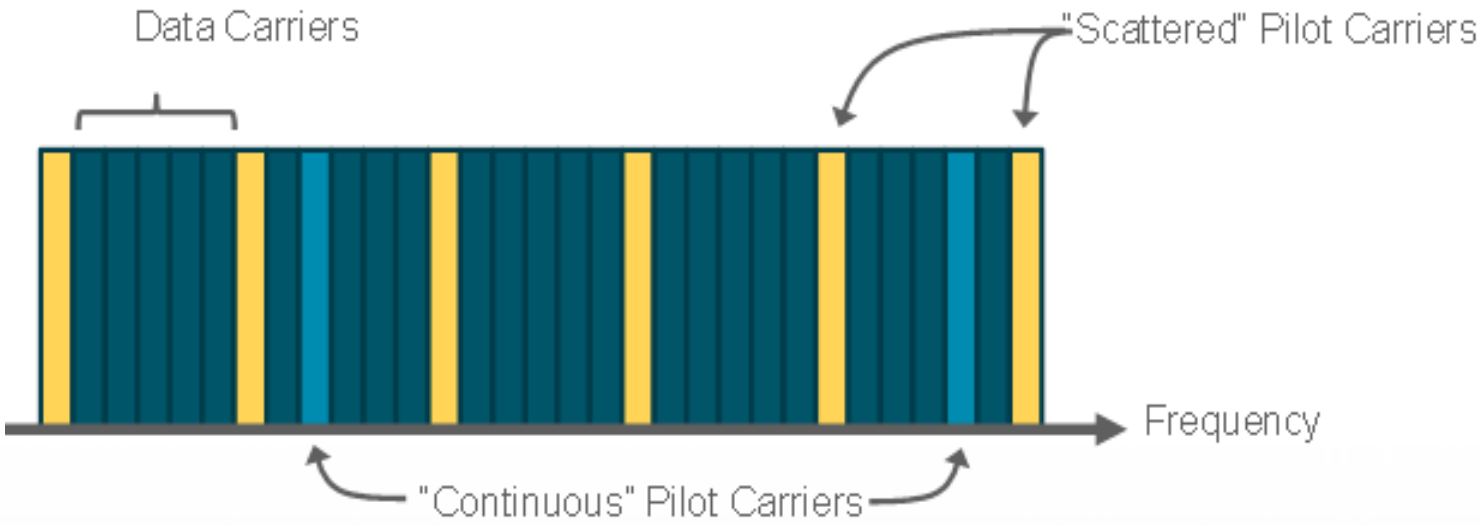
Frequency Synchronization Error



Clock Synchronization Error

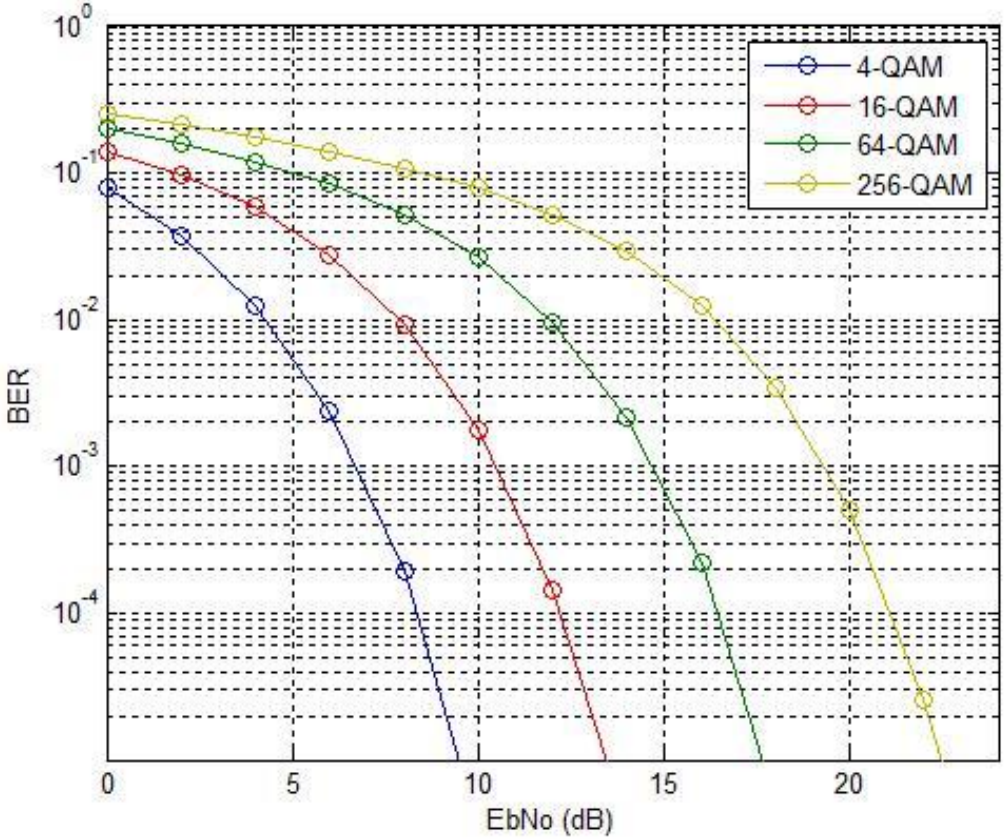


PILOT TONES IN OFDM



BER PERFORMANCE IN AWGN

- These curves are ***the same*** for OFDM as for S-CDMA and ATDMA in an additive white Gaussian noise (AWGN) channel

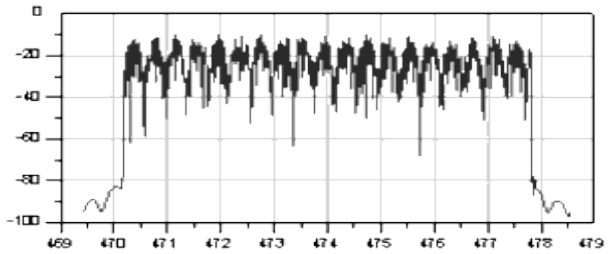


PART 3: PERFORMANCE DETAILS

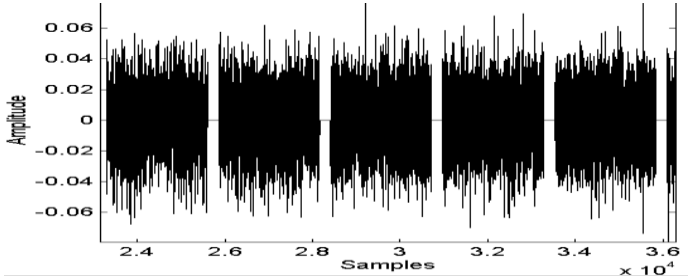
- **MAIN OBJECTIVES:** As we go through Part 3 of today's lecture, you will be able to answer the following questions:
  - ***Why is OFDM better on the upstream in impulse and narrow band ingress?***
  - ***What are the advantages/disadvantages of OFDM?***
  - ***What are some key areas that cable operators can focus on when preparing to deploy OFDM in their networks?***
  - ***How will operators transition to OFDM and higher order QAM rates?***
  - ***What are the operational system and network implications of OFDM and its deployment?***

OFDM'S SECRET WEAPON

- **Narrow subcarriers mean long symbols**

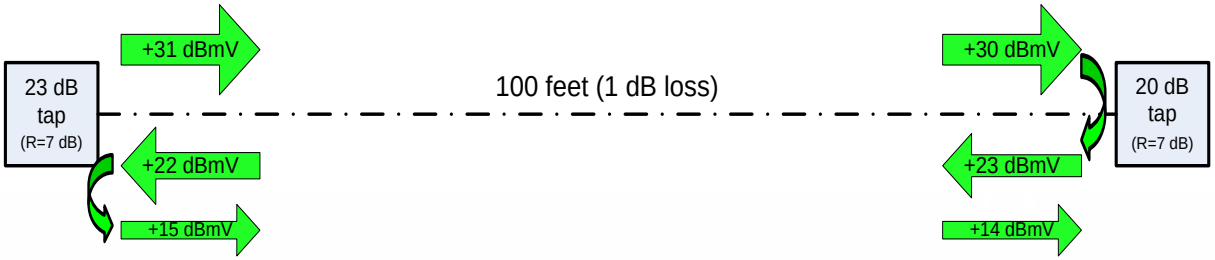


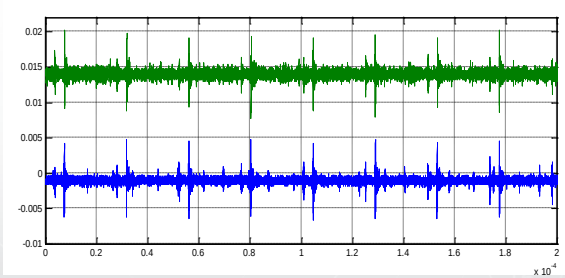
frequency

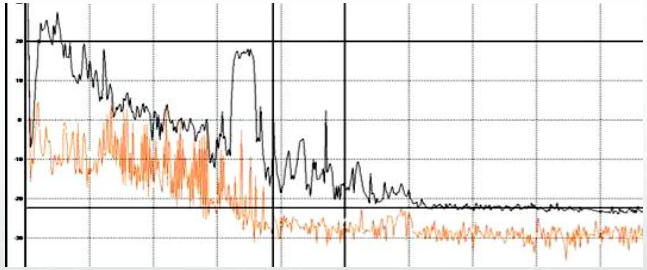


time

- **Benefits are easy mitigation of:**
  - Micro-reflections
  - Ingress, impulse and burst noise

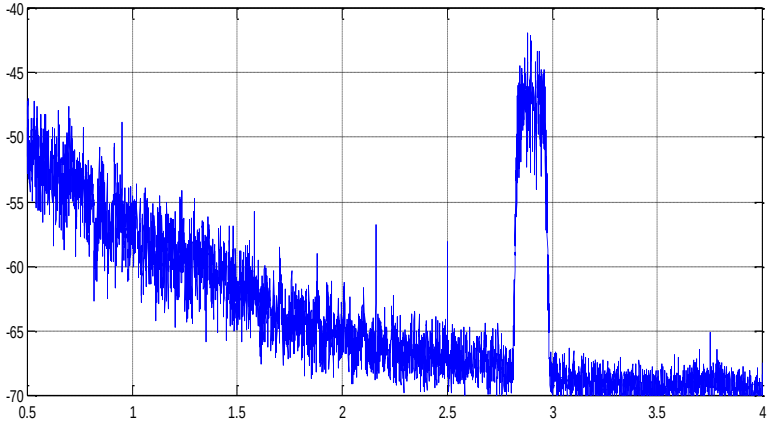




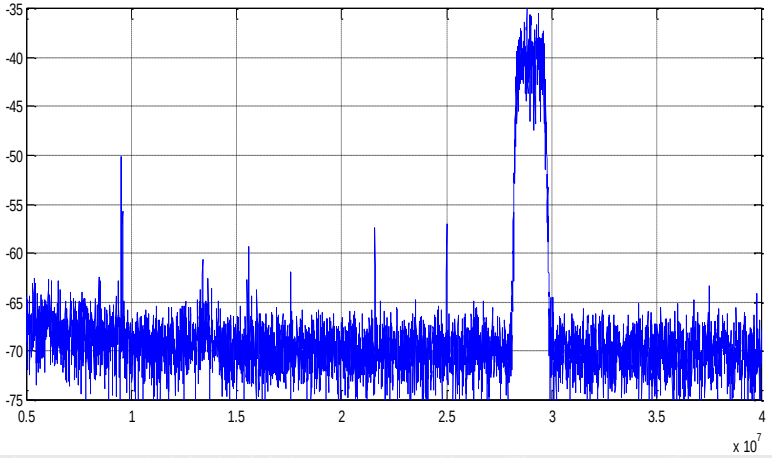


BURST NOISE PERFORMANCE DETAILS

- FFT of oscilloscope capture of burst noise event on upstream

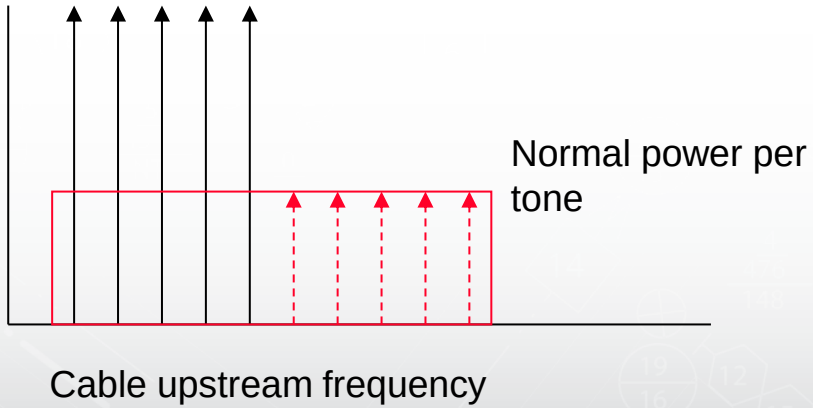


- Same trace with burst noise event clipped out of time capture
  - Reveals ingress and flatness of actual channel



HIGHLY ATTENUATED UPSTREAMS

- MDU cable modems can have highly attenuated upstreams
- S-CDMA and OFDM modulations allow Tx power to be concentrated on fewer tones (or codes in S-CDMA)
  - SNR per tone is much higher
  - Reduces burst rate, but keeps spectral efficiency high



HIGHER PEAK TO AVERAGE POWER RATIO OF OFDM

- OFDM has a high peak-to-average power ratio (PAPR), but so does a spectrum full of SC-QAM

$$\textbf{PAPR} = \frac{(|x|^2)_{peak}}{x_{rms}^2}$$

- PAPR can be reduced, but probably not necessary

PART 4: DEPLOYMENT PLANNING

- **MAIN OBJECTIVES:** As we go through Part 4 of today's lecture, you will be able to answer the following questions:
  - ***How will operators transition to OFDM and higher order QAM rates?***
  - ***What are the operational system and network implications of OFDM and its deployment?***
  - ***What are some key areas that cable operators can focus on when preparing to deploy OFDM in their networks?***
  - ***How will the SCTE help operators deploy DOCSIS 3.1 OFDM in their networks?***

OPERATION ON HFC NETWORKS

- Key aspects:
  - Upstream spectrum remains below downstream
  - CPE devices support current and future upstream splits
  - CPE devices operate in current and future downstreams

- Deployment implications
  - No plant changes required to deploy DOCSIS 3.1 equipment
  - Future proof - no CPE or infrastructure swap required

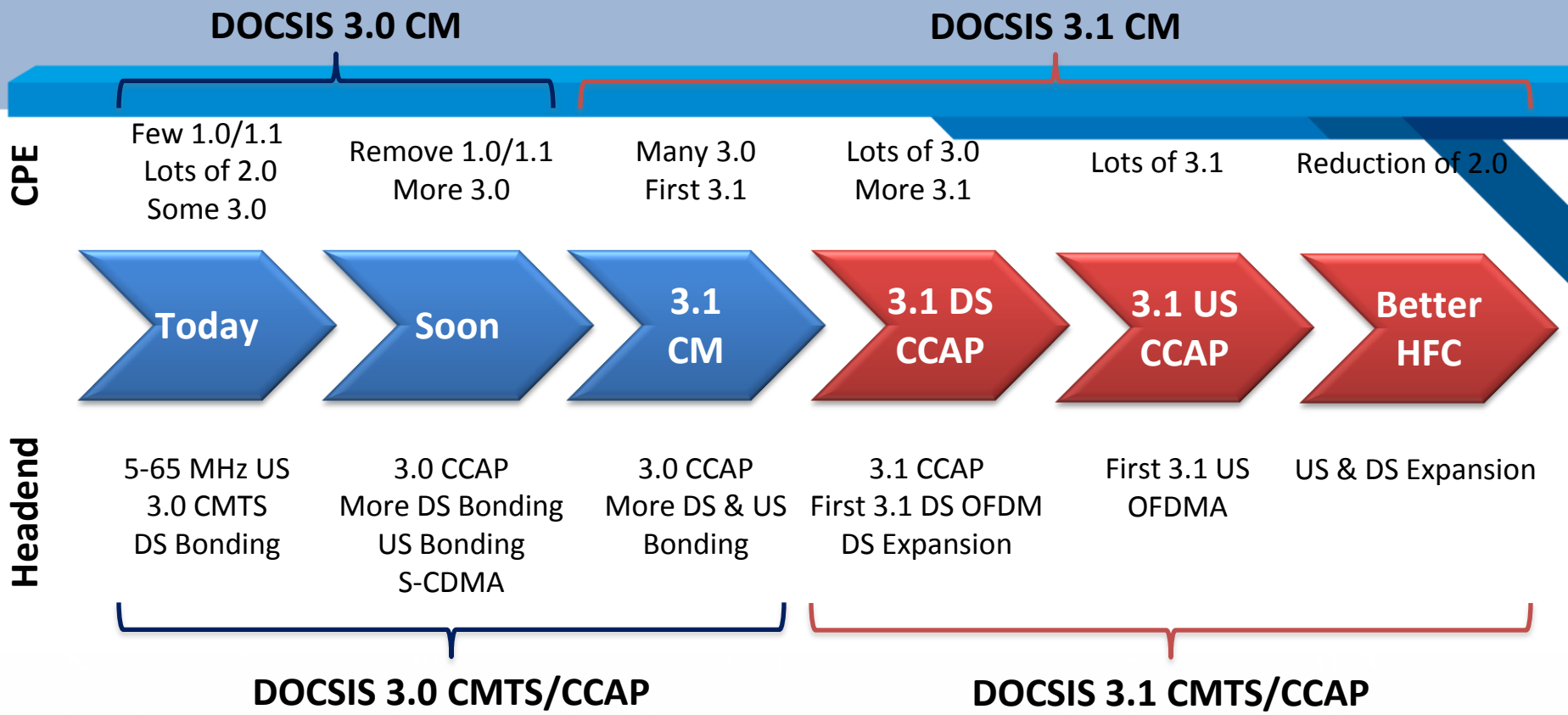
EFFECTIVE MIGRATION STRATEGY

- Achieved primarily by including:
  - Backward compatibility requirements
  - Support for upgrades to DOCSIS 3.1 technology in CCAP
- How does that enable an effective migration strategy?
  - Incremental deployment of DOCSIS 3.1 modems
  - Continued use of DOCSIS 2.0 & 3.0 modems after 3.1 upgrades

DOCSIS 3.1 TECHNOLOGY - MIGRATION

- Backward compatibility
  - Support of at least 24 bonded SC-QAMs in downstream and 8 in upstream
  - S-CDMA in the upstream
  - DOCSIS 3.1 CMs required to operate on DOCSIS 3.0 CMTSs
  - DOCSIS 3.1 CMTSs required to support DOCSIS 3.0 (and 2.0) CMs
  - To be implemented also with CCAP equipment
- Operation on existing HFC networks
  - Upstream spectrum remains below downstream
  - Supports operation with existing upstream splits (42/65 MHz as mostly in operation, 85 MHz as specified in DOCSIS 3.0)
  - Supports spectrum enhancement in upstream (e.g. 200 MHz) and downstream (e.g. 1.2 GHz or even 1.7 GHz)
  - Supports the ability to take advantage of enhanced capabilities when network, headend and CPE equipment permit

DOCSIS 3.1 Use Cases

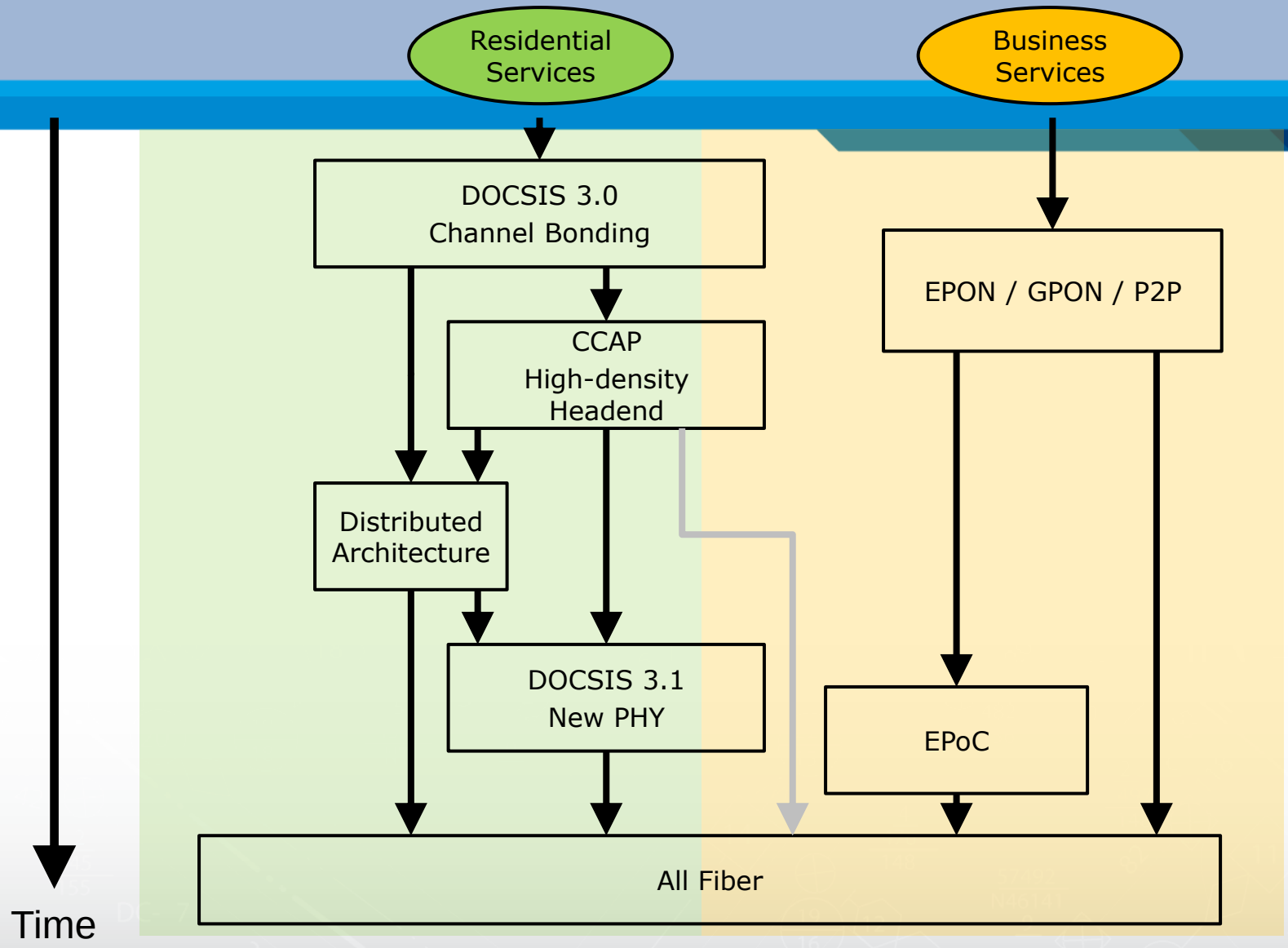


Considerations when introducing DOCSIS 3.1

- DOCSIS 3.0 CCAP before DOCSIS 3.1 available
- First DOCSIS 3.1 CM with DOCSIS 3.0 CCAP
- Introducation of DOCSIS 3.1 DS in CCAP via Firmware Upgrade
- Introducation of DOCSIS 3.1 US in CCAP via Line Card swap
- Expansion of frequency range particularly in US very complex

(Source: CableLabs, Comcast)

TOWARDS FTTH ?



SCTE SUPPORT FOR DOCSIS 3.1

- SCTE engineering support to 3.1 spec development
- DOCSIS training/certification update for 3.1
- Other content
- DOCSIS 3.1 landing zone: SCTE Standards
- SCTE recommended practice documents
- New SCTE HFC readiness working group
- Symposium on 3.1/HFC readiness

SCTE HFC READINESS SPECIAL WORKING GROUP (SWG)

- Goal: Accelerate deployment of 3.1
- Output: Best practices documents for optimizing network capacity with DOCSIS 3.x
- Kickoff meeting 24 May 2013
  - Phase 1: Optimizing loaded DOCSIS 3.0 networks
    - Delivery: 1 Sep 2013
  - Phase 2: Optimizing loaded DOCSIS 3.1 networks
- Measurement project to be undertaken
  - Procedures being written up for MSOs
  - Webinar planned to demonstrate procedures
  - SWG team as backup to do measurements

PHASE 1 GENERAL ISSUES

- How fully loaded D3.0 network capacity is affected by equipment performance limits and plant impairments
  - Planning and optimization recommendations
- Recommendations for network equipment and monitoring equipment
- How to configure, monitor, and maintain a fully utilized DOCSIS 3.0 upstream and downstream

SWG TOPICS FOR PHASE 1 DOCUMENT

Laser linearity and dynamic range (headroom**)**

Noise measurement recommendation (Measurements for accurate noise/interference diagnostics)

Impairment visibility on fully loaded plants

Effect of changing signal levels (increase for High Order Modulation, distortion, etc)

Educating the workforce for High order Modulation with existing equipment (new tools)

Availability of test & diagnostics equipment (to add intelligence and higher measurement resolution)

LTE ingress, TV white space, satellite and MoCA

Minimum standards for plant & maintenance (+evolution)

Beyond MER (higher order moments in measurements)

Dynamic modulation rollback and proactive network maintenance (PNM) actions

Best mix of SCDMA and ATDMA

Improve Home/Biz/MDU installation practices (certificate of install, better records, trends/tracking, operations and field)

Impairment library, map to migration strategy

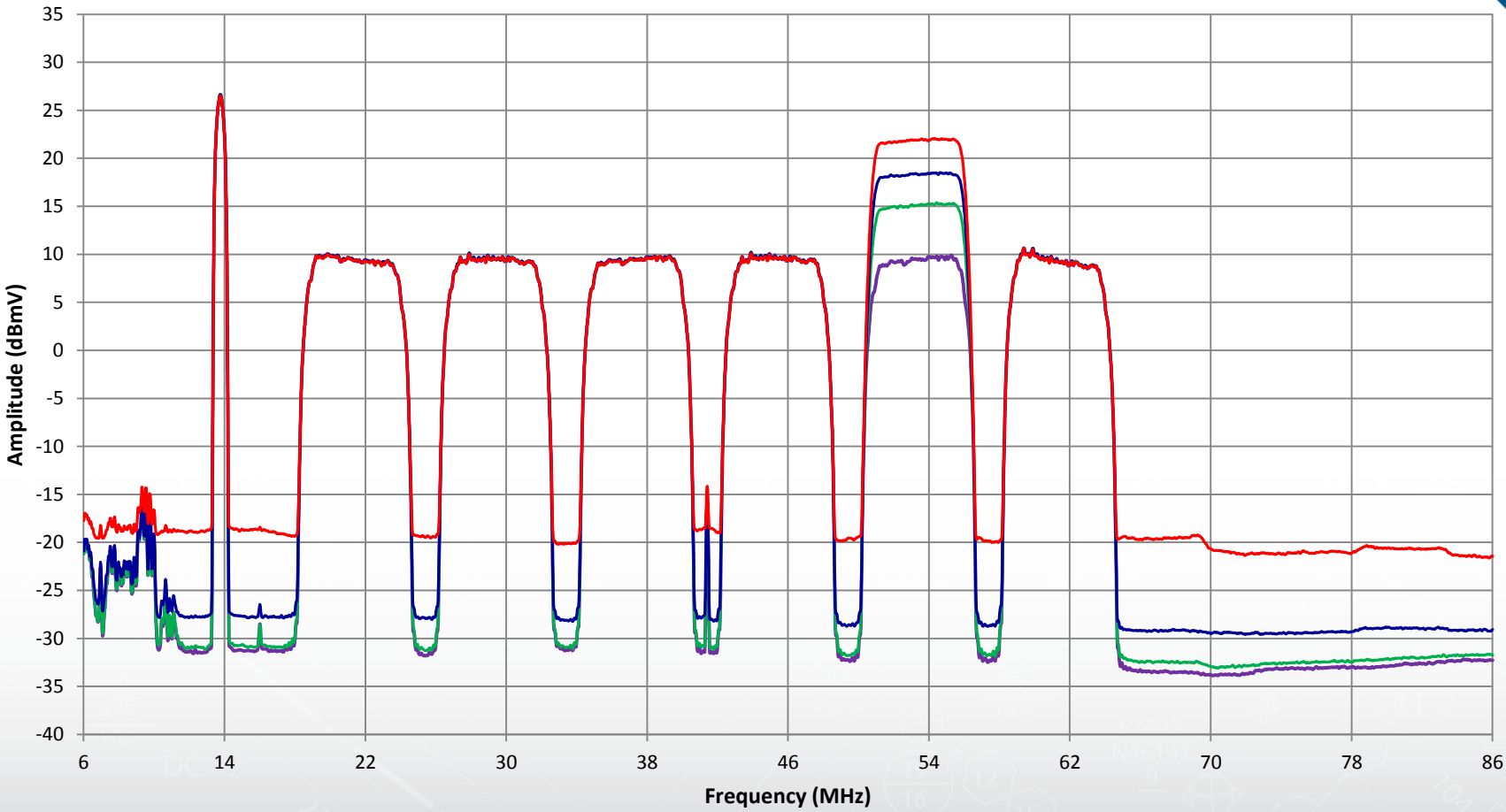
Better CMTS metrics

Configuration/optimization planning (CMTS, plant specific, key knobs)

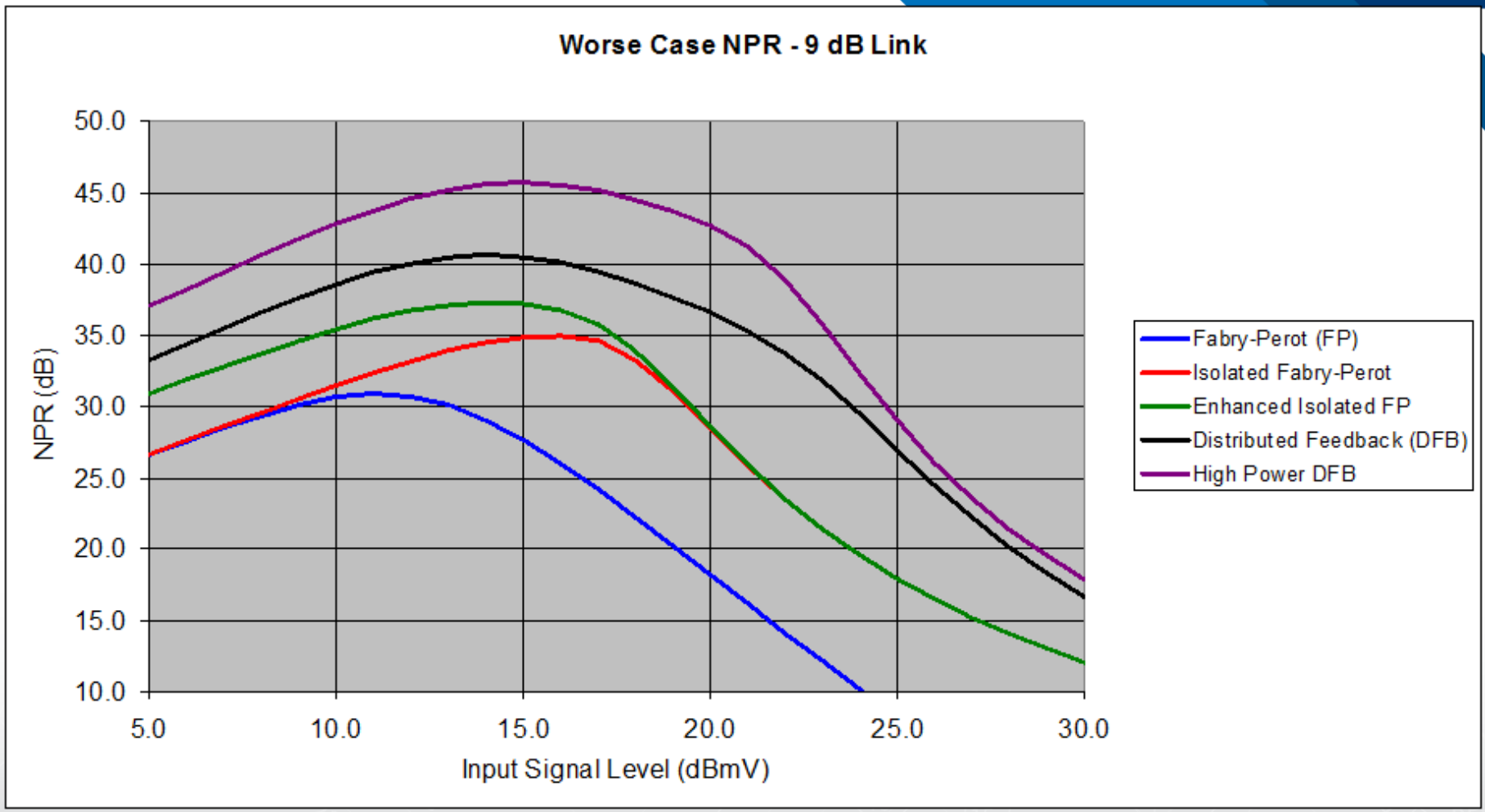
TUTORIALS IN PHASE 1 DOCUMENT

- Upstream laser characterization using D3.0 bonded carriers
  - Steady state ingress, transient noise, and high levels of collisions in contention mini-slots with modern equipment (VSA, DSO, CMTS)
- RF spectral power density considerations for the upstream:
  - Constant power per Hz, constant power per carrier, other power profiles, and other methods to optimize total upstream capacity
- Correlation of RF leakage measurements to downstream and upstream ingress and transient noise estimation; and
- New measurement procedures oriented towards determining how best to maximize the capacity of fully loaded DOCSIS 3.x networks.

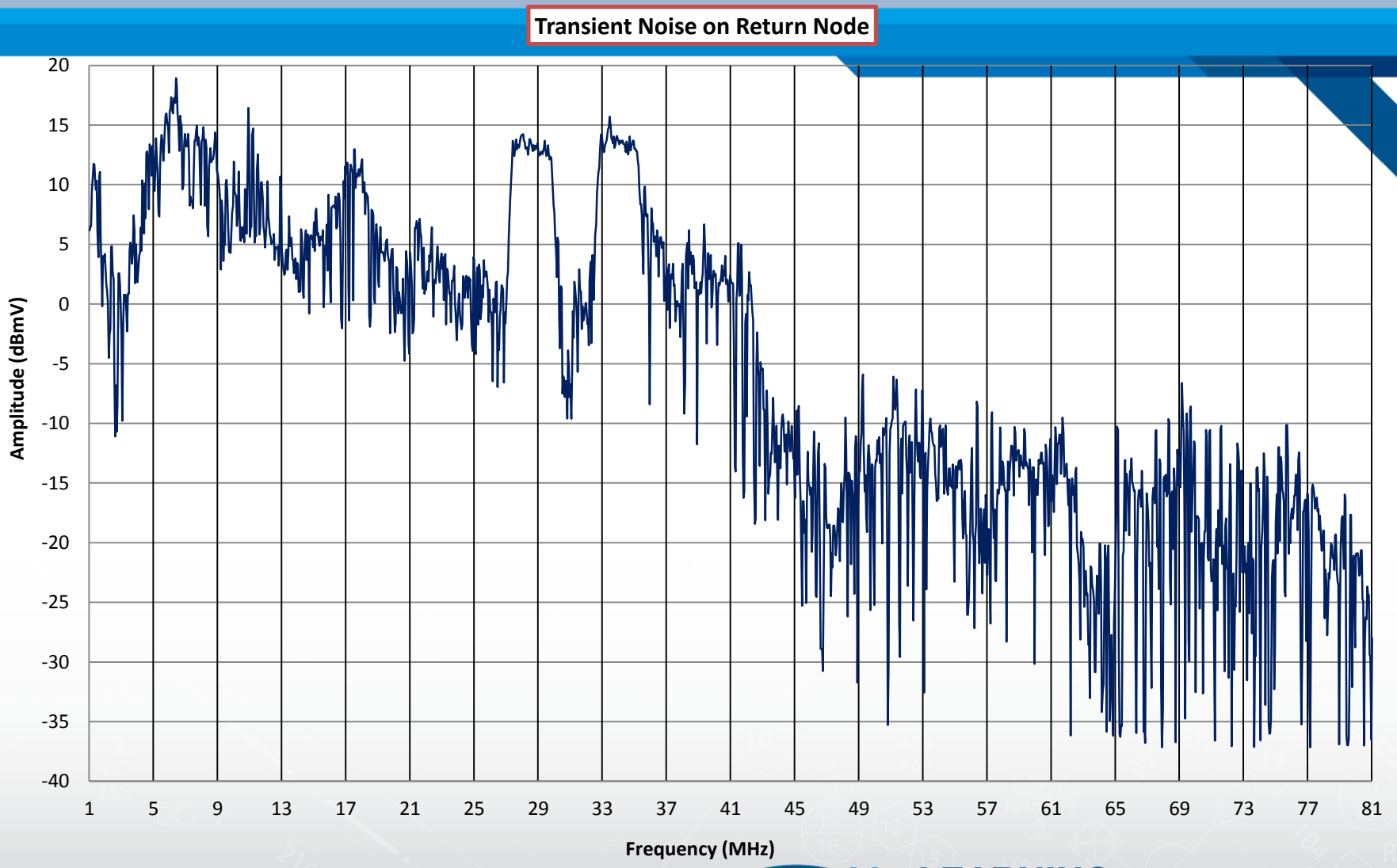
IMPACT OF INGRESS AND CONTENTION COLLISIONS ON UPSTREAM LASER



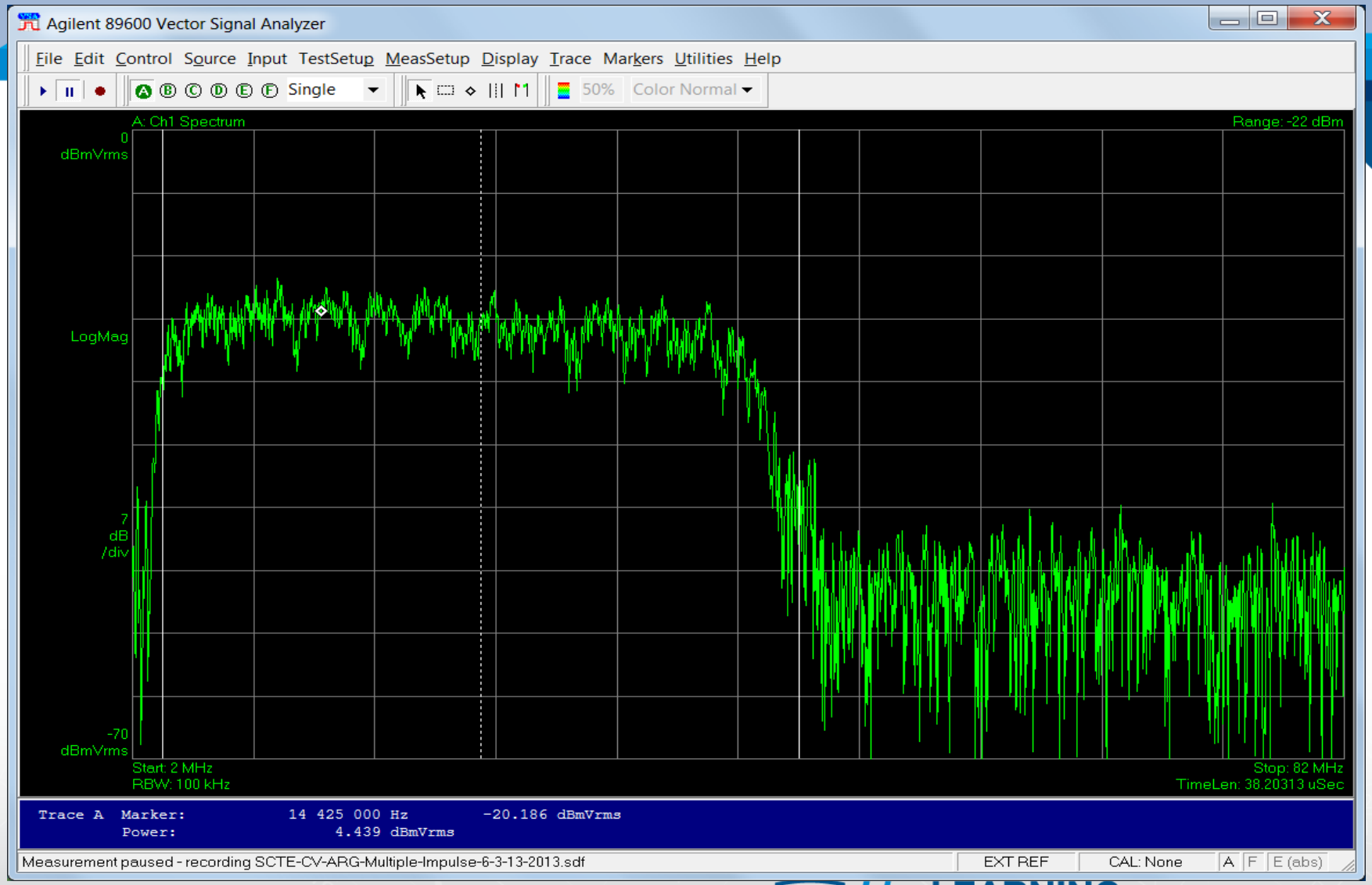
DYNAMIC RANGE VS. LASER TYPE



IMPAIRMENT VISIBILITY OUT OF BAND



HOMEPLUG INTERFERENCE SEEN ON UPSTREAM



WHAT TO MEASURE

- Attenuation and thermal noise in the channel vs. transmit power limit
- Capabilities of existing optics
- Frequency response/Micro-reflections
- Ingress, impulse and burst noise
- Non-linear impairments (CSO, CTB)

LONG TERM REQUIREMENTS

- Objectives of 10 Gbit/s DS and 1 Gbit/s US capacity requires more RF spectrum
  - 1.2-1.5 GHz on the downstream, 200-400 MHz on the upstream
- Highest availability and capacity may ultimately require
  - Better DFB cooled downstream lasers
  - Higher powered upstream lasers
  - Improved passives and RF amplifiers

  These improvements can be done surgically, only on nodes where needed

- Characterizing current plant performance will determine how close an MSO can come to the objectives with minor to moderate tweaks to the existing HFC Infrastructure

REFERENCES / FOR MORE INFO

- OFDM basics tutorial
  - http://www.radio-electronics.com/info/rf-technology-design/ofdm/ofdm-basics-tutorial.php
- What is OFDM (Hranac)
  - http://www.cablefax.com/cfp/ct/news/ctreports/commentary/What-Is-OFDM_55404.html
- OFDM FAQ/Tutorial
  - http://mobiledevdesign.com/tutorials/ofdm/
- OFDM Tutorial
  - http://www.complextoreal.com/chapters/ofdm2.pdf
- DVB-C2: Revolutionising RF Bandwidths' Utilization in Cable
  - http://www.ict-redesign.eu/fileadmin/documents/1003_SCTE_Broadband_DVB-C2.pdf
- OFDM and the orthogonality principle
  - http://www.ice.rwth-aachen.de/research/algorithms-projects/ofdm/ofdm-and-the-orthogonality-principle/
- Wikipedia entry on OFDM
  - http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing
- The principles of OFDM (RF Design)
  - http://rfdesign.com/images/archive/0101Puegel30.pdf
- OFDM Overview (Va Tech)
  - http://www.mprg.org/research/OFDM/index.html
- OFDM Uncovered Part 1: The Architecture
  - http://www.eetimes.com/design/communications-design/4141953/OFDM-Uncovered-Part-1-The-Architecture

SCTE DOCSIS AND PHY LAYER LEARNING RESOURCES

- Courses
  - Channel Bonding in DOCSIS 3.0
    - http://www.scte.org/professional_development/channel_bonding_in_docsis_30_on_demand_description.aspx
  - Coaxial Cable in the HFC Plant
    - http://www.scte.org/professional_development/_coaxial_cable_in_the_hfc_plant.aspx
  - Data Communications
    - http://www.scte.org/professional_development/data_communications_description.aspx
  - Digital Basics and DOCSIS Fundamentals
    - http://www.scte.org/events/Digital_Basics_and_DOCSIS%C2%AE_Fundamentals_.aspx
  - DOCSIS Systems
    - http://www.scte.org/events/DOCSIS%E2%84%A2_Deployment_Detail.aspx
  - Return Path
    - http://www.scte.org/events/Return_Path_Detail.aspx
- Primers:
  - What is LTE?
    - http://www.scte.org/resources/SCTE_Primers_for_Download.aspx#LTE
  - What is Modulation?
    - http://www.scte.org/resources/SCTE_Primers_for_Download.aspx#modulation