Access Networks Solutions

DOCSIS 3.0 Upstream: Technology, RF Variables & Case Studies

Dr. Robert Howald
Technology Office
Motorola Home & Networks Mobility
rob.howald@motorola.com

Agenda

- DOCSIS 3.0 A-TDMA
  - Return Path Readiness
    - QAM, SNR, MER and Margin
    - Optical Links
    - Spectrum Fidelity
    - Frequency Response Distortion
  - Combined Impairment Testing & Analysis
  - Summary
- Example Plant Assessments
  - RF Upstream System Characterization
  - Upstream Spectrum: Snapshots & Indicators
- DOCSIS 3.0 S-CDMA - Introduction

DOCSIS 3.0 – What's New

- **NOT New**
  - 64-QAM is a DOCSIS 2.0-specified upstream modulation
  - 5.12 Msps (6.4 MHz) is a DOCSIS 2.0-specified upstream symbol rate
  - S-CDMA is a DOCSIS 2.0-specified format
  - Support for advanced *equalization* (Pre-EQ) - DOCSIS 2.0 requirement

- **IS New**
  - Channel Bonding
    - Downstream
    - Upstream
  - Others that are *don't care for the plant*
    - IPv6
    - Enhanced Multicast with QoS
    - Enhanced Security
    - Network Mgmt (IPDR)

DOCSIS 3.0 – Channel Bonding

- Channel bonding is logical (two phy channels tied together at data link layer)
  - Increases peak rate, but not upstream channel capacity
- Possible physical layer impact is associated with the use of new spectrum
  - New spectrum is not always clean
  - Increased sensitivity of higher order modulations
- Moving to wideband (6.4 MHz) single channel has similar constraints as bonding – deploying new spectrum
  - Choice of center frequency and fidelity
- More channels means understanding and applying return path laser transmitter loading principles

Enabling DOCSIS 2.0 & 3.0:
Return Path Readiness

MER & Margin – What's the 64-QAM Effect?

- **64-QAM consumes ~*6-7 dB* of return path margin beyond 16-QAM**
  - This amount of margin might not be available "alarm-free"
  - If available, what's left requires more careful attention to maintain fidelity
  - Smaller dB's or accuracy, alignment, calibration, make a difference

- **Consider a functioning, practical return delivering a 31 dB MER**
  - Post-EQ MER threshold limits of approx 21/24/28 dB support 16/32/64 QAM
  - For fixed BW and level, assuming an uncorrected QAM error rate of 1e-8
    - That's **~ *17 dB*** of margin for QPSK
    - That's **~ *10 dB*** of margin for 16-QAM
    - That's **~ 7 dB** of margin for 32-QAM
    - That's **~ *3 dB*** of margin for 64-QAM
  - 3 dB is a small margin
    - Below the level of alignment accuracy that can often be guaranteed
    - Below plant-wide changes that can take place slowly over time and temperature
    - Below common MER variations observed on working channels due to dynamics of noise and interference
    - ⇒ ***Margin this small requires more attention to plant setup & maintenance***

MER & SNR – Understanding the Difference

- **What the CMTS reports as SNR is in fact MER – i.e. *all impairments are included***
  - SNR in communications literature often refers only to the noise floor
  - MER thresholds for error rate are thus *always* approximations
  - Post-EQ MER includes all impairments, but evaluated after CMTS receiver processing has worked to repair any distortion imposed
  - The difference between SNR & MER did not used to matter very much because of *margin and band of operation*

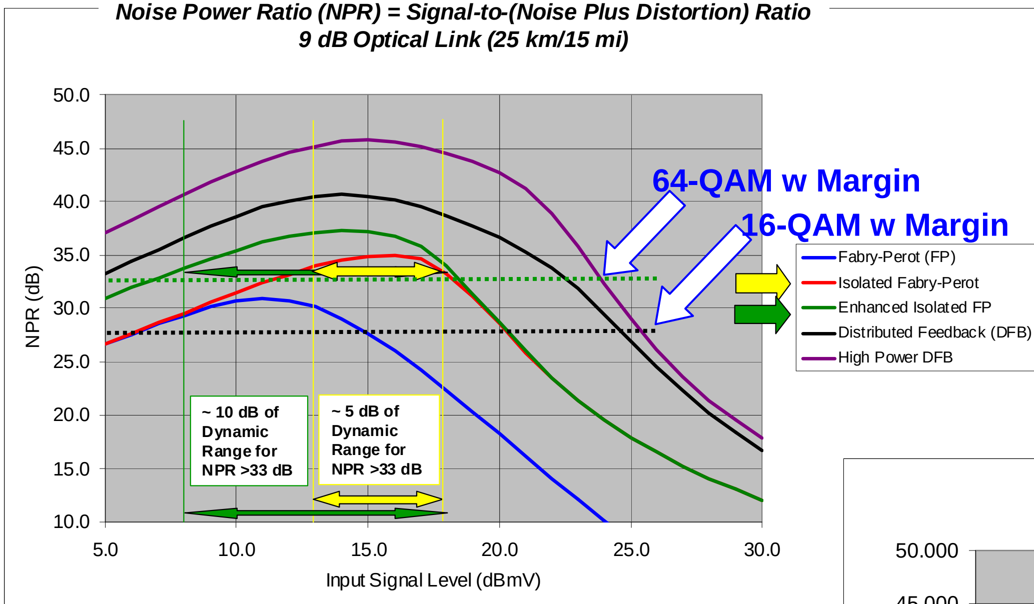
- **Facts of MER life**
  - It is impossible to extract from an MER alone the breakdown of the contributing impairments
    - Constellation plot has clues
  - MER is an averaging measurement, and impulsive events are thus not typically reflected in a way representative of their impact
  - There IS NOT a unique relationship between MER and bit or symbol error rate – the same MER can result in different error rates

Return Path Variables

- **Plant variables impacting the move to higher order modulations and higher symbol rates**
  - Link SNR and dynamic range
    - **Primarily driven by the optical link**
    - **Includes return path setup and maintenance practices**
      - Proper return laser power loading and HE levels
      - Forward path isolation
  - Spectrum Fidelity – Ingress and impulse degrading available SNR
    - **Primarily due to in-home disturbances, typically < 20 MHz**
    - **In-band interference on DOCSIS channel**
    - **Out-of-band or wideband impulse impacting laser loading**
    - **64-QAM more sensitive**
  - Choice of carrier frequency and bandwidth sensitive to cascade depth
    - **Impinging on diplexer roll-off**
    - **Combined frequency response distortions a threat for 64-QAM**
    - **Wideband channels (6.4 MHz) increase likelihood**

Available SNR – Dynamic Range vs Laser Type

QAM sensitivity to loading varies with laser type

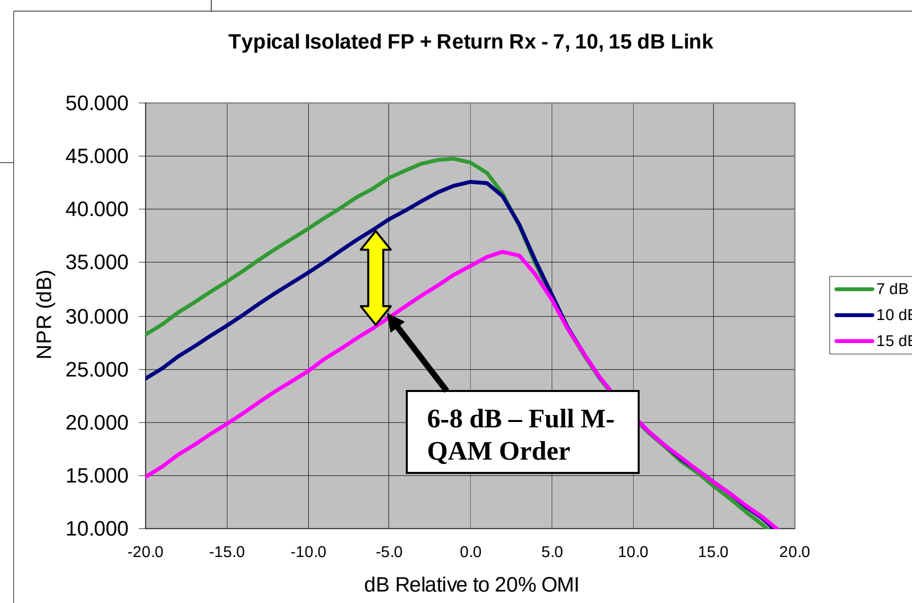


Total Power, all Signals 5-42 MHz

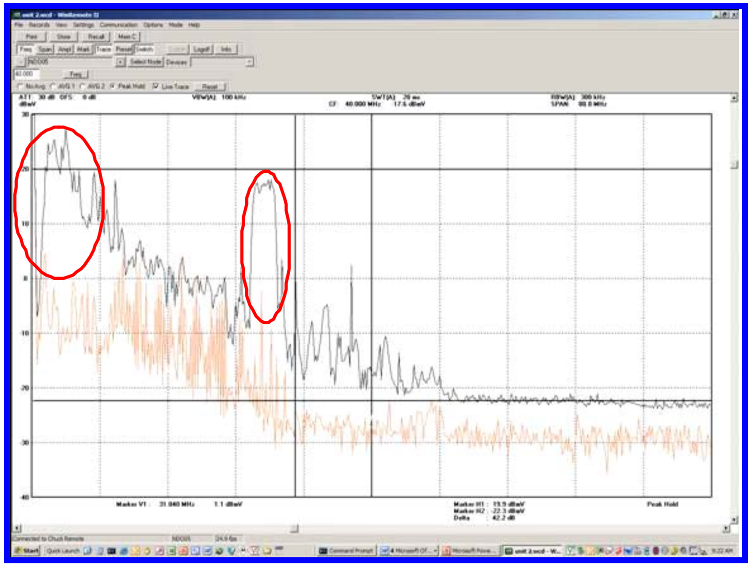
Noise Power Ratio (NPR)

- Approximates a full QAM load
- Link SNR & dynamic range
- Operating point headroom

Low Headroom or dynamic range means sensitivity to other link variables (analog return paths)



Spectrum Fidelity – Now More Critical

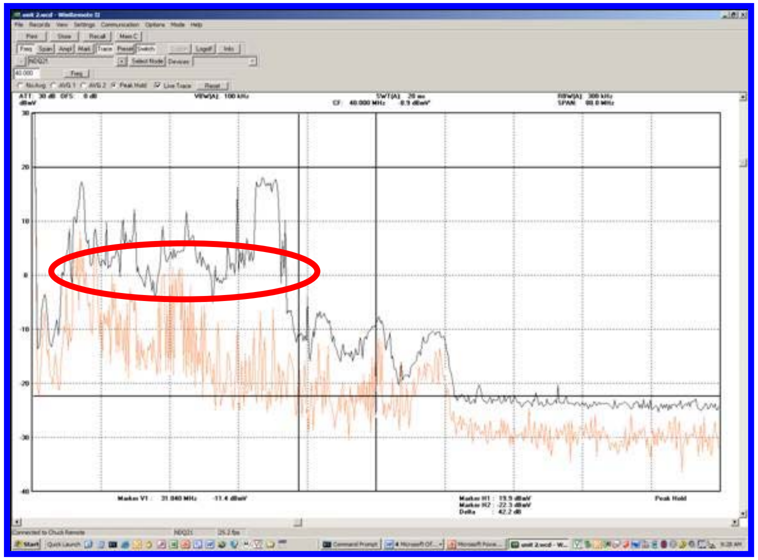


- Impulsive interference > signal power

- Laser loading concern – clipping and headroom for new carriers

- Limitations of band usage for adding new carriers

Characteristics typ of approx 15-20% of nodes in any large HE



- Impulsive noise into DOCSIS band @ ~ -15 dBc pk

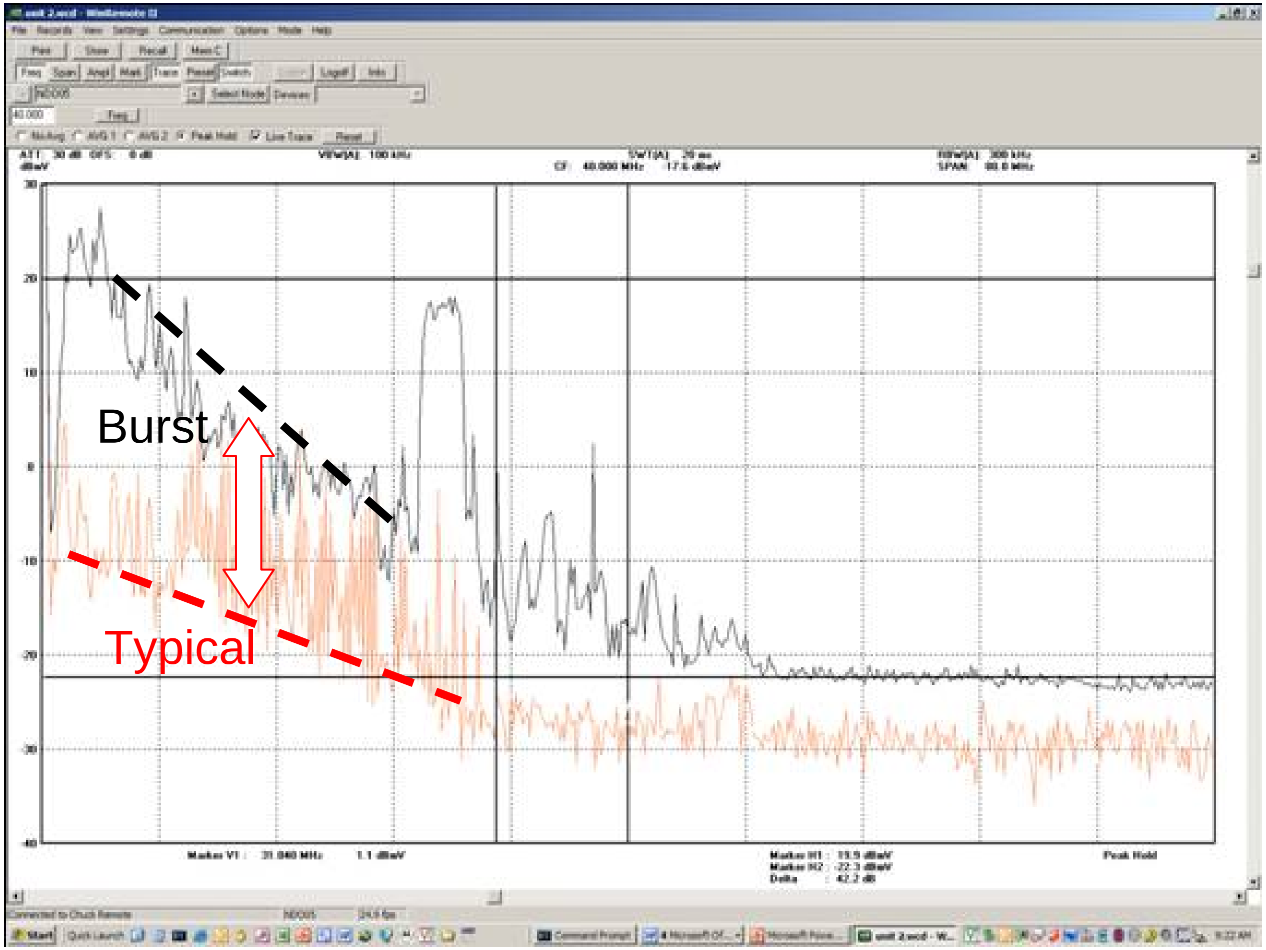
- 16-QAM supported but FEC probably working hard

- Insufficient for 64-QAM

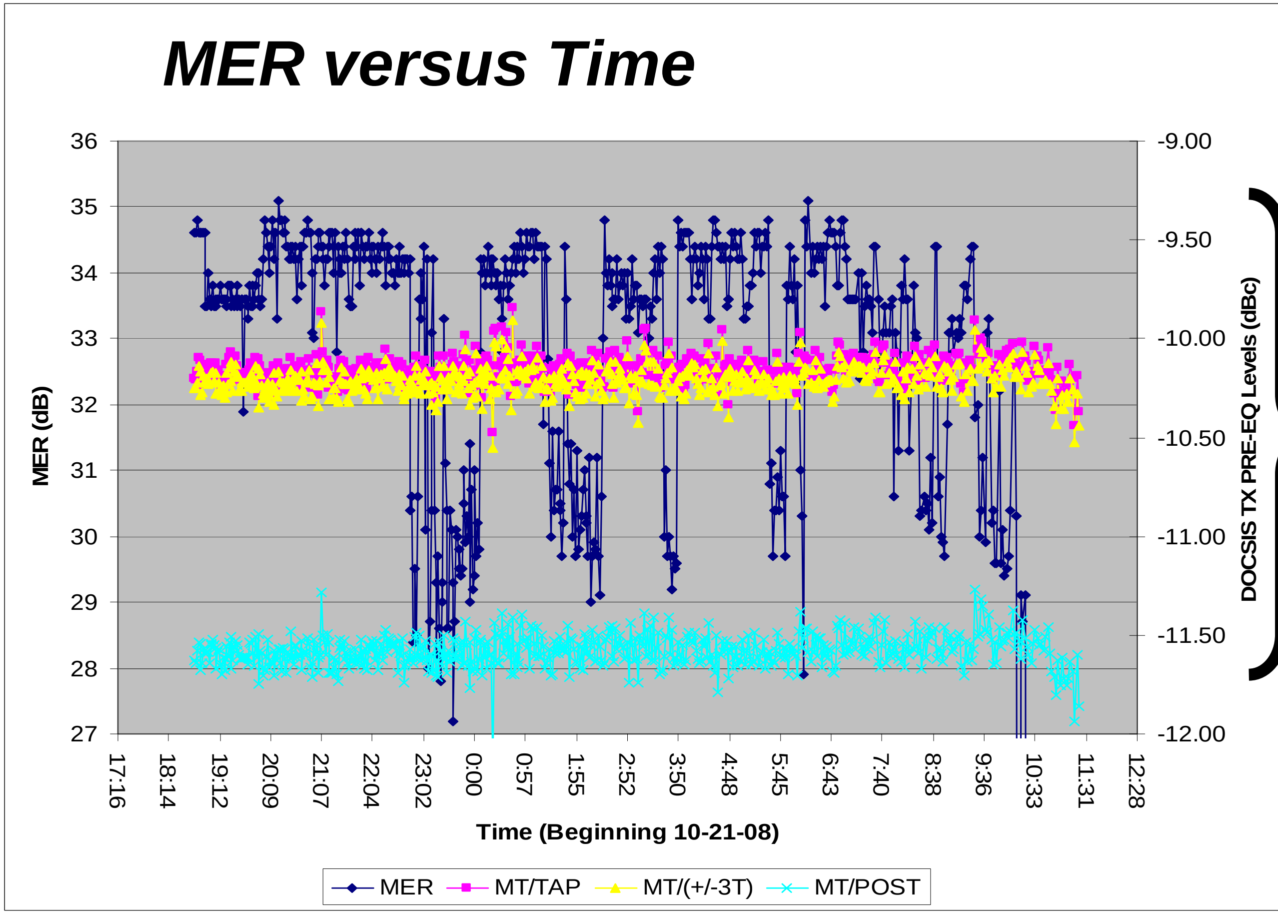
- Energy is wideband – issue for any new carriers for single or bonded channels

Impulse Noise Spectrum – A Closer Look

Impulse Noise – Typical < 20 MHz Signature and Burst



Impulse Noise – MER Perspective



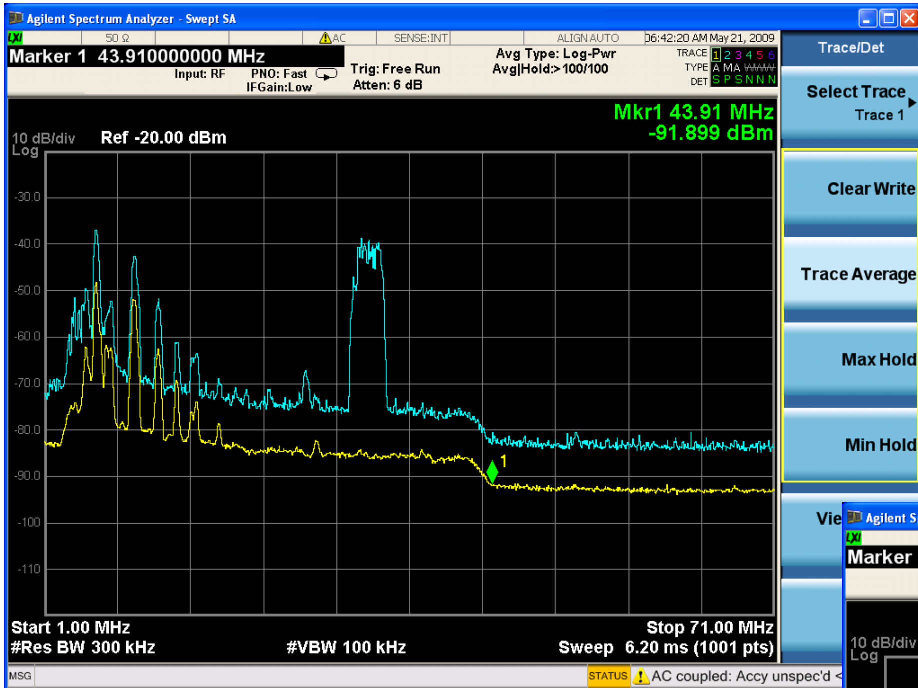
> 8 dB Range

> QAM Order (6 dB min from 16-QAM to 64-QAM)

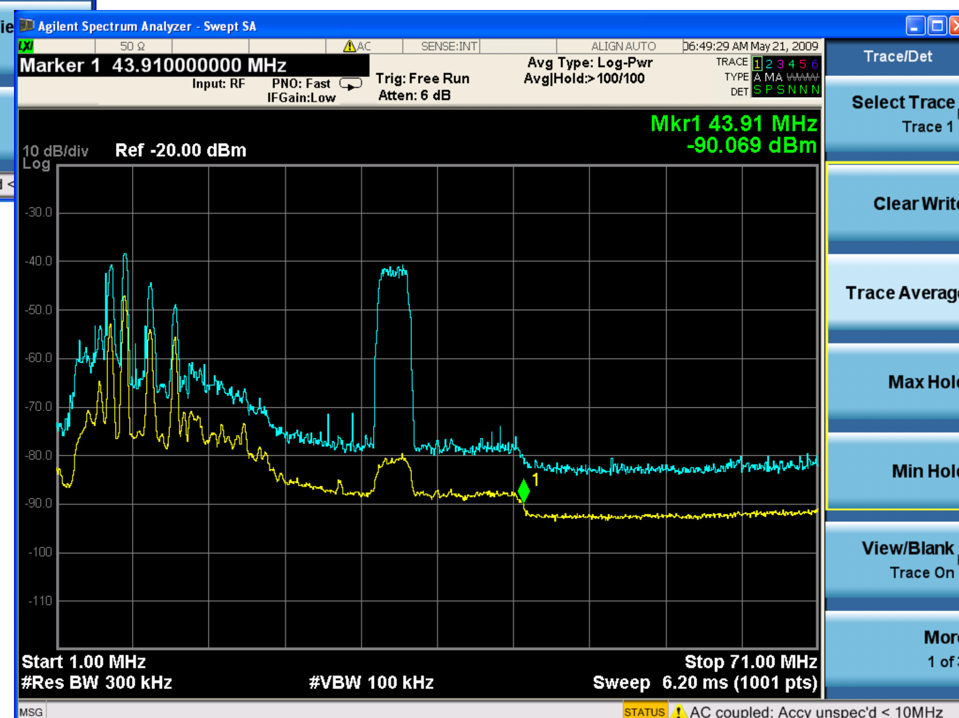
MER

Equalizer (Channel Freq Response vs Time)

Spectrum Fidelity – Clean….Except



High narrowband static interference - 9.6 MHz, 11.9 MHz, 13.8 MHz



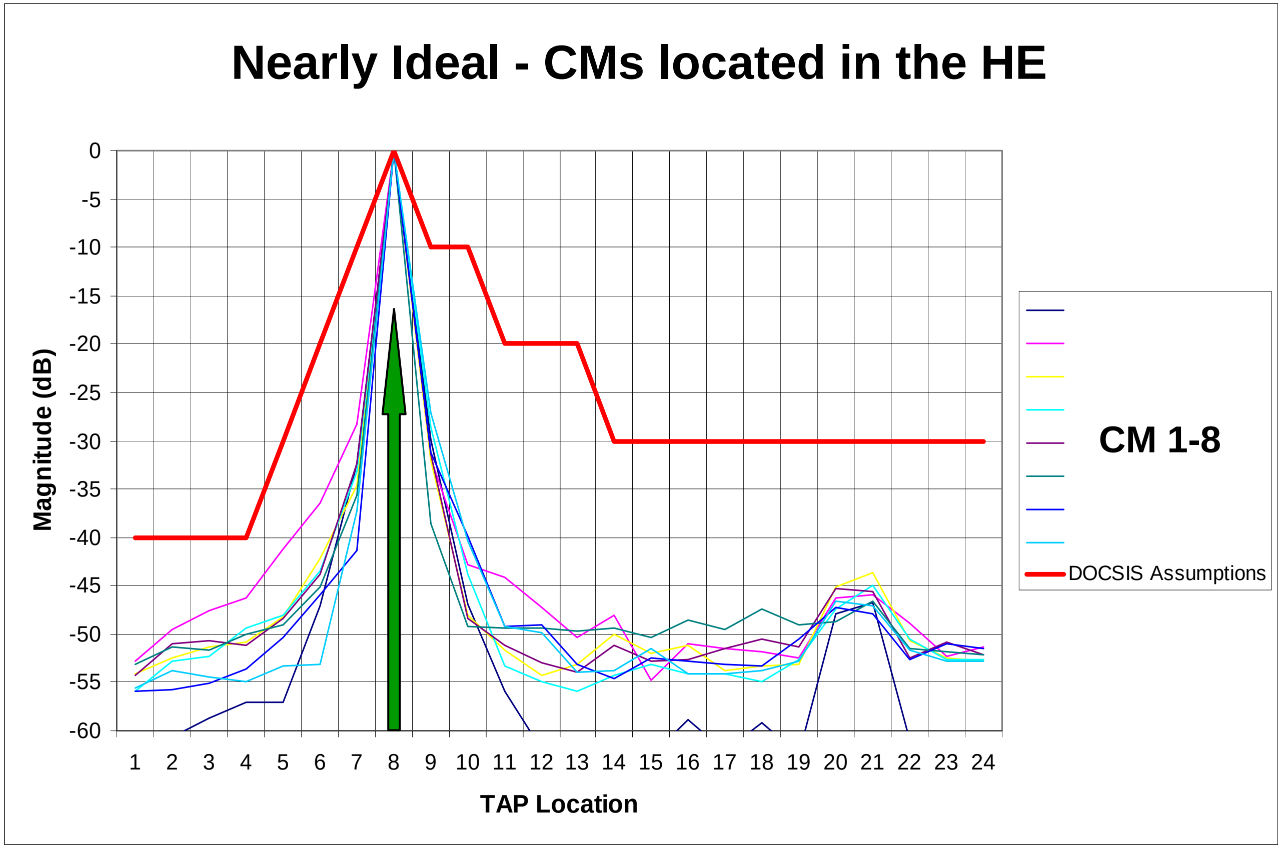
High narrowband interference coupled with low freq impulse

What's the 6.4 MHz BW Effect? (or 5.12 Msps)

- The D3.0 *Equalizer* is a fixed "24-Tap" structure designed in part to "undo" plant reflections
  - One Tap = One QAM Symbol period in time (5.12 Msps period is approx 195 nsec)
  - Total time spanned by 24 taps for 5.12 Msps is less than 5 usec
- As symbol rate *increases*, Equalizer time spanned *decreases*
  - The 5.12 Msps (6.4 MHz) span is *one-half* that of 2.56 Msps (3.2 MHz), i.e. it handles reflections closer in time only (and distance) by factor of 2
- At 5.12 Msps, time span can be shorter than some practical plant reflections, and thus they are not equalized
- This unmitigated reflection energy contributes directly as interference that degrades MER – with 64-QAM most at risk
- A reflection long enough in time and yet large enough in amplitude to cause degradation is atypical, but it has been observed in the field
  - Multi-building MDUs can be prone to these conditions
- When reflections combine with Group Delay Variation (choice of center frequency), Equalizer can be overwhelmed in broader range of cases

The 6.4 MHz Effect – A Closer Look

Impulse Responses vs. DOCSIS Mask @ 5.12 Msps

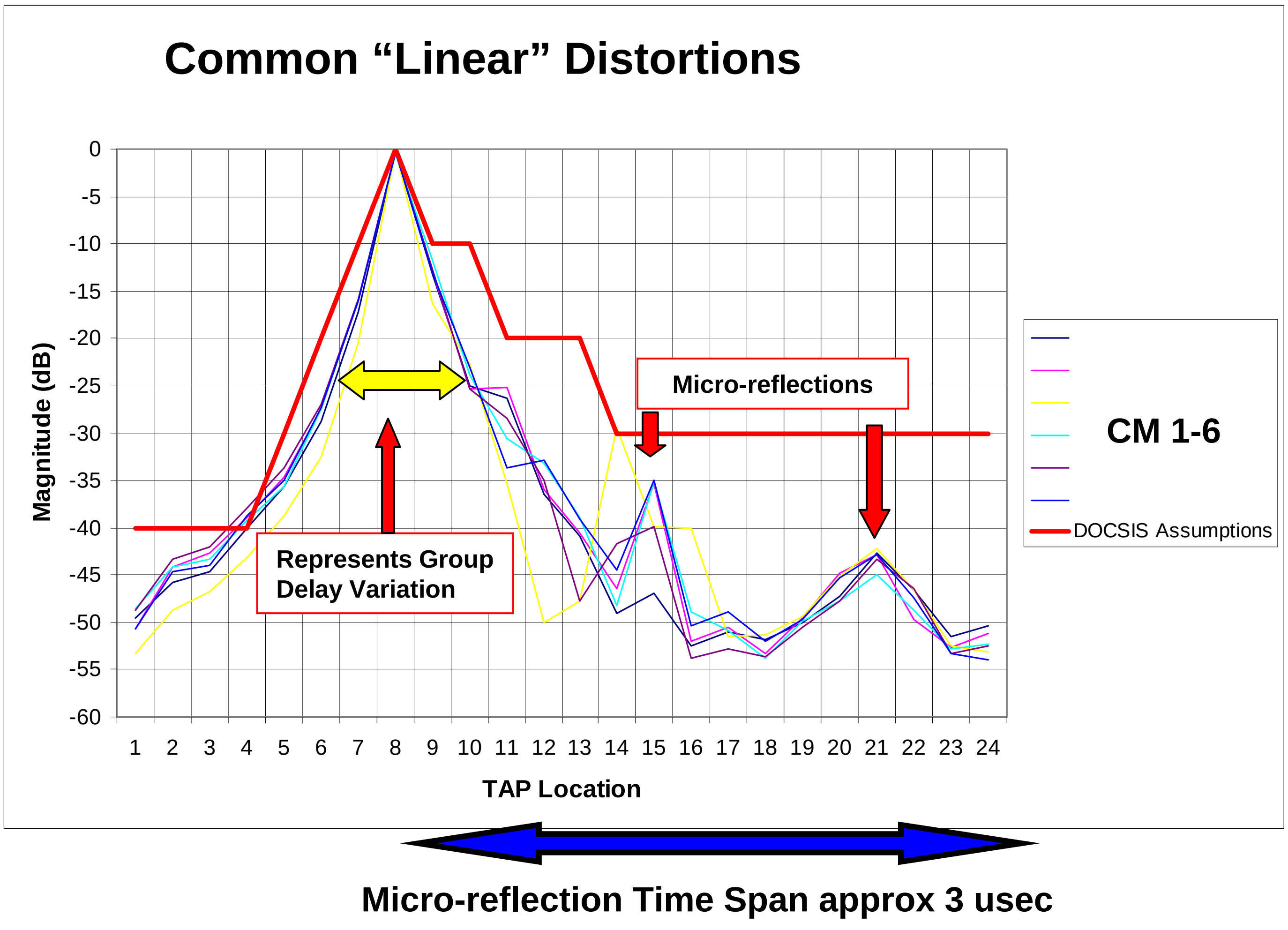


"Ideal" Channel Impulse Response

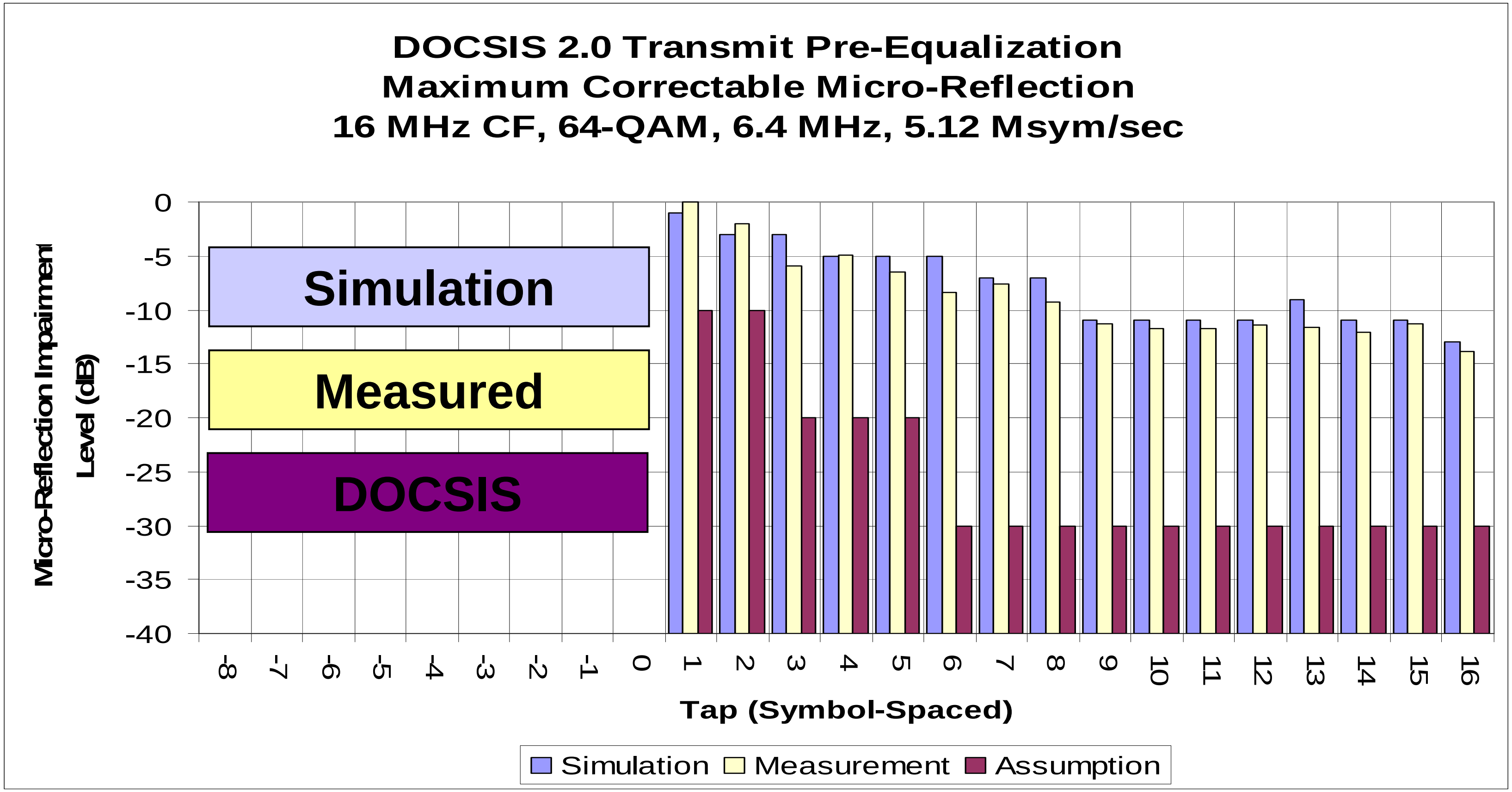
Response of Different Upstream Paths from Each CM

The 6.4 MHz Effect – A Closer Look

Impulse Responses vs. DOCSIS Mask @ 5.12 Msps



Equalizer Limits vs DOCSIS – Micro-Reflections Only



Single Dominant Micro-reflection Only

	DOCSIS 1.0 Req't	Simulated D2.0 Pre-Eq Capability	
		16-QAM	64-QAM
< .5 usec	-10	-4	-4
.5-1.5 usec	-20	-6	-7
>1.5 usec	-30	-13	-15

Equalizer mitigation limits within 2 dB

Combined Impairment Characterization: Packet Error Rate (PER) vs. Ingress + Impulse Interference

New and Improved Performance Metrics

- Wideband 64-QAM is the end of the “free margin” era of DOCSIS
- Wideband 64-QAM requires more of the return plant for high performance
- There is less performance margin as a result
- There is less room for error with the various contributions
- There is a need to understand the multiple potential contributors to performance degradation
- The MER metric is itself limited in information conveyed
- It is desirable to find other metrics of performance from available information, such as FEC statistics from the CMTS
- End-user performance is tied to packet error rate (PER)
- There is thus strong interest in understanding the correlation between PER and available FEC statistics

Refer to full analysis and results in SCTE Expo 2009 Paper:

“Characterizing and Aligning the HFC Return Path for Successful DOCSIS 3.0 Rollouts”

-Dr. R Howald, Phillip Chang, et al

Laboratory Test Conditions

Plant

- 20 km DFB link
- N+6 cascade
- 36.5 DOCSIS carrier frequency
- 40+ DOCSIS 2.0 modems (various)

Data

- 64-QAM/16-QAM @ 5.12 Msps
- Maximum FEC: K=219, T=16
- No Interleaving
- Ingress Canceller ON
- Pre-Equalization ON
- 1518-byte packets

Additive Noise & Interference

- AWGN Noise
  - SNR = 35 dB
  - SNR = 27 dB
- Static Ingress
  - Single CW Carrier @ -10 dBc
  - Three CW Carriers uniformly spread @ -15 / -20 / -25 dBc
  - Single FM Carrier @ -10 dBc
  - Three FM Carriers uniformly spread @ -15 / -20 / -25 dBc
- Impulse Noise
  - 4 usec AWGN pulse @ 100 Hz
    -10 dBc and -5 dBc
  - 10 usec AWGN pulse @ 1 kHz
    -10 dBc and -15 dBc

Sampling of Lab Test Results

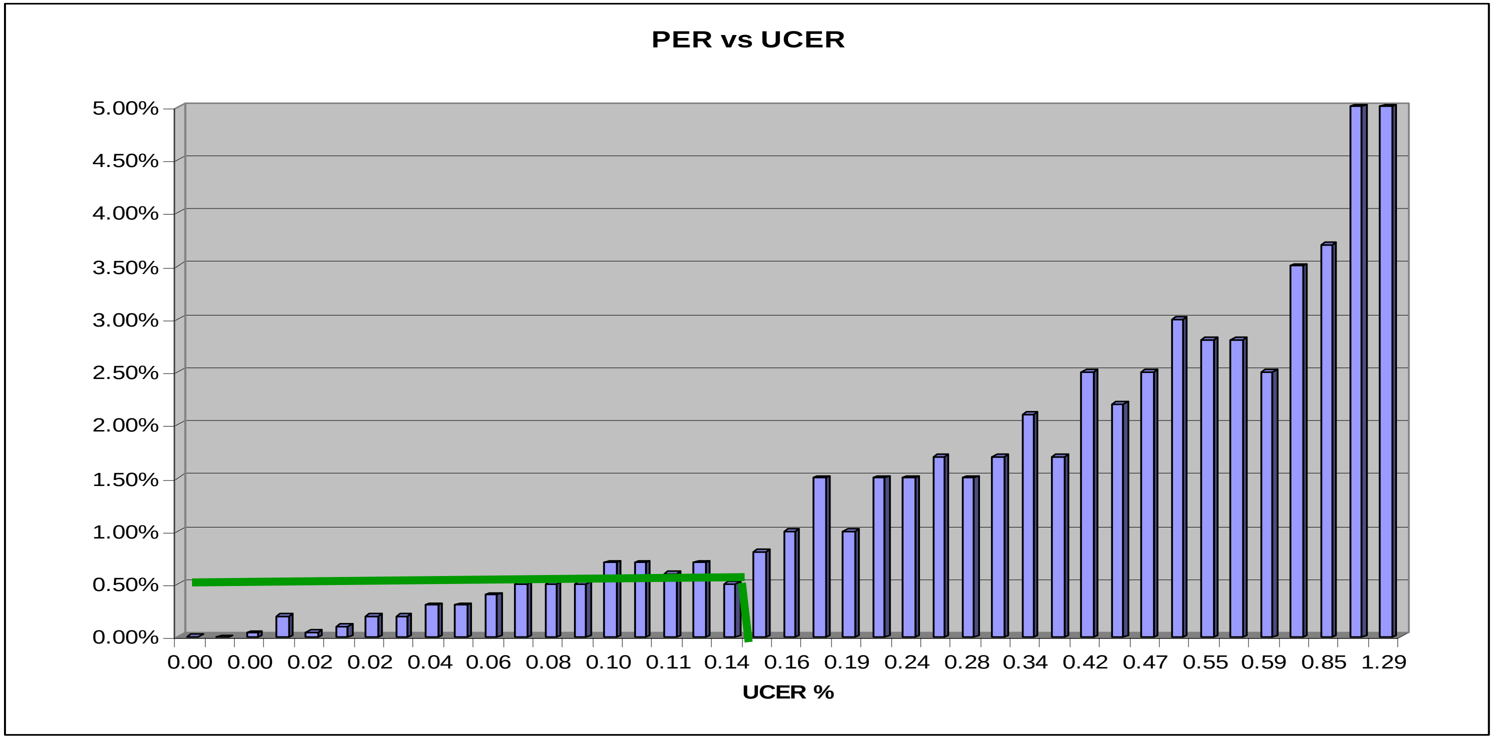
16-QAM vs 64-QAM: Impulse + Ingress Thresholds

	Impulse (dBc-pk) - Gated AWGN @ 10 MHz BW							
	10 usec @ 1 kHz							
1518-Byte Packets	-15				-10			
Noise Floor = 35 dB	16-QAM		64-QAM		16-QAM		64-QAM	
Ingress (dBc)	UCER/CCER	PER	UCER/CCER	PER	UCER/CCER	PER	UCER/CCER	PER
CW Interference								
1x @ -10 dBc	0.055 / 0	0.00%	6.03 / 2.12	6.00%	7.9 / 0.2	0.70%	2.05 / 9.4	38.00%
3x @ -15 dBc/tone	0.07 / 0.007	0.04%	6.36 / 0.98	5.00%	8.2 / 0.1	0.80%	3.5 / 4.3	27.00%
FM Modulated (20 kHz BW)								
1x @ -10 dBc	0.17 / 0.017	0.07%	5.05 / 5.51	15.00%	8.2 / 1.9	4.50%	1.4 / 15.4	42.00%
3x @ -15 dBc/tone	0.2 / 0.02	0.10%	4.59 / 4.44	21.00%	8.5 / 0.6	4.00%	1.4 / 12.5	44.00%
Noise Floor = 27 dB	16-QAM		64-QAM		16-QAM		64-QAM	
Ingress (dBc)	UCER/CCER	PER	UCER/CCER	PER	UCER/CCER	PER	UCER/CCER	PER
CW Interference								
1x @ -10 dBc			14.46 / 0.807	3.00%	8.2 / 0.03	0.20%	9.86 / 8.11	40.00%
3x @ -15 dBc/tone			16.9 / 1.21	8.00%	8.5 / 0.04	0.40%	13.12 / 9.09	42.00%
FM Modulated (20 kHz BW)								
1x @ -10 dBc	0.3 / 0.01	0.05%	18.96 / 8.0	20.00%	9.1 / 1.4	4.00%	18.48 / 16.9	46.00%
3x @ -15 dBc/tone	0.5 / 0	0.00%	23.1 / 5.56	18.00%	8.7 / 0.2	1.70%	18.3 / 15.1	47.00%

- *FEC is always working hard for AWGN = 27 dB – a 64-QAM margin issue*
- *Modulated ingress is noticeably worse on error rate performance vs CW*
- *MER is not very informative under these relatively harsh impairments*
- *Impulse noise can dominate PER, overwhelm FEC and be invisible to MER*
- *Without impulse, the ingress canceller is excellent at mitigating interference*

Sampling of Lab Test Results - PER

Packet Error Rate vs Uncorrectable Codewords



- ***CMTS reports FEC statistics, while PER is what the service QoE is tied to***
- ***Above charts estimates a quantifiable correlation between uncorrectable codeword errors and PER for this set of conditions***
- ***There is an expected correlation between UCER and PER***
- ***Apparent knee in the degradation curve of packet delivery as the uncorrectable codewords reach approximately 1e-3***

DOCSIS 3.0 A-TDMA: Summary

- **Early DOCSIS**
  - Very robust modulations – GONE
  - Low bandwidth – GONE
  - Anywhere in the spectrum – GONE
  - All the laser load you needed – GONE

- **For wideband 64-QAM every dB will matter more**
  - Most of current link margin to 16-QAM gets removed
  - DFBs can restore some margin being lost
  - Upstream alignment & maintenance practices have added importance
  - Become accustomed to looking at acceptable margins differently

- **Spectrum**
  - Wideband QAM, micro-reflections, and cascade effects constrain location of channels
  - Combined freq response distortions can overwhelm the equalizer
  - Typical upstream fidelity not suited to instant 64-QAM success for 100% of footprint
  - S-CDMA allows use of full band - need A-TDMA **and** S-CDMA to optimize upstream

- **MER is an insufficient and non-unique predictor of performance**
  - Hidden by the large margins available to date inherent in 16-QAM
  - Does not capture impulse noise in particular in a way representative of impact
  - Combined impairment effects and less available margin require additional metrics