DEPLOYING VOIP ON THE OUTSIDE PLANT

RON HRANAC

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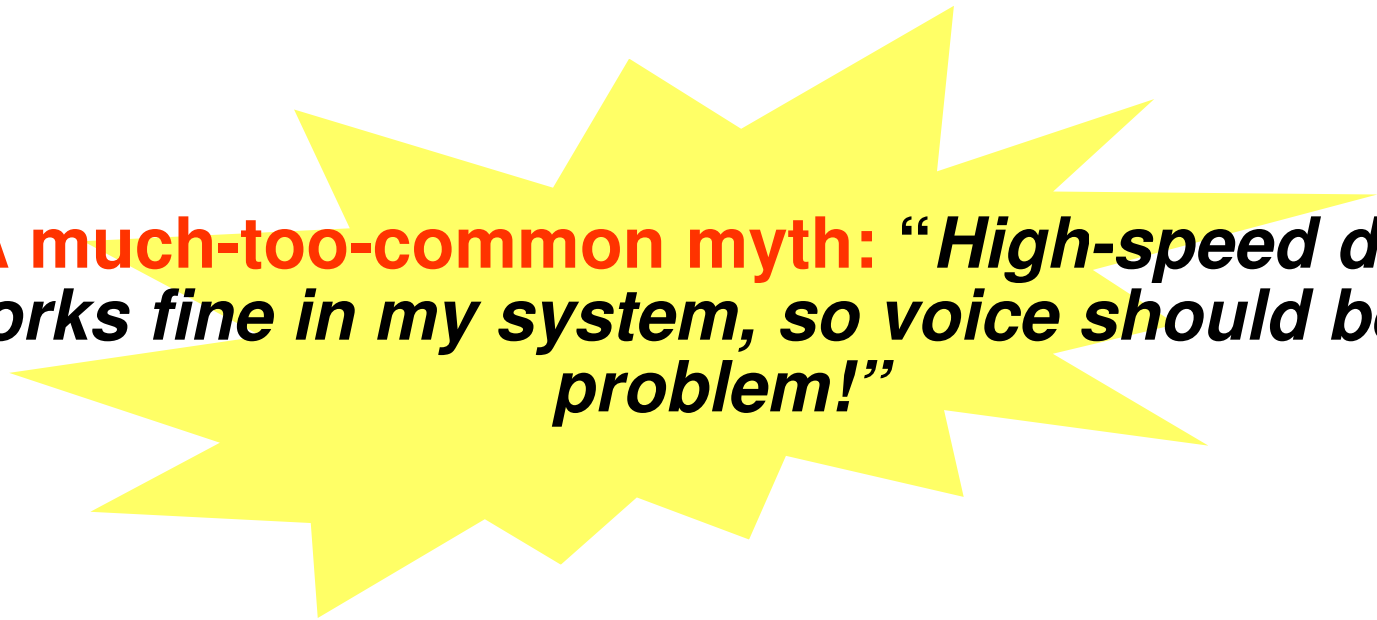
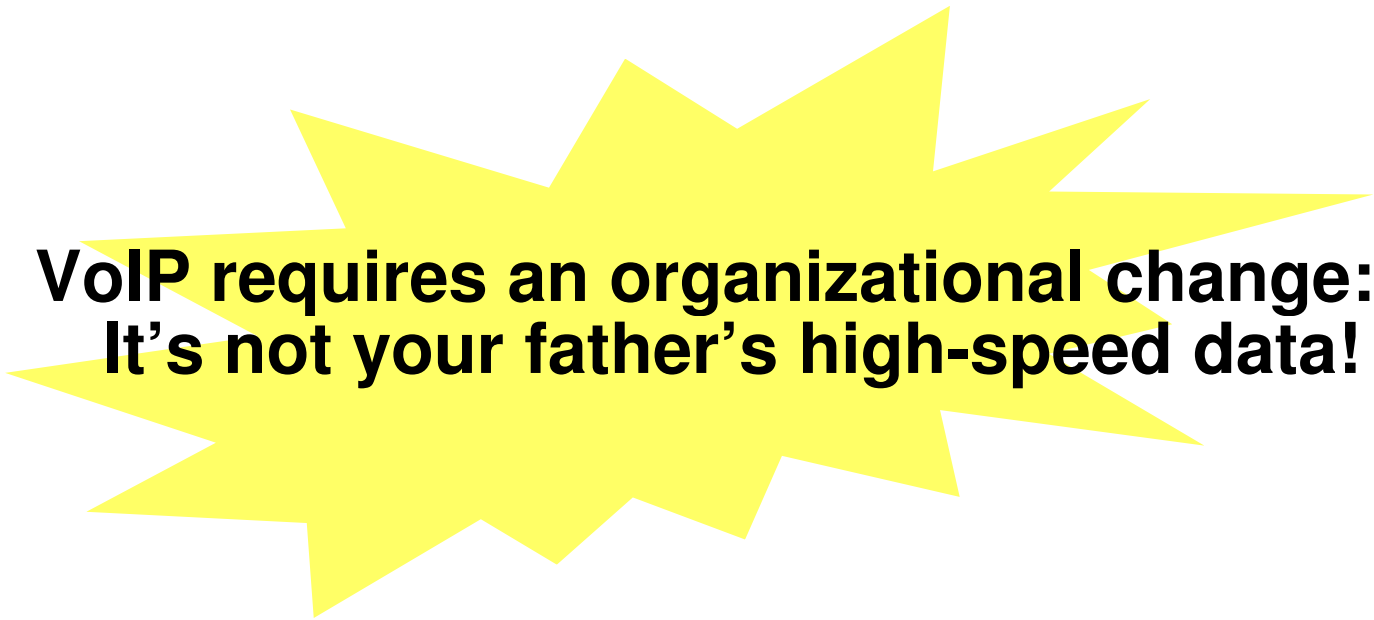
VoIP—Voice Over Internet Protocol



VoIP—The Philosophy



VoIP—The Reality

- **High-speed data *and* voice services can in most cases be successfully deployed on a CATV network if the ENTIRE cable system—headend, distribution network, and subscriber drops—meets or exceeds certain minimum technical performance parameters.**

Recommended Network Specifications

- **The first is the technical requirements in Part 76 of the FCC Rules**

  www.access.gpo.gov/nara/cfr/waisidx_03/47cfr76_03.html

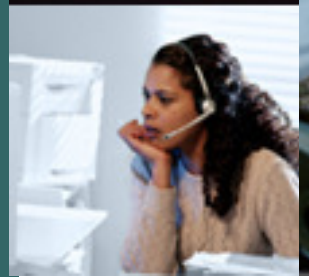
- **The second is the assumed RF channel transmission characteristics outlined in the DOCSIS® Radio Frequency Interface Specification**

  www.cablemodem.com/specifications

- **The third is ensuring the HFC plant's unavailability contribution does not exceed 0.01% as described in the PacketCable™ Availability Reference Architecture**

  www.packetcable.com/specifications

FCC Rules



FCC Rules: Part 76

- **Minimum visual carrier amplitude:**

  0 dBmV at the subscriber terminal; +3 dBmV at the end of a 30 meter drop.

- **Maximum visual carrier amplitude:**

  Do not overload the subscriber's receiver or terminal

- **Aural carrier amplitude:**

  10 dB to 17 dB below the visual carrier

- **Visual carrier amplitude change:**

  No more than 8 dB variation on any channel within any six month interval

  No more than 3 dB variation during a 24-hour period between any adjacent visual carriers within the cable system bandwidth

  No more than 10 dB difference between any two channels in 300 MHz systems, +1 dB for each additional 100 MHz bandwidth

FCC Rules: Part 76

- **Aural carrier frequency:**

  No more than +/- 5 kHz from nominal frequency (i.e., for NTSC channels, the aural carrier must be 4.5 MHz +/- 5 kHz above the visual carrier)

- **In-channel frequency response:**

  +/- 2 dB (for 6 MHz NTSC channels this specification must be met from 0.75 MHz to 5.0 MHz above the lower frequency boundary of the channel)

- **Visual carrier-to-noise ratio:**

  43 dB (relative to a 4 MHz noise bandwidth for NTSC television channels)

- **Visual carrier-to-coherent disturbance ratio (CTB, CSO, XMOD)**

  51 dB for standard and IRC channelization; 47 dB for HRC channelization

- **Terminal isolation:**

  Minimum 18 dB, and sufficient to prevent reflections caused by open- or short-circuited subscriber terminals from producing visible picture impairments at any other subscriber terminal

FCC Rules: Part 76

- **Low frequency disturbances (hum):**

  The peak-to-peak variation in visual signal level caused by undesired low-frequency disturbances is not to exceed 3% of the visual signal level

- **Chrominance-to-luminance delay inequality:**

  170 nanoseconds or less

- **Differential gain:**

  Maximum +/-20%

- **Differential phase:**

  Maximum +/-10 degrees

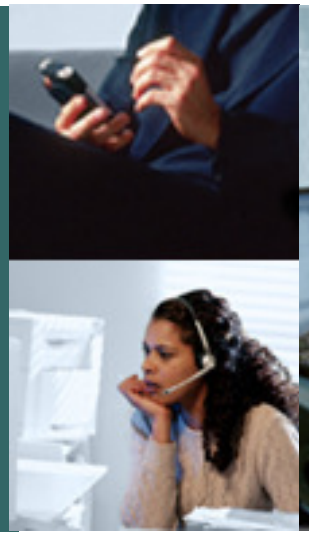
- **Signal leakage (less than and including 54 MHz and greater than 216 MHz):**

  No more than 15 µV/m field strength at a 30 meter measurement distance using a resonant half-wave dipole

- **Signal leakage (over 54 MHz up to and including 216 MHz):**

  No more than 20 µV/m field strength at a three meter measurement distance using a resonant half-wave dipole

DOCSIS® Radio Frequency Interface Specification



DOCSIS® 1.1 Assumed Downstream RF Channel Transmission Characteristics

Parameter	Value
Frequency range	Cable system normal downstream operating range is from 50 MHz to as high as 860 MHz; however, the values in this table apply only at frequencies >= 88 MHz
RF channel spacing (design bandwidth)	6 MHz
Transit delay from headend to most distant customer	<=0.800 msec (typically much less)
Carrier-to-noise ratio in a 6 MHz band (analog video level)	Not less than 35 dB[3]
Carrier-to-Composite triple beat distortion ratio	Not less than 41 dB[3]
Carrier-to-Composite second order distortion ratio	Not less than 41 dB[3]
Carrier-to-Cross-modulation ratio	Not less than 41 dB[3]
Carrier-to-any other discrete interference (ingress)	Not less than 41 dB[3]
Amplitude ripple	3.0 dB within the design bandwidth
Group delay ripple in the spectrum occupied by the CMTS	75 ns within the design bandwidth
Micro-reflections bound for dominant echo	-10 dBc@ <= 0.5 µsec -15 dBc@ <= 1.0 µsec -20 dBc@ <= 1.5 µsec -30 dBc@ > 1.5 µsec
Carrier hum modulation	Not greater than –26 dBc (5%)
Burst noise	Not longer than 25 µsec at a 10 Hz average rate
Maximum analog video carrier level at the CM input	17 dBmV
Maximum number of analog carriers	121

RF Channel Spacing (Design Bandwidth)

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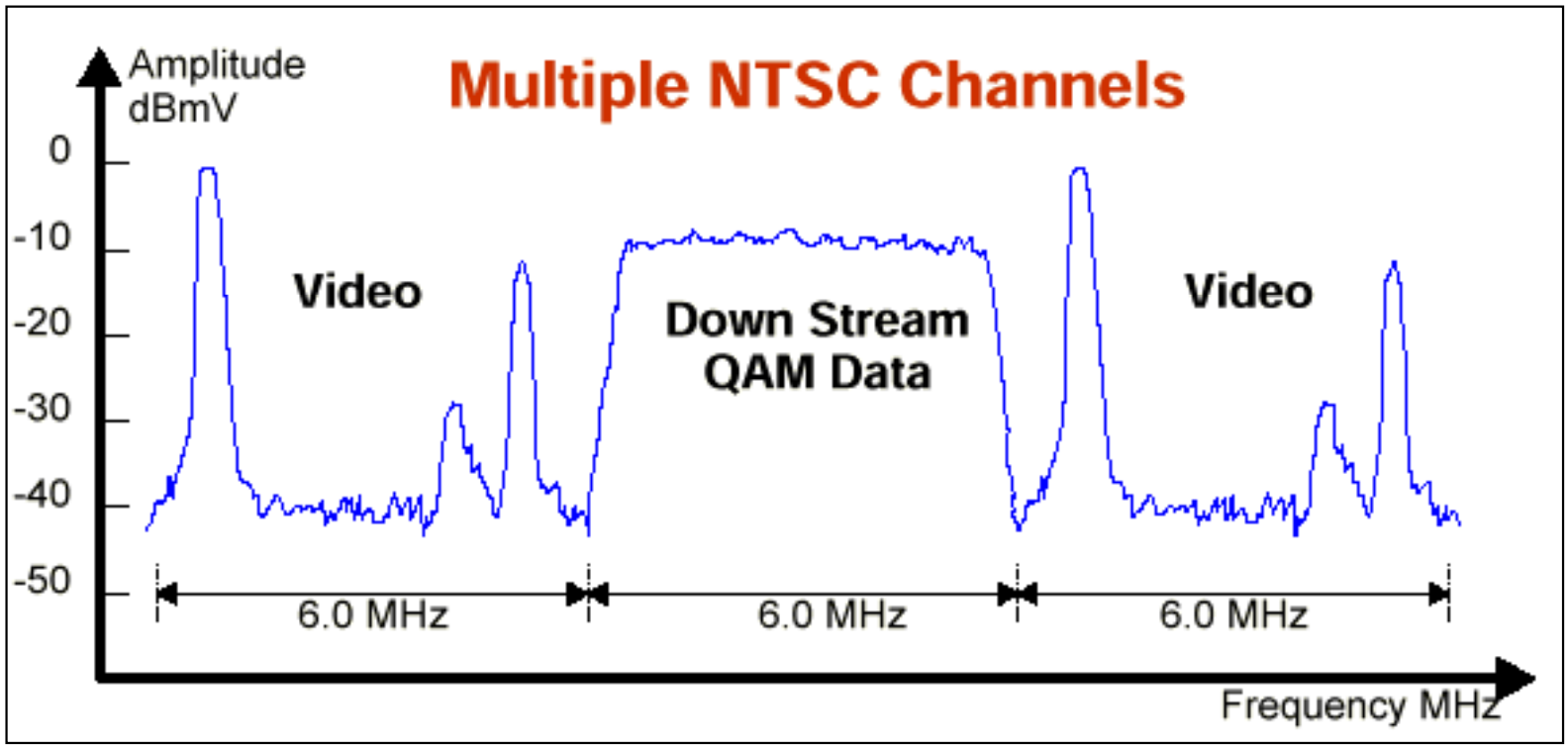
6 MHz

RF Channel Spacing (Design Bandwidth)



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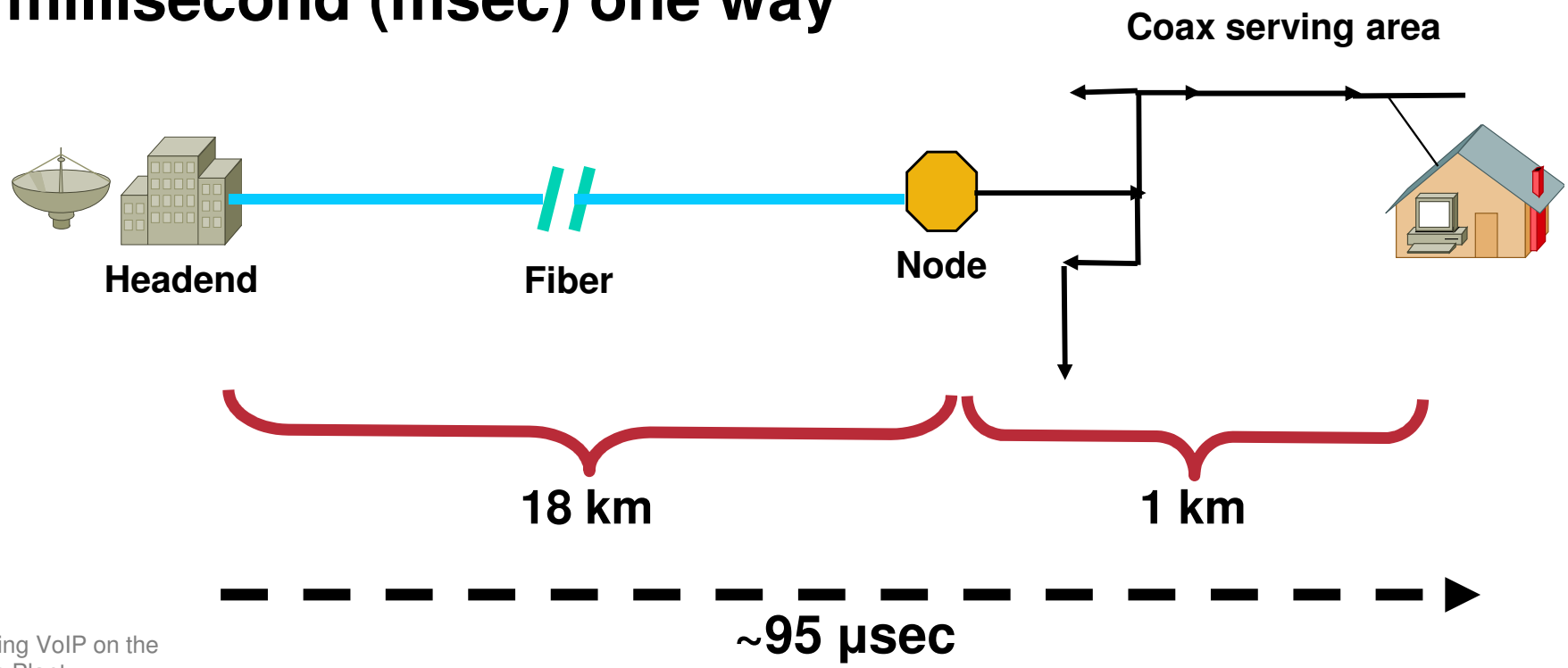
<=0.800 msec

Transit Delay

- Signals traveling one way from the headend to the subscriber through, say, 18 km of fiber and 1 km of coax: about 95 microseconds (µsec) transit delay
- The DOCSIS transit delay specification is <0.800 millisecond (msec) one way



Carrier-to-Noise Ratio

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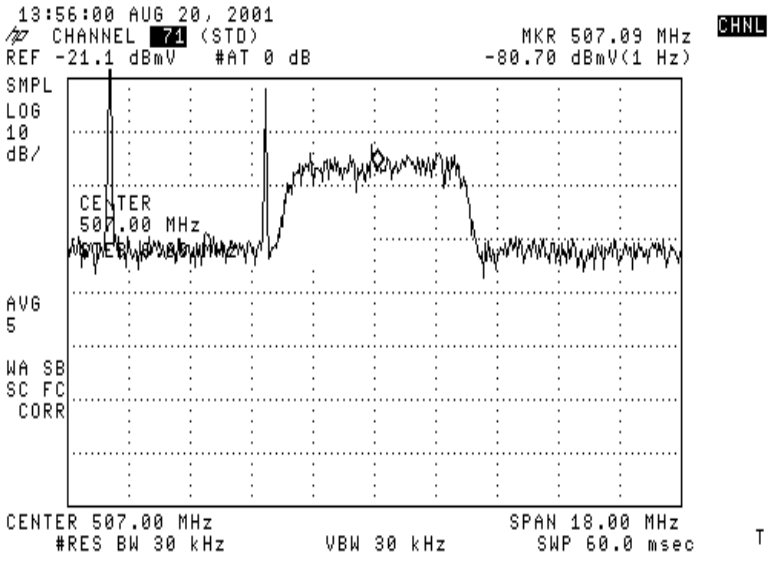
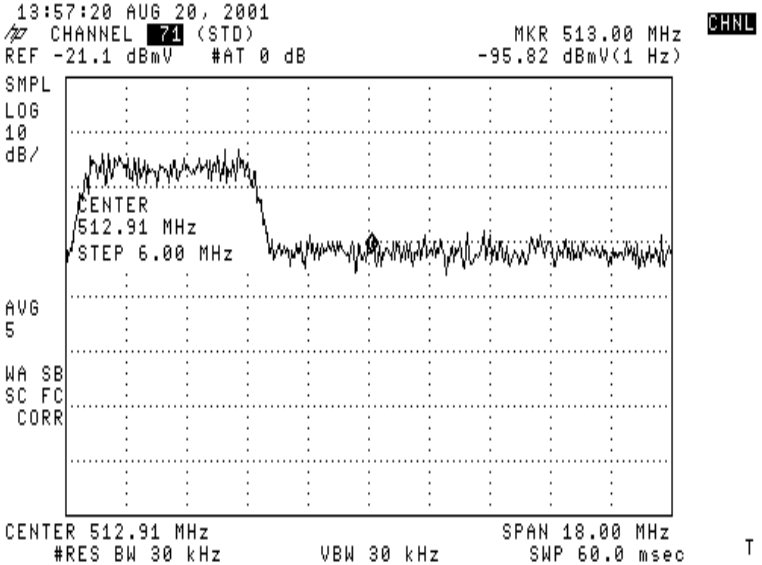
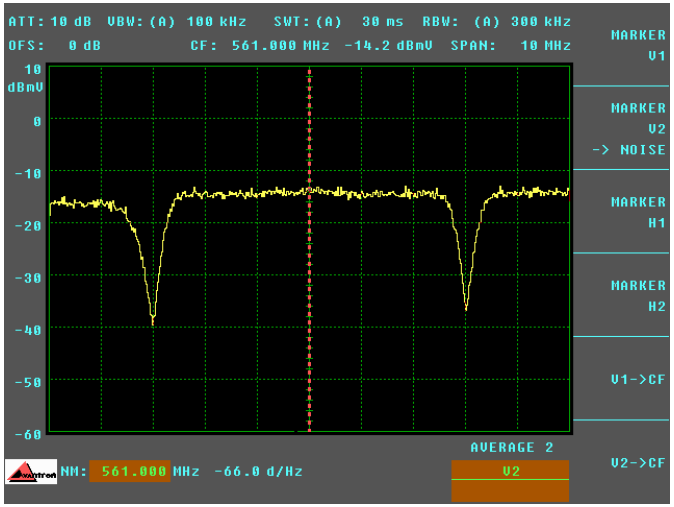
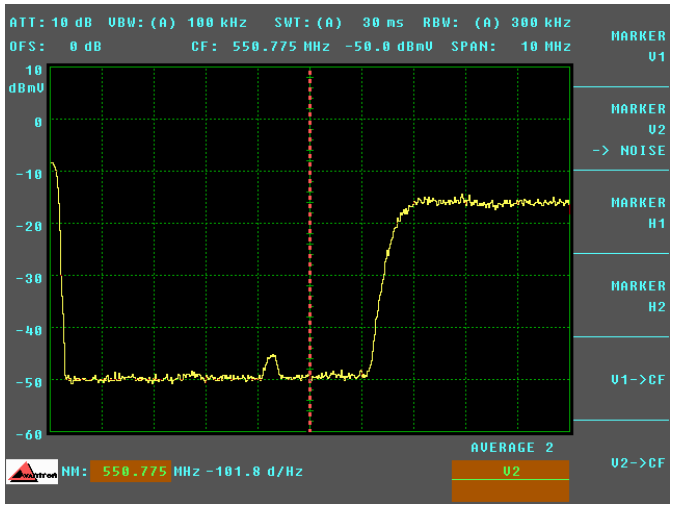
Not less than 35 dB

Carrier-to-Noise Ratio









Courtesy of Agilent Technologies and Sunrise Telecom

Digitally Modulated Signal CNR vs. BER

Modulation format	1.0E-04	1.0E-06	1.0E-08	1.0E-10	1.0E-12
ASK & FSK	7 dB	9 dB	10 dB	11 dB	12 dB
BPSK	9 dB	11 dB	12 dB	13 dB	14 dB
QPSK	12 dB	14 dB	15 dB	16 dB	17 dB
16-QAM	19 dB	21 dB	22 dB	23 dB	24 dB
32-QAM	21 dB	23 dB	24 dB	25 dB	26 dB
64-QAM	25 dB	27 dB	28 dB	29 dB	30 dB
256-QAM	32 dB	34 dB	35 dB	36 dB	37 dB

Digitally Modulated Signal CNR vs. BER

256-QAM requires 6~7 dB better CNR to achieve the same bit error rate as 64-QAM!!!

Many cable operators transmit 64-QAM digitally modulated signals at -10 dBc relative to analog TV channels, and increase the amplitude of 256-QAM digitally modulated signals to -5 to -6 dBc.

Carrier-to-Distortion or Interference Ratio

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Maximum analog video carrier level at the CM input	17 dBmV
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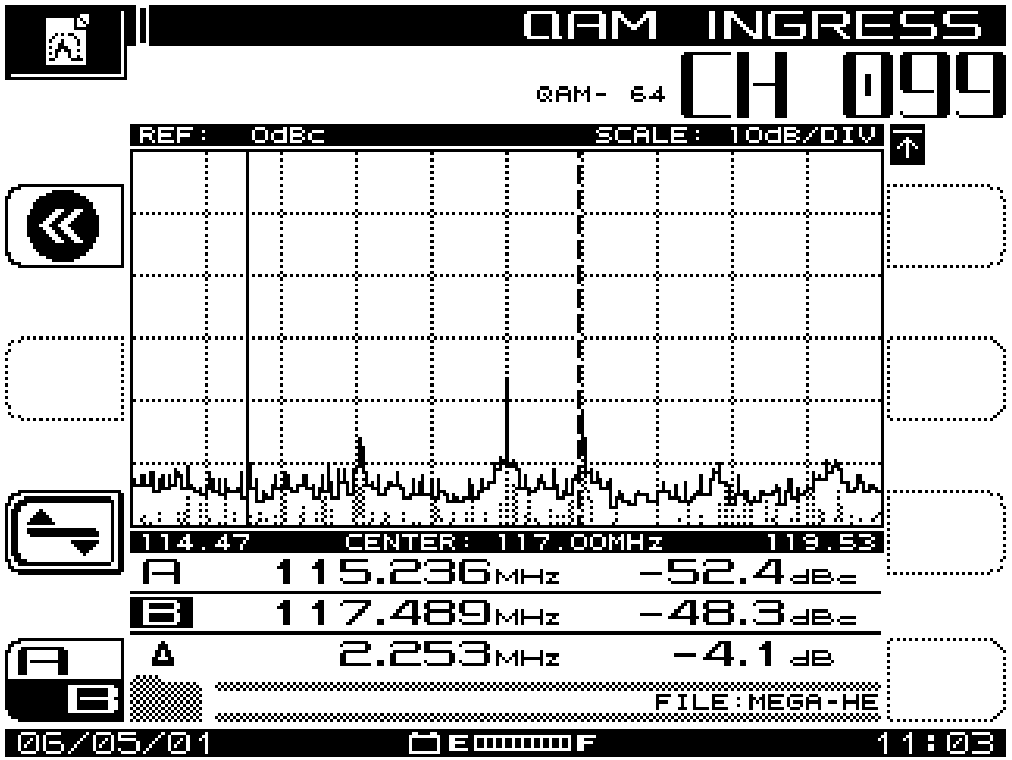
Not less than 41 dB

Carrier-to-Distortion or Interference Ratio

This example shows in-channel carrier-to-interference ratio of 48.3 dB about 0.5 MHz above center frequency



Courtesy of Acterna

Amplitude Ripple

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Frequency range	Cable system normal downstream operating range is from 50 MHz to as high as 860 MHz; however, the values in this table apply only at frequencies >= 88 MHz
RF ch…	
T…	
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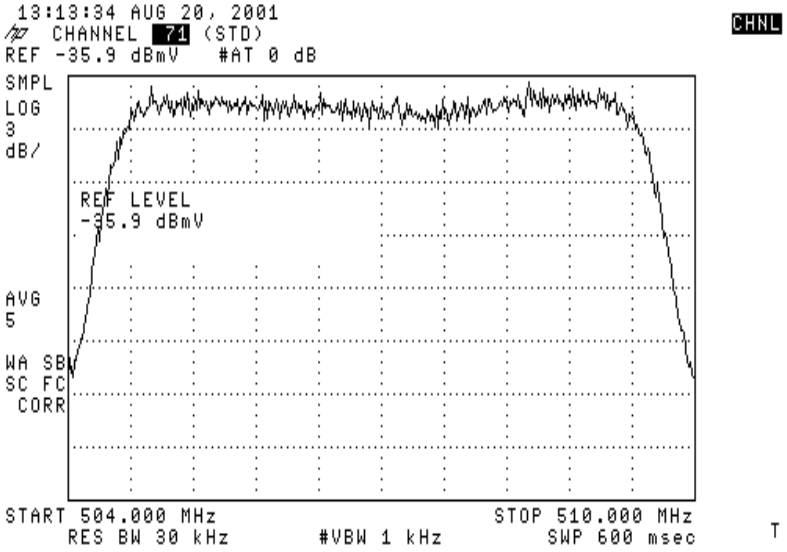
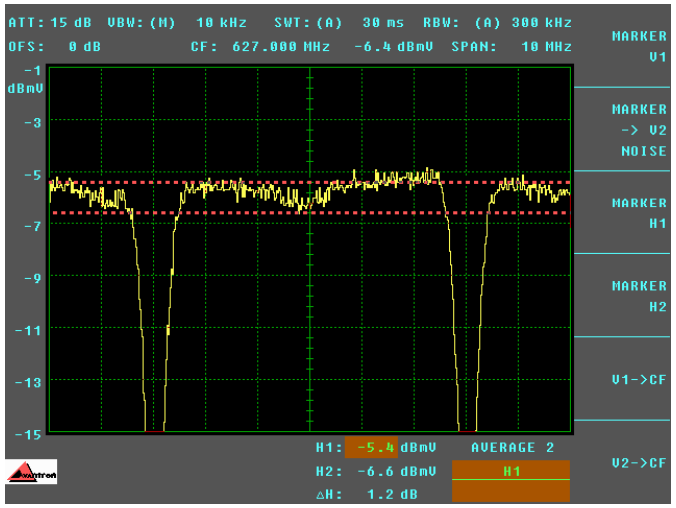
3.0 dB within the design bandwidth

Amplitude Ripple

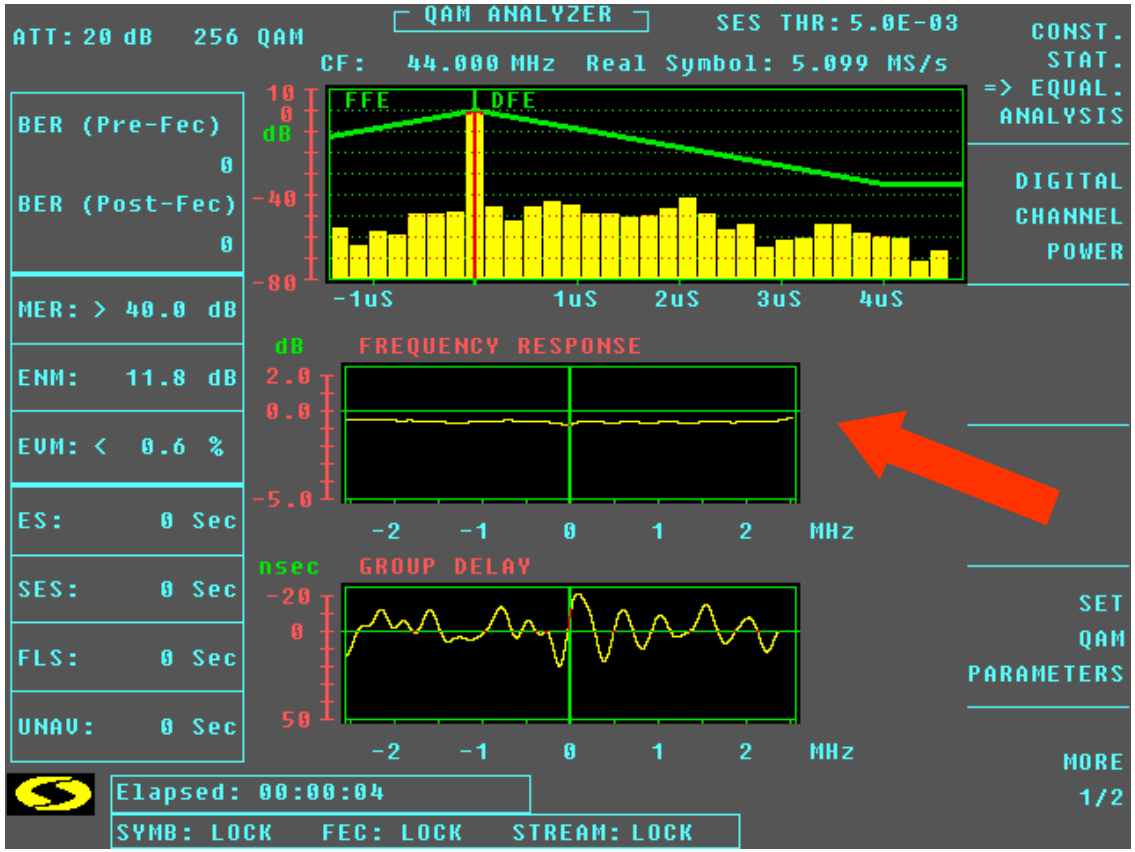




Courtesy of Agilent Technologies and Sunrise Telecom

Amplitude Ripple

This example shows less than 1 dB peak-to-peak amplitude ripple (in-channel frequency response flatness)



Courtesy of Sunrise Telecom

Group Delay

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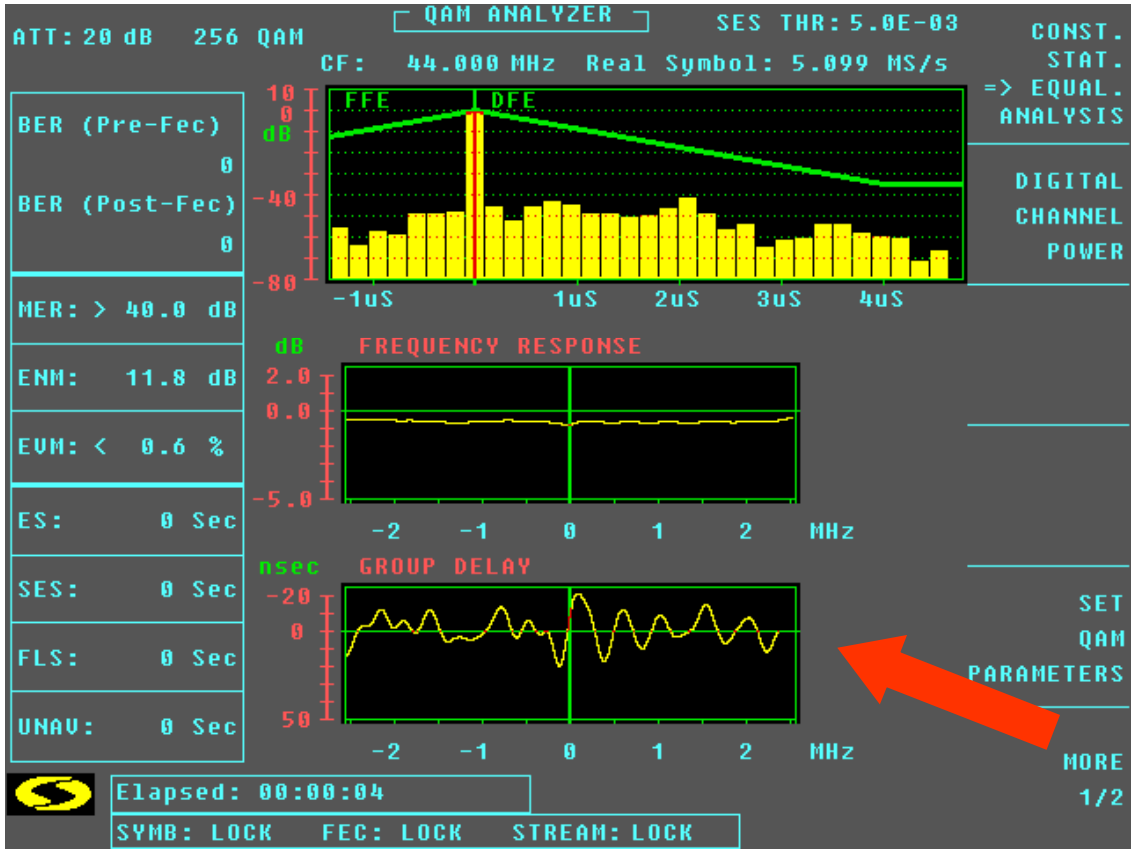
75 ns within the design bandwidth

Group Delay

This example shows about 40 nanoseconds of in-channel group delay ripple



Courtesy of Sunrise Telecom

Micro-reflections

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-10 dBc @ <= 0.5 µsec
-15 dBc @ <= 1.0 µsec
-20 dBc @ <=1.5 µsec
-30 dBc @ > 1.5 µsec

Micro-reflections

- Micro-reflections—also called reflections or echoes—are caused by impedance mismatches
- In the real world of cable networks, impedance can at best be considered nominal
- Impedance mismatches are everywhere: connectors, amplifiers inputs and outputs, passive device inputs and outputs, and even the cable itself
- Upstream cable attenuation is lower than downstream cable attenuation, so upstream Micro-reflections tend to be worse
- Anywhere an impedance mismatch exists, some of the incident energy is reflected back toward the source

Micro-reflections

- The reflected and incident energy interact to produce standing waves, which manifest themselves as the “standing wave” amplitude ripple one sometimes sees in sweep receiver displays
- Higher orders of modulation are affected by micro-reflections to a much greater degree (e.g., 256-QAM vs 64-QAM, 16-QAM vs QPSK)
- Downstream micro-reflections and group delay may be compensated for using adaptive equalization, a feature available in all DOCSIS modems
- Upstream micro-reflections and group delay may be compensated for using adaptive equalization, a feature available in DOCSIS 1.1 and 2.0 cable modems
  - Upstream adaptive equalization is *not* supported by most DOCSIS 1.0 modems

Micro-reflections

Causes:

- Damaged or missing end-of-line terminators
- Damaged or missing chassis terminators on directional coupler, splitter, or multiple-output amplifier unused ports
- Loose center conductor seizure screws
- Unused tap ports not terminated—this is especially critical on low value taps
- Unused drop passive ports not terminated
- Use of so-called self-terminating taps at feeder ends-of-line

Micro-reflections

Causes (cont'd):

- Kinked or damaged cable (includes cracked cable, which causes a reflection *and* ingress)
- Defective or damaged actives or passives (water-damaged, water-filled, cold solder joint, corrosion, loose circuit board screws, etc.)
- Cable-ready TVs and VCRs connected directly to the drop (return loss on most cable-ready devices is poor)
- Some traps and filters have been found to have poor return loss in the upstream, especially those used for data-only service

Micro-reflections

- Here's an approx. -40 dBc echo at just over 2 µsec
- This echo easily meets the DOCSIS downstream *-30 dBc @ >1.5 µsec* parameter
- Amplitude ripple is negligible, and group delay ripple is slight

Courtesy of Sunrise Telecom

DOCSIS® 1.1 Assumed Upstream RF Channel Transmission Characteristics

Parameter	Value
Frequency range	5 to 42 MHz edge to edge
Transit delay from the most distant CM to the nearest CM or CMTS	<=0.800 msec (typically much less)
Carrier-to-interference plus ingress (the sum of noise, distortion, common-path distortion and cross-modulation and the sum of discrete and broadband ingress signals, impulse noise excluded) ratio	Not less than 25 dB (Note 2)
Carrier hum modulation	Not greater than –23 dBc (7%)
Burst noise	Not longer than 10 µsec at a 1 kHz average rate for most cases (Notes 3 and 4)
Amplitude ripple 5-42 MHz	0.5 dB/MHz
Group delay ripple 5-42 MHz	200 ns/MHz
Micro-reflections—single echo	-10 dBc@ <= 0.5 µsec -20 dBc@ <= 1.0 µsec -30 dBc@ > 1.0 µsec
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max

Transit Delay

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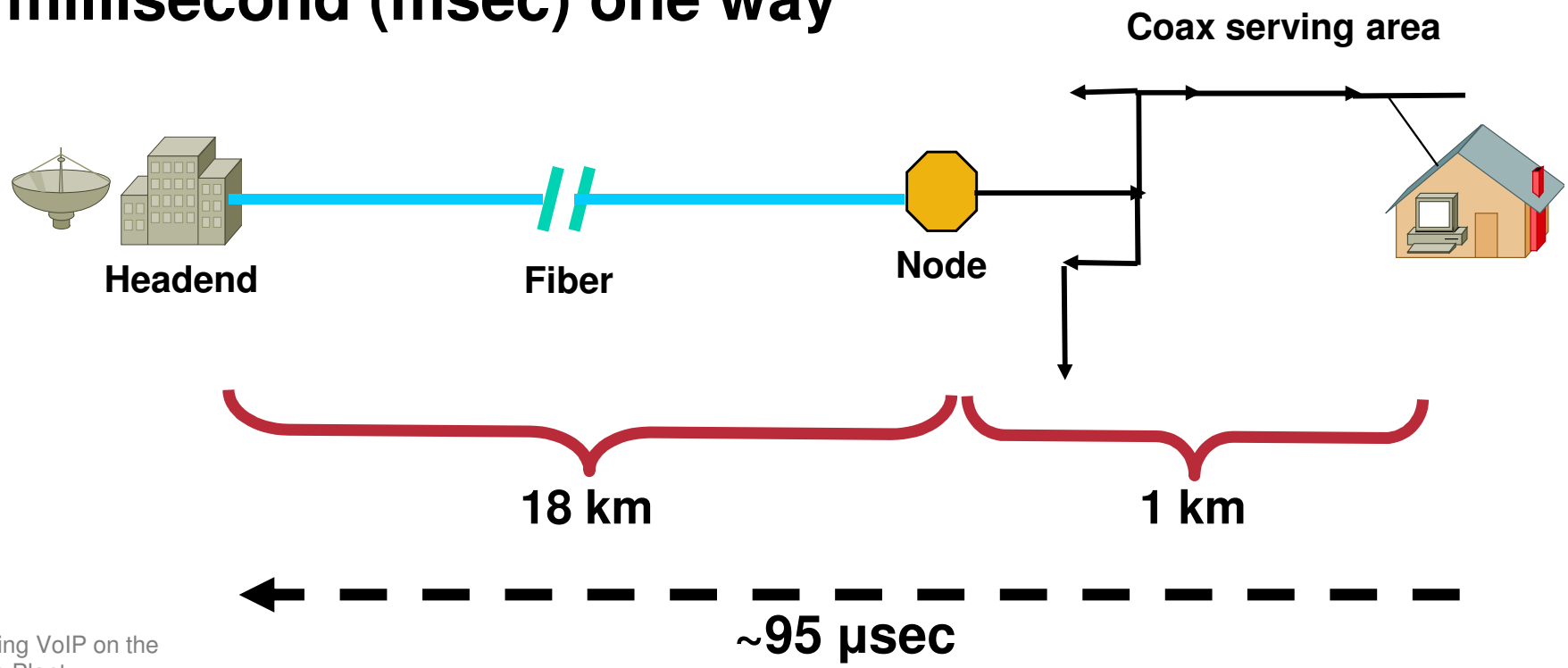
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max

<=0.800 msec

Transit Delay

- **Signals traveling one way from the subscriber to the headend through, say, 1 km of coax and 18 km of fiber: about 95 microseconds (µsec) transit delay**
- **The DOCSIS transit delay specification is <0.800 millisecond (msec) one way**



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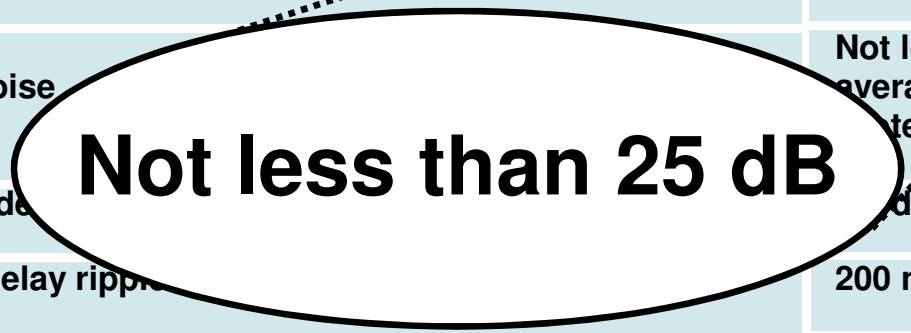
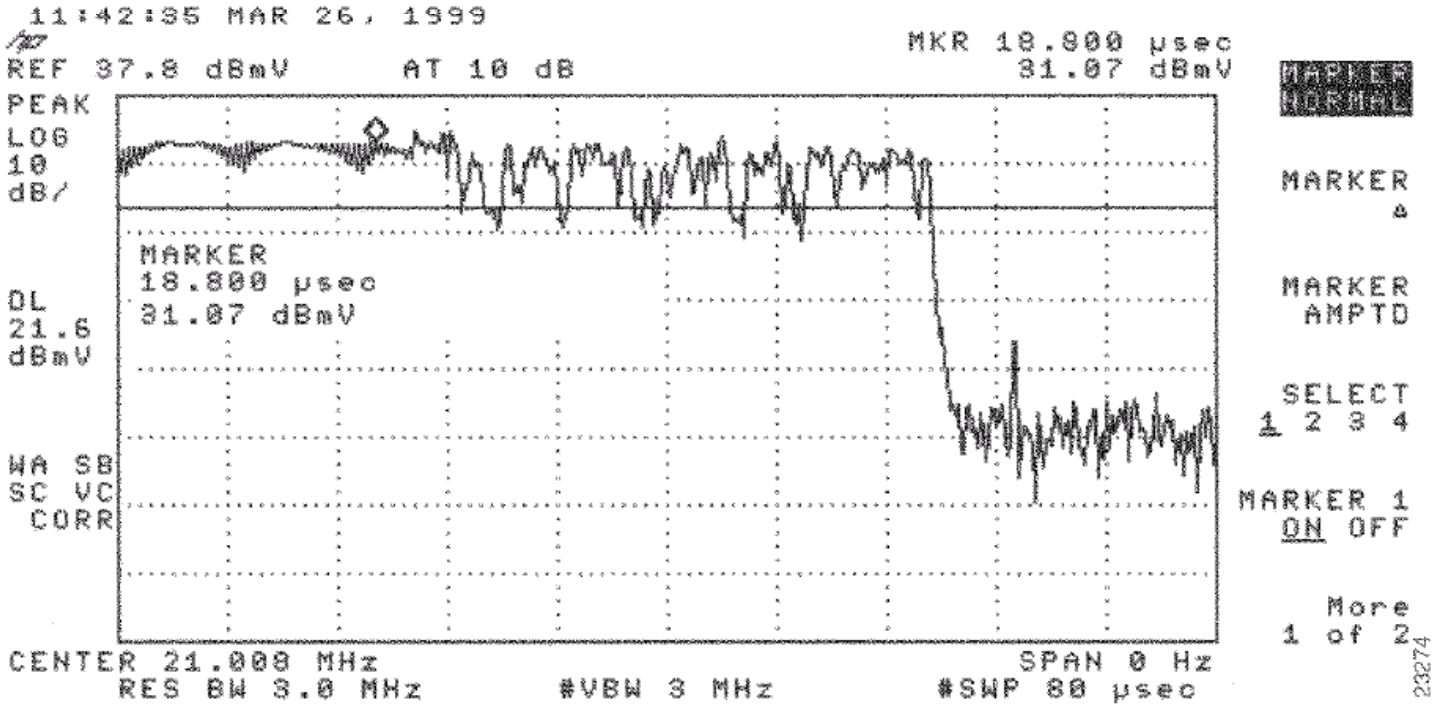
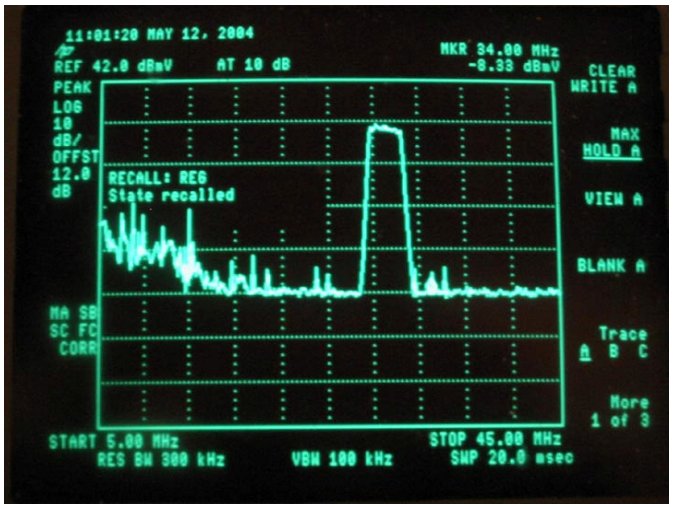


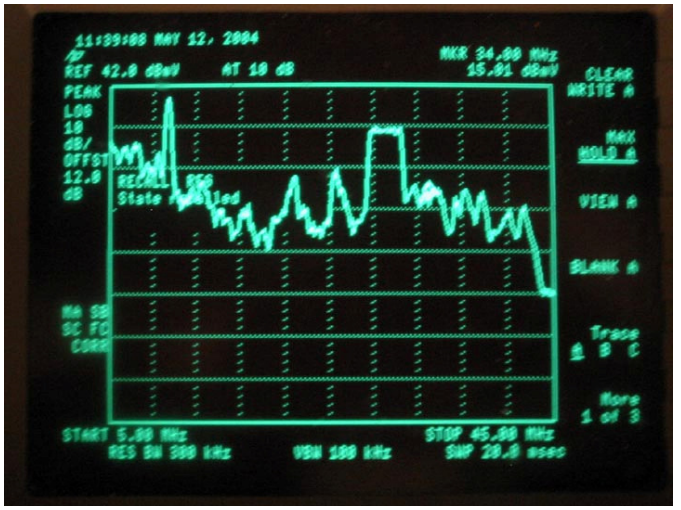
Upstream Digitally Modulated Signal Amplitude

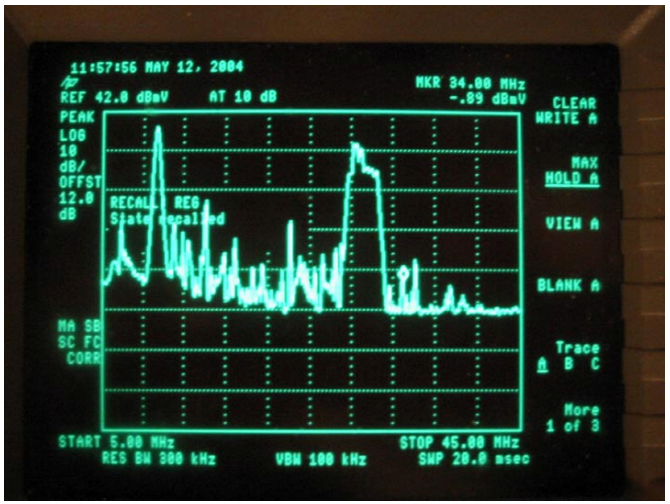
- Because of the bursty nature of upstream digitally modulated carriers, it's difficult to measure average power level
- The zero-span method is the easiest way to obtain an accurate amplitude measurement

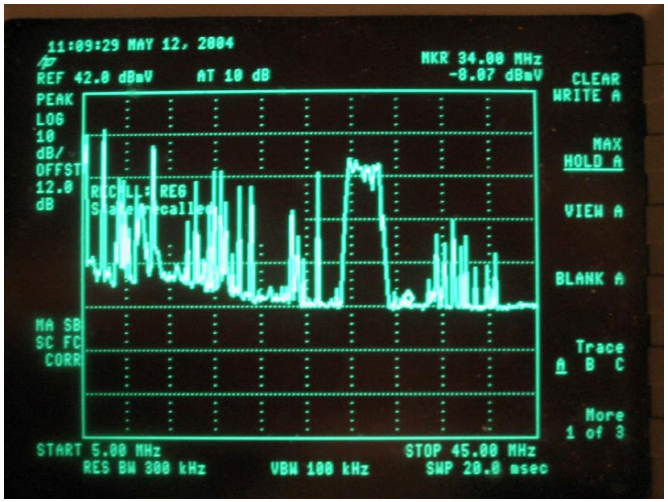


Upstream Carrier-to-Interference



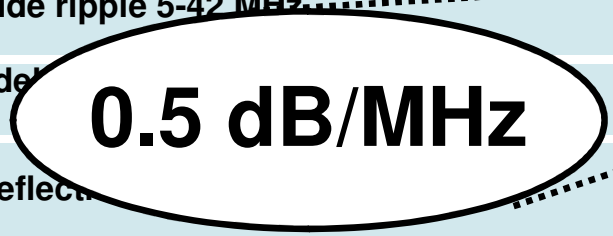






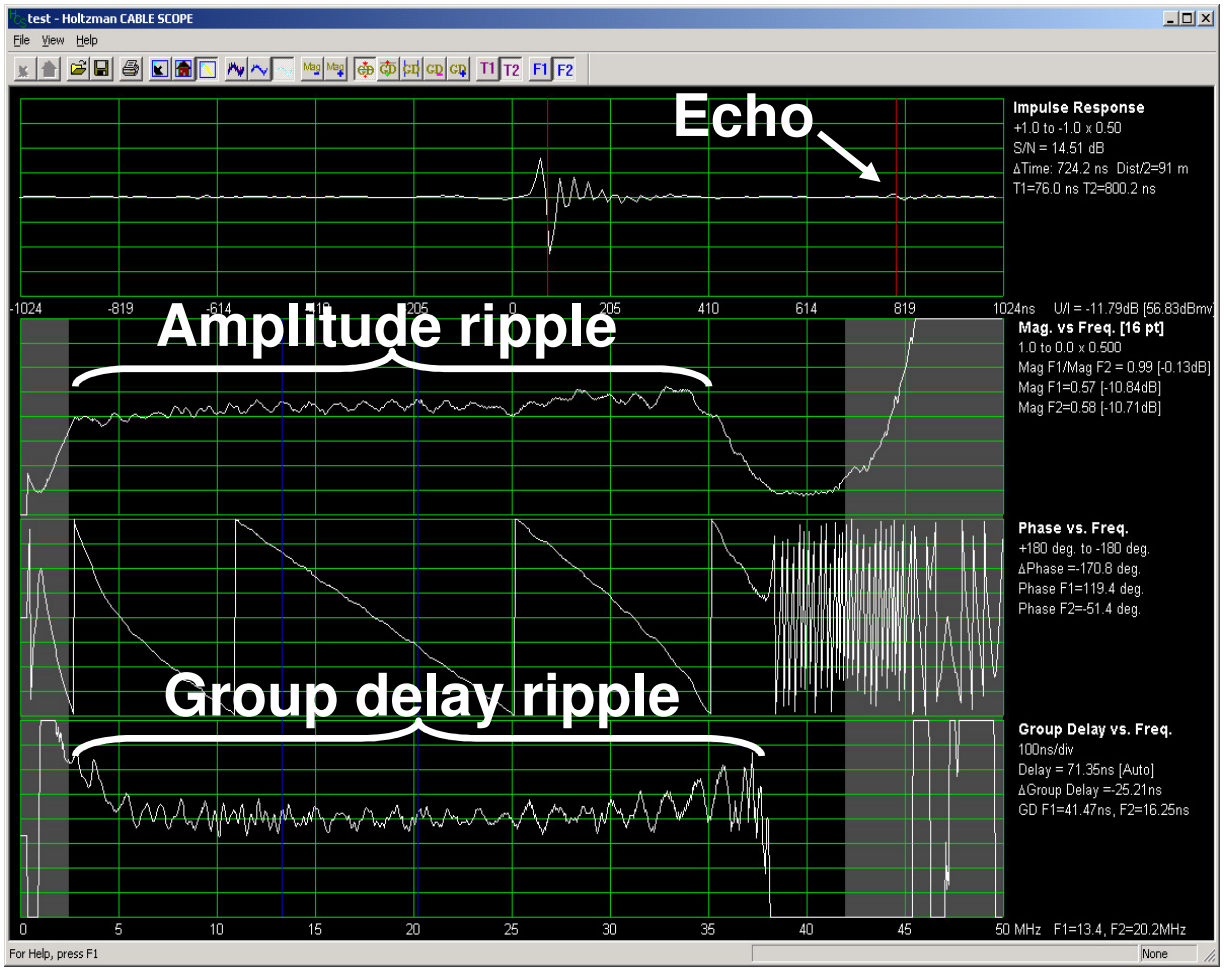
Amplitude Ripple

Parameter	Value
Frequency range	5 to 42 MHz edge to edge
Transit delay from the most distant CM to the nearest CM or CMTS	<=0.800 msec (typically much less)
Carrier-to-interference plus ingress (the sum of noise, distortion, common-path distortion and cross-modulation and the sum of discrete and broadband ingress signals, impulse noise excluded) ratio	Not less than 25 dB (Note 2)
Carrier hum modulation	Not greater than –23 dBc (7%)
Burst noise	Not longer than 10 µsec at a 1 kHz average rate for most cases (Notes 3 and 4)
Amplitude ripple 5-42 MHz	0.5 dB/MHz
Group de	200 ns/MHz
Micro-reflect	-10 dBc@ <= 0.5 µsec -20 dBc@ <= 1.0 µsec -30 dBc@ > 1.0 µsec
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max



Amplitude Ripple

- In this example, an approx. -23 dBc echo at ~720 ns causes visible amplitude ripple across the 5-40 MHz spectrum
- Group delay ripple also is present



Courtesy of Holtzman, Inc.

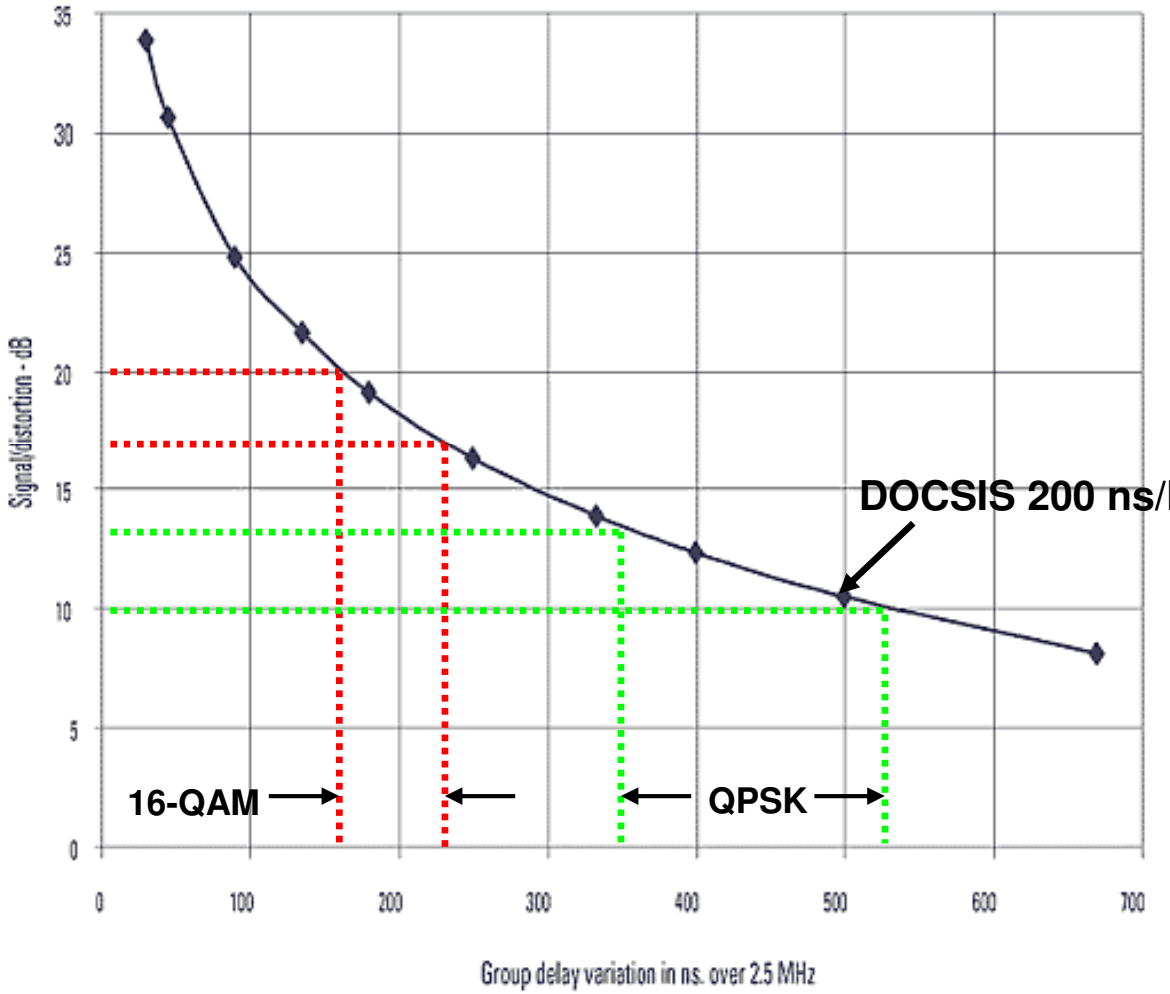
Group Delay

Parameter	Value
Frequency range	5 to 42 MHz edge to edge
Transit delay from the most distant CM to the nearest CM or CMTS	<=0.800 msec (typically much less)
Carrier-to-interference plus ingress (the sum of noise, distortion, com… …nd cross-modulation and the … …gress signals, impuls…	Not less than 25 dB (Note 2)
Carrier…	Not greater than –23 dBc (7%)
Burst noise	Not longer than 10 µsec at a 1 kHz average rate for most cases (Notes 3 and 4)
Amplitude ripple 5-42 MHz	0.5 dB/MHz
Group delay ripple 5-42 MHz	200 ns/MHz
Micro-reflections—single echo	-10 dBc@ <= 0.5 µsec -20 dBc@ <= 1.0 µsec -30 dBc@ > 1.0 µsec
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max

200 ns/MHz

Group Delay

- QPSK typically requires a *minimum* MER of 10~13 dB, depending on CMTS make/model
- 16-QAM typically requires a *minimum* MER of 17~20 dB, depending on CMTS make/model

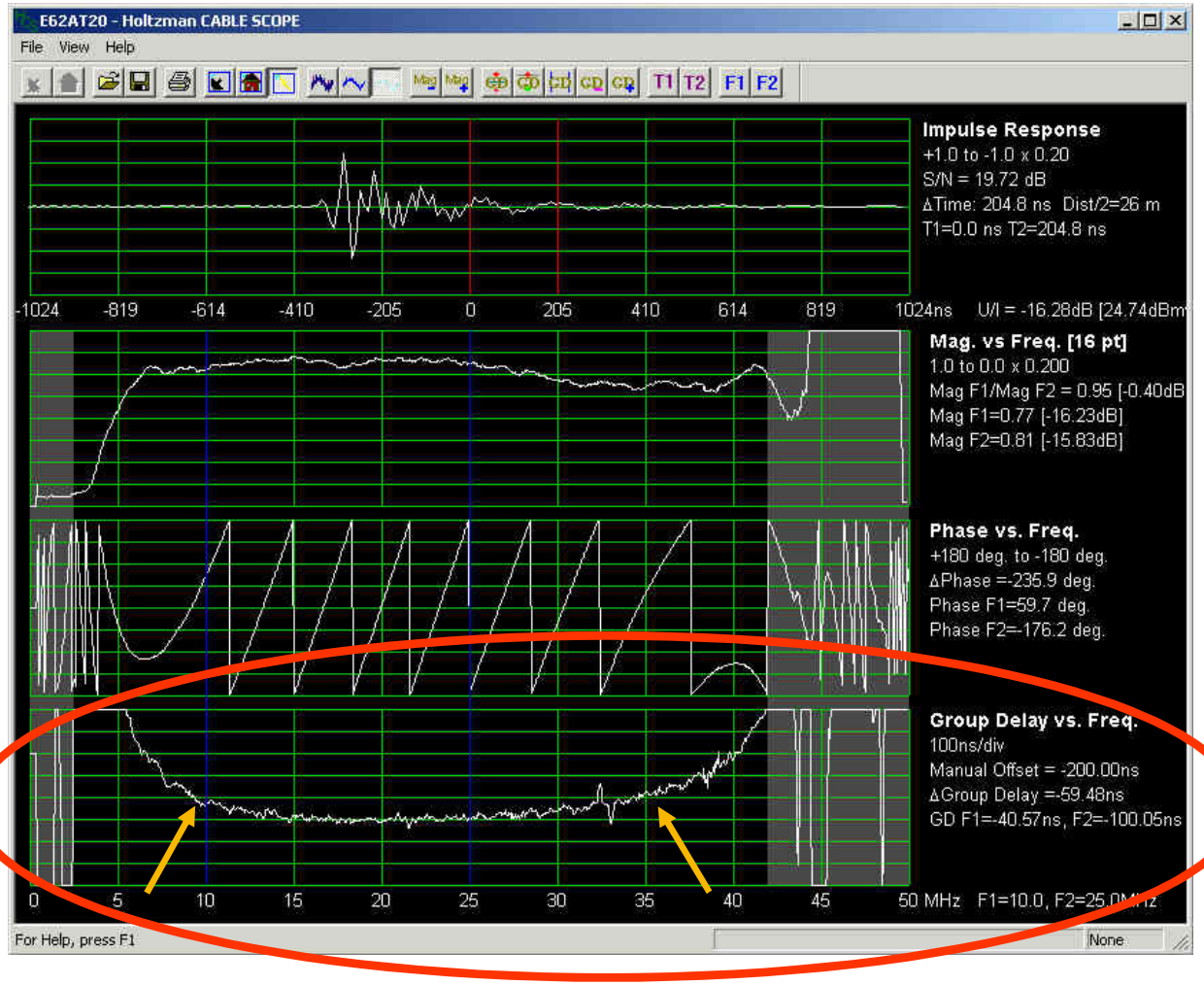


* A Plot of QPSK MER vs. group delay variation over 2.5 MHz, where group delay increases steadily across the channel. Note that DOCSIS 1.0 limit is 500 ns.

Courtesy of Holtzman, Inc.

Group Delay

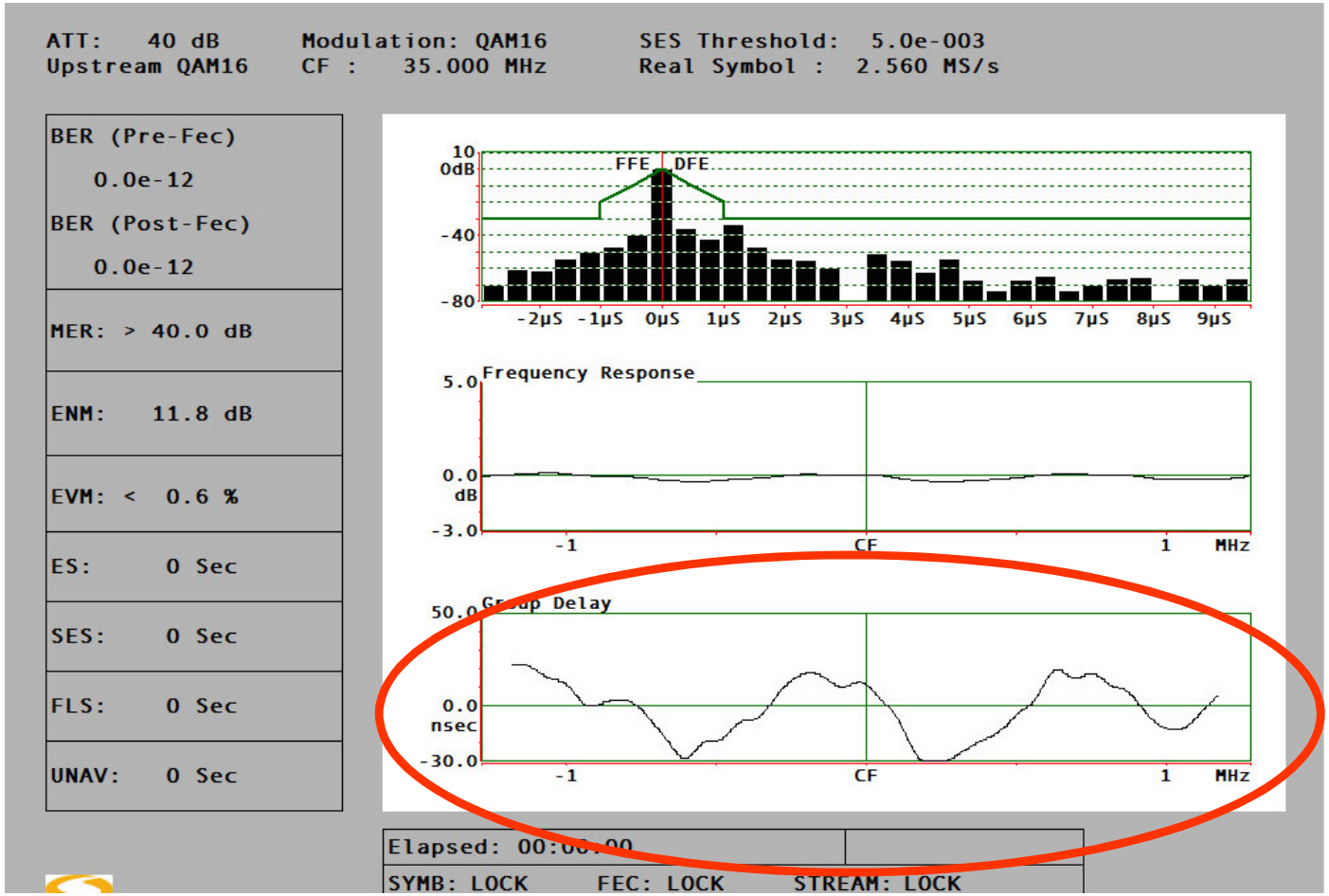
- Upstream group delay measurements require specialized equipment
- In this example, group delay is nearly constant (within about 100 ns) between 10 and 35 MHz



Courtesy of Holtzman, Inc.

Group Delay

- Specialized test equipment can be used to characterize upstream in-channel performance
- In this example, in-channel group delay ripple is about 60 ns



Courtesy of Sunrise Telecom

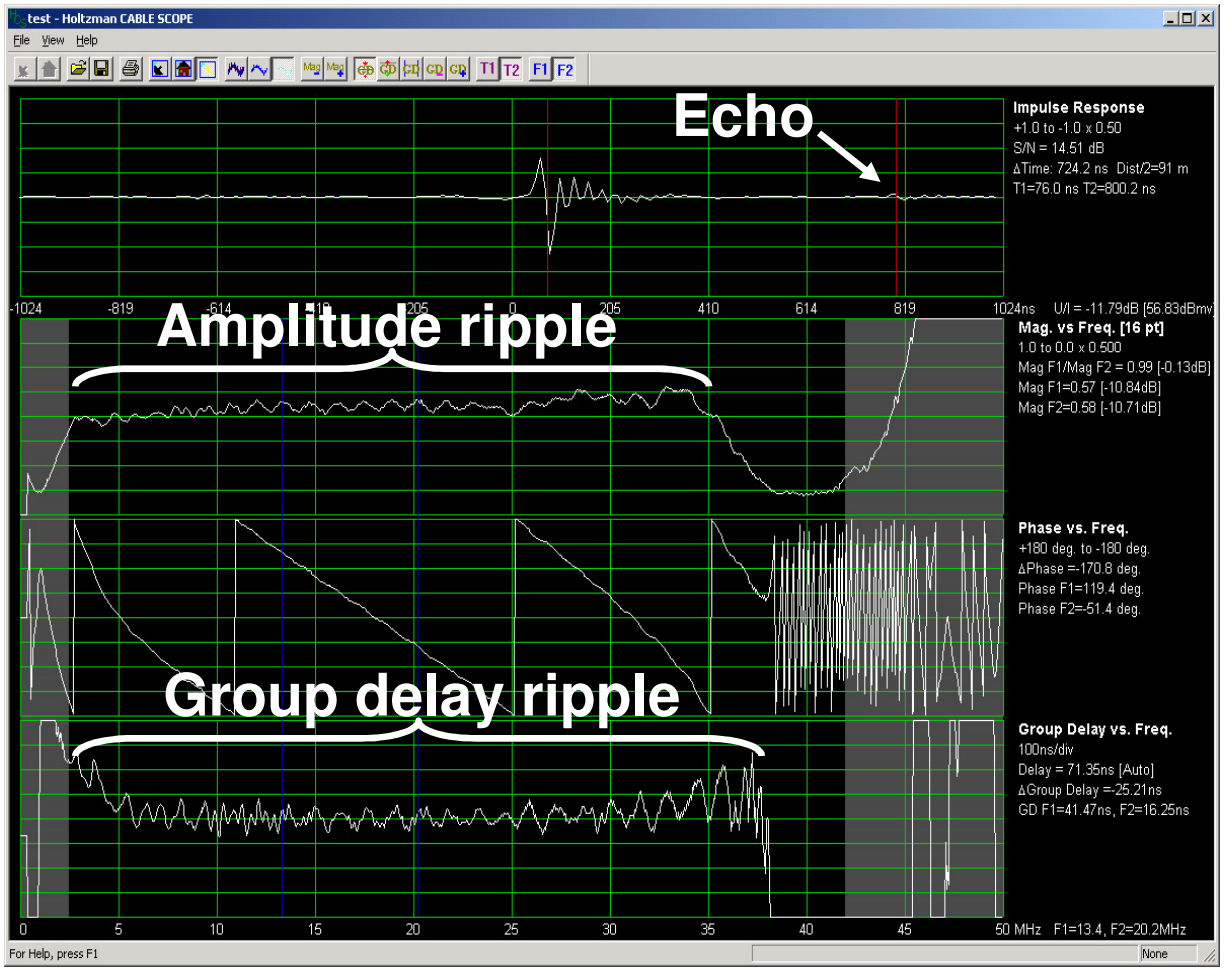
Micro-reflections

Parameter	Value
Frequen…	5 to 42 MHz edge to edge
…st CM	<=0.800 msec (typically much less)
…on …,	Not less than 25 dB (Note 2)
Ca…	Not greater than –23 dBc (7%)
Burst noise	Not longer than 10 µsec at a 1 kHz average rate for most cases (Notes 3 and 4)
Amplitude ripple 5-42 MHz	0.5 dB/MHz
Group delay ripple 5-42 MHz	200 ns/MHz
Micro-reflections—single echo	-10 dBc@ <= 0.5 µsec -20 dBc@ <= 1.0 µsec -30 dBc@ > 1.0 µsec
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max

-10 dBc @ <=0.5 µsec
-20 dBc @ <=1.0 µsec
-30 dBc @ >1.0 µsec

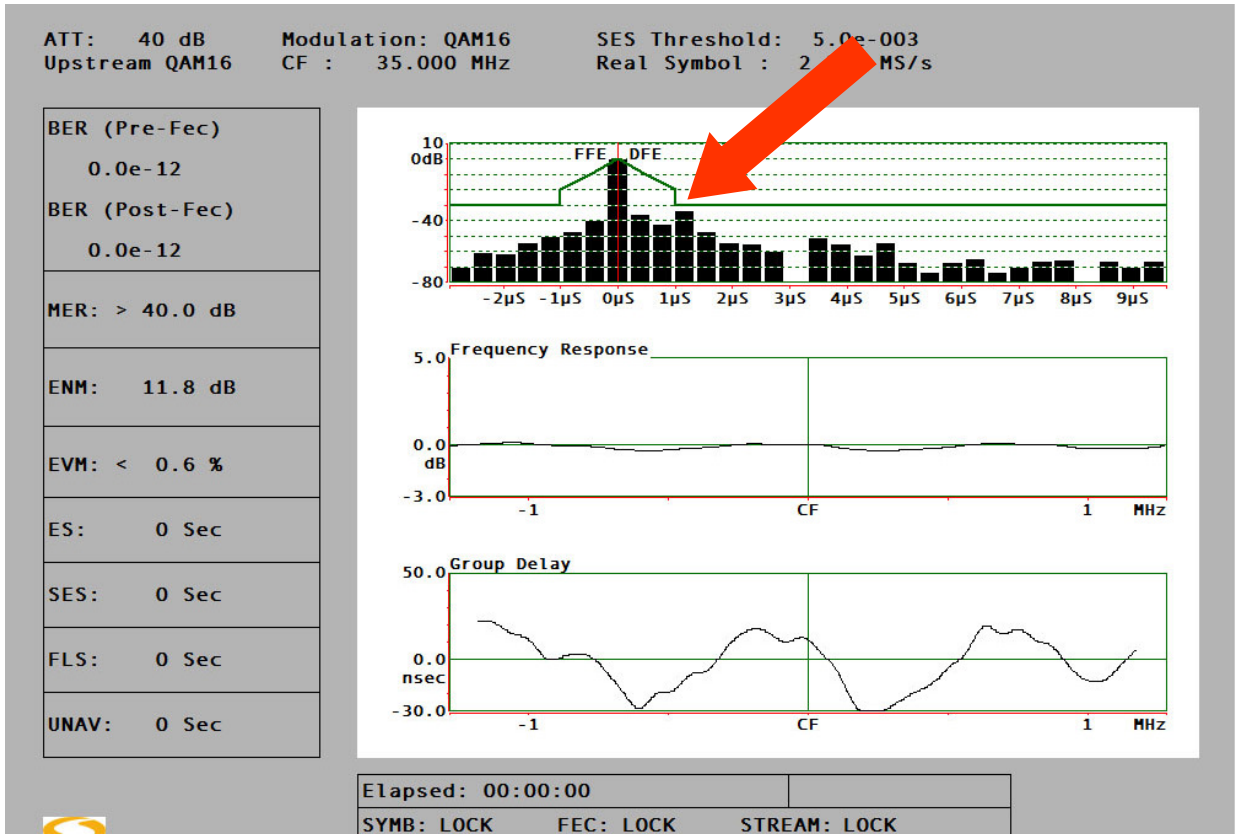
Micro-reflections

- In this example, an approx. -23 dBc echo is visible at ~720 ns (0.720 µsec)
- This echo meets the DOCSIS upstream *-20 dBc at <=1.0 µsec* parameter
- Note that the echo is still sufficient to cause amplitude and group delay ripple



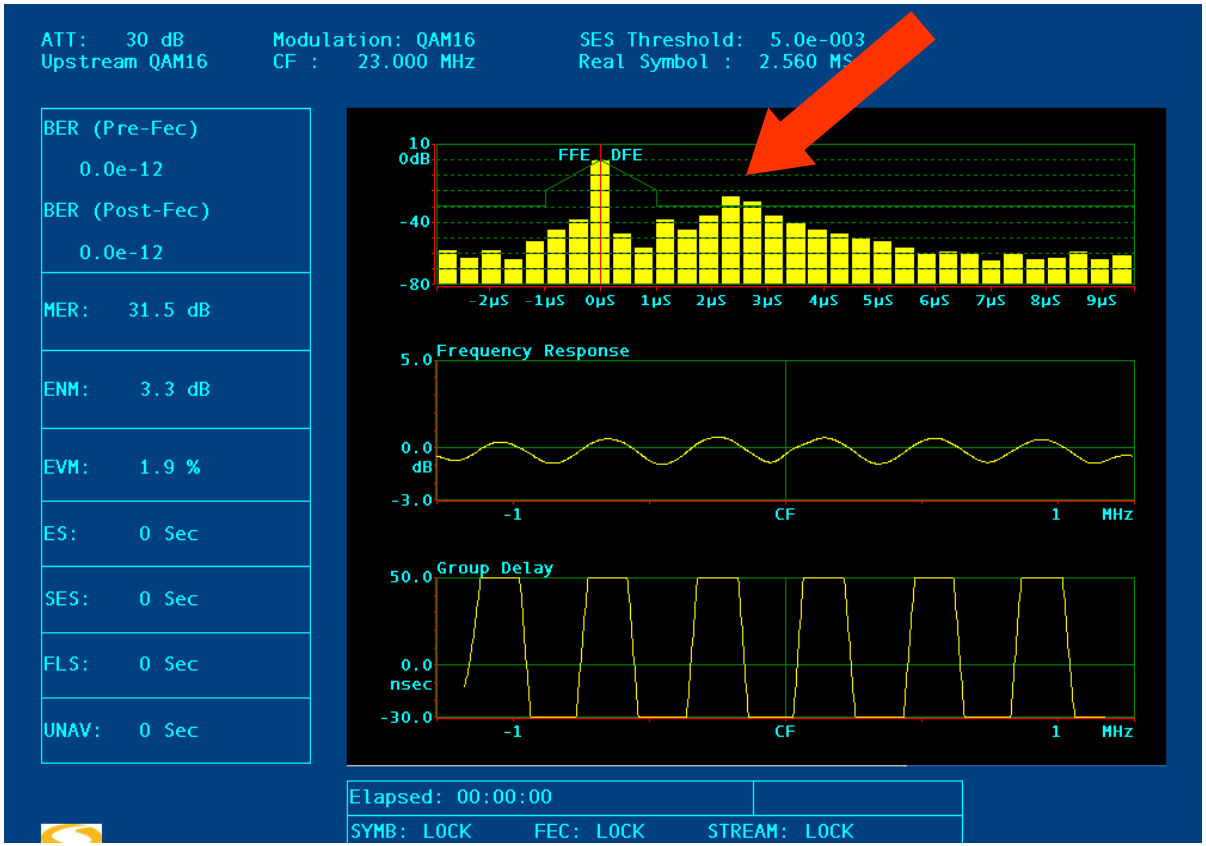
Micro-reflections

- Here's another example: An approx. -33 dBc echo at just over 1 µsec
- This echo meets the DOCSIS upstream *-30 dBc at >1.0 µsec* parameter
- Here, too, the echo is sufficient to cause some amplitude and group delay ripple



Micro-reflections

- Here's yet another example: An approx. -22 dBc echo at about 2.5 µsec
- This echo **does not** meet the DOCSIS upstream *-30 dBc at >1.0 µsec* parameter
- In-channel amplitude ripple is 1.6 dB, and group delay ripple is about 270 ns



16-QAM would not work on this upstream!

DOCSIS® 1.1 Electrical Input to the Cable Modem

Parameter	Value
Center frequency	91 to 857 MHz, ±30 kHz
Level range (one channel)	-15 dBmV to +15 dBmV
Modulation type	64-QAM and 256-QAM
Symbol rate (nominal)	5.056941 Msym/sec (64-QAM) and 5.360537 Msym/sec (256-QAM)
Bandwidth	6 MHz (18% Square Root Raised Cosine shaping for 64-QAM and 12% Square Root Raised Cosine shaping for 256-QAM)
Total input power (40-900 MHz)	< 30 dBmV
Input (load) impedance	75 ohms
Input return loss	> 6 dB (88-860 MHz)
Connector	F connector per [ISO-169-24] (common with the output)

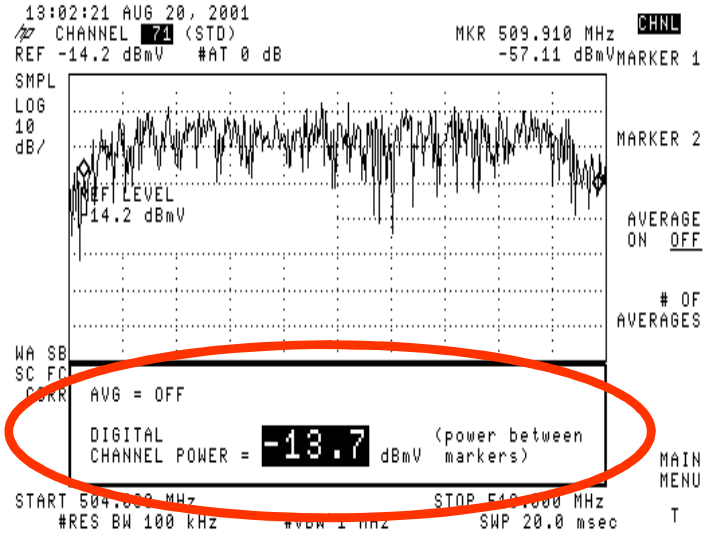
Downstream Digitally Modulated Signal Amplitude

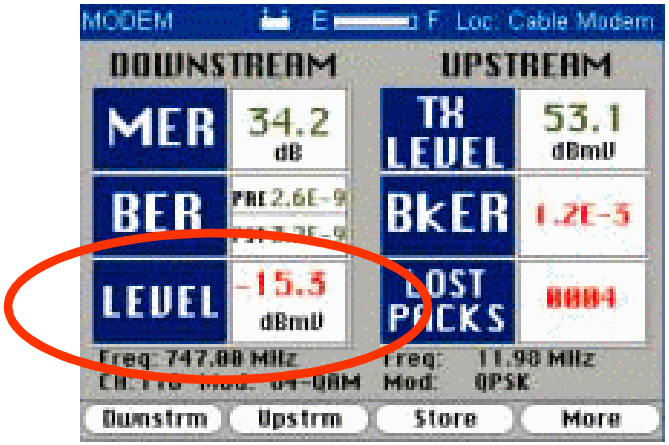
Parameter	Value
Center frequency	91 to 857 MHz, ±30 kHz
Level range (one channel)	-15 dBmV to +15 dBmV
Modulation type	64-QAM and 256-QAM
Symbol rate	5.056941 Msym/sec (64-QAM) and 5.360537 Msym/sec (256-QAM)
Bandwidth	6 MHz (18% Square Root Raised Cosine shaping for 64-QAM and 12% Square Root Raised Cosine shaping for 256-QAM)
Total input power (40-900 MHz)	< 30 dBmV
Input (load) impedance	75 ohms
Input return loss	> 6 dB (88-860 MHz)
Connector	F connector per [ISO-169-24] (common with the output)

-15 to +15 dBmV

Downstream Digitally Modulated Signal Amplitude

- When measuring the amplitude of a digitally modulated signal, make certain you are measuring its *average power level*
- Use test equipment that performs automated measurements, rather than trying to make error-prone manual measurements that require bandwidth, IF filter, log amplifier and detection corrections
- A "sweet spot" for downstream digitally modulated signal amplitude at the modem or EMTA input is -10 to +5 dBmV





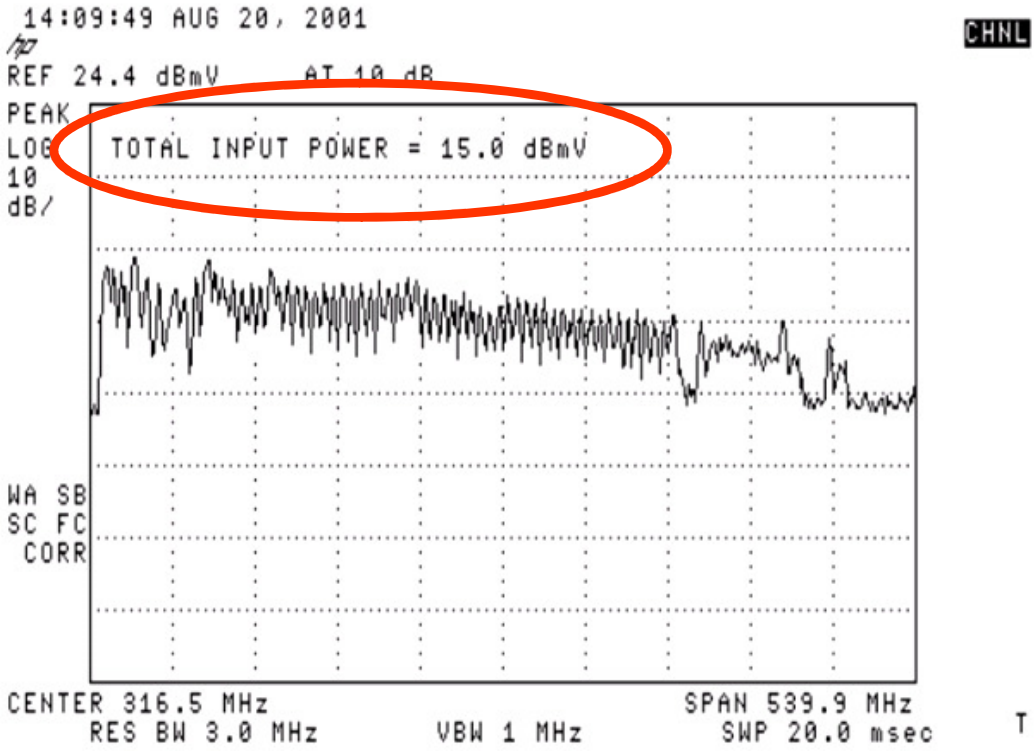
Courtesy Agilent Technologies and Sunrise Telecom

Cable Modem Total Input Power

Parameter	Value
Center frequency	91 to 857 MHz, ±30 kHz
Level range (one channel)	-15 dBmV to +15 dBmV
Modulation type	64-QAM and 256-QAM
Symbol rate (nominal)	5.056941 Msym/sec (64-QAM) and 5.360537 Msym/sec (256-QAM)
< +30 dBmV	6 MHz (18% Square Root Raised Cosine shaping for 64-QAM and 12% Square Root Raised Cosine shaping for 256-QAM)
Total input power (40-900 MHz)	< 30 dBmV
Input (load) impedance	75 ohms
Input return loss	> 6 dB (88-860 MHz)
Connector	F connector per [ISO-169-24] (common with the output)

Cable Modem Total Input Power

This example shows total input power is +15 dBmV



Courtesy of Agilent Technologies

Cable Modem Total Input Power

- **A quick way to estimate approximate total power is based on the rule-of-thumb that each time the number of channels doubles (assuming all channels have the same signal level), the total power increases 3 dB (3.01 dB).**

Number of Channels	Power per Channel	Total Power
1	0 dBmV	0 dBmV
2	0 dBmV	+3 dBmV
4	0 dBmV	+6 dBmV
8	0 dBmV	+9 dBmV
16	0 dBmV	+12 dBmV
32	0 dBmV	+15 dBmV
64	0 dBmV	+18 dBmV
128	0 dBmV	+21 dBmV

Other DOCSIS® RFI Spec Parameters

- Downstream digitally modulated signal average power level relative to analog visual carrier levels: -10 dBc to -6 dBc
- 64-QAM bit error rate: Cable modem post-FEC BER must be less than or equal to 10^{-8} when operating at a C/N ratio (E_S/N_0) of 23.5 dB or greater
- 256-QAM bit error rate: CM post-FEC BER must be less than or equal to 10^{-8} when operating at a C/N ratio (E_S/N_0) of
  - 30 dB or greater when the input receive signal level is -6 dBmV to +15 dBmV
  - 33 dB or greater when the input receive signal level is -6 dBmV down to -15 dBmV

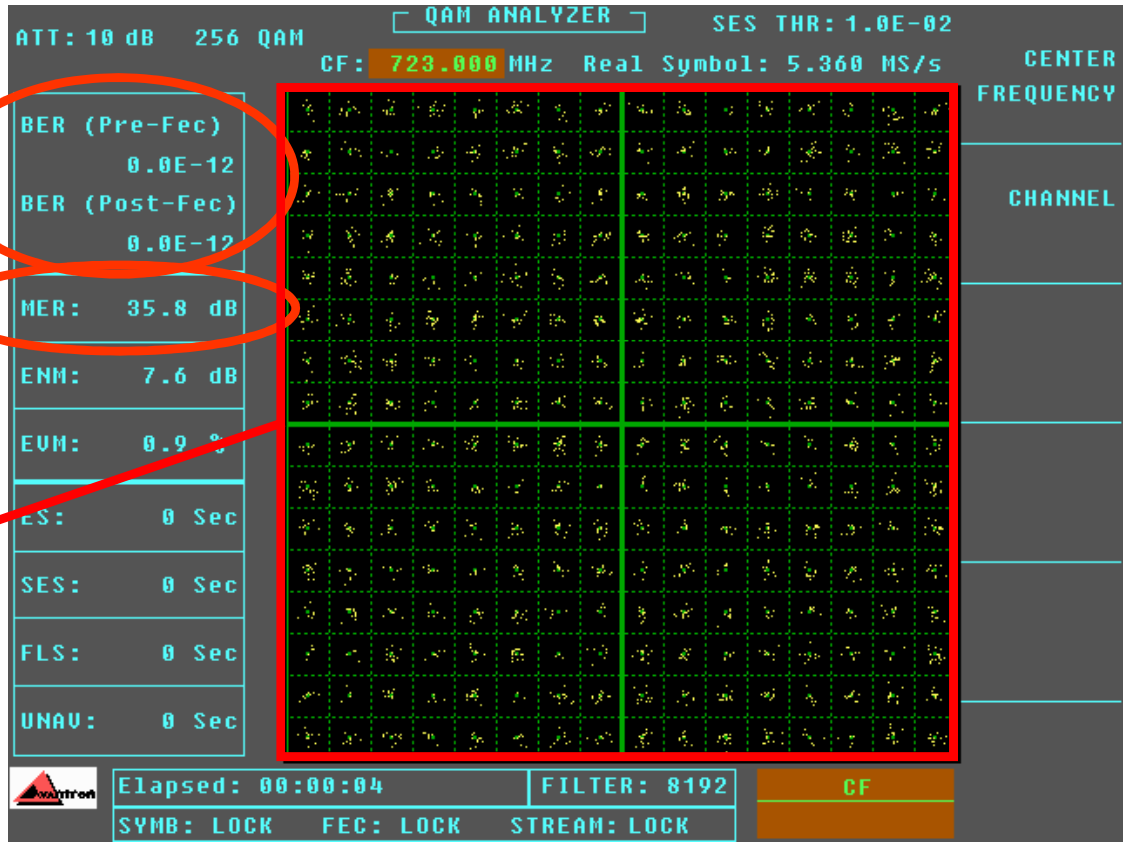
Downstream Performance: QAM Analyzer

Pre- and post-FEC BER

MER

64-QAM: 27 dB minimum
256-QAM: 31 dB minimum

Constellation



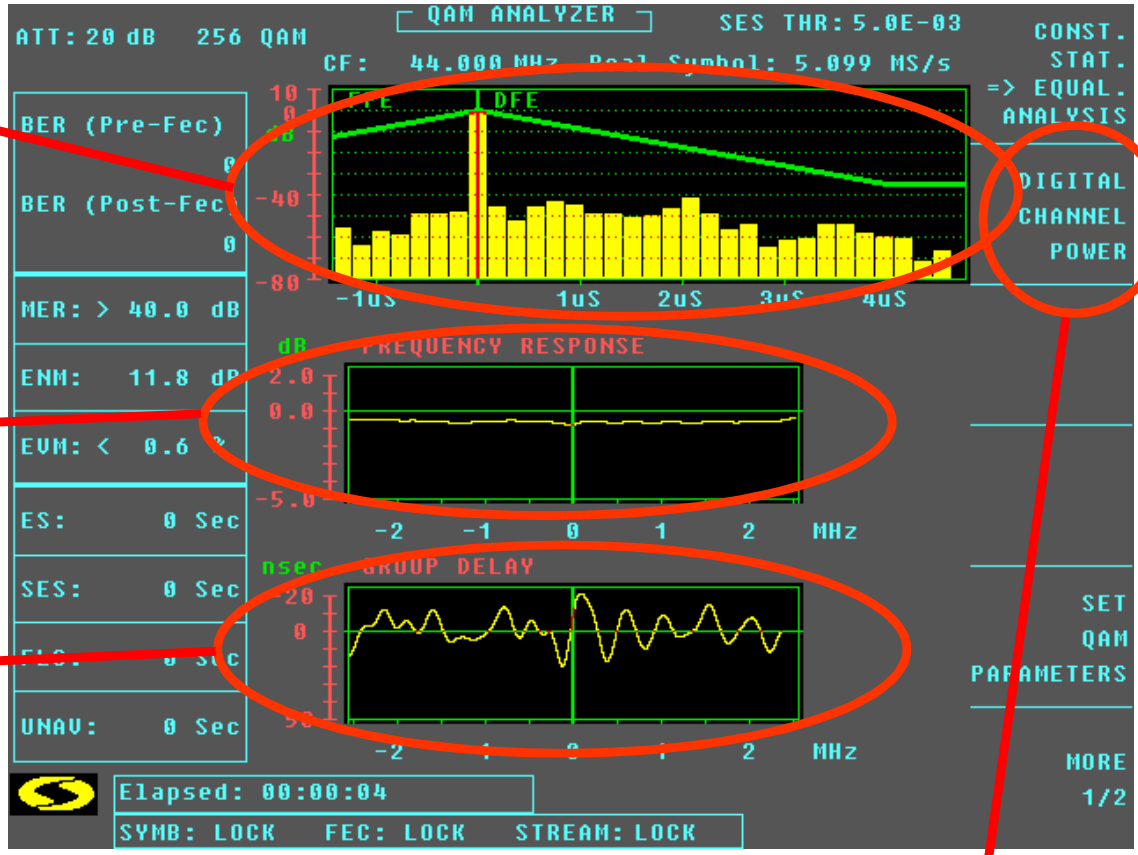
Graphic courtesy of Sunrise Telecom

Downstream Performance: QAM Analyzer

Equalizer graph

In-channel frequency response

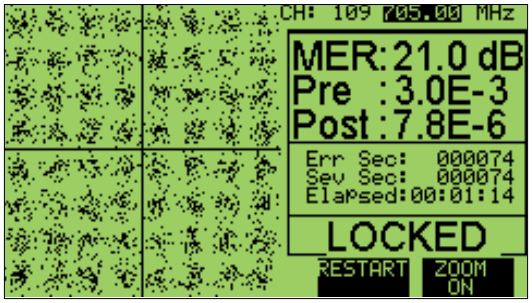
In-channel group delay



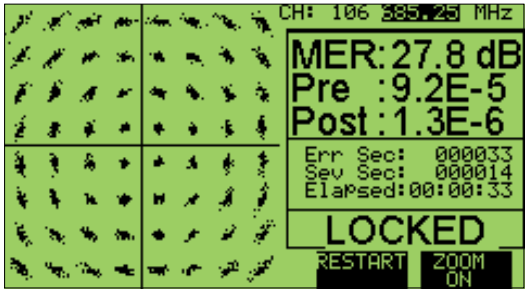
Digital channel power

Graphic courtesy of Sunrise Telecom

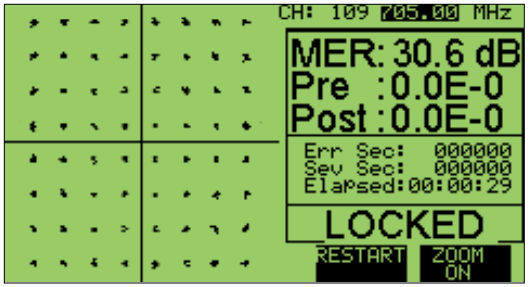
Downstream Performance: QAM Analyzer



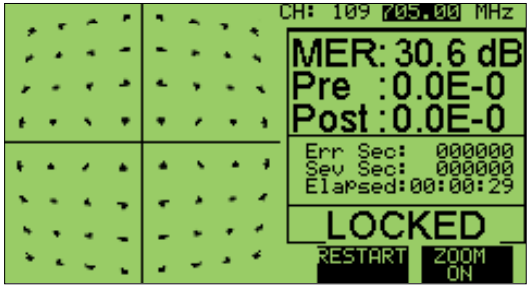
Poor carrier-to-noise ratio



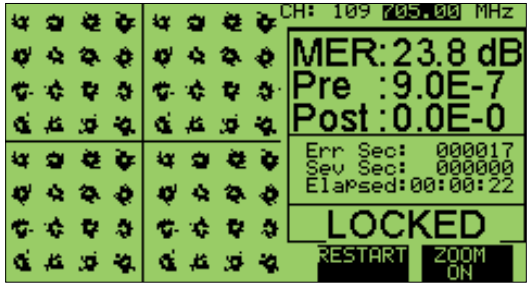
Phase noise



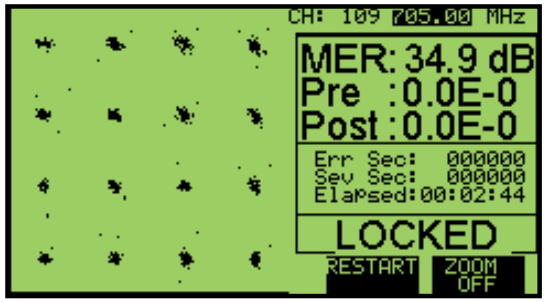
I-Q imbalance



Gain compression



Coherent interference



Zoom function

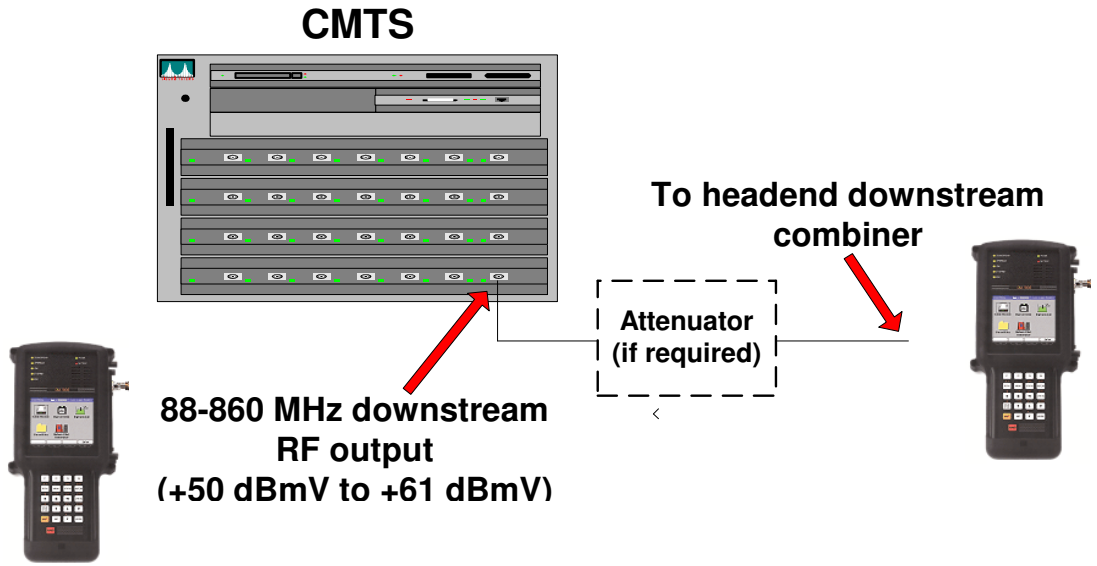
Headend RF Levels—Integrated Upconverter

- **Verify correct average power level**

  Integrated upconverter RF output should be set in the DOCSIS-specified +50 to +61 dBmV range

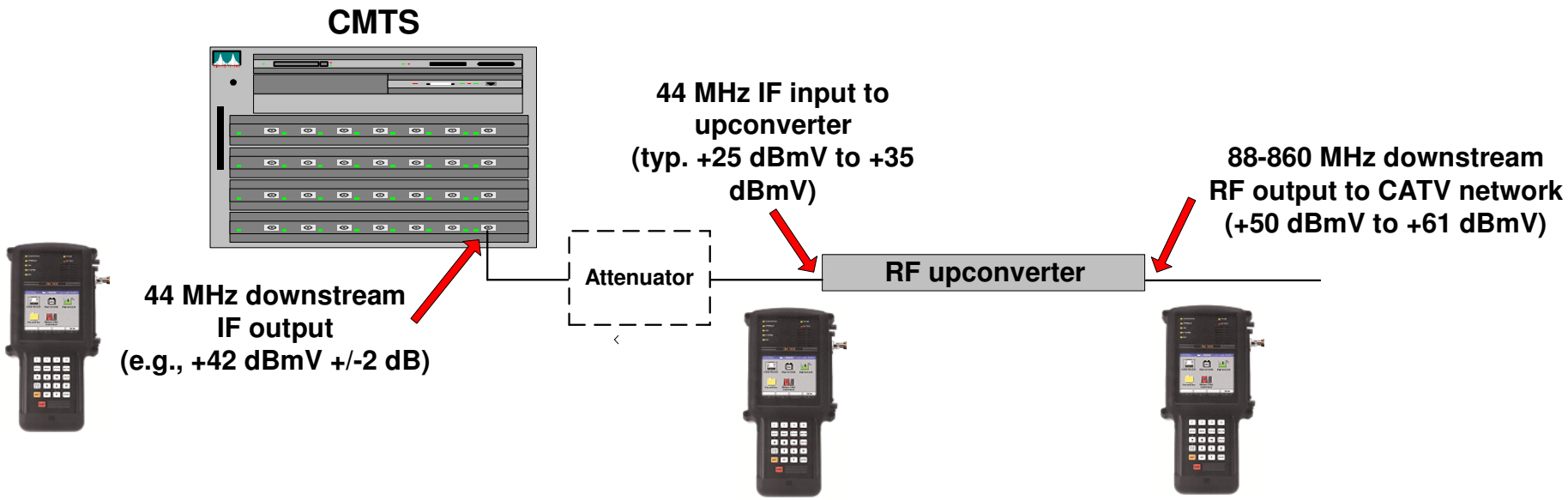
  Typical levels are +55 to +58 dBmV

- **Also check BER, MER and constellation**



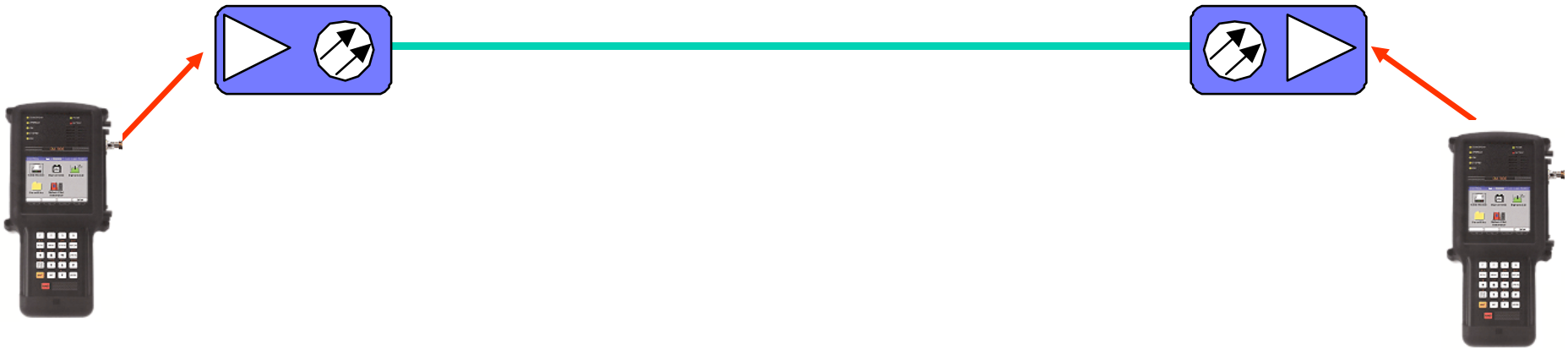
Headend RF Levels—External Upconverter

- **Verify correct average power level, BER, MER and constellation**
  - **CMTS downstream IF output**
  - **External upconverter IF input**
  - **External upconverter RF output**



Downstream Performance: QAM Analyzer

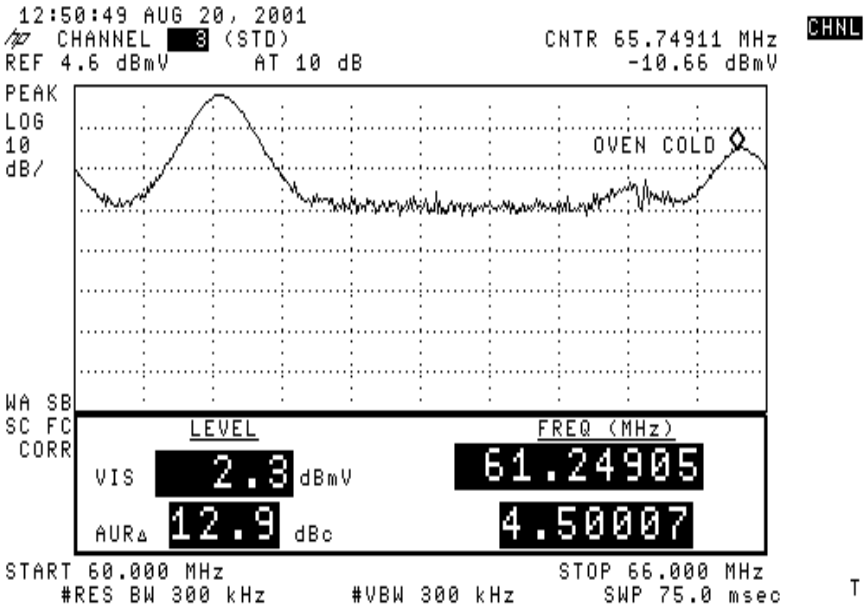
- **Check signal levels and BER at downstream laser input and node output**
  - **Bit errors at downstream laser input but not at CMTS or upconverter output may indicate sweep transmitter interference, loose connections or combiner problems**
  - **Bit errors at node output but not at laser input are most likely caused by downstream laser clipping**

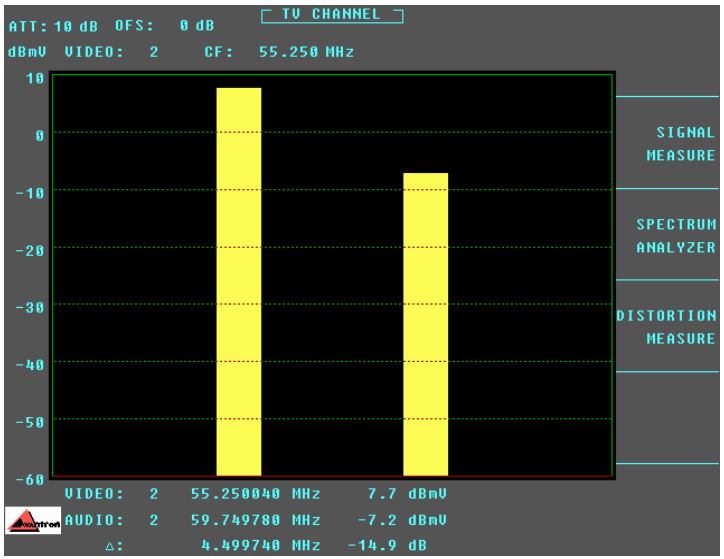


Headend RF Levels

- DOCSIS recommends that the digitally modulated carrier's average power level be set 6 dB to 10 dB below what the visual carrier level of an analog TV channel on the same frequency would be
- This ratio should be maintained throughout the entire cable network

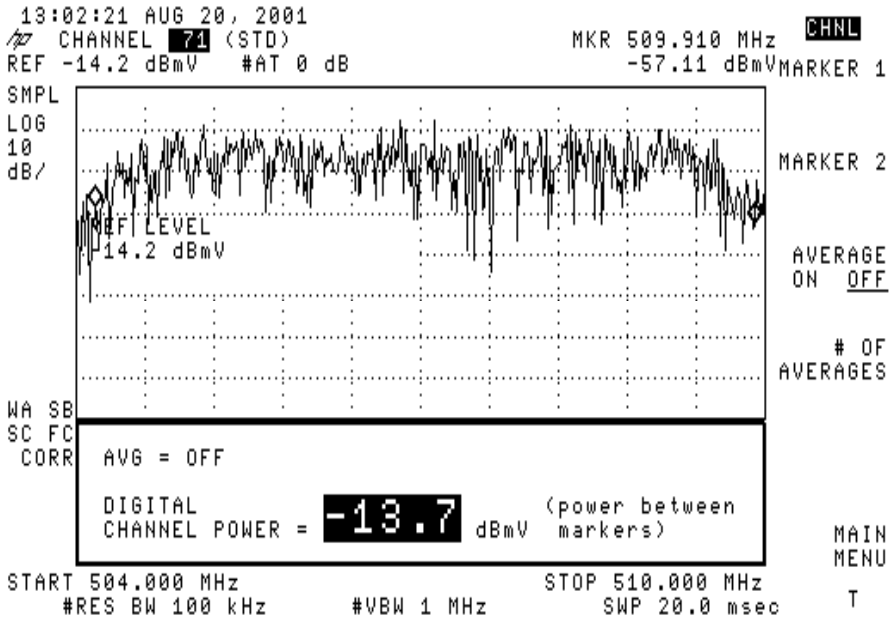
Analog TV Channel Amplitude Measurement

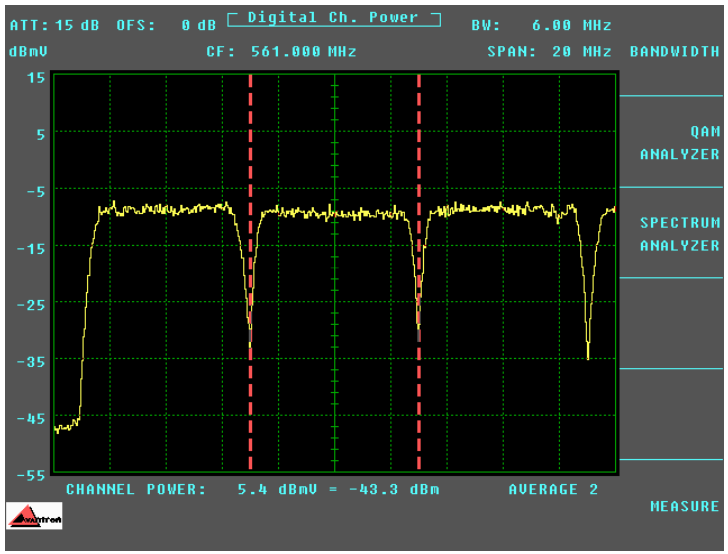




Courtesy Agilent Technologies and Sunrise Telecom

Downstream Digitally Modulated Signal Amplitude Measurement

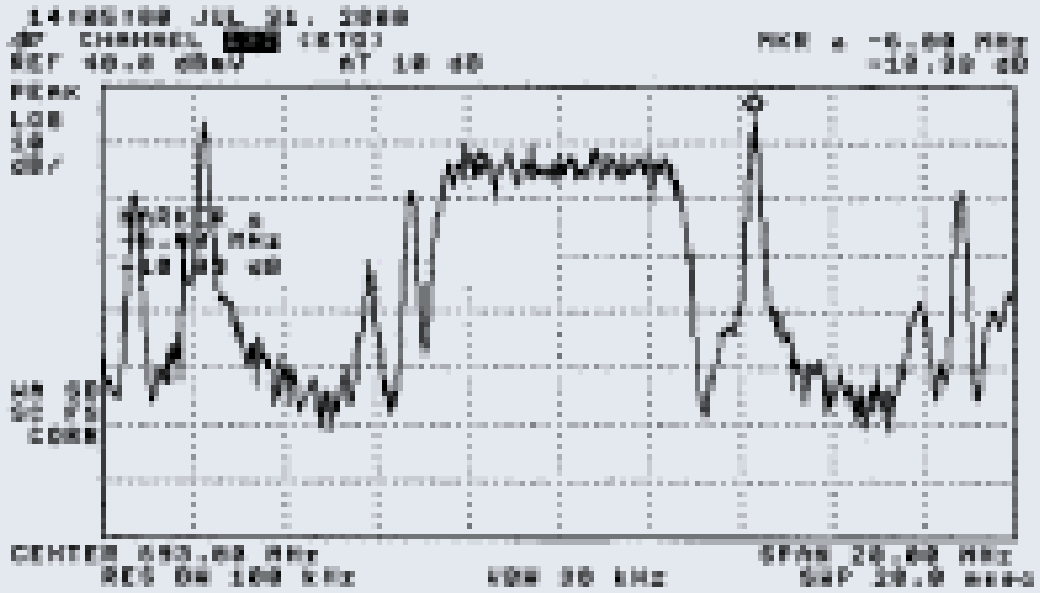




Courtesy Agilent Technologies and Sunrise Telecom

Downstream Digitally Modulated Signal Amplitude Measurement

FIGURE 1

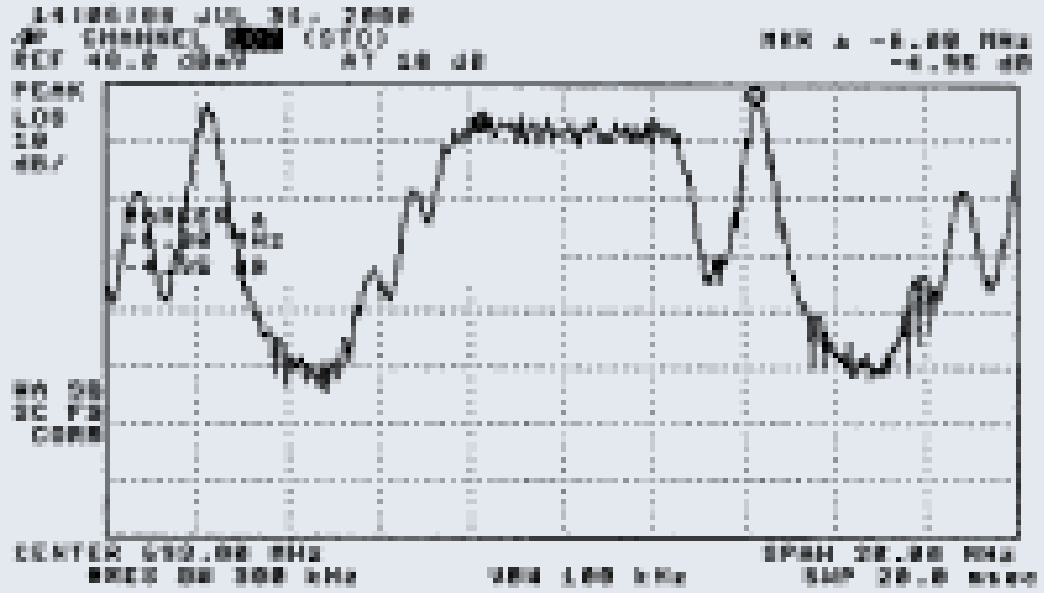


At the spectrum analyzer settings shown, the digitally modulated carrier appears to be +25 dBmV or so, which is 10 dB below the adjacent visual carrier levels.

Courtesy *Communications Technology* Magazine

Downstream Digitally Modulated Signal Amplitude Measurement

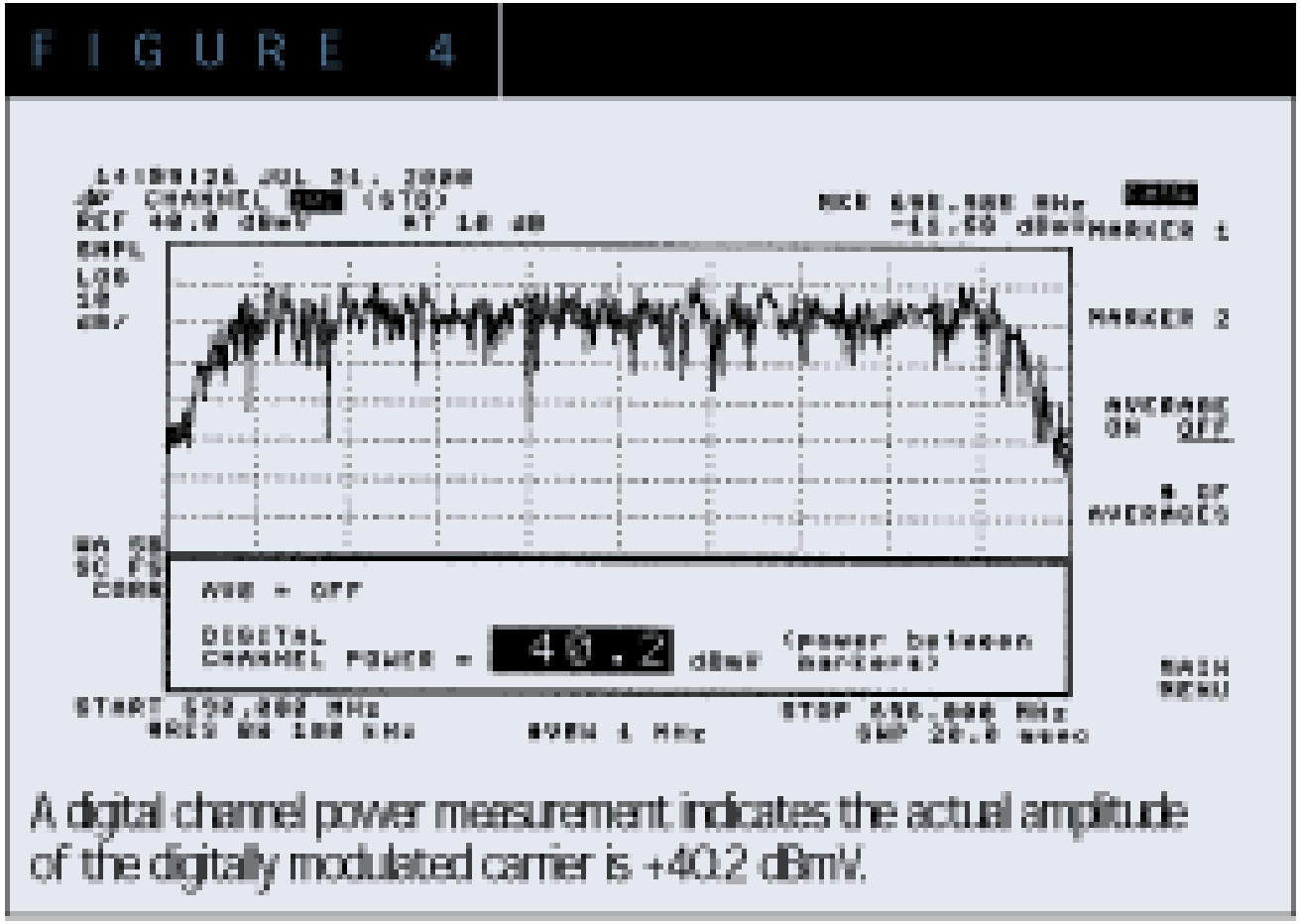
FIGURE 3



When the spectrum analyzer resolution bandwidth is changed from 100 kHz to 300 kHz the apparent amplitude of the digitally modulated carrier increased to +32 dBmV.

Courtesy *Communications Technology* Magazine

Downstream Digitally Modulated Signal Amplitude Measurement

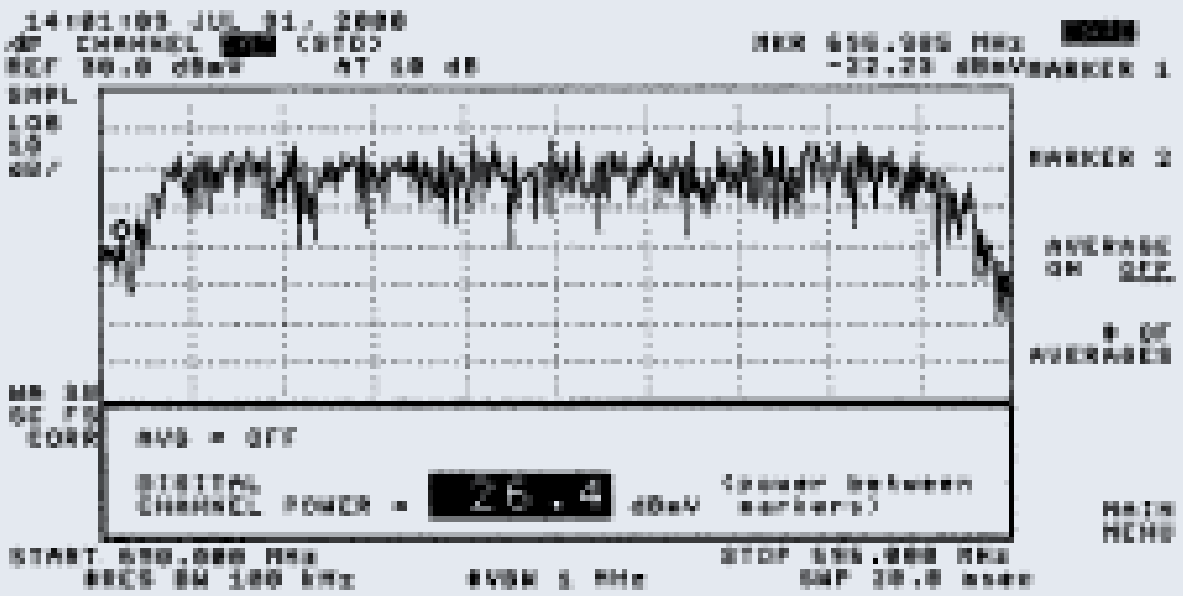


A digital channel power measurement indicates the actual amplitude of the digitally modulated carrier is +40.2 dBmV.

Courtesy *Communications Technology* Magazine

Downstream Digitally Modulated Signal Amplitude Measurement

FIGURE 5

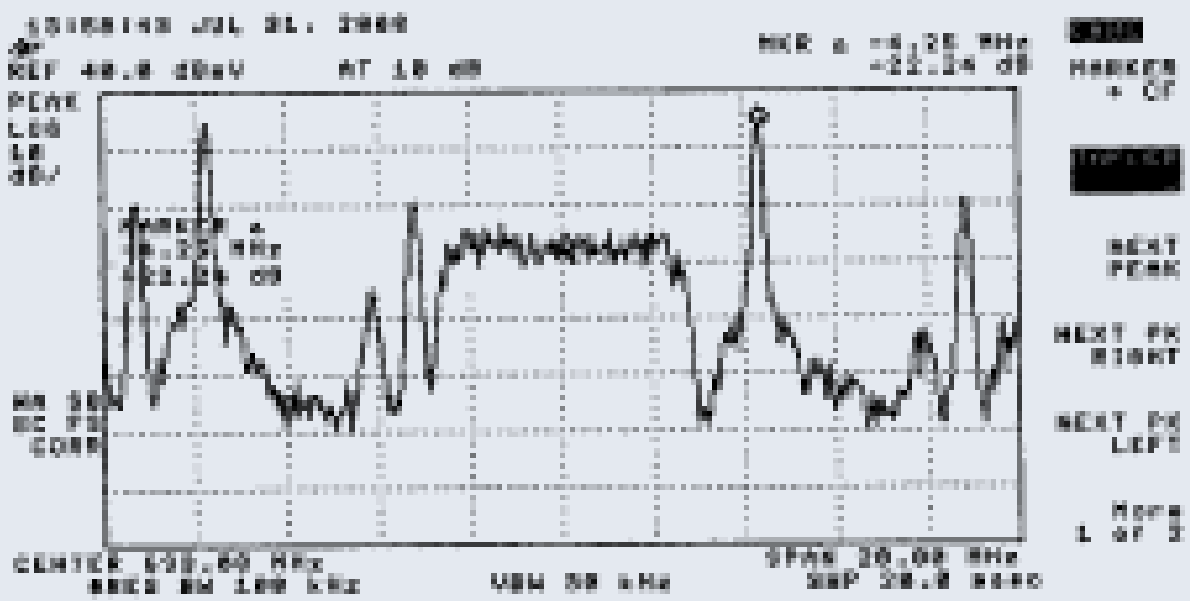


The digitally modulated carrier amplitude has been set to the correct level (+26 dBmV total power), which is 10 dB below the adjacent channel visual carrier levels.

Courtesy *Communications Technology* Magazine

Downstream Digitally Modulated Signal Amplitude Measurement

FIGURE 6

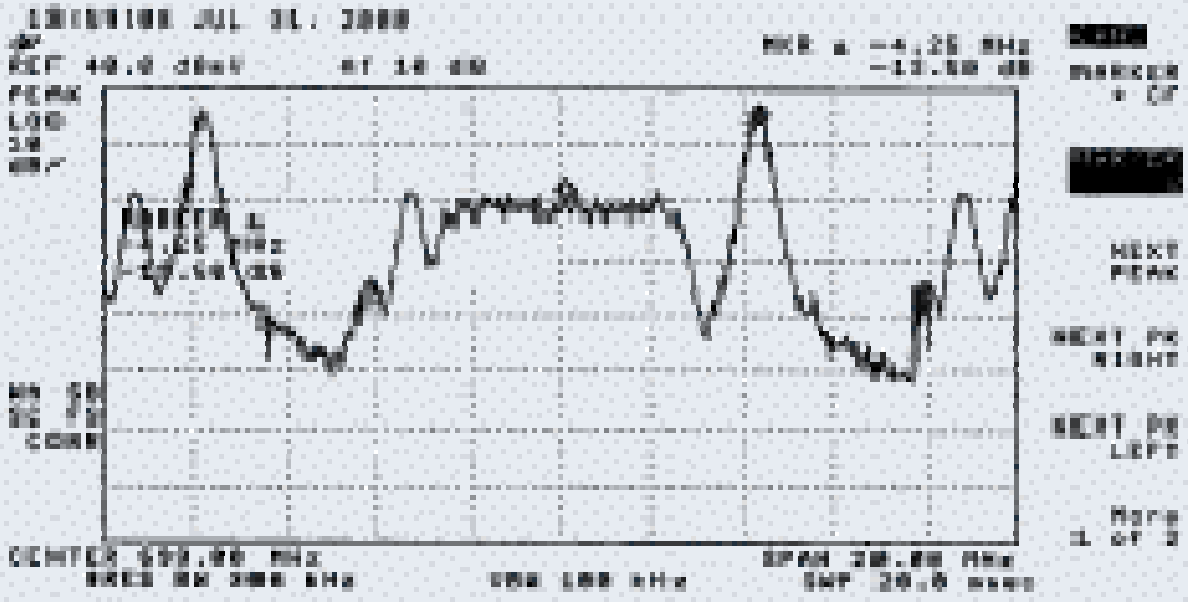


Going back to the original instrument settings used in Figure 1, the apparent amplitude of the digitally modulated carrier is now about +12 dBmV. The total power is correct, but the displayed amplitude does not seem to be.

Courtesy *Communications Technology* Magazine

Downstream Digitally Modulated Signal Amplitude Measurement

FIGURE 7

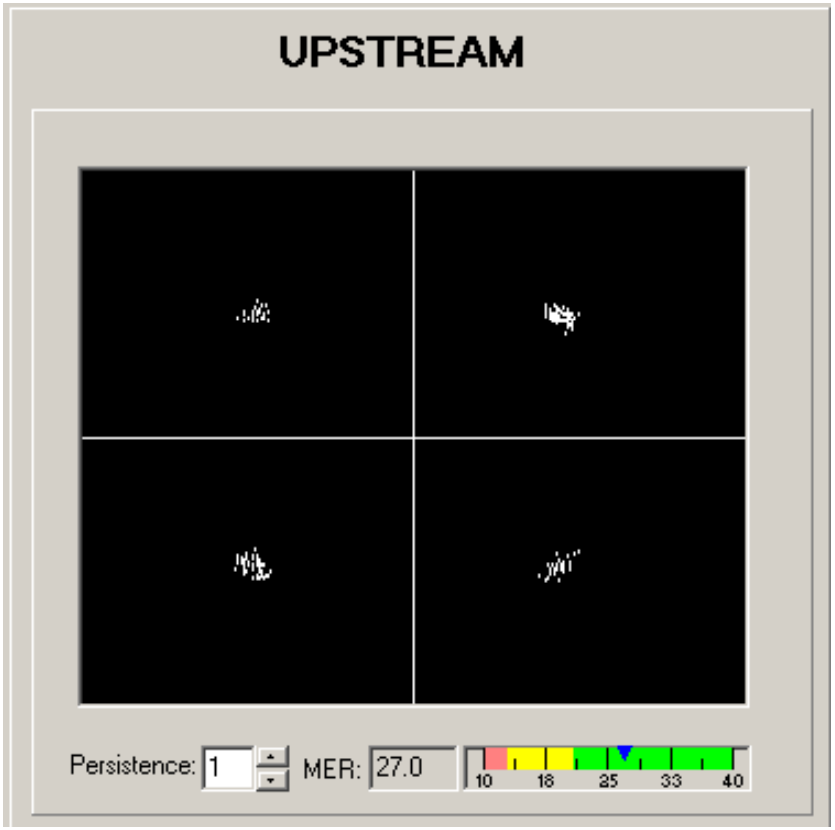


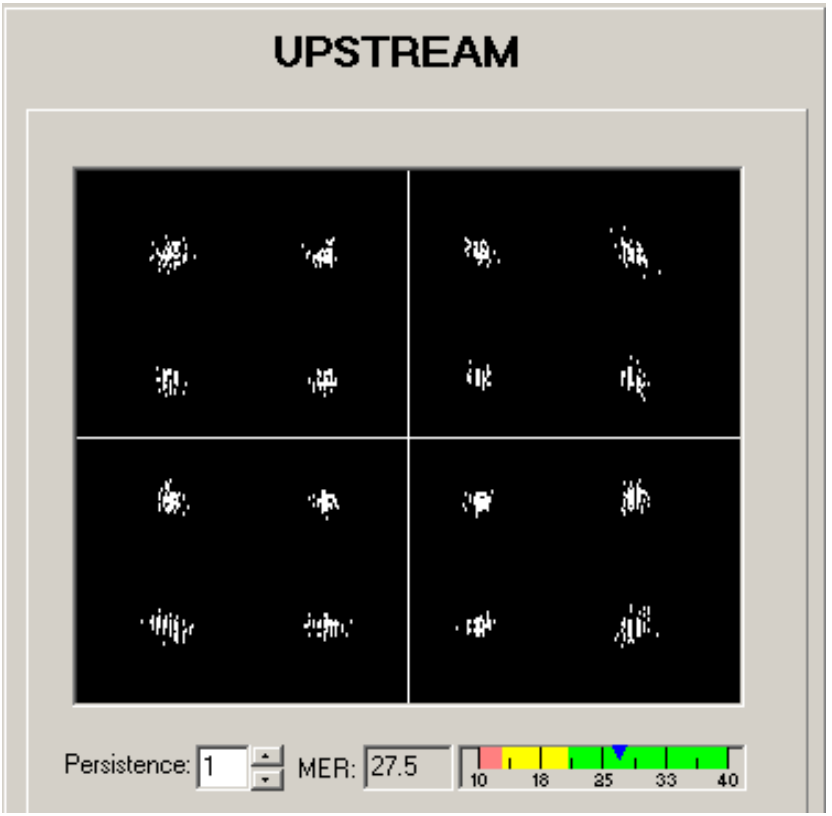
Changing the analyzer resolution bandwidth setting to 300 kHz once again shows a higher apparent amplitude for the digitally modulated carrier.

Courtesy *Communications Technology* Magazine

Upstream Performance: Constellations and MER

Good QPSK and 16-QAM constellations

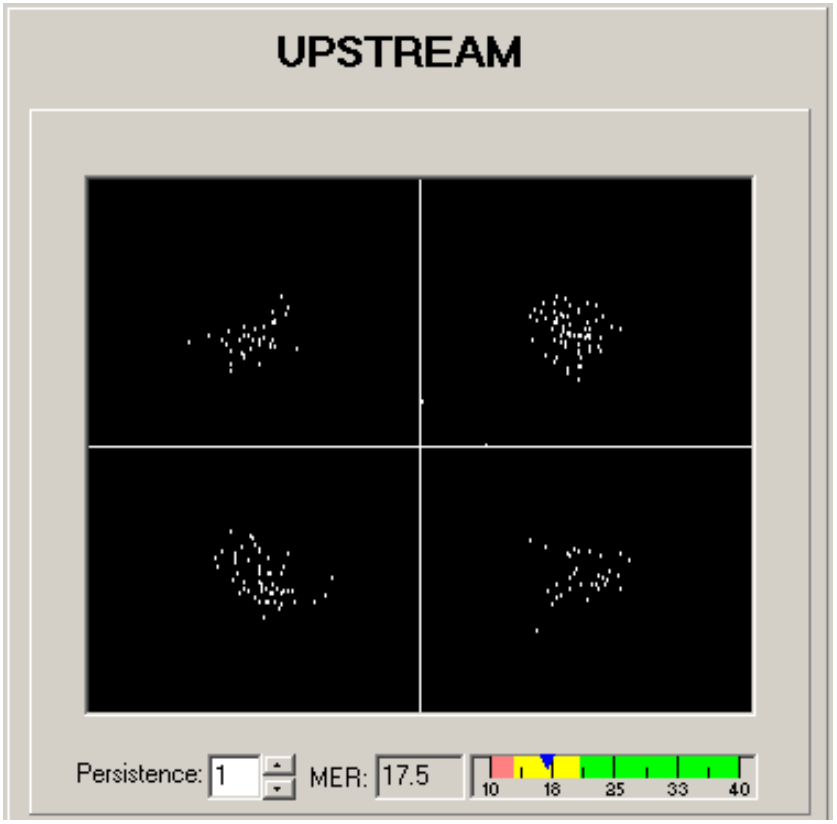


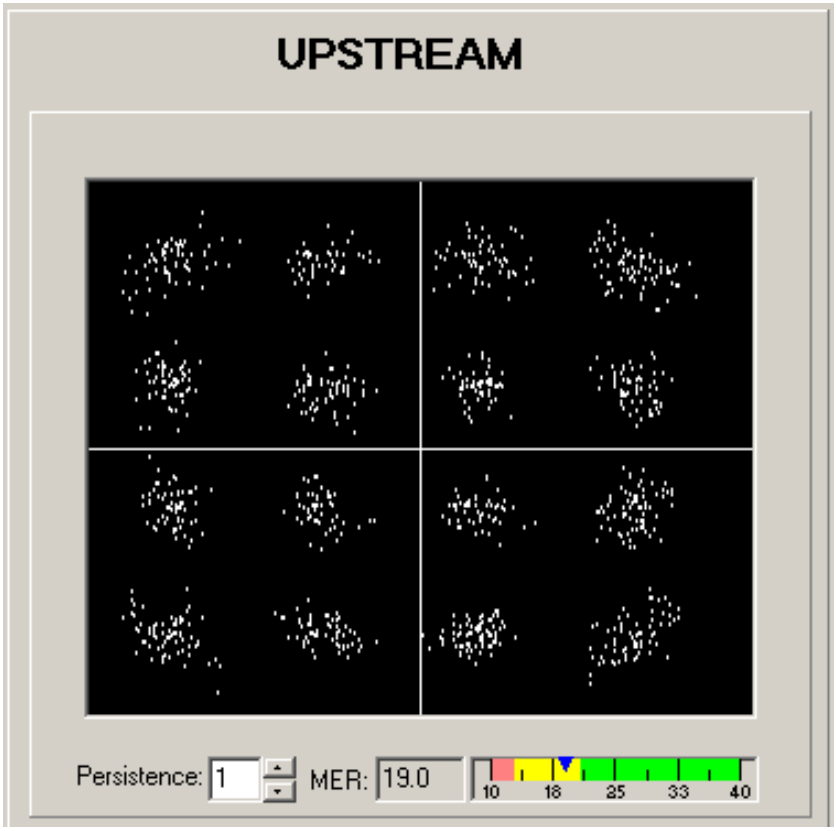


Graphics courtesy of Filtronic Sigtek, Inc.

Upstream Performance: Constellations and MER

Poor carrier-to-noise ratio, low MER





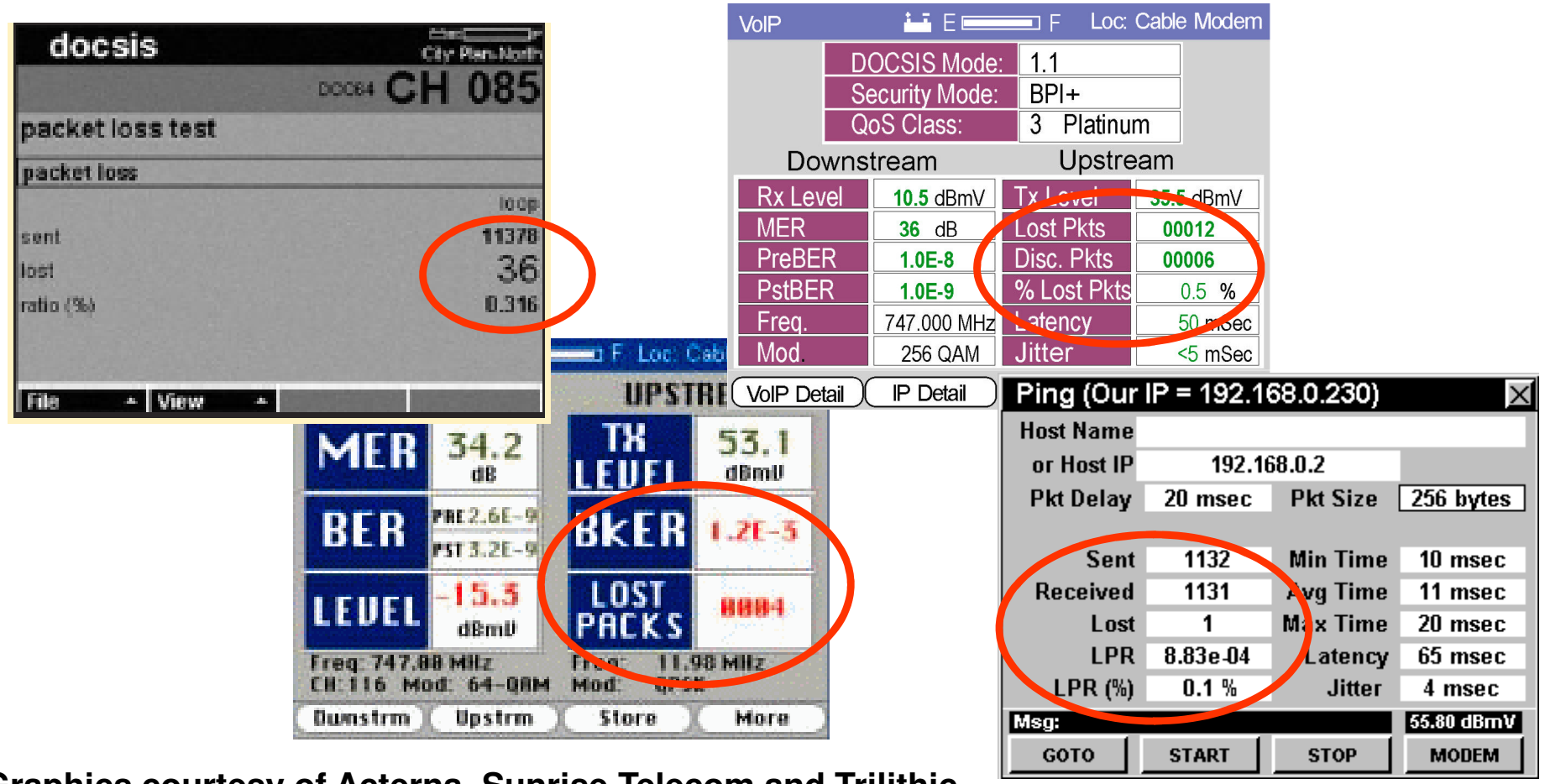
Graphics courtesy of Filtronic Sigtek, Inc.

Other Challenges

- **Dealing with the slightly lower dynamic range of 16-QAM modem transmission compared to QPSK**
  - **DOCSIS specifies that cable modems must support +8 to +58 dBmV upstream transmission levels for QPSK, and +8 to +55 dBmV for 16-QAM**
- **A switch to 16-QAM loses 3 dB of headroom**
  - **If some modems are transmitting at their maximum level with QPSK, they may exhibit problems when switched to 16-QAM**
- **Typical fix is to correct excessive upstream attenuation between the affected modem and the first upstream active**
  - **Usually drop- or network alignment-related**

Upstream Performance: Packet Loss

Some QAM analyzers support upstream packet loss measurements



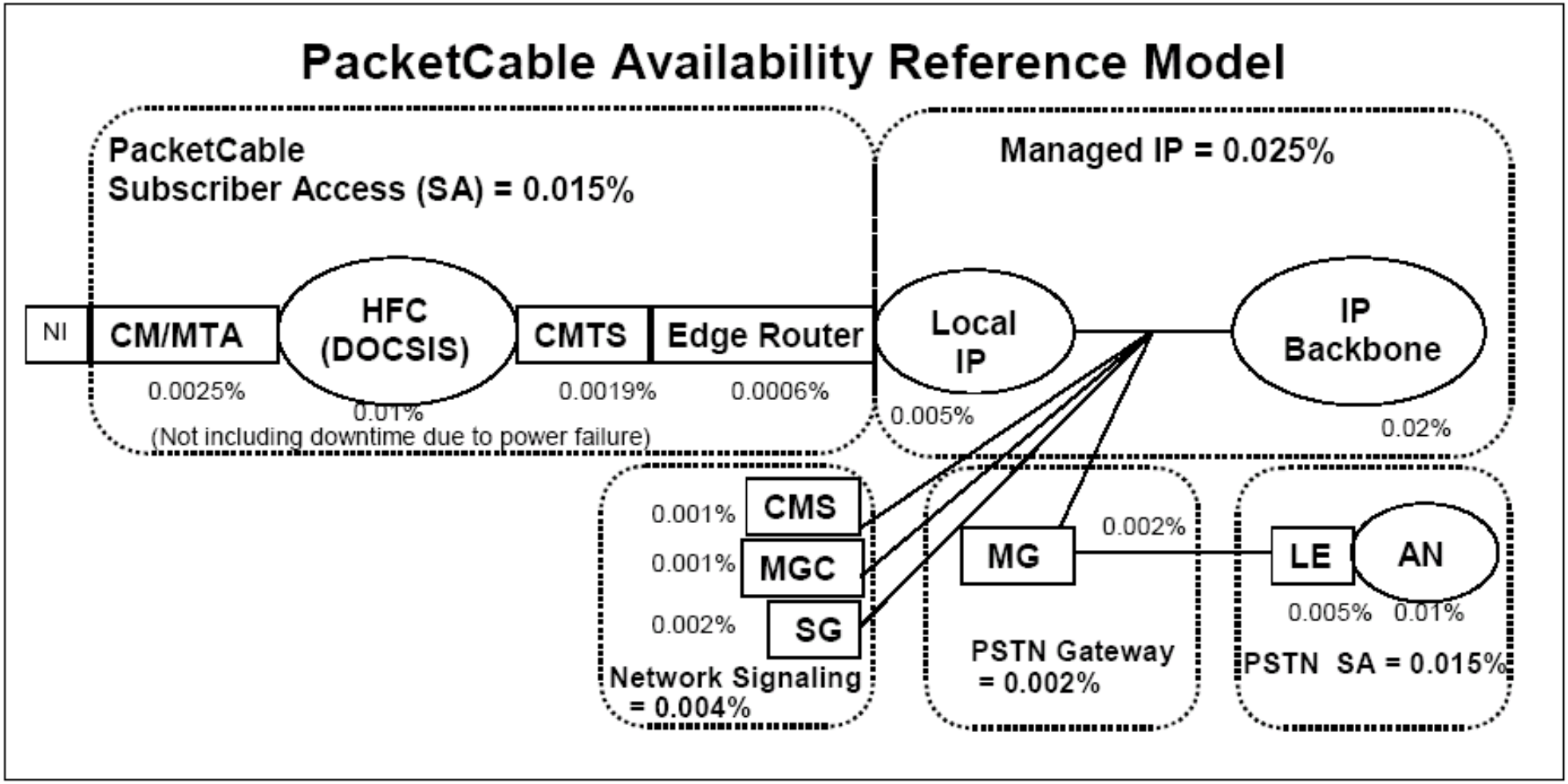
Graphics courtesy of Acterna, Sunrise Telecom and Trilithic

PacketCable™ Availability Reference Model

First, Some Definitions

- **Availability:** ***The ratio of time that a service is available for use to total time. PacketCable's reference model assumes 99.94% end-to-end availability. The HFC network maximum contribution to this is 0.01% unavailability, or 99.99% availability—the so-called four nines.***
- **Reliability:** ***Probability that a system or device will not fail during some specified period.***

PacketCable™ Availability Reference Model

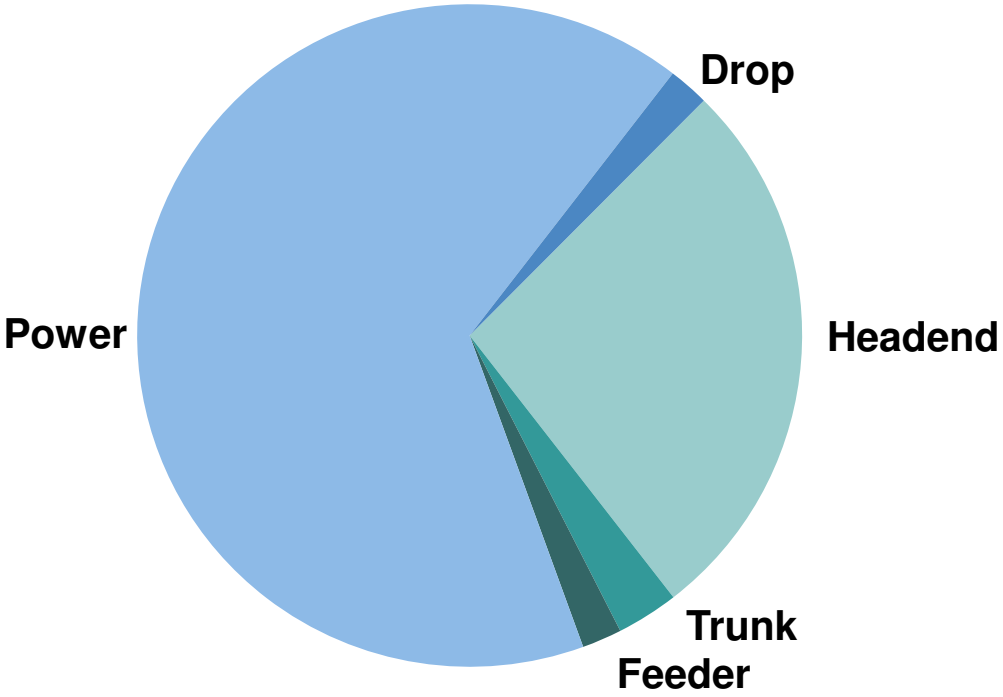


Source: ***VoIP Availability and Reliability Model for the PacketCable™ Architecture*** **(PKT-TR-VoIPAR-V01-001128)**

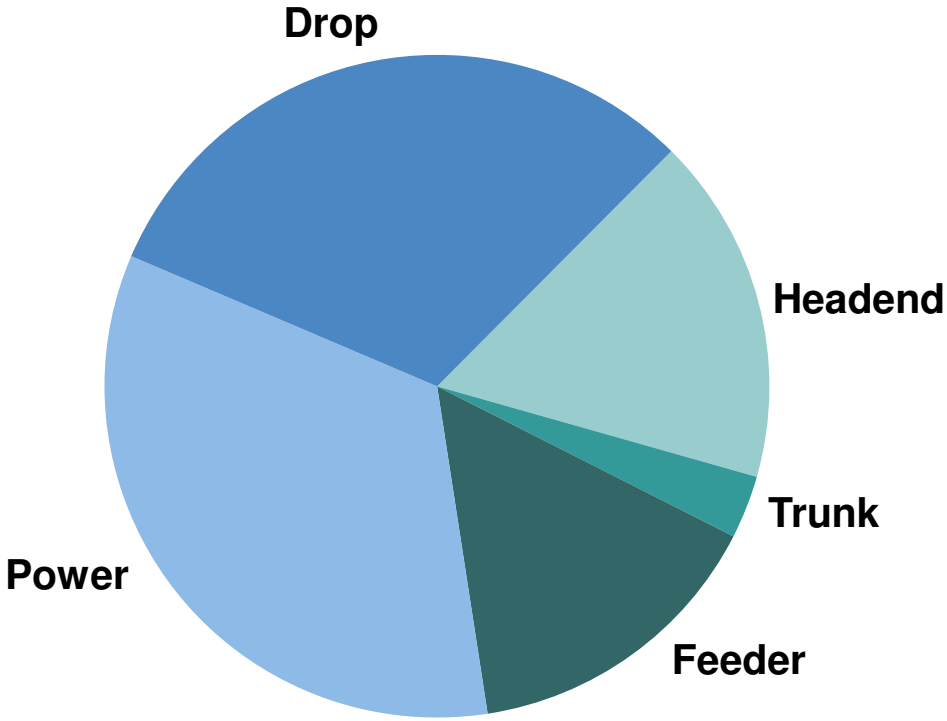
Contributors to *Network* Availability

- Network architecture
- System powering
- Redundancy
- Status monitoring
- System maintenance practices
- Subscriber drop installation quality
- Service restoration

Relative Network Contributors to Outages



Relative network section contributions to outage rate



Relative network section contributions to outage hours

Source: *Modern Cable Television Technology, 2nd Ed.;* Ciciora, Farmer, Large, Adams; ©2004, Morgan Kaufmann Publishers

Network Availability

Can a cable network meet 99.99%?

- **According to an analysis in *Modern Cable Television Technology, 2nd Ed.*, achieving 99.99% availability requires:**
  - **Improved HDT and NID reliability**
  - **Hardened and more reliable powering**
  - **Shorter cascades of both coaxial equipment and power supplies**
  - **Reliable status monitoring throughout the network**
- **Proactive maintenance**
- **High quality drop installations**

Source: *Modern Cable Television Technology, 2nd Ed.;* Ciciora, Farmer, Large, Adams; ©2004, Morgan Kaufmann Publishers

Network Impairments That Affect *Service* Availability

- Ingress and impulse noise
- Improper network alignment
- Distortions (CPD, hum, CSO, CTB)
- Poor in-channel frequency response (amplitude tilt and ripple)
- Group delay
- Micro-reflections
- Intermittent connections
- Sweep transmitter interference
- Laser clipping—upstream and downstream

Downstream Checklist

- ✓ Entire cable network—headend, distribution network and subscriber drops—DOCSIS-compliant
- ✓ Upconverter setup, IF input/RF output levels
- ✓ Downstream laser input levels
- ✓ Avoid downstream frequencies near band edges or rolloff areas
- ✓ Avoid downstream frequencies that may be susceptible to ingress from strong over-the-air signals[1]
- ✓ Forward and reverse properly aligned
- ✓ Frequency response flat
- ✓ Signal leakage and ingress management
- ✓ Good installation practices

Upstream Checklist

- ✓ CMTS modulation profile optimized for modulation format in use—for instance, 16-QAM
- ✓ Entire cable network—headend, distribution network and subscriber drops—DOCSIS-compliant
- ✓ Select upstream frequency that avoids diplex filter roll-off area
- ✓ Forward and reverse properly aligned
- ✓ Signal leakage and ingress management
- ✓ Good installation practices

DOCSIS Checklist

Headend (downstream) CMTS or upconverter output

Test performed ✓	Parameter	Parameter value	Measured value/comments
	CMTS downstream IF output	+42 dBmV[1]	
	Digitally modulated carrier amplitude at upconverter input	+25 to +35 dBmV[2]	
	Digitally modulated carrier amplitude at upconverter output	+50 to +61 dBmV	
	Digitally modulated carrier center frequency	91-857 MHz	
	Carrier-to-noise ratio	Not less than 35 dB	
	Modulation error ratio (MER)[3]	64-QAM: 27 dB minimum 256-QAM: 31 dB minimum	
	Pre-FEC BER[4]	N/A	
	Post FEC BER[5]	Less than or equal to 10^{-8}	
	Amplitude ripple (in-channel flatness)	3 dB[6]	
	Group delay ripple	75 ns maximum	
	Constellation evaluation	Look for evidence of gain compression; phase noise; I-Q imbalance; coherent interference; excessive noise; and clipping	

DOCSIS Checklist

Headend (downstream) laser transmitter or first amplifier input, node output

Test performed ✓	Parameter	Parameter value	Measured value/comments
	Digitally modulated carrier average power level relative to analog TV channel visual carrier amplitude	-10 to -6 dBc	
	Digitally modulated carrier center frequency	91-857 MHz	
	Carrier-to-noise ratio	Not less than 35 dB	
	Modulation error ratio (MER)[1]	64-QAM: 27 dB minimum 256-QAM: 31 dB minimum	
	Pre-FEC BER[2]	N/A	
	Post FEC BER[3]	Less than or equal to 10^{-8}	
	Amplitude ripple (in-channel flatness)	3 dB[4]	
	Group delay ripple	75 ns maximum	
	Constellation evaluation	Look for evidence of gain compression; phase noise; I-Q imbalance; coherent interference; excessive noise; and clipping	

DOCSIS Checklist

Downstream input to cable modem

Test performed ✓	Parameter	Parameter value	Measured value/comments
	Digitally modulated carrier center frequency	91-857 MHz	
	Digitally modulated carrier average power level relative to analog TV channel visual carrier amplitude	-10 to -6 dBc	
	Digitally modulated carrier average power level[1]	-15 to +15 dBmV	
	Carrier-to-noise ratio	Not less than 35 dB	
	Total downstream RF input power[2]	<+30 dBmV	
	Modulation error ratio (MER)[3]	64-QAM: 27 dB minimum 256-QAM: 31 dB minimum	
	Pre-FEC BER[4]	N/A	
	Post FEC BER	Less than or equal to 10^{-8}	

DOCSIS Checklist

Downstream input to cable modem (cont'd)

Test performed ✓	Parameter	Parameter value	Measured value/comments
	Constellation evaluation	Look for evidence of gain compression; phase noise; I-Q imbalance; coherent interference; excessive noise; and clipping	
	Amplitude ripple (in-channel flatness)	3 dB[4]	
	Hum modulation	5% (-26 dBc)	
	Maximum analog TV channel visual carrier level	+17 dBmV	
	Minimum analog TV channel visual carrier level	-5 dBmV	
	Transit delay from CMTS to most distant cable modem[5]	<=0.800 millisecond	
	Signal level slope, 50-750 MHz	16 dB	
	Group delay ripple[6]	75 ns	

DOCSIS Checklist

CMTS upstream input

Test performed ✓	Parameter	Parameter value	Measured value/comments
	Digitally modulated carrier bandwidth	200, 400, 800, 1,600 or 3,200 kHz	
	Digitally modulated carrier symbol rate	160, 320, 640, 1,280 or 2,560 ksym/sec	
	Digitally modulated carrier center frequency	Must be within 5-42 MHz spectrum	
	Digitally modulated carrier amplitude[1]	-16 to +26 dBmV depending on symbol rate	
	Total 5-42 MHz RF spectrum power	Must not exceed +35 dBmV	
	Carrier-to-noise ratio	Not less than 25 dB[2]	
	Carrier-to-interference ratio	Not less than 25 dB[2]	
	Carrier-to-ingress power ratio	Not less than 25 dB[2]	

DOCSIS Checklist

CMTS upstream input (cont'd)

Test performed ✓	Parameter	Parameter value	Measured value/comments
	Hum modulation	7% (-23 dBc)	
	Amplitude ripple	0.5 dB/MHz	
	Group delay ripple[3]	200 ns/MHz	
	Transit delay from most distant cable modem to CMTS[4]	<=0.800 millisecond	

References

- Farmer, J., D. Large, W. Ciciora and M. Adams. *Modern Cable Television Technology: Video, Voice and Data Communications, 2nd Ed.*, Morgan Kaufmann Publishers; 2004
- Hranac, R., "What's in a Number? Defining Availability is Tricky", December 1999 *Communications Technology*

  www.ct-magazine.com/archives/ct/1299/hranac.htm
- Thadani, N., "VoIP Availability: Will Your Net Thrive Under Pressure?", November 2003 *Communications Technology*

  www.ct-magazine.com/archives/ct/1103/1103_voip.html
- Thadani, N., "VoIP Availability – Part 2: Will Your Net Thrive Under Pressure?, December 2003 *Communications Technology*

  www.ct-magazine.com/archives/ct/1203/1203_voip2.html

References

- Hranac, R. "16-QAM Success Story." *Communications Technology*, September 2002

www.ct-magazine.com/archives/ct/0902/0902_broadband.html

- Hranac, R. "More on 16-QAM." *Communications Technology*, January 2003

www.ct-magazine.com/archives/ct/0103/0103_broadband.html

- Hranac, R. "Mystified by Return Path Activation? Get Your Upstream Fiber Links Aligned." *Communications Technology*, March 2000

www.ct-magazine.com/archives/ct/0300/feature1.htm

- Hranac R. "Seek Balance in All Things: A Look at Unity Gain in the Upstream Coax Plant." *Communications Technology*, June 2000

www.ct-magazine.com/archives/ct/0600/0600fe8.htm

References

- Williams, T. “Tackling Upstream Data Impairments, Part 1” *Communications Technology*, November 2003

www.ct-magazine.com/archives/ct/1103/1103_upstreamdata.html

- Williams, T. “Tackling Upstream Data Impairments, Part 2” *Communications Technology*, December 2003

www.ct-magazine.com/archives/ct/1203/1203_upstreamdata2.html

- Hranac, R. “Linear Distortions, Part 1” *Communications Technology*, July 2005

www.ct-magazine.com/archives/ct/0705/0705_lineardistortions.htm

- Hranac, R. “Linear Distortions, Part 2” *Communications Technology*, August 2005

www.ct-magazine.com/archives/ct/0805/0805_lineardistortions.htm

- Hranac, R. “Microreflections and 16-QAM” *Communications Technology*, March 2004

www.ct-magazine.com/archives/ct/0304/0304_broadband.html

References

- Hranac, R. "Hum Got You Down? Block Capacitors Fix Reverse Path Woes" *Communications Technology*, May 1999
  www.ct-magazine.com/archives/ct/0599/ct0599d.htm

- Hranac, R., M. Millet. "Upstream Power Measurements: Watts Up Doc?" *Communications Technology*, December 2000
  www.ct-magazine.com/archives/ct/1200/064_upstream.htm

- Hranac, R. "Two-Way Success Secrets Revealed" *Communications Technology*, April 2001
  www.ct-magazine.com/archives/ct/0401/034_broadband.htm

- Hranac, R., M. Millet. "Downstream Power Measurements: Watts Up Doc?" *Communications Technology*, September 2000
  www.ct-magazine.com/archives/ct/0900/0900fea08.htm

References

- Hranac, R. "Understanding Reverse Path Problems, Part 1" *Communications Technology*, September 2000
www.ct-magazine.com/archives/ct/0900/0900col01.htm

- Hranac, R. "Understanding Reverse Path Problems, Part 2" *Communications Technology*, October 2000
www.ct-magazine.com/archives/ct/1000/032_broadband.htm

- Hranac, R. "Understanding Reverse Path Problems, Part 3" *Communications Technology*, November 2000
www.ct-magazine.com/archives/ct/1100/038_broadband.htm

Hranac, R. "Microreflections and 16-QAM" *Communications Technology*, March 2004
http://www.ct-magazine.com/archives/ct/0304/0304_broadband.html

References

From back issues prior to January 1999 (not available in publisher's on-line archives):

- **Hranac, R. "A Unique Approach to Reverse Path Testing" *Communications Technology*, December 1997**

- **Hranac, R. "Impulse Noise in Two-Way Systems" *Communications Technology*, July 1996**

- **Hranac, R. "Combating Impulse Noise With Common Mode Suppression" *Communications Technology*, August 1996**

- **Hranac, R. "Passive Device Intermod" *Communications Technology*, September 1998**

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