Measuring Digital and DOCSIS Performance

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Today's Agenda

- Digital signals
- DOCSIS®
- Testing and Troubleshooting Digital
- Return Path
- Q and A

Acronyms & Terms

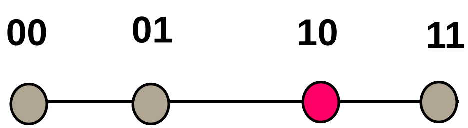
- QAM - Quadrature Amplitude Modulation
- Symbols - Collection of Bits
- Symbol Rate - Transmission Speed
- I & Q - Components of QAM data
- Constellation - Graph of QAM Data
- MER - Modulation Error Ratio
- BER - Bit Error Rate
- FEC - Forward Error Correction

Why Go Digital?

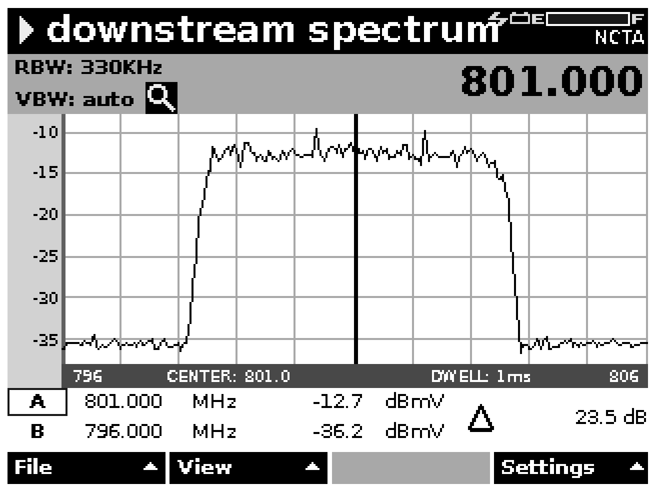
- **Efficiency**
  - **Source signals are digital**
    - Standard and High Definition TV (SDTV, HDTV)
  - **High Speed Data and Digital Video is more efficient than analog**
    - Transmit equivalent of 6 to 10 analog channels (VCR quality) over one 6 MHz bandwidth
- **Quality**
  - **Better Picture and Sound Quality**
  - **Less Susceptible to noise**
    - Error detection and correction is possible
- **Flexibility**
  - **Data-casting easily multiplexed into digital signal**
  - **Higher Data Security**

What is Digital?

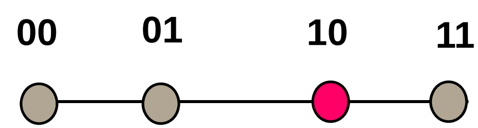
- Source and Destination is digital data
  - Assign unique patterns of 1’s and 0’s
- Transmission path is via an analog carrier
  - Choice of modulation is the one that optimizes bandwidth (data versus frequency ‘space’) and resiliency to noise



Generate Digital

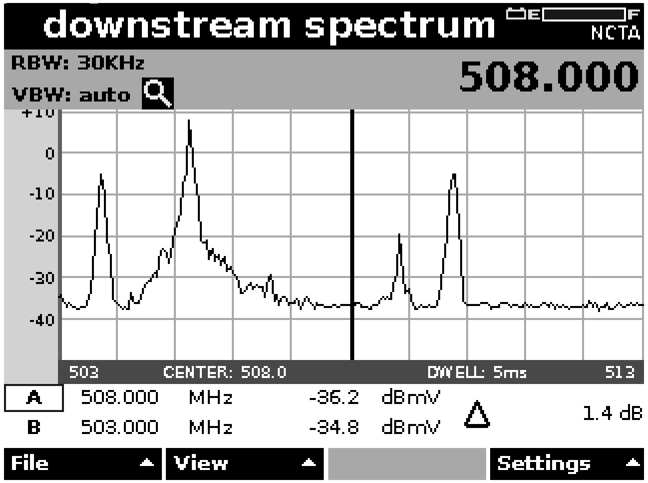


Transmit Analog

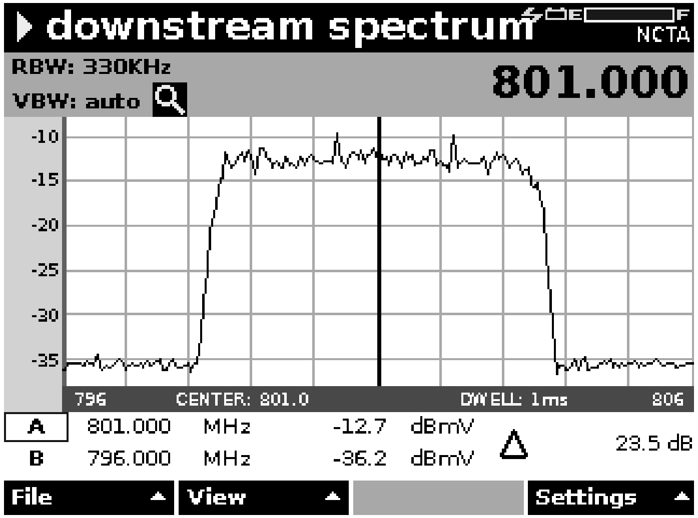


Receive Digital

The Carrier, by the way, is ANALOG Modulation



Analog Content –
Analog Carrier



Digital Content –
Analog Carrier

Some good news…and some bad news

- **Good**
  - Digital TV, DOCSIS, Digital Voice all use SAME type of RF Modulation – QAM
  - Same measurements apply
  - Signal level, Modulation Error Ratio, Bit Error Rate, in-band frequency response, are all similar, if not identical.
- **Bad**
  - Each service has different threshold of impairments
  - What is noticeable in Digital voice may not be perceptible in DOCSIS, what is bothersome in DOCSIS is different than digital video.

QAM and CATV

- **16 QAM is part of the DOCSIS® 1.0/1.1 upstream specifications**
- **64 QAM and 256 QAM is used for both digital video and DOCSIS downstream, allowing more digital data transmission using the same 6 MHz bandwidth**
  - Transmit equivalent of 6 to 10 analog channels (VCR quality) over one 6 MHz bandwidth
- **Standard for data over Cable**
  - Cable systems provide higher signal to noise ratios than over-the-air transmission. A well designed and maintained cable plant meets these QAM signal to noise requirements.

QAM Data Capacity (Annex B)

	16 QAM (Upstream)	64 QAM (Downstream)	256 QAM (Downstream)
Symbol Rate (Msps)	2.560 (@ 3.20 MHz)	5.0569 (@ 6 MHz)	5.3605 (@ 6 MHz)
Bits per symbol	4	6	8
Channel Data Rate (Mbps)	10.24	30.3417	42.8843
Information bit rate(Mbps)	9.0	26.9704	38.8107
Overhead	12.11%	11.11%	9.5%

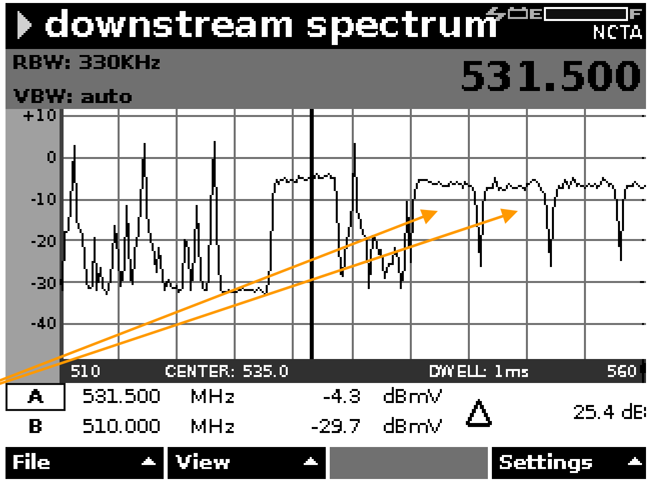
DOCSIS®

What is it?

What differs among versions?

What is a DOCSIS Signal??

- Data over a digital QAM signal
  - Digital signal
    - Downstream usually 64 or 256 QAM
    - Upstream usually QPSK or 16 QAM
  - Uses Data Packets
    - Information broken into chunks
  - Asymmetrical communication
    - More Info Downstream
    - Less Info Upstream



Digital "haystack"

DOCSIS® Versions at a Glance

DOCSIS 1.0 (High Speed Internet Access)

– 23 million products shipped worldwide as of YE2002
– 228 CM Certified, 29 CMTS Qualified

DOCSIS 1.1 (Voice, Gaming, Streaming)

– Interoperable and backwards-compatible with DOCSIS 1.0
– "Quality of Service" and dynamic services, a MUST for PacketCable™
– In the field NOW - 64 CM Certified, 22 CMTS Qualified

DOCSIS 2.0 (Capacity for Symmetric Services)

– Interoperable and backwards compatible with DOCSIS 1.x
– More upstream capacity than DOCSIS 1.0 (x6) & DOCSIS 1.1 (x3)
– Improved robustness against interference (A-TDMA and S-CDMA)
– Available NOW – Number of CM & CMTS Qualified growing

DOCSIS 3.0 (Channel Bonding)

– Interoperable and backwards compatible with DOCSIS 1.x & 2.0
– Specification released earlier this month – Devices not yet available

DOCSIS 1.1 Overview

- **Interoperable** with DOCSIS 1.0, plus more…
  – Access to bandwidth at high data rates or lower latency adds more value
- **Enhanced** “Quality of Service” (QoS)
  – Guarantees and/or limits for data rates
  – Guarantees for latency
- **Improved security** - designed to reduce possibility of “theft of service, provide secure software downloading.” – BPI+
- **Interoperability** - DOCSIS 1.0 and DOCSIS 1.1 cable modems and CMTSs on the same plant. Better operation and OSS features
- **Transmit Equalization** - more robust transmission
- **Max Modulation**
  – 256 QAM Downstream (~40Mbps)
  – 16 QAM Upstream @ 3.2MHz (~10Mbps)

DOCSIS 2.0 Overview

- Symmetrical services are enabled by DOCSIS 2.0
  - 1.5x greater efficiency
    - operates at 64 QAM
  - 2x wider channels
    - new 6.4 MHz wide channel
- 3x better upstream performance than V1.1
- 6x better upstream performance than V1.0
- DOCSIS 2.0 widens the pipe for IP traffic, allowing cable providers to create more and better services for voice, video, and data
- It does this by using enhanced modulation and improved error correction
- Superior ingress and impulse noise performance
- 100% backward compatible with DOCSIS 1.0/1.1

DOCSIS 3.0 Overview

- Specification late last year
  - DOCSIS 3.0 Interface Specifications (Released December 2006)
  - CPE equipment in development stages
- Downstream data rates of 160 Mbps or higher
  - Channel Bonding
  - 4 or more channels

256QAM => ~40Mbps

4 x 256QAM => ~160 Mbps

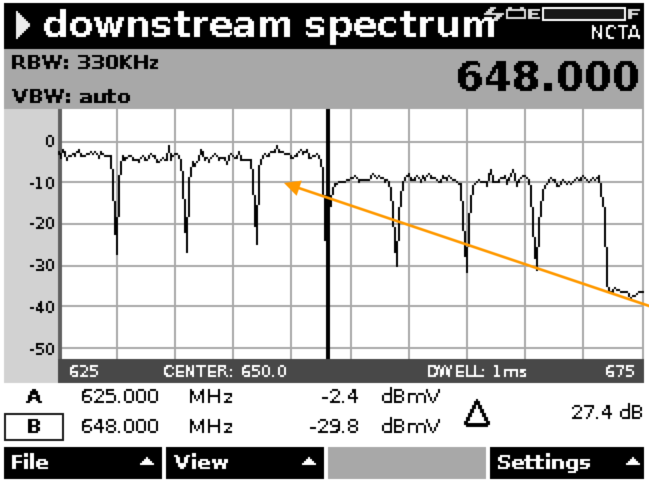
- Upstream data rates of 120 Mbps or higher
  - Channel Bonding
  - 4 or more channels

64QAM => ~30Mbps

4 x 64QAM => ~120 Mbps

- Internet Protocol version 6 (IPv6)
  - IPv6 greatly expands the number of IP addresses
    - Expands IP address size from 32 bits to 128 bits
    - IPv6 supports 3.4×10^{38} addresses;
    - Colon-Hexadecimal Format 4923:2A1C:0DB8:04F3:AEB5:96F0:E08C:FFEC
- 100% backward compatible with DOCSIS 1.0/1.1/2.0

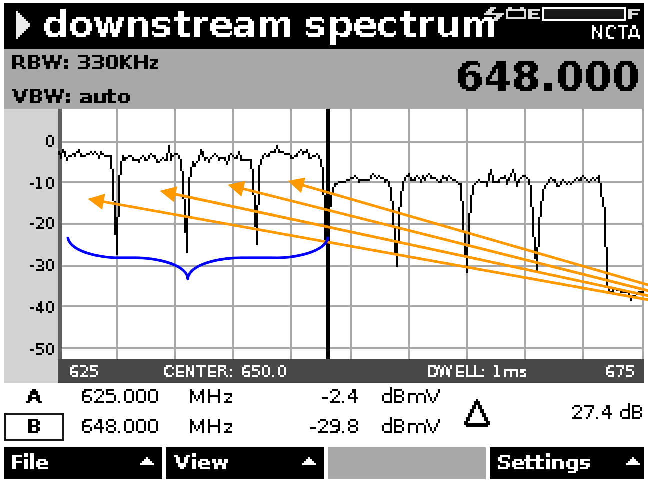
DOCSIS 3.0 – Channel Bonding



Individual QAM 256 DOCSIS channel

Versions 1.0/1.1/2.0 used only one channel for upstream and one channel for downstream communications

256QAM => ~40Mbps



4 Bonded QAM 256 DOCSIS channels

DOCSIS v3.0 Spec requires devices to be able to bond a minimum of 4 upstream channels into one and 4 downstream channels into one for 4 times increased throughput in both directions

The MSO does not have to use all 4 channels, but the devices which are 3.0 compliant must have the ability to bond 4 or more channels in both directions

4 x 256QAM:

4 x 40Mbps = 160 Mbps

Digital Testing and Troubleshooting

How?

What does it mean?

QAM Digital Measurements

- Spectrum & Digital Average Power Level
- MER QAM
- Pre/post FEC BER
- Constellation Display

- Advanced Tests
  - QAM Ingress Under The Carrier
  - Group Delay
  - In-Channel Frequency Response
  - Equalizer Stress (Adaptive Equalization)

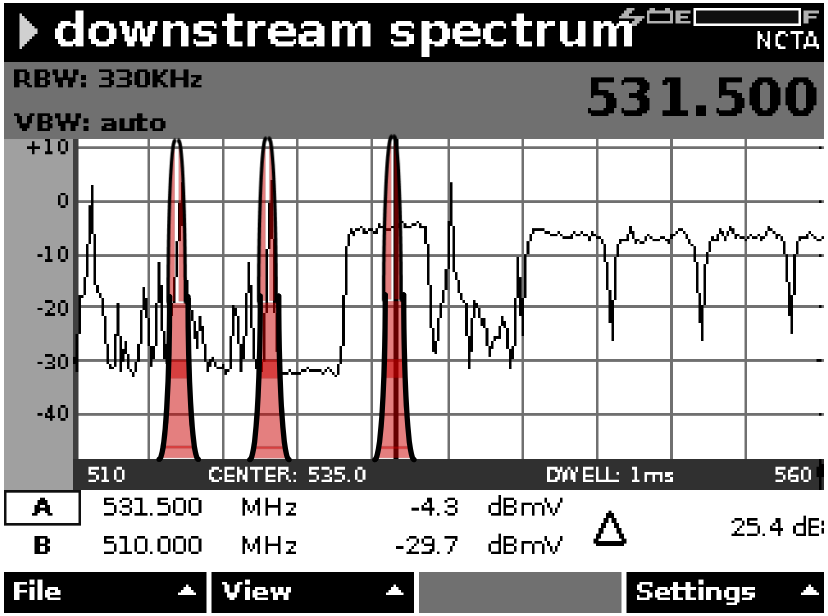
QAM Digital Measurements

- Measuring the quality of QAM digital carriers is significantly different than measuring analog carriers.
- Measurement of digital carriers is important to determine how close the carrier is to failing (how much margin) since there may be no quality degradation.

Digital Average Power Level Measurements

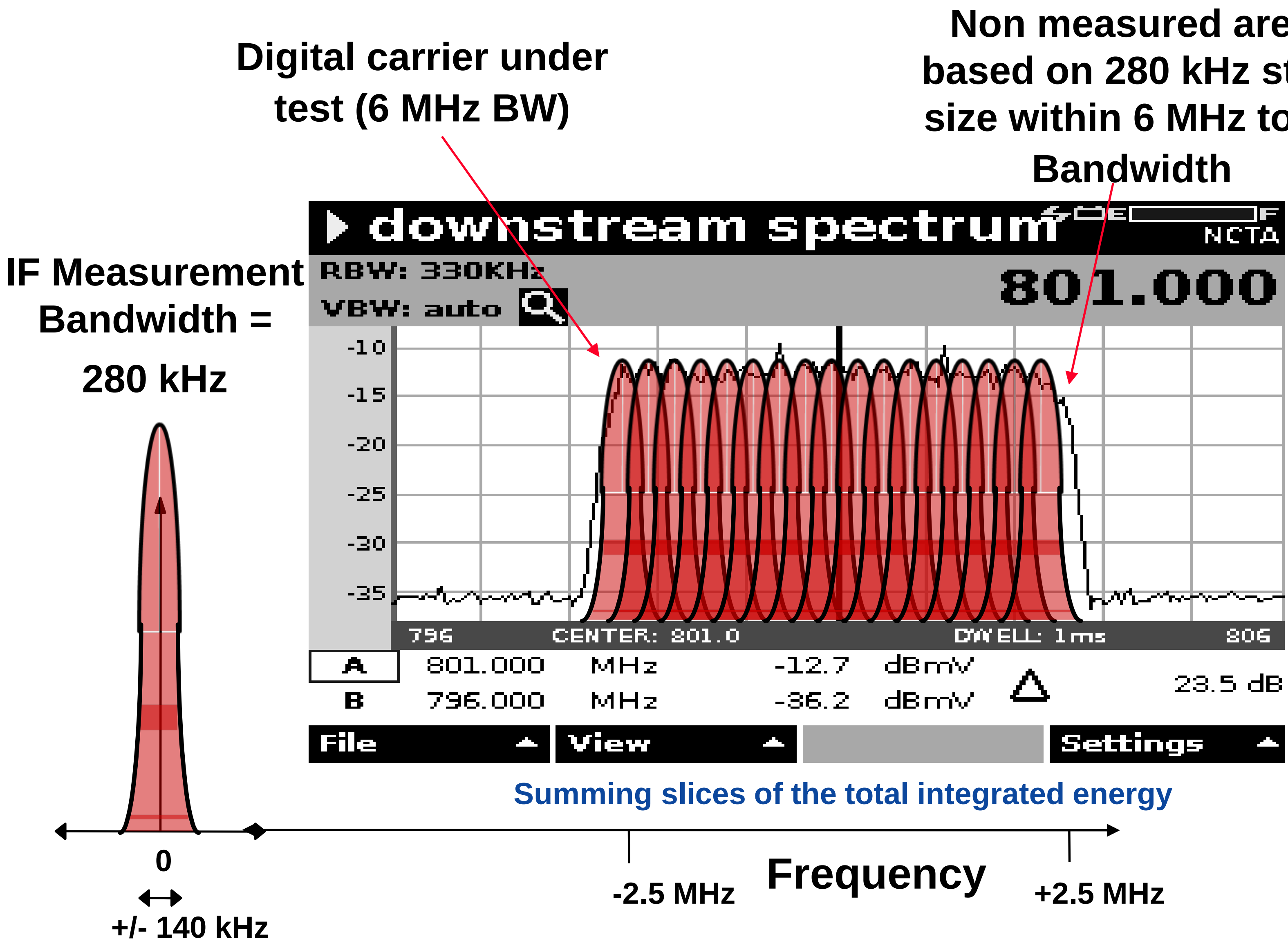
Digital Average Power Measurements and Measurement Bandwidth

- The spectrum analyzer view is an excellent tool to see discreet RF-carriers.
  - Caution is needed when viewing digital modulated signals (haystack). The signal's level measurement is derived from the selected measurement bandwidth (resolution bandwidth). At an RBW of 300 kHz, a 64QAM - 6 MHz wide digital signal reads in the spectrum analyzer trace 3 dB too low.
- The Average Power principle takes small slices from the integrated RF-energy, summing them together to one total power reading in the LEVEL-mode.



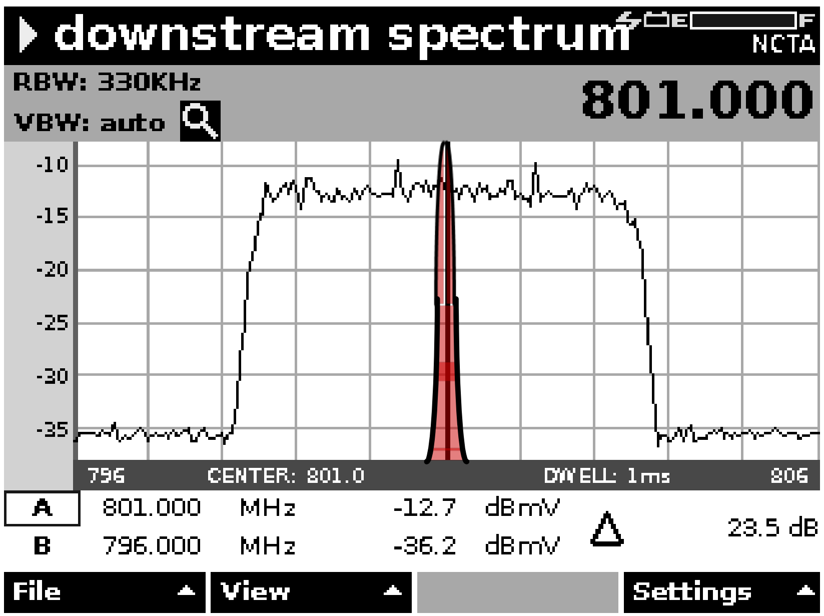
Analog and digital (broadcast) QAM signal. The recommended delta in level should be 6 to 10 dB.

Measuring the Digital "Haystack"



Measuring the Digital “Haystack”

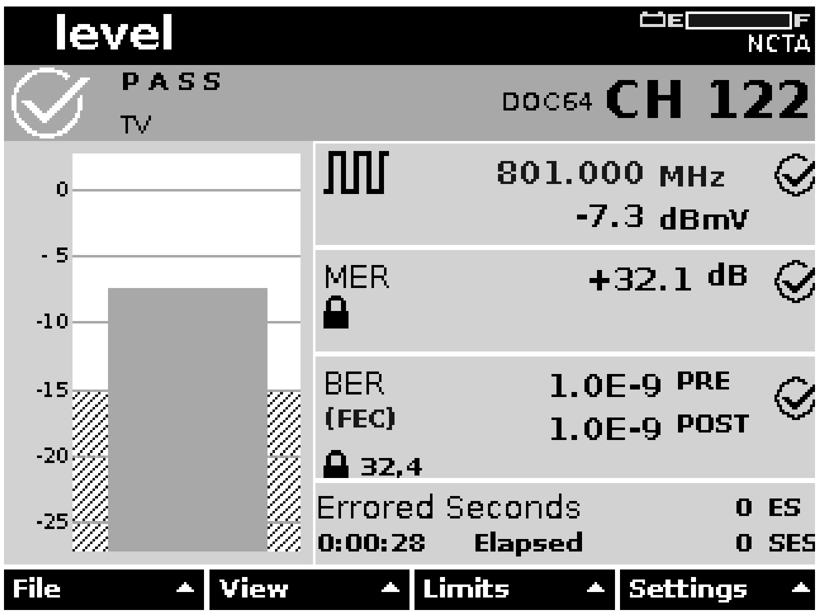
Measuring the Peak Level of the Digital Haystack



280 kHz

Bandwidth power

Measuring the Average Level of the Digital Haystack

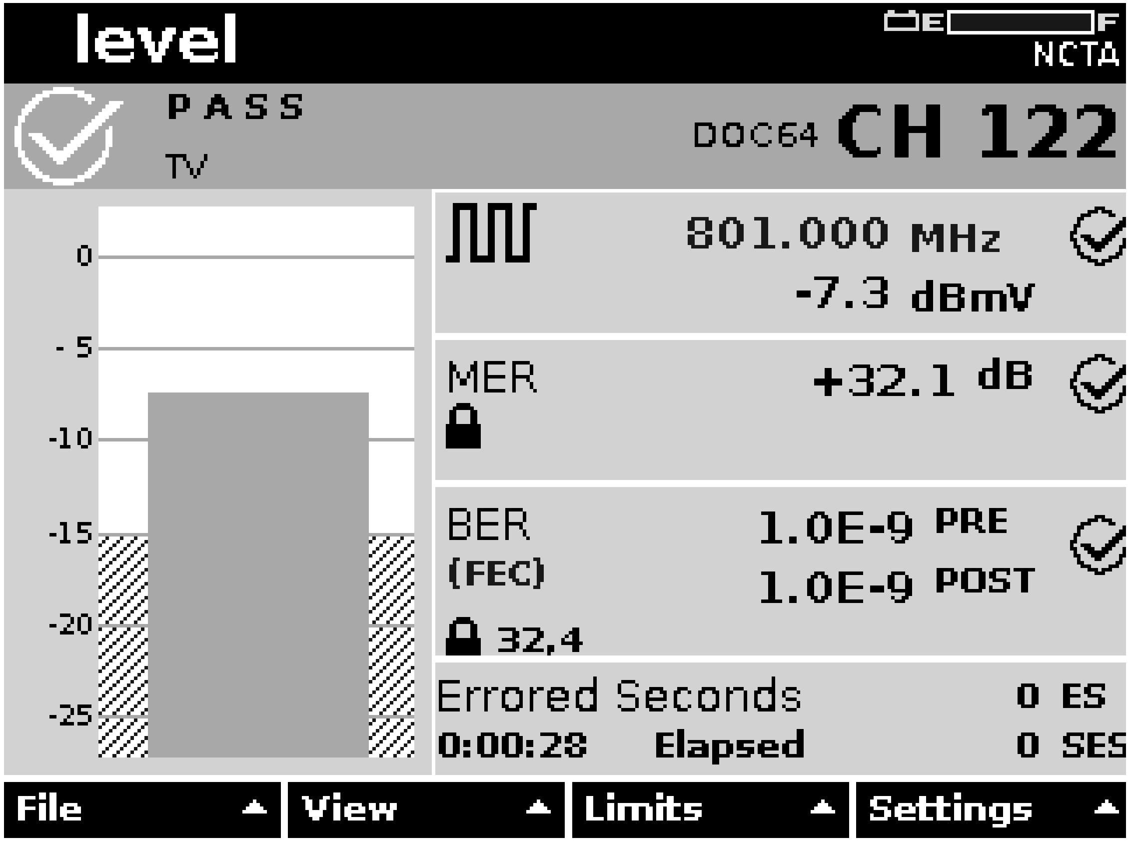


6 MHz

Bandwidth power

Digital – more than just dB's

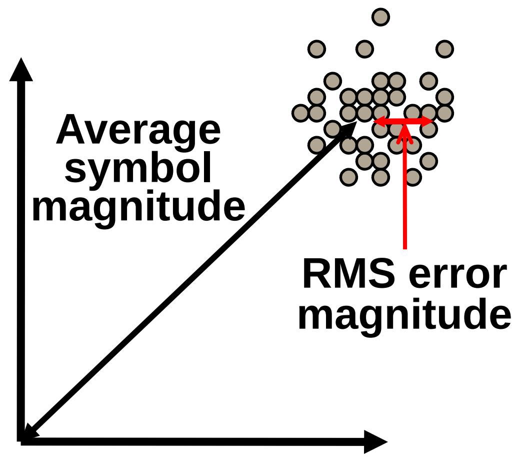
MER and Pre and Post BER measurements are key to insuring Digital Quality



Modulation Error Ratio (MER)

- Analogous to S/N
- A measure of how symbols (I vs. Q) are actually placed, compared to ideal placement

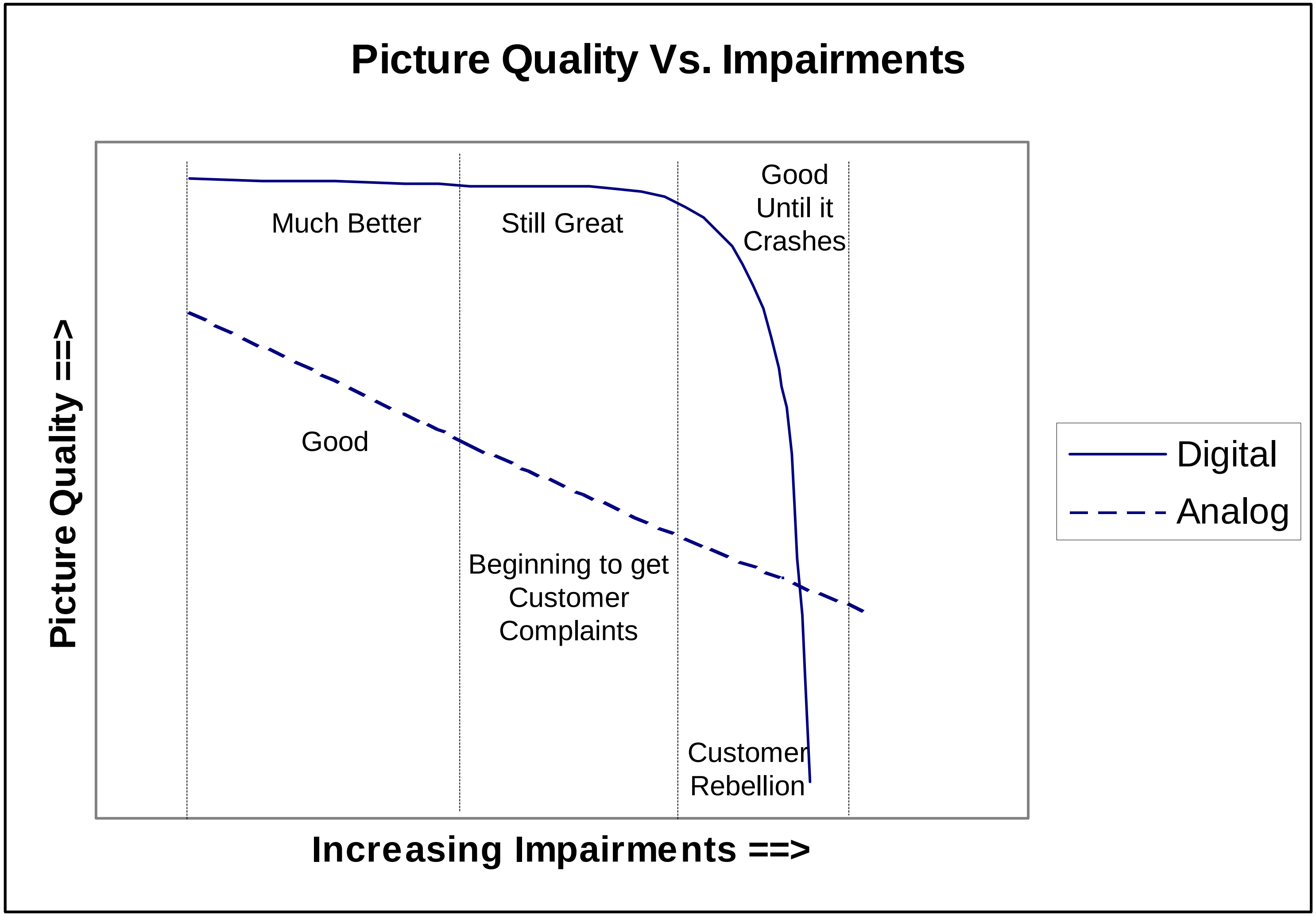
- $\text{MER(dB)} = 20 \times \log \left[\dfrac{\text{RMS error magnitude}}{\text{average symbol magnitude}} \right]$
- Good MER
  - 64 QAM: 28 dB MER
  - 256 QAM: 32 dB MER



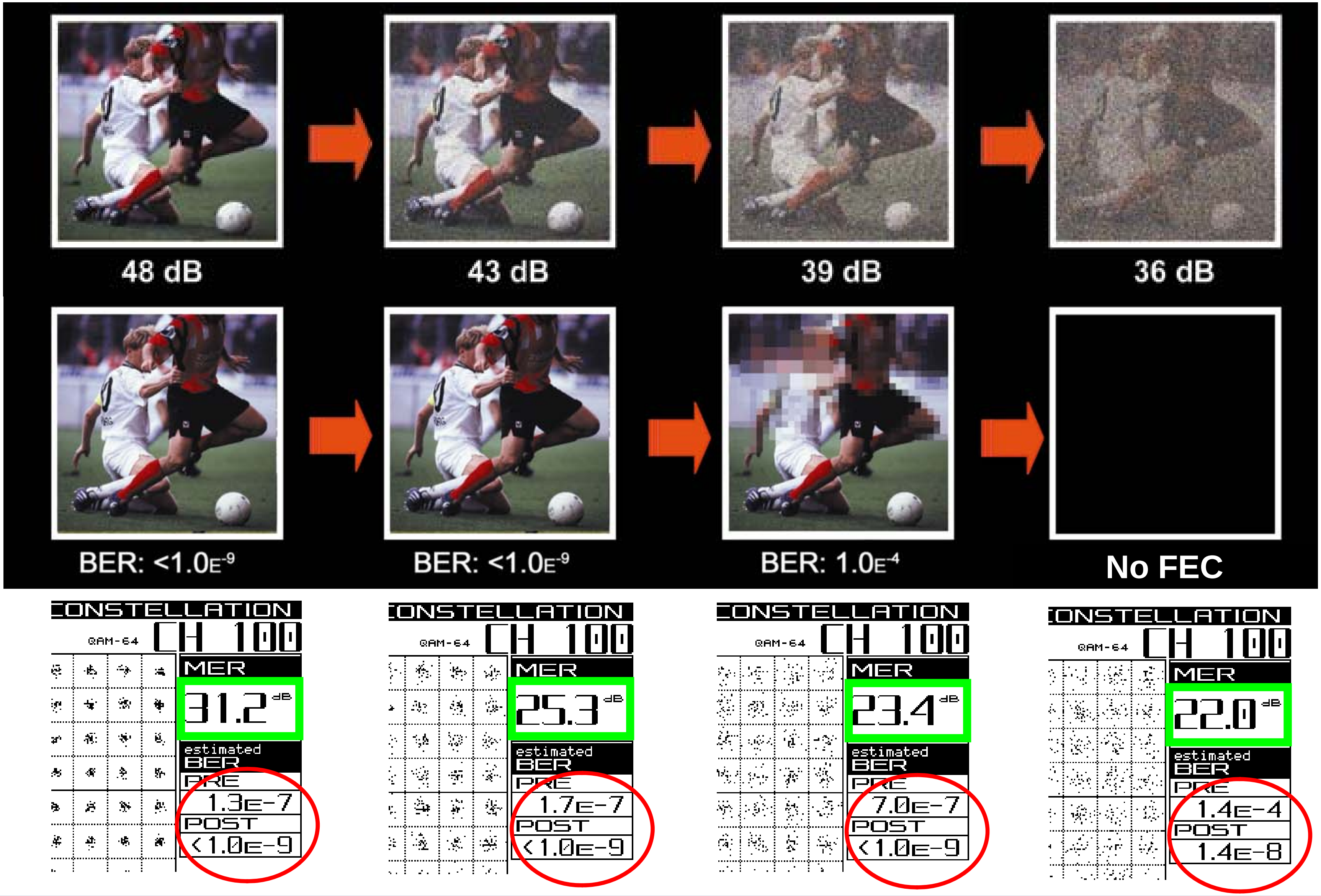
More MER

- Modulation Error Ratio (MER) in digital systems is similar to S/N or C/N used in analog systems
- MER determines how much margin the system has before failure
  - Analog systems that have a poor C/N show up as a "snowy" picture
  - A poor MER is not noticeable on the picture right up to the point of system failure - "Cliff Effect"
- Can't use the TV as a piece of test equipment anymore

Digital TV Waterfall Graph



C/N vs. BER vs. MER



Lets have some MER review…

- "MER" is to Digital, what signal to noise is for analog
- MER is affected by high noise, low signal
- Also ANY other continuous impairments
- MER readings are relatively immune to "brief bursty" interference
- MER is a predictor of BER

  - 256 QAM *needs* 29dB or better to work.
  - 64 QAM *needs* 25dB or better to work.
  - Add at least 3db to above figures to allow headroom.

Bit Error Rate (BER)

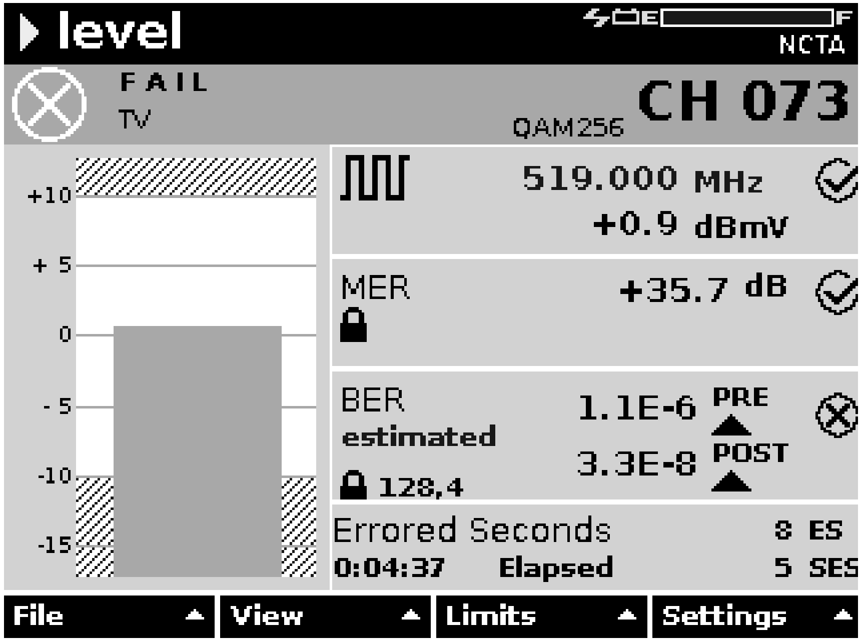
- **Bit errors result when the receiver interprets the wrong symbol and hence the wrong bits**
- **The number of bit errors versus the number of bits transmitted is Bit Error Rate (BER)**
- **The more bits that are incorrect, the more the signal will be affected**
- **Good signal: BER 10^{-10} (1.0 E^{-9})**
- **Threshold for visible degradation: BER $1E^{-6}$**
  - One error in every 1,000,000 bits

More on BER

- "BER" is HOW many errors per HOW many bits of data
- BER is affected by bursty interference
- Also, any other impairments will adversely affect BER
- Some amount of errors can be corrected by digital receivers.
- POST errors are uncorrected errors – always unacceptable!!!
- Measurement reads in scientific notation
- 1.0 E-9 is the best on a handheld test meter

Pre and Post FEC BER

- Number of bad bits for every good bit.
- Forward Error Correction when working will output $>10^{-11}$
  - 1 error in 100 billion bits
  - 1 error every 42 minutes
  - MPEG-2 likes good BER
- FEC will work to about 10^{-4}
  - 1 error in 10,000 bits
  - 1 error every 276 uses
- FEC causes Cliff Effect



BER Example

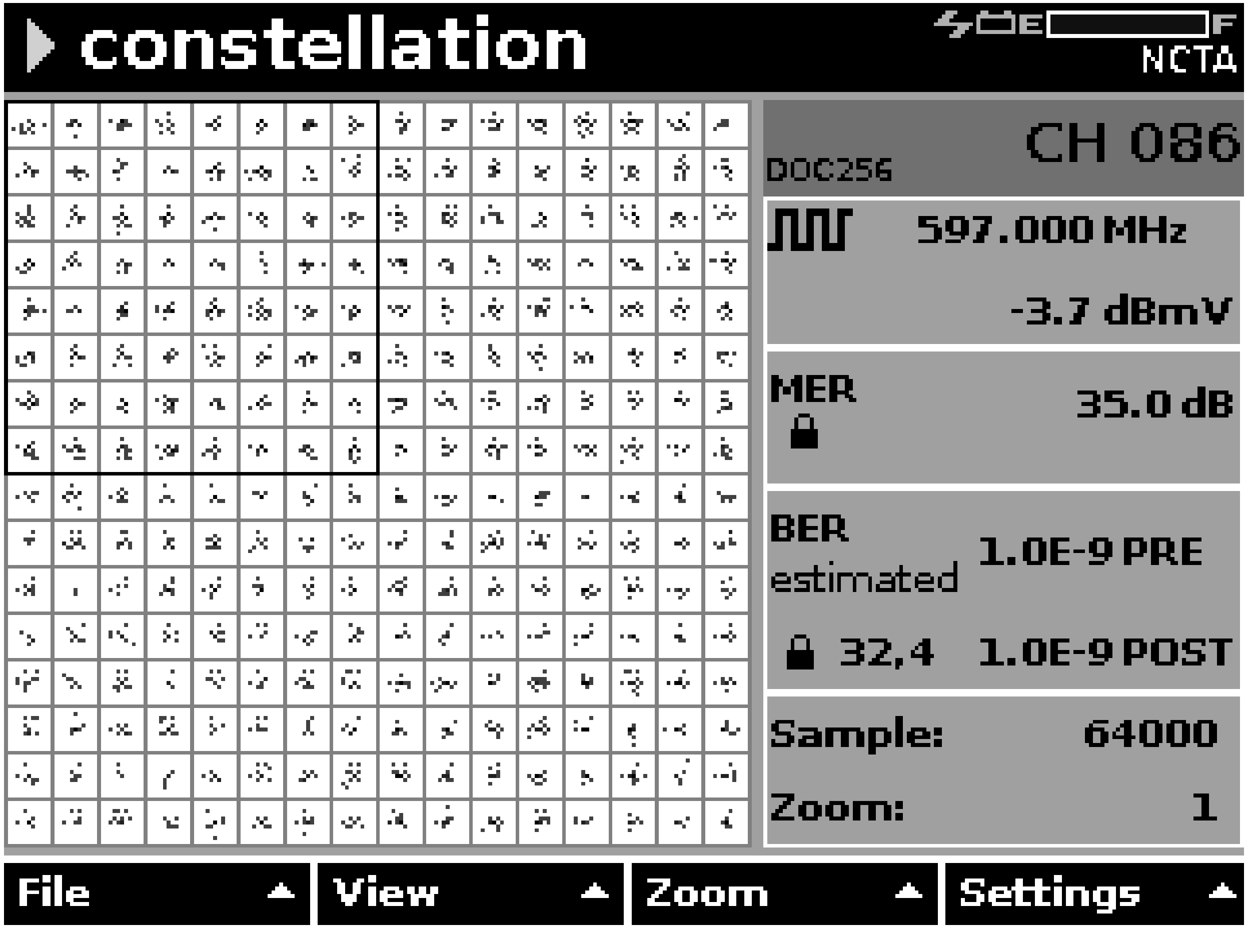
- **A 256QAM channel transmits at a symbol rate of 5M symbols per second**
- **Bit rate = 8 bits per symbol X 5M symbol per second =40M bits per second**
- **Error Incident = Bit rate X BER = Errors Per Second**

BER	Error Frequency	Error Incident
10^{-12}	1 in 1 Trillion bits	25000 secs between errs (6.94 hrs)
10^{-11}	1 in 100 Billion bits	2500 secs between errs (41.67 mins)
10^{-10}	1 in 10 Billion bits	250 secs between errs (4.167 mins)
10^{-9}	1 in 1 Billion bits	25 seconds between errors
10^{-8}	1 in 100 Million bits	2.5 seconds between errors
10^{-7}	1 in 10 Million bits	4 errors per second
10^{-6}	1 in 1 Million bits	40 errors per second
10^{-5}	1 in 100 Thousand bits	400 errors per second
10^{-4}	1 in 10 Thousand Bits	4000 errors per second
10^{-3}	1 in 1 Thousand bits	40000 errors per second

What Causes MER and BER to degrade? “ Noise”

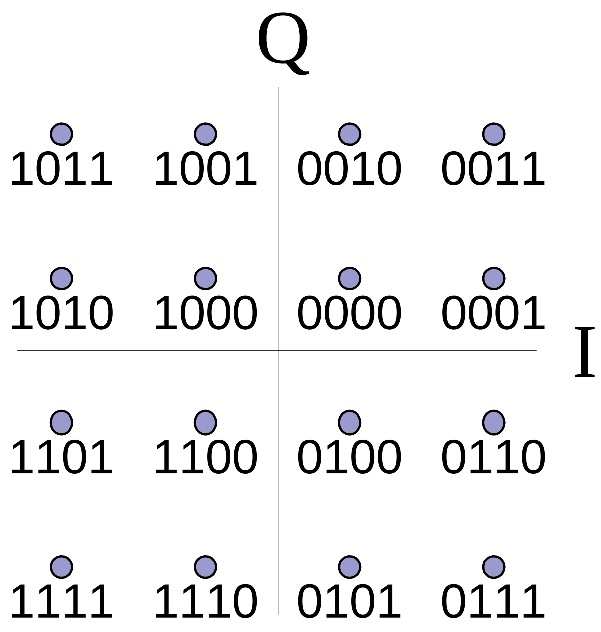
- The most common problem with digital-TV and cable modem services is interference under the digital carriers and Noise(stated by most larger operators with experience in digital transmission services).
- Most common sources are:
  – Ingress due to off-air UHF TV channels
  – Intermittent ingress due to pager transmitters or two-way
  radio base stations.
  – CSO/CTB-intermodulation

QAM Constellations



Constellations, Symbols and Digital Bits

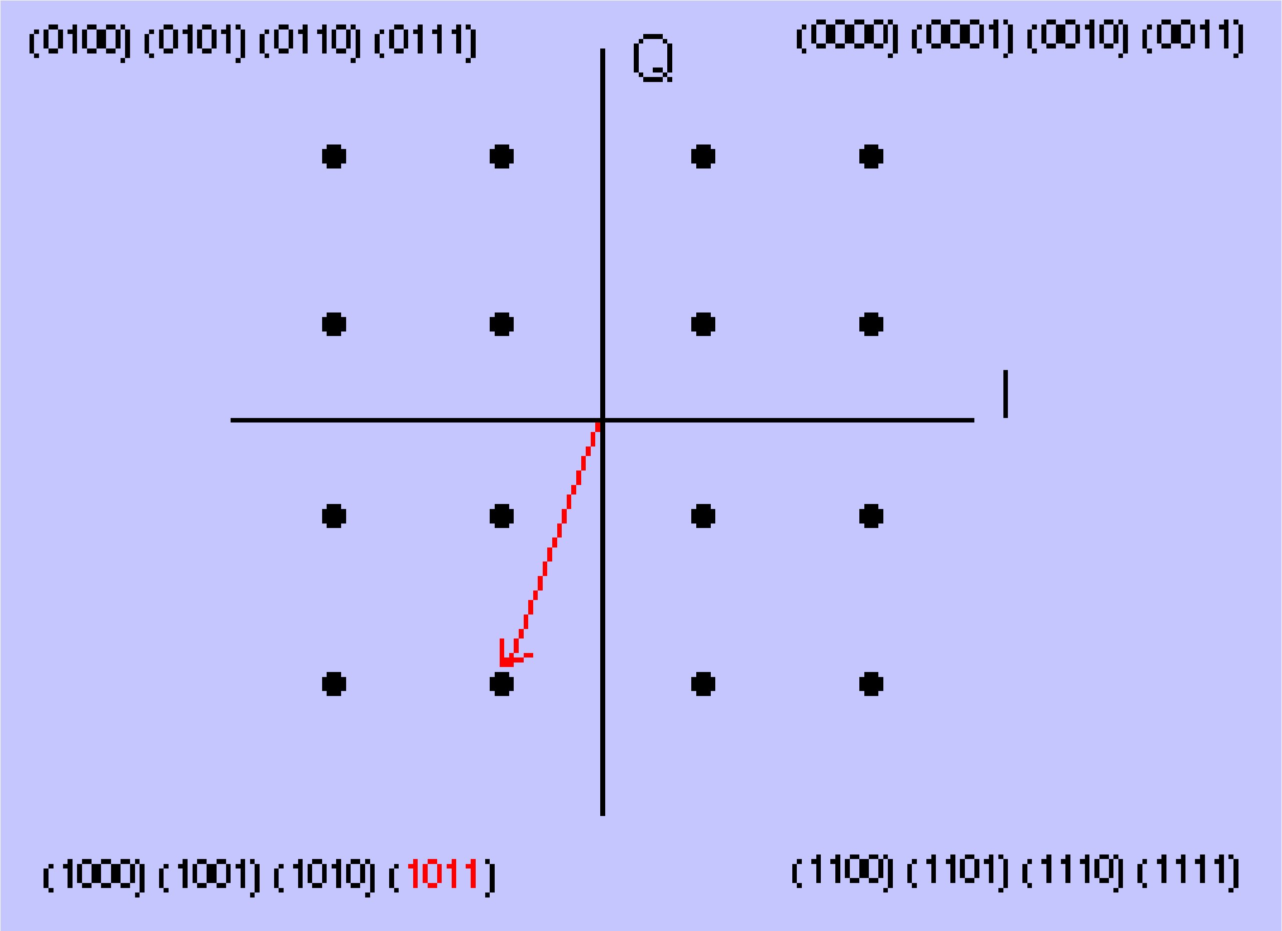
- Each “dot” on constellation represents a unique symbol
- Each unique symbol represents unique digital bits
- Digital data is parsed into data lengths that encode the symbol waveform



16 QAM

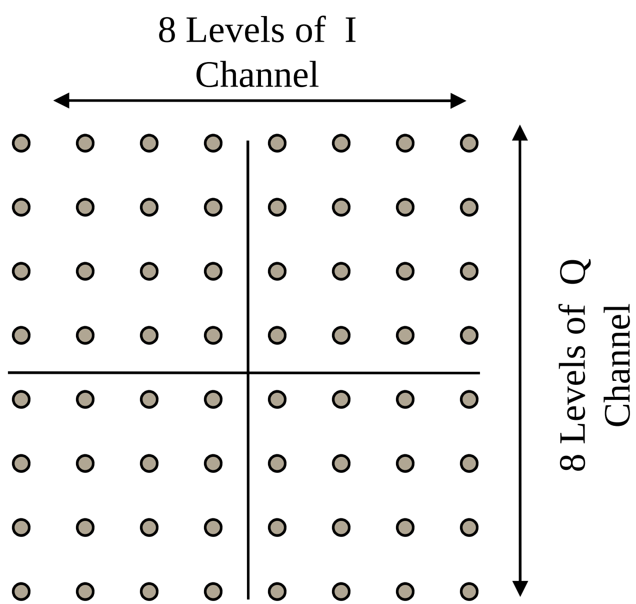
Constellation Display

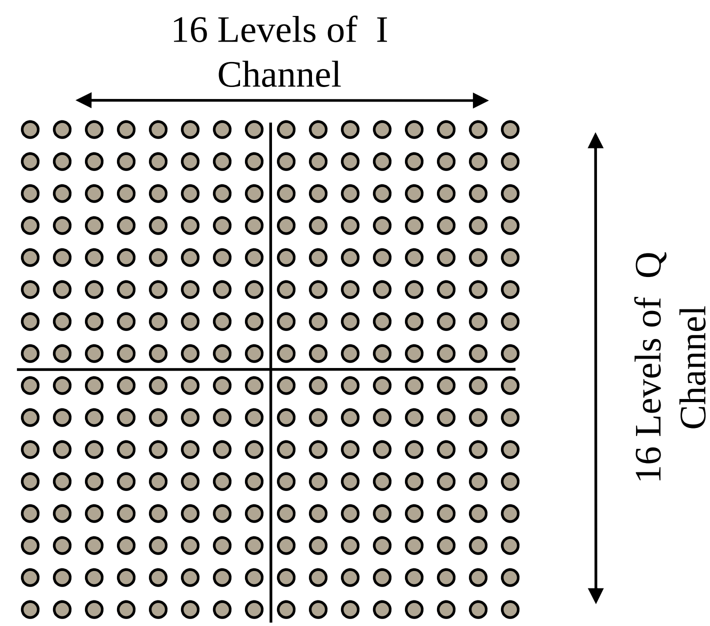
- This is a visual representation of the I and Q constellation plots on a 16 QAM carrier



64 QAM and 256 QAM

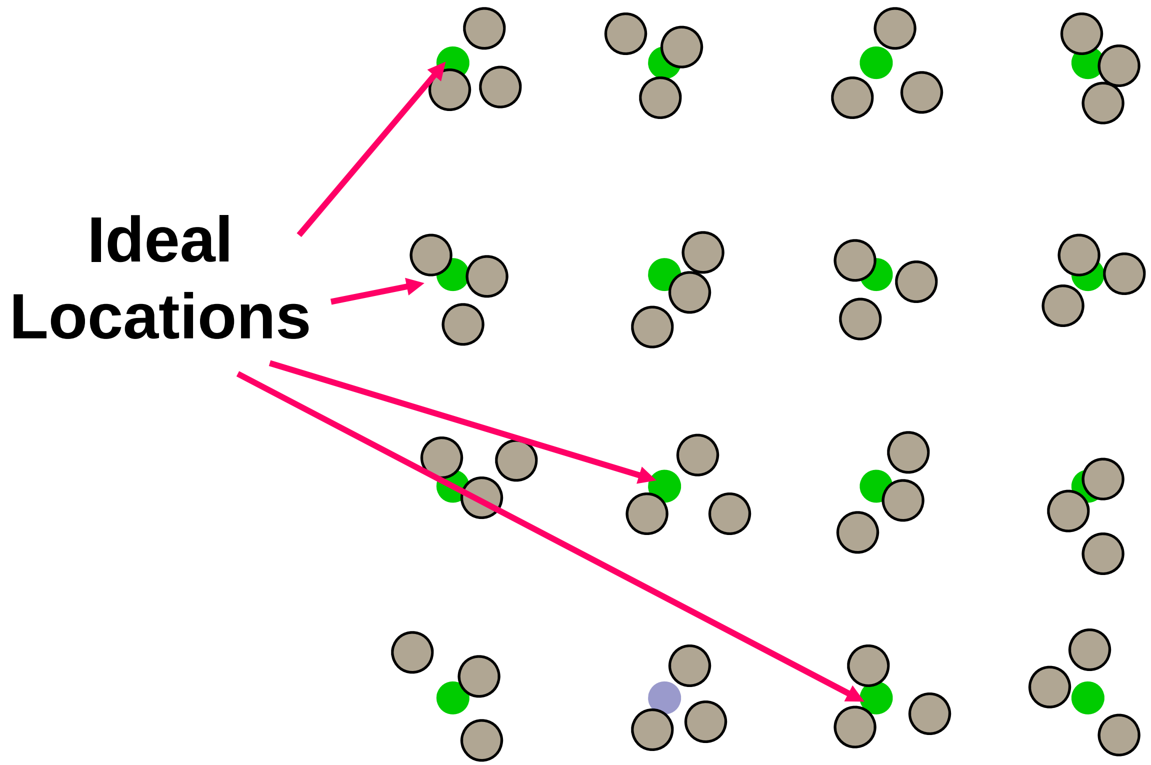
- 64 QAM has 8 levels of I and 8 levels of Q making 64 possible locations for the carrier.
- 256 QAM has 16 levels of I and 16 levels of Q making 256 possible locations for the carrier.





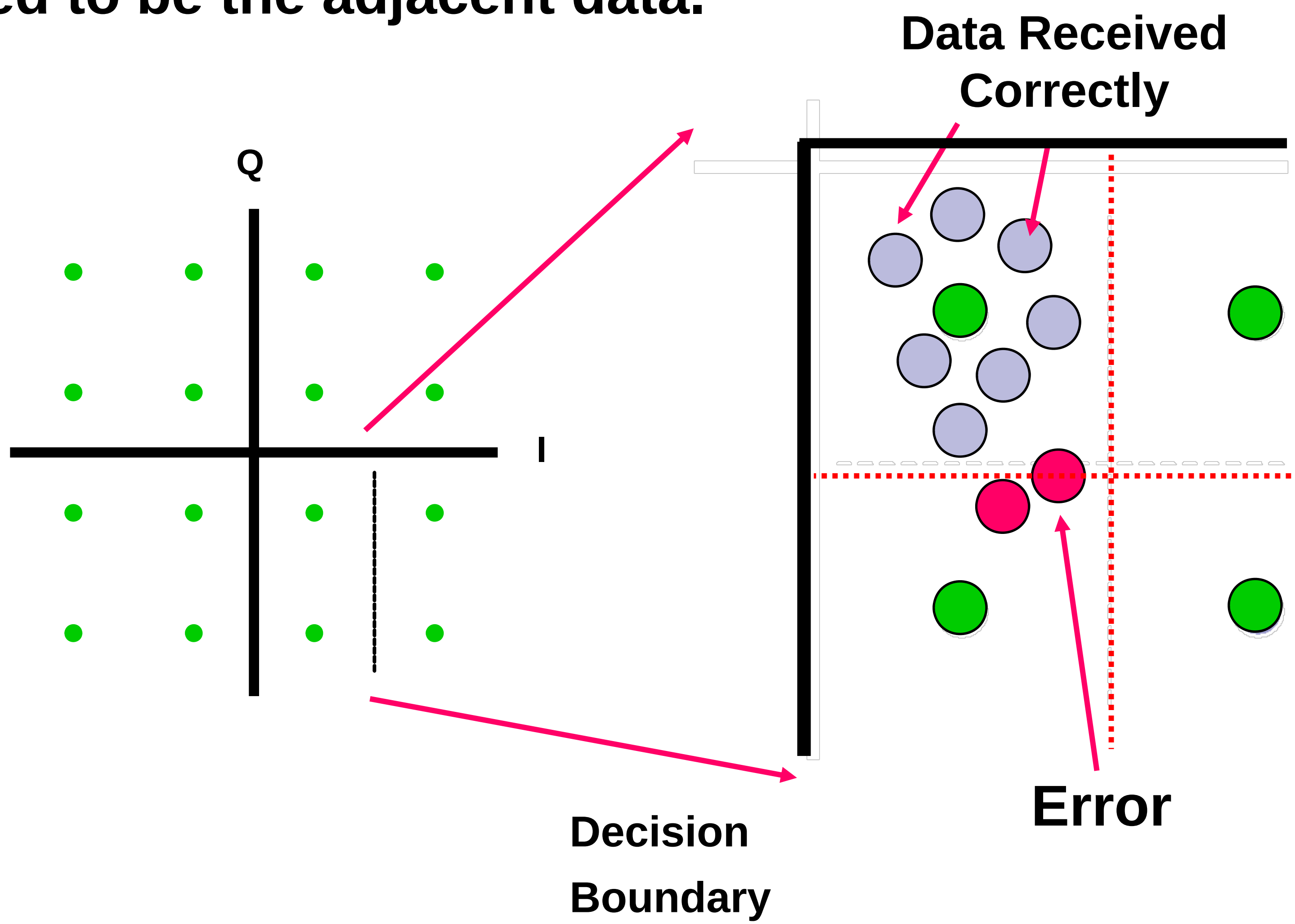
Effects of Noise and Interference

- **Noise and Interference moves the carrier away from its ideal location causing a spreading of the cluster of dots.**



Decision Boundaries

- **Data that falls outside the decision boundaries will be assumed to be the adjacent data.**



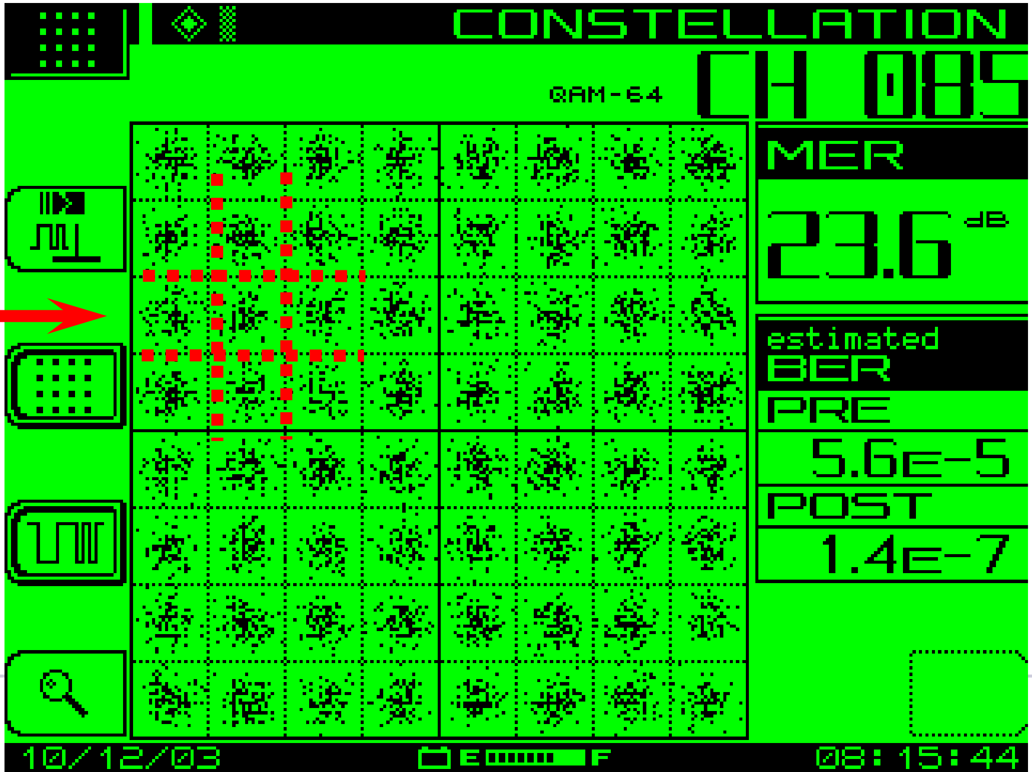
Constellation

- Typical errors which originate from the headend:
  - Phase Noise
    - **The constellation appears to be rotating at the extremes while the middle ones remain centered in the decision boundaries. Phase Noise is caused by headend converters.**
  - Gain Compression
    - **The outer dots on the constellation are pulled into the center while the middle ones remain centered in the decision boundaries. Gain Compression is caused by filters, IF equalizers, converters, and amplifiers.**
  - I Q Imbalance
    - **The constellation is taller than it is wide. This is a difference between the gain of the I and Q channels. I Q Imbalance is caused by baseband amplifiers, filters, or the digital modulator.**
  - Carrier Leakage

System Noise

- **A constellation displaying significant noise**
- **Dots are spread out indicating high noise and most likely significant errors**
  - An error occurs when a dot is plotted across a boundary and is placed in the wrong location
- **Meter will not lock if too much noise present**

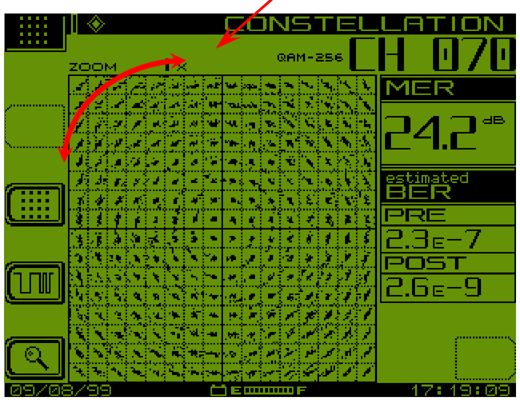
Dots are spread out showing error



Phase Noise

- Display appears to rotate at the extremes
- HE down/up converters can cause phase noise
- Random phase errors cause decreased transmission margin
- Caused by transmitter symbol clock jitter

Rotation



Constellation with Phase Noise

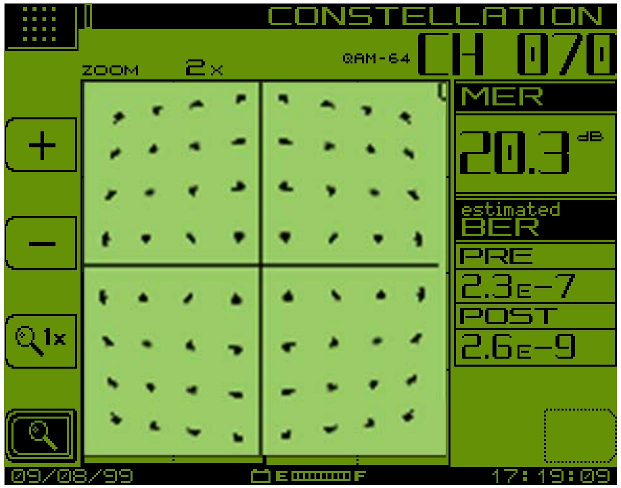
Rotation

Zoomed Constellation with Phase Noise

Gain Compression

- If the outer dots are pulled into the center while the middle ones are not affected, the signal has gain compression
- Gain compression can be caused by IF and RF amplifiers and filters, up/down converters and IF equalizers

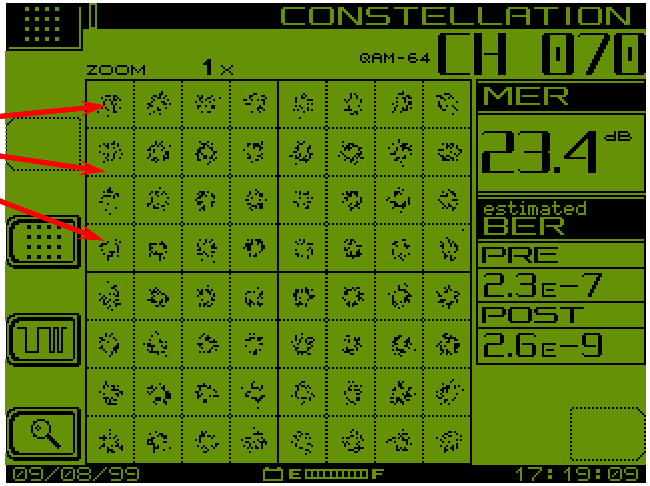
Outer edges pulled in

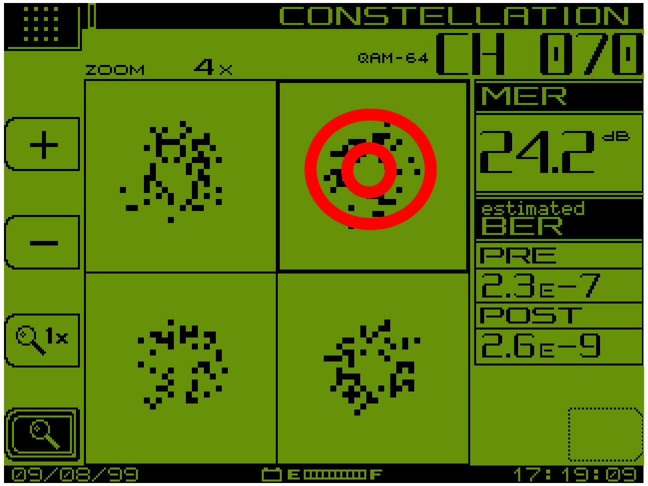


Coherent Interference

- **If the accumulation looks like a "donut", the problem is coherent interference**
  - CTB, CSO, Off-Air Carriers (ingress)
- **Sometimes only a couple dots will be misplaced**
  - This is usually laser clipping or sweep interference

Circular "donuts"





DOCSIS & IP Testing

What is important?

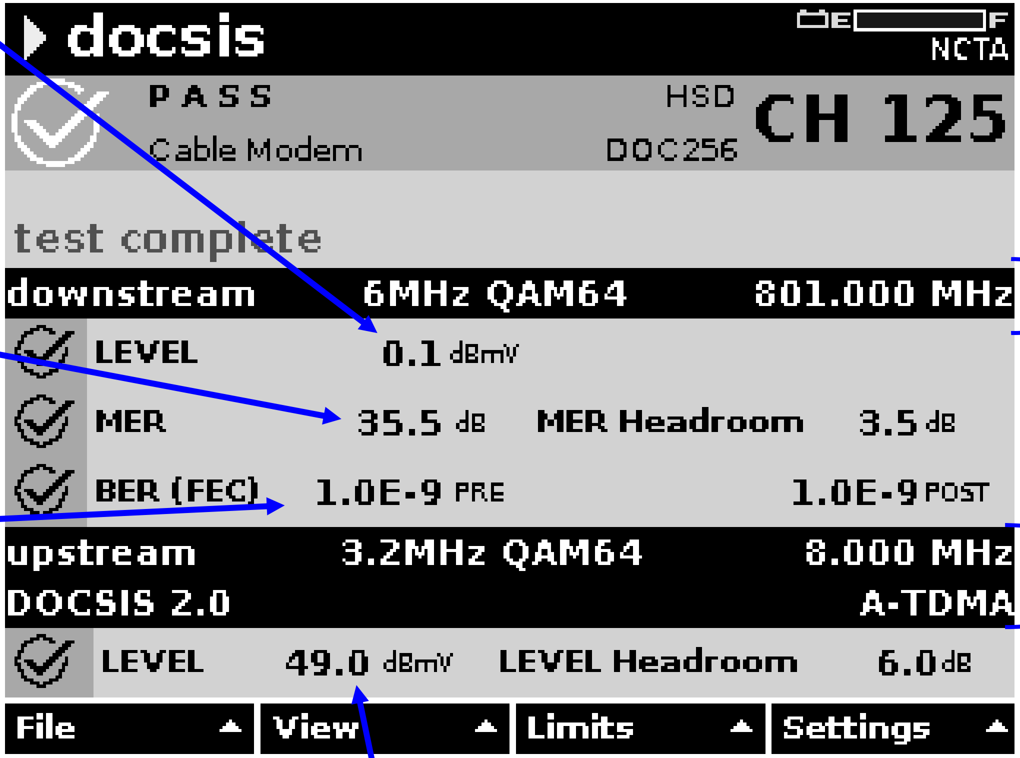
What can be done?

DOCSIS® Testing - Levels

Verify proper receive level at cable modem

MER shows that downstream is clean and clear with margin

BER shows that downstream is clean and clear of impulse noise



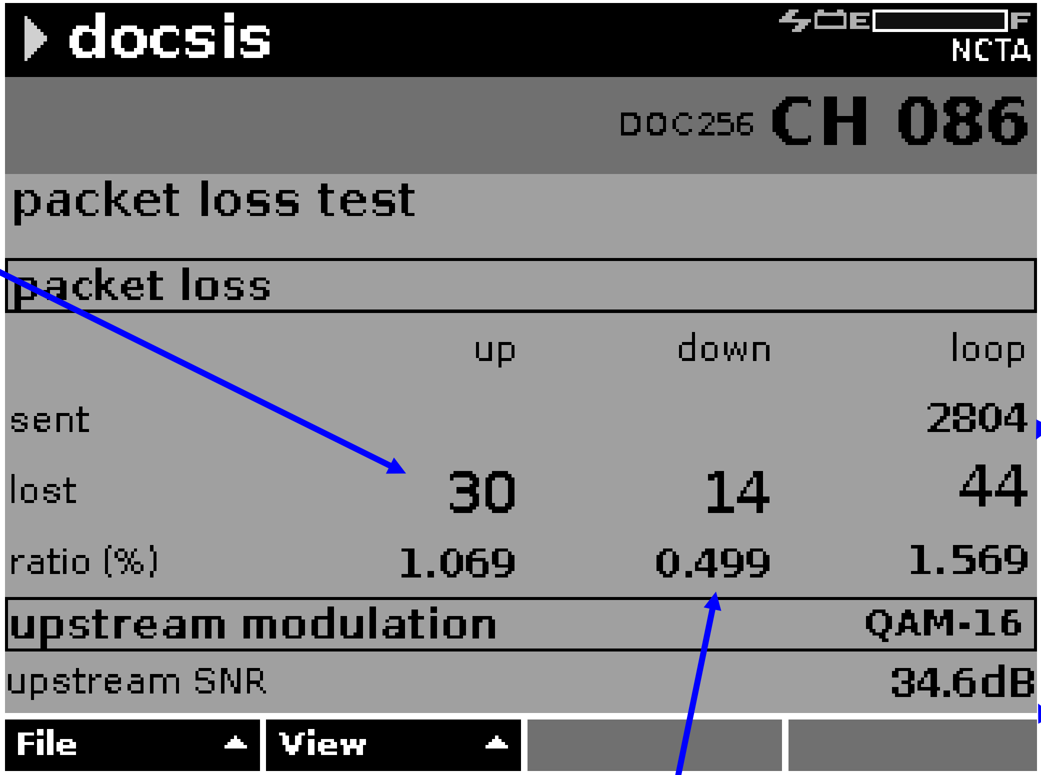
Downstream Information Frequency, Modulation type, Channel

Upstream Frequency, Modulation type, Channel BW, DOCSIS version

Shows that upstream is properly aligned and CMTS has “ideal” receive level with margin to spare

DOCSIS – Packet Loss Testing

Check Packet Loss and determine if upstream is good



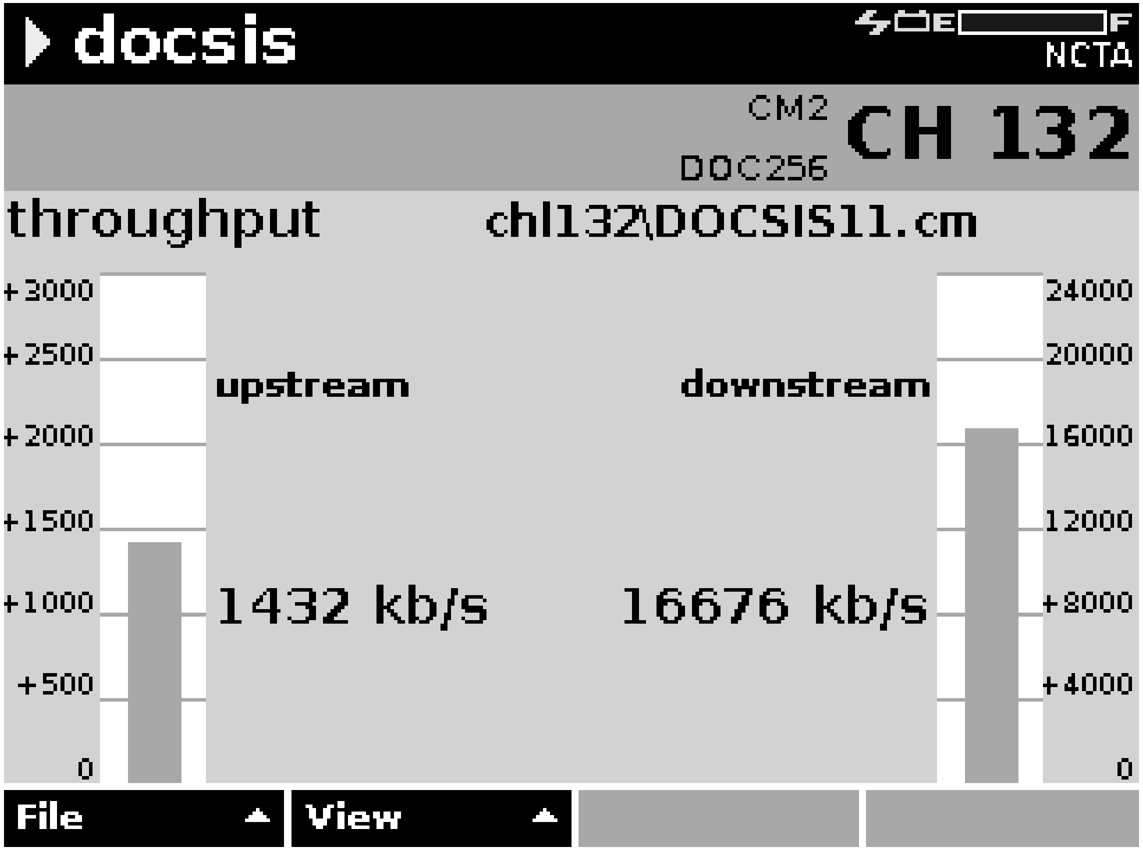
Overall loop information, Up+Downstreams

View Downstream performance

Upstream Signal to Noise Ratio

DOCSIS – Throughput Testing

Check Throughput for proper speeds



Ensure customer can get what they pay for

Correlate Data & Voice with RF

Compare Node Outages with your Return Path performance history to QUICKLY identify the cause of the problem – RF or Data layer!

Reset Alarm	Node ID	Node Status	US RF Interface--CMTS	CMEx Alarms	Current CMTS CMs Online	Cabletools CM Count	Most Recent Trap Time	Trouble Ticket Number
Verify	HI29	Possible Full Node Outage	Cable6/0-upstream0 (up) -- Chicago CMTS 1	1	0 of 15	29	06/05/02 13:10:56 MDT	BIS01640560
Verify	RI44	Possible Full Node Outage	Cable3/0-upstream1 (up) -- Chicago CMTS 8	1	4 of 70	71	06/05/02 15:12:24 MDT	BIS01481022
Verify	HI35	Full or Partial Node Outage	Cable6/0-upstream0 (up) -- Chicago CMTS 14	1	3 of 6	6	06/05/02 13:10:56 MDT	BIS01640623
Verify	HI24A	Full or Partial Node Outage	Cable2/0-upstream2 (down) -- Chicago CMTS 3	1	60 of 120	125	06/05/02 18:12:51 MDT	BIS12930781
Verify	EI19	Full or Partial Node Outage	Cable4/0-upstream0 (up) -- Chicago CMTS 13	1	3 of 21	25	06/05/02 20:11:16 MDT	BIS01640623
Verify	HI28	Full or Partial Node Outage	Cable5/0-upstream1 (up) -- Chicago CMTS 5	1	18 of 76	80	06/05/02 21:04:29 MDT	BIS08299910
Verify	HI31	Partial Node Outage	Cable5/0-upstream3 (down) -- Chicago CMTS 1	1	4 of 6	6	06/05/02 03:10:56 MDT	BIS01640603
Verify	RI18	Partial Node Outage	Cable2/0-upstream1 (up) -- Chicago CMTS 7	1	79 of 153	162	06/05/02 05:10:56 MDT	BIS01198764

HSD Node Outage Report Courtesy of Auspice Corporation

Return Path

Why is it important?

What can be done?

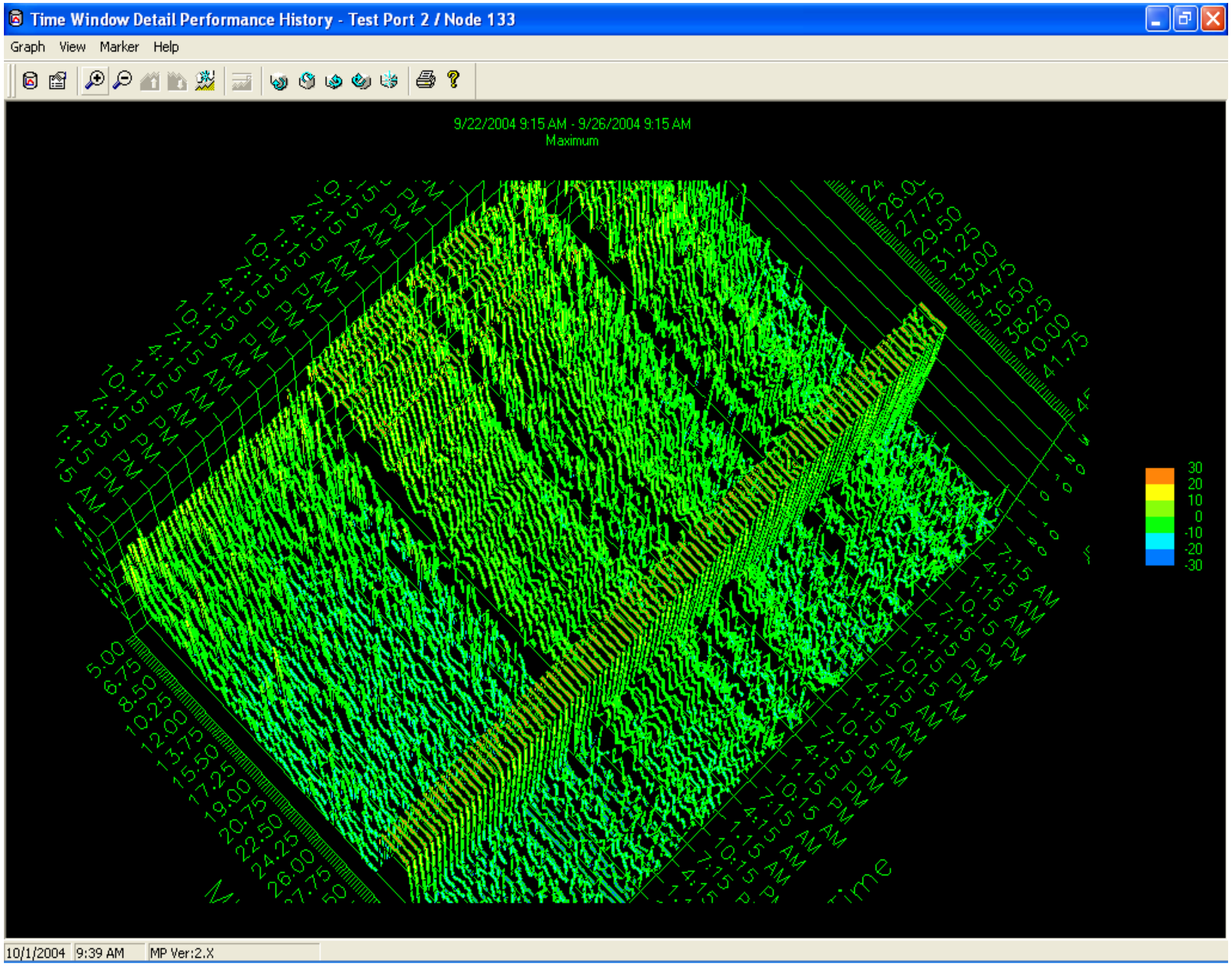
Why care about Return Path?

- DOCSIS and VoIP is a two-way communication
  - Downstream (Forward Path)
  - Upstream (Return Path)

- Can’t have one without the other

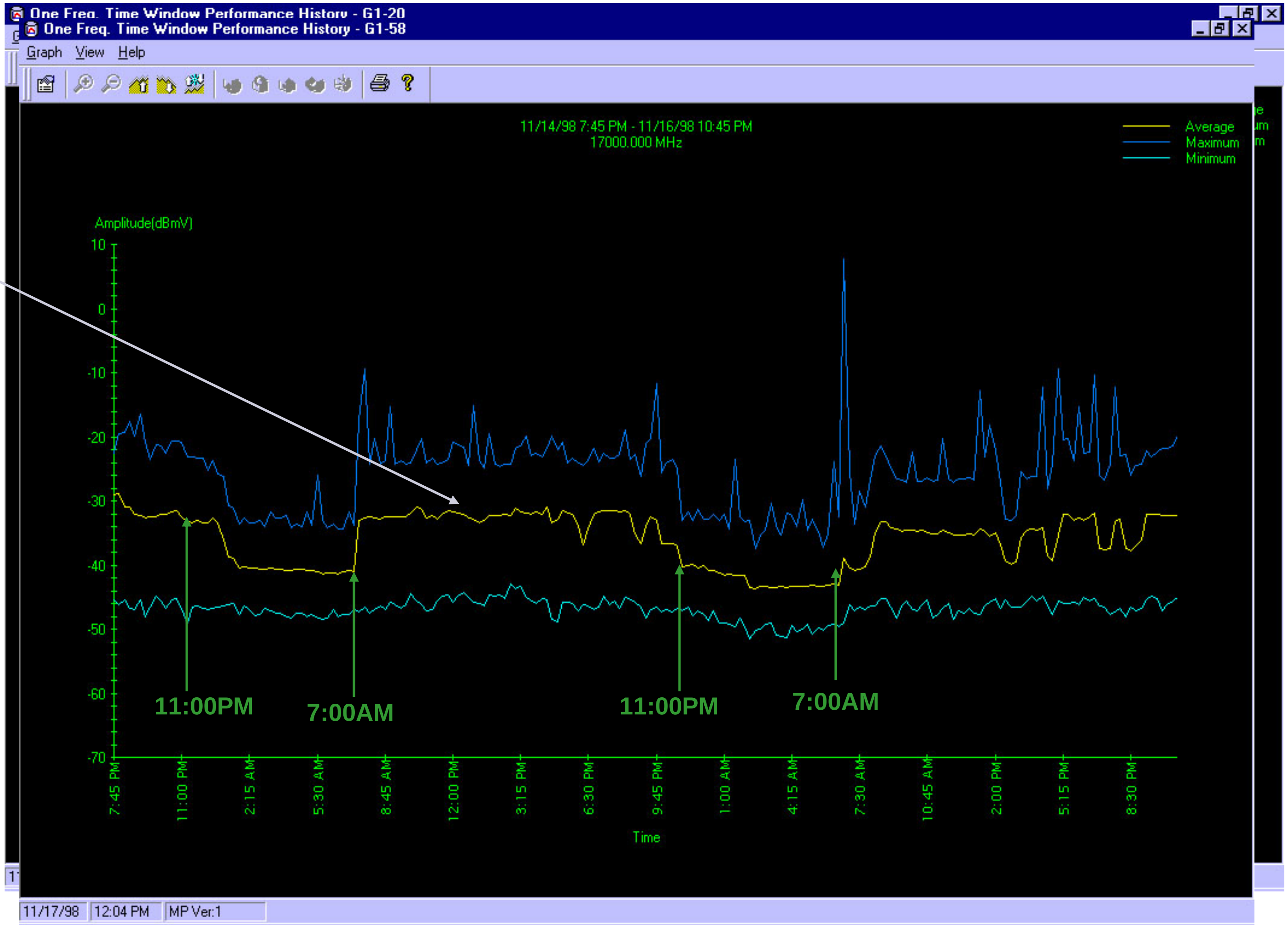
- Can not neglect the return path and expect DOCSIS to work properly

Monitor and Trend the Return Path



Return Path RF Trending Identifies Marginal Nodes

- Average noise floor varies consistently by time of day
- Indication of return path with an ingress problem.
- May be “ok” but maintenance now may prevent future problem

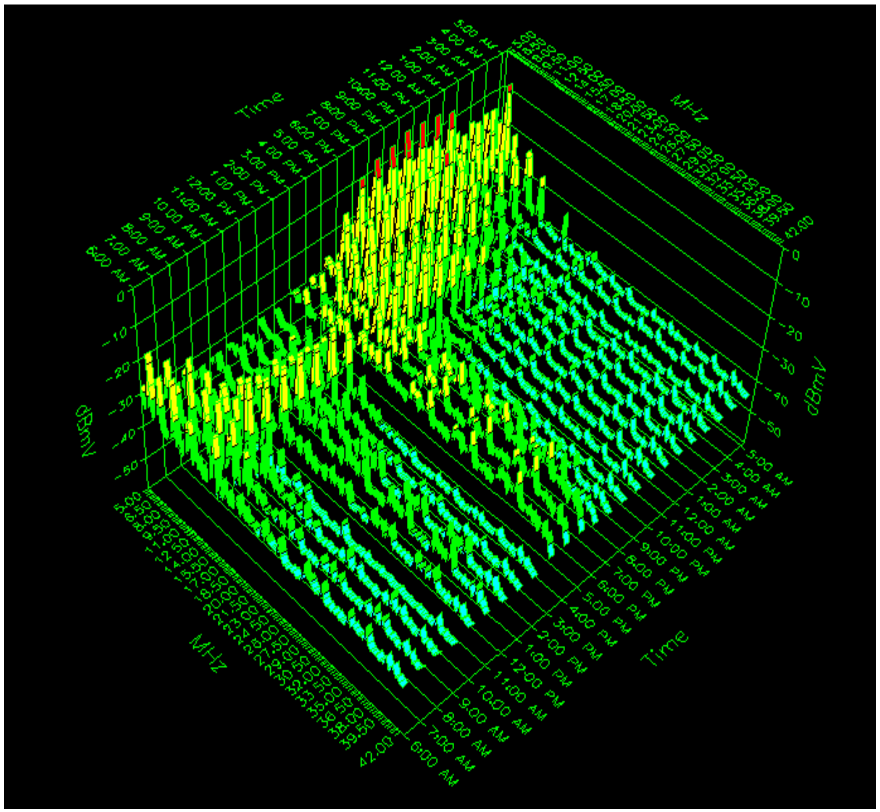


Reverse Path Performance History Report over 48 Hours from one return path

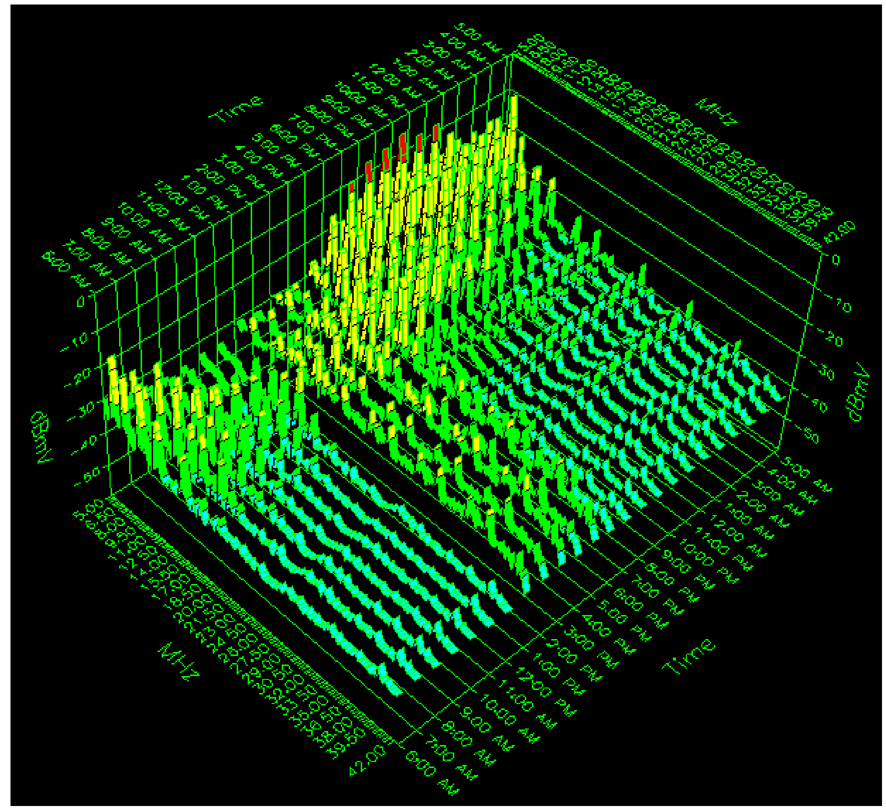
…. Find Intermittent Issues

Average Noise by Hour

Day 1

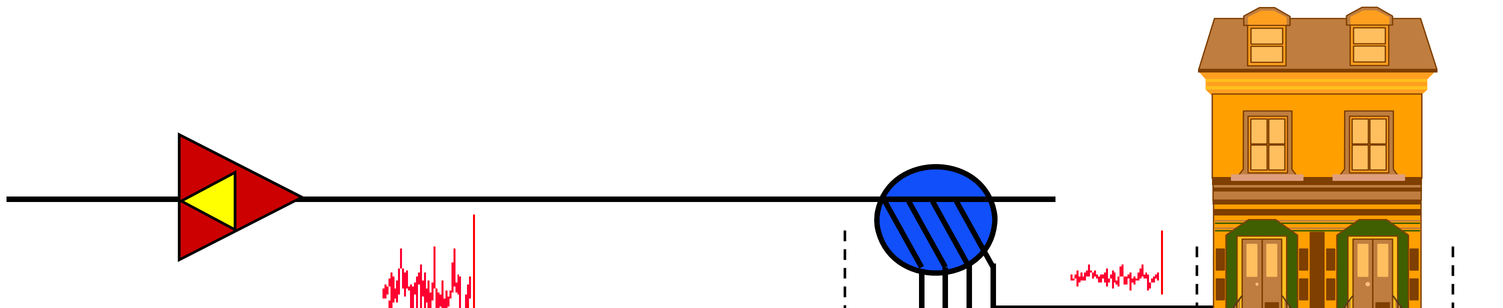


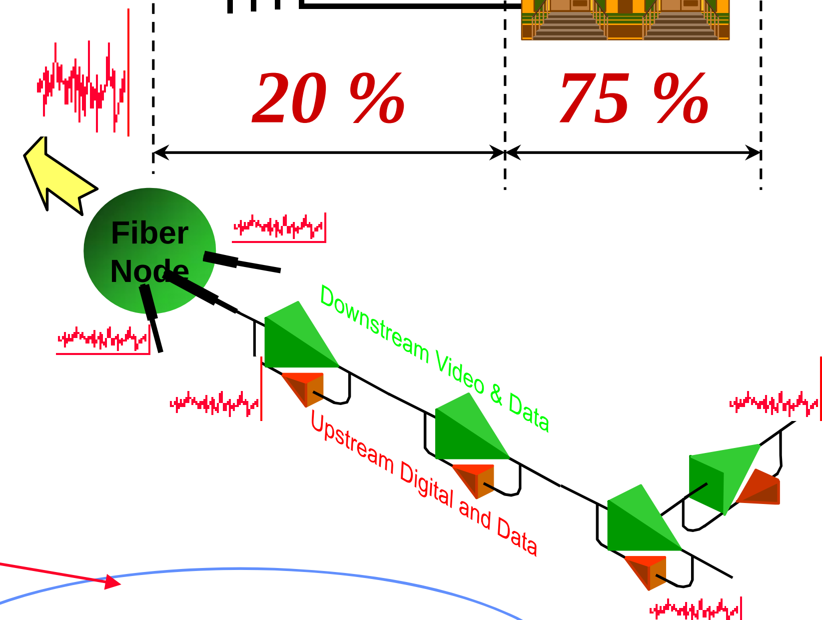
Day 2



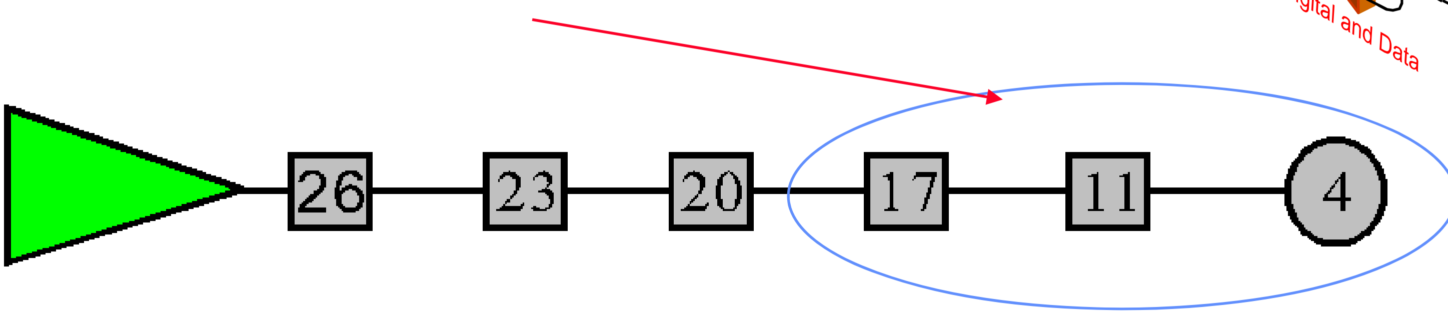
Reverse Path Performance History shows intermittent CPD that varies by time of day. If you only look at snapshot of performance during day you would miss what would affect customer service at night.

Ingress & Leakage
Ingress = Egress



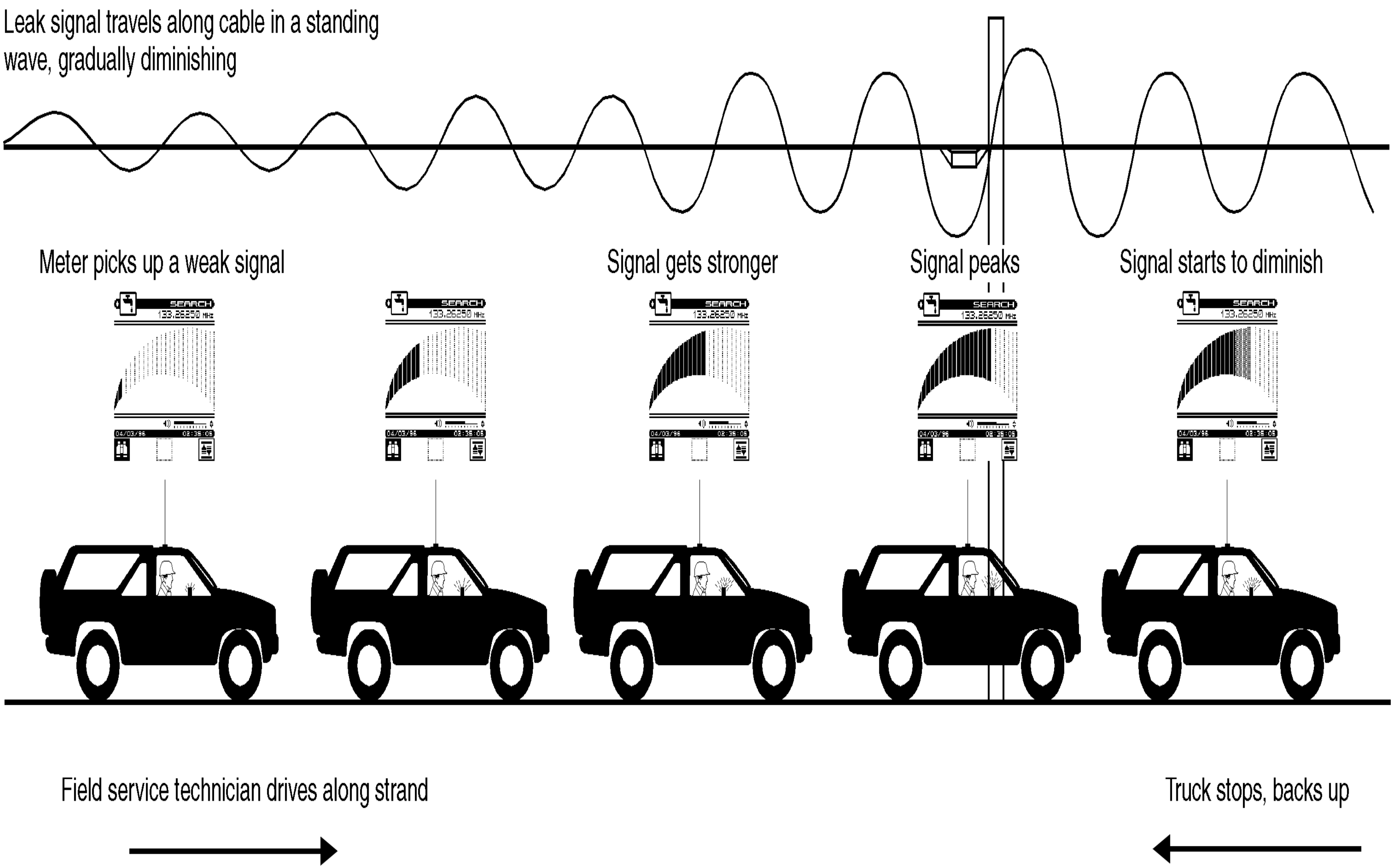


- Ingress; largest enemy against interactive reverse path services.
- 95% of all ingress comes from the tap and the customers premises
- Leakage and ingress are directly coupled problems.
  - A leak ‘out’ can also be an ‘opening’ for ingress to enter the cable system..
- Most ingress comes from houses with tap values of 17 dB or less



JDSU

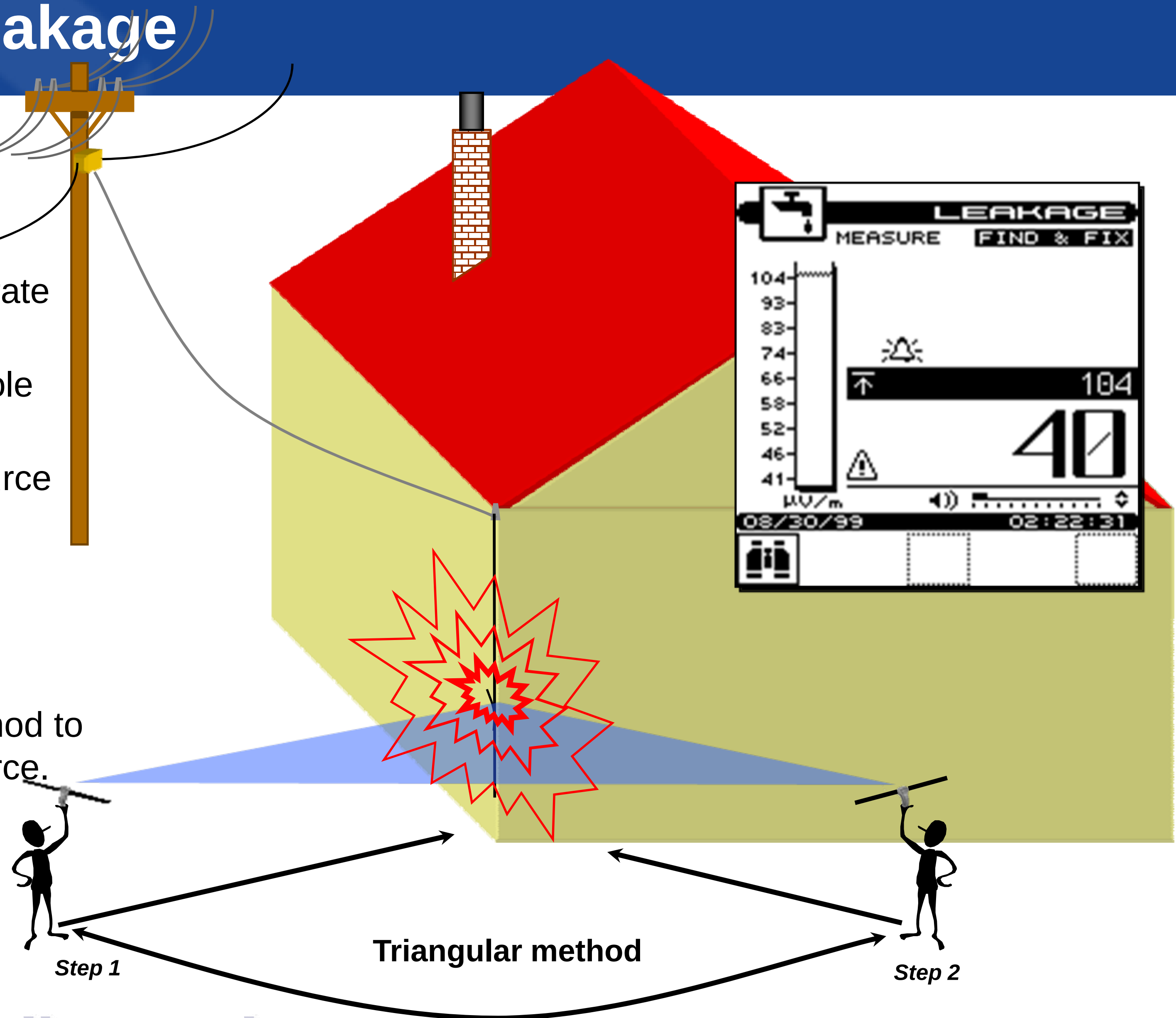
Ingress & Leakage Patrolling For Leakage



Ingress & Leakage

- Select fast update rate for detection
- Use directional dipole antenna
- Locate leakage source easy

- Use triangular method to locate leakage source.



Easy walk around

Wrap-Up

Troubleshooting is “Back to the Basics”

- Majority of problems are basic physical layer issues
- Most of the tests remain the same
- Check power
- Check forward levels, analog and digital
- Check forward / reverse ingress
- Do a visual check of connectors / passives
- Replace questionable connectors / passives
- Tighten F-connectors per your company’s installation policy
  - Be very careful not to over tighten connectors on CPE (TVs, VCRs, converters etc.) and crack or damage input RFI integrity

Common problems typically identified in outside plant

- 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 lower value taps.
- Unused drop passive ports not terminated.
- Use of so-called self-terminating taps (4 dB two port; 8 dB four port and 10/11 dB eight port) at feeder ends-of-line. Such taps are splitters, and do not terminate the line unless all F ports are properly terminated.

Common problems typically identified in outside plant

- Kinked or damaged cable (including 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.

Questions

- Thank you for your time…
- Any Questions???