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Measuring and Qualifying the Docsis Upstream Path

SCTE May2010

My Business Card

SUNRISE TELECOM®

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Purpose

- Better understand how to make upstream signals and measurements
- What are the signal impairments on the reverse path

Agenda

- **Return Path Measurements**
  - **Spectrum Analysis**
  - **Constellation**
  - **MER and BER**
  - **Adaptive Equalizer**
  - **Case Study**
- **Return Path Alignment**
  - **Node Optimization**
    - Laser link opitmization
    - Return receiver optimization
  - **Coaxial Plant Alignment and sweep**
- **Troubleshooting Hints**

Why 64-QAM?

- Higher upstream data throughput required for:
  - Voice
  - Peer to Peer
  - Up to 120 Mbs for 4 bonded channels for DOCSIS 3 in the upstream
  - Competition
  - Business Services

Upstream 64 QAM Challenges

- Once interference occurs in voice the data cannot be retransmitted.
- Measurements are more difficult because the signals are bursty.
- 64 QAM looses 3 dB of headroom because the maximum modem output is 52 dBmV as opposed to 58 dBmV for QPSK.

More Upstream Challenges with 64 QAM

- 64 QAM is less robust than 16 QAM
  - Requires better SNR and MER

- QAM means that the carrier is amplitude modulated and therefore more susceptible to amplitude based impairments such as:
  - Ingress
  - Micro-reflections
  - Compression

Recommended Network Specifications

- Part 76 of the FCC Rules
- DOCSIS for upstream and downstream
- NCTA Recommended Practices for upstream carriers

Spectrum Analyzer and QAM Upstream Measurements at the headend

- Upstream Carrier Levels
- Spectrum Analysis
- Constellation Measurements and Diagnosis
  - MER, BER, and Constellation Analysis
- Upstream Linear Distortion Measurements
  - Group Delay
  - Amlitude Response

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Upstream Signal Measurements

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Upstream Level Measurement
The First Step

- Verify the upstream carrier amplitude at the input to the CMTS upstream port is within spec.
- Usually 0 dBmV at the input, some systems may vary.
  - Can be measured using peak power on the preamble of the carrier
- An average power measurement could also be made on a constant carrier injected at the correct level.
- Measure total power at the input to the CMTS (<35dBmV, TP)

Spectrum Analysis
-CNR
-C/I

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DOCSIS 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

Upstream CNR

- **Check the upstream carrier-to-noise, carrier-to-ingress, and carrier-to-interference ratios**
  - **DOCSIS assumes a *minimum* of 25 dB for all three parameters**
  - **This is measured at the CMTS upstream port**
- **Remember that we loose 3 dB of dynamic range with 64 QAM at 6.4 MHz.**
- **CNR and SNR are different measurements!**

CNR or SNR

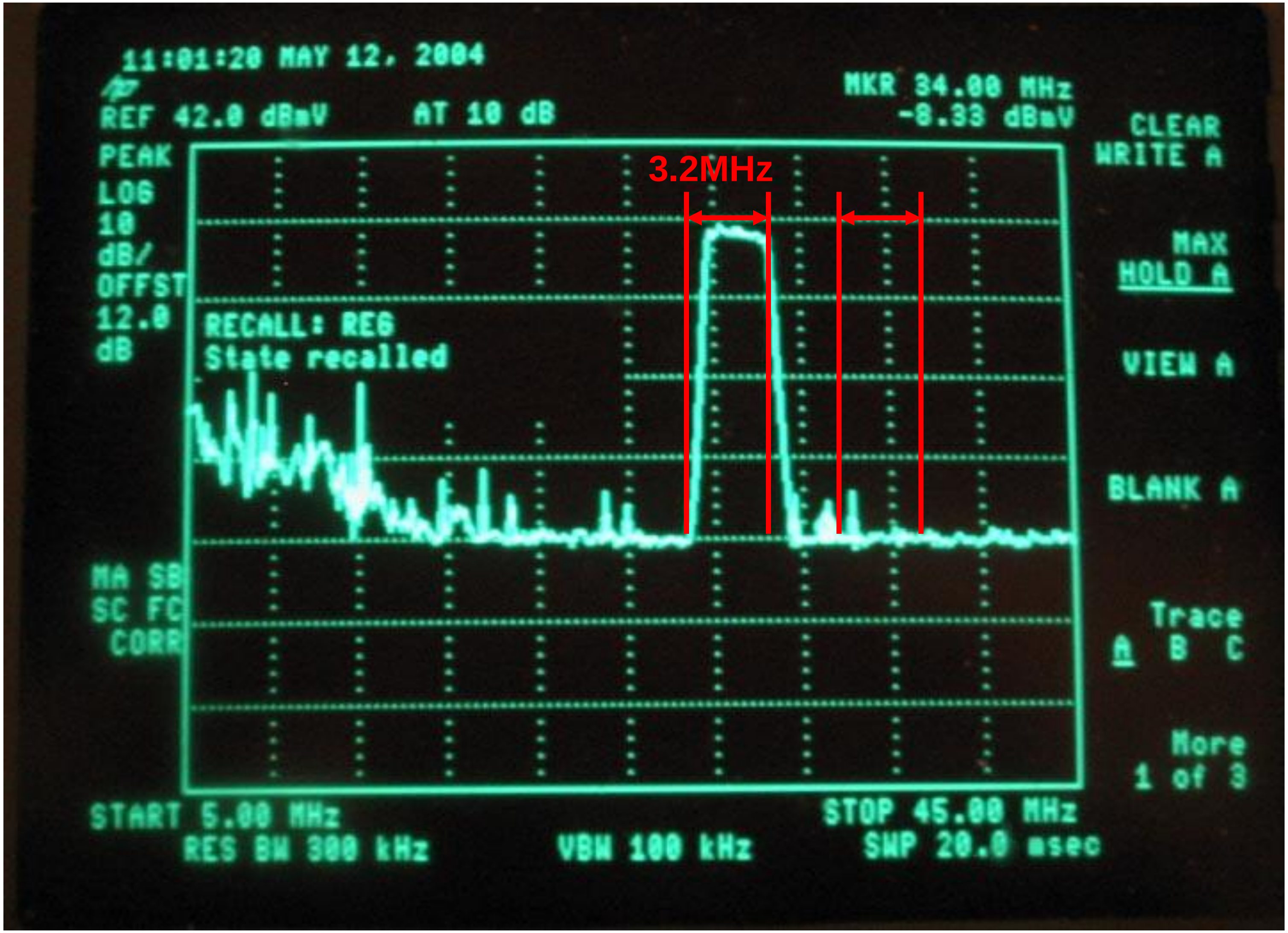
- **CNR is a measurement performed on RF signals**
  - Raw carrier power to raw noise power in the RF transport path only
  - Ideal for characterizing network impairments

- **SNR is a pre-modulation or post-detection measurement performed on baseband signals**
  - Includes noise in original signal, transmitter or modulator, transport path, and receiver & demodulator
  - Ideal for characterizing end-to-end performance—the overall signal quality seen by the end user

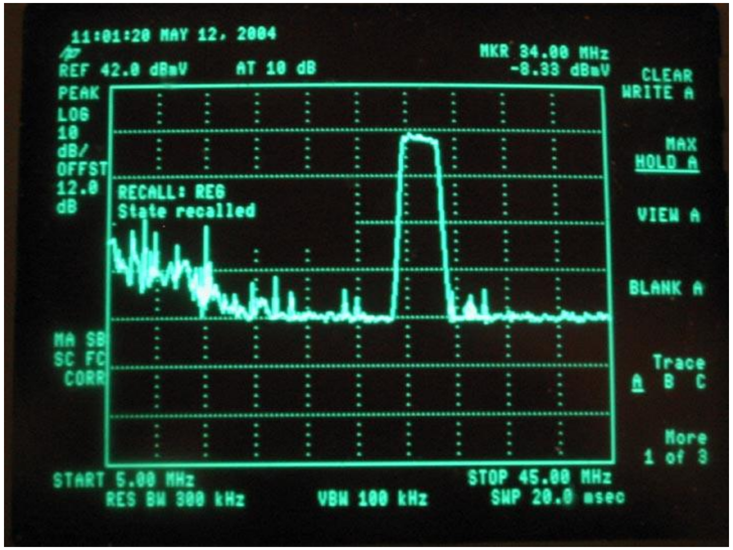
Upstream Spectrum Analysis

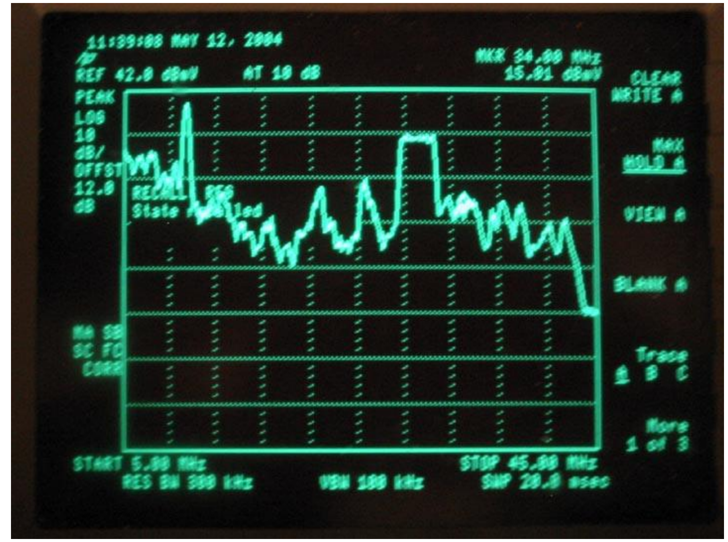
- Make sure noise floor of system is being displayed 10 db out of the spectrum analyzer noise floor
- Use peak hold to capture transients
- Use Averaging to capture CPD

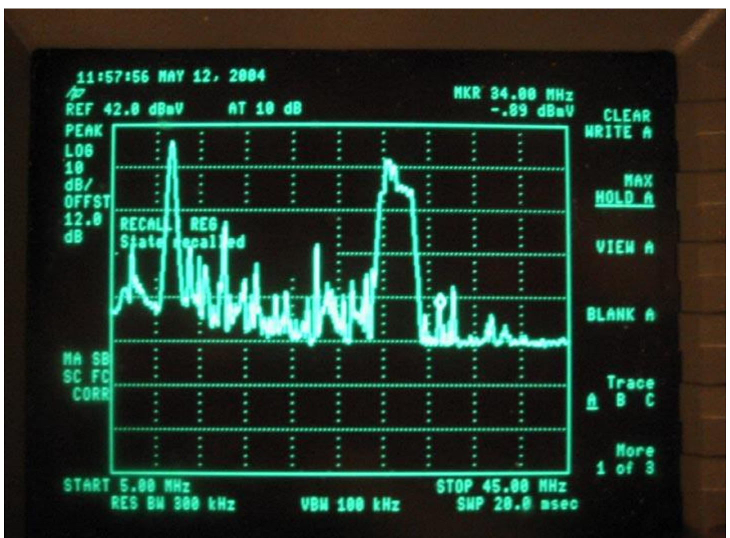
Good CNR and C/I

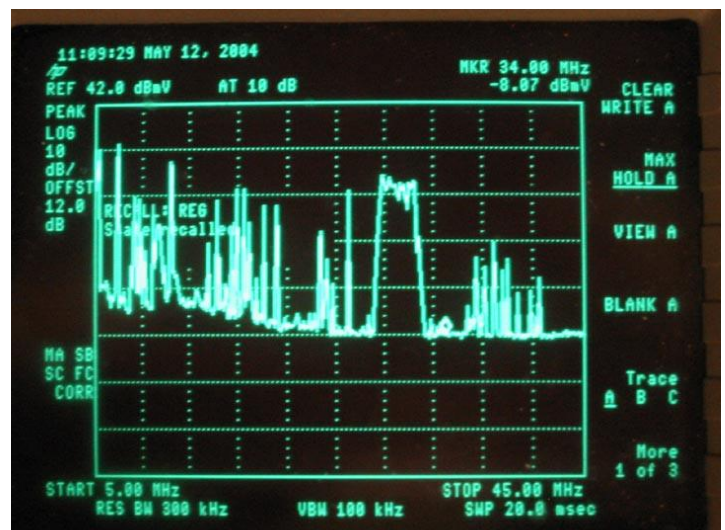


Upstream Carrier-to-Interference

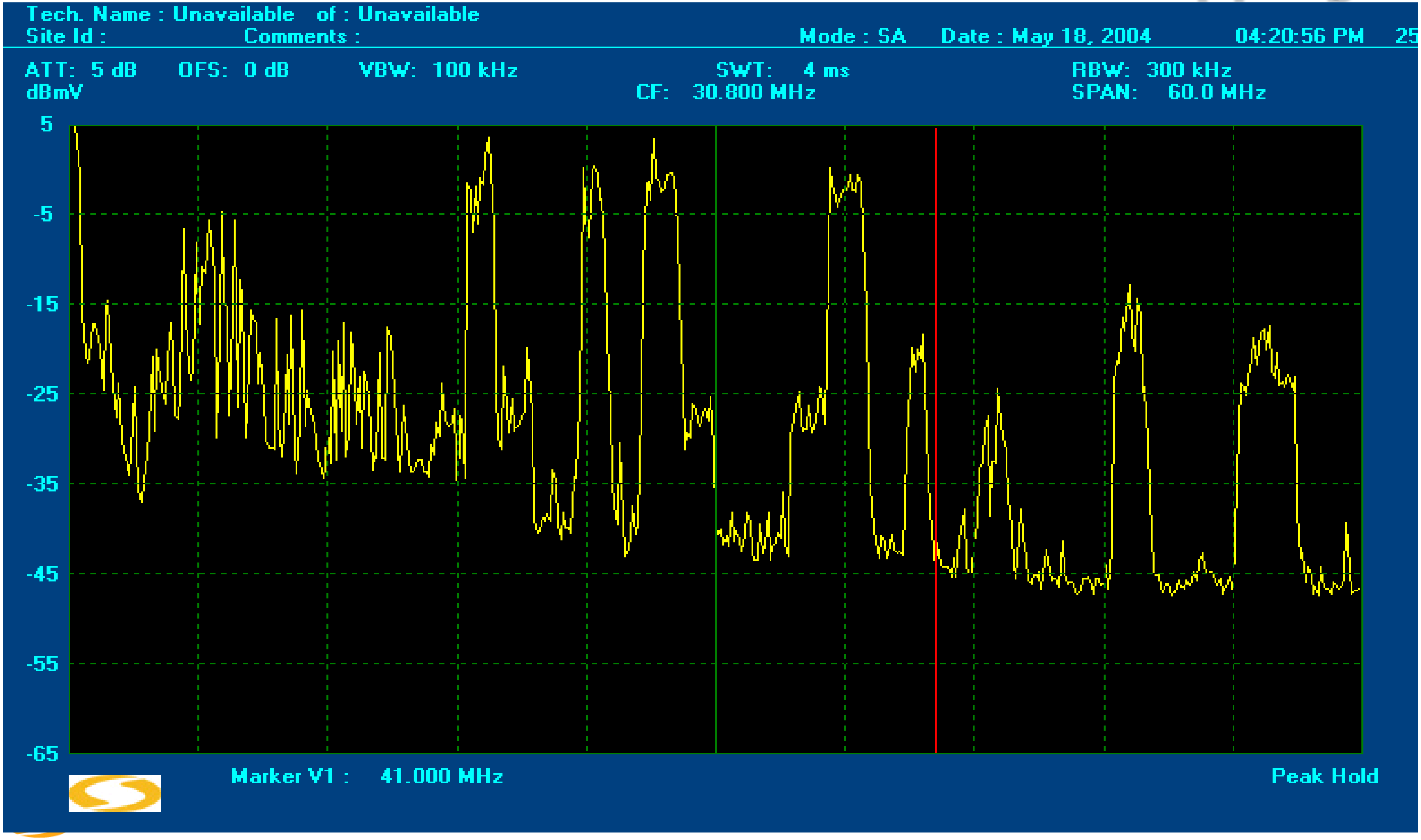








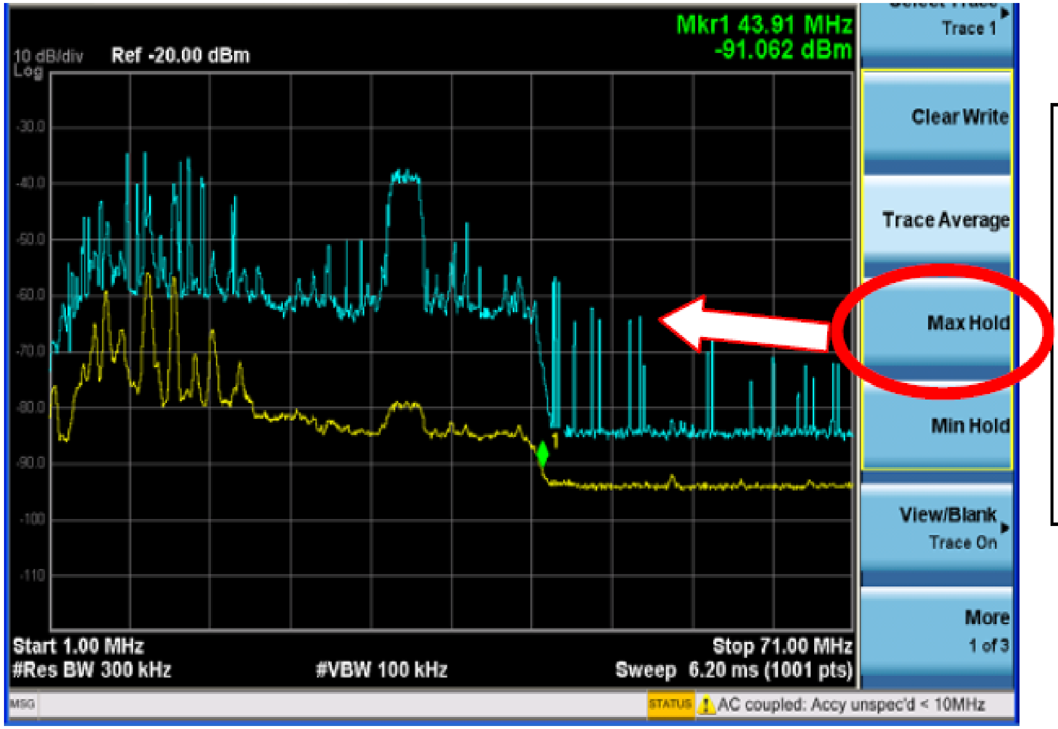
Upstream Spectrum Display Showing Laser Clipping



Upstream Spectrum Analysis

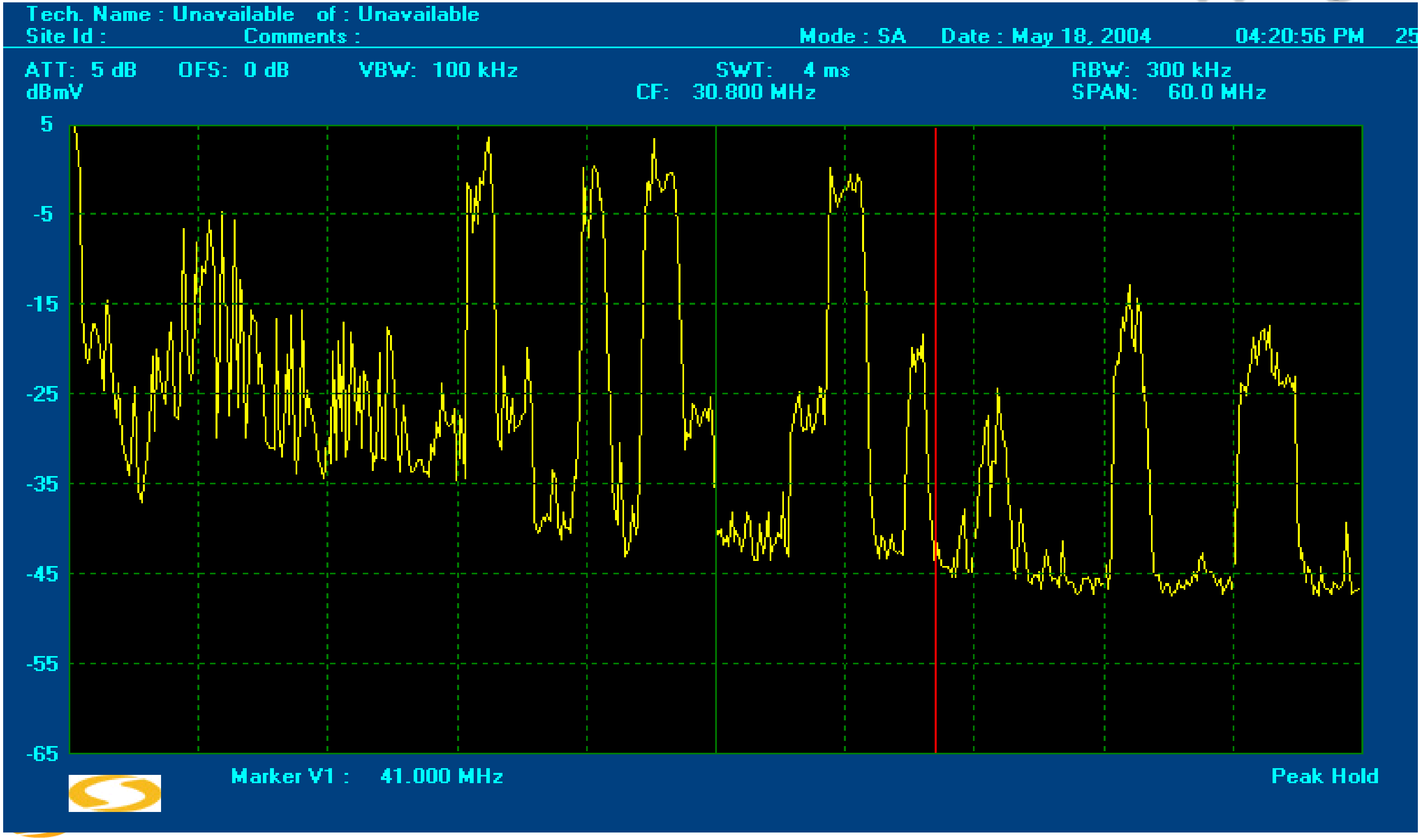
- **Make sure noise floor of system is being displayed 10 db out of the spectrum analyzer noise floor**
- **Use peak hold to capture transients**
- **Use Averaging to capture CPD**

Impulse Noise



- Narrowband interference
- High pk-avg, impulsive
- Possible laser overload (wideband components)
- Likely supports 16-QAM
- Insufficient for 64-QAM

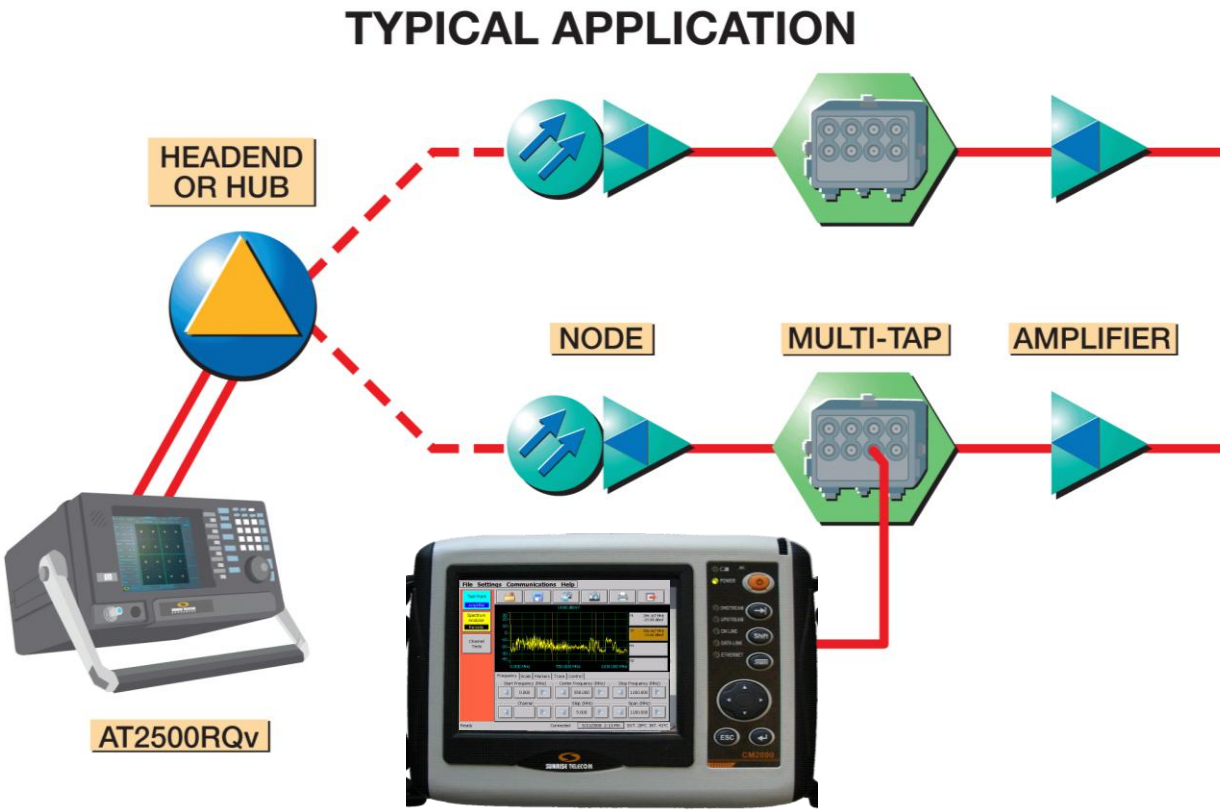
Upstream Spectrum Display Showing Laser Clipping



Return Path Constellation Analysis

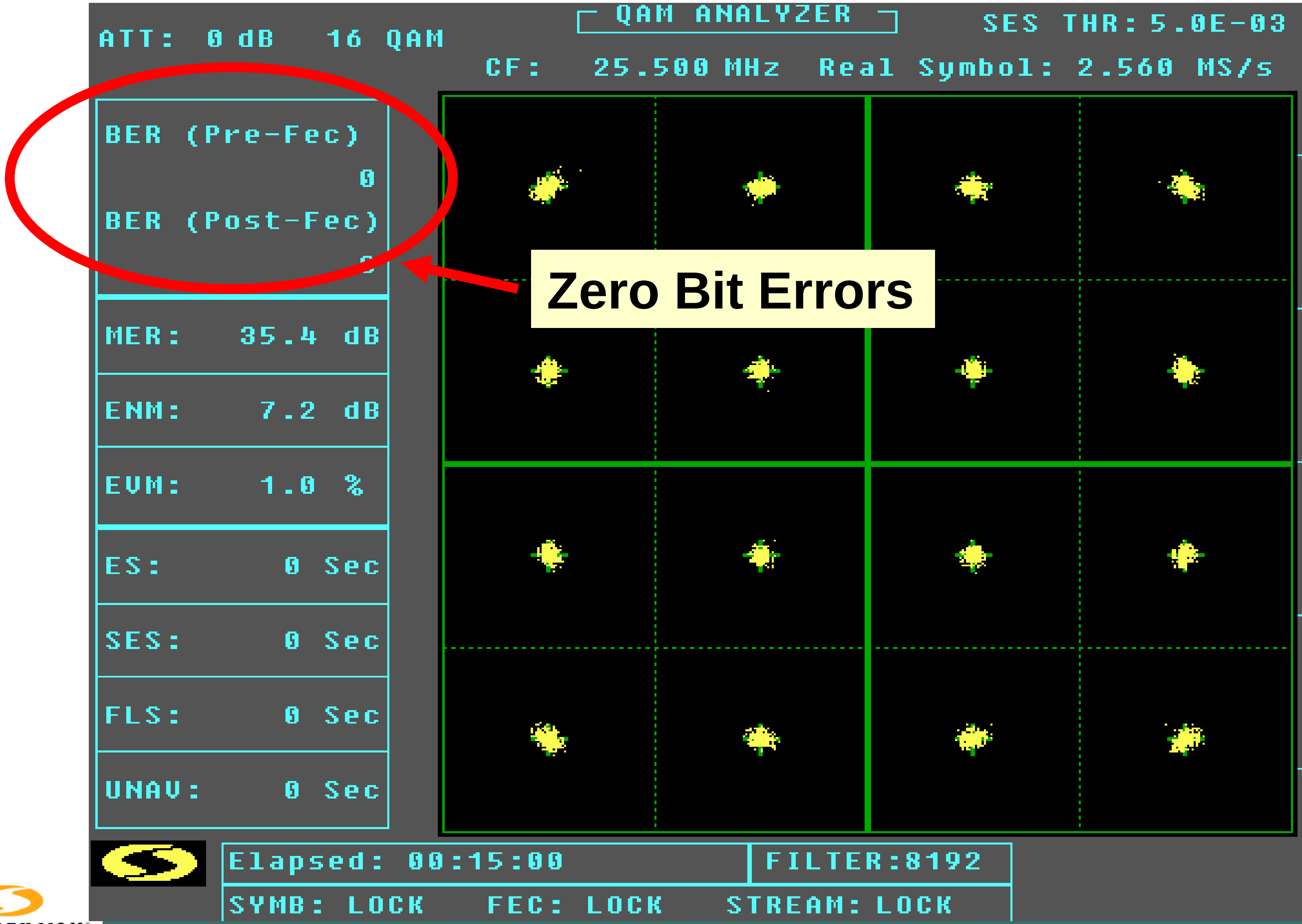
Upstream Path

AT2500RQv / CM2000E-USG toolkit

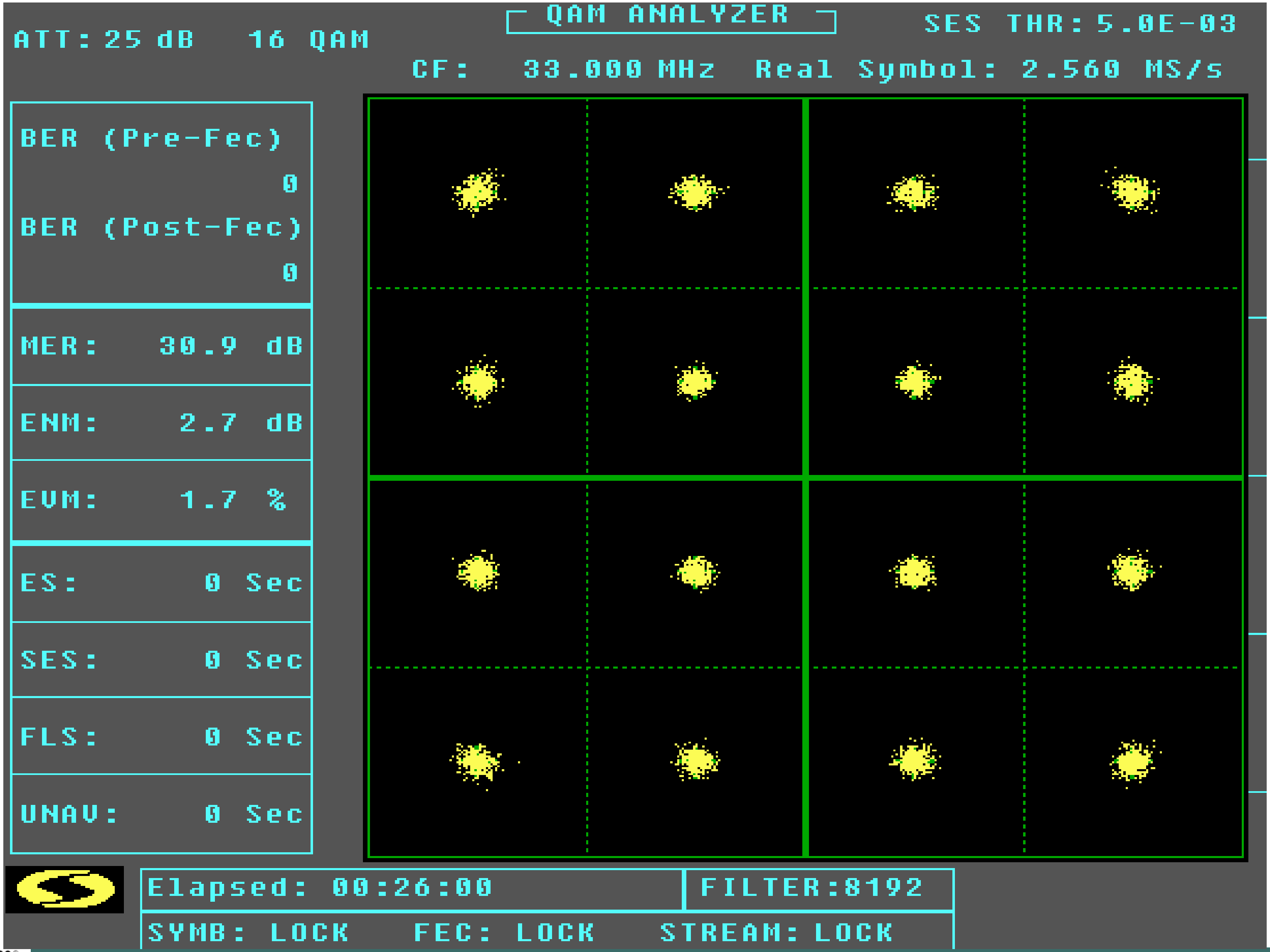


- **Frequency response alignment or diplex filter roll-off**
- **Quantify linear distortions between two points**
- **QAM16/QAM64**
- **Micro-reflections caused by impedance mismatches**
- **Group delay**
- **Non Linear operation of the Return laser**
- **Bit transmission errors**
- **Random Non Linear network events detected by Pre-Post BER**

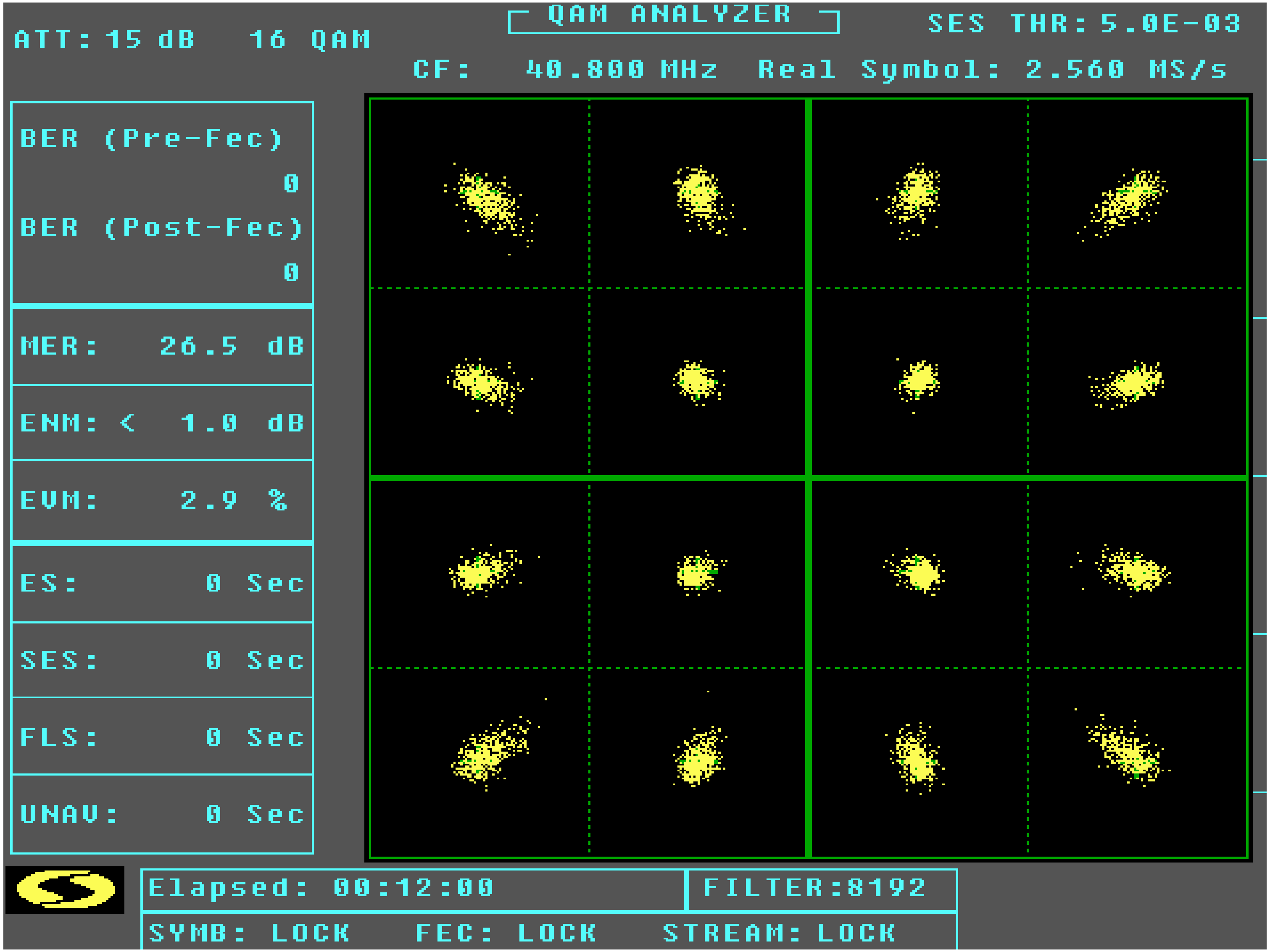
A Good 16 QAM Constellation



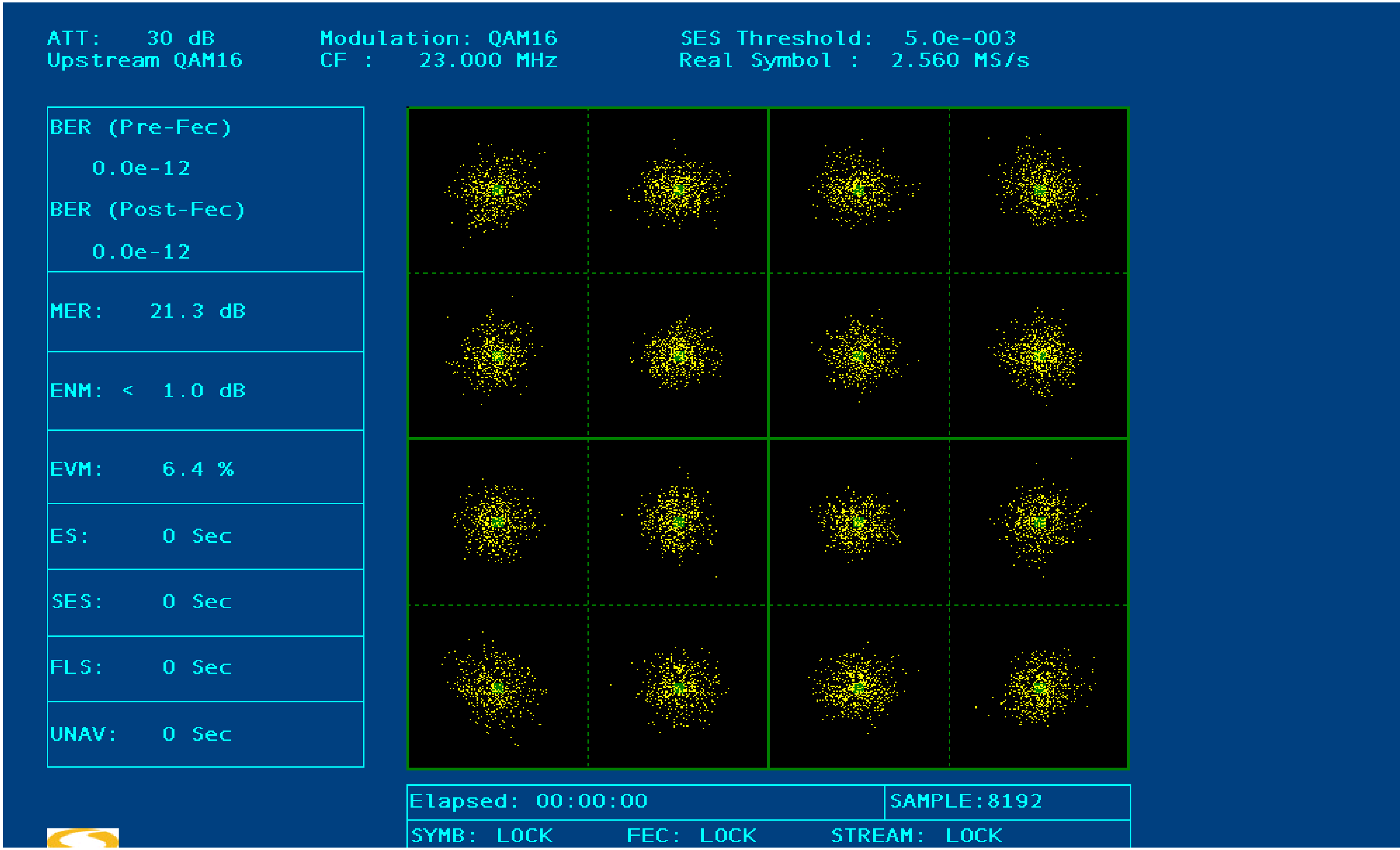
CPD and Noise



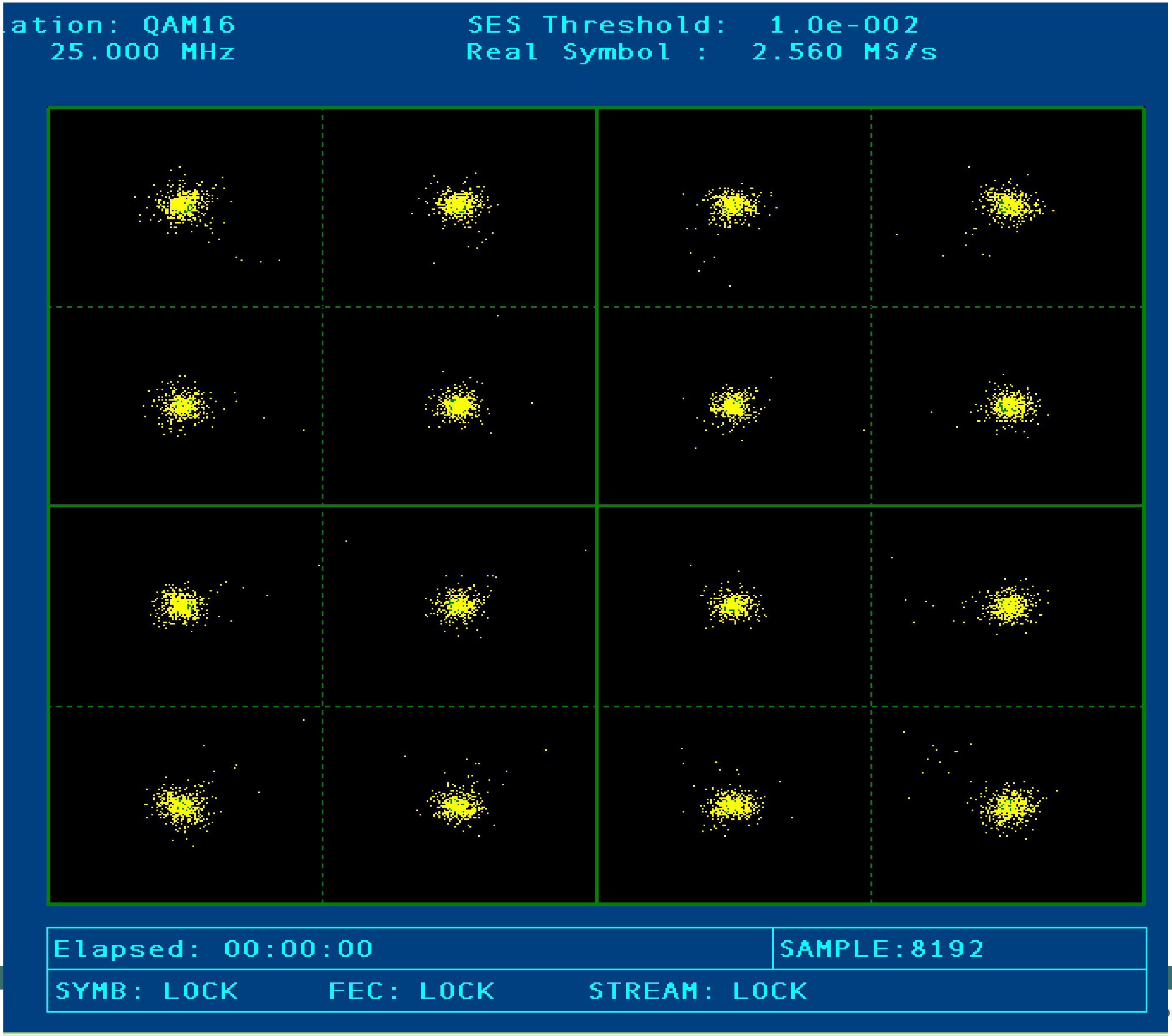
Laser Clipping



Noise


ATT: 30 dB
Upstream QAM16
Modulation: QAM16
CF : 23.000 MHz
SES Threshold: 5.0e-003
Real Symbol : 2.560 MS/s
BER (Pre-Fec)
0.0e-12
BER (Post-Fec)
0.0e-12
MER: 21.3 dB
ENM: < 1.0 dB
EVM: 6.4 %
ES: 0 Sec
SES: 0 Sec
FLS: 0 Sec
UNAV: 0 Sec
Elapsed: 00:00:00
SAMPLE:8192
SYMB: LOCK
FEC: LOCK
STREAM: LOCK

Ingress



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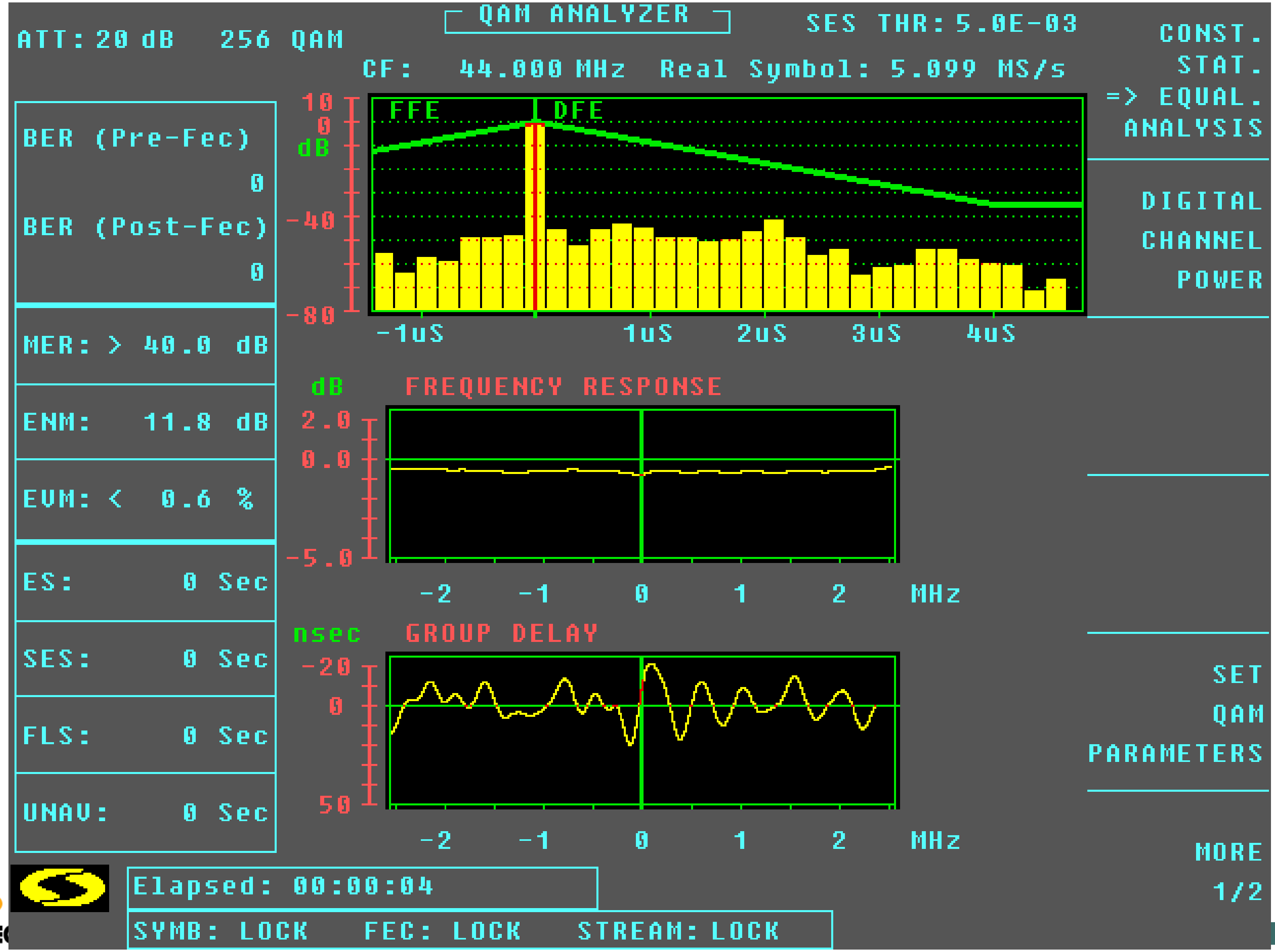
Adaptive Equalizers

- Corrects for Frequency Response imperfections
- Corrects for Group Delay
- Show impedance mismatches

Adaptive Equalizers



Microreflections

- **Micro-reflections are impedance mismatches**
- **In the real world of cable networks, 75 Ω impedance is at best considered nominal**
- **Micro-reflections cause group delay and frequency response problems.**
- **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

- **Higher orders of modulation are affected by micro-reflections to a much greater degree so 64 QAM is affected more than 16 QAM**
- **Upstream micro-reflections and group delay are minimized by using adaptive equalizers. This feature is available in DOCSIS 1.1 and 2.0 & 3.0 CMTSs , but not 1.0.**

Microreflections

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

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

Microreflections

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

Parameter	Value
Frequen[illegible]	5 to 42 MHz edge to edge
[illegible] st CM	<=0.800 msec (typically much less)
[illegible] on [illegible] s,	Not less than 25 dB (Note 2)
Ca[illegible]	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

Amplitude Ripple
(Frequency Response)

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)
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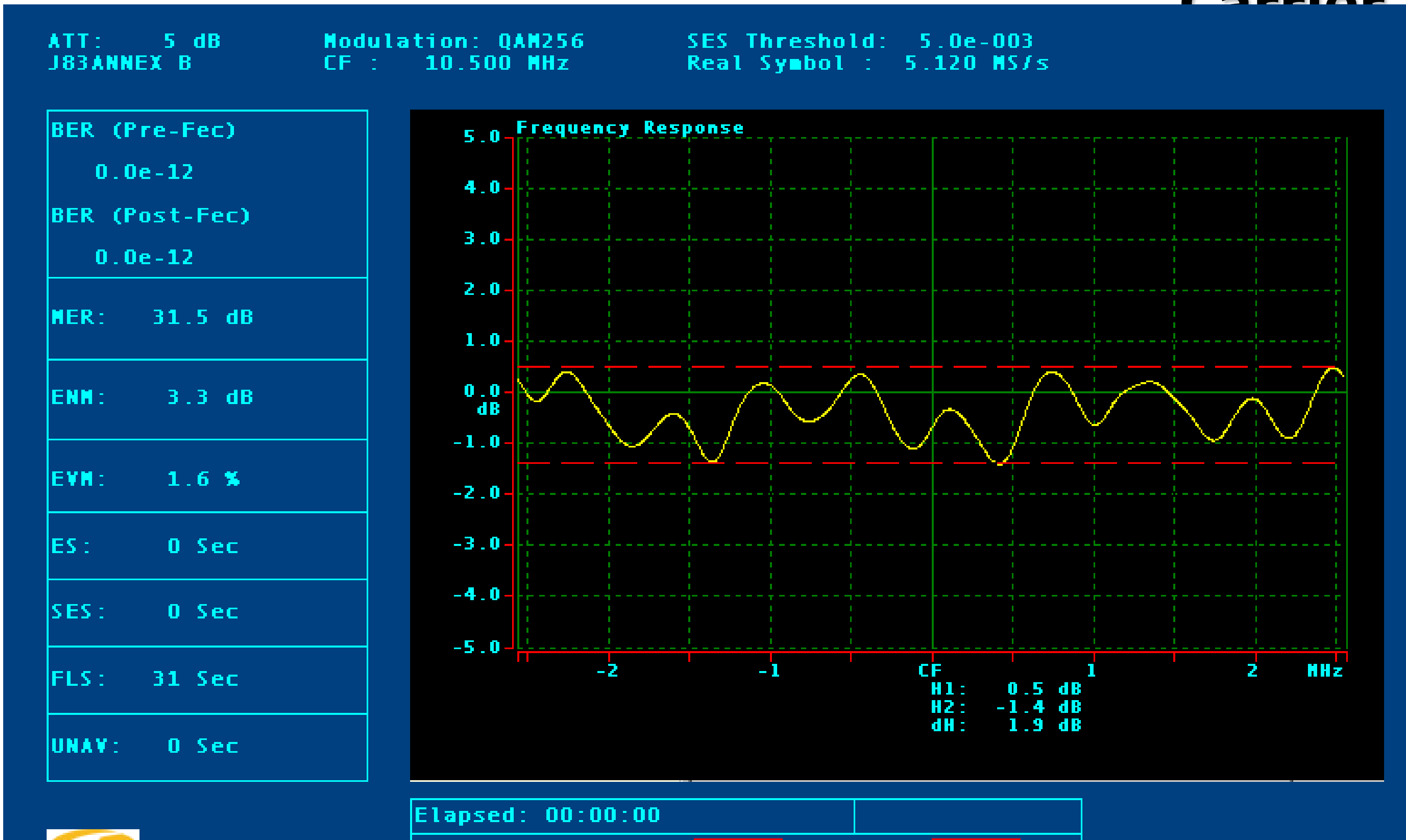
Frequency Response of an Upstream Carrier



Group Delay

- Different data travels through the same medium at different speeds. This is Group Delay
- Group delay is defined in units of time, typically nanoseconds (ns) over frequency. In other words how much GD per each MHz.
- In a system, network or component with no group delay, all frequencies are transmitted through the system, network or component with equal time delay
- Frequency response problems in a CATV network will cause group delay problems
- Group delay is worse near band edges and diplex filter roll-off areas

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Upstream frequency

- Keep the upstream QAM digitally modulated carrier well away from diplex filter roll-off areas (typically above about 35~38 MHz), where group delay can be a major problem
- Choose an operating frequency that will minimize the likelihood of group delay
  - Frequencies in the 20~35 MHz range generally work well
- Group delay may still be a problem when the frequency response is flat

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

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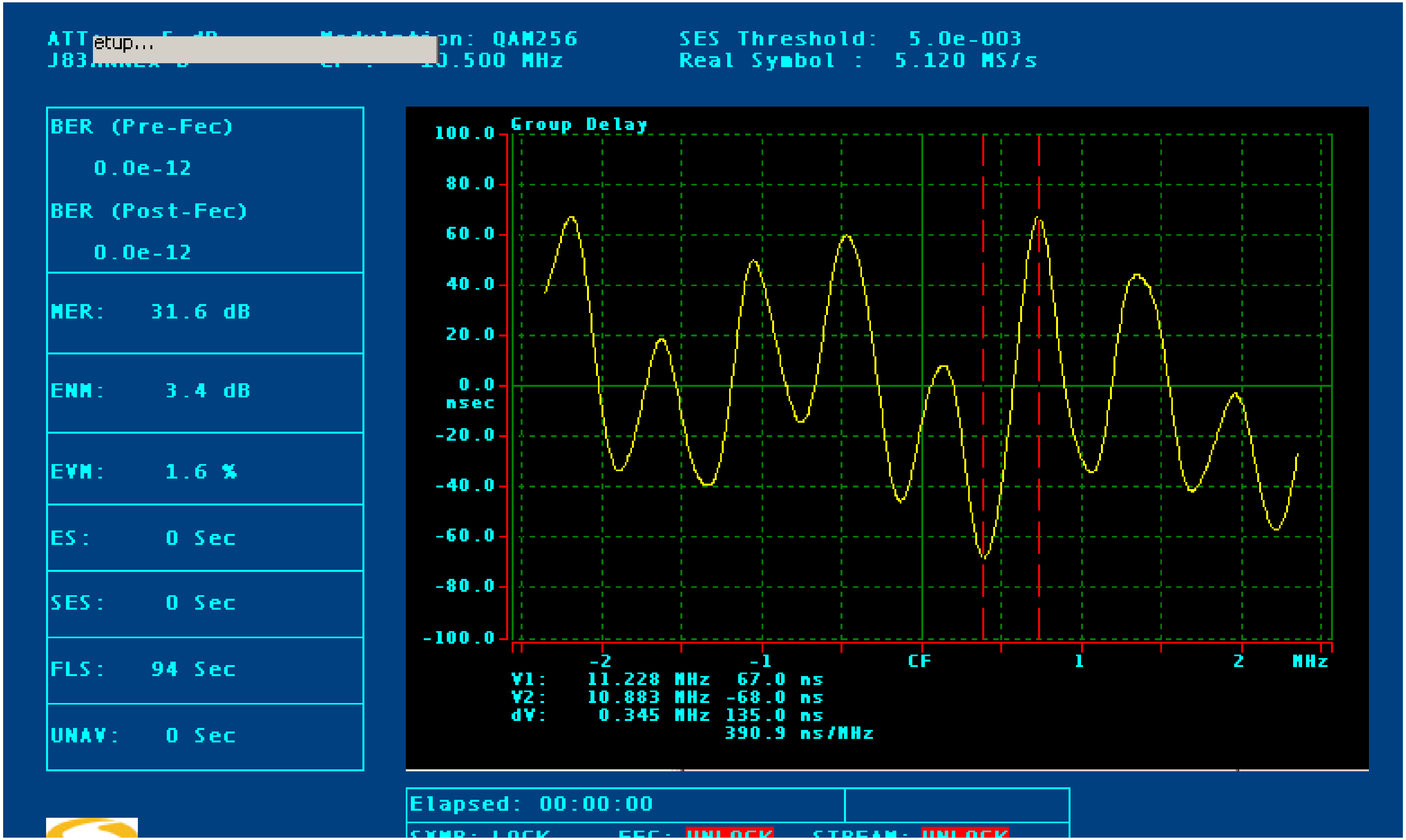
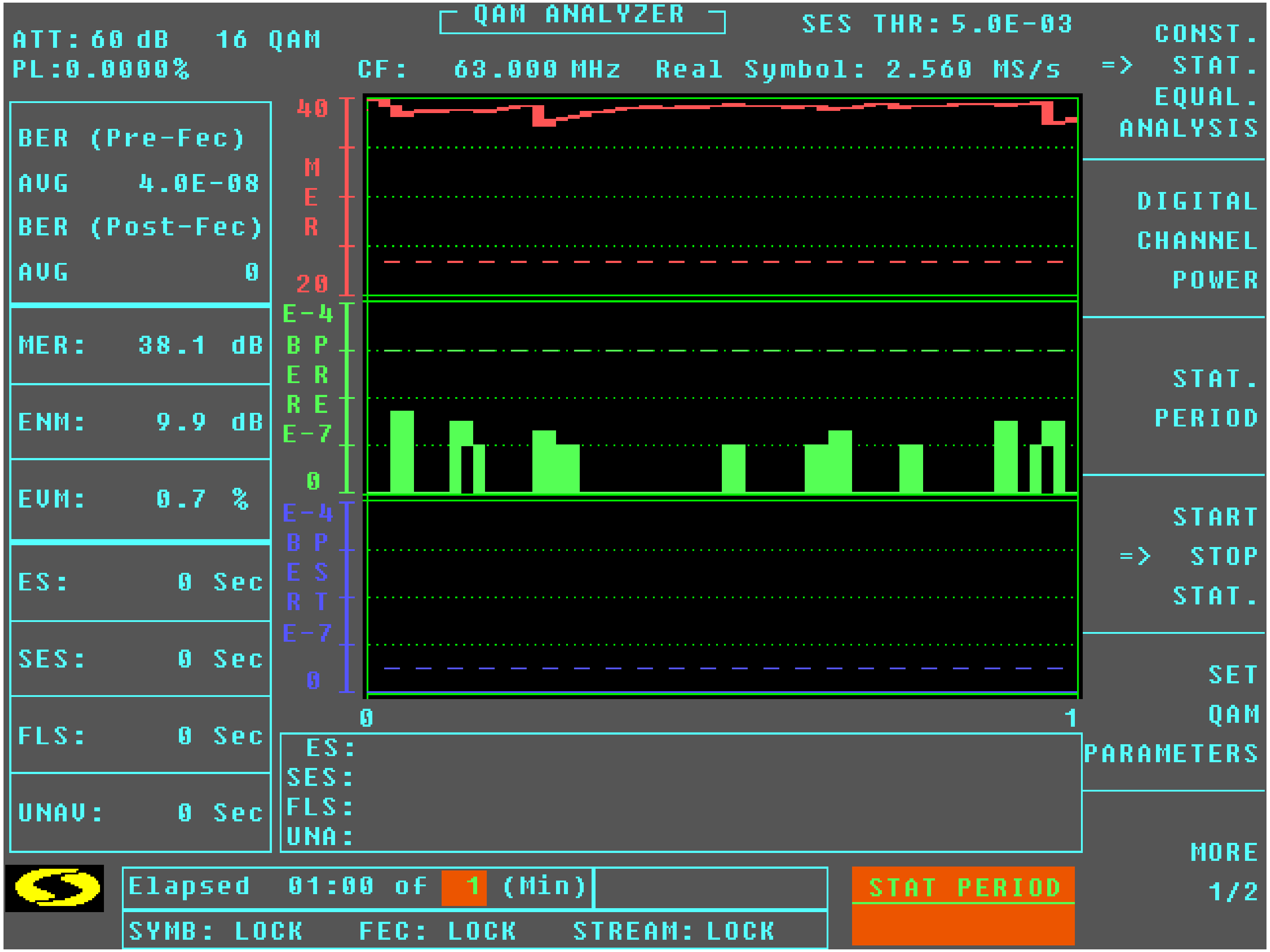
Group Delay Measurement



Statistics Mode

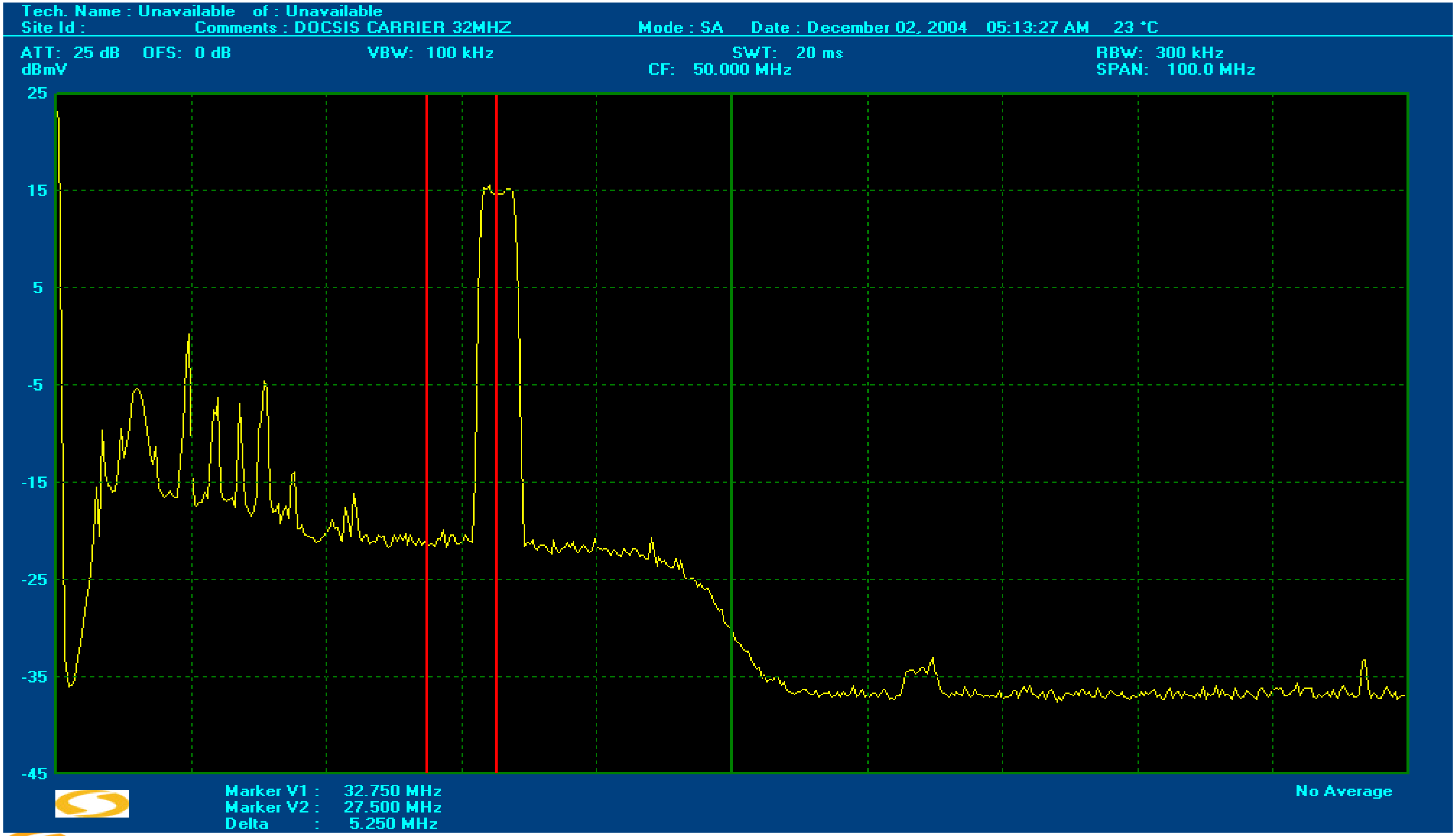


Some things to check out!

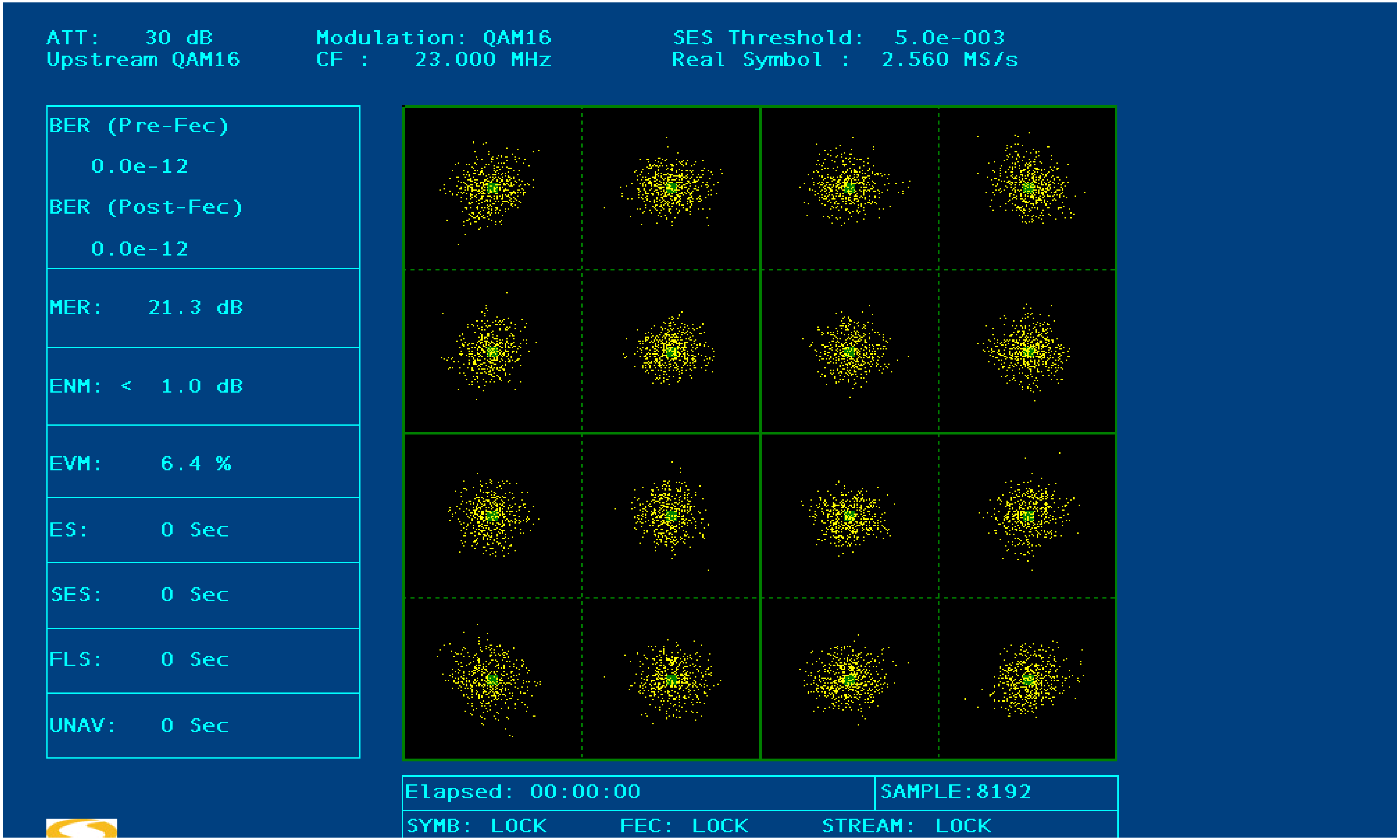
- Before adding a 64 QAM carrier the following should be checked
  - Compression of the return laser due to added carrier or a carrier with added bandwidth
  - MER and BER over a period of time
  - Group Delay of a new carrier
  - MER and BER of the new carrier.
  - Amplitude Ripple
  - Microreflections

A Case Study

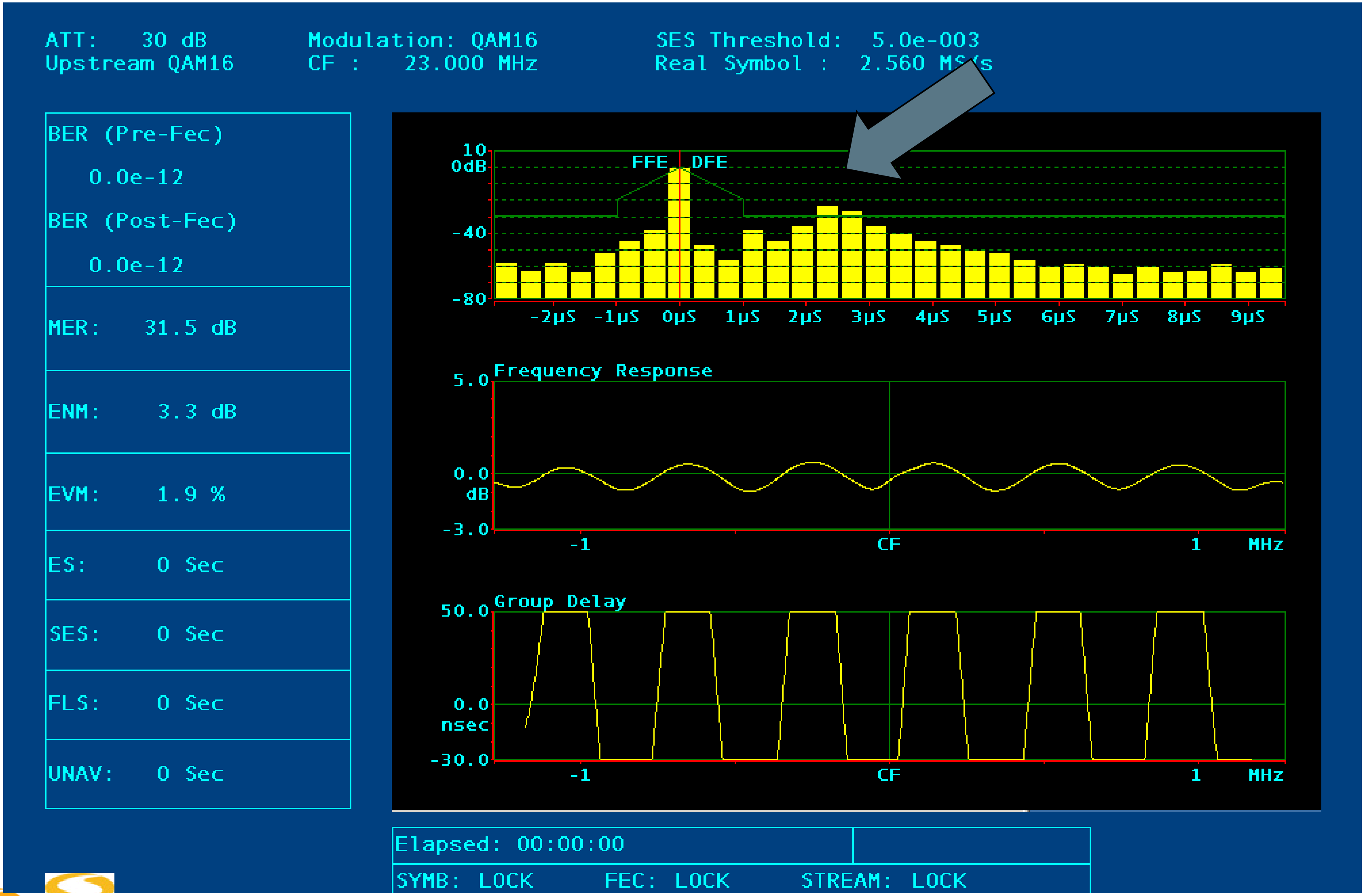
Upstream Spectrum



Unequalized MER

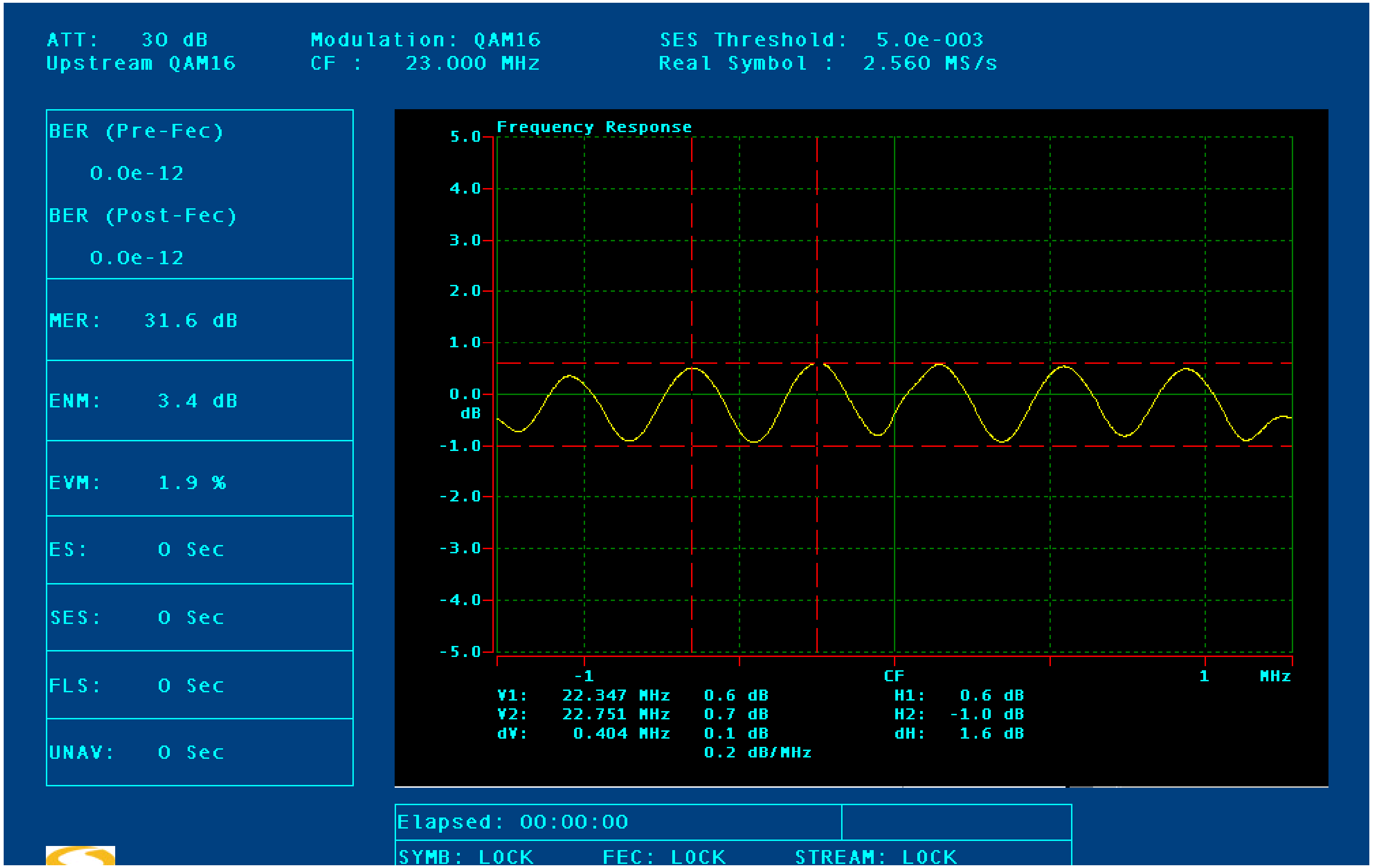


Oops!



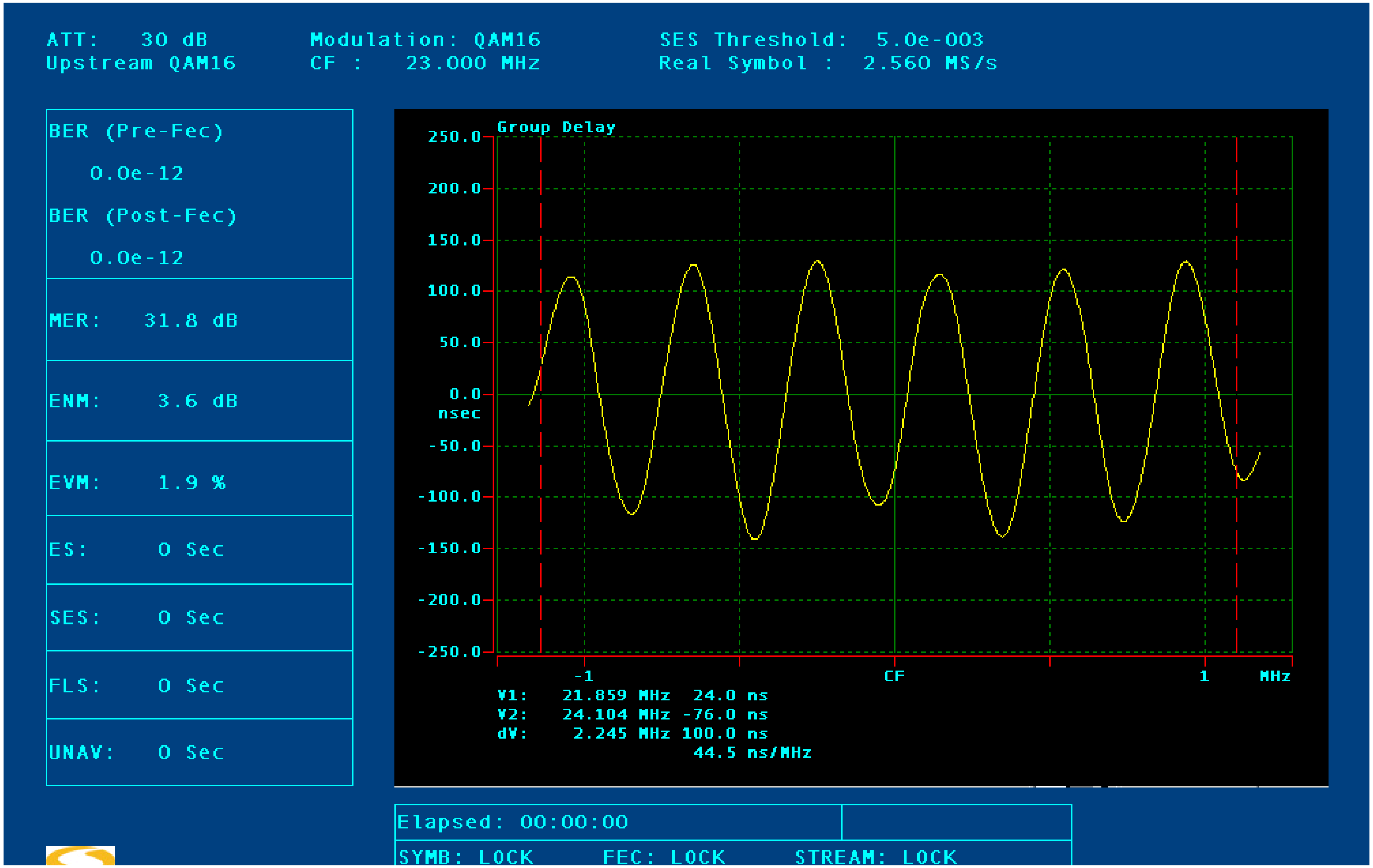
ATT: 30 dB
Upstream QAM16
Modulation: QAM16
CF : 23.000 MHz
SES Threshold: 5.0e-003
Real Symbol : 2.560 MS/s
BER (Pre-Fec)
0.0e-12
BER (Post-Fec)
0.0e-12
MER: 31.5 dB
ENM: 3.3 dB
EVM: 1.9 %
ES: 0 Sec
SES: 0 Sec
FLS: 0 Sec
UNAV: 0 Sec
10
0dB
-40
-80
FFE
DFE
-2μS -1μS 0μS 1μS 2μS 3μS 4μS 5μS 6μS 7μS 8μS 9μS
Frequency Response
5.0
0.0
dB
-3.0
-1
CF
1
MHz
Group Delay
50.0
0.0
nsec
-30.0
-1
CF
1
MHz
Elapsed: 00:00:00
SYMB: LOCK
FEC: LOCK
STREAM: LOCK

Amplitude Ripple



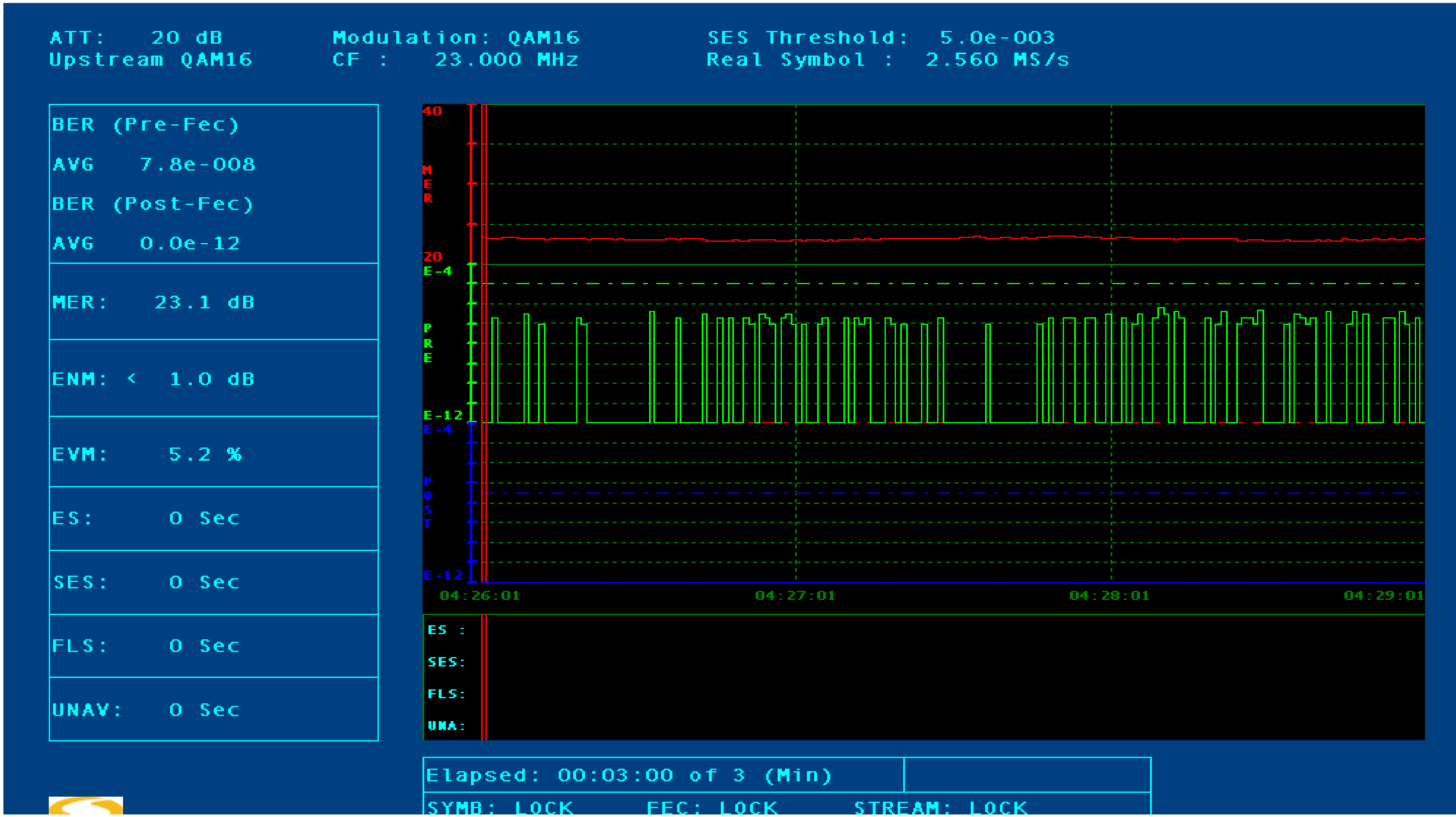
D = 492(VP/F) = 492(87%/≈.4MHz) ≈ 1100 feet

Group Delay



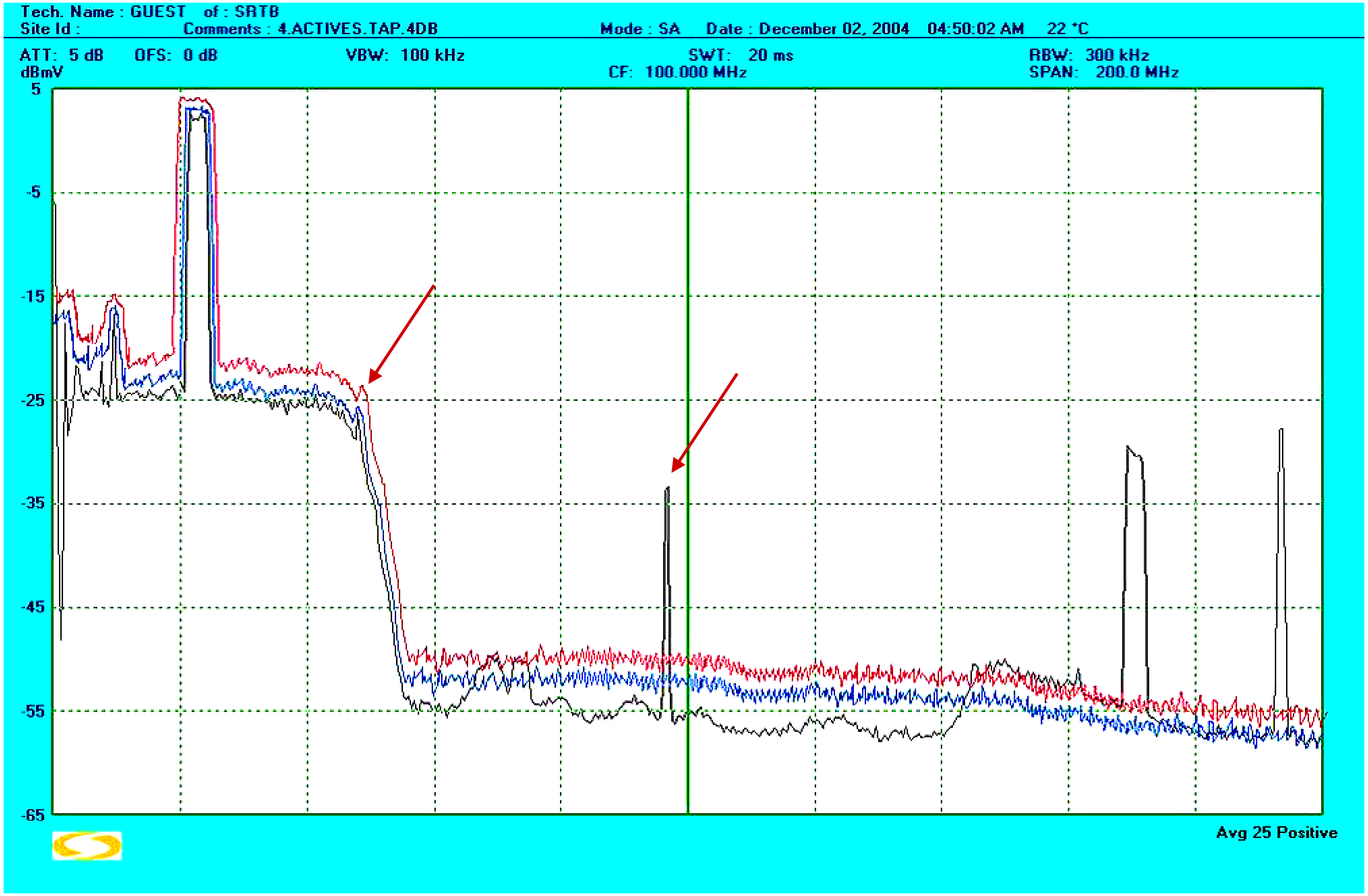
Peak to Valley Group Delay ≈ 270 nSeconds

Bit Errors



ATT: 20 dB
Upstream QAM16
Modulation: QAM16
CF : 23.000 MHz
SES Threshold: 5.0e-003
Real Symbol : 2.560 MS/s
BER (Pre-Fec)
AVG 7.8e-008
BER (Post-Fec)
AVG 0.0e-12
MER: 23.1 dB
ENM: < 1.0 dB
EVM: 5.2 %
ES: 0 Sec
SES: 0 Sec
FLS: 0 Sec
UNAV: 0 Sec
40
MER
20
E-4
PRE
E-12
E-4
POST
E-12
04:26:01
04:27:01
04:28:01
04:29:01
ES :
SES:
FLS:
UNA:
Elapsed: 00:03:00 of 3 (Min)
SYMB: LOCK
FEC: LOCK
STREAM: LOCK

Effects of Over-Driving a Laser



Moral of the Story?

- CNR and Distortion measurements from a spectrum analyzer are great but, don't tell the whole story.
- Other digital measurements are advised using a vector analyzer to ensure QAM reliability
  - MER and BER
  - Group Delay and other Equalizer measurements
  - Constellation
  - Statistic Measurement

Measurement Summary

- Check for laser clipping
- Measure over time
- Measure for frequency response of the carrier
- Measure group delay of the carrier
- Measure MER and BER of upstream carrier
- Can be accomplished by inserting a QAM carrier at the EOL and using a digital analyzer in the headend.

64 QAM Pre-Launch Checklist

- ✓ CMTS modulation profile optimized for 64-QAM
- ✓ Vector Analysis, not just spectrum analysis
- ✓ 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

Ron Hranac wrote the book

- Hranac R., "CNR versus SNR" March 2003 *Communications Technology*
- Hranac R., "Spectrum analyzer CNR versus CMTS SNR" September 2003 *Communications Technology*
- Hranac R., "16 QAM Plant Preparation"
- Hranac R., "Deploying VOIP on the Outside Plant"
- Hranac R., "Linear Distortions," Last 2 issues of CT Magazine

References

- "RF Impairments in the Return Path and their impact on DOCSIS performance", by Jack Moran, Motorola
- National Cable Television Association's Recommended Practices for Measurements on Cable Television Systems, 2nd Edition, October 1997 "Supplement on Upstream Transport Issues."
- "Modern Cable Television Technology", by Walter Cicora, James Farmer and David Large
- Return Path Familiarization and Node Return Laser Setup," by Frank Eichenlaub, Cisco Systems
- Characterizing and Aligning the HFC return path for Sucessful DOCSIS 3.0 Rollouts, Dr. Robert L. Howald et all, Motorola, SCTE Cable Tech Expo 2009

More References

- "Mystified by Return Path Activation?" Get your Upstream Fiber Links Aligned, by Ron Hranac, Communications Technology, March 2000
- "Seek Balance in All Things" A Look at Unity Gain in the Upstream Coax Plant, by Ron Hranac, Communications Technology, June 2000
- "A Primer on Common Path Distortion", by Nick Romanick, Communications Technology, April 2001
- "

Thank You!

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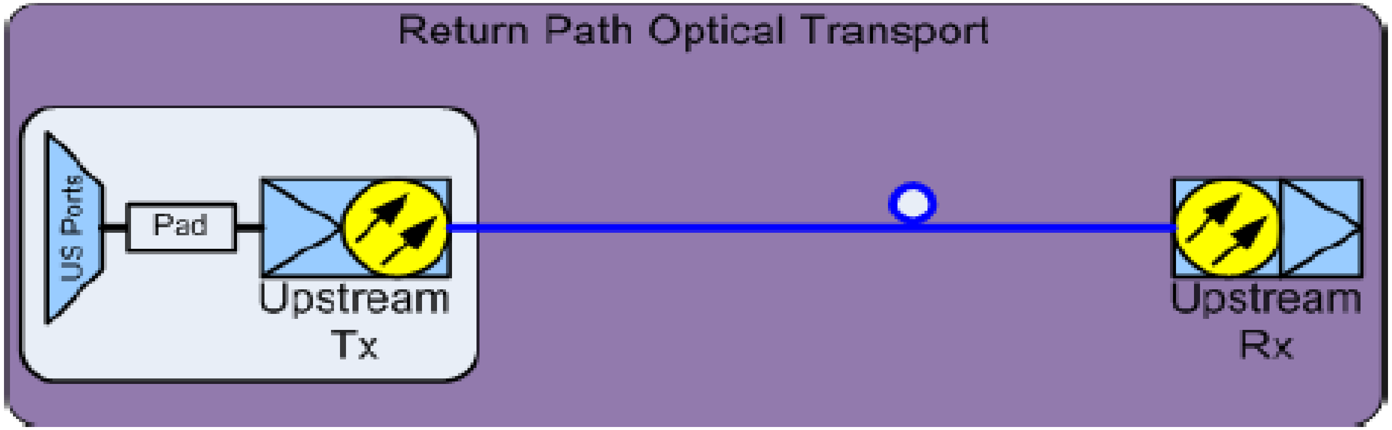
The return optical link

Return Optics

- We discuss this first because it has the greater impact on the MER at the CMTS input because it has the lowest dynamic range
- Optimized by measuring NPR at the input to the CMTS by injecting different total power at the input to laser.
- Carriers should be derated according to bandwidth using power per hertz.
- Not part of the unity gain portion of the HFC plant.
- Set up is laser and node specific



Power per Hertz Calculation

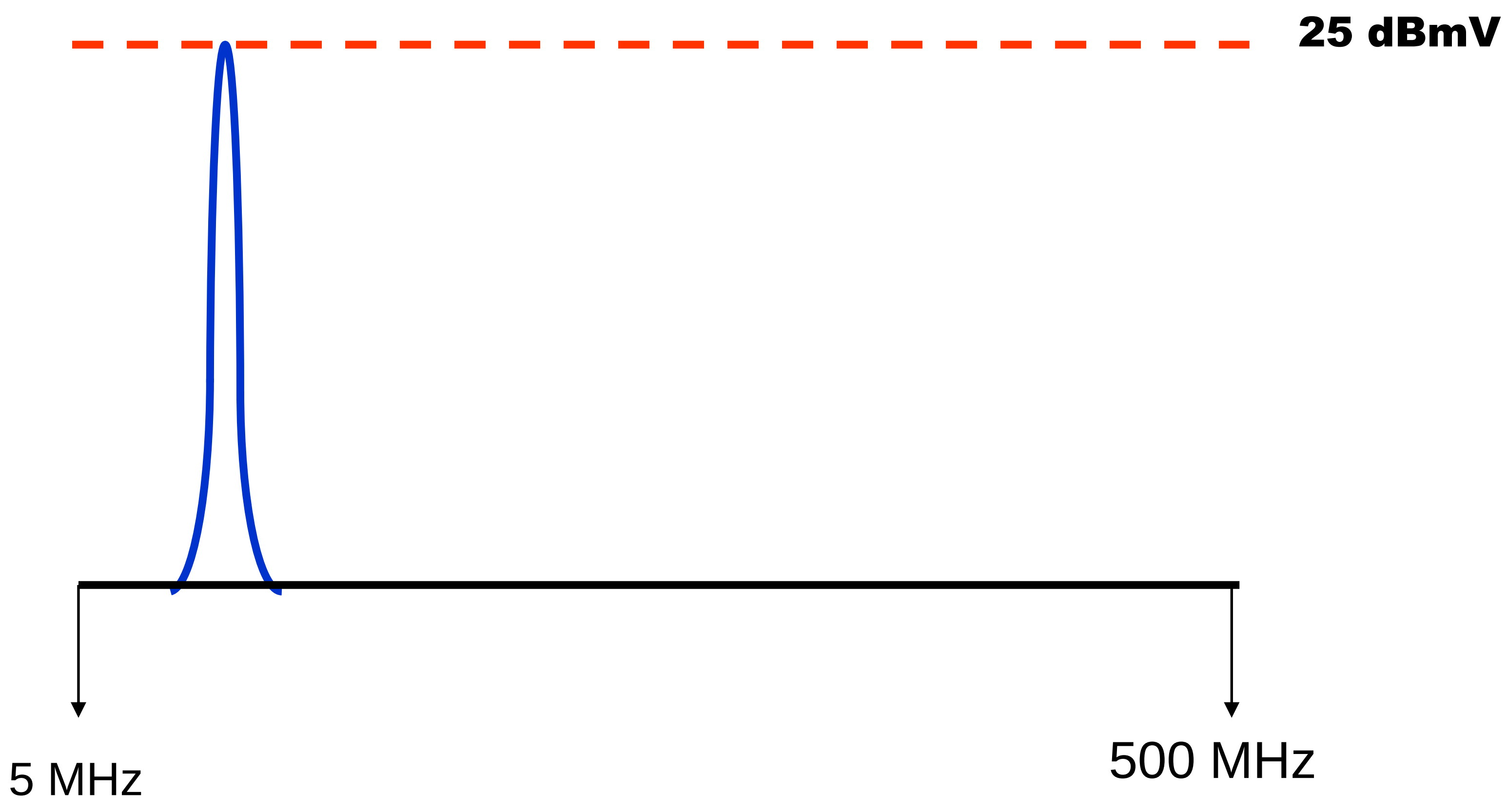
Power per Hertz

dBmV/Hz = Total Power – 10 Log (BW)
dBmV/HZ = 45 – 10 Log (37,000,000)
dBmV/ Hz = 45 – 10 (7.57)
dBmV/ Hz = 45 – 75.7
dBmV/ Hz = -29.3

Total Power Input for 6.4 MHz 64 QAM

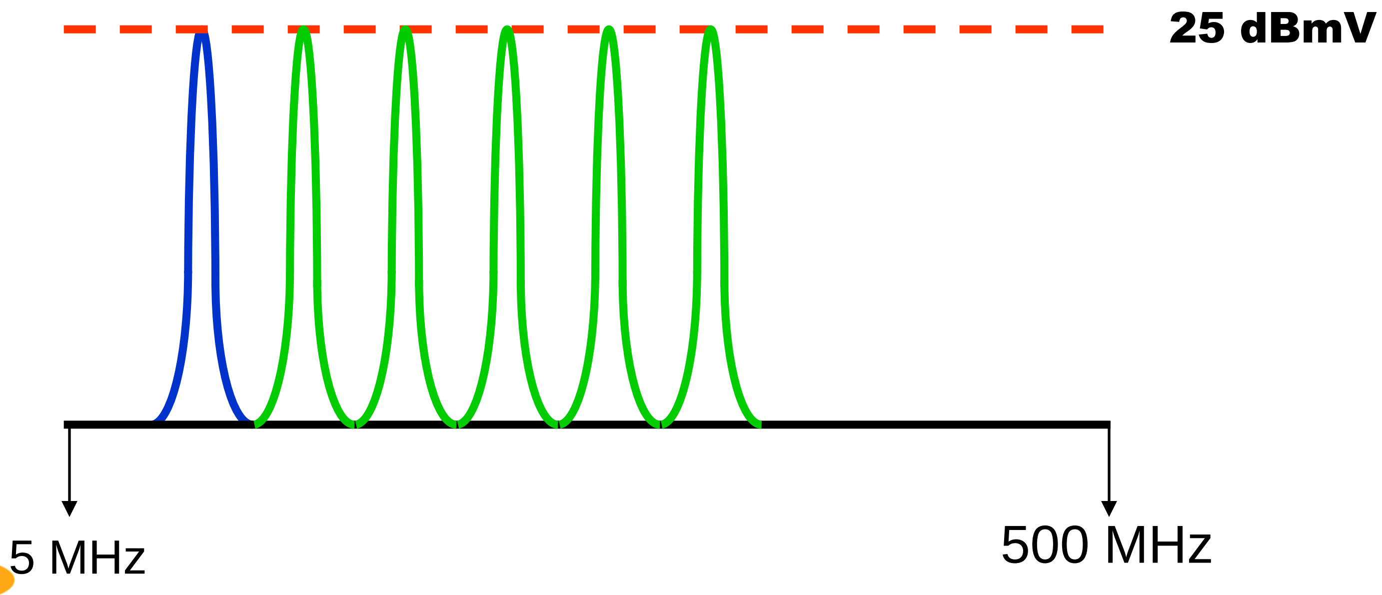
dBmV = -29.3 + 10 Log (BW)
dBmV = -29.3 + 10 Log (6,400,000)
dBmV = -29.3 + 10 (6.8)
dBmV = -29.3 + 68
dBmV = 38.7

Total Power



Total Power at the input of the Analyzer

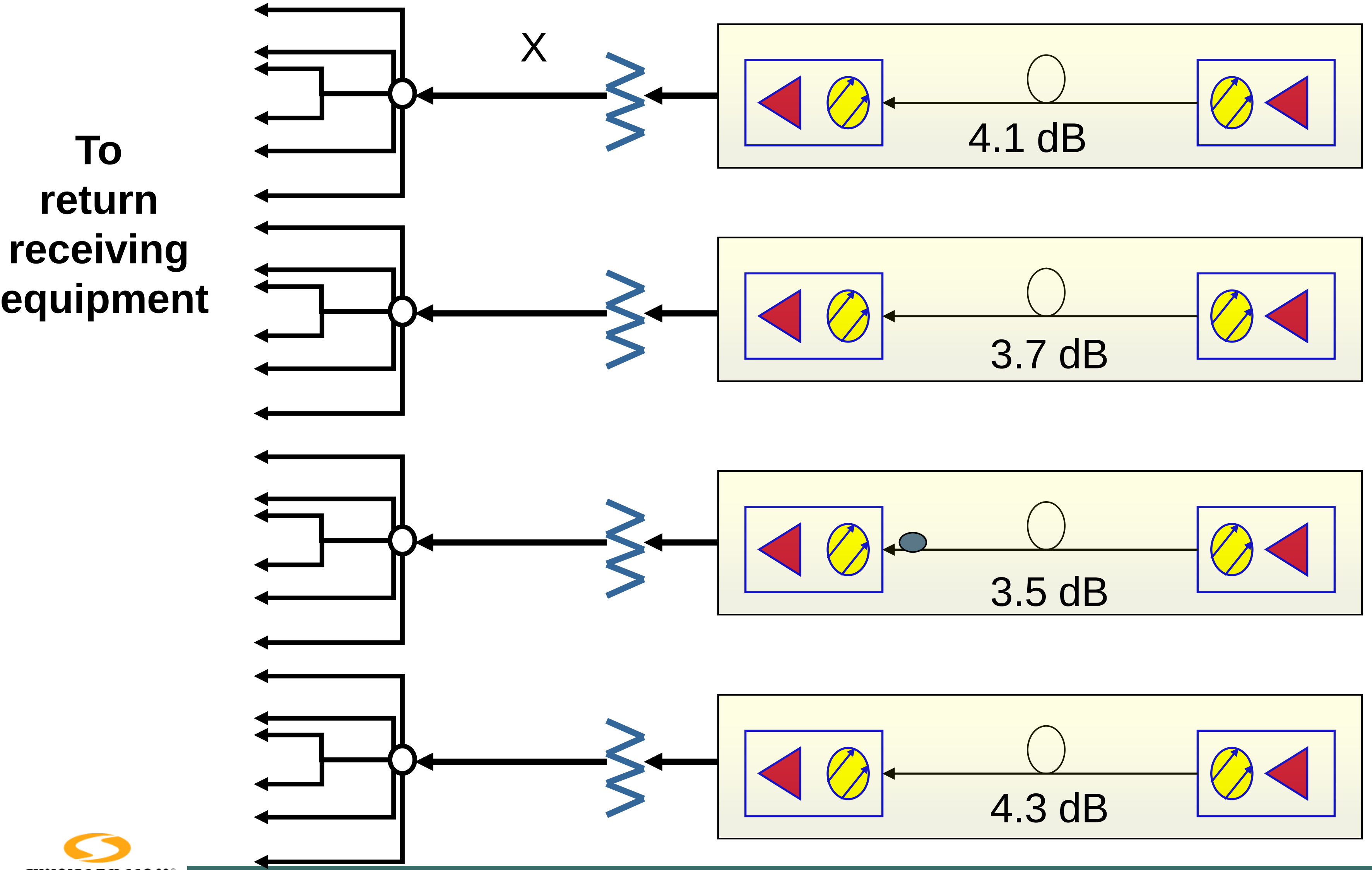
- **Several Carriers:**
- **Total Power = Carrier Level+10 log(#of carriers)**
  - ***Total Power = 25 dBmV + 10 log (6)***
  - ***Total Power = 25 + 7.78 = 32.78 dBmV***



Minimum CNR requirements to get 1E-7 BER (not good enough)

- QPSK 15 dB
- 16 QAM 22 dB
- 64 QAM 28 dB plus a window

Finding the “X” value in the headend



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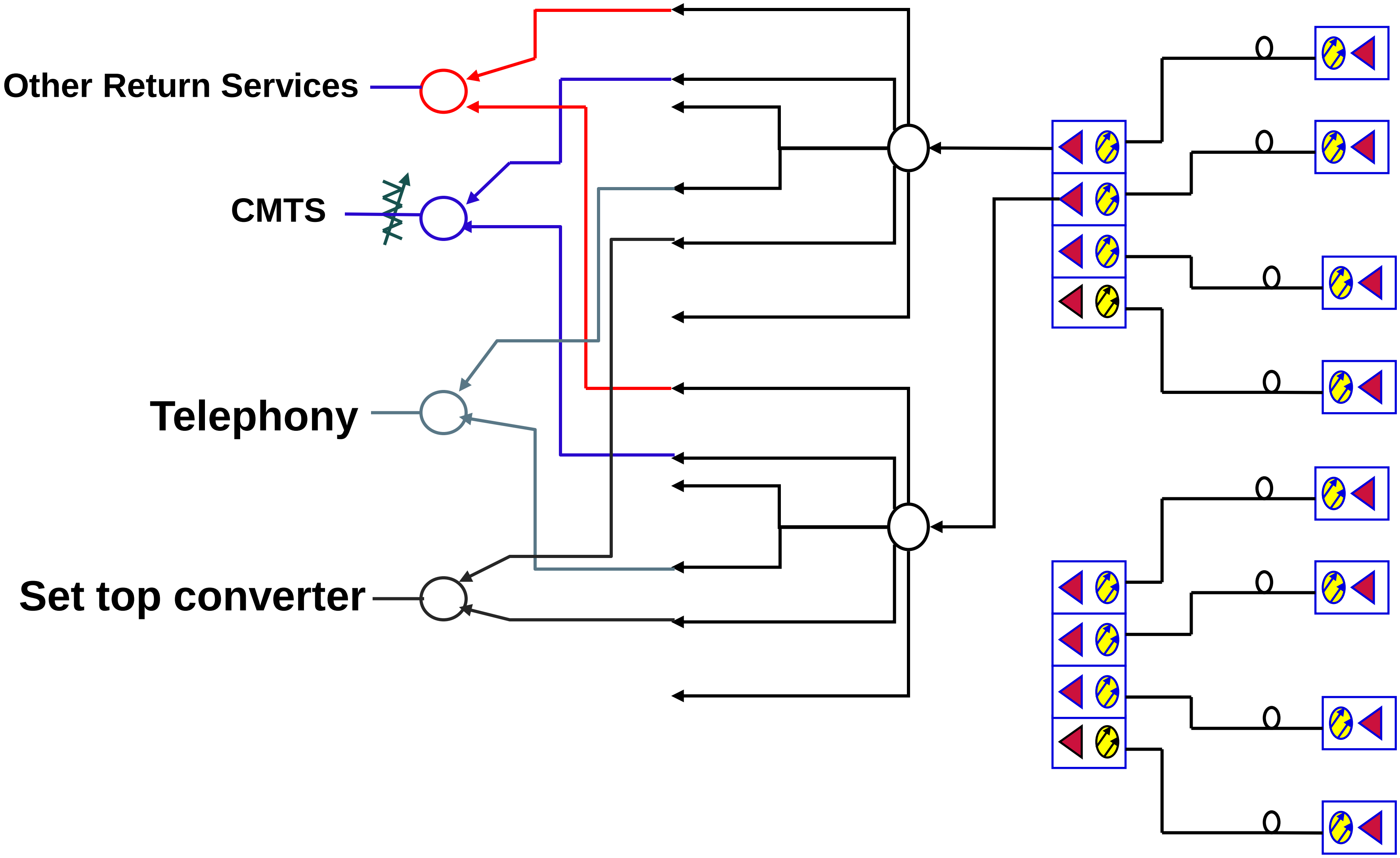
Headend combining and splitting



The outside plant

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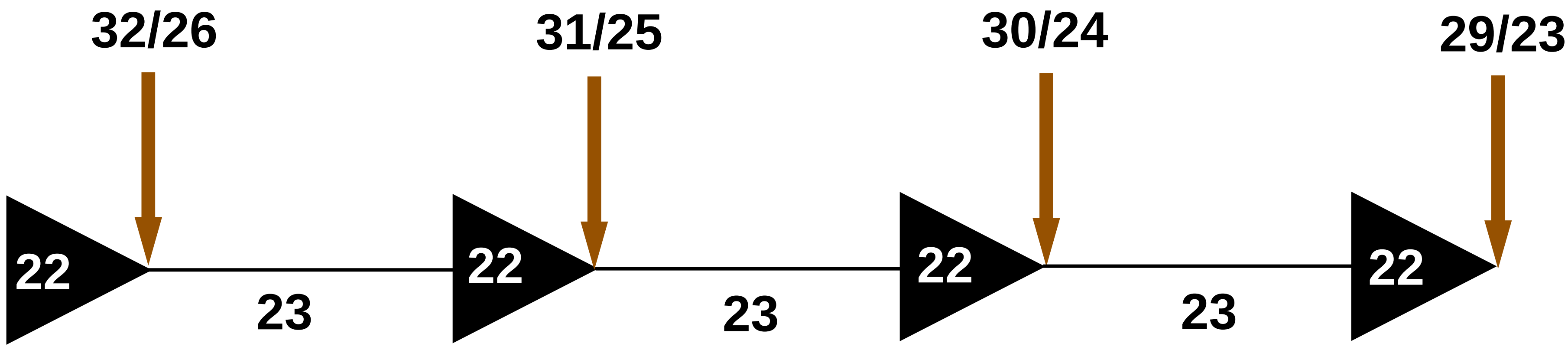
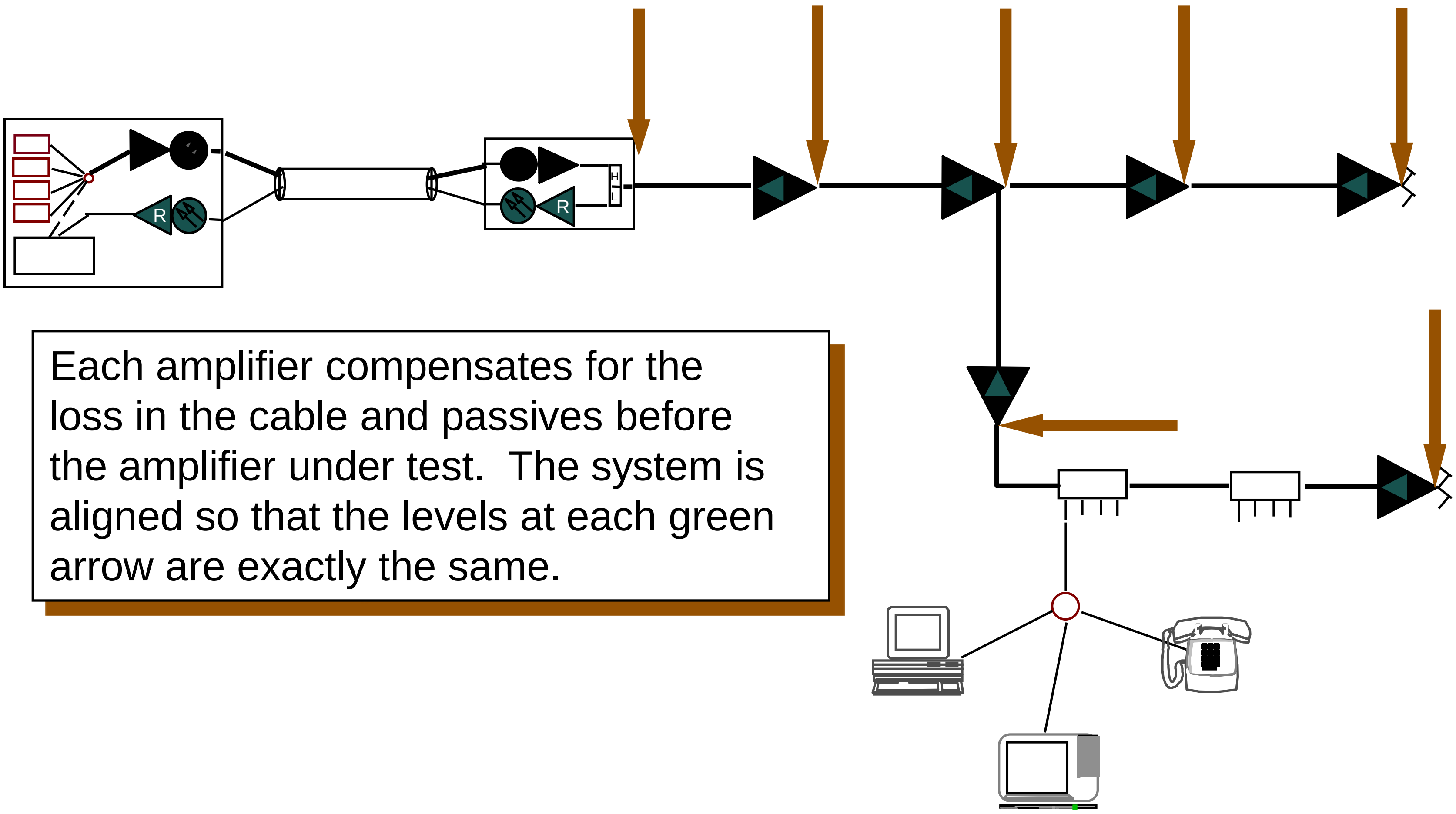
We Make Networks Work

Why do we need Unity Gain?



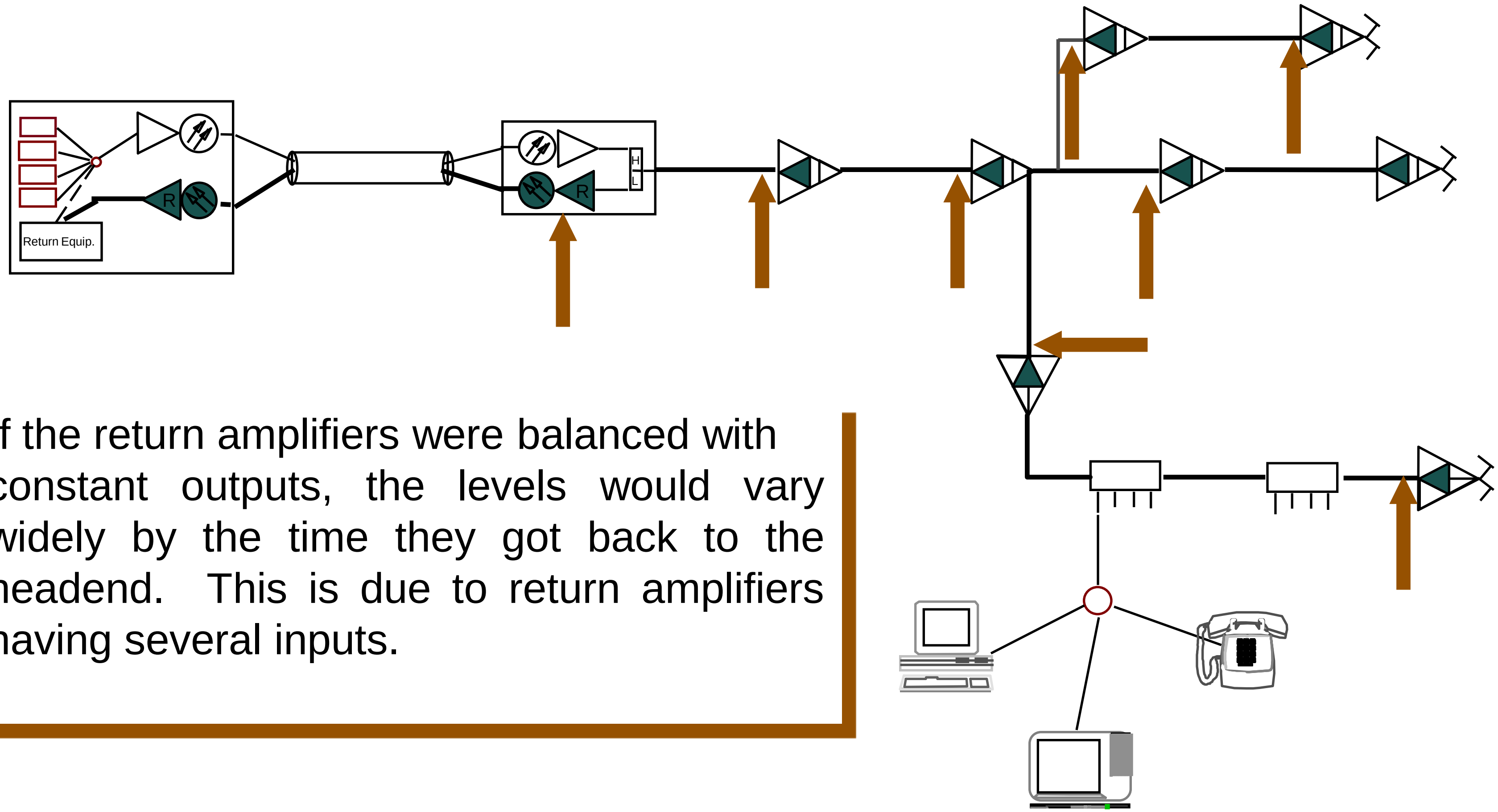
If Unity Gain is not observed distortions and or noise build up quickly!

Unity Gain in the forward path



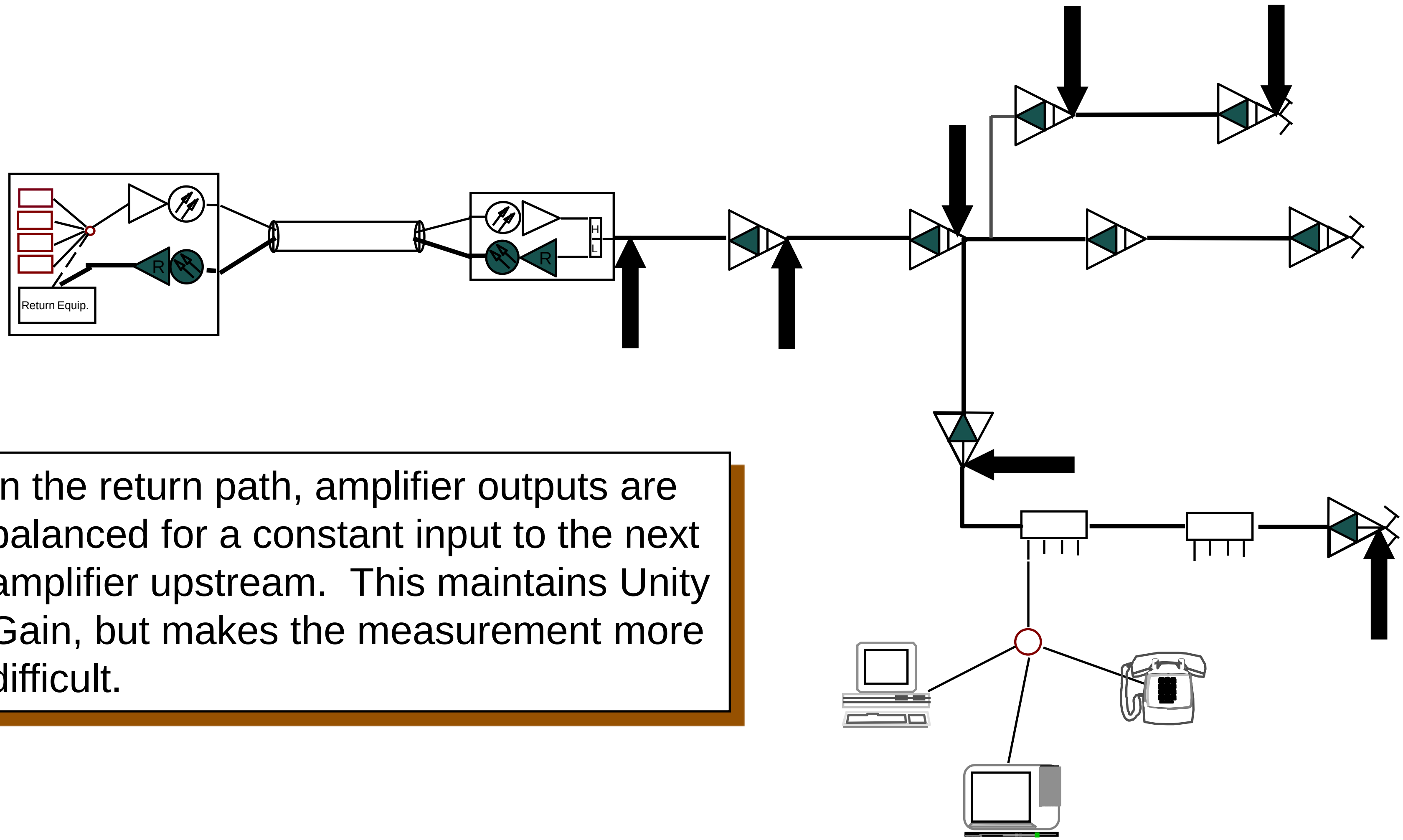
Each amplifier compensates for the loss in the cable and passives before the amplifier under test. The system is aligned so that the levels at each green arrow are exactly the same.

Constant outputs in the return path?



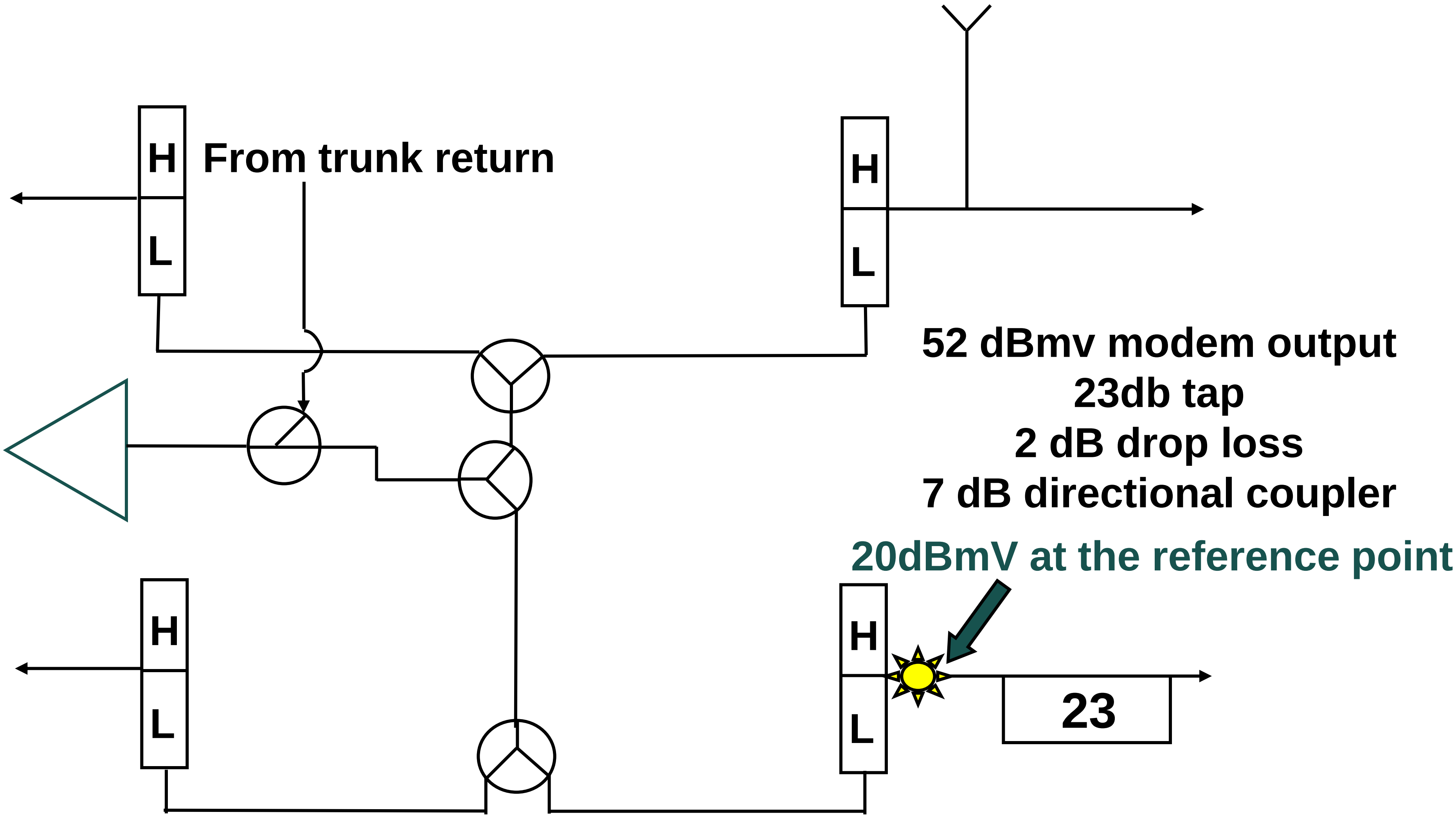
If the return amplifiers were balanced with constant outputs, the levels would vary widely by the time they got back to the headend. This is due to return amplifiers having several inputs.

Constant inputs instead of constant outputs for Unity Gain



In the return path, amplifier outputs are balanced for a constant input to the next amplifier upstream. This maintains Unity Gain, but makes the measurement more difficult.

How is a reference level determined?



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Advantages of return sweep over the older methods

- **Not as labor intensive as the older methods.**
- **Align forward and reverse with the same stop at the amplifier**
- **No cumbersome equipment in the field or the headend**
- **Minimum use of bandwidth for test equipment**
- **Control over the measurements**
- We are aligning the entire spectrum in both directions, not just 2 carriers!

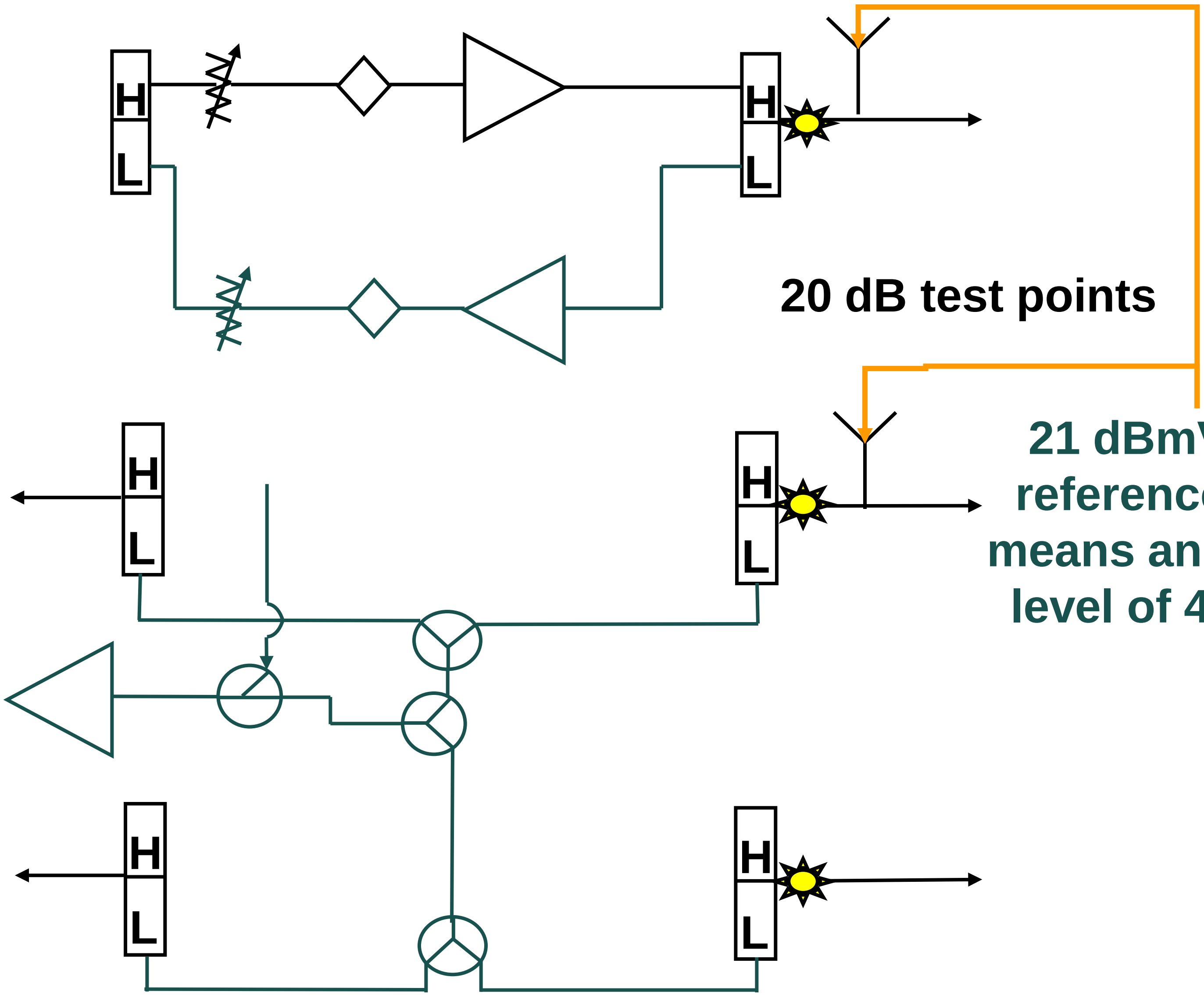
5 steps to set up your return path correctly

- Know your equipment
- Determine reference levels
- Determine reference points
- Optimize return lasers portion first
- Sweep coaxial portion of the plant

Know your equipment, know your system

- Block diagrams of amplifiers, nodes, receivers, etc.
- Test Equipment
- What are the return design levels
- What are the injection points

Injection levels



20 dB test points

21 dBmV at the reference points means an injection level of 41 dBmV

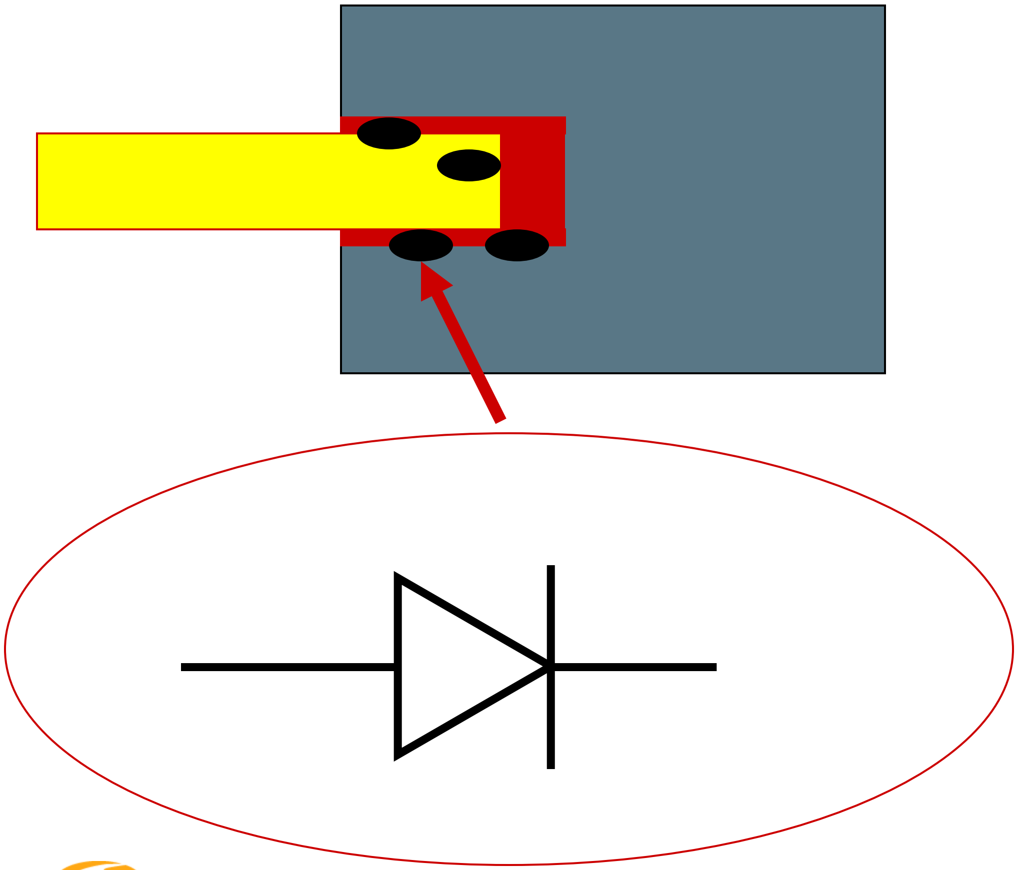
Upstream Impairments

- RF Ingress
- Intermodulation Distortions
- Laser Clipping
- Group Delay
- Amplitude Response

Common Path Distortion

- A series of beats easily seen in the return spectrum at repetitive 6 MHz spacings
- Ingress does not cause repeatable patterns
- Usually caused by corrosion at a dissimilar metals interface acting as a diode
- Actually caused by the forward carriers and also increases distortions in the forward path
- The higher in level the forward carrier levels are at the source of the problem, the worse CPD will be

Corrosion & Diode Effect



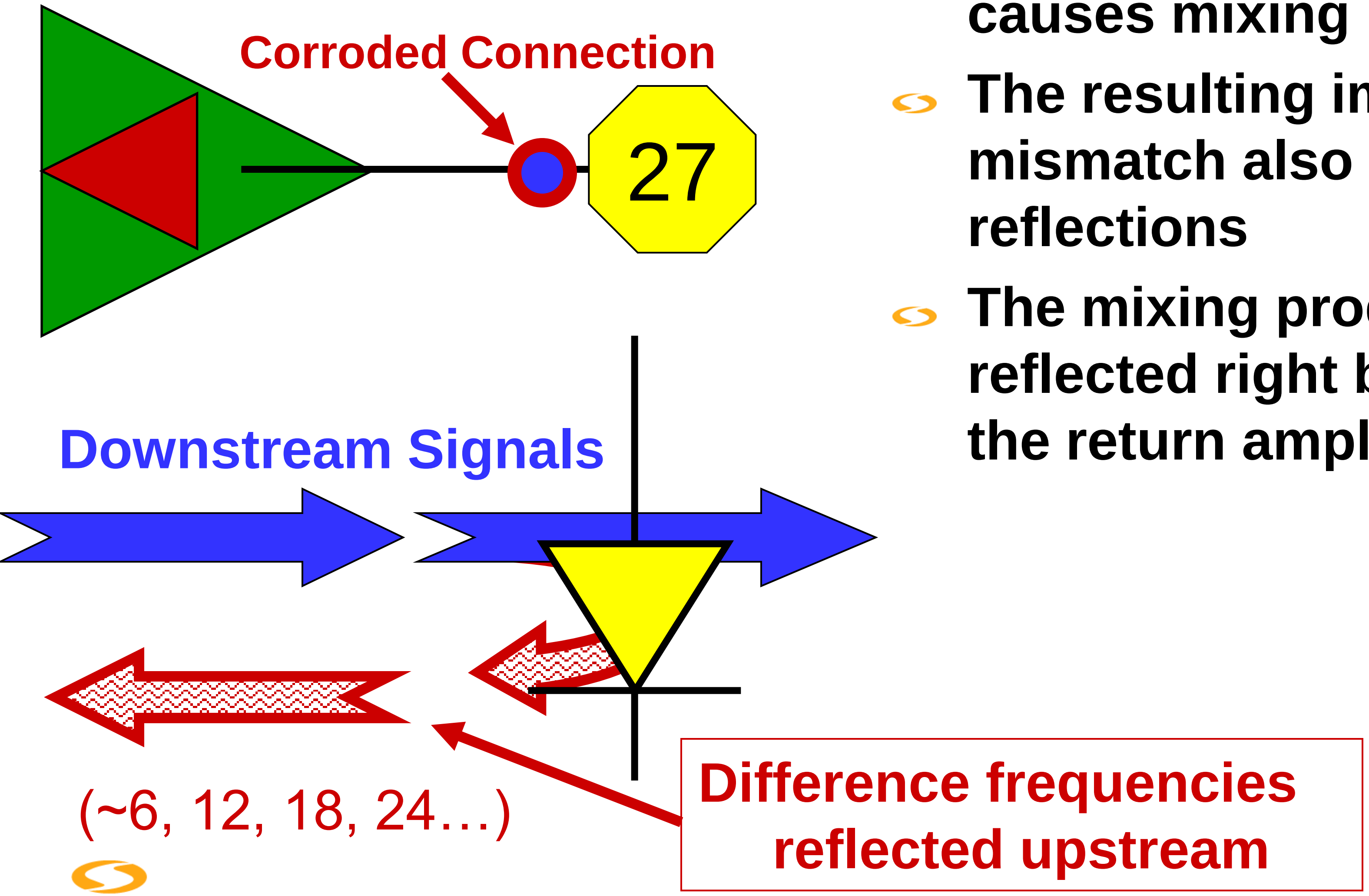
- Crystallization occurs and the corrosion creates thousands of small diodes between the two metals
- Diodes are non-linear devices that can act as frequency “mixers” in a CATV plant

Mixing two frequencies (F1 & F2) will yield four results:

F1	55.25 MHz
F2	61.25 MHz
F1 + F2	116.50 MHz
F2 – F1	6.00 MHz

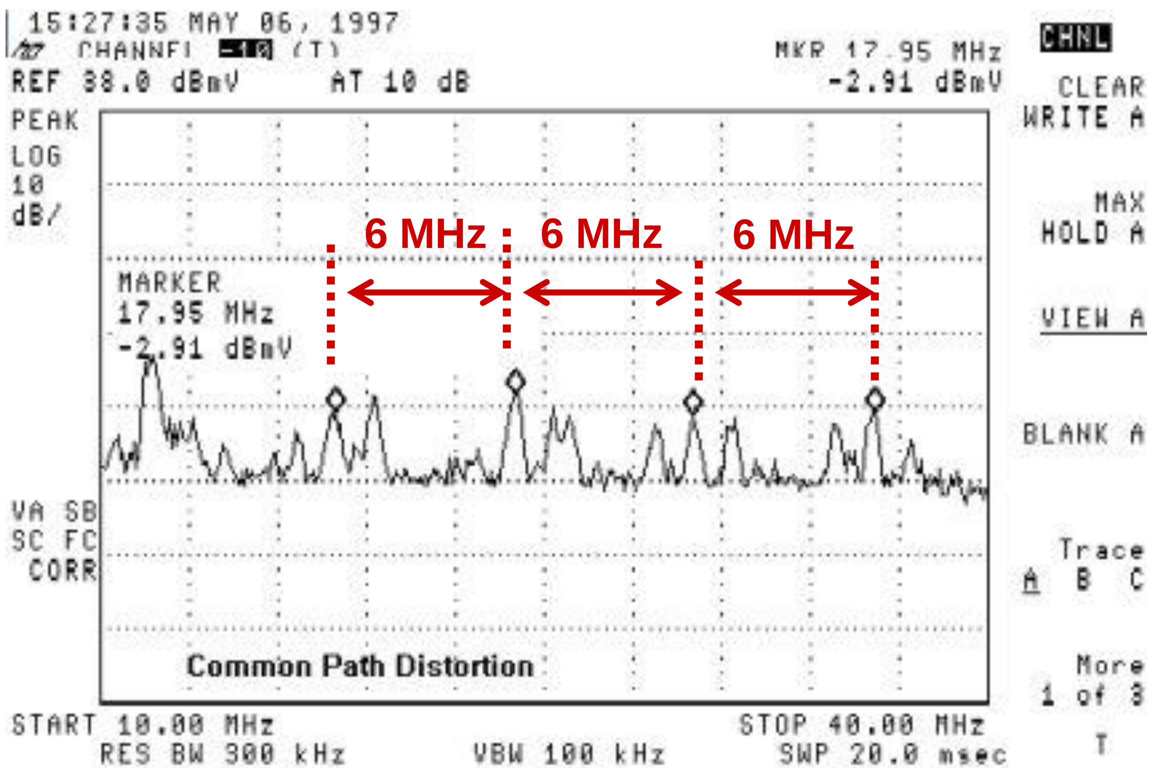
Common Path Distortion

- A corroded connection causes mixing
- The resulting impedance mismatch also causes reflections
- The mixing products are reflected right back into the return amplifier.



CPD in 6 MHz Intervals

- Because the channels in the forward system are 6 Mhz apart, the sum and difference frequencies occurr at 6 MHz intervals as well.



CPD common sources

- Loose or over-tightened seizure screws
- Loose hold down screws on modules and circuit boards
- Feed through connectors
- Loose and corroded terminators on taps
- Bad line terminators on taps
- Anything that allows moisture to enter a device

CPD troubleshooting tips

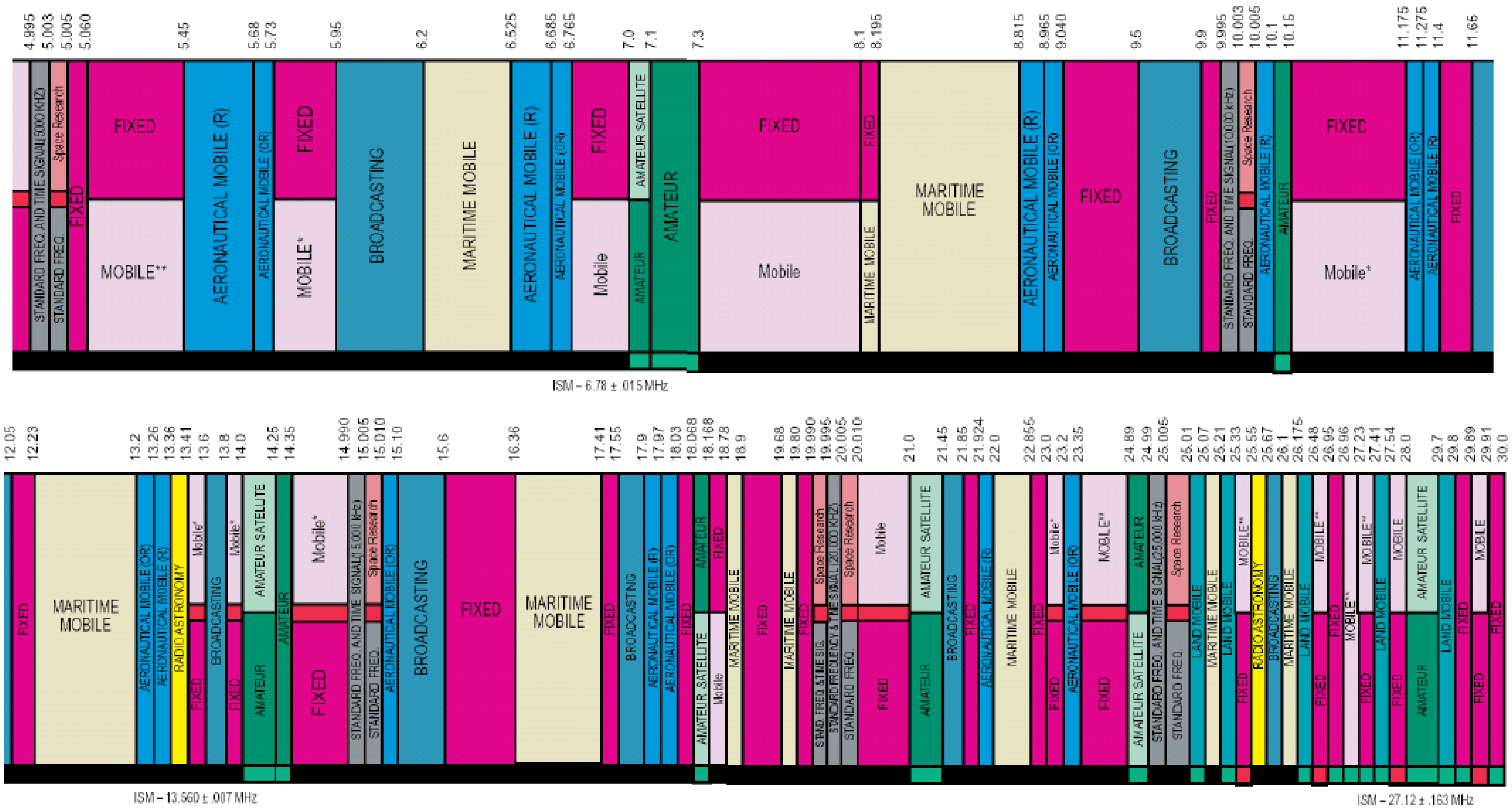
- When return sweeping, set up sweep from 5-50 MHz
- Check distortions on the forward path above your highest channel
- Once the feeder leg is found, troubleshoot from the termination and work back toward the amplifier

Ingress

- Ingress is a combination of random and periodic noise and discrete signals leaking into the cable
- Usually generated in the customer's home
- Excessive ingress can cause the return laser to clip, but not usually
- Ingress from anywhere affects the entire system
- One bad egg takes down the node

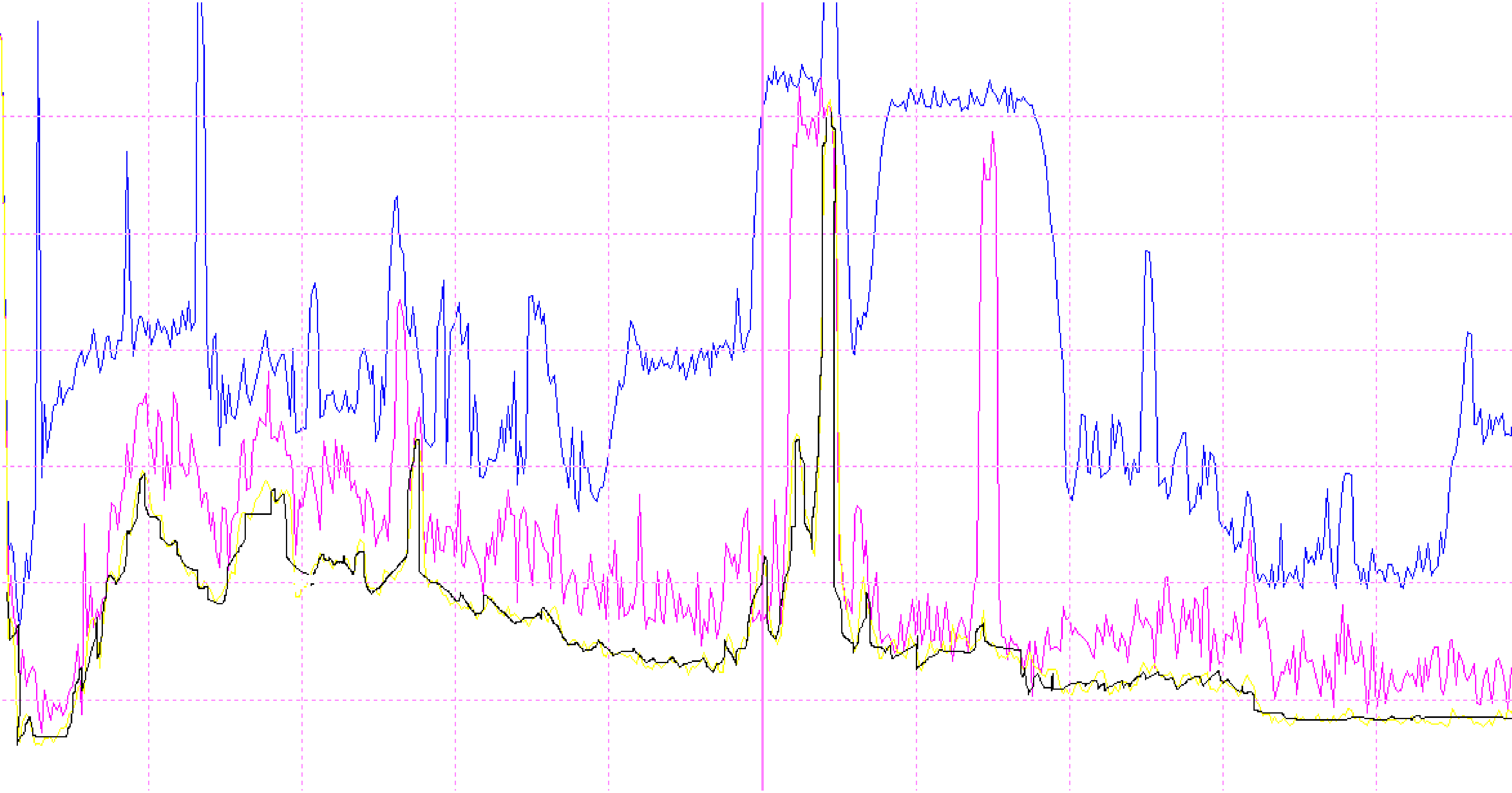
Where does Ingress come from?

Upstream Over-The-Air Spectrum, 5-30 MHz



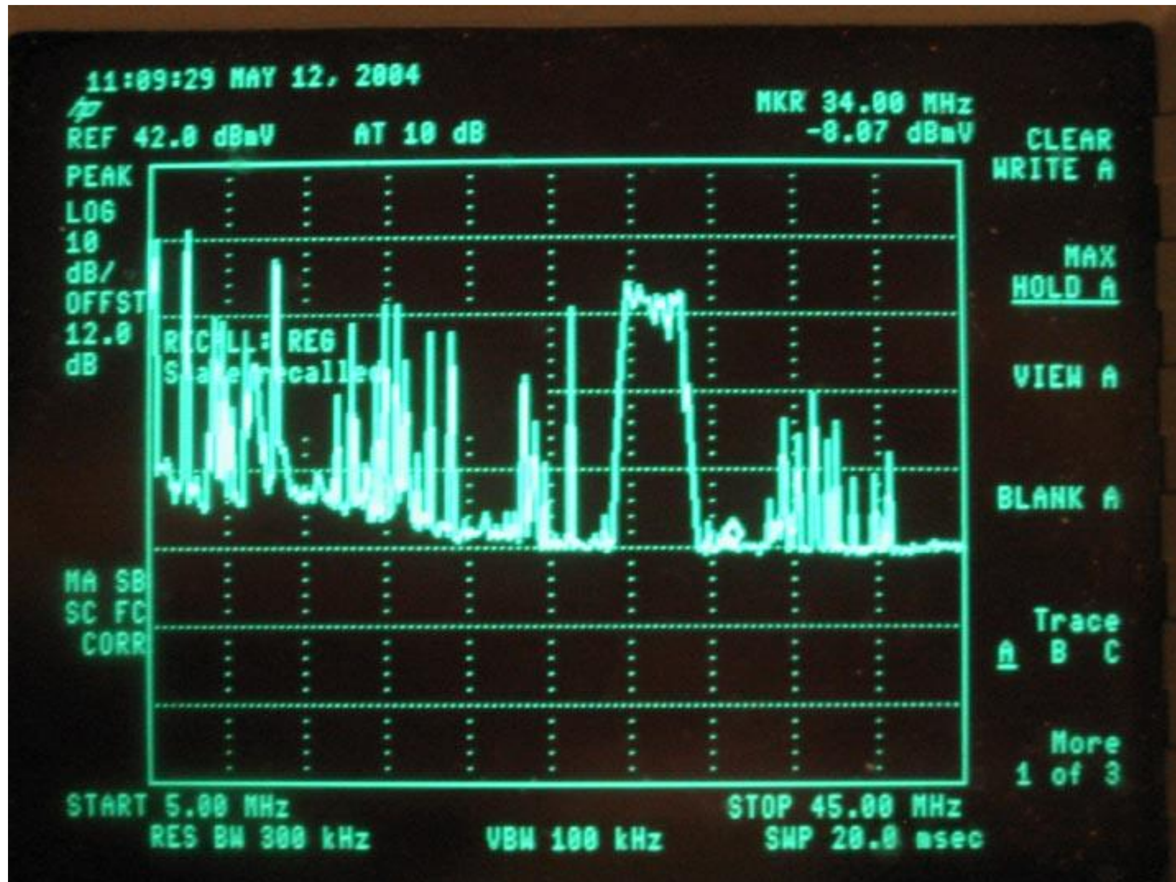
Source: NTIA (http://www.ntia.doc.gov/osmhome/allochrt.pdf)

CB Interference

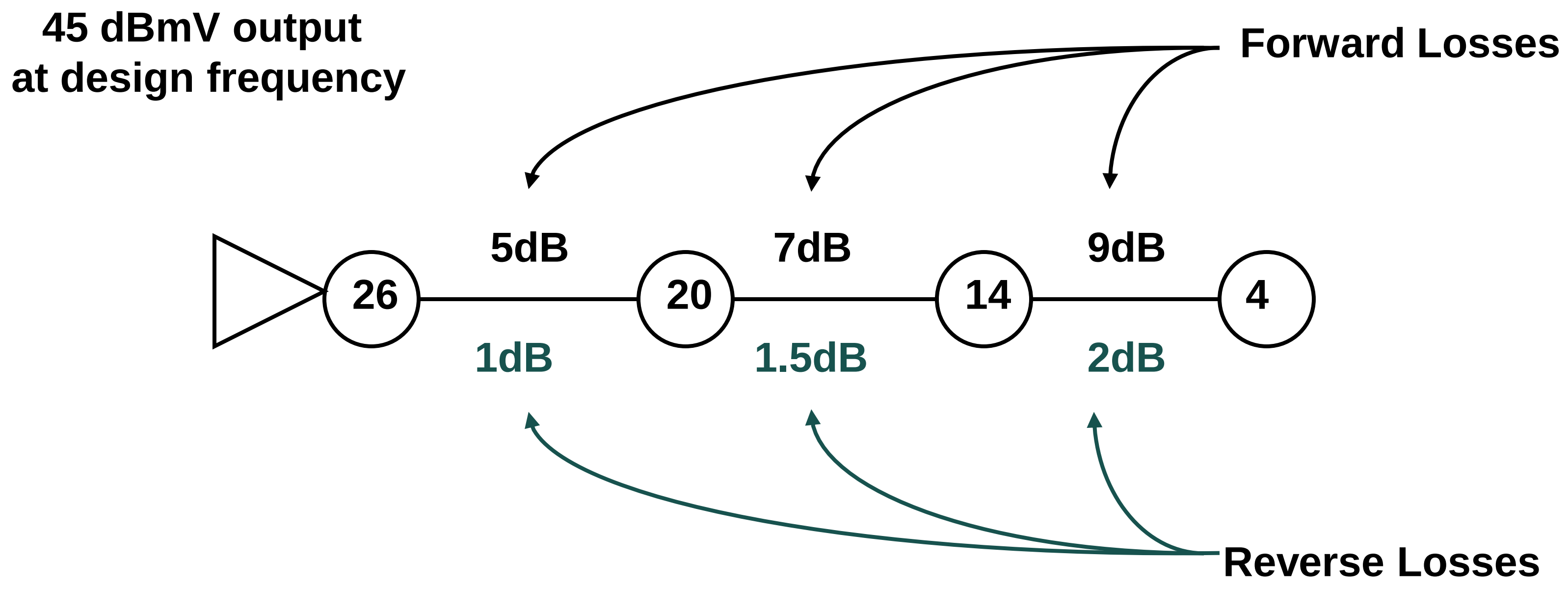


Impulse Noise

- Short duration usually less than 100 micro seconds.
- Use peak hold
- Sources:
  - Ignitions
  - Arc Welders
  - Vacuum Cleaners
  - Electric Motors



Ingress is always worse from the lower value taps!



How can we minimize ingress?

- Quality cable and connectors
- Good installation practices
- Better than mandatory leakage program
- Taps with equalizers

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Troubleshooting Goals

- To be able to localize problems without taking the system down!
- Identify problems from the field without a trip to the hub or headend first.
  - Visability into at the hub or headend the return path from the field

Troubleshooting

- Isolate the node
- Isolate the feeder
- Isolate the tap

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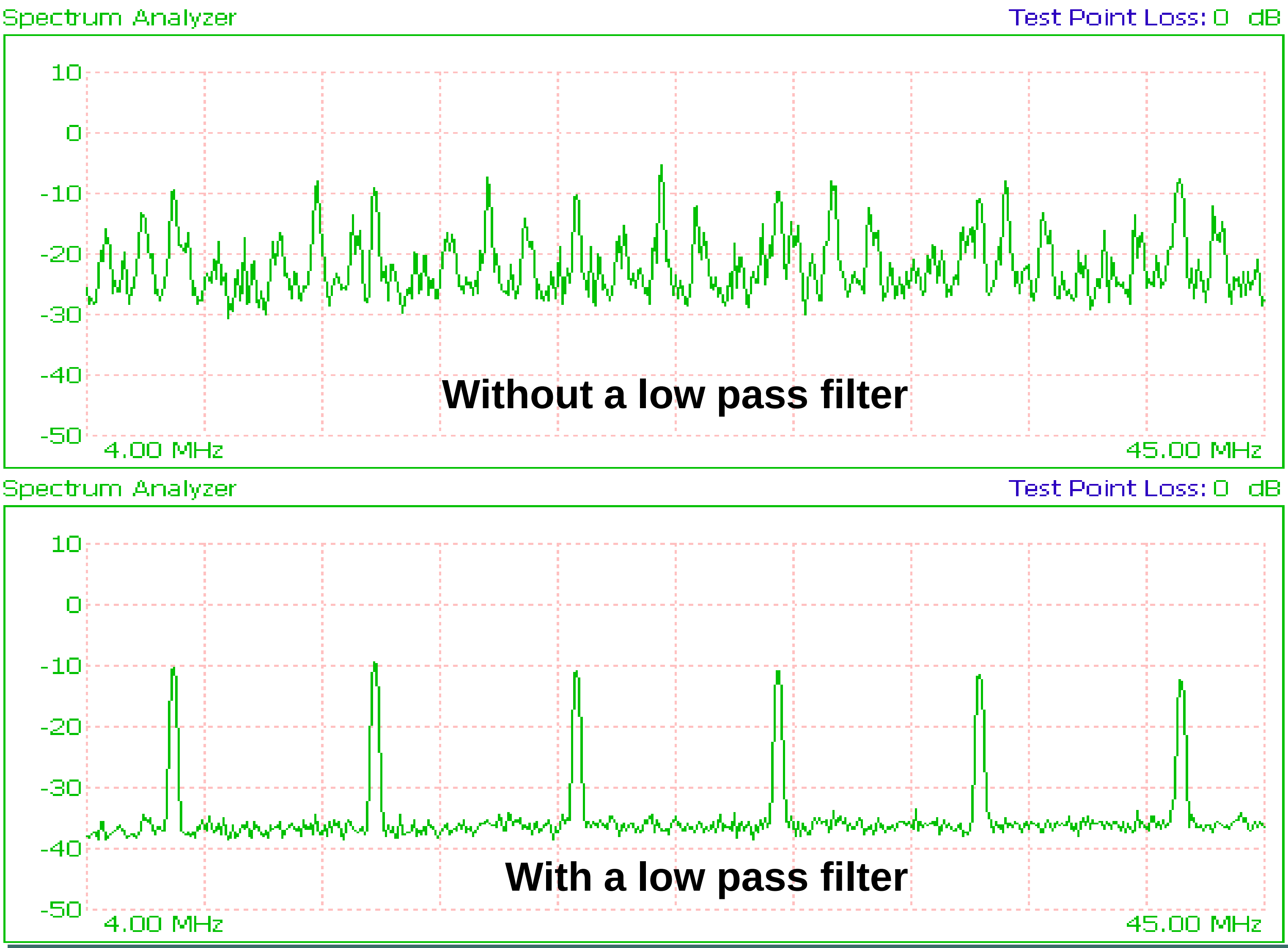
Troubleshooting Hints and Tools

- Know your test equipment
- Know your amplifier configurations
- Low pass filter on the spectrum analyzer
- AC blocking seizure screw probe
- Tap jumpers
- Return Path problems have relative levels depending on where they are being measured

Using a Low Pass Filter



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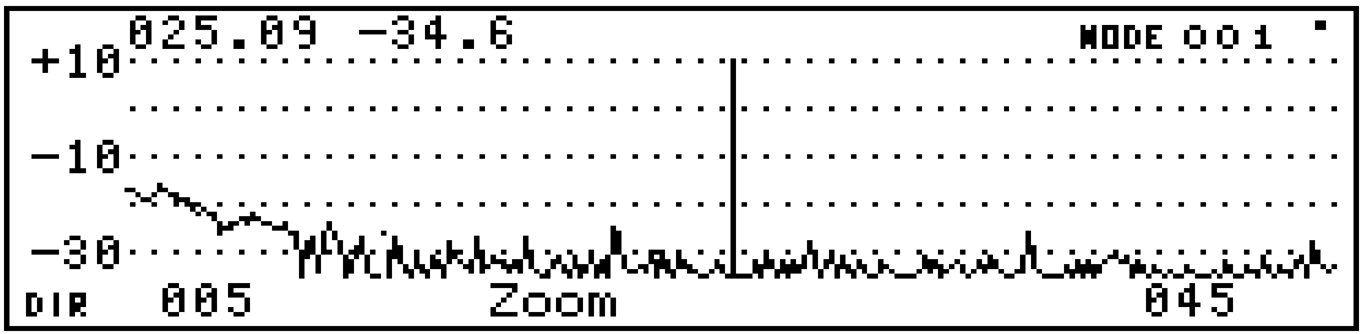
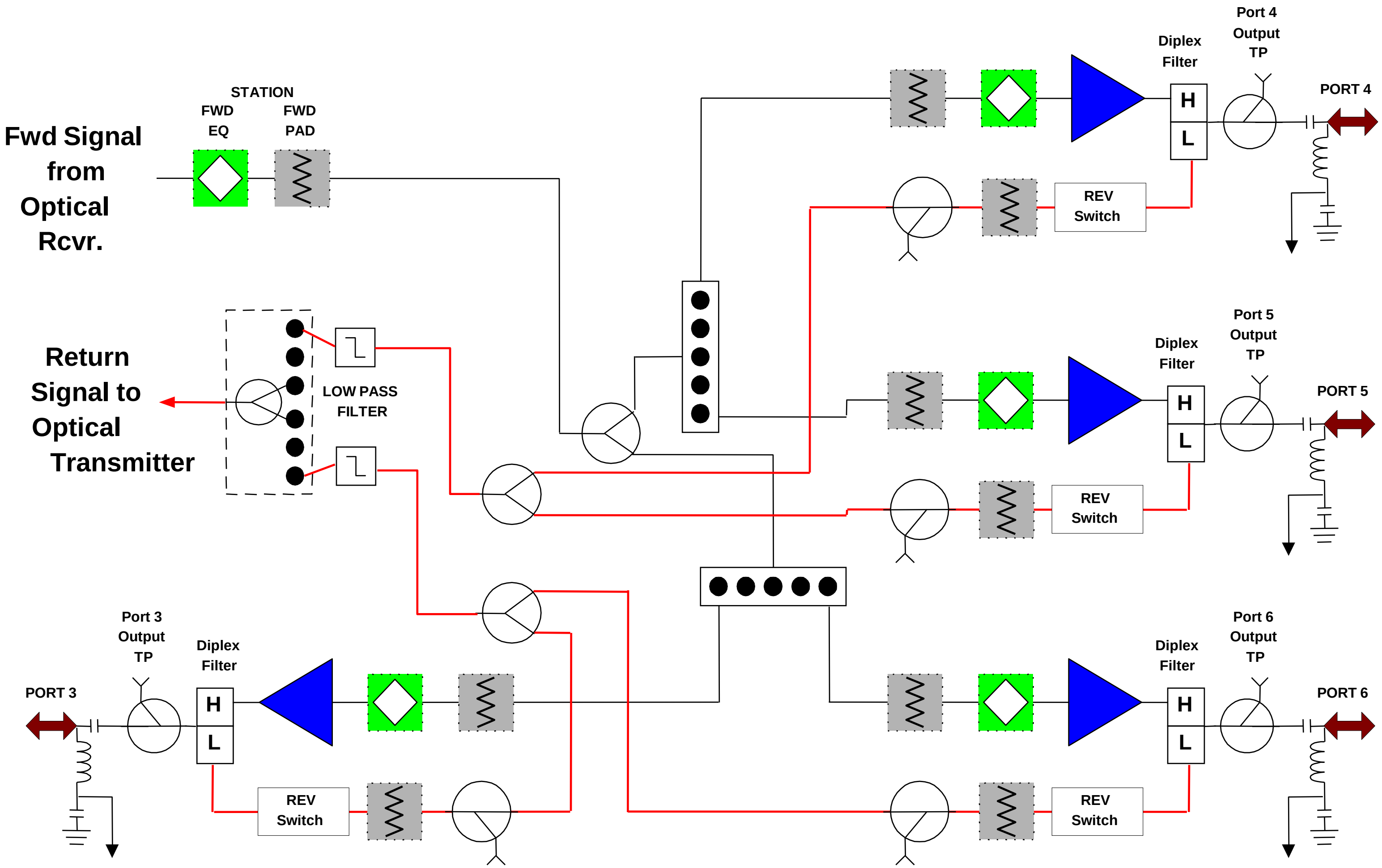
3010R Return Spectrum

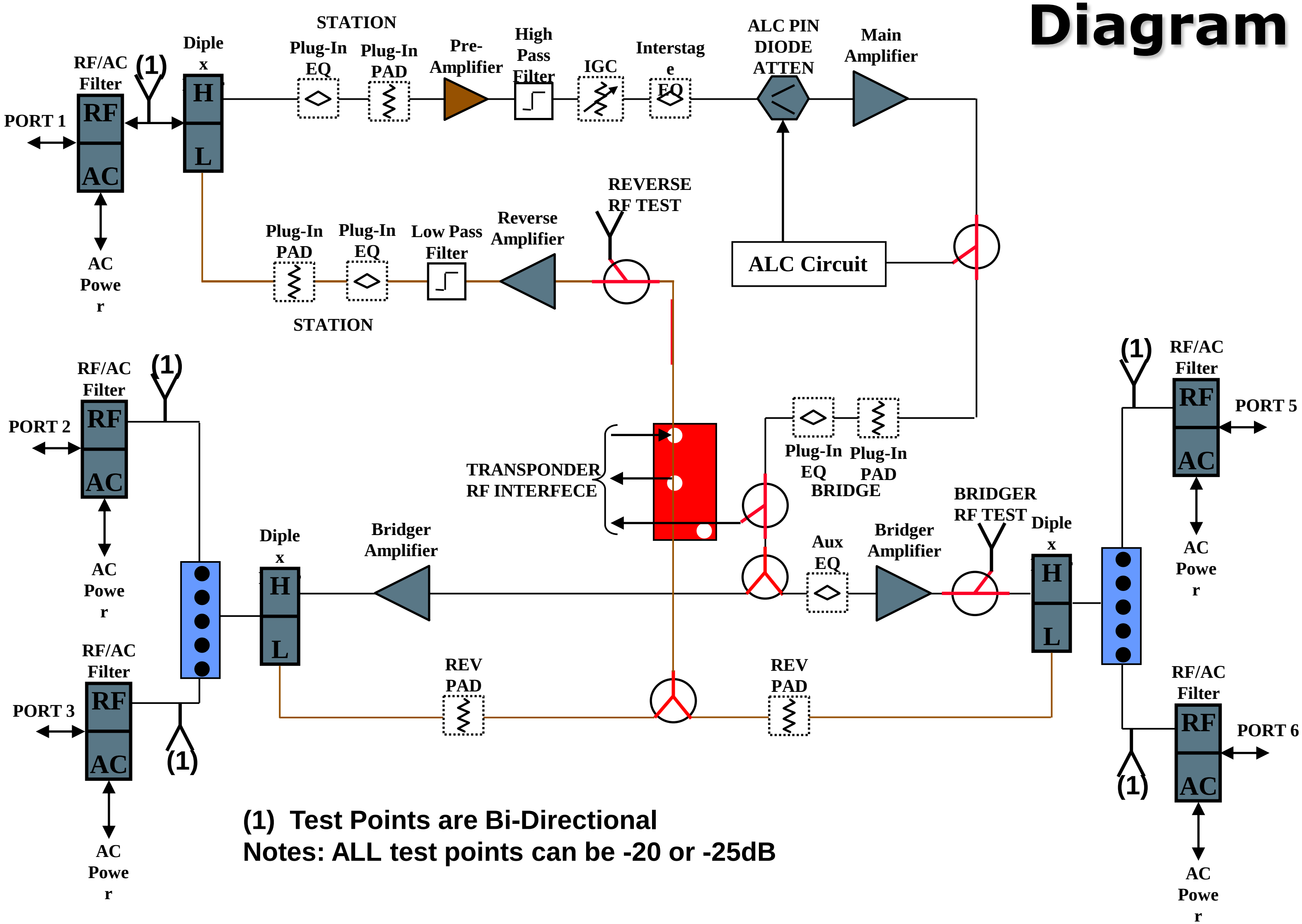
Current Node



Typical Node RF Block Diagram



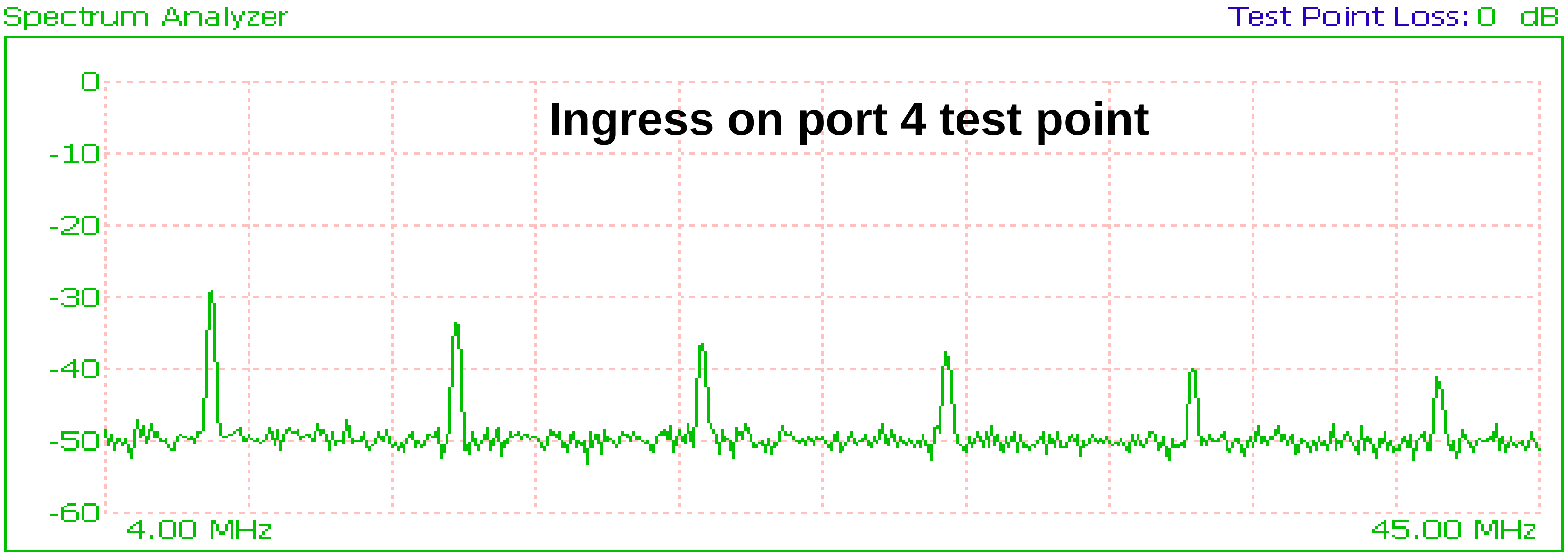
Typical RF Bridging Amplifier Block Diagram

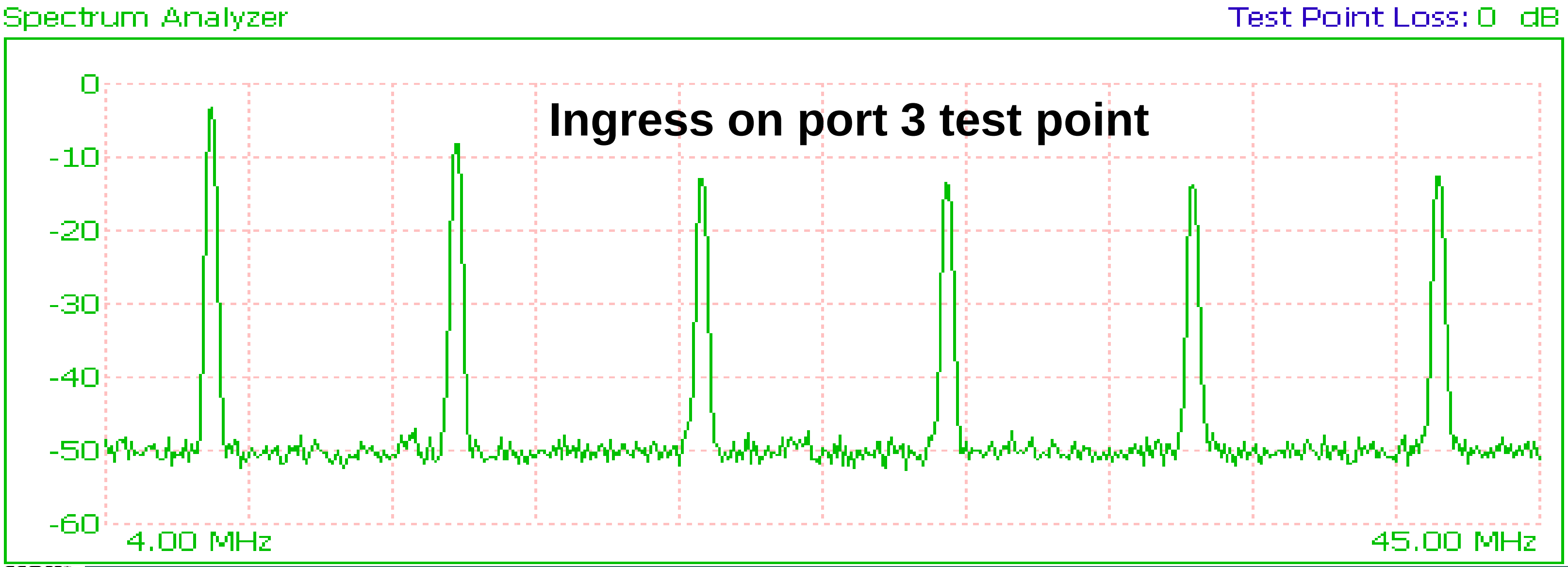


(1) Test Points are Bi-Directional

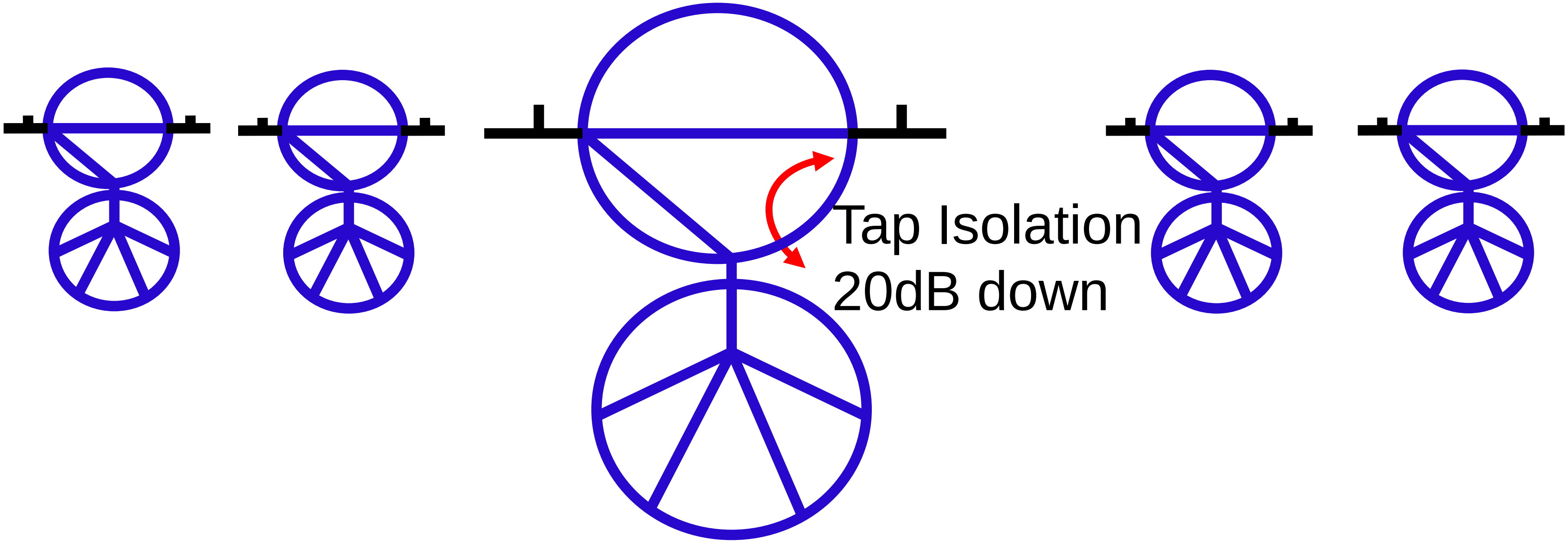
Notes: ALL test points can be -20 or -25dB

Difference Between Ports on an r

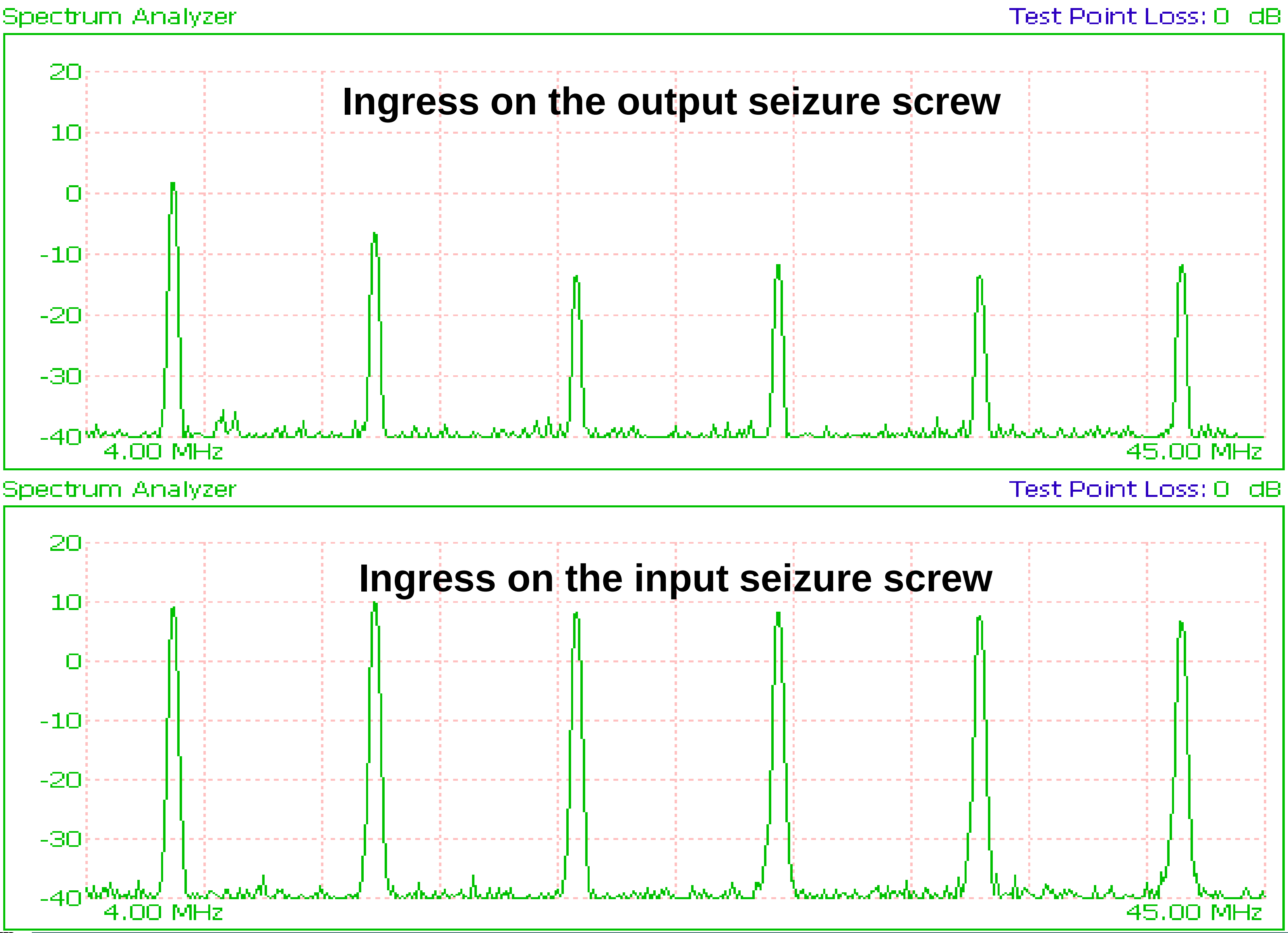




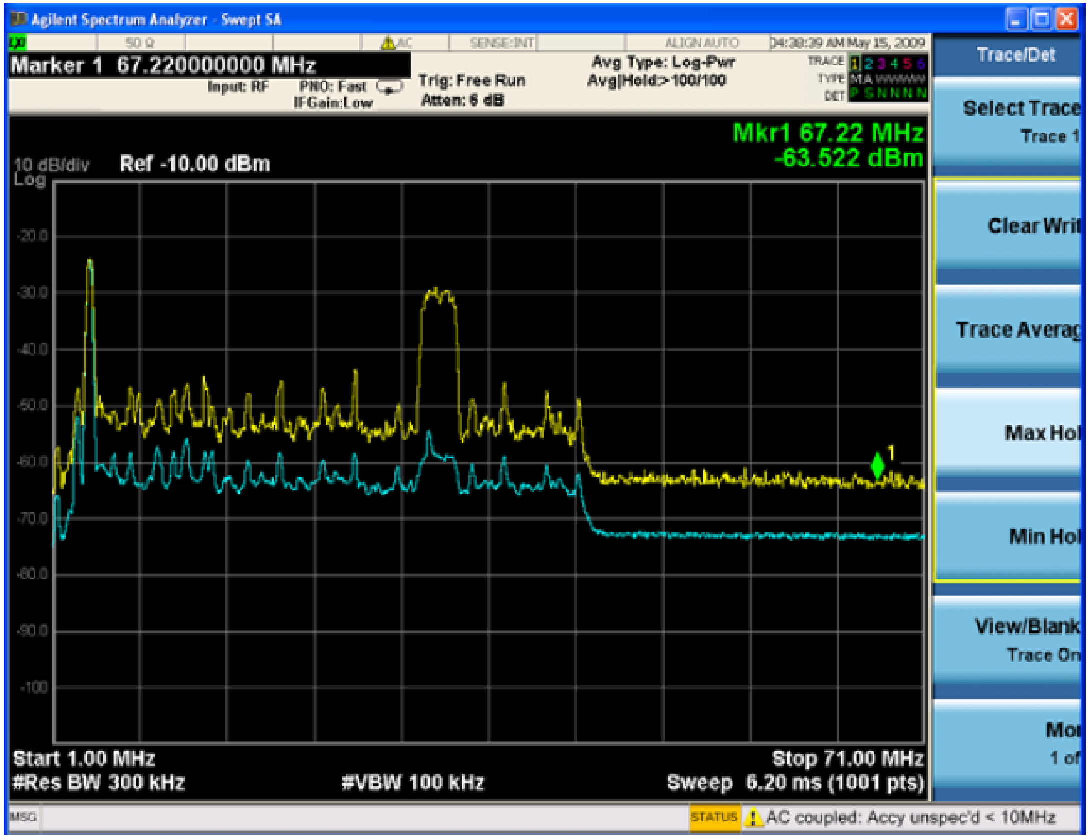
Troubleshooting to the tap



Ingress at the input and output seizure



CPD and a carrier



- Shortwave Interferer (high level)
- Evidence of CPD tones – tolerable but can degrade and associate with a microreflection
- Noise floor of FP return, stable
- Adequate for 16-QAM, poor conditions for 64-QAM

Constellation Analysis

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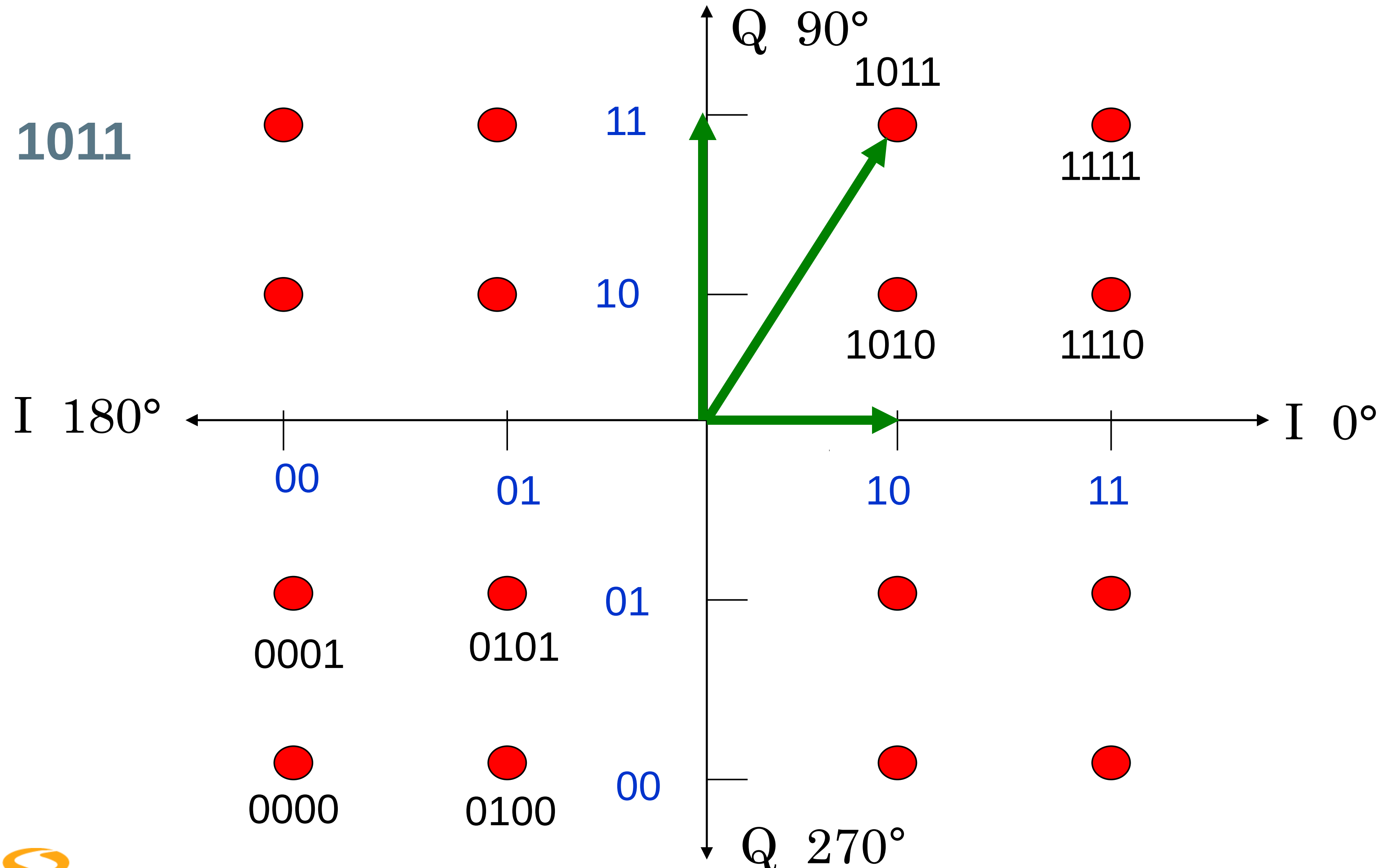
Patterns in the Constellation

MER, A Better Measurement

- A better parameter than SNR is modulation error ratio (MER) or error vector magnitude (EVM)
- MER takes into account:
  - CNR
  - Phase Noise (jitter of phase of QAM modulator's carrier)
  - Intermod Distortions
  - Compression of Lasers and Amplifiers
  - Frequency Response
  - THE SUM OF ALL EVILS
- MER is a single figure of merit for the quality of an RF QAM modulated signal.
- MER and EVM are the same thing. MER is expressed in dB; EVM is expressed in %.
- Can be directly linked to BER

Vectors and QAM

1011



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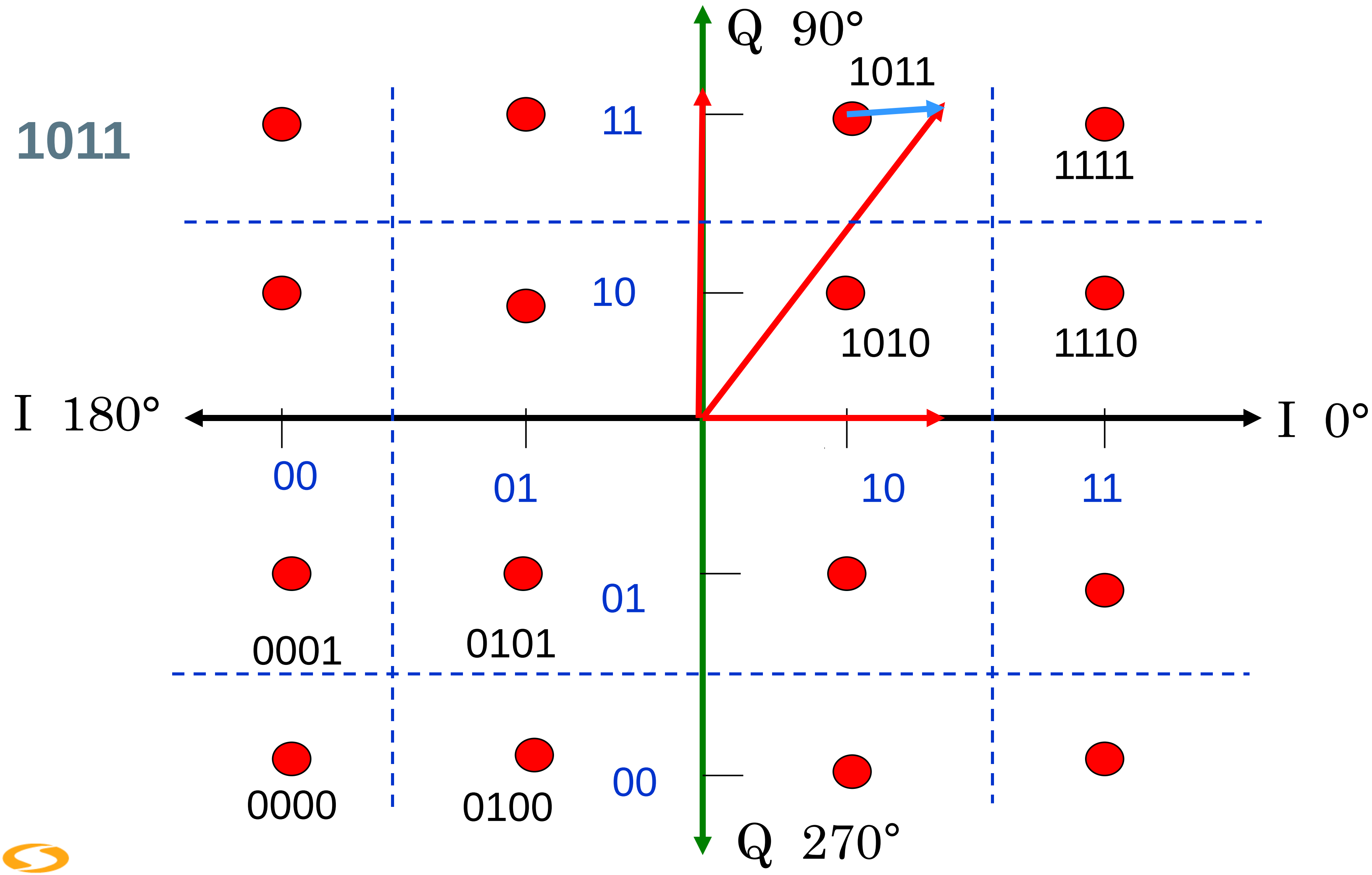
Vectors and QAM

1011



Introduction to BER

- **Bit Error Rate (BER) is an important concept to understand in any digital transmission system since it is a major indicator of the quality of the digital system.**
- **As data is transmitted some of the bits may not be reproduced at the receiver correctly. The more bits that are incorrect, the more the signal will be affected.**
- **BER is a ratio of incorrect bits to the total number of bits measured.**
- **Its important to know what portion of the bits are in error so you can determine how much margin the system has before failure.**

What is BER?

- BER is defined as the ratio of the number of wrong bits over the number of total bits.
- BER is measured by sending a known string of bits and then counting the errored bits vs. the total number of bits sent.
- This is technically an out of service measurement.

Sent Bits	1101101101
Received Bits	1100101101

error

$$BER = \frac{\#\text{ of Wrong Bits}}{\#\text{ of Total Bits}} = \frac{1}{10} = 0.1$$

What is BER?

- **BER is normally displayed in Scientific Notation.**
- **The more negative the exponent, the better the BER.**
- **Better than 1.0E-6 is needed after the FEC for the system to operate.**
- **The only thing you need to remember is the higher the negative exponent the better**

Decimal	Scientific Notation
1	1.0E+00
0.1	1.0E-01
0.01	1.0E-02
0.001	1.0E-03
0.0001	1.0E-04
0.00001	1.0E-05
0.000001	1.0E-06
0.0000001	1.0E-07
0.00000001	1.0E-08
0.000000001	1.0E-09

Lower and Better BER

Decimal	Scientific Notation
0.00001	1.0E-05
0.000009	9.0E-06
0.000008	8.0E-06
0.000007	7.0E-06
0.000006	6.0E-06
0.000005	5.0E-06
0.000004	4.0E-06
0.000003	3.0E-06
0.000002	2.0E-06
0.000001	1.0E-06

Noise and Intermittents

- Errors caused by noise or intermittent causes can have the same BER, but very different effects.
- Errors that are spread out are due to noise problems
- Errors that are grouped are due to intermittent problems such as ingress or loose connectors.

Spaced Errors	11011010110100111100
Burst Errors	11111010111011101101

This Example Shows the Same Error Rate But the Burst Errors are More Difficult to Correct