Return Plant Issues

SCTE Cascade Range Chapter

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Agenda

- Experience with DOCSIS upgrade
- Digital review & digital modulation
- Carrier to Noise issues
  - Coaxial Plant
  - Optical Plant
- What has changed & how to address

Upgrade to DOCSIS 3.0

- Was at DOCSIS 1.1
- Upgraded return to DOCSIS 2.0
- Upgraded forward to DOCSIS 3.0
- Majority of issues are with return upgrade to DOCSIS 2.0
- Reference to Comcast experience, but lessons learned are generic

Data Rates of DOCSIS

Version	Downstream	Upstream
1.0 & 1.1	42.88	10.24
2.0	42.88	30.72
3.0 (four channels)	171.52	122.88
3.0 (eight channels)	343.04	122.88

DOCSIS 3.0 Improvements

- Bonding up to 4 downstream channels
- Bonding up to 4 upstream channels
- Internet Protocol version 6
  - Running out of IP addresses
  - IPv4 today 4,000,000,000 addresses
  - IPv6 1,000,000,000,000,000,000 addresses
- Advanced encryption
- Modular CMTS (M-CMTS)

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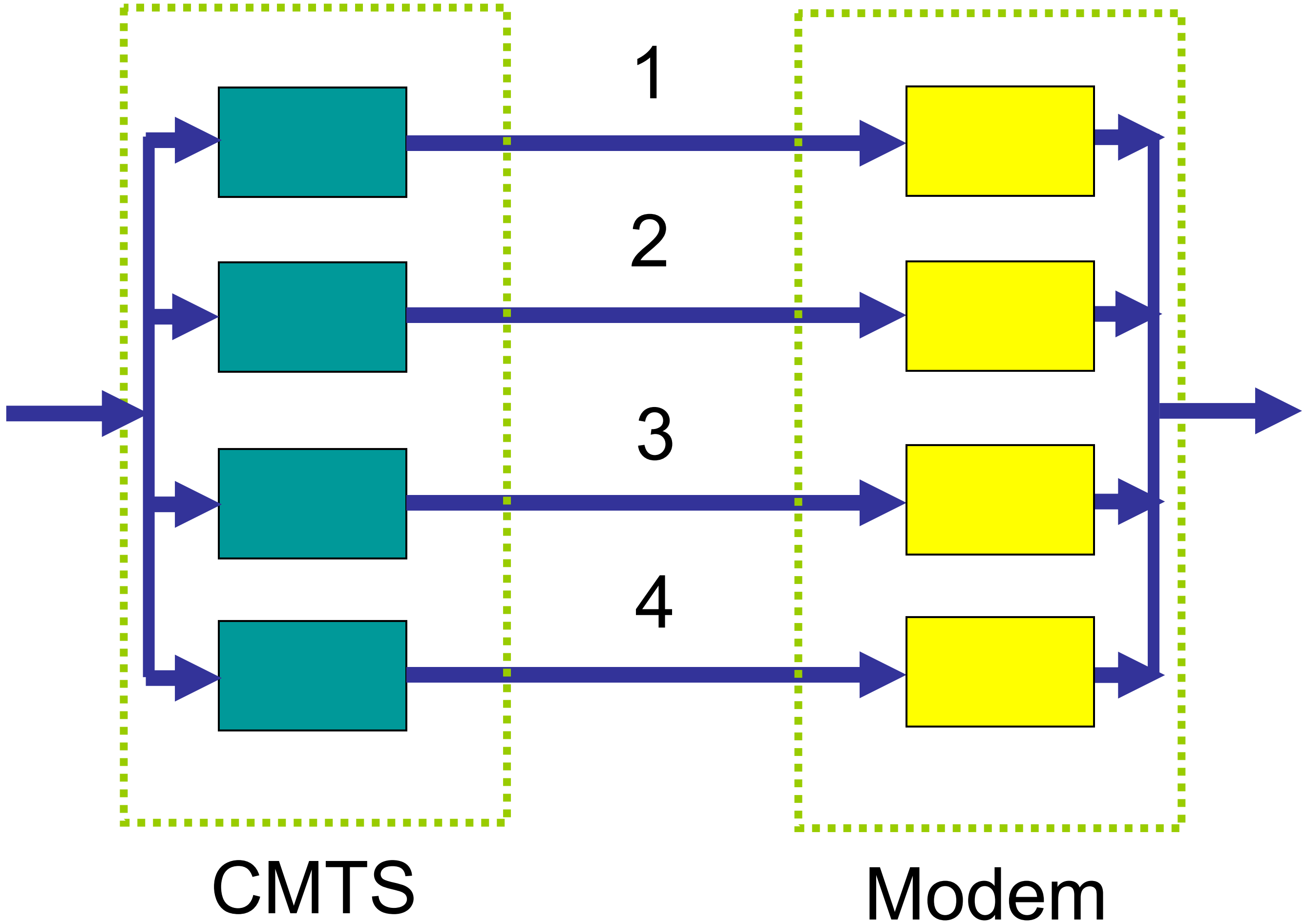
Channel Bonding



First Phase

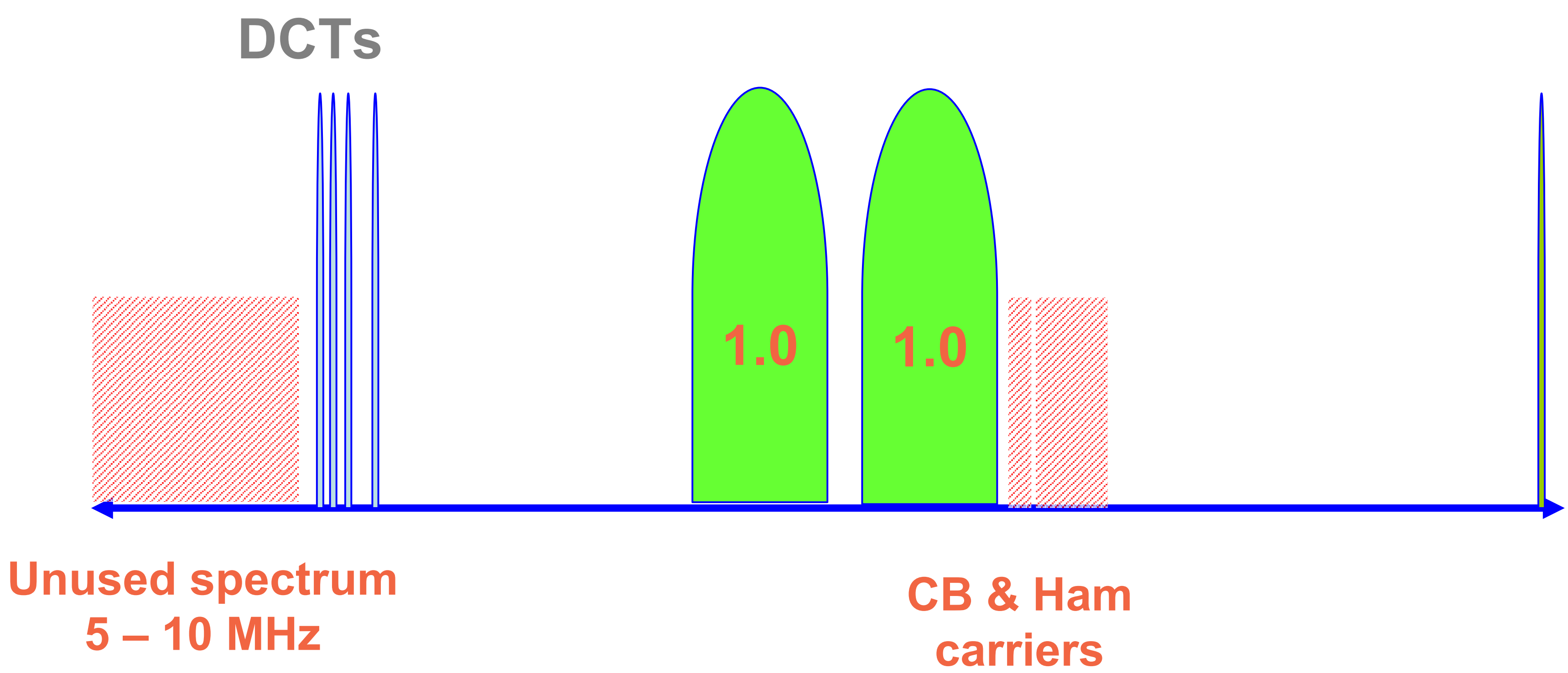
- DOCSIS 3.0 downstream
  - Three carriers total
  - Bond 2 of the 3 carriers
  - Effective bandwidth of 116.4 Mb/s

- DOCSIS 2.0 upstream
  - Two carriers total
  - One 64 QAM 30 Mb/s
  - One 16 QAM 10 Mb/s

DOCSIS 2.0 Upstream

- Have legacy DOCSIS 1.0 & 1.1 modems
- Not forward compatible with DOCSIS 2.0
- Solution is to keep one DOCSIS 1.1 carrier and add a DOCSIS 2.0 carrier
- DOCSIS 2.0 is 6.4 MHz carrier with 64 QAM modulation
- Increase from 10 mbps to 30 mbps

Typical Return Before Upgrade



Spectrum susceptible to interference

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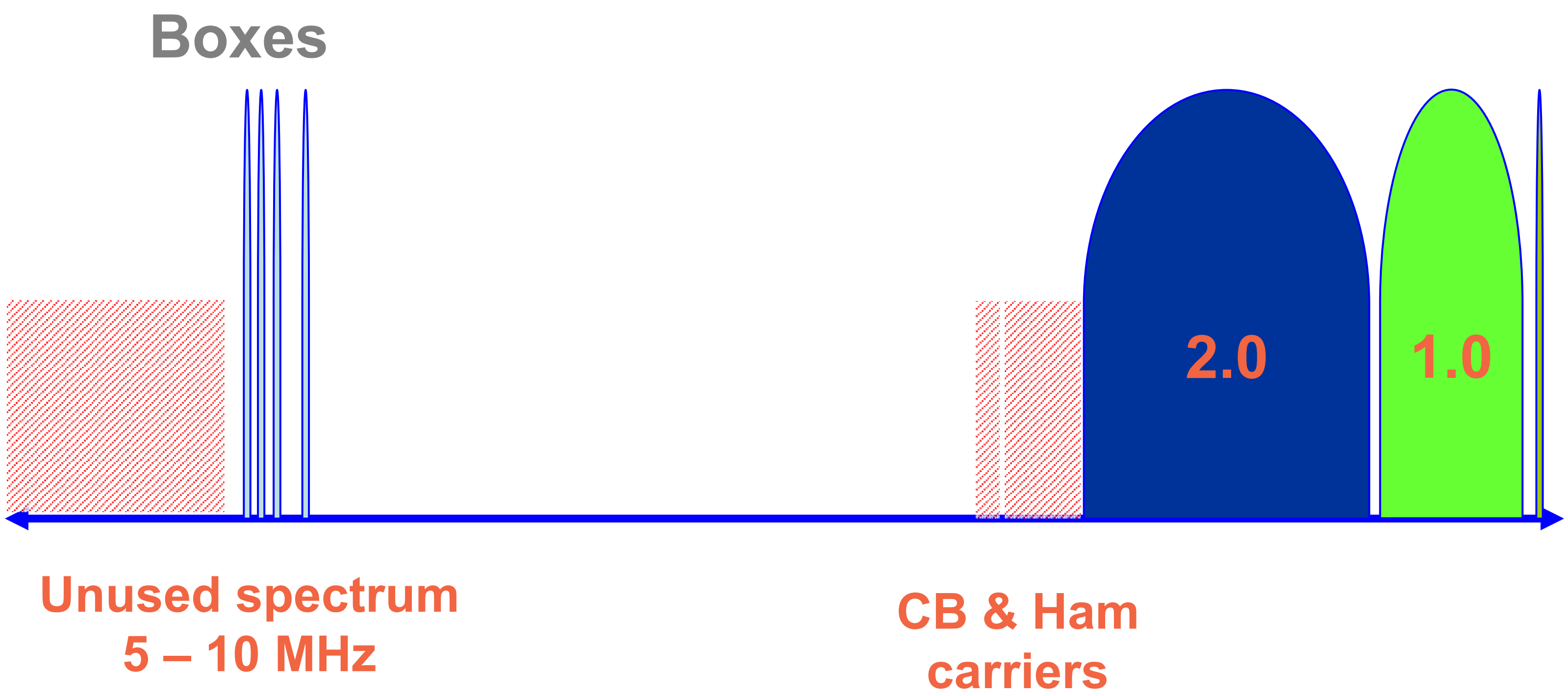
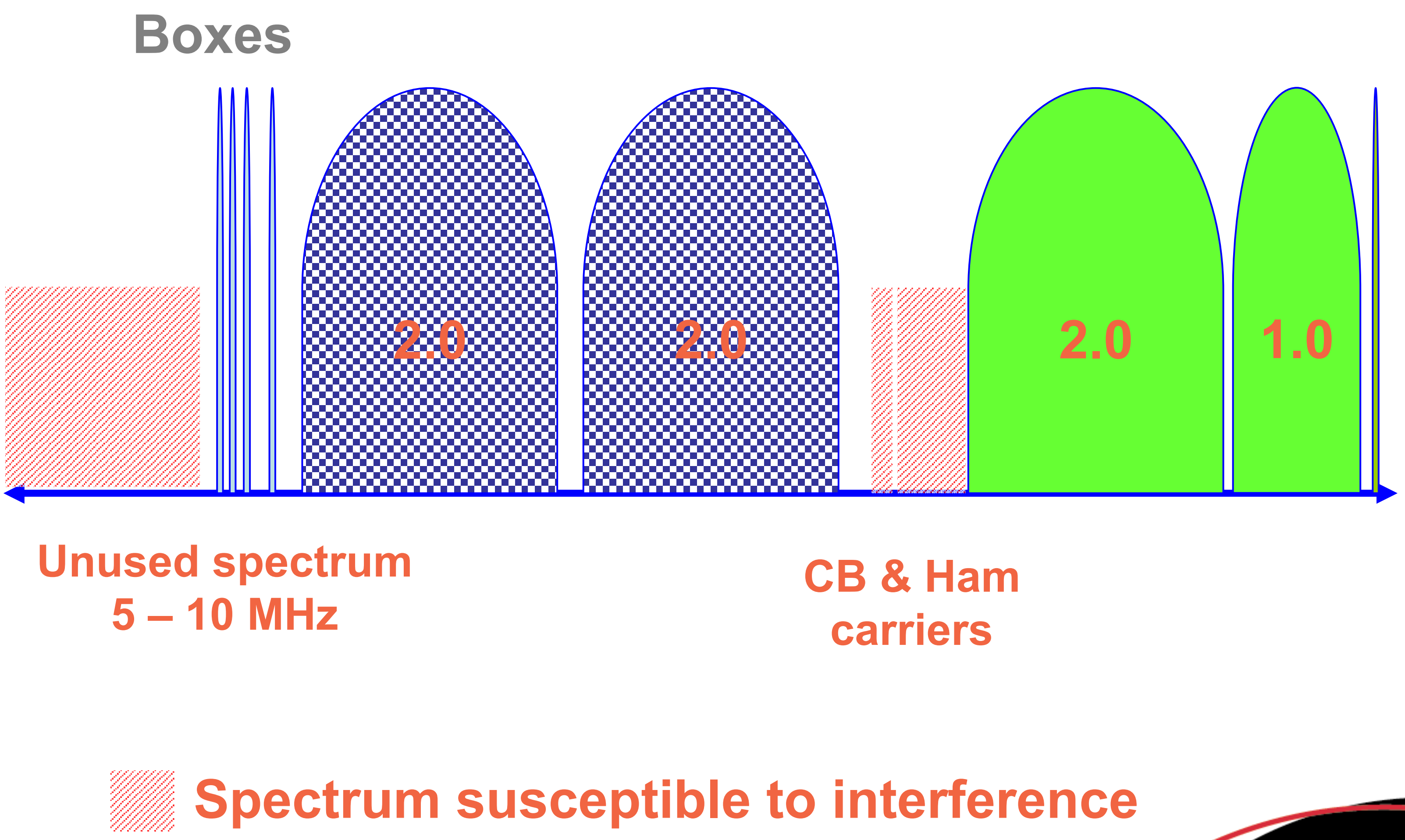
Return with DOCSIS 2.0 Today



Spectrum susceptible to interference

Return Carriers Future DOCSIS 3.0



3.2 MHz vs. 6.4 MHz

- DOCSIS 2.0 carrier located at lower frequency than DOCSIS 1.0 carrier
- DOCSIS 1.1 16 QAM carrier more robust, therefore at band edge
- Diplex filter can effect performance of carriers at frequency edge
- Most likely would be near ends of cascade

Digital Modulation

Digital Review

- Binary Digit or Bit
- Represents a “1” or “0”
- We can change the frequency, phase or amplitude of a signal to convey information
- This is know a modulation
- Morse code is digital modulation

1 Bit

- 1 bit = 2^1= 2x1 = 2 values

1	0

2 Bits

- 2 bits = 2^2= 2x2 = 4 values

00	10
01	11

3 Bits

- 3 bits = 2^3 = 2x2x2 = 8 values

000	100
001	101
010	110
011	111

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4 Bits

- 4 bits = 2^4 = 2 x 2 x 2 x 2 = 16 values

0000	0100	1000	1100
0001	0101	1001	1101
0010	0110	1010	1110
0011	0111	1011	1111

6 Bits

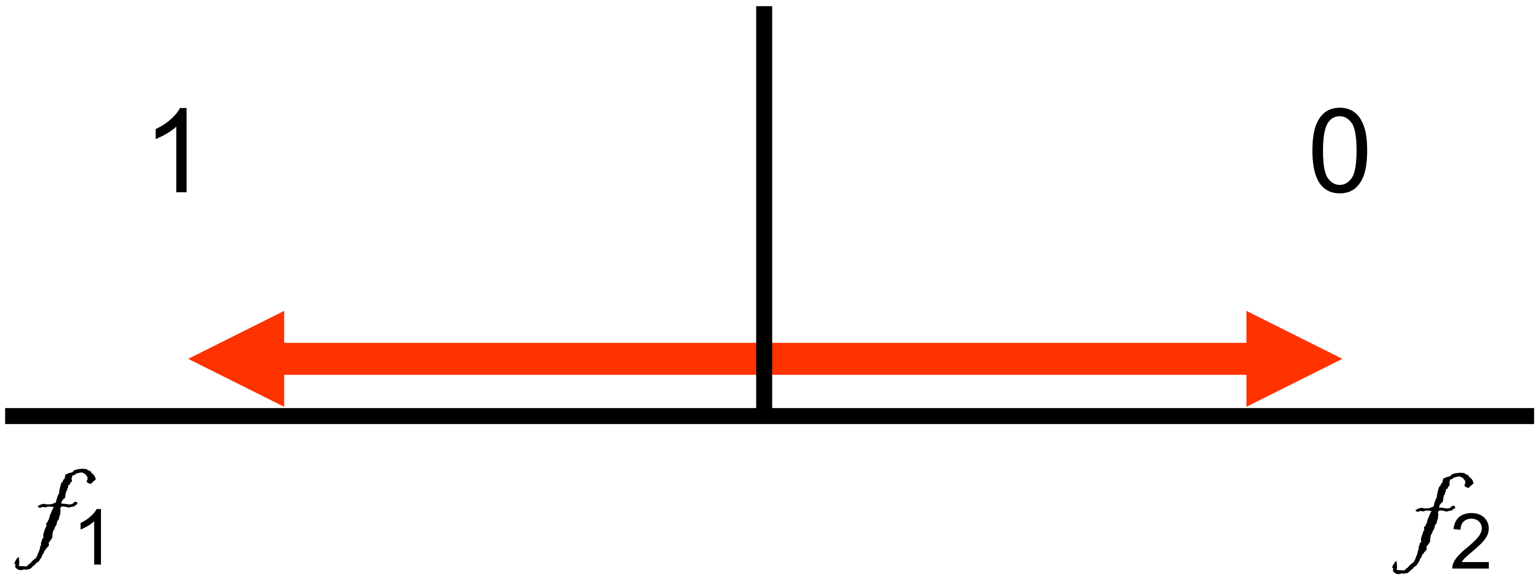
- 6 bits = 2^6 = 2x2x2x2x2x2 = 64 values

000000	001000	010000	011000	100000	101000	110000	111000
000001	001001	010001	011001	100001	101001	110001	111001
000010	001010	010010	011010	100010	101010	110010	111010
000011	001011	010011	011011	100011	101011	110011	111011
000100	001100	010100	011100	100100	101100	110100	111100
000101	001101	010101	011101	100101	101101	110101	111101
000110	001110	010110	011110	100110	101110	110110	111110
000111	001111	010111	011111	100111	101111	110111	111111

8 Bits

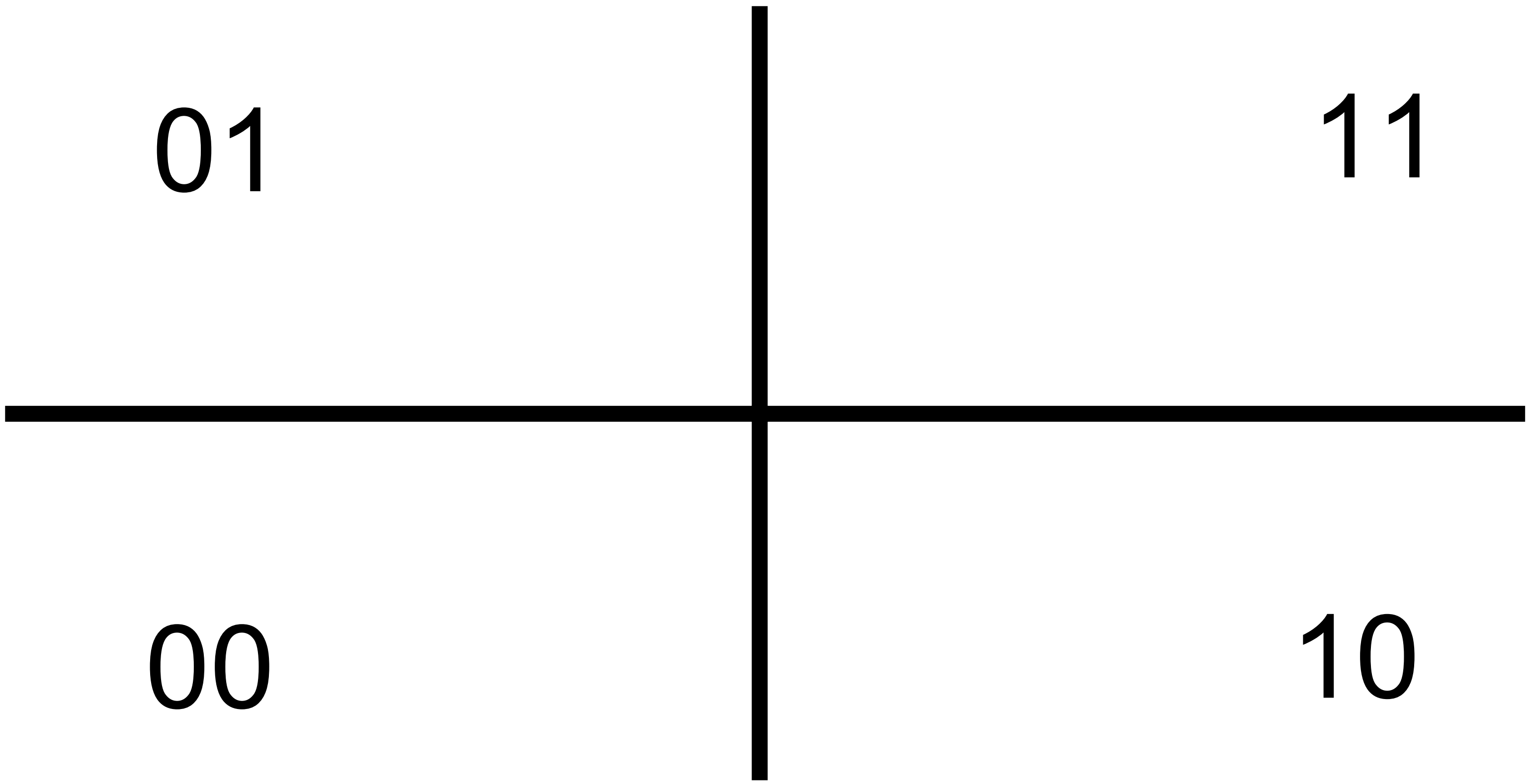
- 8 bits = 2^8 = 2x2x2x2x2x2x2x2 = 256 values
- I skipped the chart, but just trust me!
- 00000000 to 11111111

1 Bit Modulation



- Two states can be represented by frequency or phase
- FSK or PSK

2 Bit Modulation



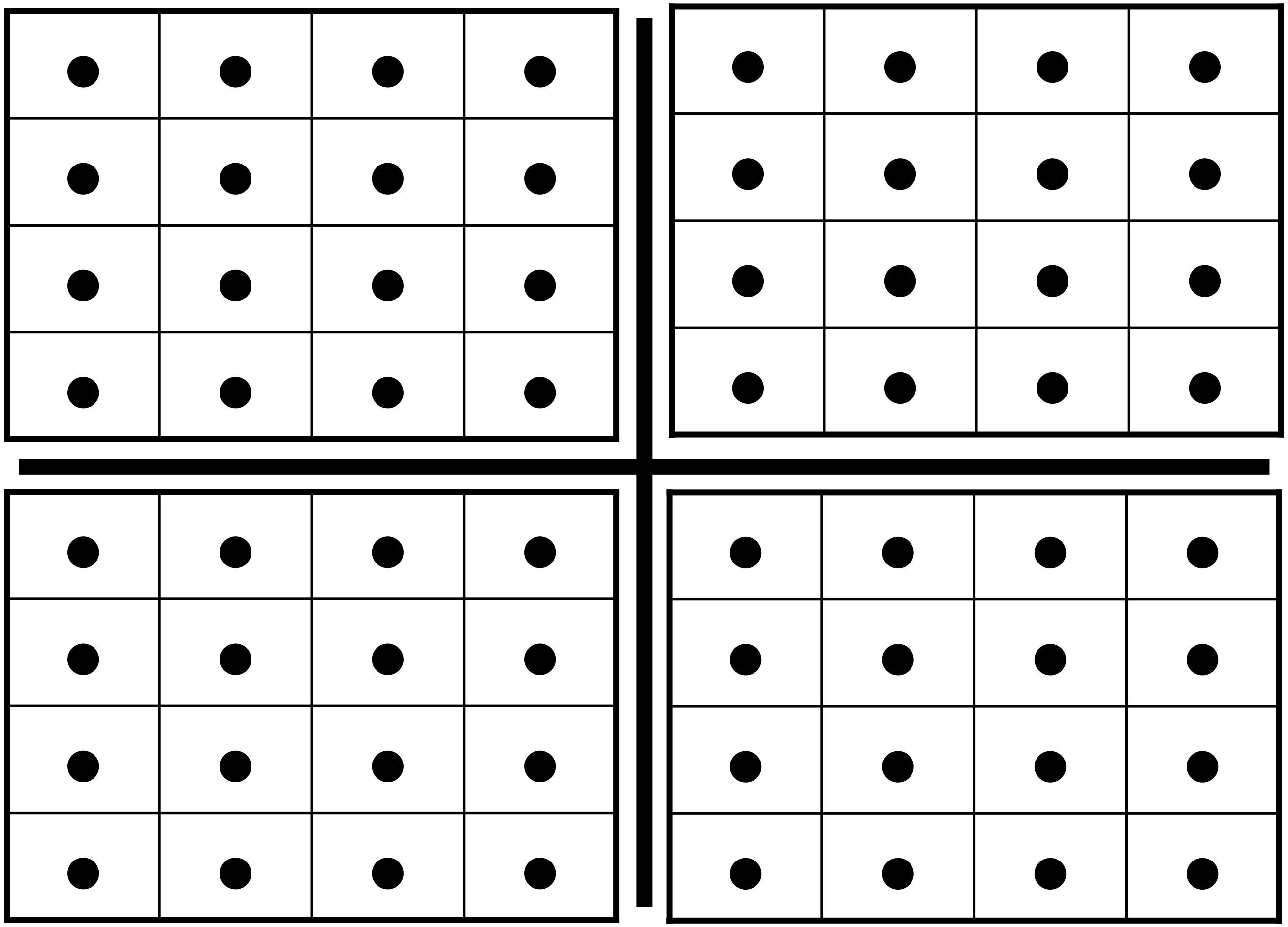
- 90 degree changes in phase
- QPSK or Quadrature Phase Shift Keying

4 Bit Modulation

0000	0100	1100	1000
0001	0101	1101	1001
0011	0111	1111	1011
0010	0110	1110	1010

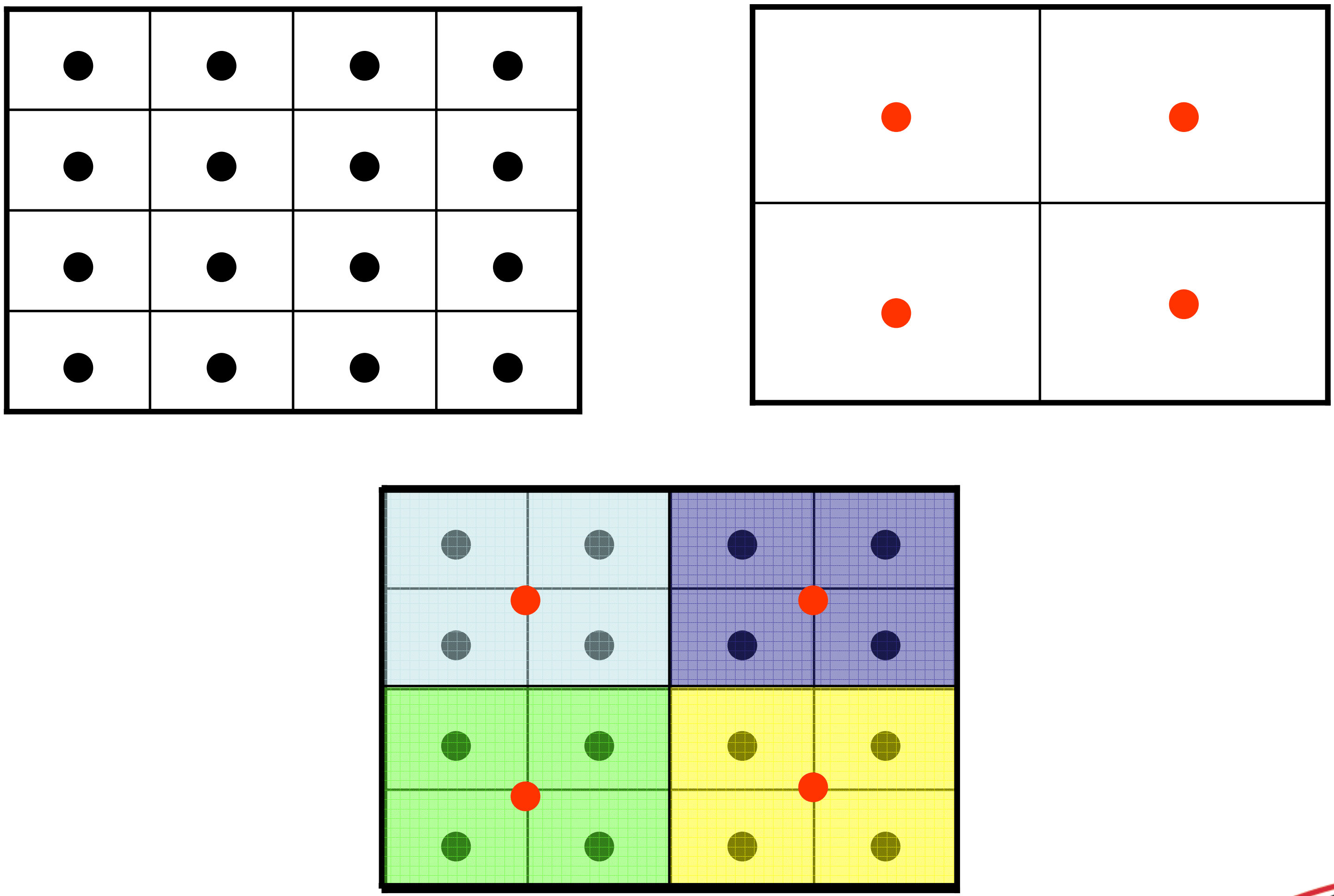
- 16 QAM or Quadrature Amplitude Modulation
- Changes in phase and amplitude

6 Bit Modulation



- 64 QAM or Quadrature Amplitude Modulation
- Changes in phase and amplitude

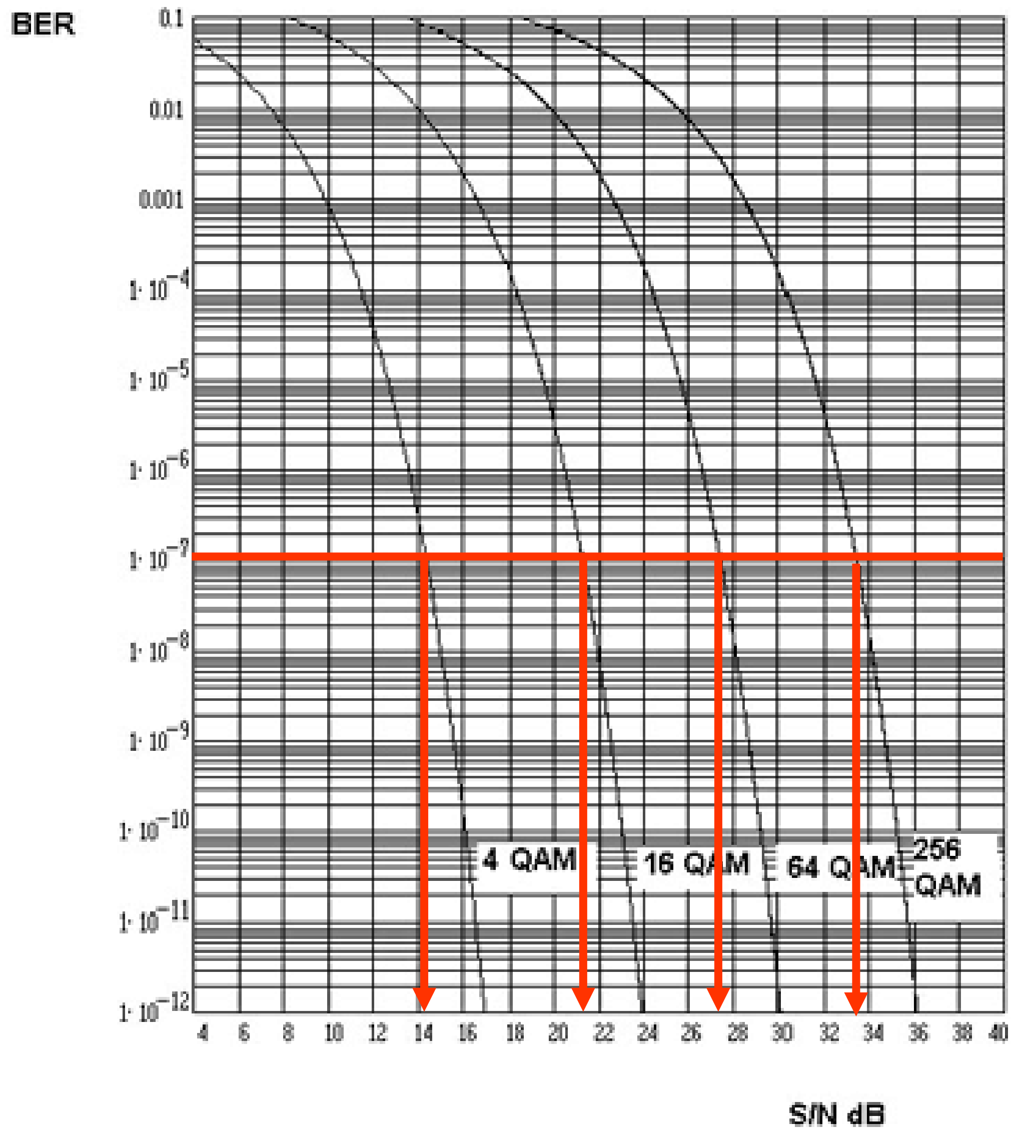
16 QAM vs. 64 QAM



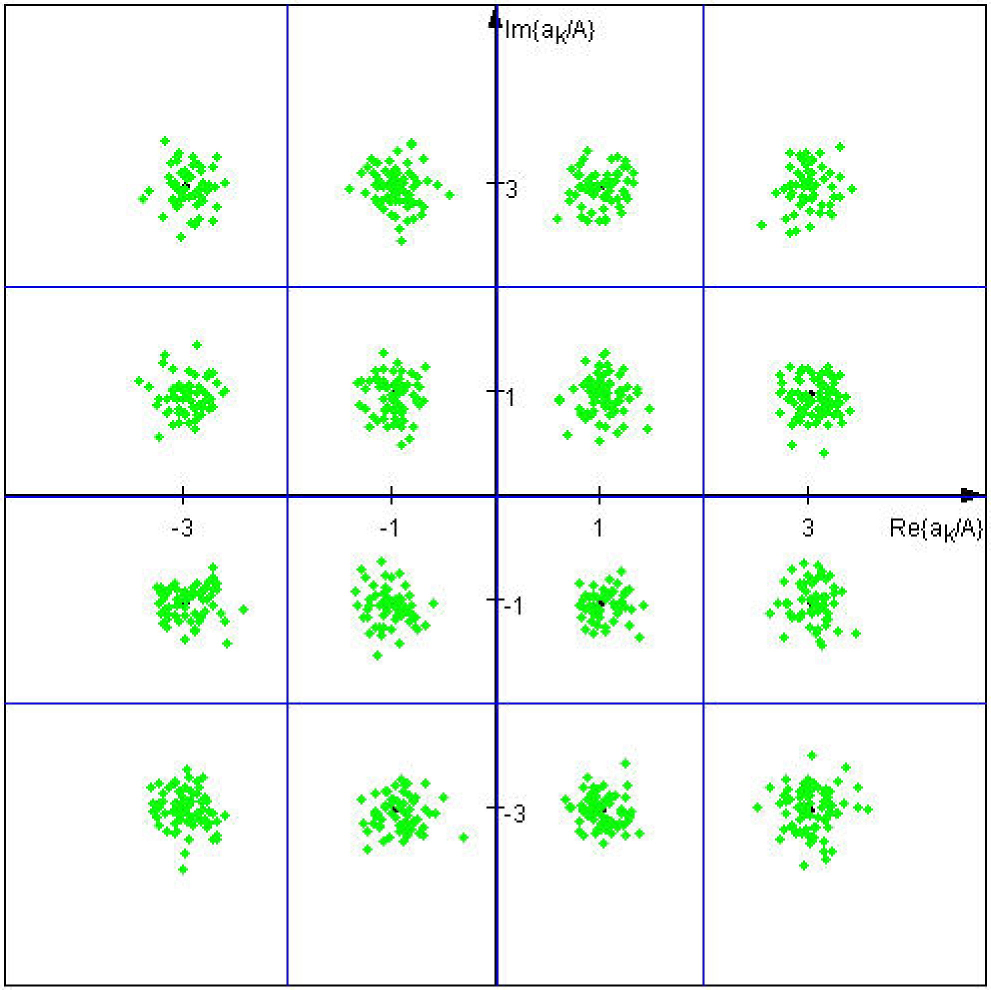
Increasing Bit Efficiency

- Each dot represents six bits
- 64 QAM decreased the size of the box
- Using more bandwidth can regain some of the size of the box which is more headroom
- With 256 QAM, each dot represents 8 bits
- 16 QAM to 64 QAM = 300% increase in efficiency – from ≈ 10 mbs to ≈ 30 mbs

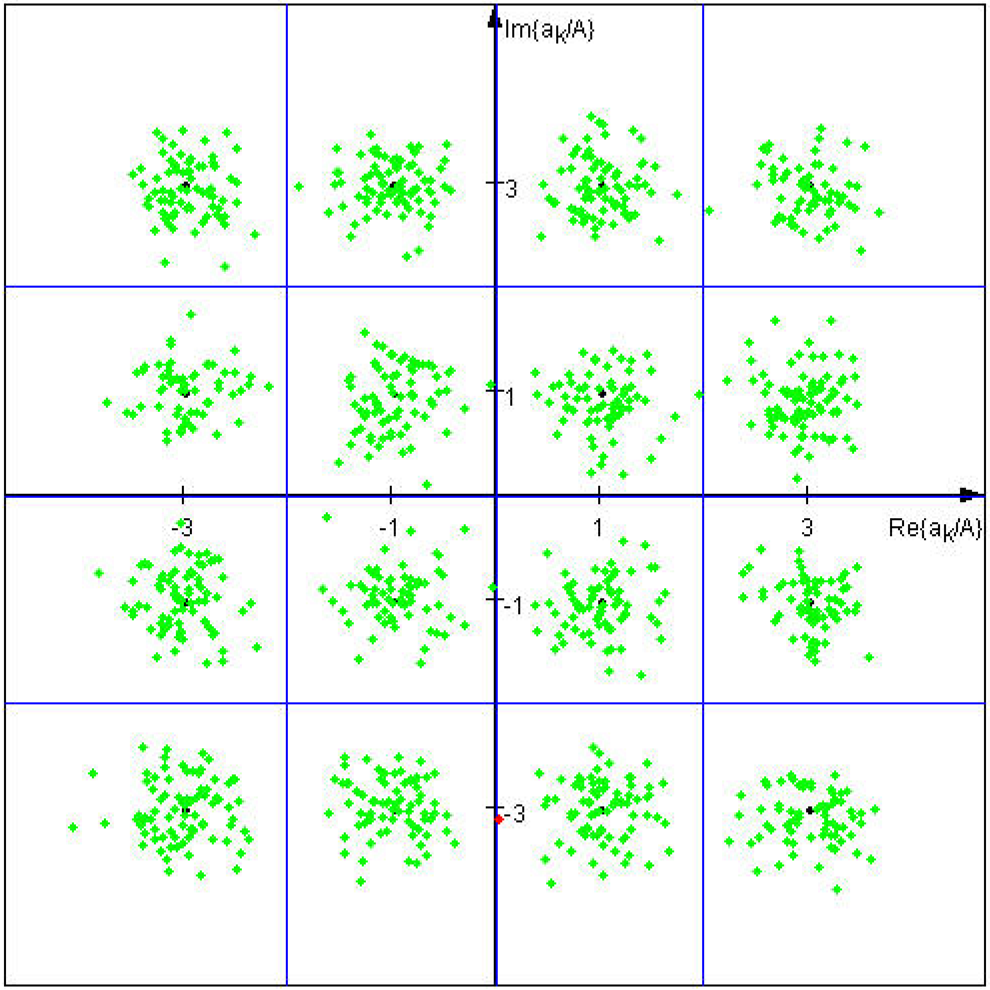
Theoretical SNR vs. BER



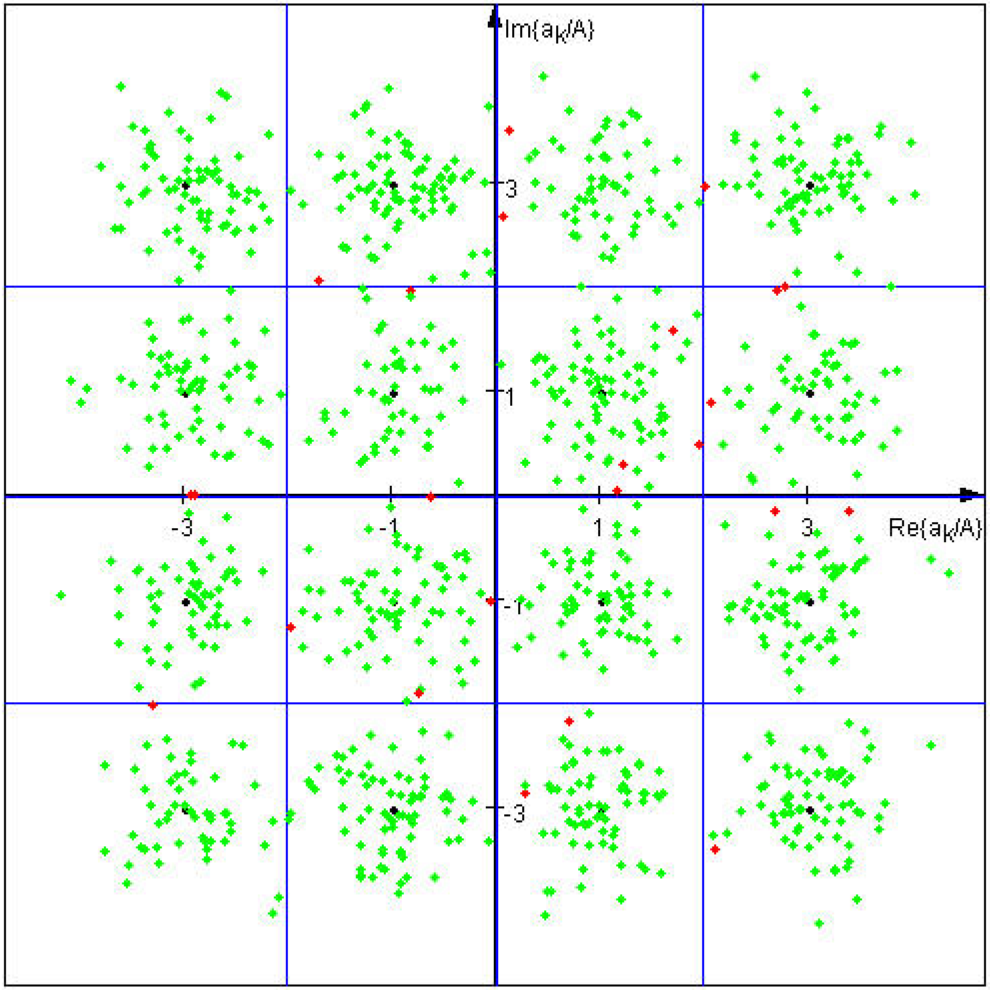
24 dB SNR Constellation



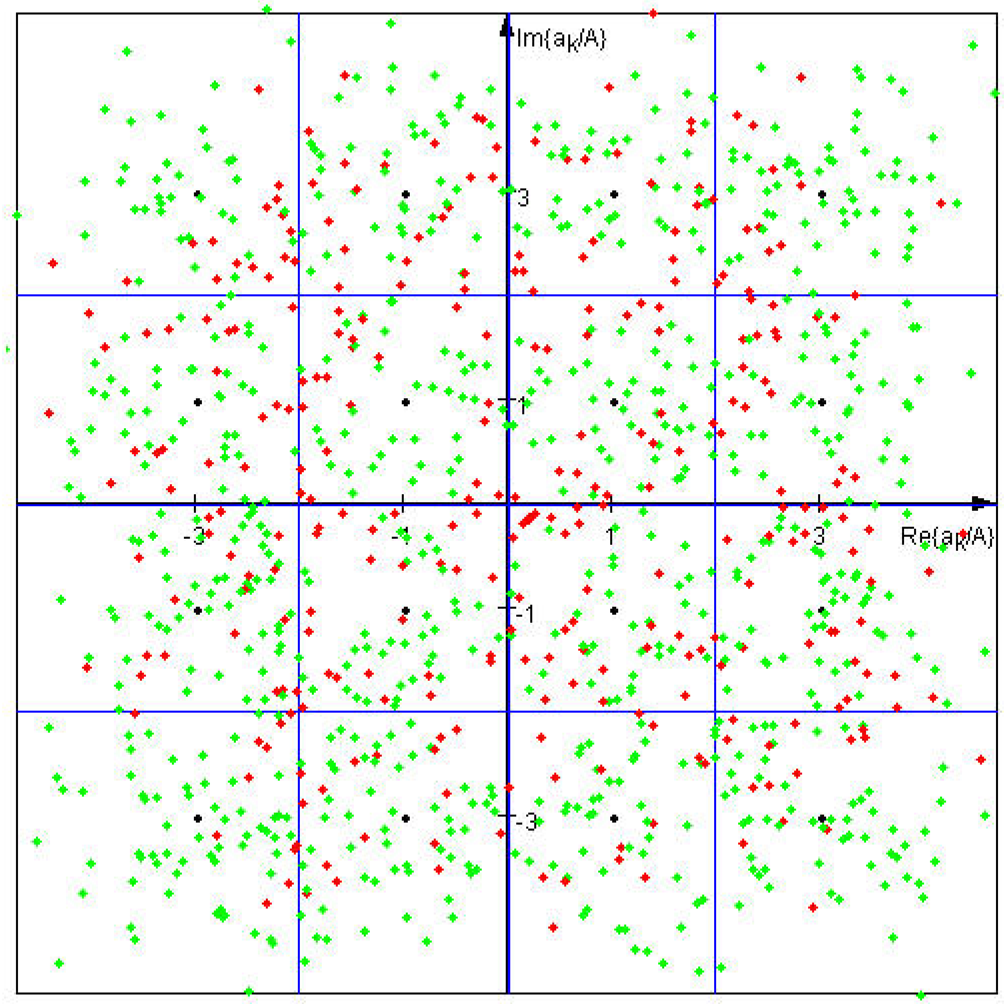
21 dB SNR Constellation



18 dB SNR Constellation



12 dB SNR Constellation



DOCSIS 2.0 Return Specifications

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 (7.0%)
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

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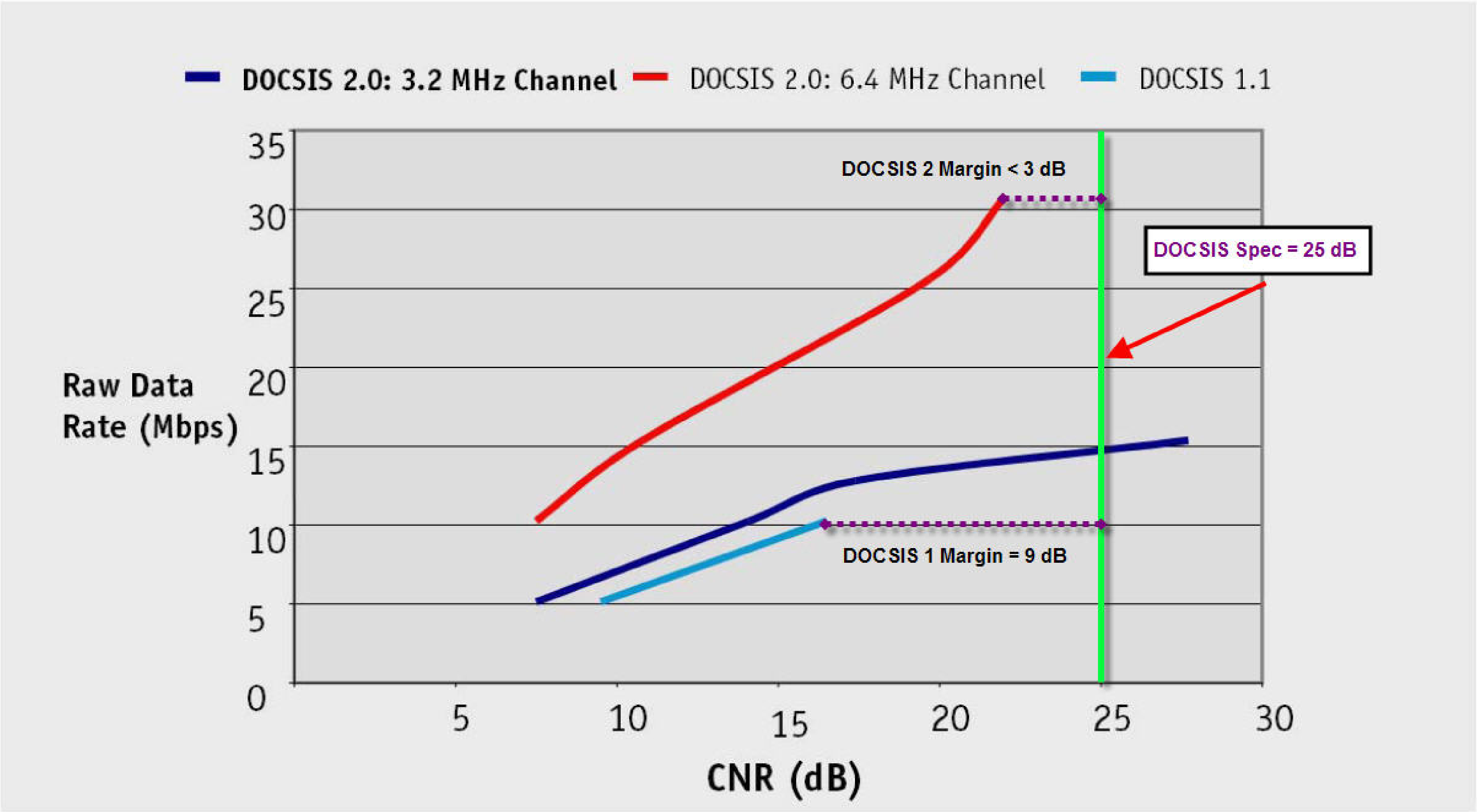
Two Upstream Choices

- Size of Carrier
  - 3.2 MHz QAM
  - 6.4 MHz QAM
- Modulation of Carrier
  - 16 QAM
  - 32 QAM
  - 64 QAM

64 QAM Has Less Margin



Same Specifications

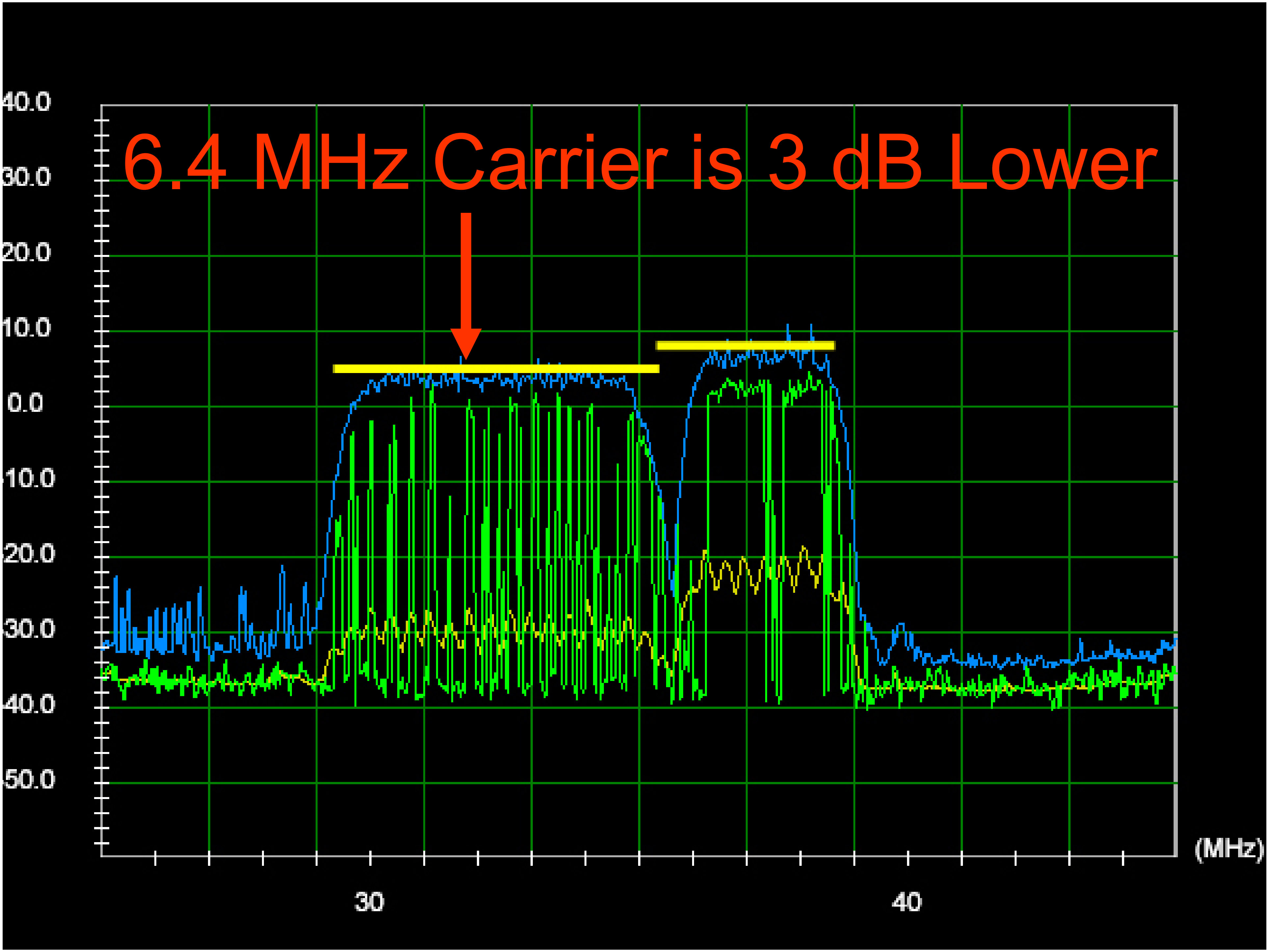
- DOCSIS 2.0 return specifications are the same as DOCSIS 1.1 return specifications
- If specifications are the same, then why would there be problems with DOCSIS 2.0 that were not evident with DOCSIS 1.1?
- Answer: Upstream modulation changed from 16 to 64 QAM which has less margin

DOCSIS 2.0 Modem Levels

- DOCSIS 2 carriers have less output range:
  - 8 to 58 dBmV for QPSK
  - 8 to 55 dBmV for 16 QAM
  - 8 to 54 dBmV for 64 QAM
- High transmit installs should be corrected by the installer
- Low transmit level installs should be investigated for proper return plant alignment

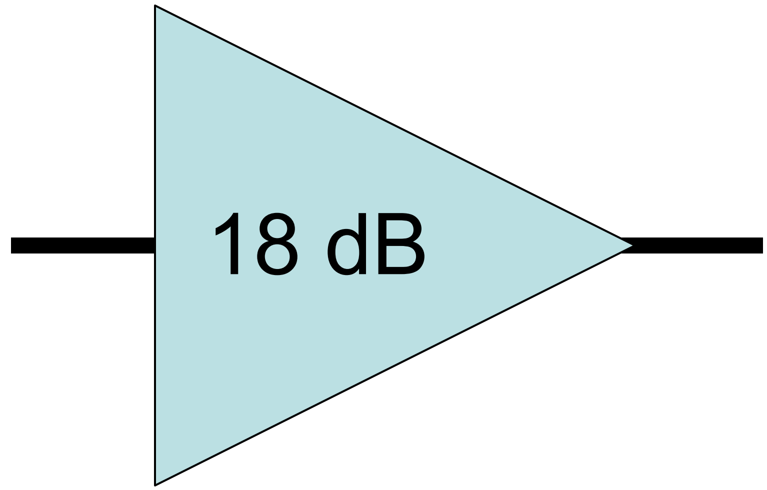
DOCSIS 2.0 Return Power

- CMTS measures *power* of return, not *level*
- Sets both carriers for same power
- DOCSIS 1.1 carrier is 3.2 MHz
- DOCSIS 2.0 carrier is 6.4 MHz
- Twice the bandwidth means 3 dB less carrier level


6.4 MHz Carrier is 3 dB Lower
40.0
30.0
20.0
10.0
0.0
10.0
20.0
30.0
40.0
50.0
30
40
(MHz)

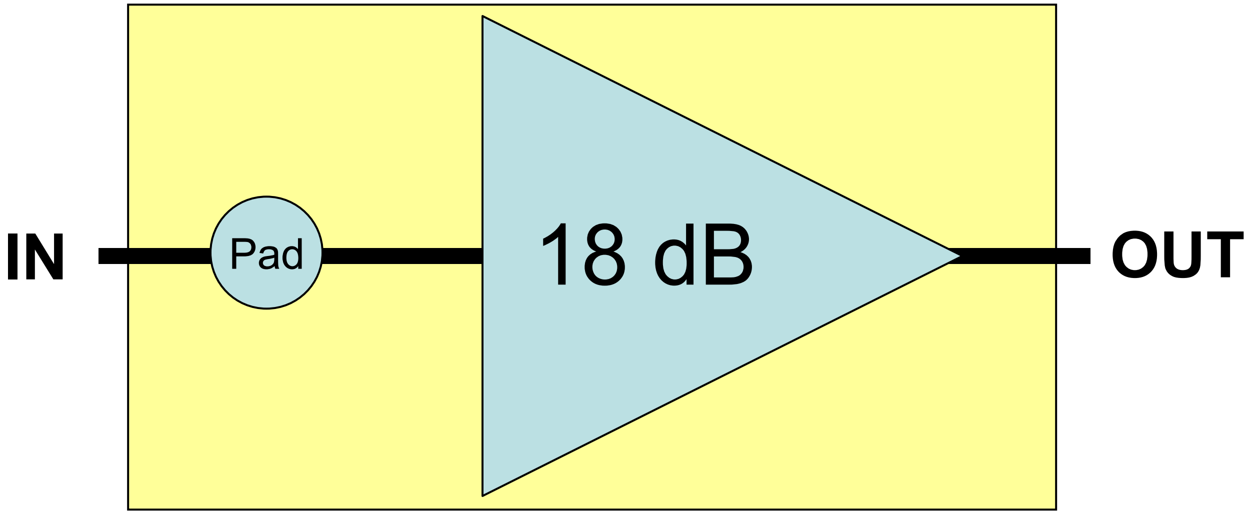
Coaxial Carrier to Noise

Hybrid Chips



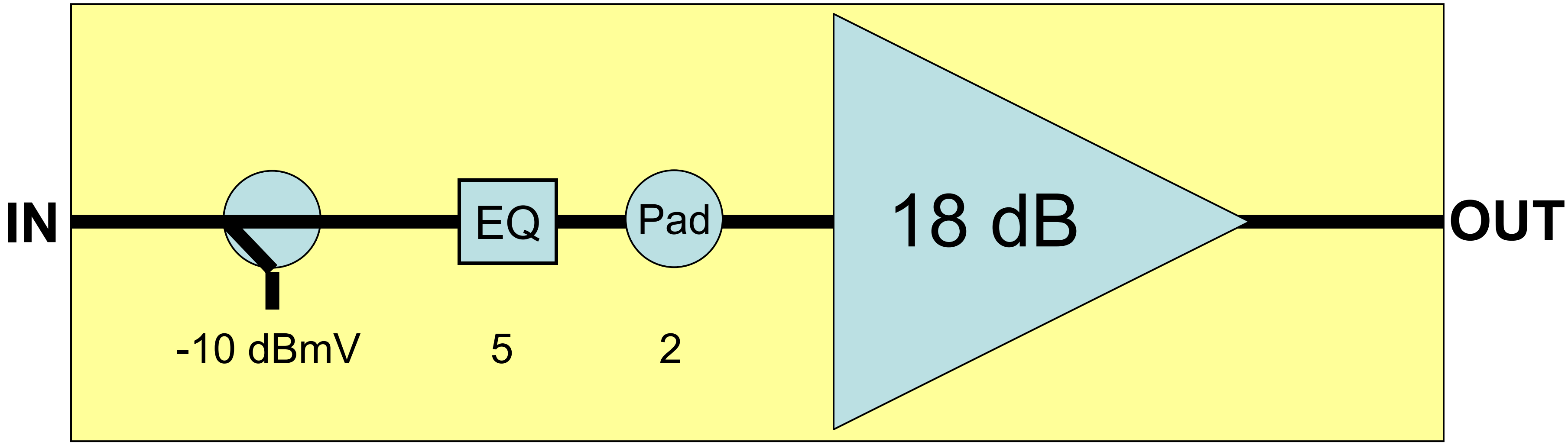
- Hybrid amplifier chips produced by Philips or Motorola
- Gain is fixed and cannot be adjusted
- Higher gains can be achieved by cascading two hybrids

Gain



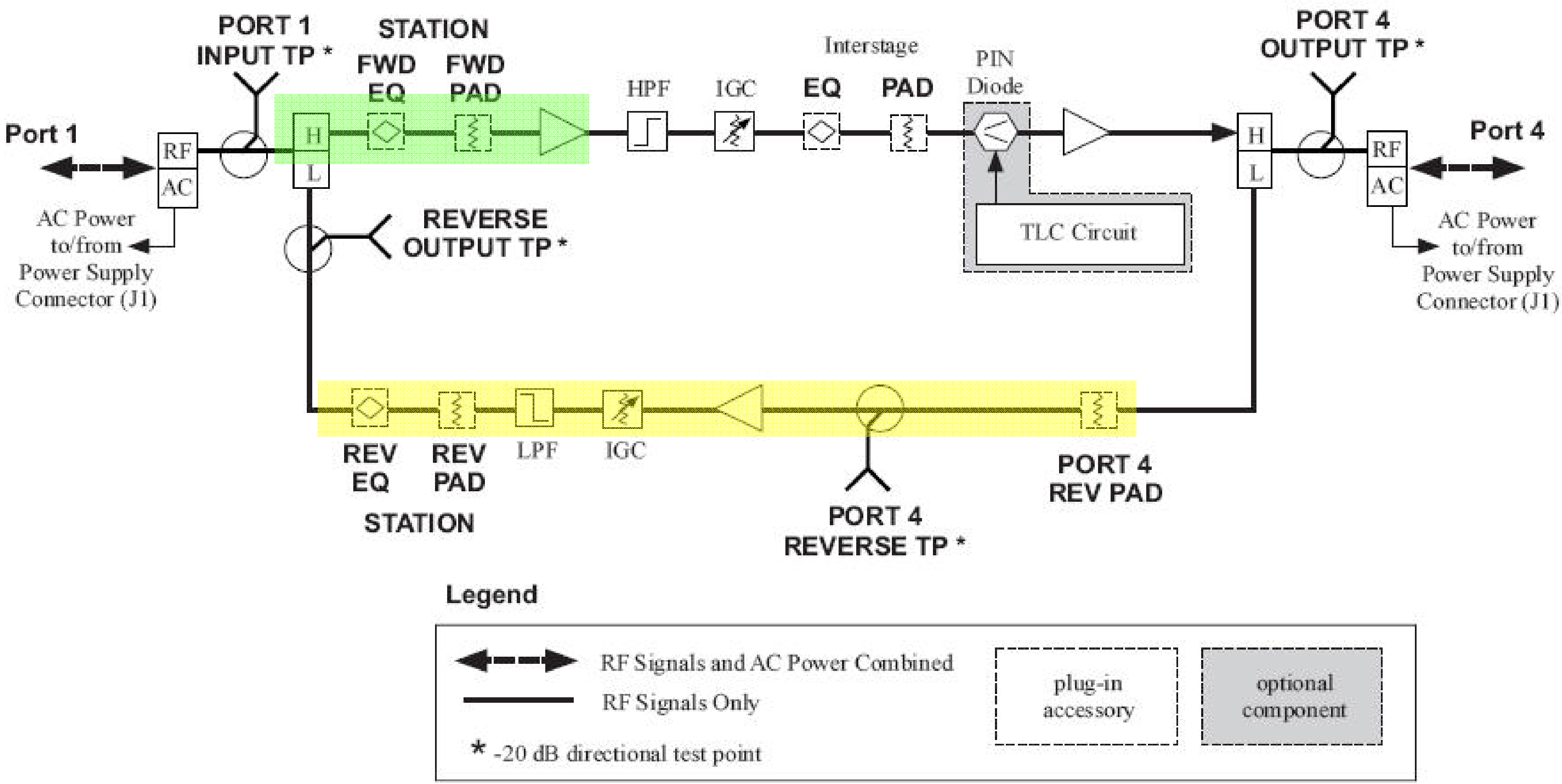
- Appearance of gain is achieved with pad
- Full gain = 0 pad
- If 3 dB pad installed in above example, the gain is 15 dB

Effect of Pads & Equalizers



- Input level to hybrid is not the same as test point level
- Must subtract pad and equalizer values from test point level
- 10 dBmV – 4 dB EQ – 2dB pad = 4 dBmV input
- 4 dBmV input + 18 dB gain = 22 dBmV output

TP Level = Hybrid Input Level?



Distortions

- Noise is determined by *input* levels
- CSO is determined by *output* levels
- CTB is determined by *output* levels

Noise Figure

- Noise created by the hybrid
- Measured in dB
- Obtain from manufacturer's specifications
- Pay attention to footnotes

Typical Operating Conditions					
Frequency (MHz)	Minimum Input (dBmV)	Output[2] (dBmV)	Operational Gain (dB)	Full Gain-w/o EQ & ALC (dB)	Noise Figure w/o EQ (dB)
40/5	17/17	35/35	18.0	19.0	7.0
40/5	17/17	35/35	18.0	19.0	7.0
40/5	17/17	35/35	18.0	19.0	8.0
42/5	17/17	35/35	18.0	19.0	7.0
42/5	17/17	35/35	18.0	19.0	7.0

Carrier to Noise One Amplifier

$$Carrier\ to\ Noise = Input + 59.2 - nf$$

- Where:
  - ❖ Input is RF level in dBmV
  - ❖ 59.2 is theoretical noise floor for 4 MHz at 75Ω
  - ❖ nf is the noise figure of the amplifier
  - ❖ nf is not the same at all frequencies

C/N Cascade of Identical Amplifiers

$$C/N_{cascade} = C/N_{\text{one amplifier}} - (10\log \text{N})$$

- Where:
  - ❖ *C/N cascade* is the total C/N of all amplifiers
  - ❖ *C/N one amplifier* is the C/N of one amplifier
  - ❖ N is the number of identical amplifiers in the cascade

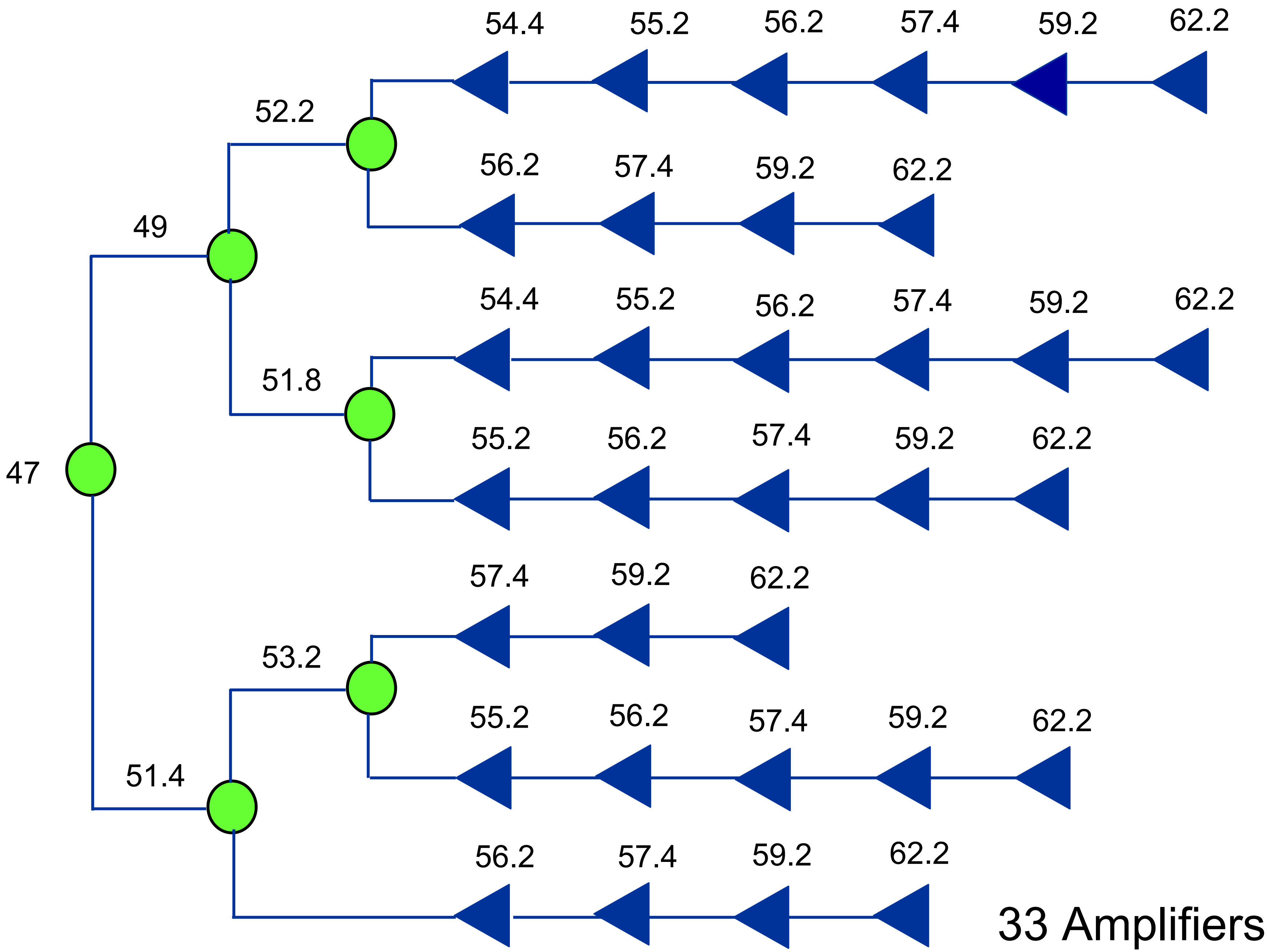
Combining C/N

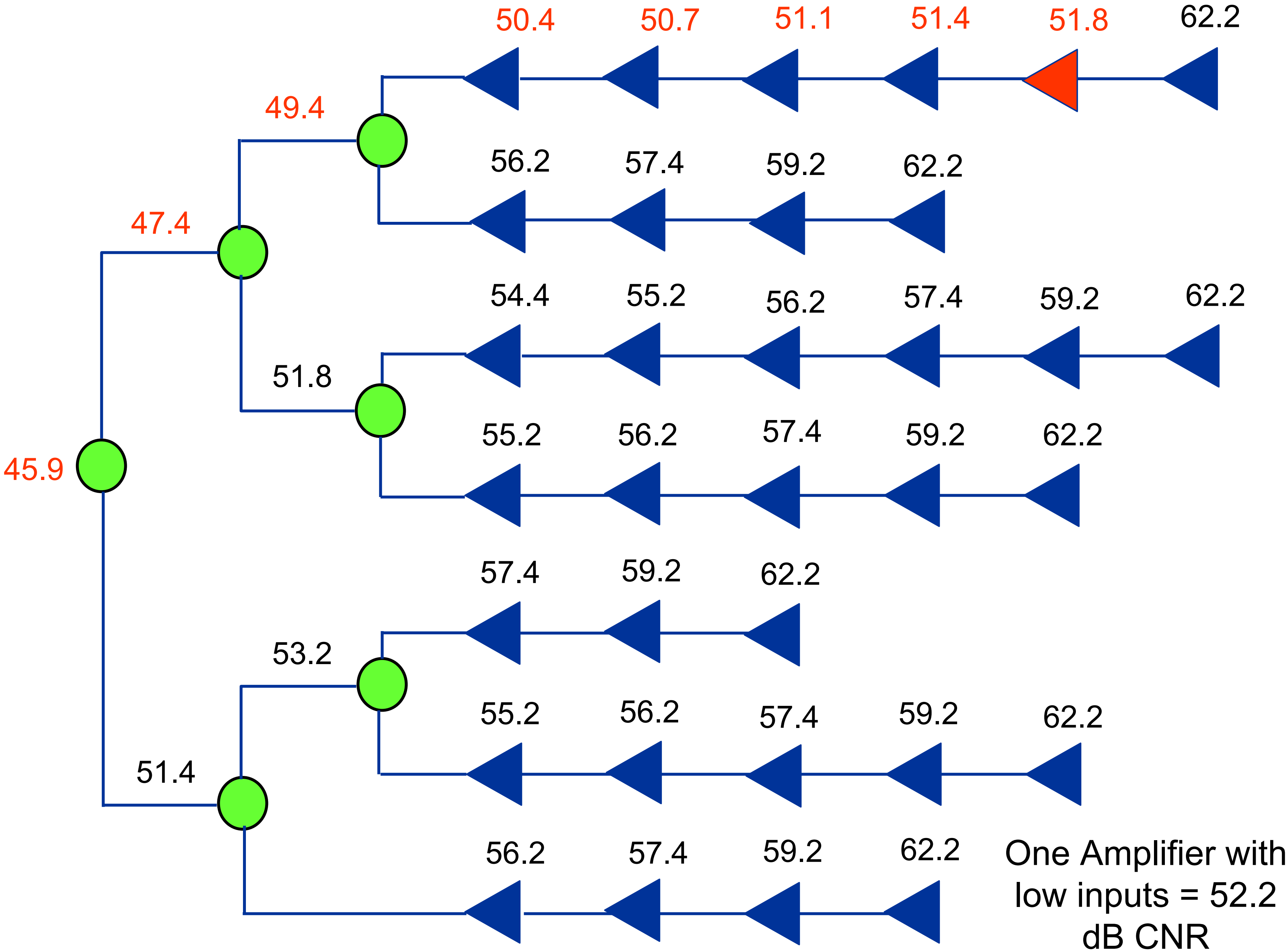
$$\frac{C}{N}_{total} = -10\log(10^{\frac{C/N_1}{10}} + 10^{\frac{C/N_2}{10}} \ldots + 10^{\frac{C/N_n}{10}})$$

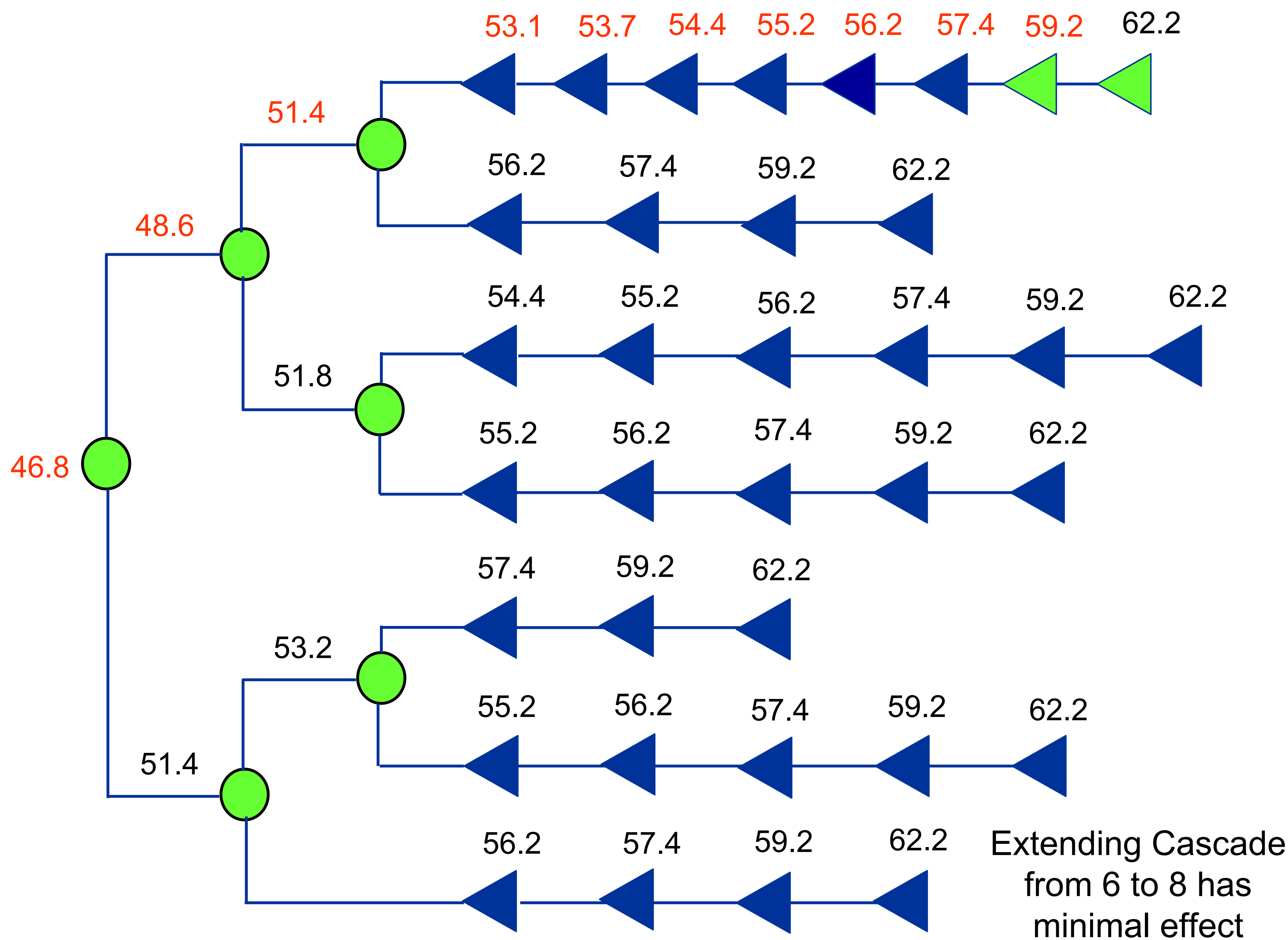
- Where:
  - *C/N_1, C/N_2, C/N_n = individual C/N ratios*

Return Levels

- Forward amplifiers typically have same *output* levels for all amplifiers
- Return amplifiers typically have same *input* levels for all amplifiers
- Return input levels at test points may be different
- Return input levels at hybrid, after pads and EQs should be the same for all return amplifiers in a cascade
- If so, calculation of total CNR can simplified as a *cascade of identical amplifiers*


54.4
55.2
56.2
57.4
59.2
62.2
52.2
56.2
57.4
59.2
62.2
49
54.4
55.2
56.2
57.4
59.2
62.2
51.8
55.2
56.2
57.4
59.2
62.2
47
57.4
59.2
62.2
53.2
55.2
56.2
57.4
59.2
62.2
51.4
56.2
57.4
59.2
62.2
33 Amplifiers


50.4
50.7
51.1
51.4
51.8
62.2
49.4
56.2
57.4
59.2
62.2
47.4
54.4
55.2
56.2
57.4
59.2
62.2
51.8
45.9
55.2
56.2
57.4
59.2
62.2
57.4
59.2
62.2
53.2
55.2
56.2
57.4
59.2
62.2
51.4
56.2
57.4
59.2
62.2
One Amplifier with
low inputs = 52.2
dB CNR


53.1
53.7
54.4
55.2
56.2
57.4
59.2
62.2
51.4
56.2
57.4
59.2
62.2
48.6
54.4
55.2
56.2
57.4
59.2
62.2
51.8
55.2
56.2
57.4
59.2
62.2
46.8
57.4
59.2
62.2
53.2
55.2
56.2
57.4
59.2
62.2
51.4
56.2
57.4
59.2
62.2
Extending Cascade from 6 to 8 has minimal effect

Noise Rules of Thumb

- Double or halve a cascade = 3 dB change
- Combined noise never gets better than the worst component
- Noise is the “floor” that you cannot get better than
- Poor C/N = poor S/N = bit errors on digital signals

Noise vs. Channel Load

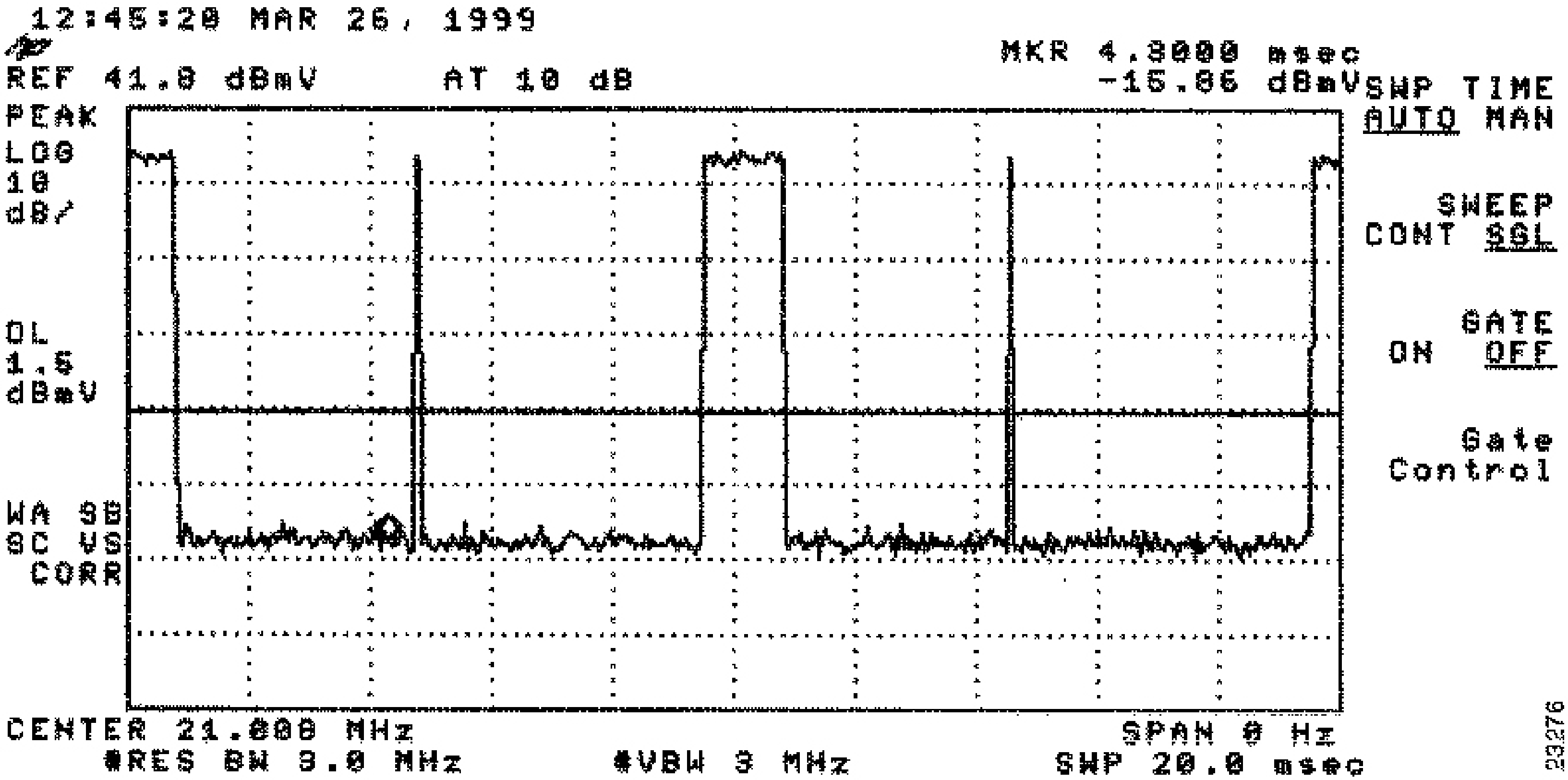
$$CN = 10 * \log\left(\frac{Bandwidth_{new}}{Bandwidth_{reference}}\right)$$

- Where:
  - ❖ Bandwidth $_{new}$ is the new channel load
  - ❖ Bandwidth $_{reference}$ is specified load

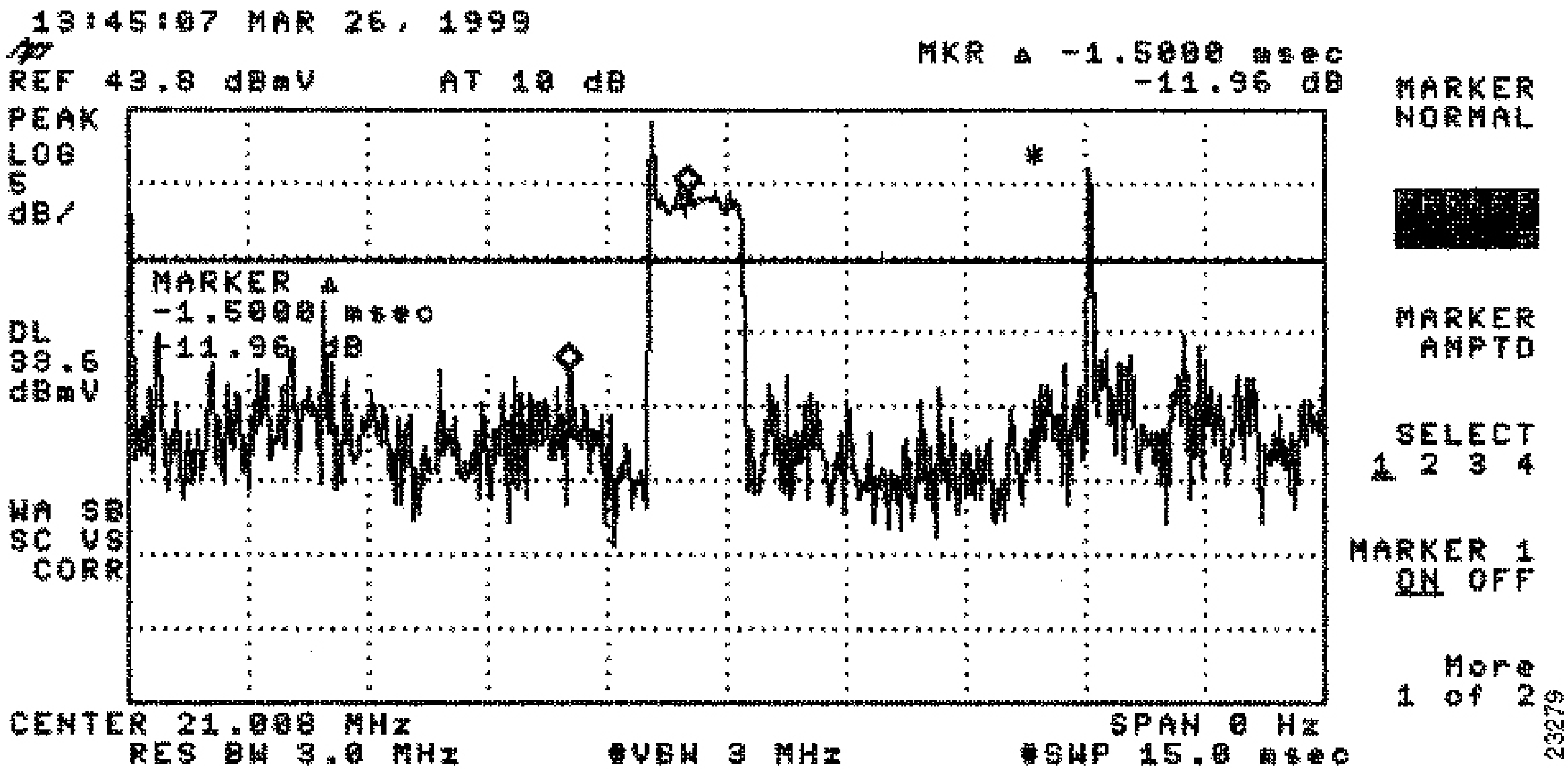
Coaxial Return Plant

- The CNR of every amplifier adds to the final CNR at the CMTS
- Just one misaligned amplifier sets the CNR for the entire node or service group
- Most of the return crud comes from the coaxial plant
- 80 to 90% of problems are drop related
- A single home can take down everyone in a node or service group

Good CNR ≈ 50 dB

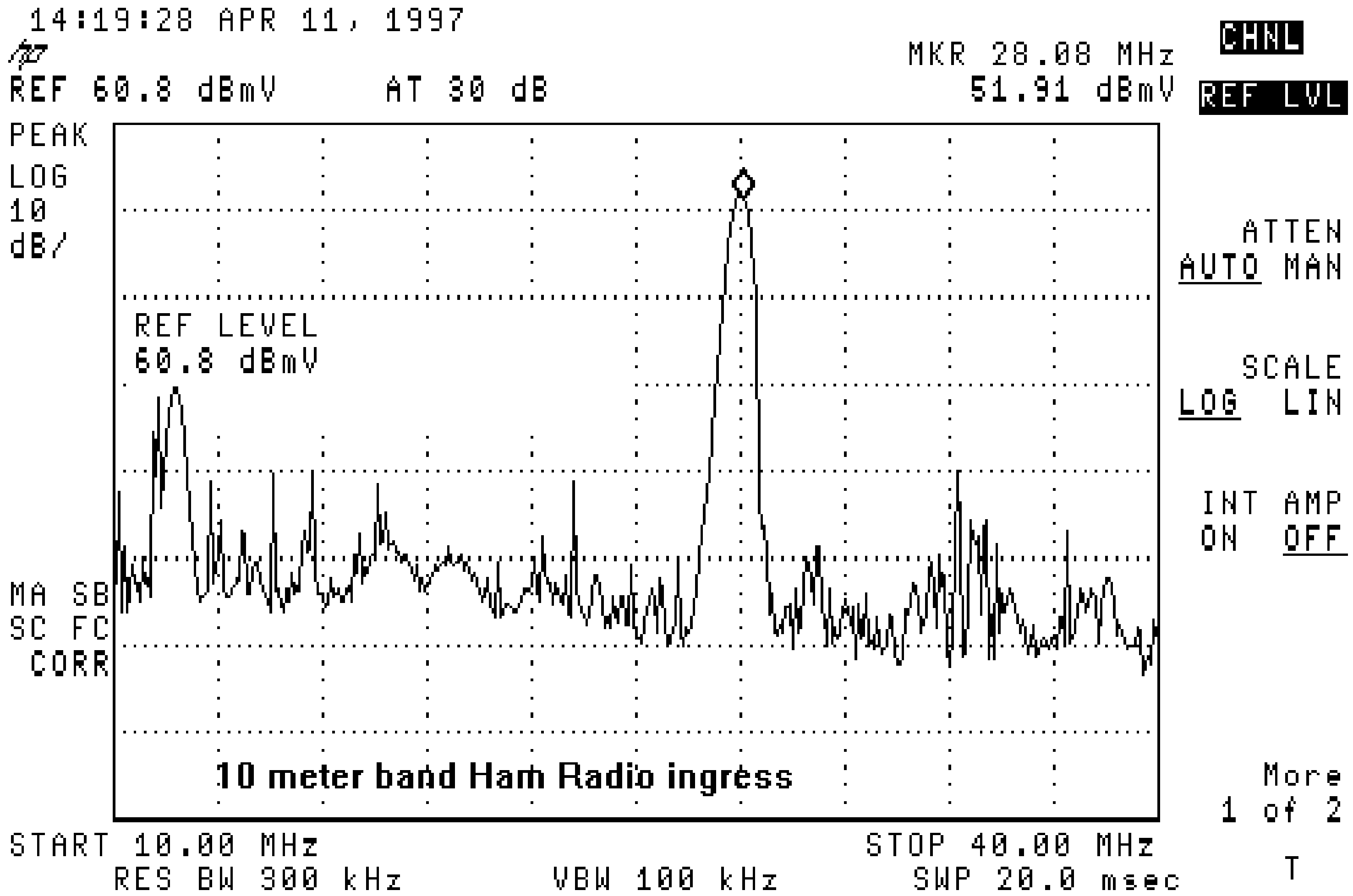


Bad CNR < 20 dB



13:45:07 MAR 26, 1999
MKR Δ -1.5000 msec
-11.96 dB
REF 43.8 dBmV
AT 10 dB
PEAK
LOG
5
dB/
MARKER Δ
-1.5000 msec
-11.96 dB
DL
33.6
dBmV
WA SB
SC VS
CORR
CENTER 21.000 MHz
RES BW 3.0 MHz
#VBW 3 MHz
SPAN 0 Hz
#SWP 15.0 msec
MARKER
NORMAL
MARKER
AMPTD
SELECT
1 2 3 4
MARKER 1
ON OFF
More
1 of 2
23279

Drops Cause Most Return Issues



Optical Carrier to Noise

Fiber Optic Links

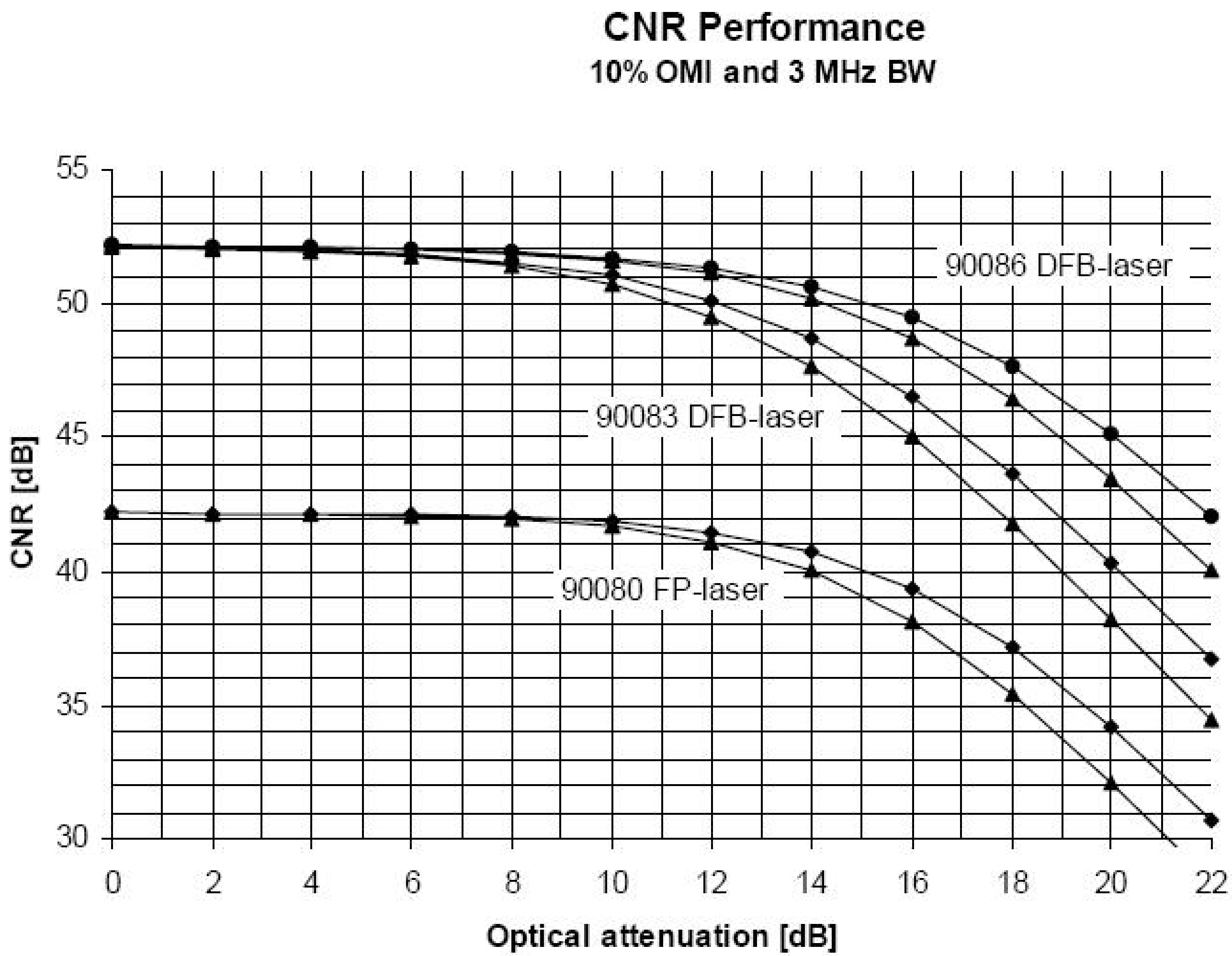
- Main contributor to CNR
- Link performance is determined by:
  - Optical input into receiver
    - Distance related
    - RF output vs. Light input is 2:1 ratio
  - Modulation of the laser
    - Determined by RF input ***power*** to laser
    - RF input to laser vs. RF output of receiver is 1:1 ratio

RF Output vs. Optical Input

2 dB increase in optical receive power = 4 dB increase in receiver RF output

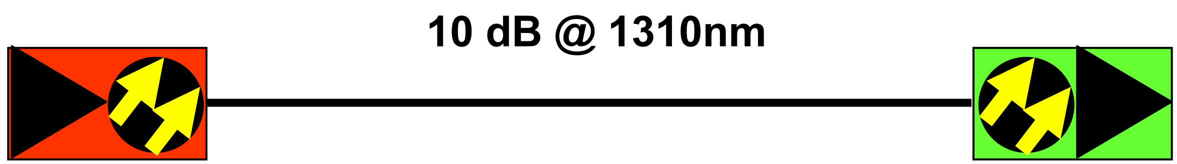
1 dB decrease in optical receive power = 2 dB increase in receiver RF output

CNR vs. Optical Distance

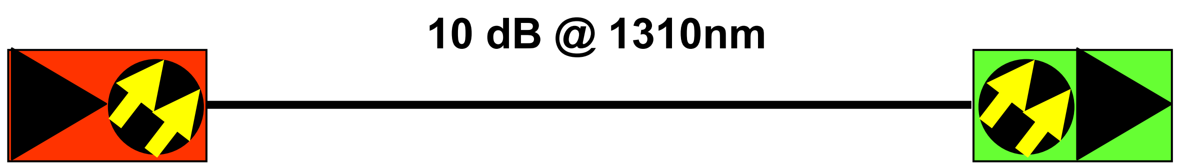


10 dB Laser Link

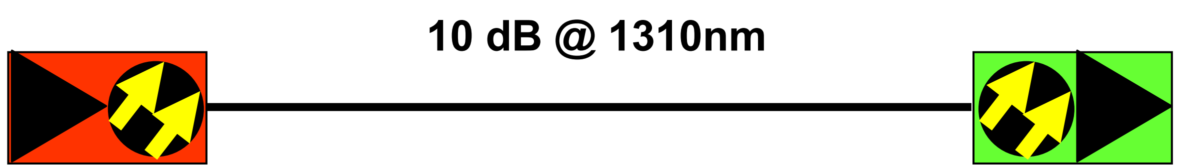
1 dB increase in laser RF input power = increase in receiver C/N ratio & 1 dB RF level



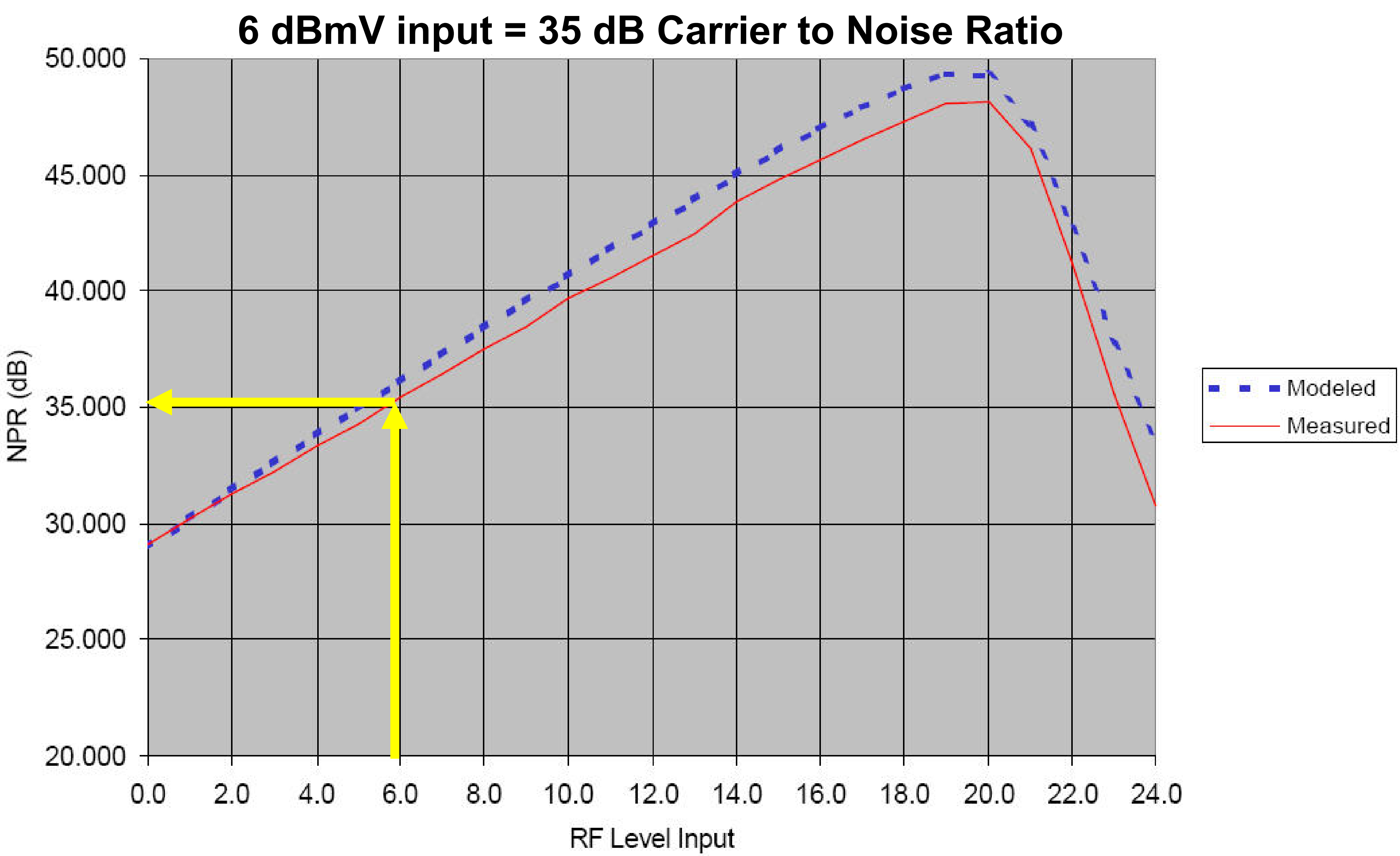
2 dB increase in laser RF input power = increase in receiver C/N ratio & 2 dB RF level



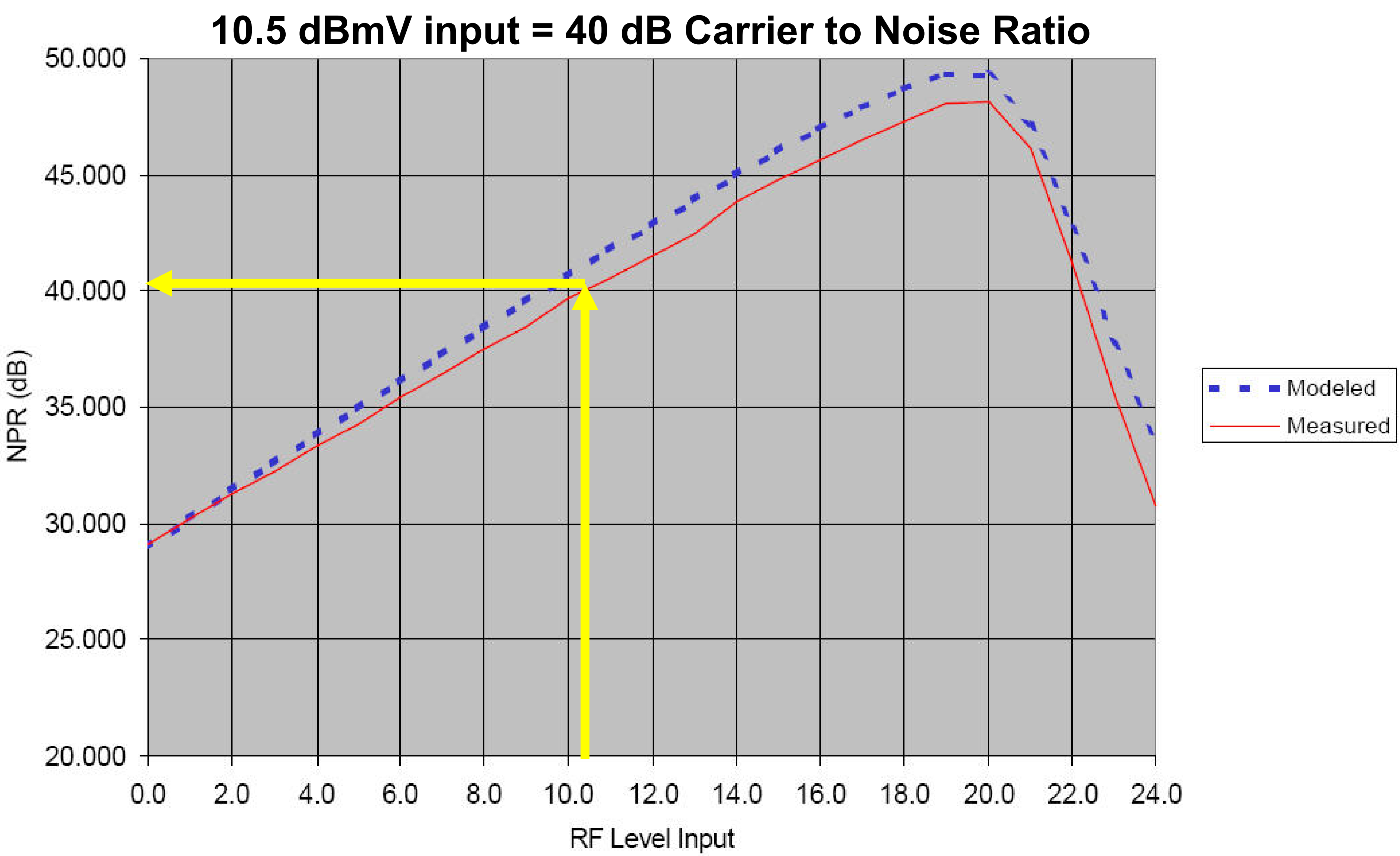
2 dB decrease in laser transmit power = decrease in receiver C/N ratio & 2 dB RF level



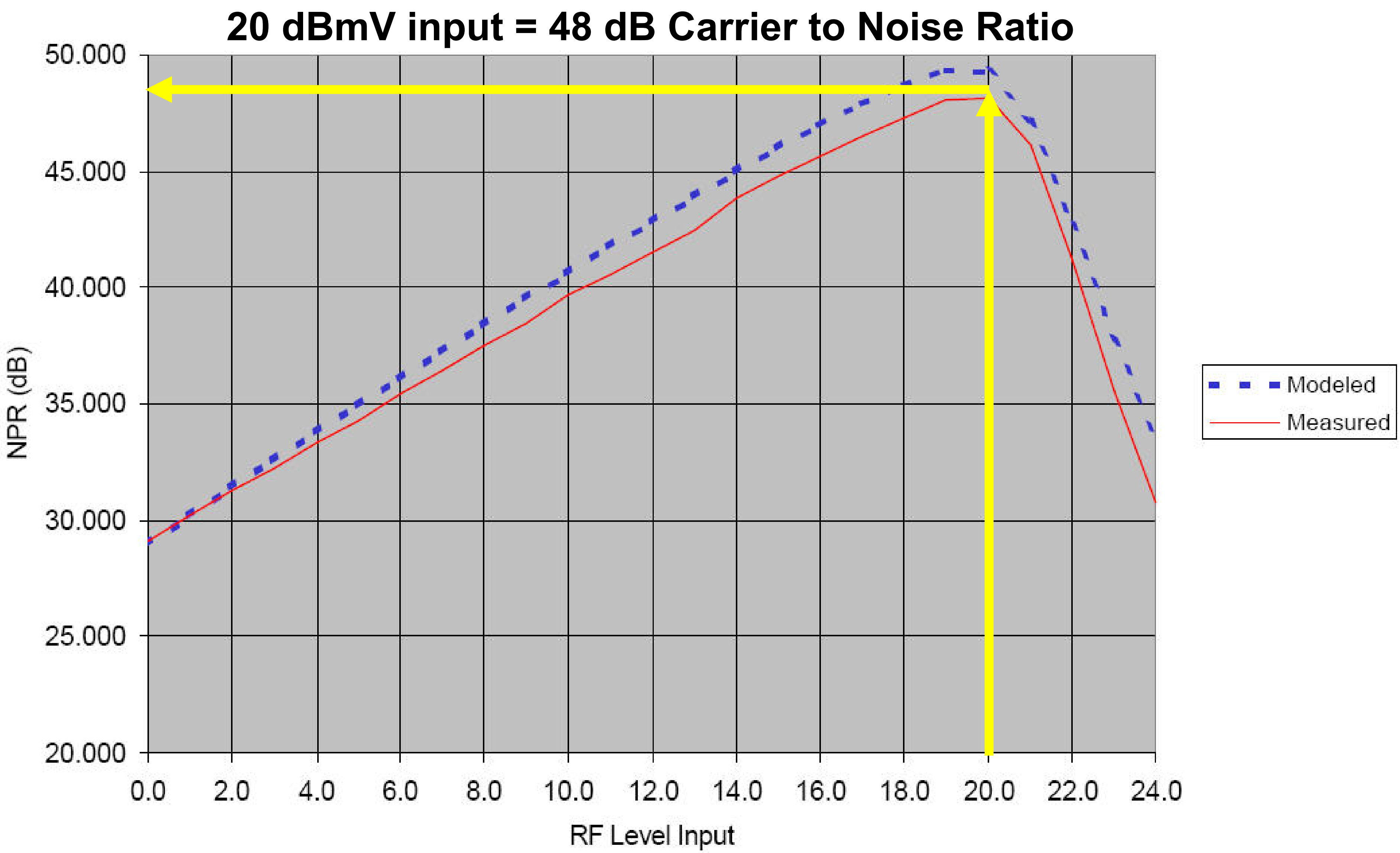
Input RF vs. CNR



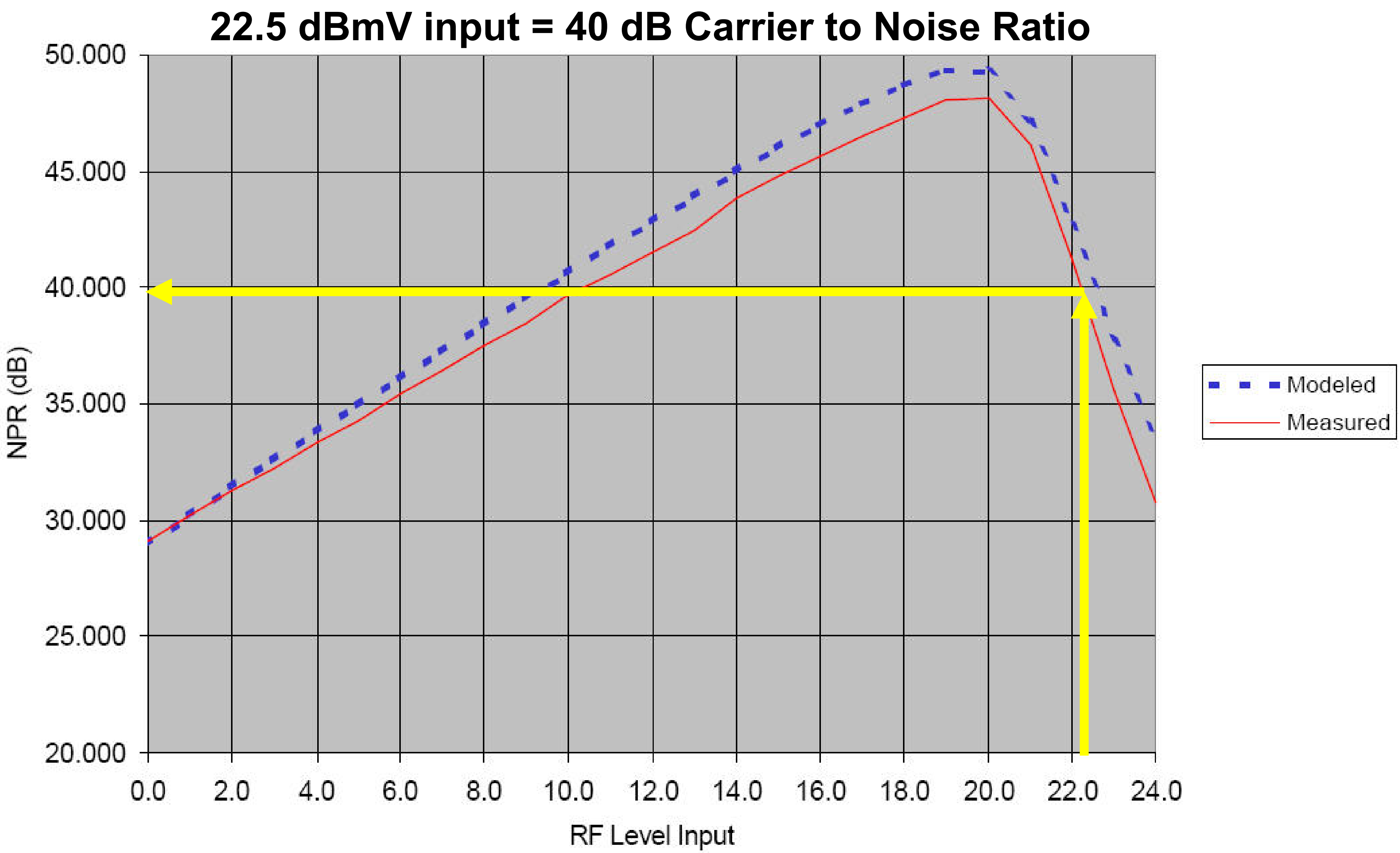
Input RF vs. CNR



Input RF vs. CNR



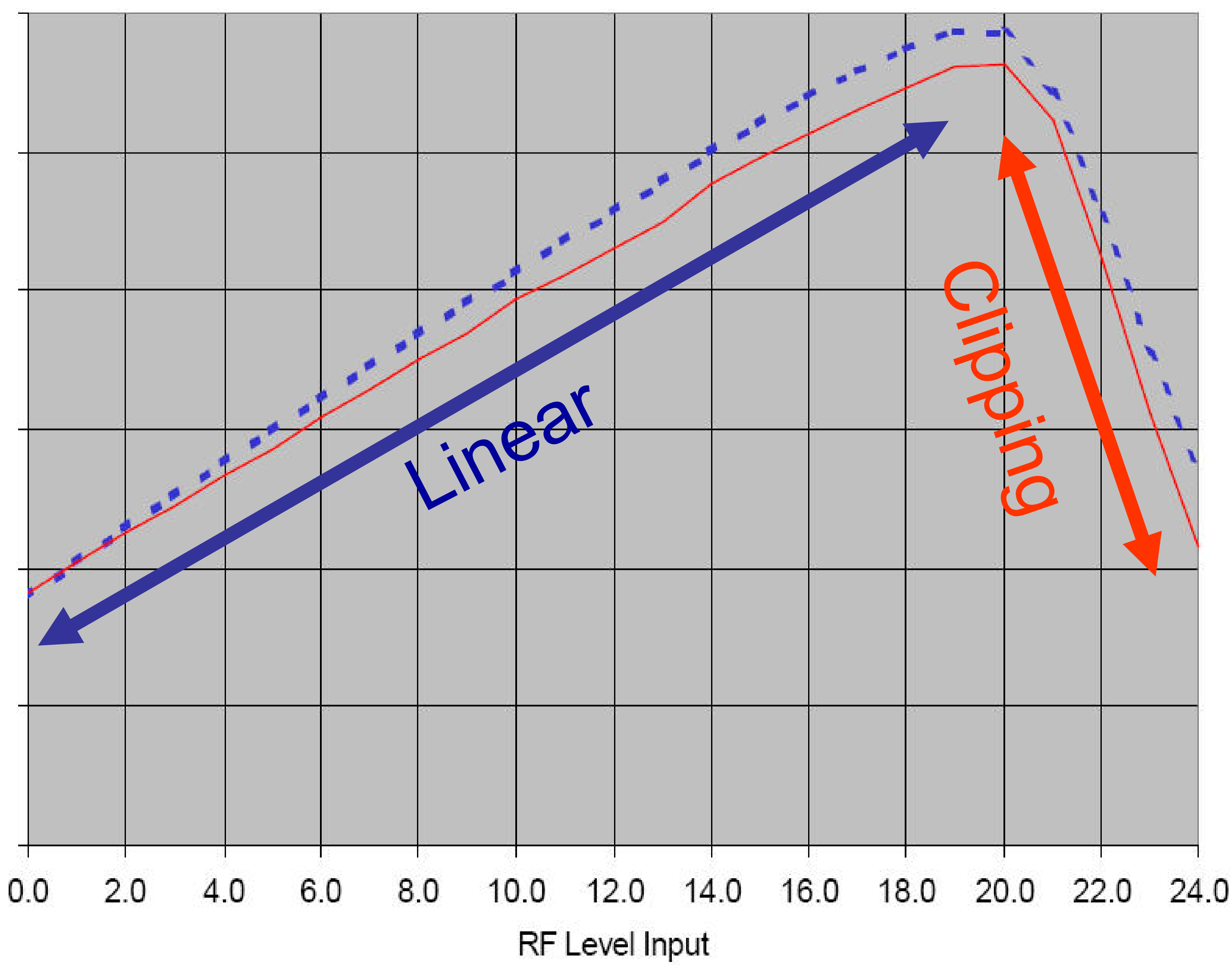
Input RF vs. CNR



Why Did CNR Decrease?

- Lasers have a ***linear*** range of operation
- Once the linear range is exceeded, performance degrades
- Exceeding the linear range is “***clipping***”
- Clipping creates so many beats they appear to be noise
- This is why CNR decreases once the laser input power is increased beyond it’s linear range causing clipping

Linear Range vs. Clipping



RF Power

- It would appear that 20 dBmV would be the optimum input level to maximize CNR
- RF levels across bottom of chart are for one video carrier 6 MHz wide
- What would the RF level be for more carriers?
- Need to maintain the power into the laser to properly modulate it

Optical Modulation Index (OMI)

- RF power into laser modulates it to create light output
- Laser clipping occurs at 100% OMI
- OMI is set at lower levels to create headroom
- Fabrey Perot (FP) lasers typically are specified for 50% OMI
- Distributed Feedback (DFB) lasers operate at lower OMI and have more dynamic range

Equivalent Power to 20 dBmV

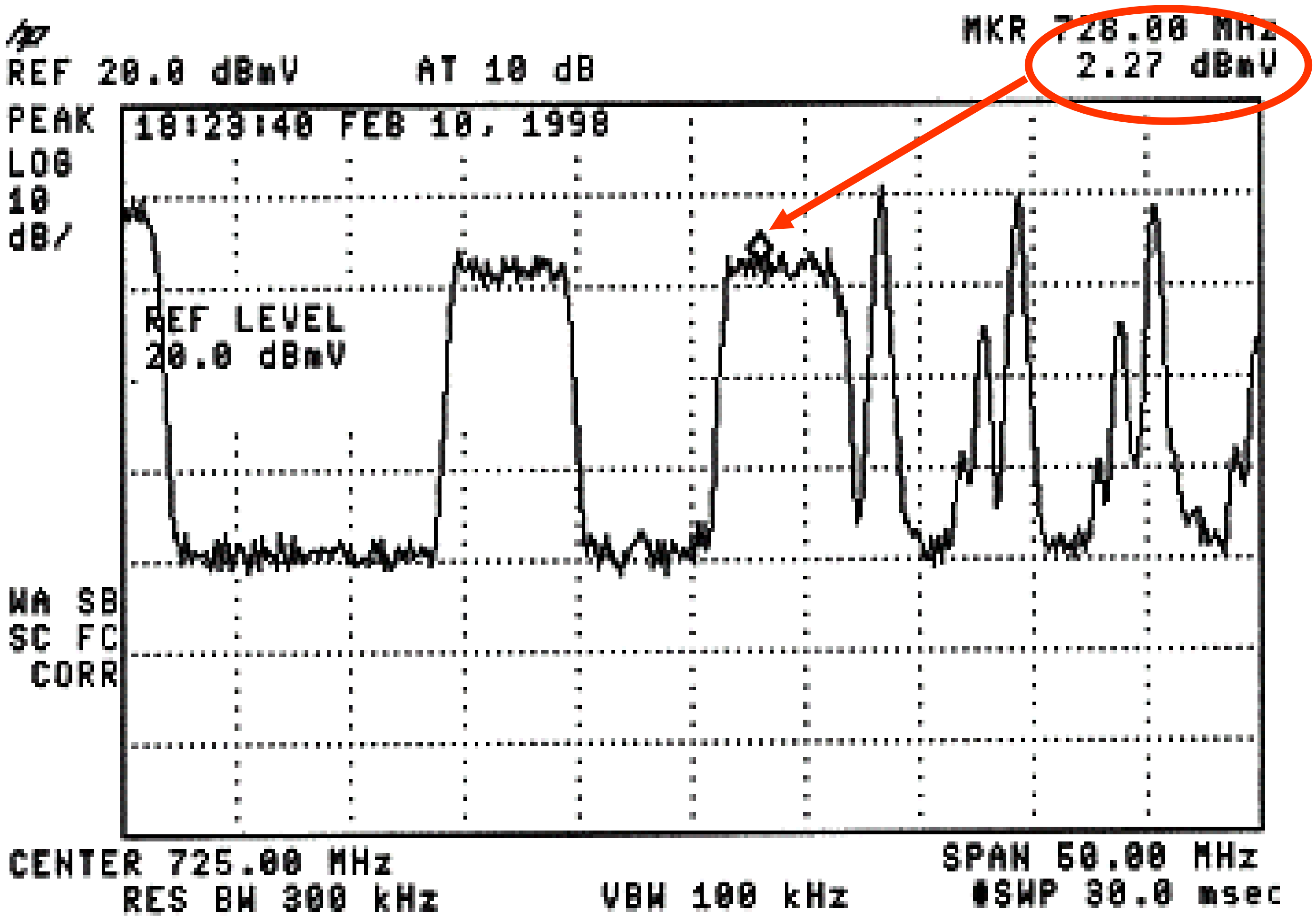
No of Carriers	Level
2	17 dBmV
4	14 dBmV
35,000,000	-55.4 dBmV

- The entire bandwidth is filled with 1 Hz carriers
- The level of these carriers to achieve full loading is known as power per hertz

Power Per Hertz

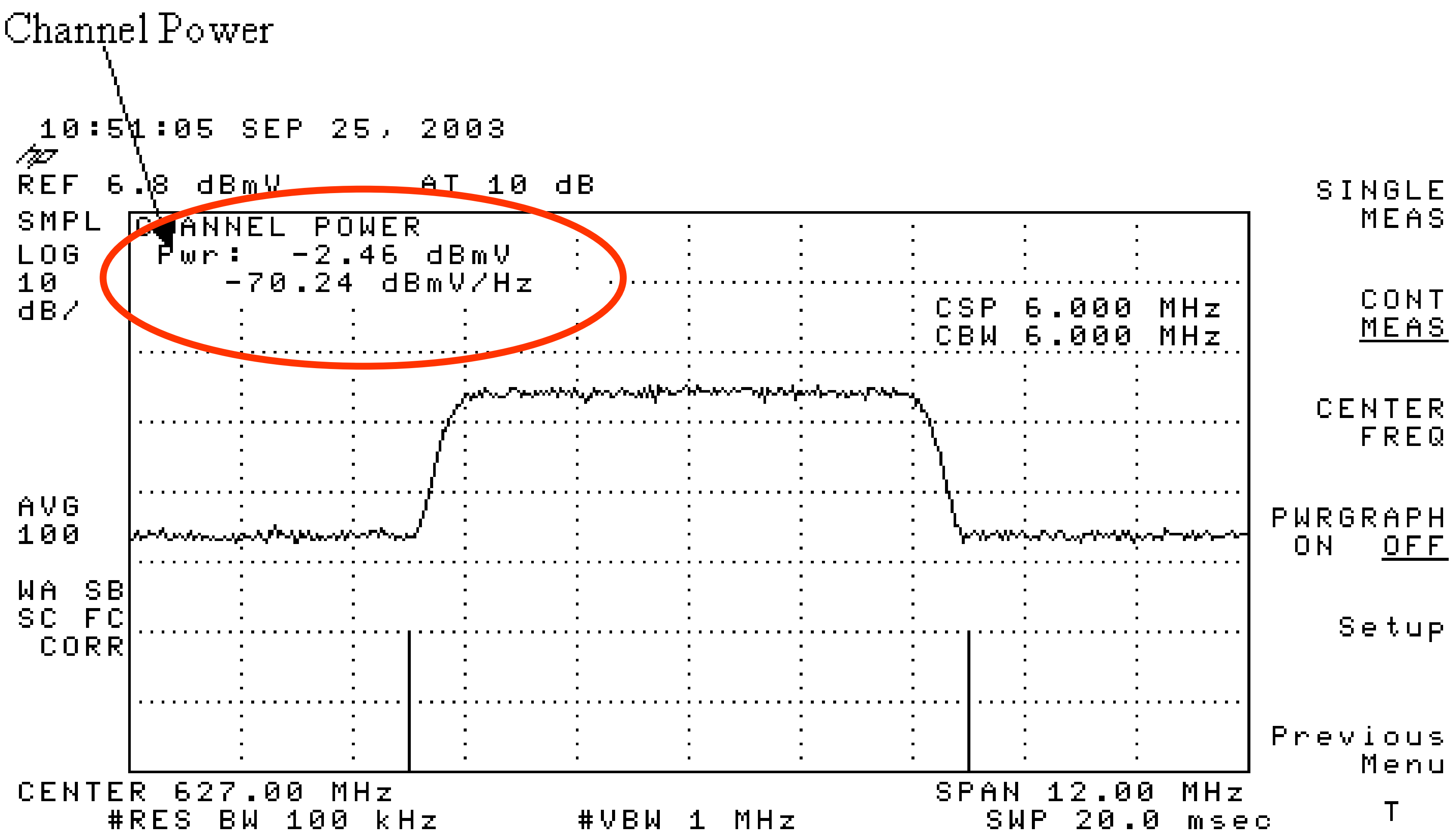
- Allows different carriers to have same power
- Power per Hz Calculation:
  - *Power per Hz = total power - 10log(total bandwidth in Hz)*
- Channel power from power per Hz Calculation
  - *Channel power = power per Hz + 10log(channel bandwidth in Hz)*

P/Hz with Spectrum Analyzer

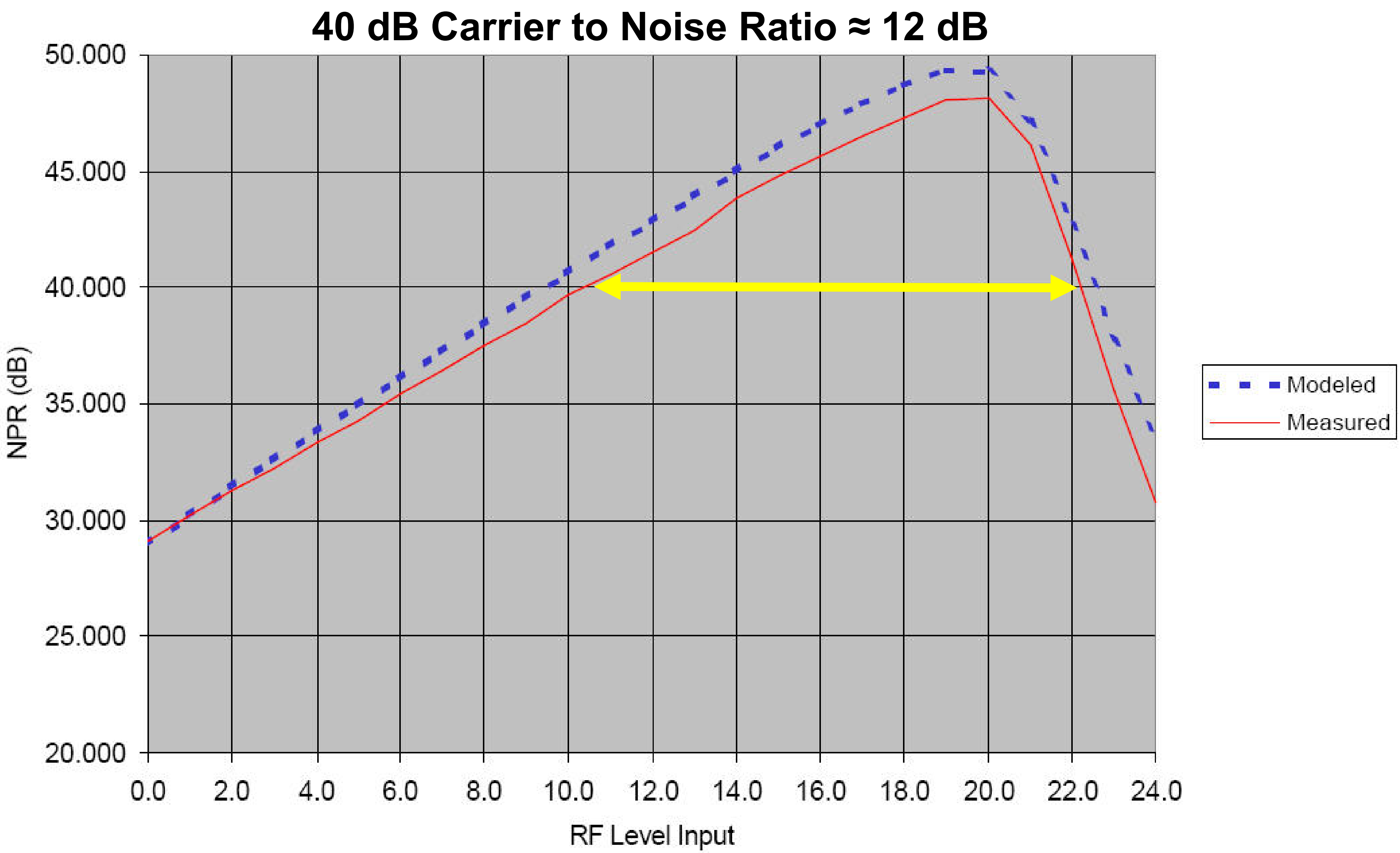


http://www.cisco.com/application/pdf/paws/47064/spectrum_47064.pdf

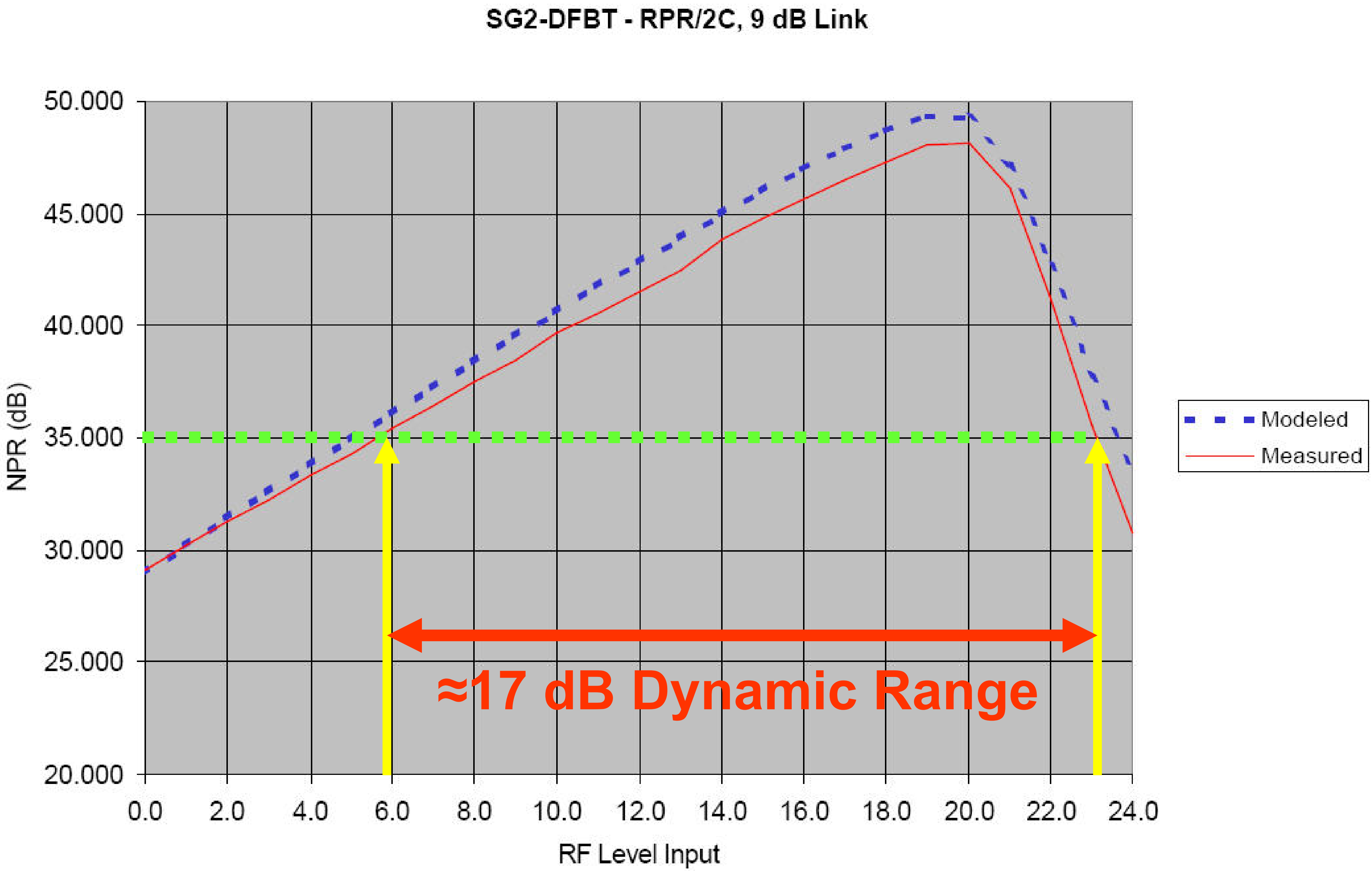
Power/Hz using HP 8591C



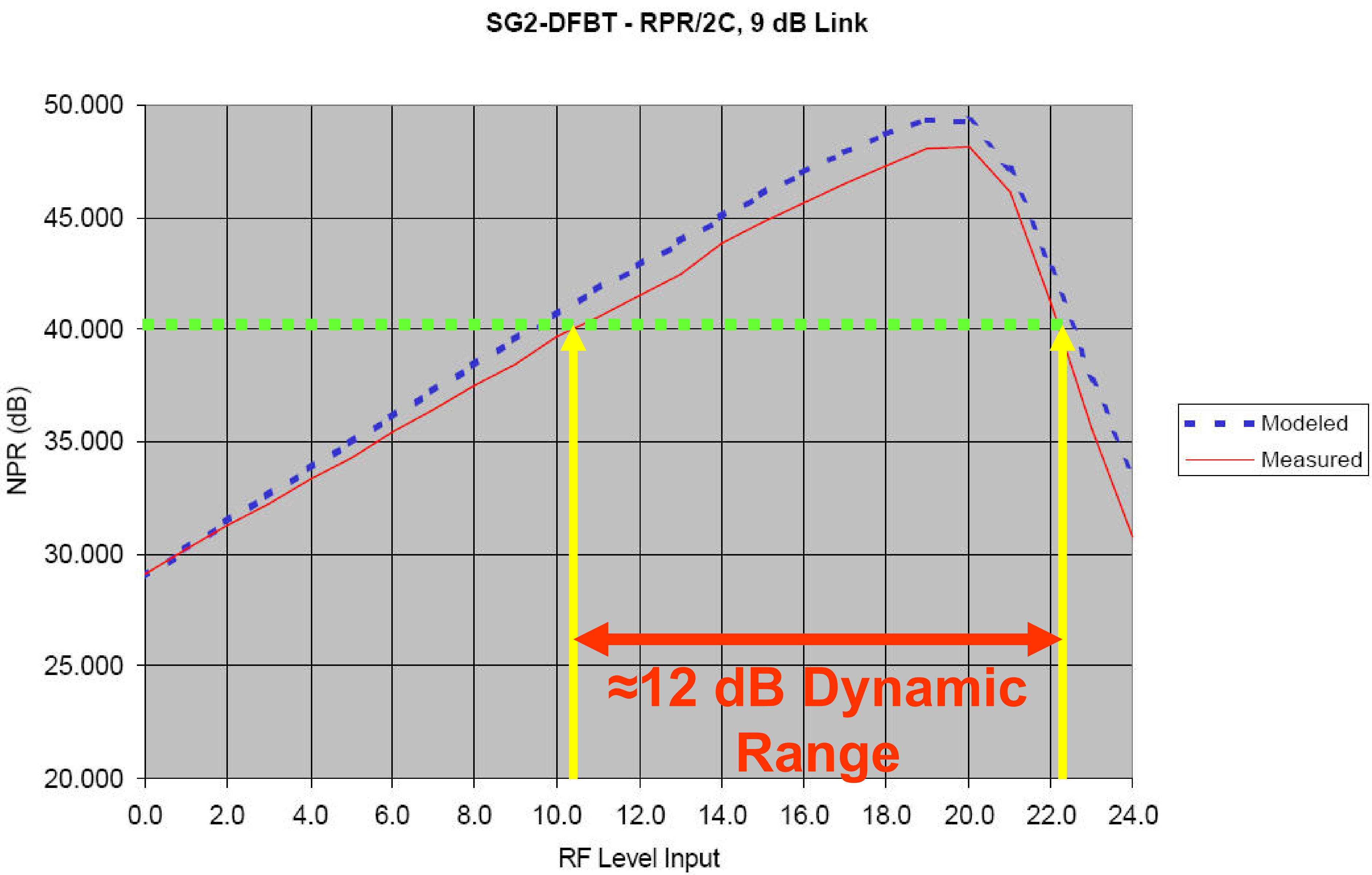
Dynamic Range



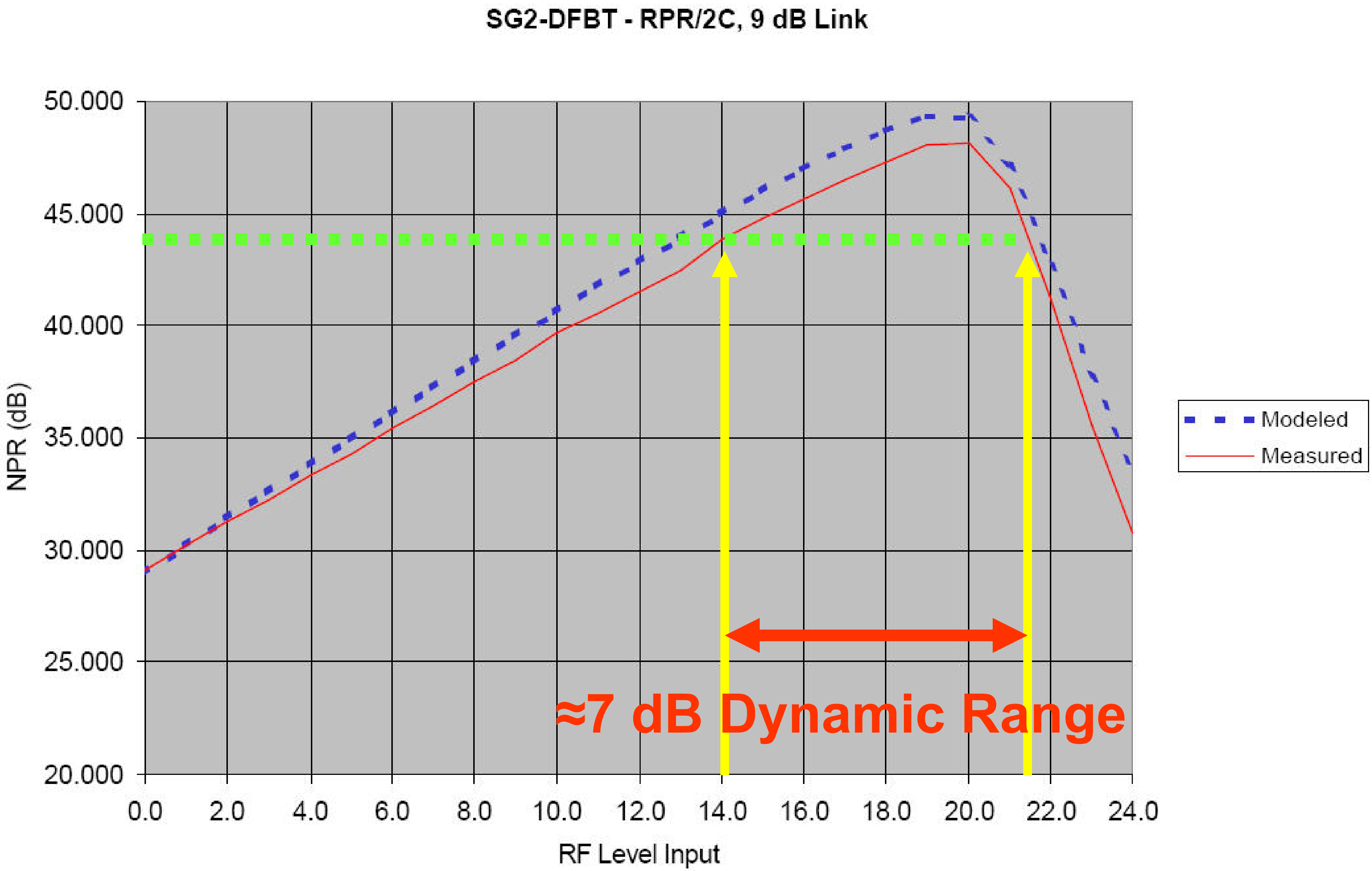
Motorola 1310 Return Laser



Motorola 1310 Return Laser



Motorola 1310 Return Laser

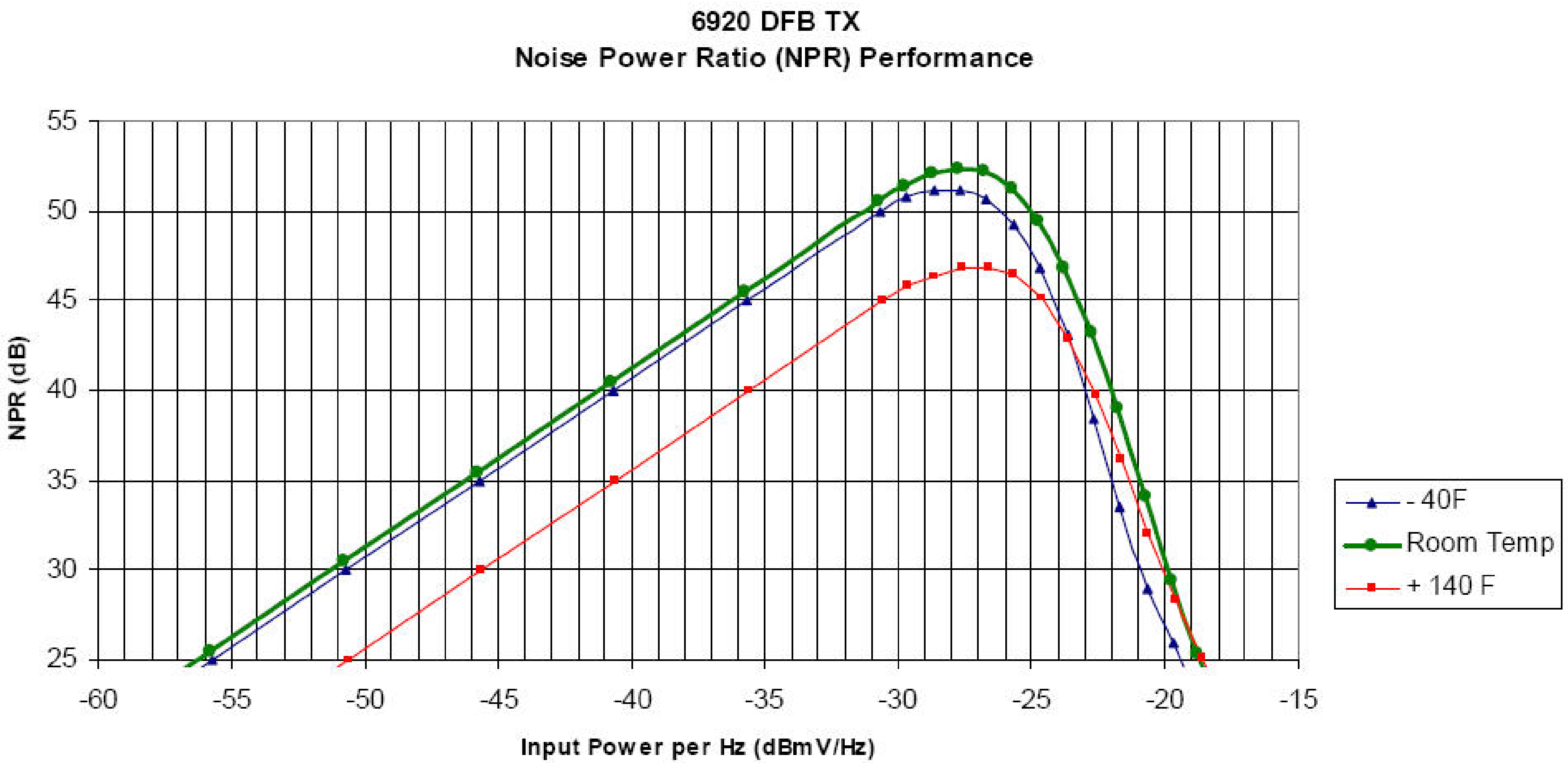


C/N vs. Dynamic Range

- Increasing C/N ratio decreases dynamic range
- Analog return optical links designed for up to 44dB C/N
- Provides about 7 dB dynamic range at 44 dB CNR

NPR vs. Temperature

- Reference 7 dB (15km glass plus passive loss)



NPR vs. Link Loss

- Specifications are for 7 dB link
- Add or subtract for other links

Link Loss (dB)	NPR 'Link Loss Correction Factor' (dB) Model 6920 **DFB TX**
1	+2
2	+2
3	+2
4	+1.5
5	+1
6	+1
7	0
8	-1
9	-2
10	-3
11	-4.5
12	-6
13	-7
14	-9
15	-11
16	-12
17	-14
18	-16
19	-18
20	-20

Getting More Performance

- Performance based on 35 MHz upstream channel load
- Actual load is less
- Was 2 16 QAM and 4 QPSK or 7.1 MHz
- Now 1 16 QAM, 1 64 QAM and 4 QPSK or 10.3 MHz utilized
- Future 3 64 QAM and 4 QPSK or 19.27 MHz utilized

Looking Ahead

- We are going to continue to add carriers to the return
- These will increase the total power seen by the return laser reducing dynamic range by > 1 dB
- If laser power too high – it will crash

Return Setup

- What you need is at least 1 CW carrier
- Carrier setup level ≠ modem carrier levels
- You must not use the modem transmit value (IOS) or measure the level of a DOCSIS carrier !!
- Why ?
- A modem is level controlled by the CMTS and the carrier is therefore not reliable.

Return Alignment Carriers

- Example: 20 dBmV 4MHz input to laser
- Correct setup level depends on bandwidth

Bandwidth	Level
180 kHz	+13.47 dBmV
300 kHz	+ 11.25 dBmV
800 kHz	+ 6.99 dBmV

How Much CNR?

- Required CNR determines power per hertz
- DOCSIS requires 25 dB minimum at CMTS
- Good practice calls for minimum 6 dB of margin above minimum
- Laser link CNR adds with coaxial plant CNR
- Combining of service groups decreases CNR
- Design criteria is ≥ 39 dB combined laser & coax return CNR
- Design criteria is ≥ 15 dB return laser dynamic range
- Design criteria is ≤ 80 return amplifiers on one node and return transmitter

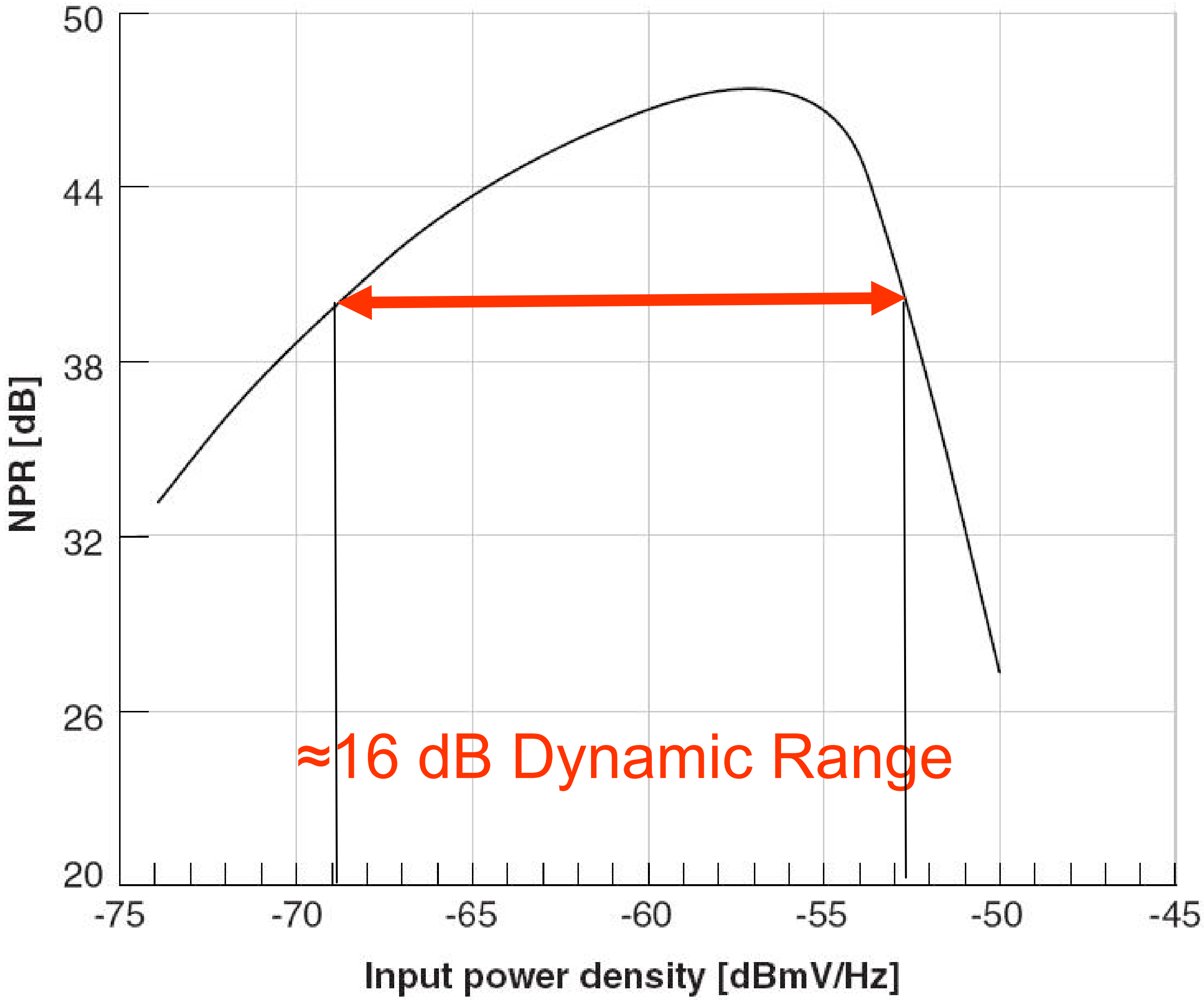
CNR + Interference

- Minimum CNR+I requirements:
- QPSK requires ~11 dB CNR+I
- 16 QAM requires ~19 dB CNR+I
- 64 QAM requires ~25 dB CNR+I
- 64 QAM requires 6 dB cleaner plant than 16 QAM
- The condition of the drop becomes critical with 64 QAM because of micro-reflections

Impulse Noise

- Impulse noise power density decreases as the frequency increases, it typically has equal power per octave.
- 5 – 10 MHz = 10 to 20 MHz = 20 to 40 MHz
- Doubling the return frequency will typically half the power density for any given impulse event!
- Lower frequency impulse noise and interference has more effect on laser clipping than higher frequency interference.
- Higher frequency carriers are more robust since impulse noise power density decreases as the frequency increases.

Digital Return Laser



Laser Set up Power

- Setup is a trade off between adequate CNR and adequate dynamic range
- Set your CNR too high, little immunity to ingress and crud
- Set your CNR too low, errors in data transmission

Effect of Proper Laser Setup

- Assumption: 40 dB is the selected CNR for the laser
- The Motorola will have 12 dB of margin for ingress and other crud before laser clipping
- The Harmonic laser will have 16 dB of margin for ingress and other crud before laser clipping

Conclusions

- Total RF Input Power is key to proper laser performance
- Ingress and “crud” count as power
- We must leave margin for impairments
- Once a return laser is properly setup, leave it alone
- “***Set It And Forget It***”

CNR vs. SNR

- CMTS reports upstream SNR
- Does SNR equal CNR?
- SNR is an *estimate* made by the CMTS
- Closer to MER
- There is a limited correlation between SNR and CNR
- SNR is always less than actual CNR
- At *best*, there is 2 dB difference (15 to 25 dB)
- About 4 dB difference (outside 15 to 25 dB)

MER Components

- Determined from demodulated information and includes:
  - Noise floor
  - In-channel frequency response
  - Group delay
  - Ripple
  - Oscillator phase noise

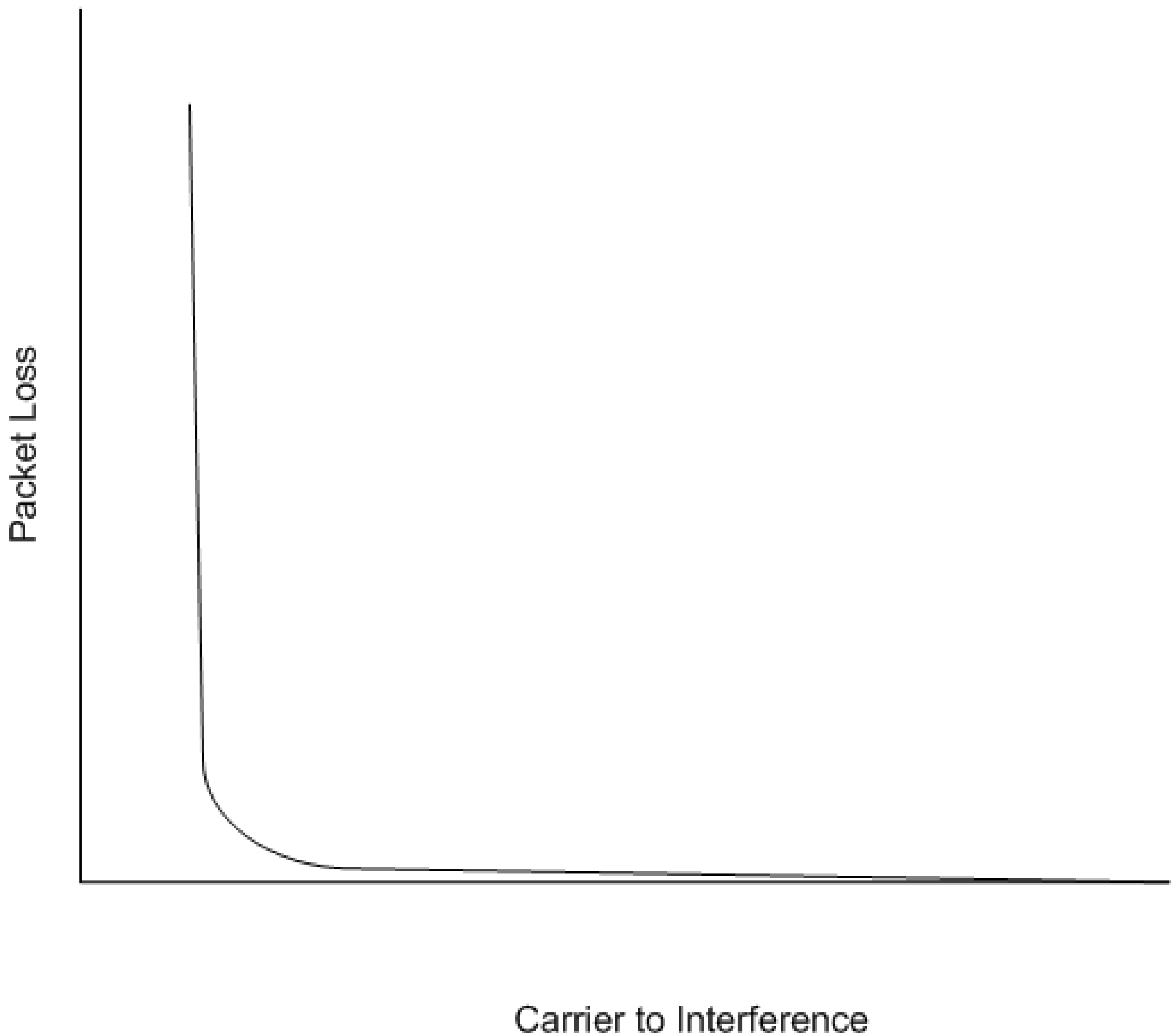
Poor SNR But Good CNR

- Poor in-channel frequency response
- Micro-reflections
- Group delay
- Upstream data collisions

Return Path Crash

- Why does HSI crash but CDV continues to work when laser problems show up?
- HSD utilizes Transmission Control Protocol (TCP) which stimulates CPE retransmission when packet errors occur
  - Manifests as very slow connection. (High utilization)
- VoIP utilizes User Datagram Protocol (UDP) which does NOT request retransmission of lost packets.
  - The user experiences a noisy call.

Data Loss vs. Interference



Plant Requirements Increase

- Modem output levels at 64 QAM -1 dB vs. 16 QAM
- Increased channel load -1.6 dB of extra margin loss
- 16 to 64 QAM modulation change = 6 dB increased requirement
- Headend combining = -3 dB of extra margin loss
- The days of forgiving return plant operation are probably over

Final Conclusions

- Maximize CNR, this is the floor
- Cleanup impairments which add to CNR (Ingress,CPD)
- Return is extremely craft sensitive
- Once aligned for proper CNR, most crud will come from the drops
- SNR ≠ CNR
- Multiple node “optimizations” are an indicator that something is wrong