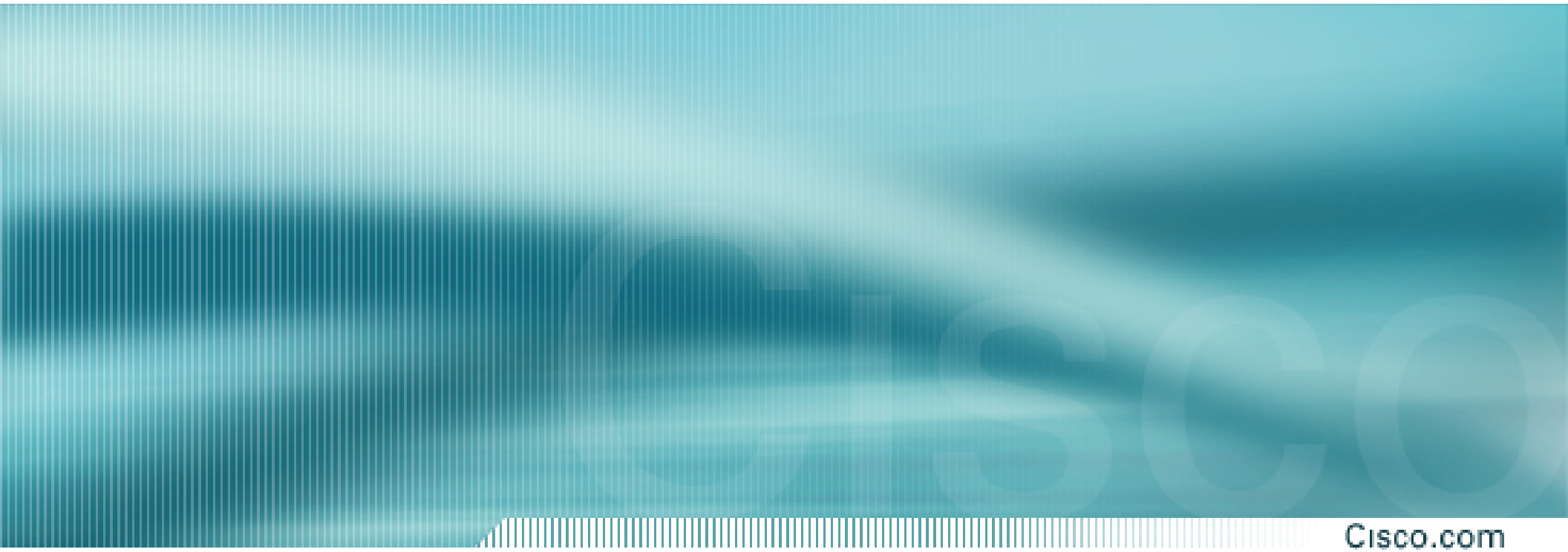

256-QAM in the Downstream

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Why 256-QAM?

- **Higher data throughput**

  Downstream throughput can be increased by switching from 64-QAM (quadrature amplitude modulation) to 256-QAM

Modulation format	Channel bandwidth, MHz	Symbol rate, Msym/sec	Raw data rate, Mbps	Nominal data rate, Mbps
64-QAM (DOCSIS)	6	5.056941	30.34	~27
256-QAM (DOCSIS)	6	5.360537	42.88	~38
64-QAM (Euro-DOCSIS)	8	6.952	41.71	~37
256-QAM (Euro-DOCSIS)	8	6.952	55.62	~50

First things first

256-QAM can in most cases be successfully deployed on a CATV network if the *entire* cable system—headend, distribution network, and subscriber drops—complies with certain minimum technical performance specifications.

First things first

Those performance specifications include relevant government technical regulations applicable to cable systems—Part 76 of the FCC's rules in the case of U.S. cable systems, or CENELEC Standard EN50083 for European cable systems—and the recommended parameters in the Data Over Cable Service Interface Specification (DOCSIS®) *Radio Frequency Interface Specification*.

First things first

- The DOCSIS *Radio Frequency Interface Specification* is part of the full DOCSIS specification, which is available at CableLabs's Web site:

  http://www.cablemodem.com/specifications

- tComLabs also has Euro-DOCSIS information at its Web site:

  http://www.tcomlabs.com/

DOCSIS 1.0 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
Carrier-to-interference ratio for total power (discrete and broadband ingress signals)	Not less than 35 dB within the design bandwidth
Composite triple beat distortion for analog modulated carriers	Not greater than –50 dBc within the design bandwidth
Composite second order distortion for analog modulated carriers	Not greater than –50 dBc within the design bandwidth
Cross-modulation level	Not greater than –40 dBc within the design bandwidth
Amplitude ripple	0.5 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
Seasonal and diurnal signal level variation	8 dB
Maximum analog video carrier level at the CM input, inclusive of above signal level variation	17 dBmV
Lowest analog video carrier level at the CM input, inclusive of above signal level variation	-5 dBmV

DOCSIS 1.0 Electrical Input to 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 [IPS-SP-406] (common with the output)

DOCSIS 1.0 Upstream RF Channel Transmission Characteristics

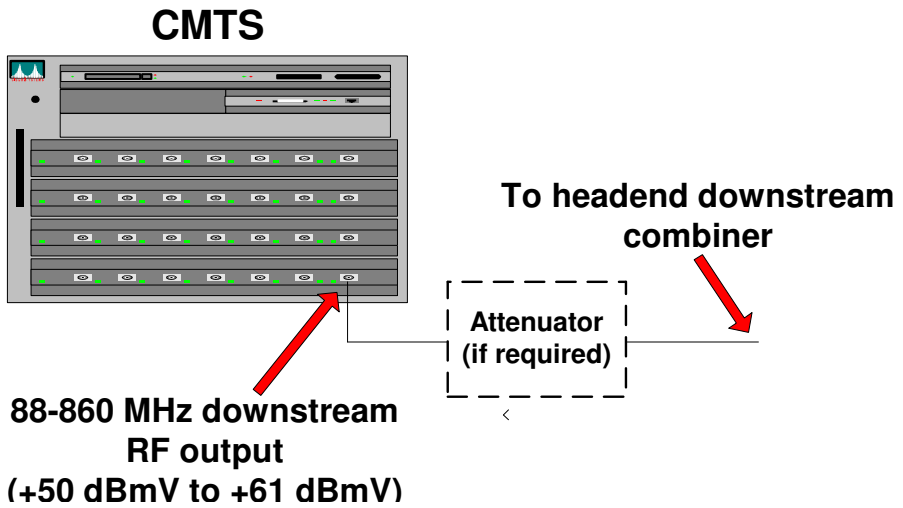
Parameter	Value
Frequency range	5 to 42 MHz edge to edge
Transit delay from the most distant CM to the nearest CM or CMTS	<=0.800 msec (typically much less)
Carrier-to-noise ratio	Not less than 25 dB
Carrier-to-ingress power (the sum of discrete and broadband ingress signals) ratio	Not less than 25 dB
Carrier-to-interference (the sum of noise, distortion, common-path distortion, and cross-modulation) ratio	Not less than 25 dB
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, 4, and 5)
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 signal level variation	Not greater than 8 dB min to max

Headend RF Levels—Integrated Upconverter

- **Verify correct average power level**

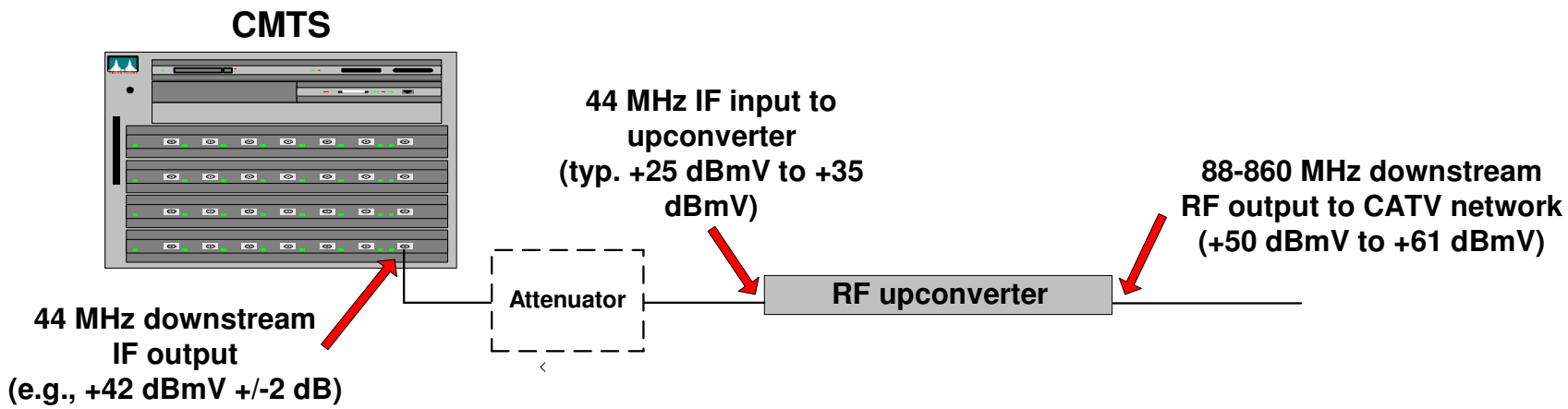
  Integrated upconverter RF output should be set in the DOCSIS-specified +50 to +61 dBmV range

  Typical levels are +55 to +58 dBmV



Headend RF Levels—External Upconverter

- **Verify correct average power level**
  - **CMTS downstream IF output**
  - **External upconverter IF input**
  - **External upconverter RF output**

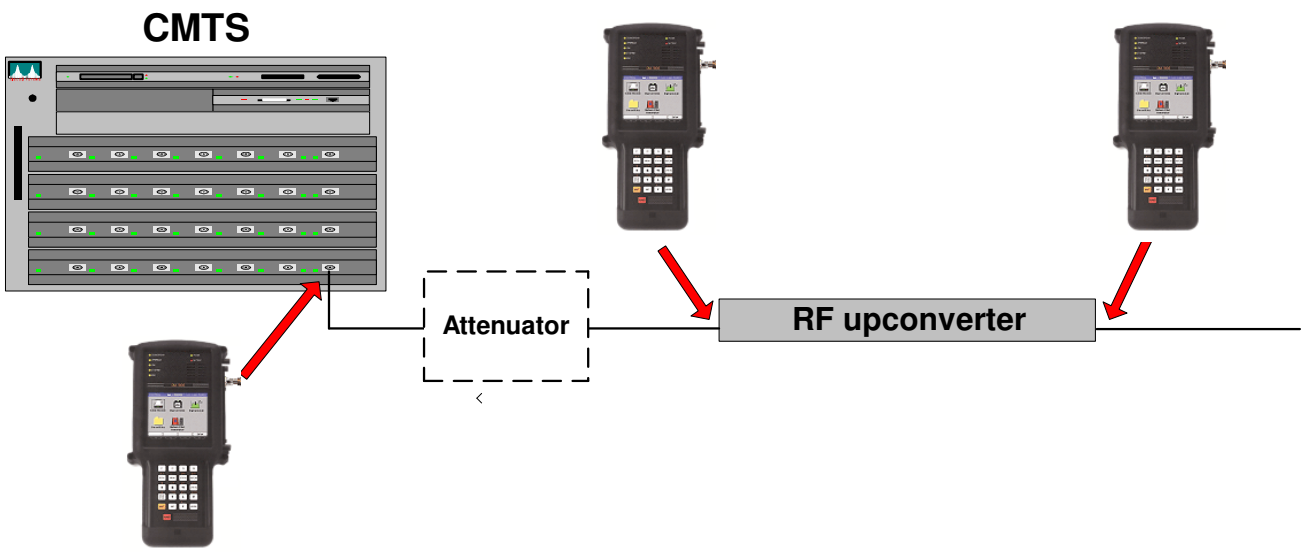


Headend RF Levels

- 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[1]
- This ratio should be maintained throughout the entire cable network

Headend Bit Error Rate Performance

- **Check BER at upconverter input and output**
  - **Some external upconverters have a very tight window with regard to IF input and RF output levels vs. BER**

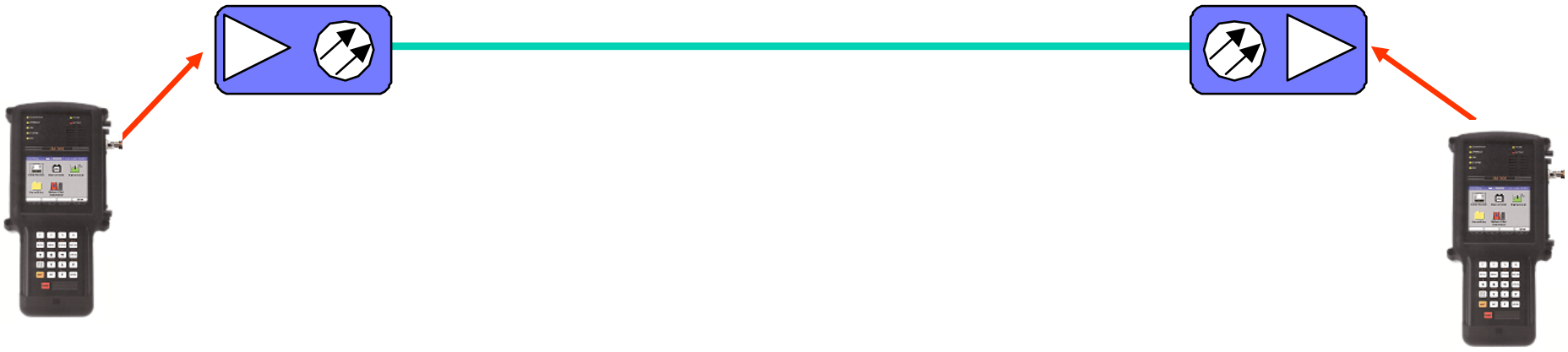


Headend Bit Error Rate Performance

- **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



Other DOCSIS RFI Spec Parameters

- **64-QAM bit error rate: Cable modem post-FEC BER must be less than or equal to 10^{-8} when operating at a carrier-to-noise 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 CNR (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**

Other Euro-DOCSIS RFI Spec Parameters

- The nominal power level of the downstream CMTS QAM signal(s) within an 8 MHz channel is targeted to be in the range -13 dBc to 0 dBc relative to the analogue video carrier level and will normally not exceed the analogue video carrier level (typically between -10 to -6 dBc for 64-QAM, and between -6 to -4 dBc for 256-QAM).
- 64-QAM bit error rate: Cable modem post-FEC BER must be less than or equal to 10^{-8} when operating at a CNR (E_S/N_0) of 25.5 dB or greater

Other Euro-DOCSIS RFI Spec Parameters

- 256-QAM bit error rate: CM post-FEC BER must be less than or equal to 10^{-8} when operating at a CNR (E_S/N_0) of
  - 34.5 dB or greater when the input receive signal level is 47 dBµV to 54 dBµV
  - 31.5 dB or greater when the input receive signal level is >54 to +77 dBµV

Digitally Modulated Carrier CNR vs. BER

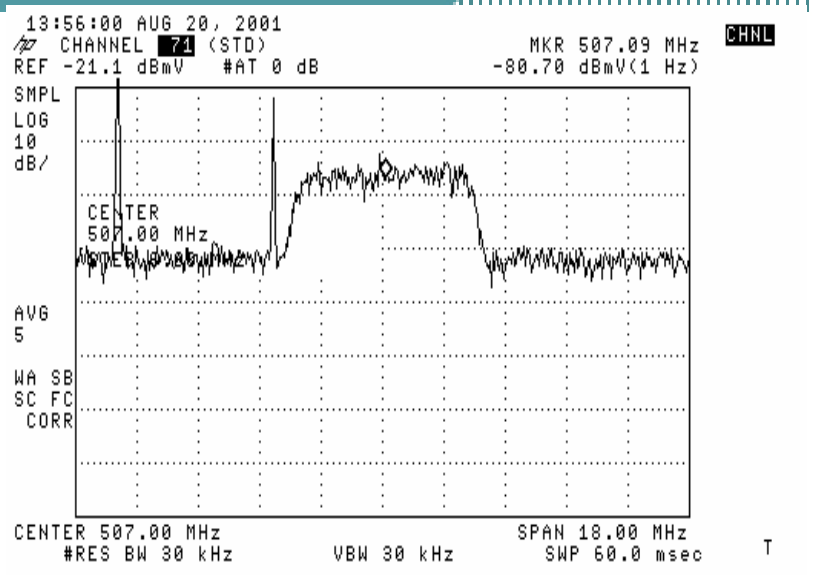
Modulation format	1.0E-04	1.0E-06	1.0E-08	1.0E-10	1.0E-12
ASK & FSK	7 dB	9 dB	10 dB	11 dB	12 dB
BPSK	9 dB	11 dB	12 dB	13 dB	14 dB
QPSK	12 dB	14 dB	15 dB	16 dB	17 dB
16-QAM	19 dB	21 dB	22 dB	23 dB	24 dB
32-QAM	21 dB	23 dB	24 dB	25 dB	26 dB
64-QAM	25 dB	27 dB	28 dB	29 dB	30 dB
256-QAM	32 dB	34 dB	35 dB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

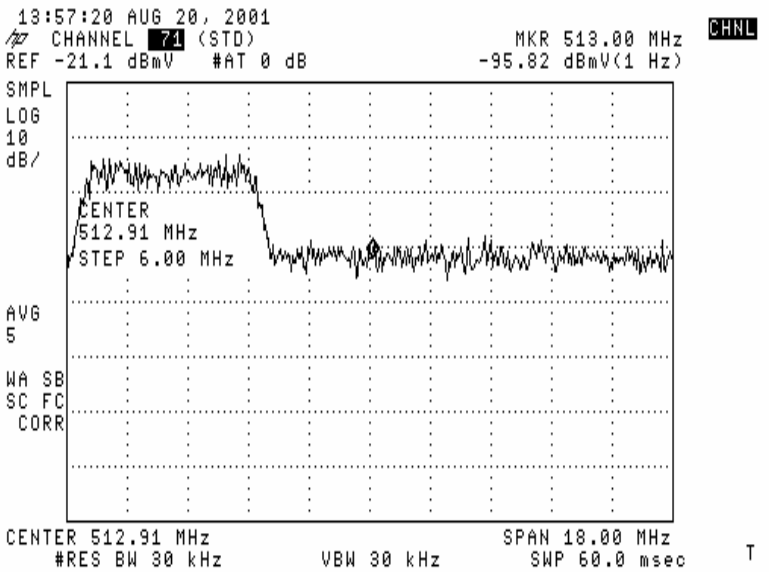
Digitally Modulated Carrier CNR vs. BER

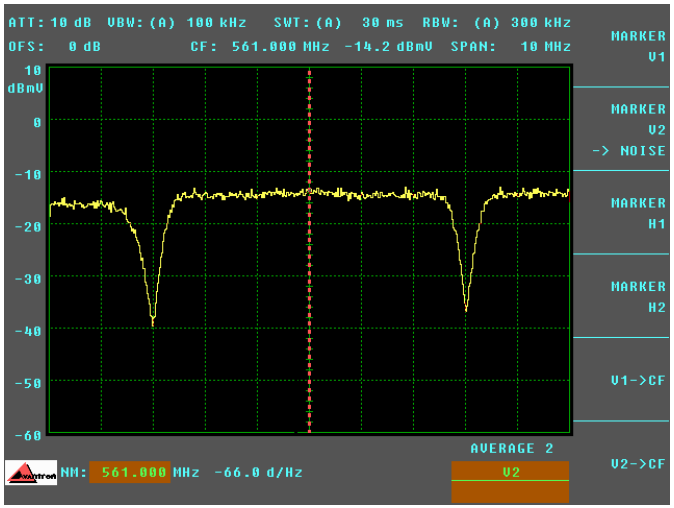
256-QAM requires 6~7 dB better CNR to achieve the same bit error rate as 64-QAM!!!

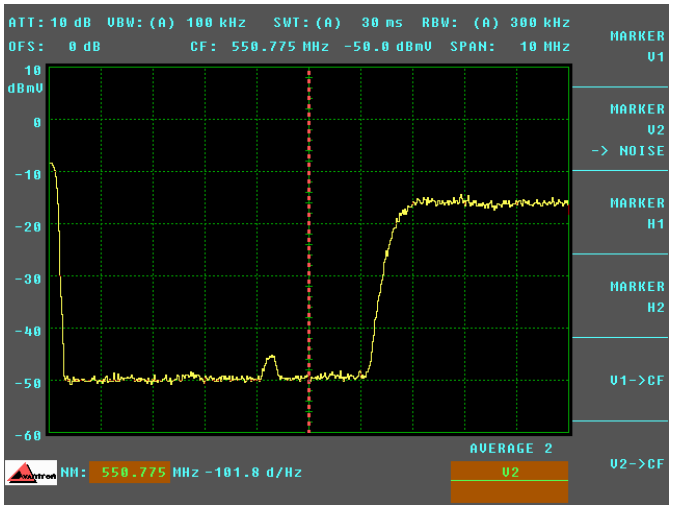
Many cable operators transmit 64-QAM digitally modulated carriers at -10 dBc relative to analog TV channels, and increase the amplitude of 256-QAM digitally modulated carriers to -5 to -6 dBc.

Downstream Digitally Modulated Carrier CNR









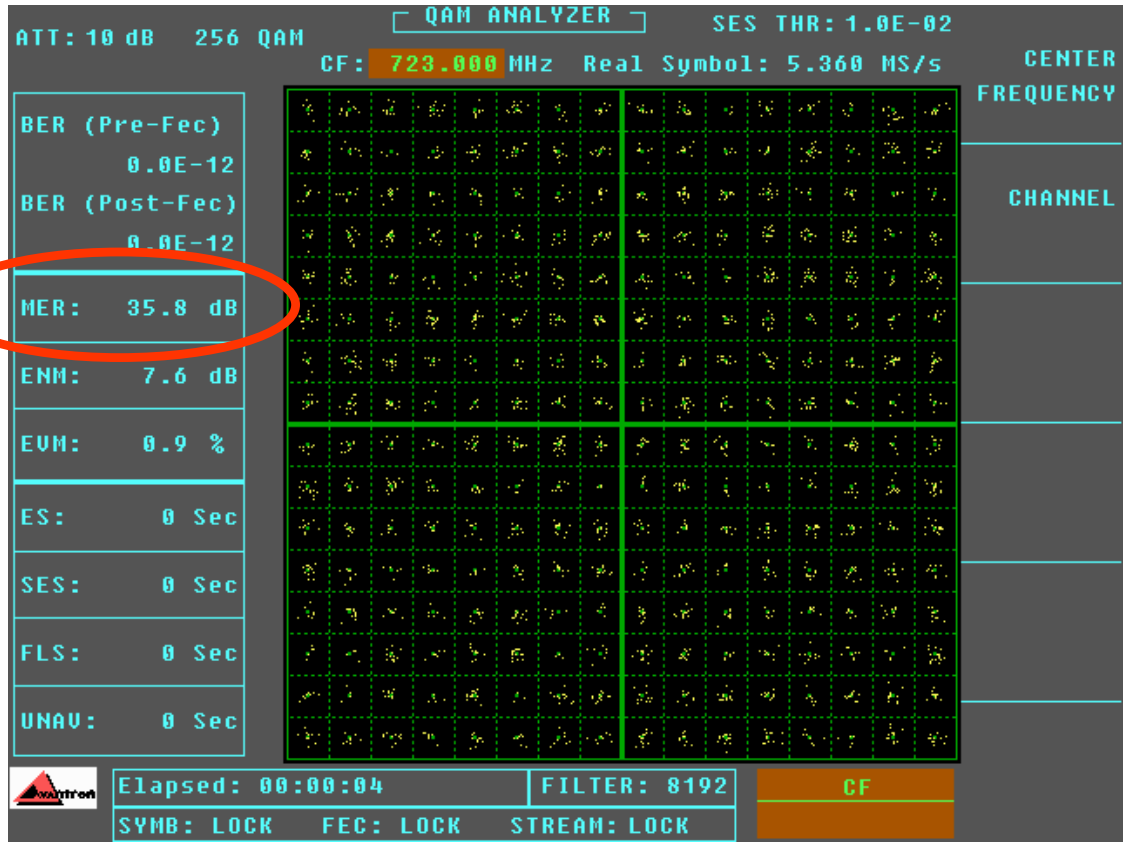
Courtesy Agilent Technologies and Sunrise Telecom

Downstream Integrity

- **How can one keep the forward plant at or better than the DOCSIS-recommended 35 dB CNR value?**
  - **Proper forward and reverse fiber link and coax plant alignment**
  - **Signal leakage and ingress management**
  - **Good installation practices**

Downstream Integrity

- **Minimum recommended downstream modulation error ratio (MER)—includes 3 to 4 dB of headroom for reliable operation**
  - **64-QAM: 27 dB**
  - **256-QAM: 31 dB**
- **Typical headend or node MER is 34 to 36 dB or greater; MER at cable modem input should be in the low- to mid-30s**



Graphic courtesy of Sunrise Telecom

Downstream Integrity

- **Amplitude ripple**
  - **In-channel flatness**
  - **DOCSIS 1.0 says 0.5 dB “within the design bandwidth,” but this parameter was relaxed to 3.0 dB in DOCSIS 1.1 and 2.0**

Downstream Integrity

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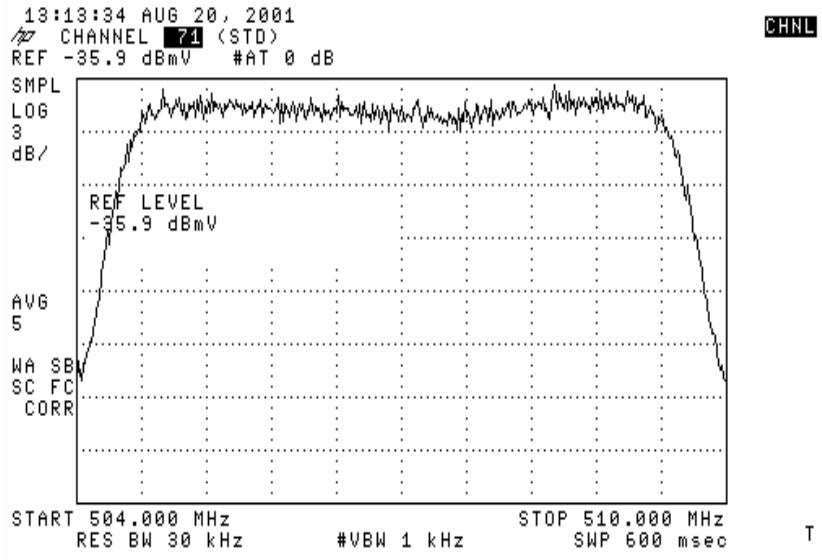
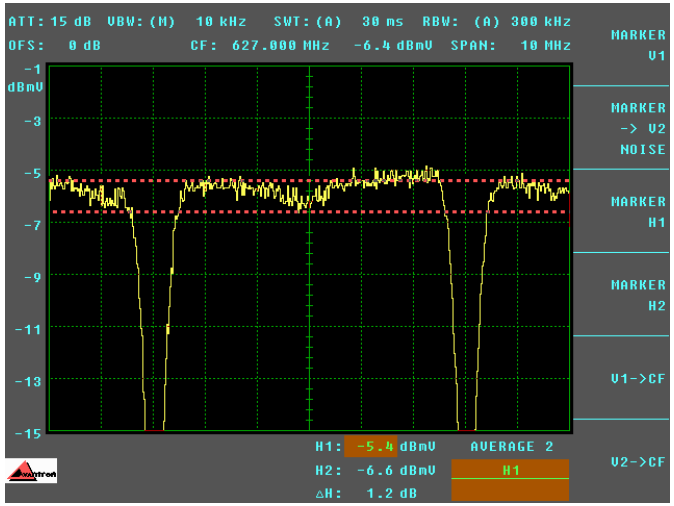
Digitally Modulated Carrier In-Channel Flatness





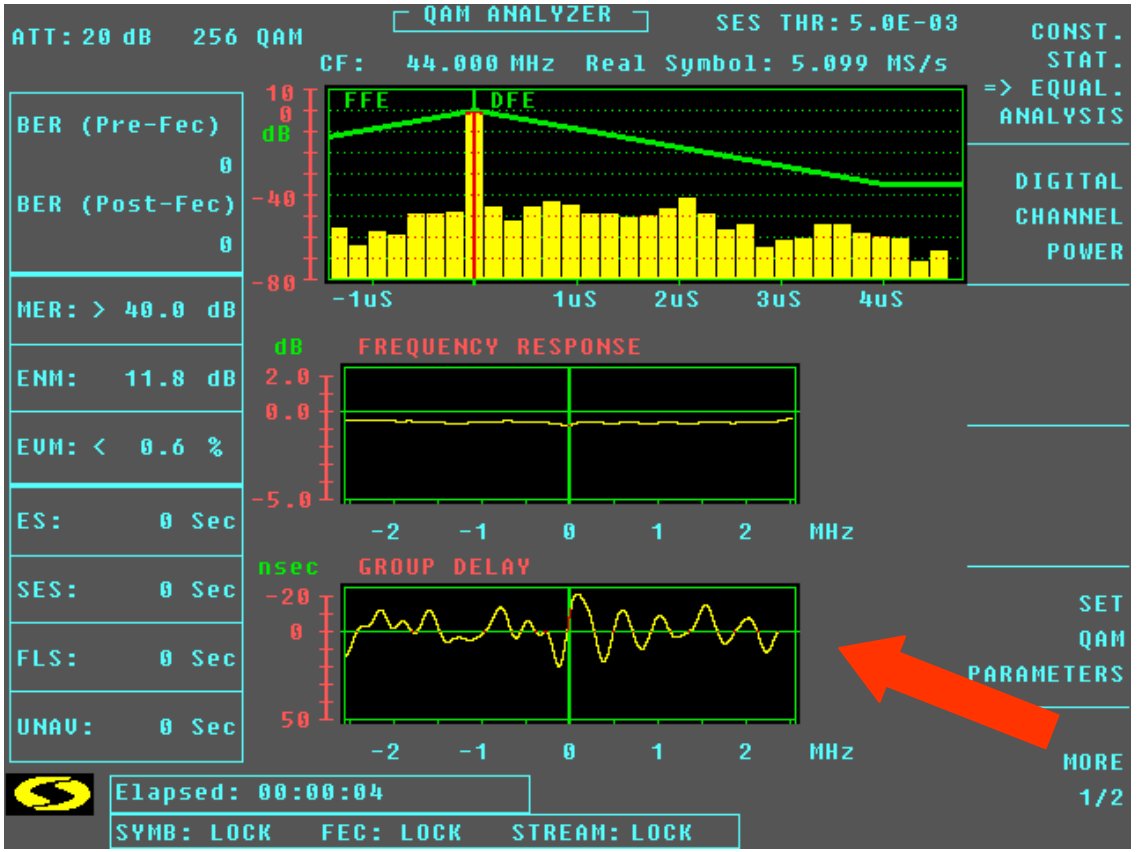
Courtesy Agilent Technologies and Sunrise Telecom

Group Delay

- Group delay is defined in units of time, typically nanoseconds (ns)
- In a system, network or component with no group delay, all frequencies are transmitted through the system, network or component with equal time delay
- Group delay causes intersymbol interference, which degrades BER performance
  - Frequency response problems in a CATV network may cause group delay
  - Group delay also is common near band edges or rolloff areas

Group Delay

DOCSIS-specified downstream maximum group delay ripple in the spectrum occupied by the CMTS is 75 ns within the design bandwidth



Graphic courtesy of Sunrise Telecom

System performance

- **Forward and reverse properly aligned**
  - **Sweep alignment is best**
- **Manage signal leakage and ingress**
  - **98th or 99th percentile flyover performance**
  - **Leaks at or below 5 µV/m (3 meter measurement distance with half-wave dipole)**

System performance

- **End-of-line and chassis (KS-port style) terminators are susceptible to sometimes being damaged by lightning-induced surges**
  - **Resulting impedance mismatches and microreflections raise havoc with proper two-way operation**
- **Loose seizure screws on connectors and terminators may cause microreflections**
- **Missing or defective tap port and drop passive terminators also will cause problems**
  - **More of an issue on low-value taps and drop passives**
- **So-called self-terminating taps do not actually terminate the end-of-line**

256-QAM 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

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