Quasonix

# Digital Signal Processing to Improve Telemetry Links

**A Short Course at the**
**International Telemetering Conference**
**Glendale, AZ • 27 October 2022**

**Terry Hill, Quasonix**

# Course Outline

- Receiver-Only DSP
  - Trellis Demodulation
  - Diversity Combining
  - Data Quality Metric / Data Quality Encapsulation
  - Adaptive Equalization
  - Best Channel Selection
  - Best Source Selection
- RX/TX DSP
  - Space-Time Coding
  - Forward Error Correction (FEC)
- Using All the Tools Together

# Receiver-Only DSP Techniques

- Receive-side processing, no transmitter impact
- Trellis demodulation
- Maximal ratio combining – optimal against AWGN
  - Polarization diversity
  - Frequency diversity
- Data Quality Metric (DQM) / Data Quality Encapsulation (DQE)
  - IRIG 118-22, Chapter 11
- Adaptive equalization
  - Powerful tool against multipath
- Best channel selection
  - Handles the “non-combinable” cases
- Best source selection
  - Combats all forms of signal impairment

# Trellis Demodulation

# Demodulation

- As the shop manual says, “Installation is reverse of removal.”
- Demodulation is intrinsically more difficult than modulation
  - Unknown carrier frequency
  - Unknown carrier phase
  - Unknown clock frequency and phase
  - Signal corruption
    - Noise
    - Interference
    - Multipath
    - Doppler shift
- Multiple techniques can be applied

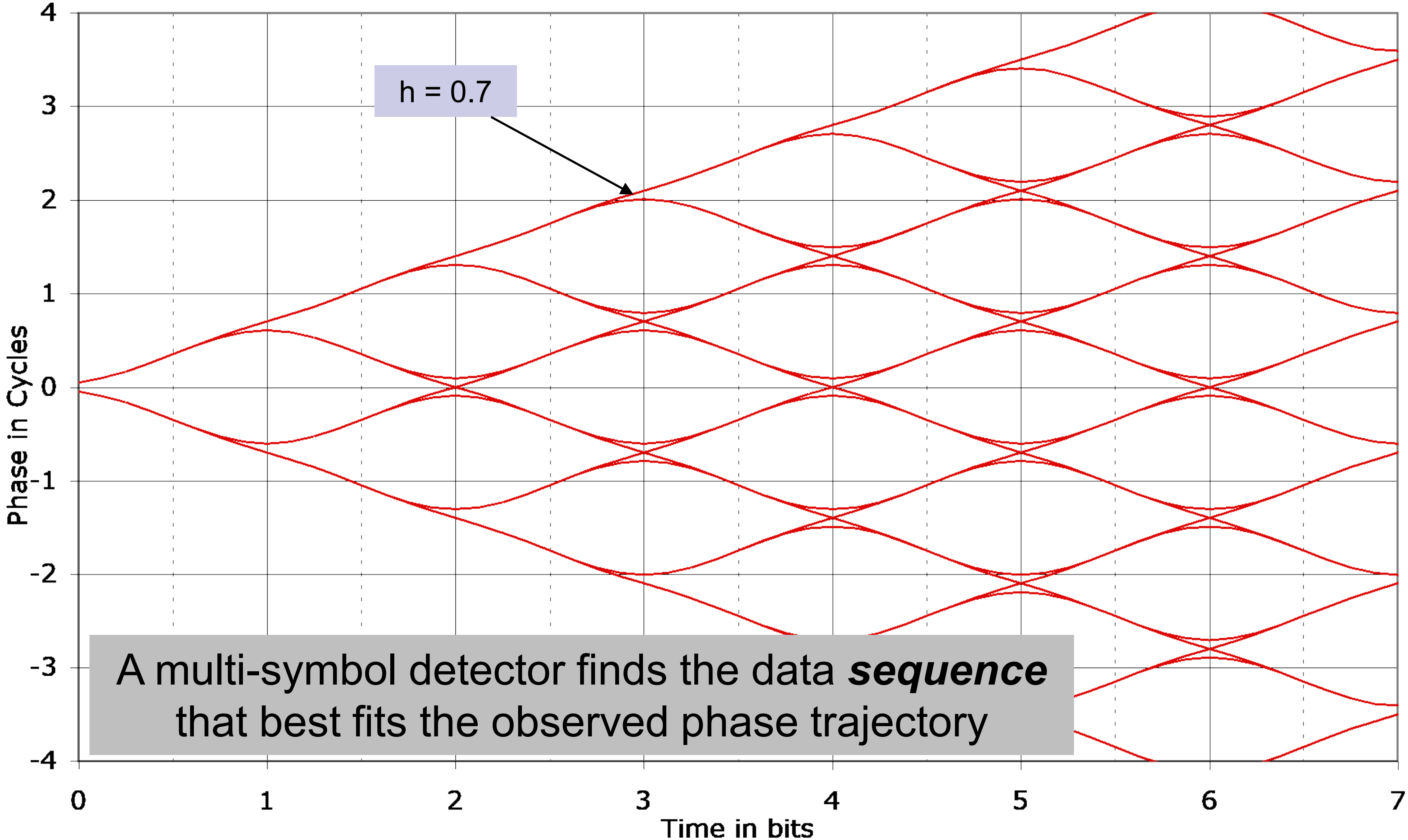
# Single-Symbol Demodulation

- Tier 0
  - Legacy (nearly exclusive in $20^{th}$ century)
  - Simple to build
  - Robust to signal defects and channel impairments
  - ~3.5 to 5 dB short of theoretical limit
- Tier I
  - Requires optimization for **S**OQPSK
  - Weakly synchronized
  - Requires high SNR for acquisition
  - ~1.0 to 1.5 dB short of theoretical limit
- Tier II
  - No practical single-symbol detectors

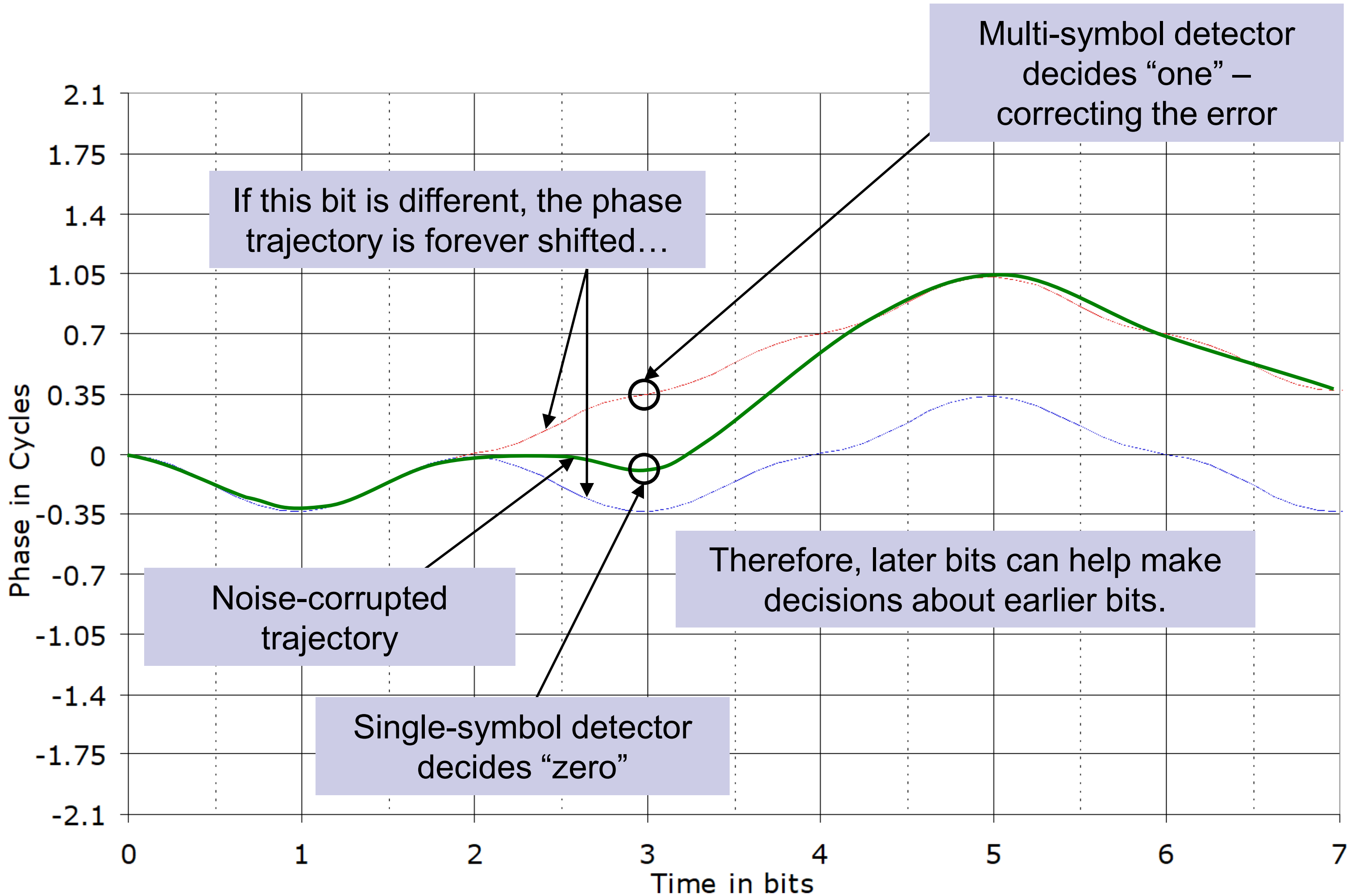
# Trellis Demodulation Overview

- Tier 0
  - Invented in 1974, introduced in 2001
    - Osborne & Luntz, “Coherent and Noncoherent Detection of CPFSK”, IEEE T-COM, August 1974
  - Requires significant signal processing power
  - Signal defects and channel impairments require attention
    - DSP techniques can be applied to solve these issues
  - Operates within 0.2 dB of theoretical limit
- Tier I
  - Strong, rapid synchronization
  - Operates within 0.2 dB of theoretical limit
- Tier II
  - Mandatory for practical implementation

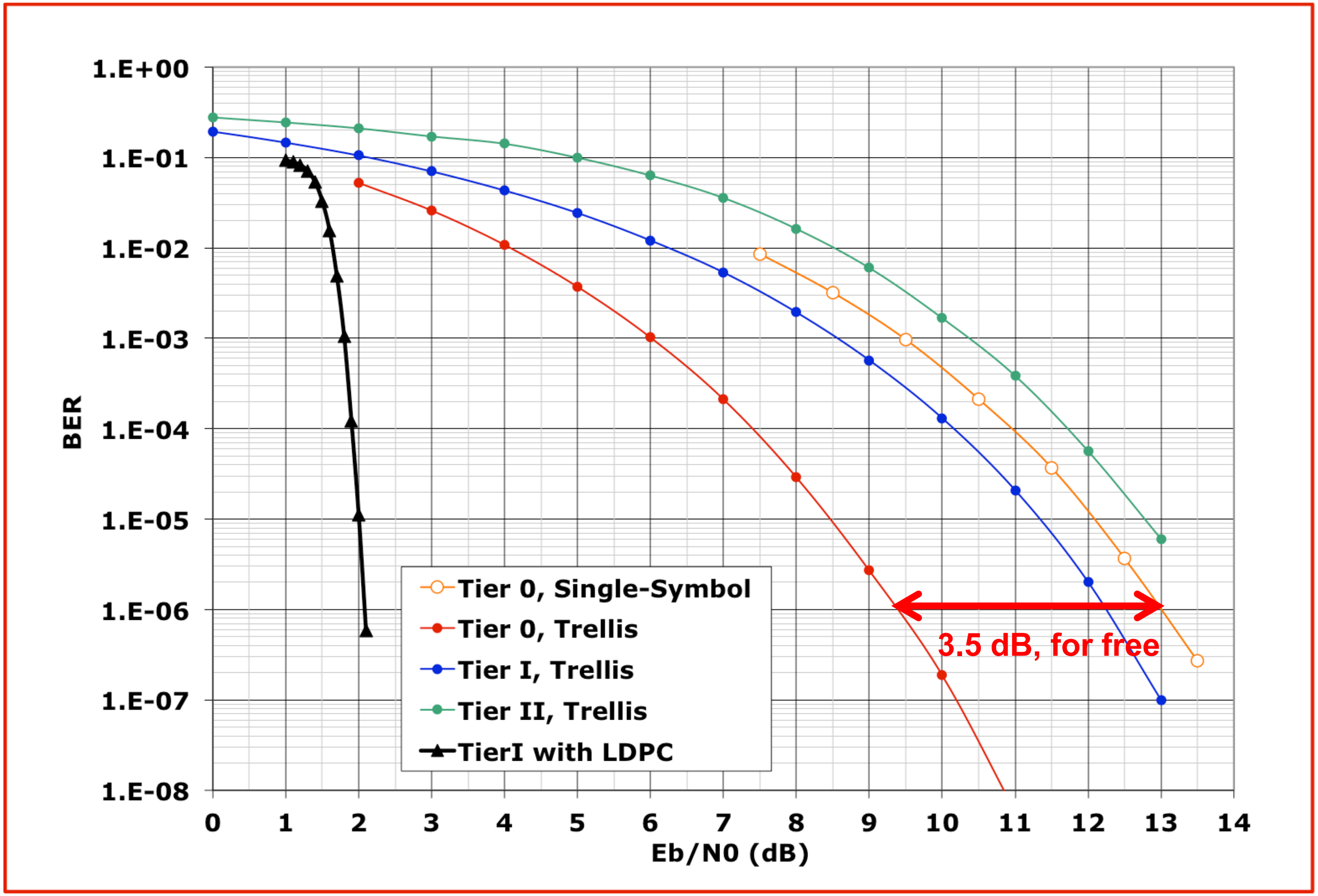
# Tier 0 Phase Tree



# Why Does It Matter?



# BER Performance Comparison

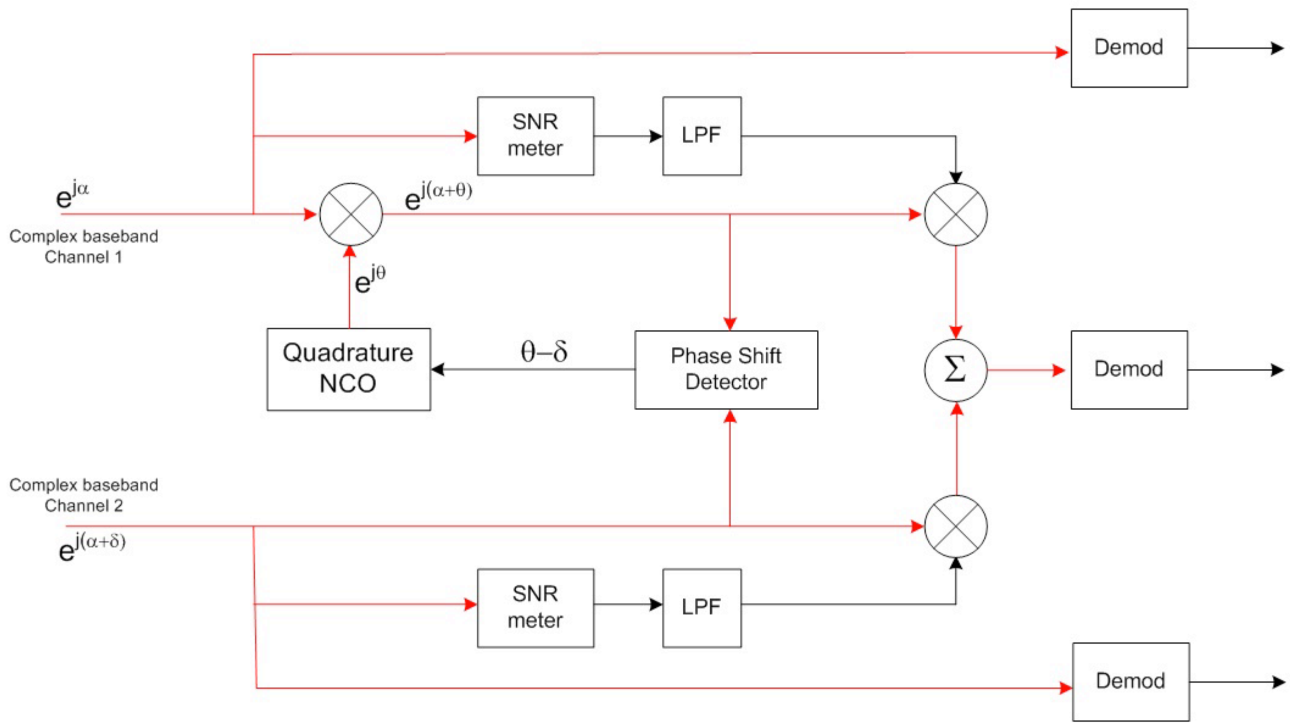


# Diversity Combining

# Maximal Ratio Combining

- Many telemetry systems utilize diversity reception
  - Frequency separation using two transmitter
  - Orthogonal polarizations using cross-polarized antenna feeds
- Combining two (or more) copies of the same signal
  - Diversity combining
  - Creates a third signal to be demodulated
  - BER performance of third signal is better than either of the individual signals
- Special case – the leading use of diversity
  - Linearly polarized transmit antenna on test article – could be at any orientation
  - Left-hand and right-hand circularly polarized receive antennas
  - Each receive antenna loses half the transmit power
  - Diversity combiner puts it all back together, eliminating the polarization loss
  - Frequency diversity works the same way, but uses twice the bandwidth

# Maximal Ratio Combining

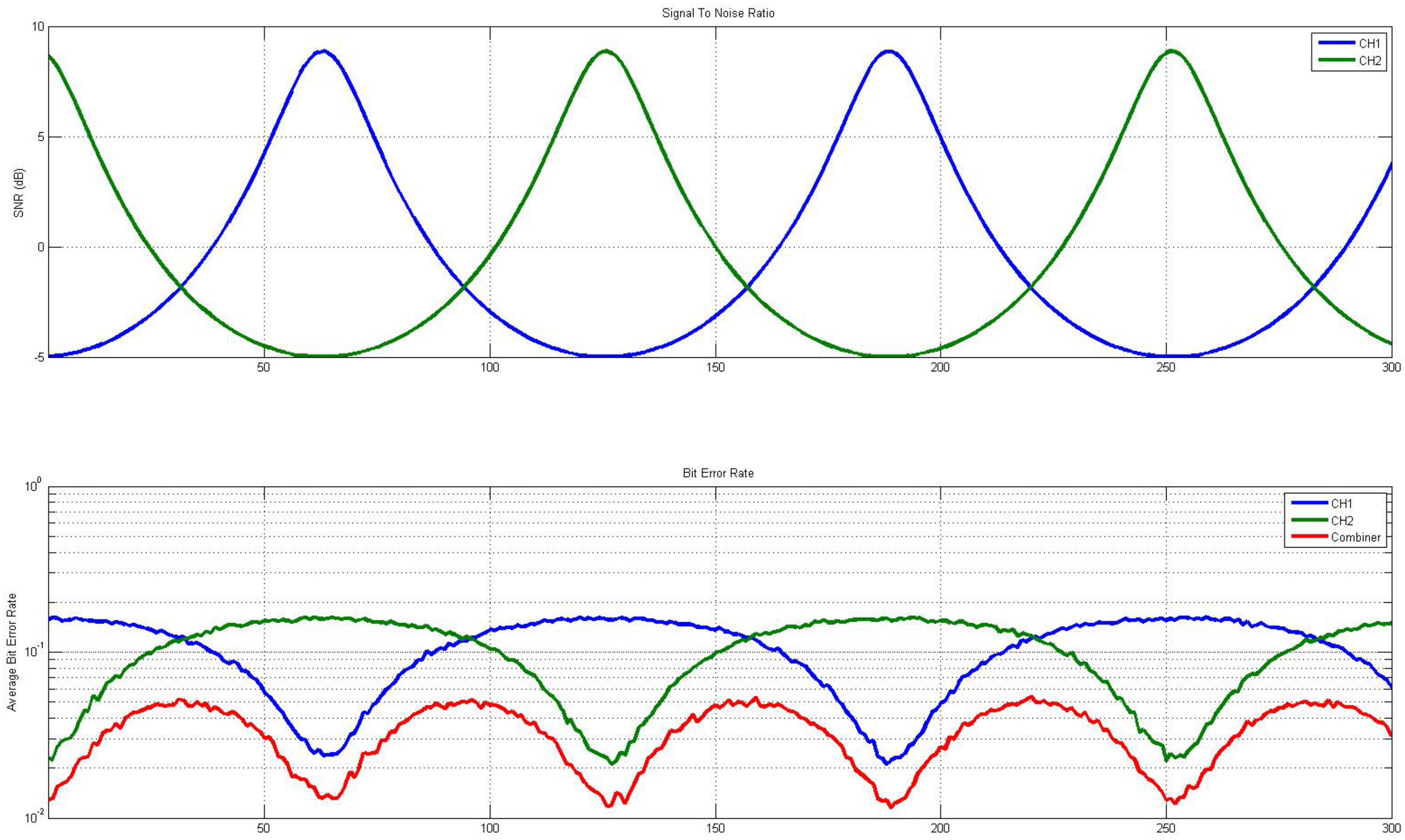



- Weight each signal in proportion to its SNR and add
- Yields optimum SNR on combined channel **in AWGN**
- $SNR_{combined} = SNR_a + SNR_b$

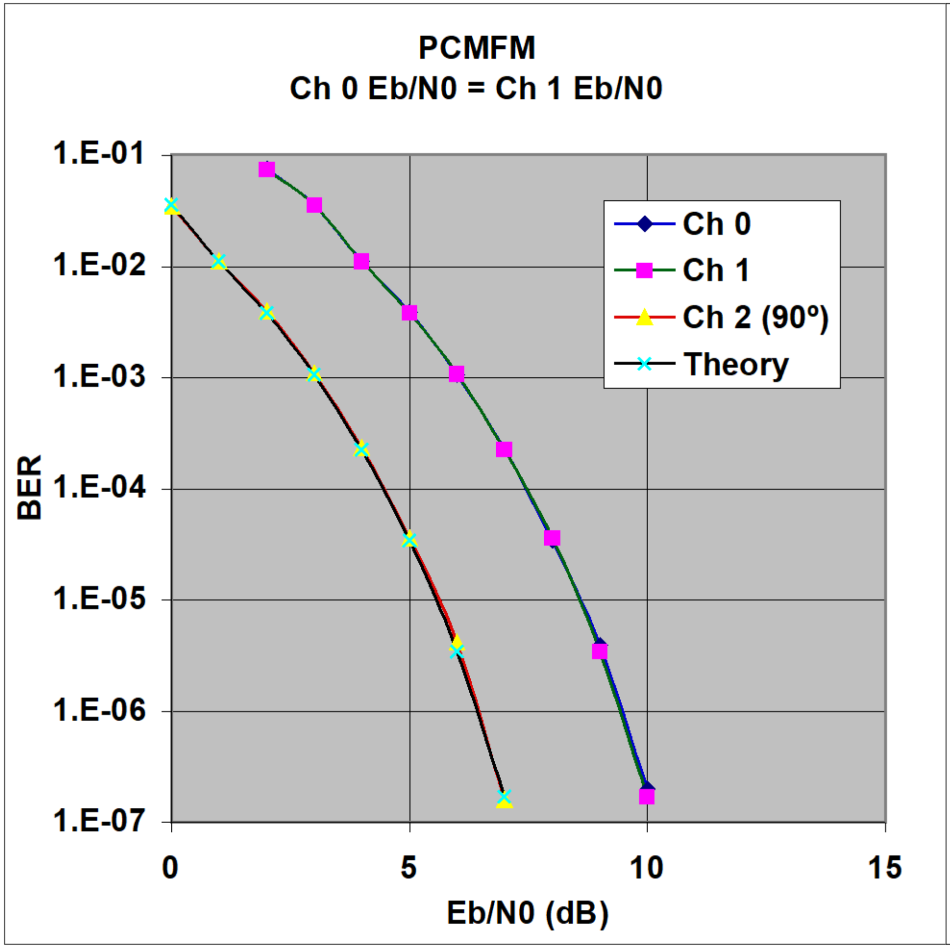
# Maximal Ratio Combining

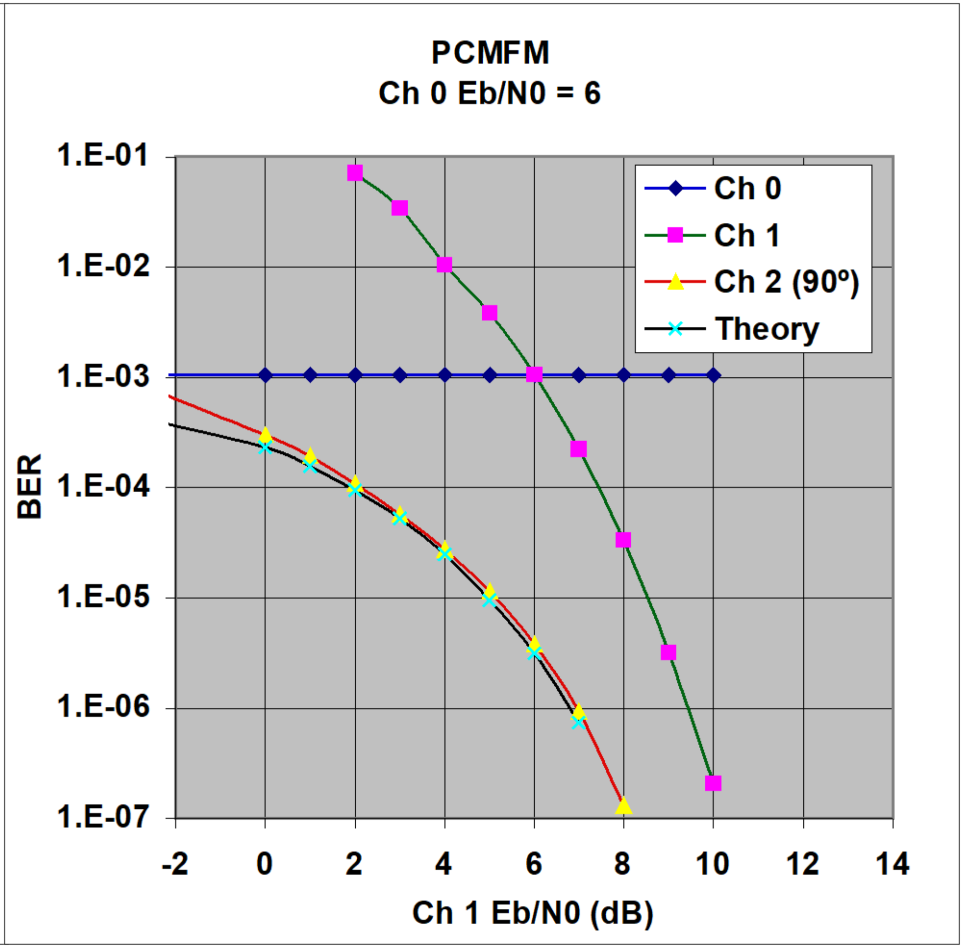
- Jump to file://localhost/Users/TerryHill/Documents/Quasonix/ITC 2015/Diversity Combiner.avi

# BER Results - Fading Signals

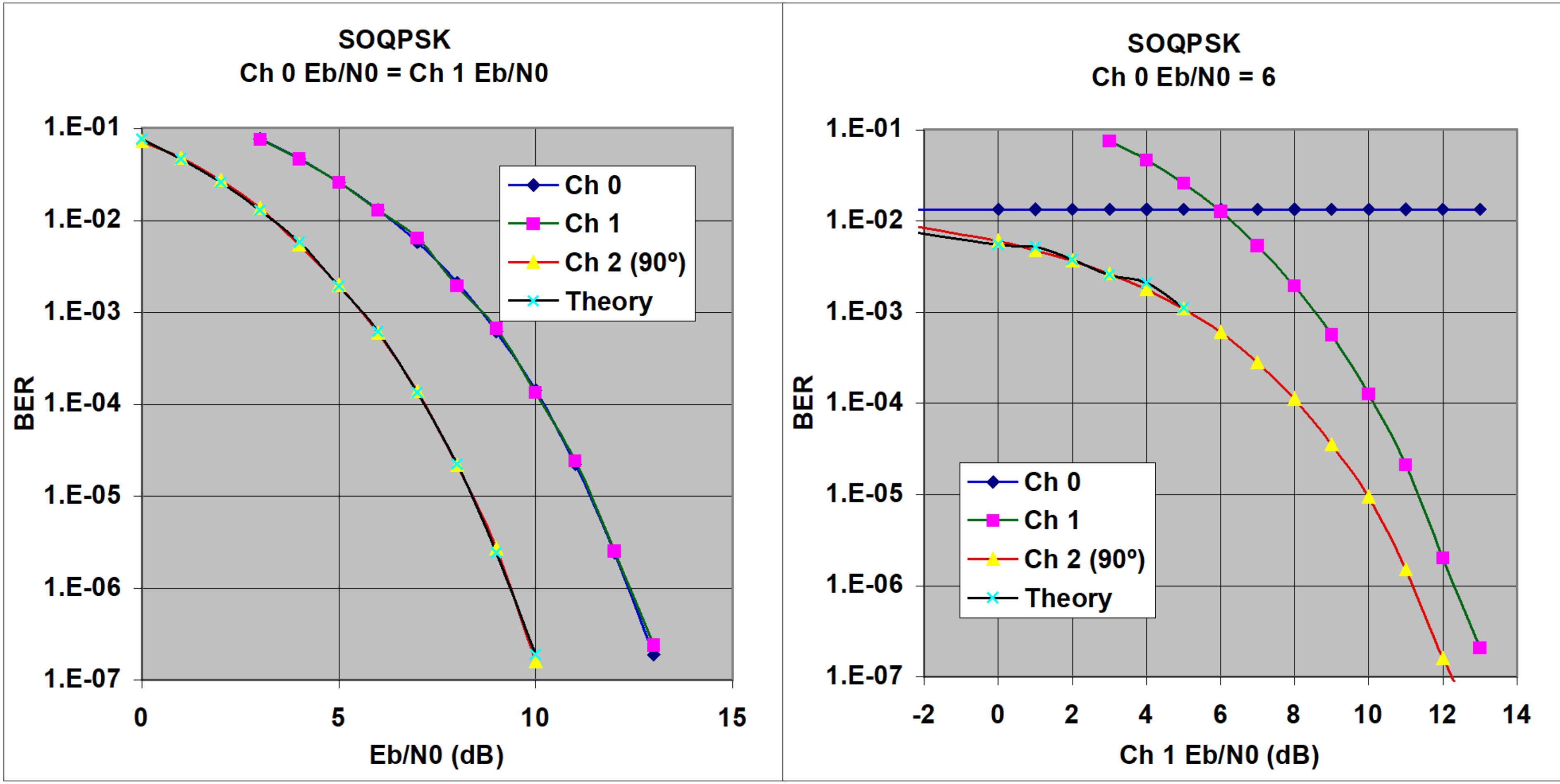


# Measured Combiner BER - Tier 0

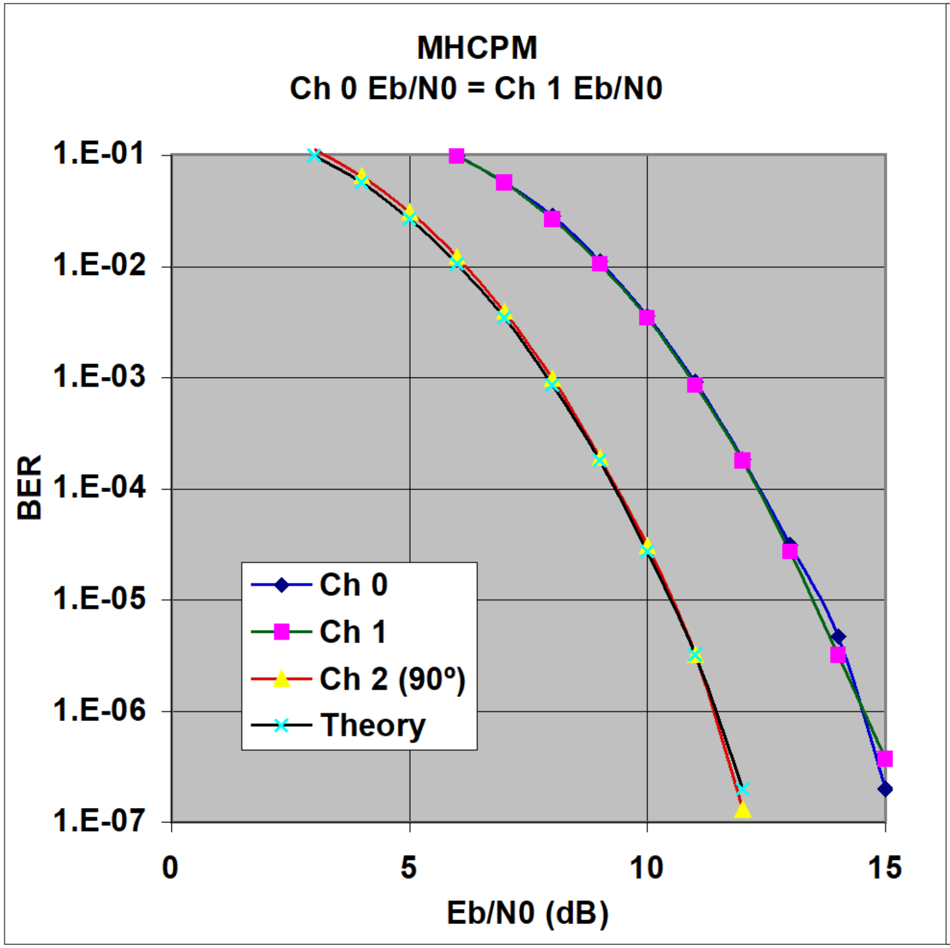


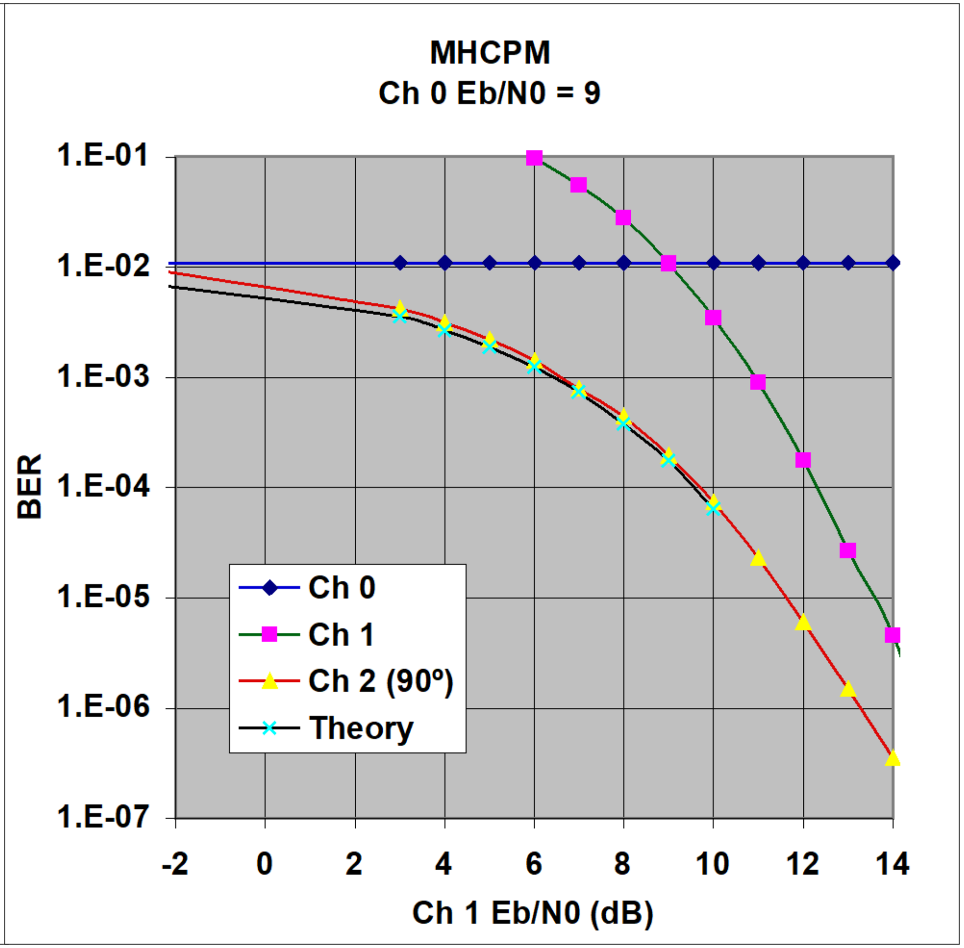



# Measured Combiner BER - Tier I



# Measured Combiner BER - Tier II



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# Combiner Summary

- Receive-side processing
  - No transmitter impact
- Phase aligns the signals
- Forms weighted sum of two inputs
- SNR of the weighted sum is at least as high as the better signal
- May be as much as 3 dB higher (equal input case)
- Conventional combiner design assumes signals are time-aligned
  - Performance falls off rapidly with increasing time skew
  - Combiner will probably fail altogether at ± ½ bit time skew
- Some combiners do both phase alignment *and* time alignment
  - Supports operation with spatially separated antennas
- If you have access to two copies of the signal, use them!

# Data Quality Metric (DQM)

# How to Assess Data Quality

- *Measured* BER is not practical
  - Requires known data in the stream – not possible with encryption
  - Takes a long time to measure low BERs
- Bit error *probability* (BEP), however…
  - Does not require any known data
  - Can be determined quickly and accurately from demodulator statistics
  - Is an *unbiased* quality metric, regardless of channel impairments
  - When calibrated per a standardized procedure, DQM based on BEP allows DQE from multiple vendors to interoperate
- Each vendor can use their own algorithm for developing BEP
- DQM is calculated directly from BEP
  - Use of Likelihood Ratio leads to maximum likelihood BSS algorithms
  - Converted to 16-bit integer on log scale

# Definition of DQM

- Start with BEP, derived within demod
- Likelihood Ratio (LR) = (1 - BEP) / BEP
- DQM = min (round (log10 (LR) / 12 * (2^16)), 2^16 -1)
  - 16-bit unsigned integer, ranges from 0 to 65,535
- Easily reversed:
  - LR = 10^(-12 * DQM / 2^16)
  - BEP = 1 / (1 + LR)
- Define “Q” as the “User’s DQM”
  - Q = 12 * DQM / 65535
  - Represents the exponent of 10 in the BEP
  - Examples:
    - Q = 3 → BEP = 1e-3
    - Q = 7 → BEP = 1e-7
  - Arbitrarily cap Q at “a perfect 10”.

| BEP | LR | DQM | Q |
|---|---|---|---|
| 0.5 | 1.00 | 0 | 0.00 |
| 1E-01 | 1.11111E-01 | 5211 | 0.95 |
| 1E-02 | 1.01010E-02 | 10899 | 2.00 |
| 1E-03 | 1.00100E-03 | 16382 | 3.00 |
| 1E-04 | 1.00010E-04 | 21845 | 4.00 |
| 1E-05 | 1.00001E-05 | 27307 | 5.00 |
| 1E-06 | 1.00000E-06 | 32768 | 6.00 |
| 1E-07 | 1.00000E-07 | 38229 | 7.00 |
| 1E-08 | 1.00000E-08 | 43691 | 8.00 |
| 1E-09 | 1.00000E-09 | 49152 | 9.00 |
| 1E-10 | 1.00000E-10 | 54613 | 10.00 |
| 1E-11 | 1.00000E-11 | 60075 | 10.00 |
| 1E-12 | 1.00000E-12 | 65535 | 10.00 |

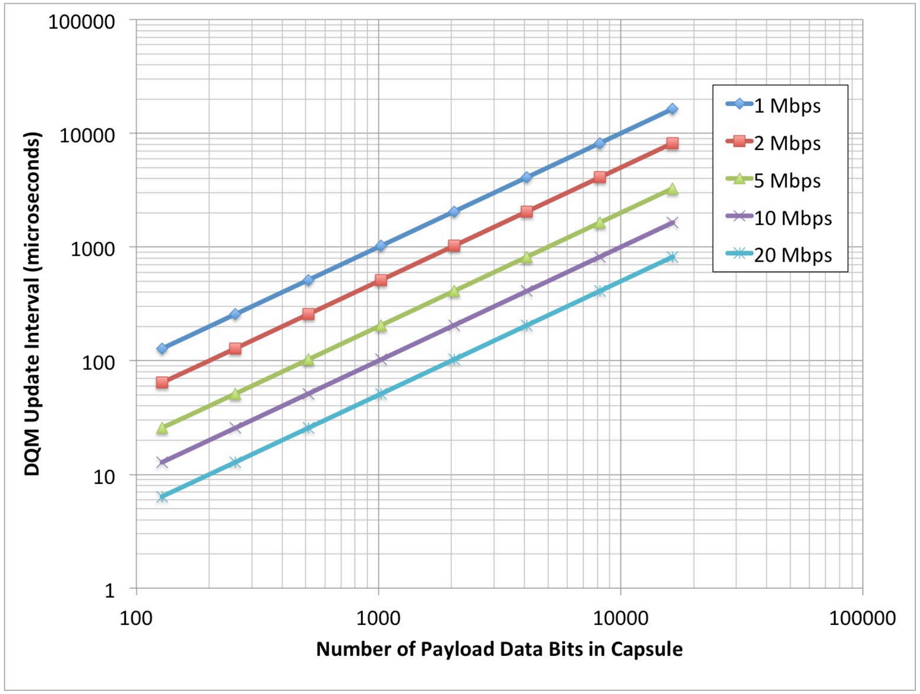
# DQE Format

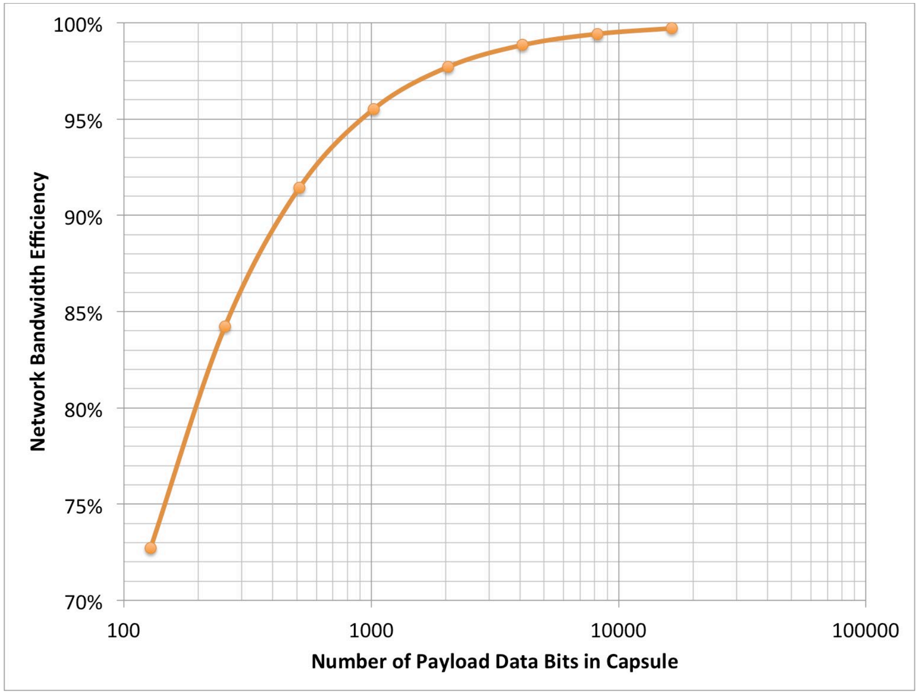
- Header
  - 16-bit sync pattern (0xFAC4)
    - MSB first: 1111101011000100
  - 8-bit reserved word, potentially for packet header version number (currently 0)
  - 8-bit reserved word, potentially for source ID tag (currently 0)
  - 16-bit DQM
- Payload data
  - User selectable length, (128 ≤ N ≤ 16,536)
  - Defaults to 4096

| | | | | |
|---|---|---|---|---|
| 16-bit Sync Pattern | 8-bit Word | 8-bit Word | 16-bit DQM | N bits of payload data (128 ≤ N ≤ 16,536) |

# DQM Parameter Trades

- Choice of N impacts both DQM update rate and network efficiency



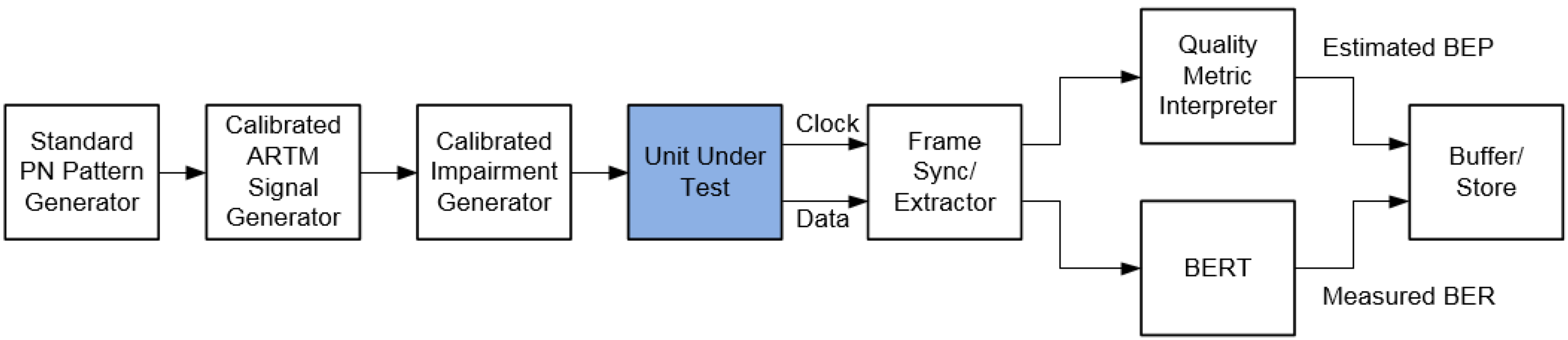



# Calibration of DQM

- Calibrate DQM under various channel impairments:
  - AWGN – static level
  - AWGN – dynamic level (step response)
  - Dropouts
  - In-band and adjacent channel interference
  - Phase noise
  - Timing jitter
  - Static multipath
- Test procedures are being developed to evaluate accuracy of DQM
  - Targeted for inclusion in IRIG 118

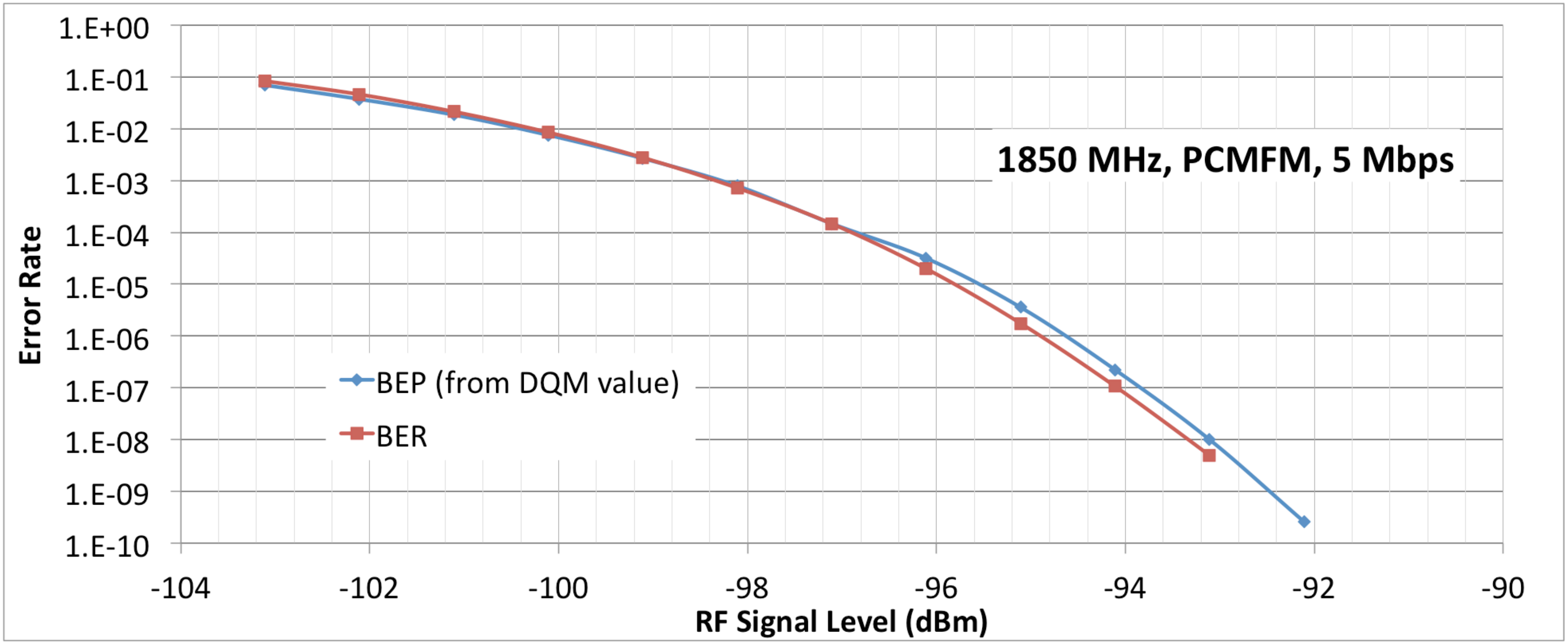
# DQM Calibration Fixture

- Synthesize “impaired” RF signal
- Recover the “corrupted” data (with clock)
- Extract the frame sync word, including DQM
- Measure BER of payload data
- Compare DQM (converted to BEP) to measured BER
    - Recorded and stored on a packet-by-packet basis



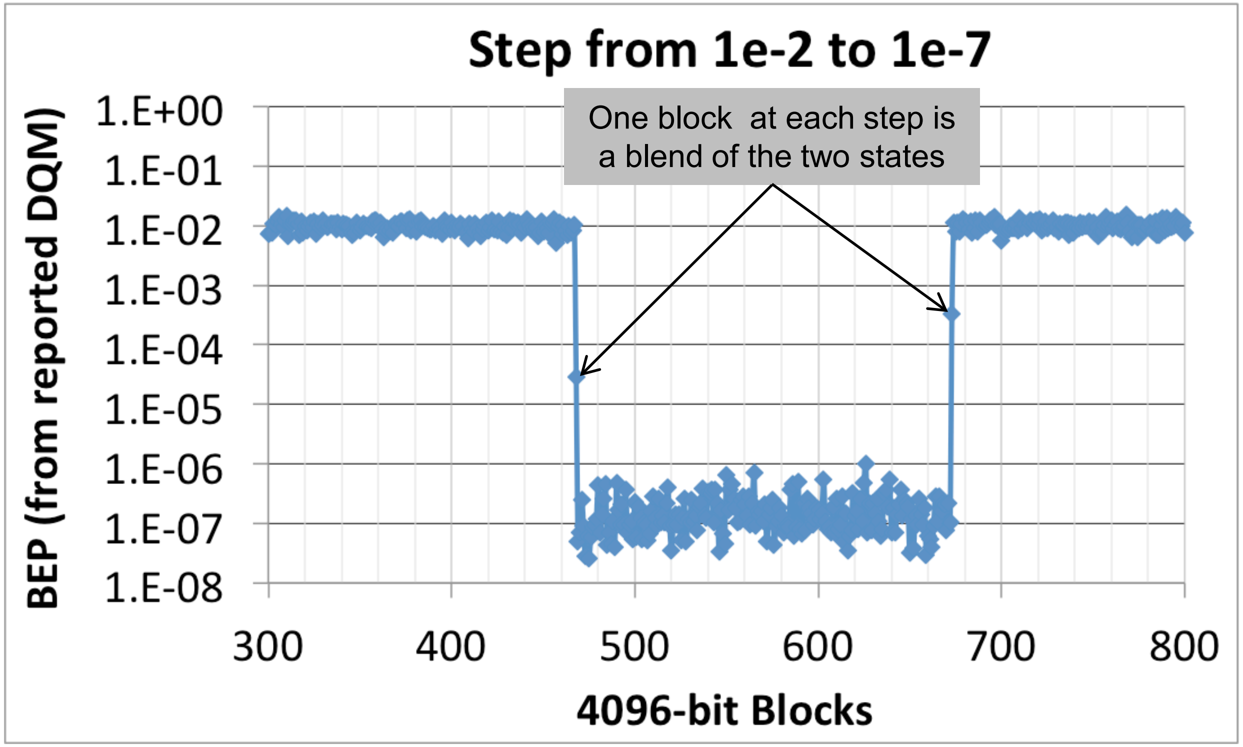
# DQM Calibration in AWGN

- Required as a baseline for all other tests



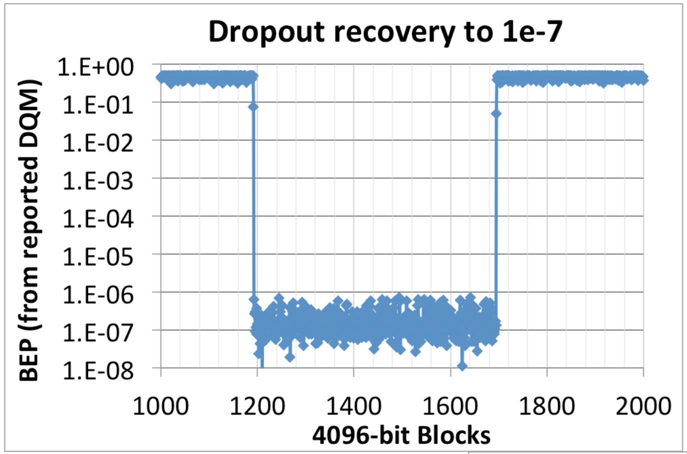
# DQM Step Response

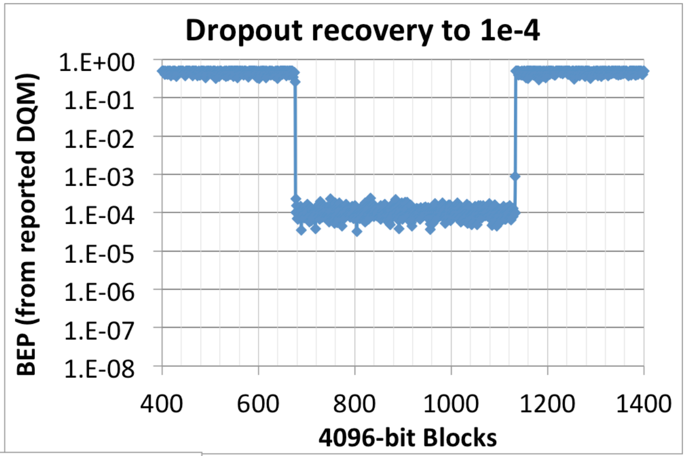
- Assesses timeliness of DQM values
- UUT stays synchronized during test

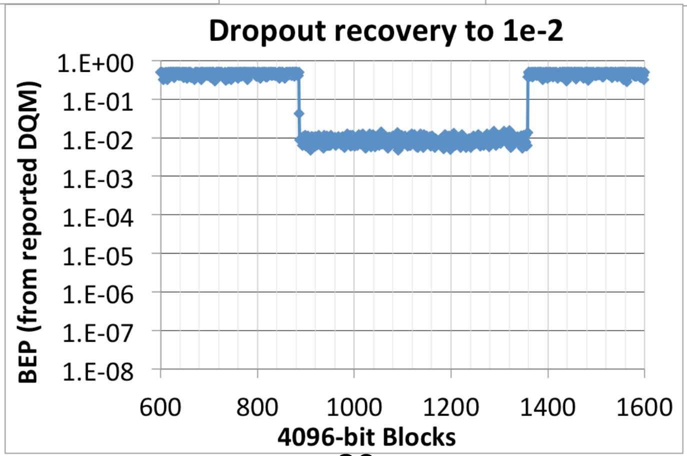


# DQM Fade Recovery

- Includes UUT synchronization time



# IRIG 118-22 Chapter 11

- First, DQE frame format must be correct

| 16 Bits | 12 Bits | 4 Bits | 16 Bits | 1024 – 16384 Bits |
|---|---|---|---|---|
| SW | RSV | VER | DQM | PAYLOAD |

a. SW = Sync Word. The sync word is a fixed value of 0xFAC4.

b. RSV = Reserved. Reserved for future use.

c. VER = IRIG 106 Version number.

d. DQM = Data Quality Metric.

e. PAYLOAD = Telemetry data payload to which the DQM value applies.

# IRIG 118-22 Ch. 11

- Defines 6 standard DQM tests

| Table 11-2. Test Matrix for Data Quality Metric Testing | |
|---|---|
| **Test Number** | **Test Description** |
| 11.1 | BER vs BEP with Additive Noise |
| 11.2 | DQM (BEP) Step and Dwell Response |
| 11.3 | BER vs BEP with Adjacent Channel Interference |
| 11.4 | BER vs BEP for Static 3-Ray Multipath Channel Conditions |
| 11.5 | BER vs BEP for Static 2-Ray Multipath Channel Conditions |
| 11.6 | DQM (BEP) Resynchronization Response |

# IRIG 118-22 Ch. 11

- Defines standard test fixture
- Each DQE frame must be scored individually

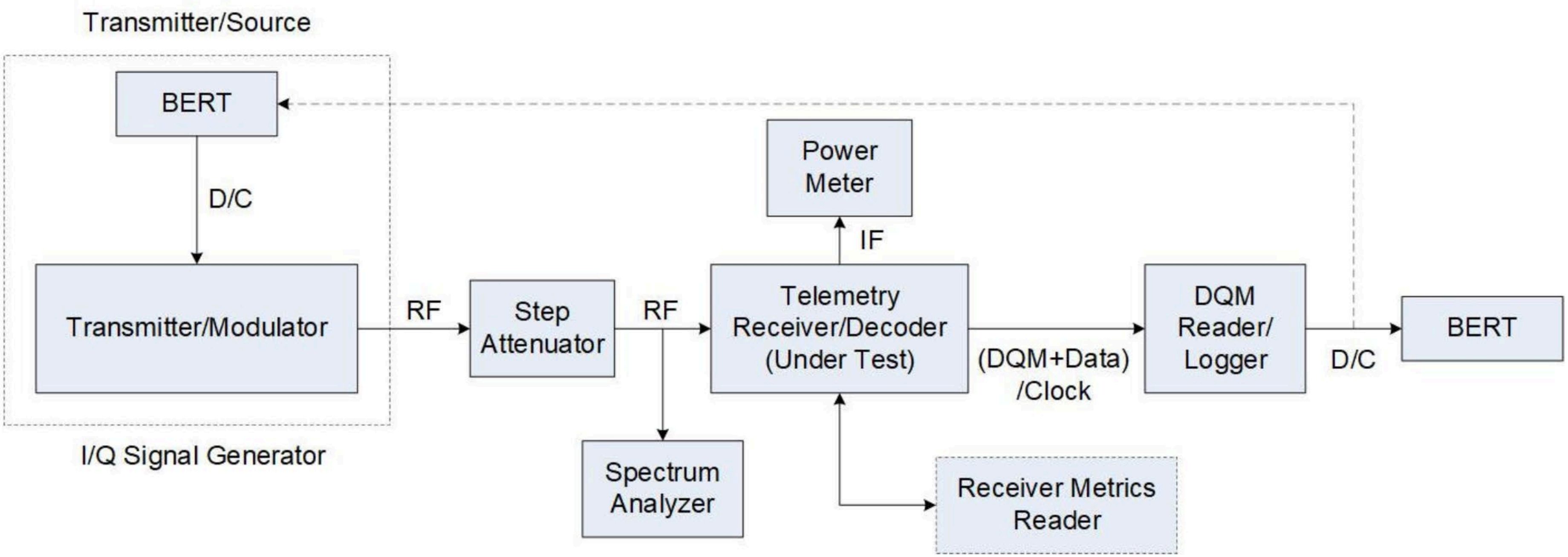
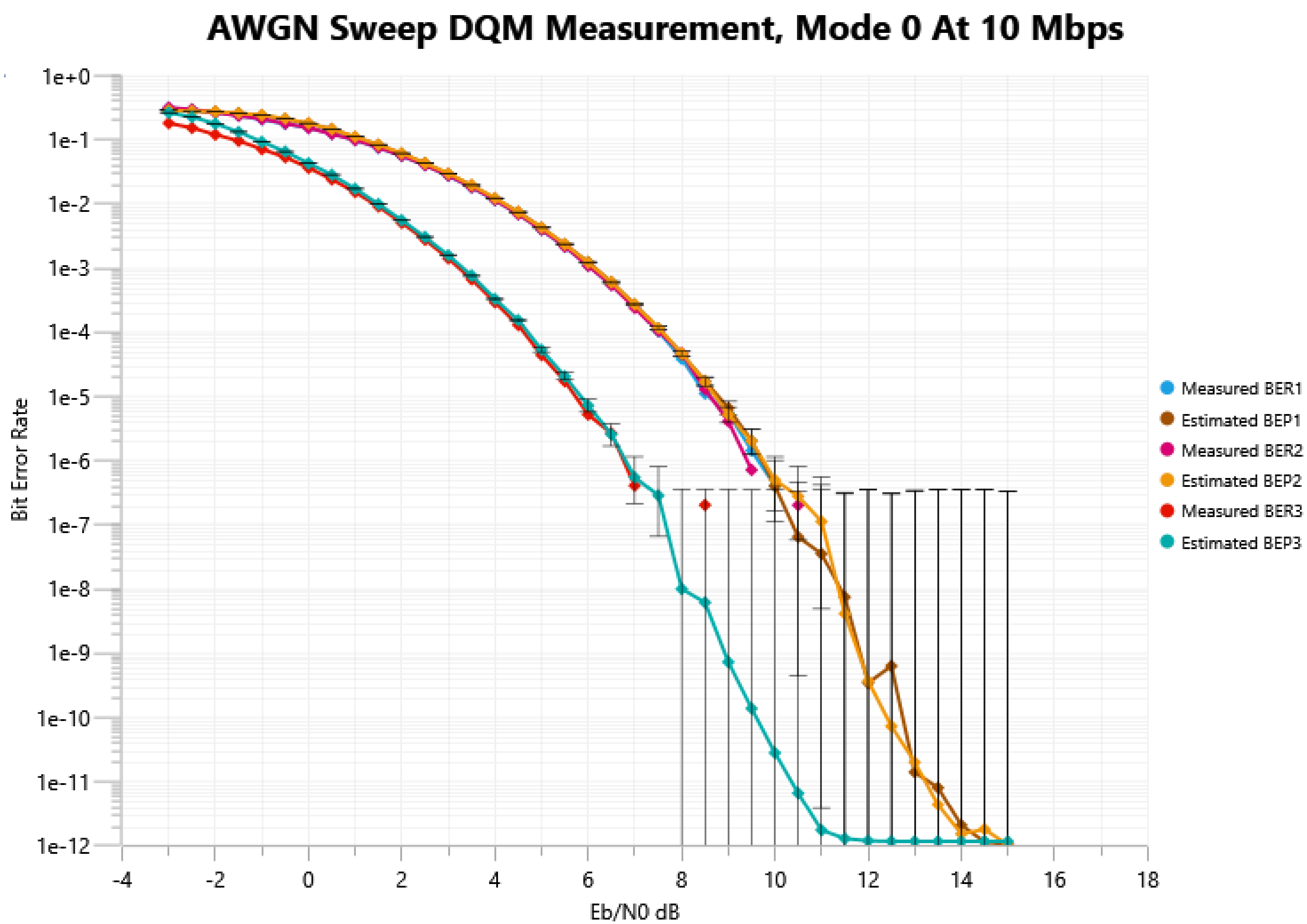
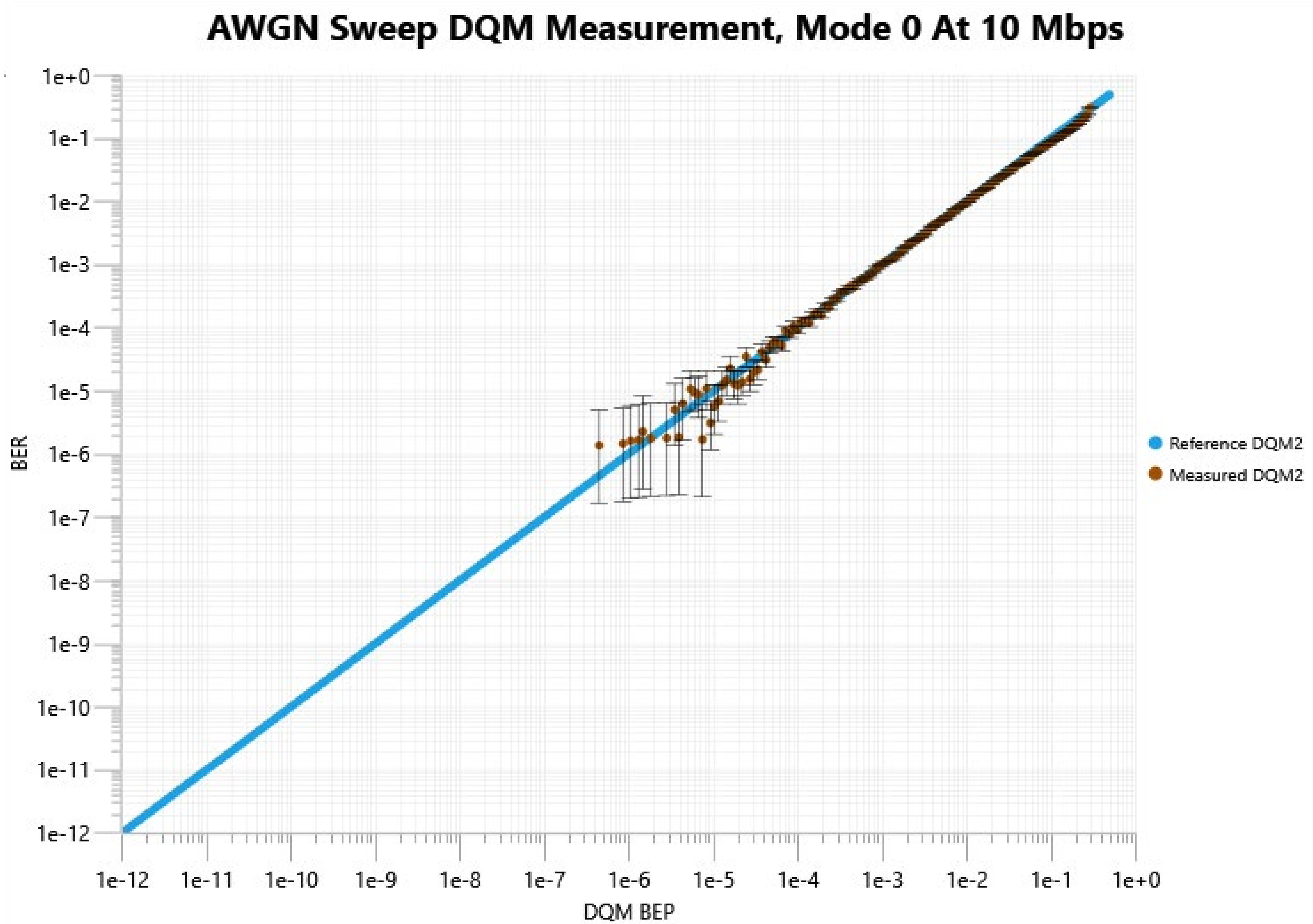



Figure 11-1. Setup for Step Attenuator/Power Meter for BER versus BEP Test

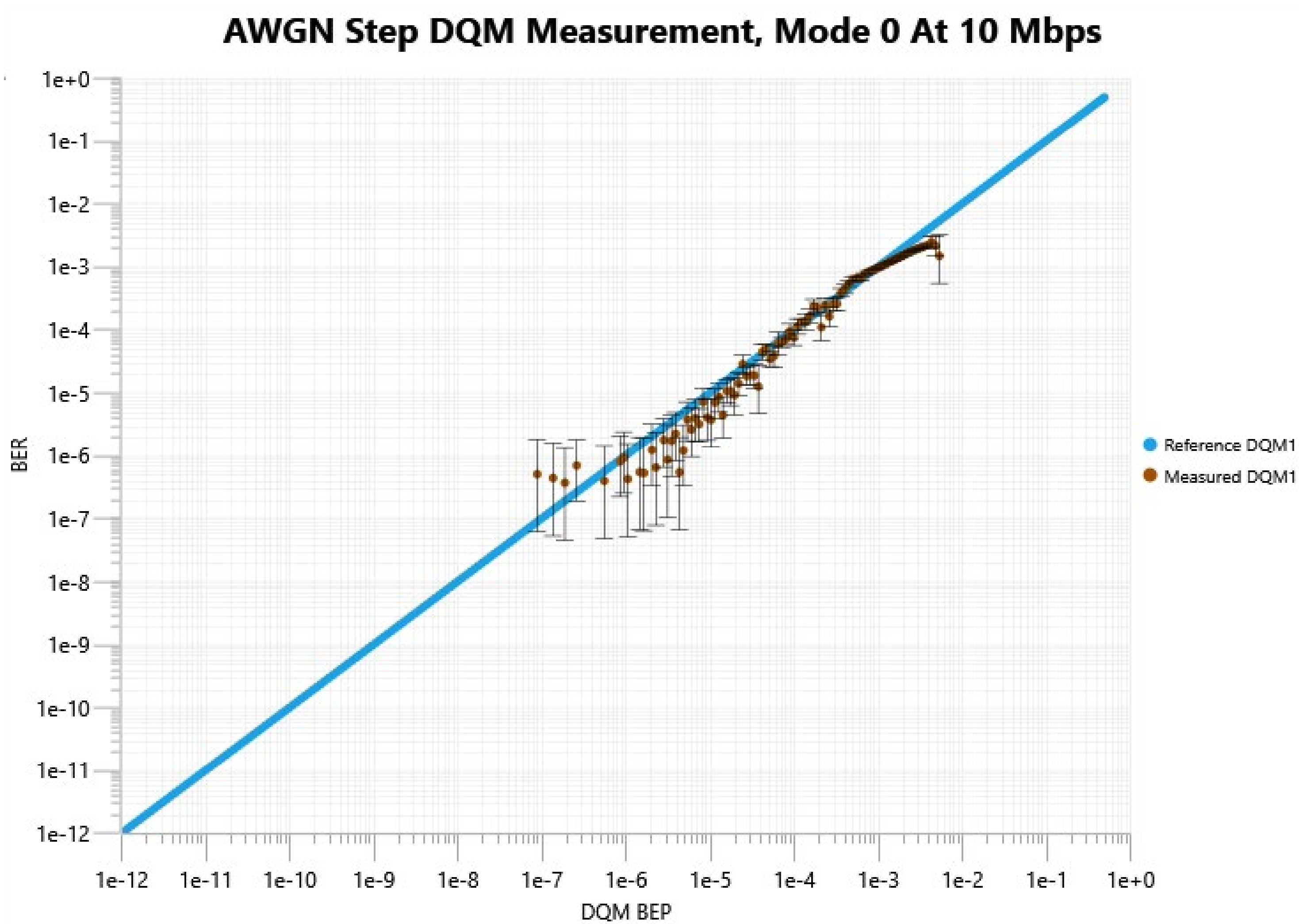
# Basic AWGN Sweep



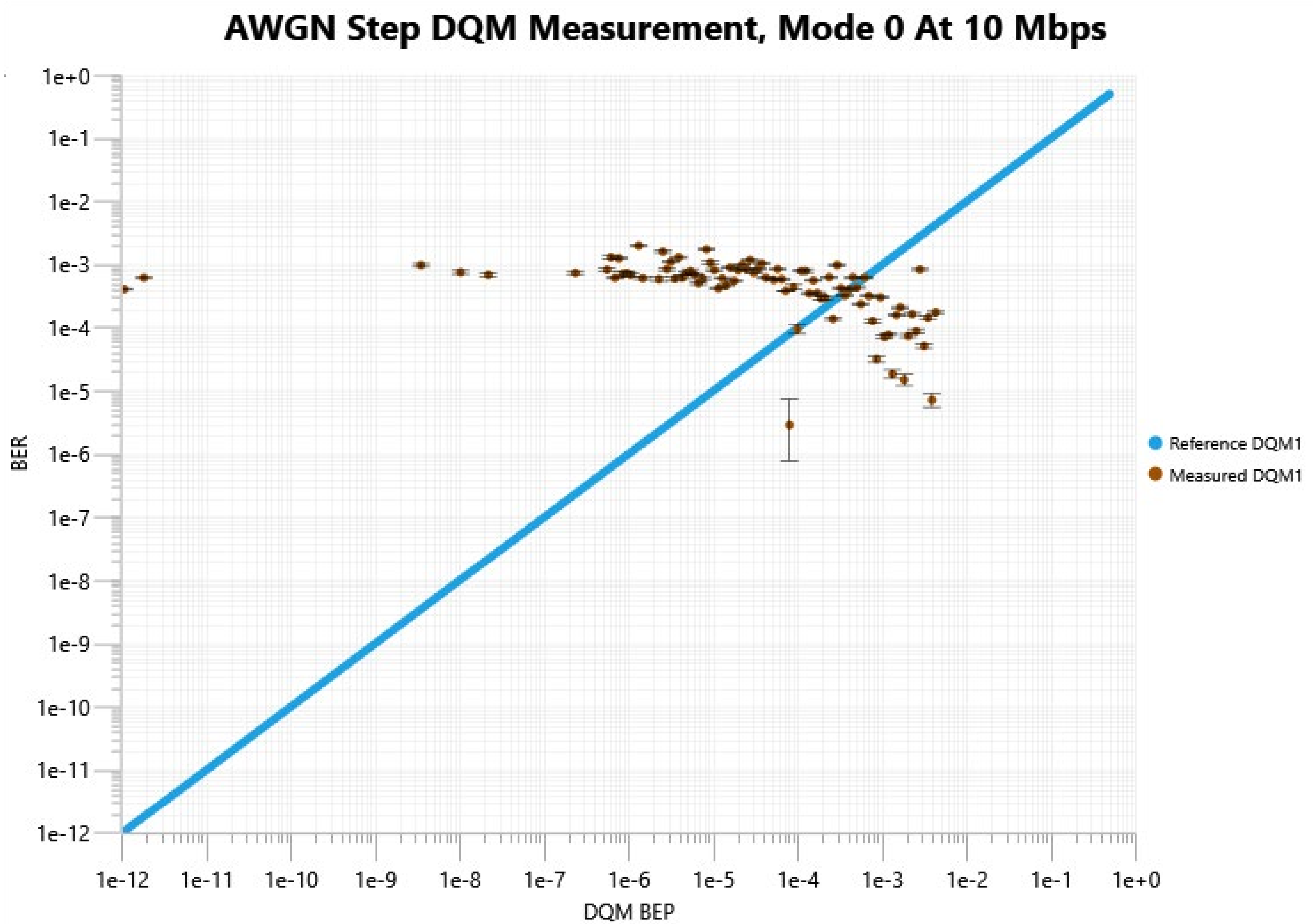
# Basic AWGN BER v. BEP



# Step AWGN BER v. BEP



# Not All DQMs are Created Equal







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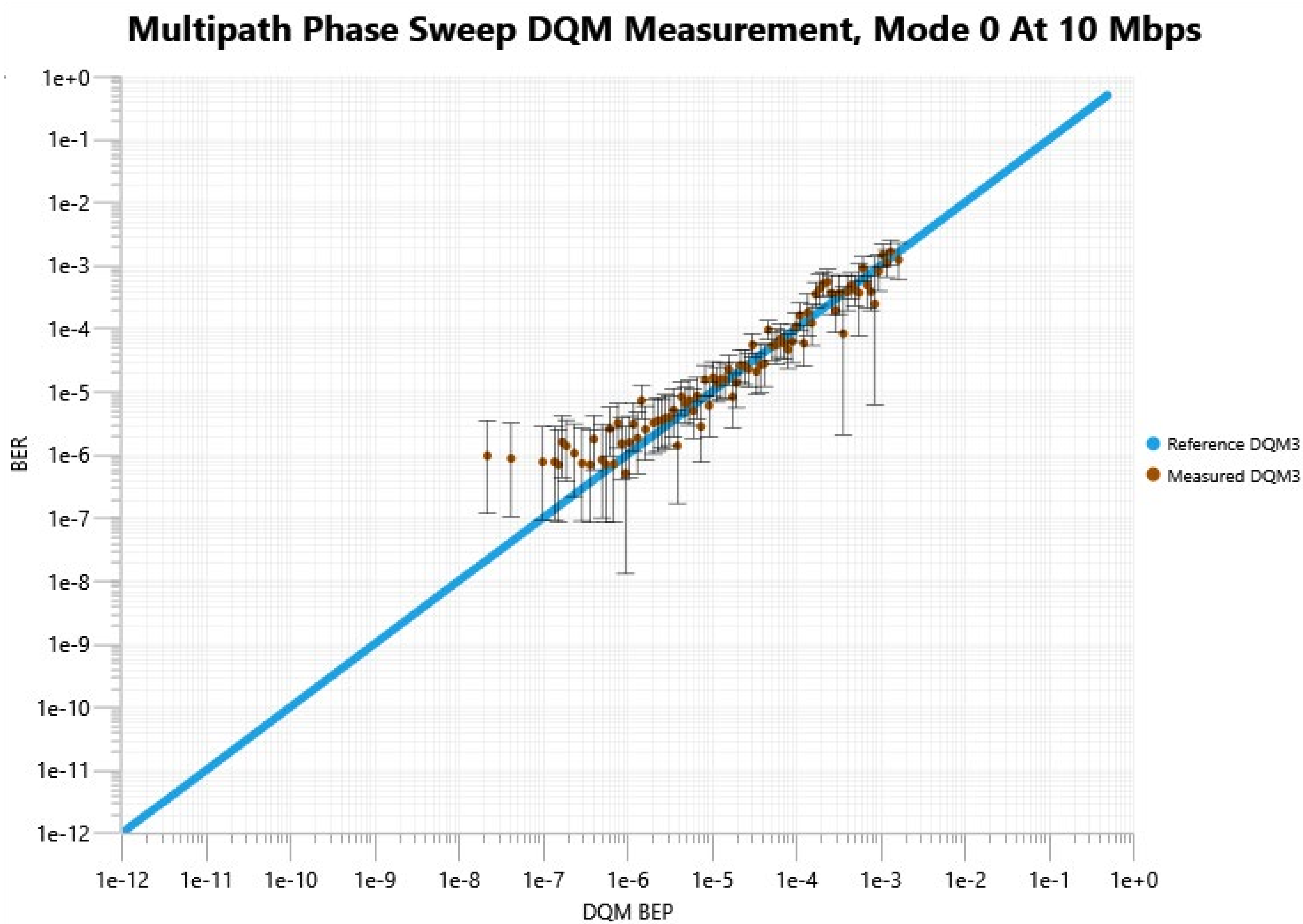
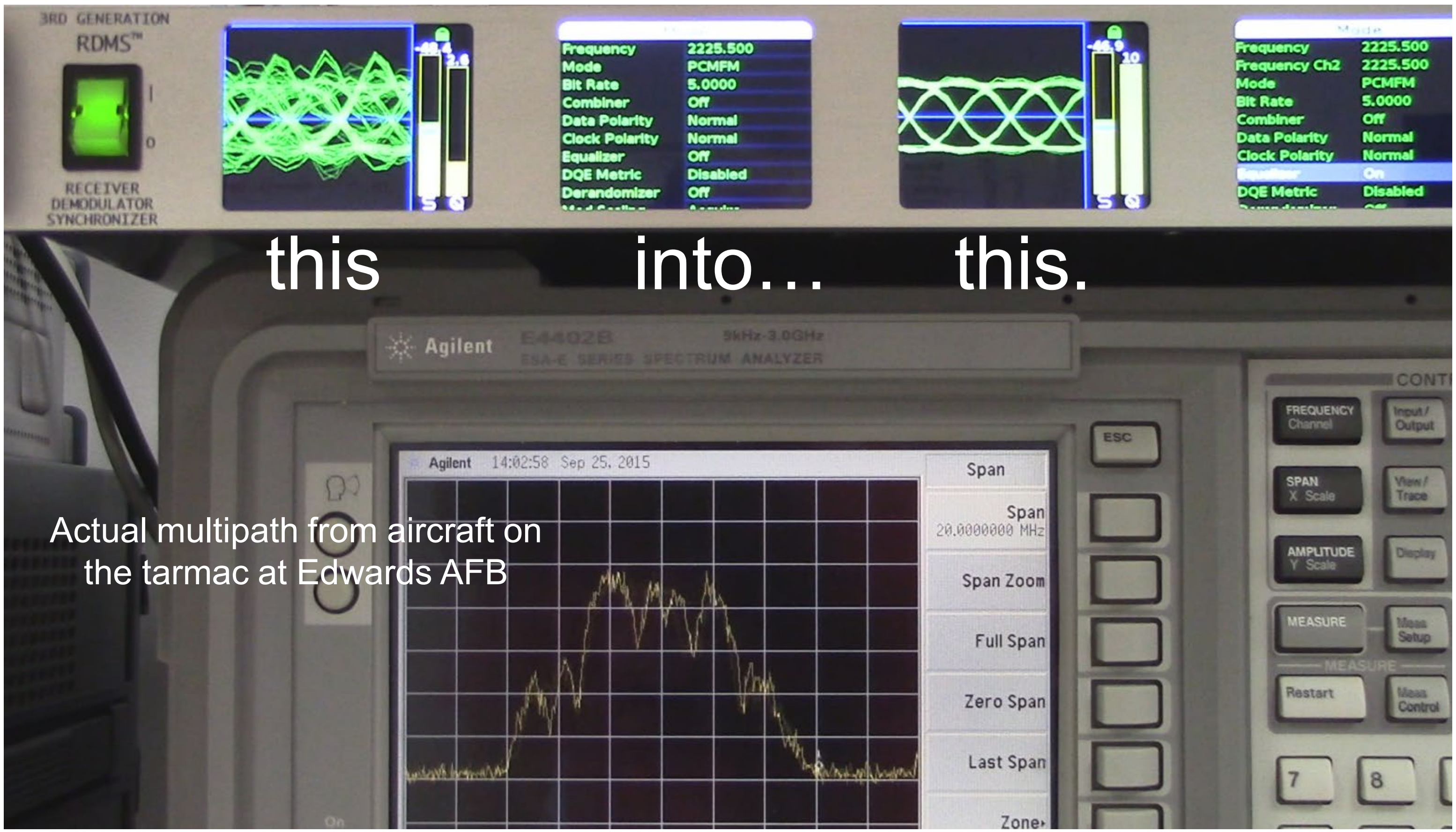
# BER v. BEP in Multipath



# Adaptive Equalization

# Multipath is Ugly

- Equalization can turn



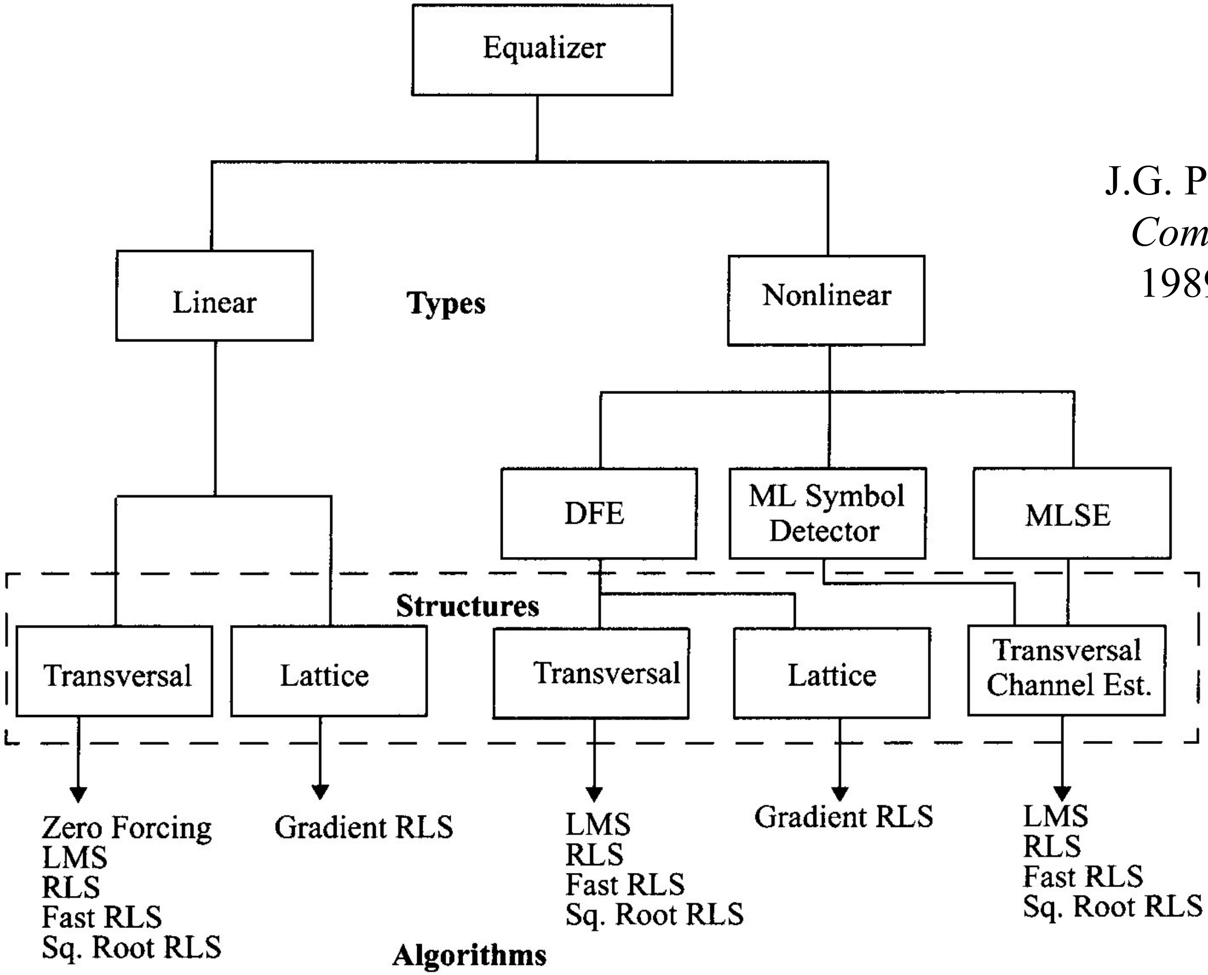

- this into… this.

Actual multipath from aircraft on the tarmac at Edwards AFB

# Adaptive Equalization

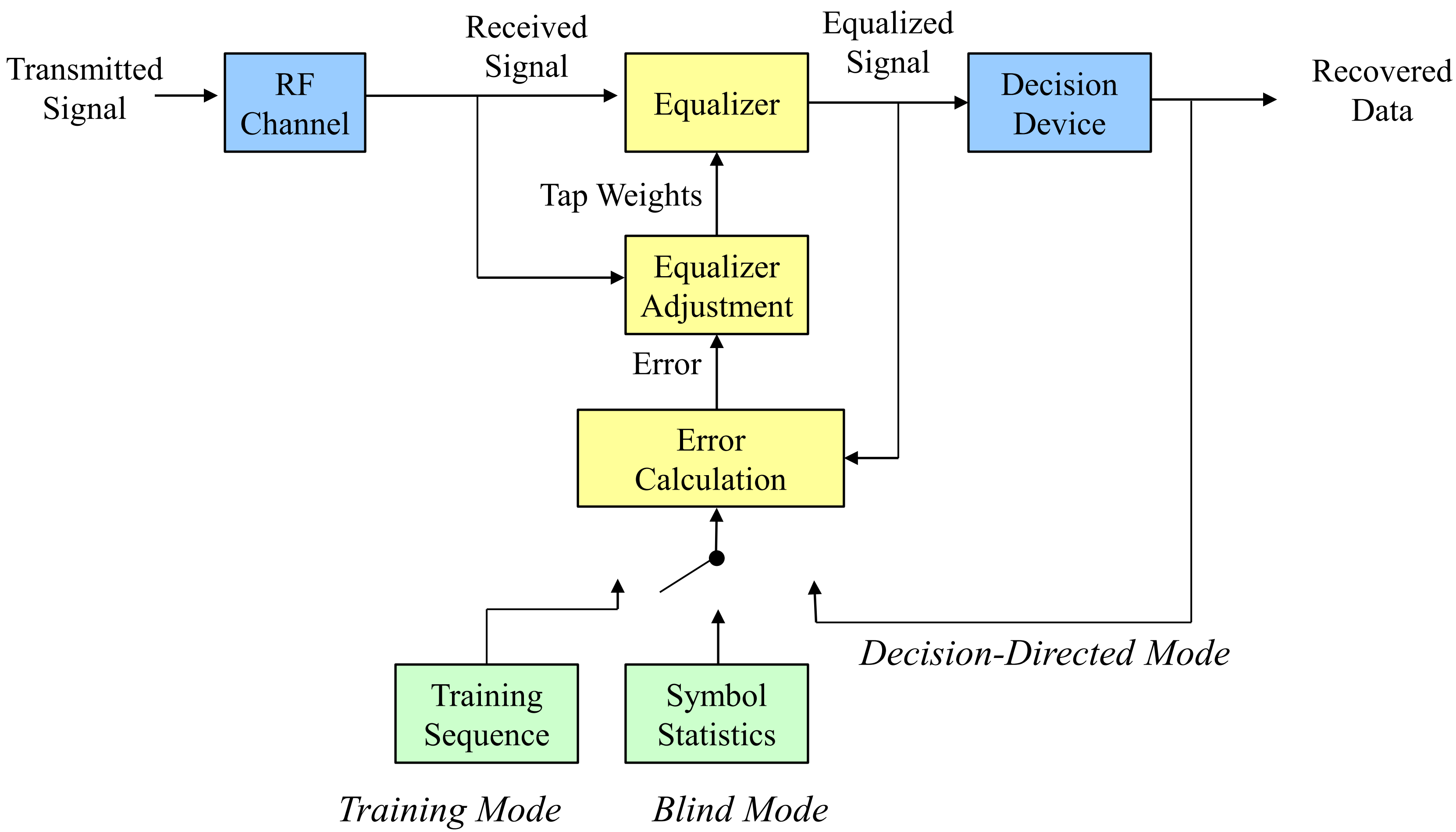
- Consider the multipath channel to be a filter
  - Varies over time
- Consider building a filter which “undoes” the filtering imposed by the channel
  - Let it keep track of the the channel and continuously adapt itself to the channel
- Presto!  You have an adaptive equalizer
  - Can repair damage done by multipath
  - Works with a single receiver
  - Requires no bandwidth expansion
  - Requires no changes to the transmitter

# Equalizer Techniques

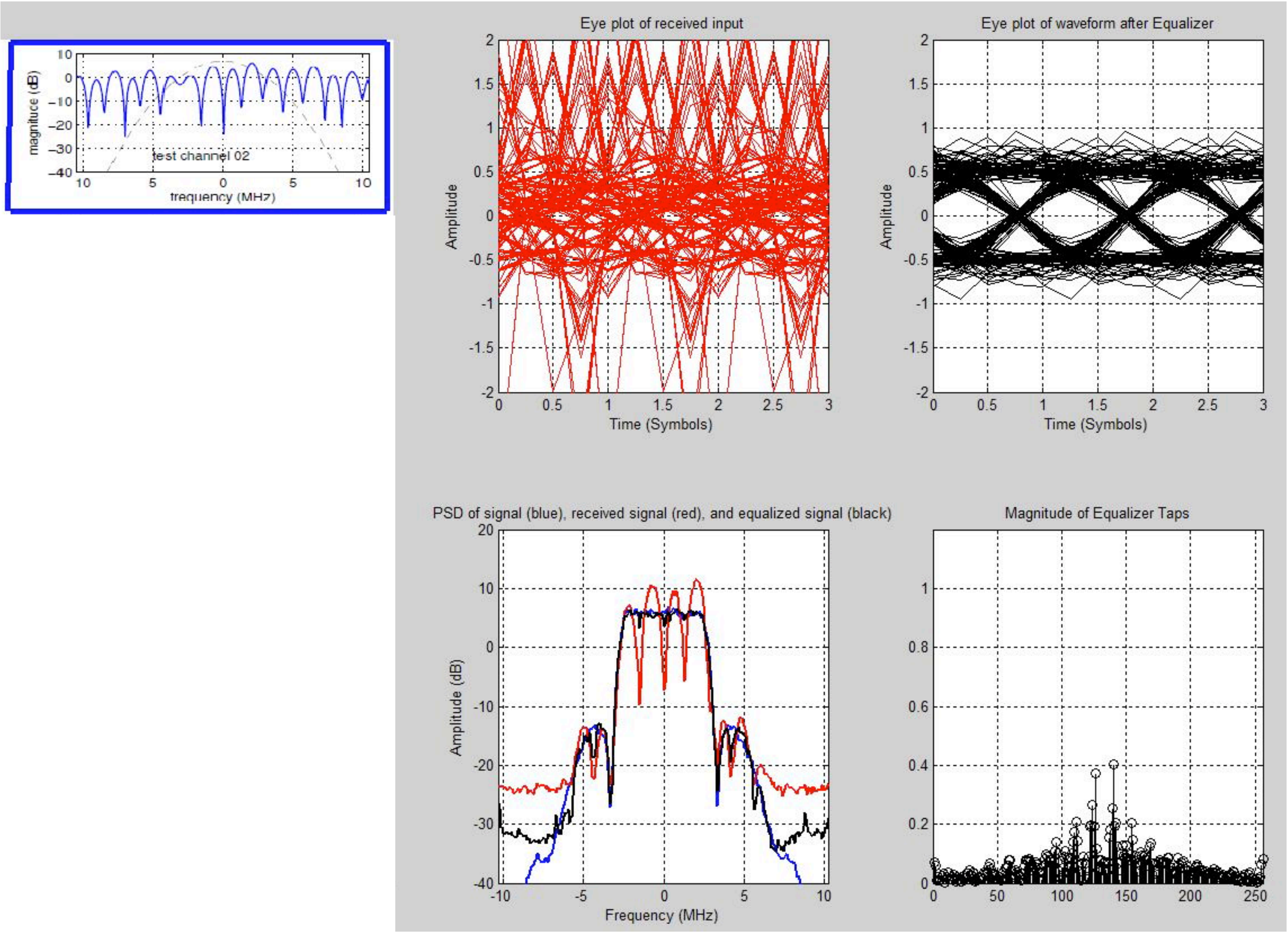



J.G. Proakis, *Digital Communications*. 1989 2nd Edition

# Generic Adaptive Equalizer



# Equalizer Adaptation



# Adaptive Equalizer in Action

# Adaptive Equalizer Summary

- Adaptive equalizer can “undo” multipath distortion
- Requires no changes at the transmit end
    - If available, a training sequence can be helpful
- Effectiveness of equalizer depends on the severity of the multipath
- Well-designed equalizers monitor their own performance, and disengage when they are doing badly.
    - This must be done without losing bit count integrity
- If you have multipath, use an equalizer!

# Performance Evaluation of Adaptive Equalizers

# So Many Channels…

- Each path is characterized by
  - Delay
  - Amplitude
  - Phase shift (potentially time-varying)
- 2, 3, or more paths
- Modulation matters
- SNR matters
- Need a 10-dimensional universe to plot the results
- Way too many test points

# Let's Simplify

- Stick to 2-ray model
  - Easy to synthesize
  - Still allows a range of channels from easy to impossible
  - Maybe we add a third ray for a limited set of tests
- Stick to one SNR
  - High enough that the equalizer works on mitigating multipath, not rejecting noise
  - Not so high that there are never any bit errors
  - Should reflect actual use cases
  - Propose 20 dB
- Limited set of amplitudes and delays
- Many phase angles

# Proposed Signal Conditions

- Pick a carrier frequency
  - How many?
  - Nulls “sweep faster” at higher frequencies (dynamic case only)
- 20 dB SNR (without multipath)
- Tier 0, I, and II
  - Tier 0: 1, 5, 10, 20 Mbps
  - Tier I and Tier II: 2, 10, 20, and 40 Mbps
- Areas for further research
  - STC – different multipath on each signal, hmmm….
  - LDPC – six codes?

# Proposed *Static* Channels

- Channel response depends on
  - Carrier frequency, $\omega_c$
  - Delay, $\tau_1$
  - Reflection amplitude, $|\Gamma_1|$
  - Reflection phase, $\angle\Gamma_1$
- Delays (in bits) of 0.5, 1, 2, 5, 10, 20, and 50
  - Delays much shorter than 0.5 bit are essentially flat fades, where the signal power is simply gone. EQ cannot help.
- Amplitudes of 0.5 to 0.9 in steps of 0.1
  - For bonus points, include 0.95 and 0.98
- Phases of 0° to 360° in 10° steps

# What is the Measured Value?

- Must be observable with EQ both on and off
- Bit error rate is universally understood
- DQM is readily computed from BER
  - With calibration, DQM is much more quickly measured
- Remind me again, what is DQM?

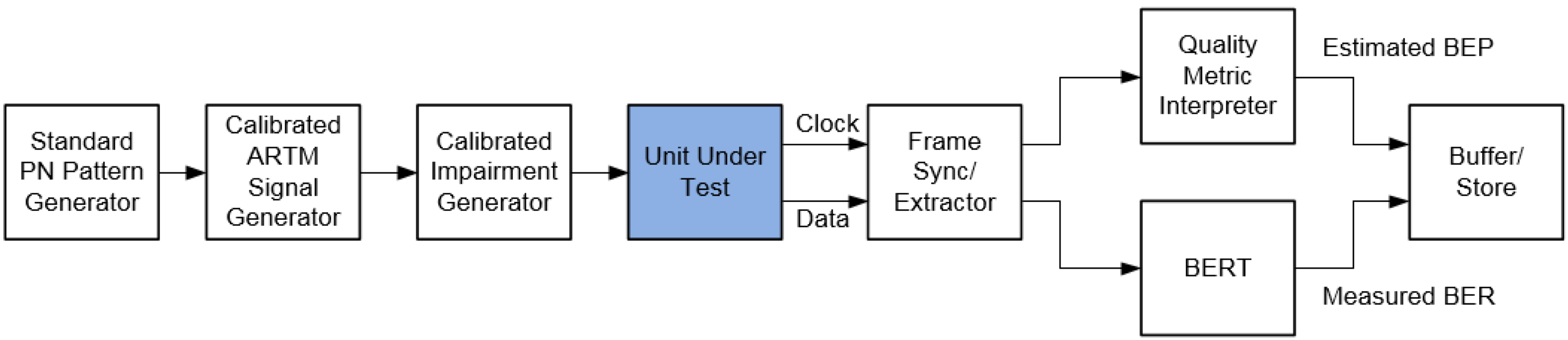
# Definition of DQM (a.k.a. Q)

- To a statistician, DQM is the “Log Likelihood Ratio”
- Start with probability of error, P
  - Be practical: 0.5 < P < 1e-12
  - BEP, derived within demod
  - BER, measured with a BERT
- Likelihood Ratio (LR) = P / (1 – P)
- $Q = \min(-\log_{10}(LR), 12)$
- Easily reversed:
  - $P = 10^{-Q} / (1 + 10^{-Q})$
- Short version
  - Q = 5 ➔ P = 1e-5

| P | Q |
|---|---|
| 0.5 | 0.000 |
| 1E-01 | 0.954 |
| 1E-02 | 1.996 |
| 1E-03 | 3.000 |
| 1E-04 | 4.000 |
| 1E-05 | 5.000 |
| 1E-06 | 6.000 |
| 1E-07 | 7.000 |
| 1E-08 | 8.000 |
| 1E-09 | 9.000 |
| 1E-10 | 10.000 |
| 1E-11 | 11.000 |
| 1E-12 | 12.000 |

# DQM Calibration Fixture

- Synthesize “impaired” RF signal
- Recover the “corrupted” data (with clock)
- Extract the frame sync word, including DQM
- Measure BER of payload data
- Compare DQM (converted to BEP) to measured BER
  - Recorded and stored on a packet-by-packet basis



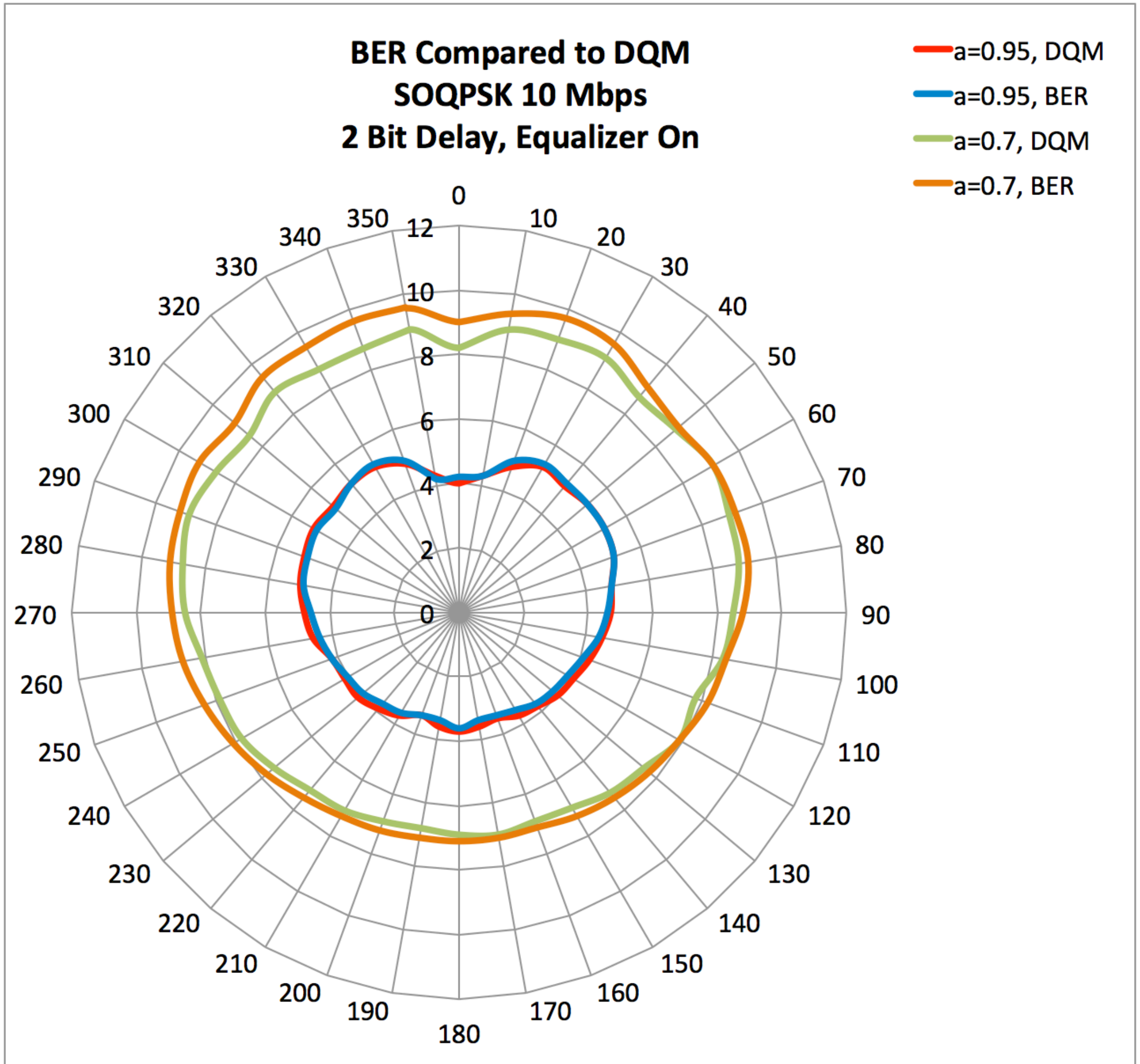
# Test Procedure

- Set frequency, modulation, and bit rate
- Turn the equalizer off
- Set $E_b/N_0$ to 20 dB
- Set direct path to delay 0, amplitude 1, angle 0
- Enable multipath
- Set reflected path delay and amplitude
- Loop through delayed path phase
  - 0 degrees to 360 degrees in 10 degree steps
  - Record DQM at each step, or record BER and calculate DQM
  - Plot DQM versus phase in polar form
- Turn equalizer on and repeat
  - If two test units are available, test EQ on and EQ off at the same time

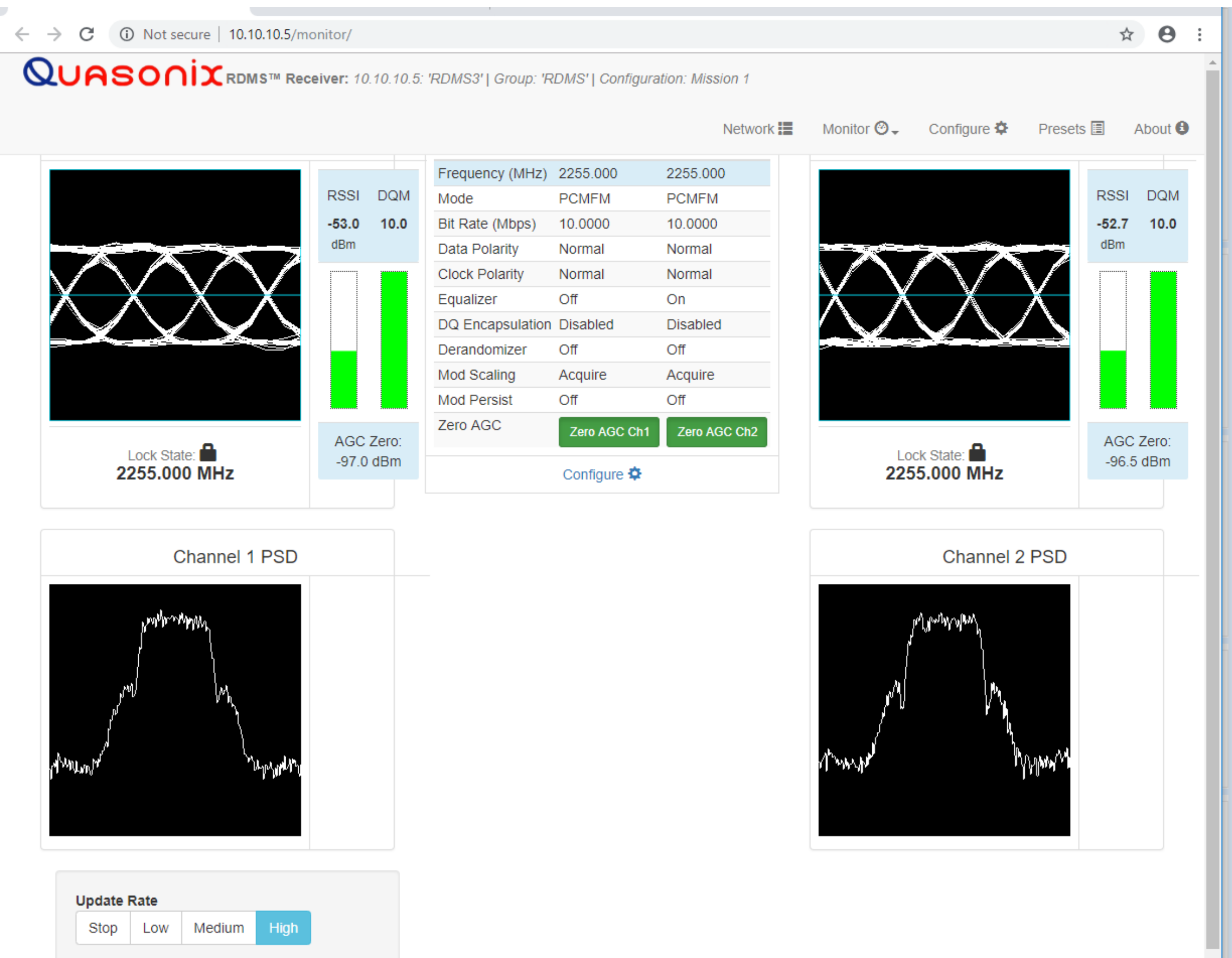
# Grading the Tests

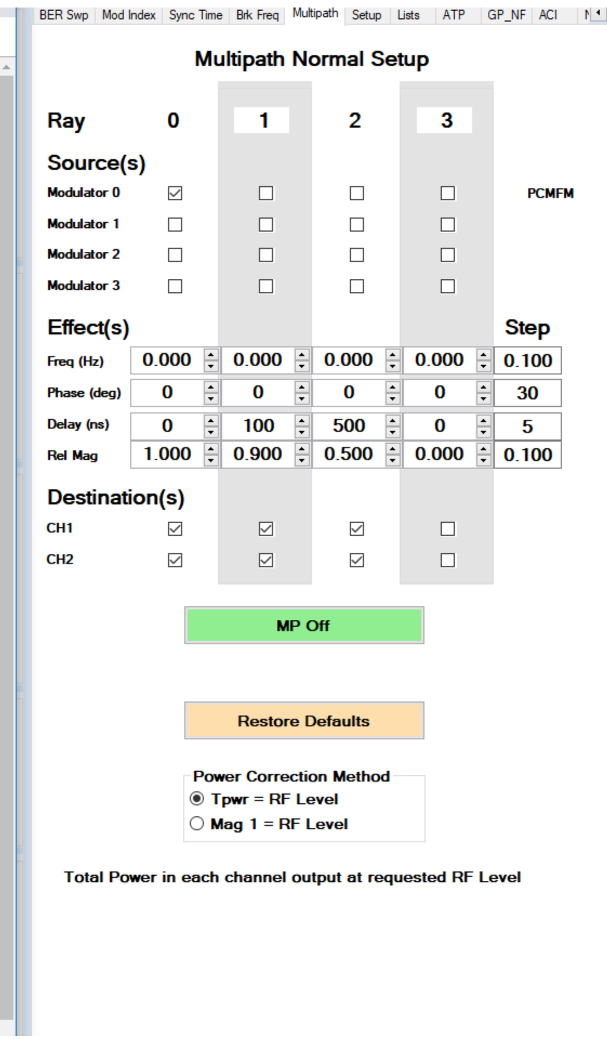
- Measure BER with EQ on and off, then compute DQM
  - If your DQM is well calibrated, measure DQM directly
- Plot DQM vs. delay path phase, in polar form
  - Radius = DQM
  - Angle = phase of delayed path
- Result will be a distorted “hoop”
  - Bigger radius is better
  - Some angles will be worse than others
- Compute the area of each “hoop” for EQ on and off
- “Equalizer Benefit” = $\text{Area}_{on} - \text{Area}_{off}$
  - Since the radius is (essentially) the logarithm of the BER, the difference is the number of orders of magnitude improvement in BER

# DQM Calibration

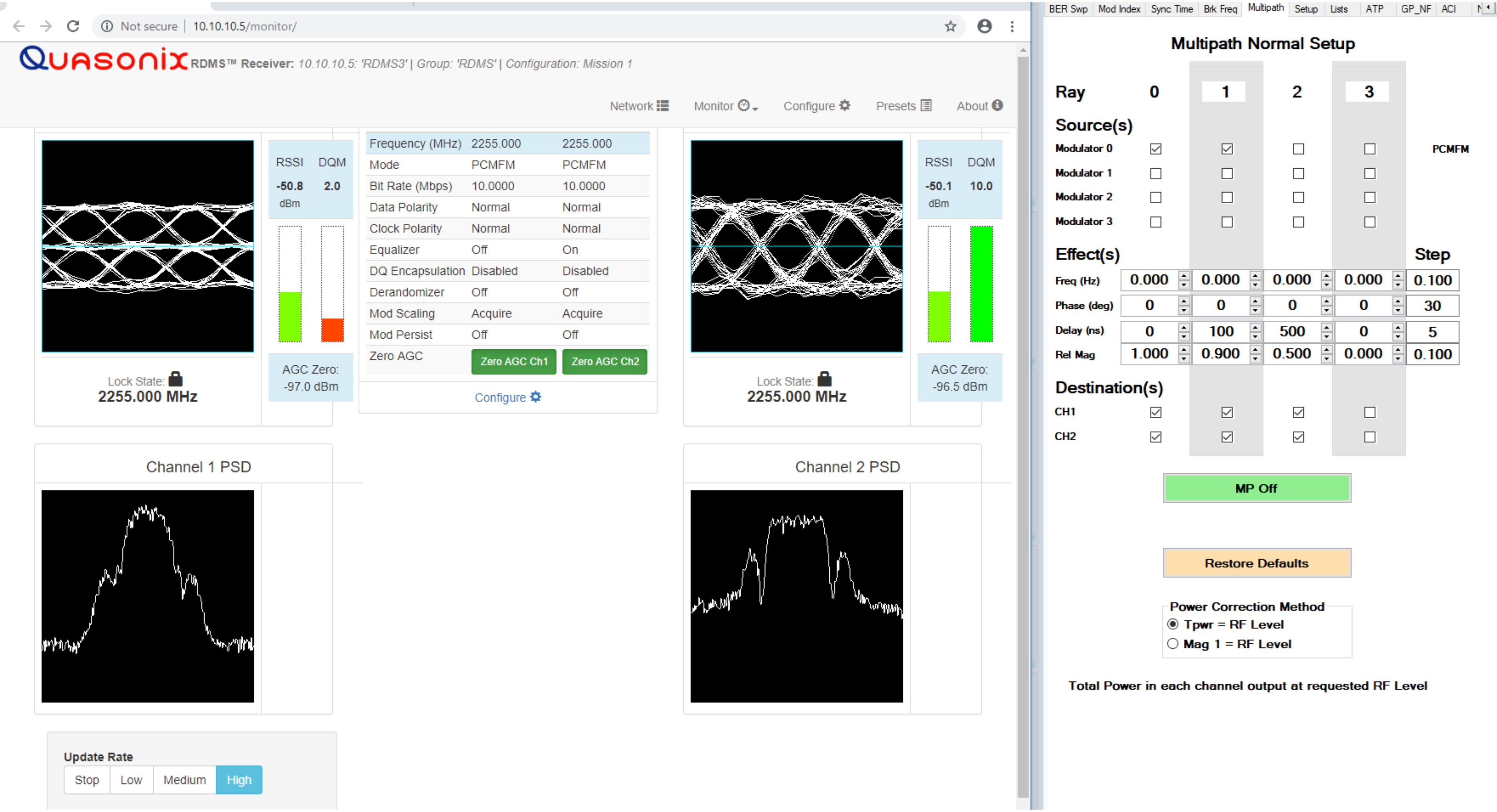


# No Multipath, No Problem



# 0-100-0.9



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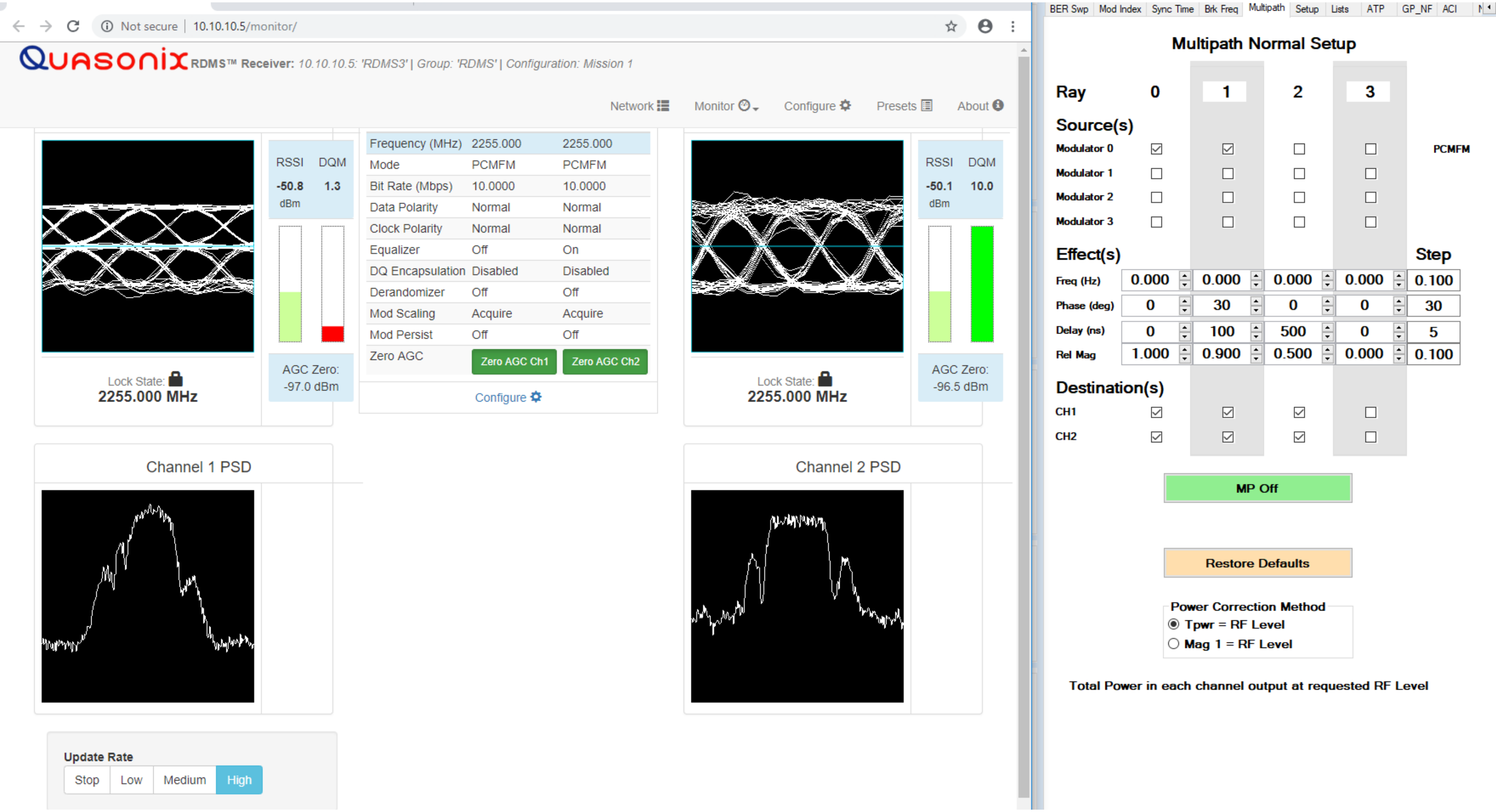
# 30-100-0.9



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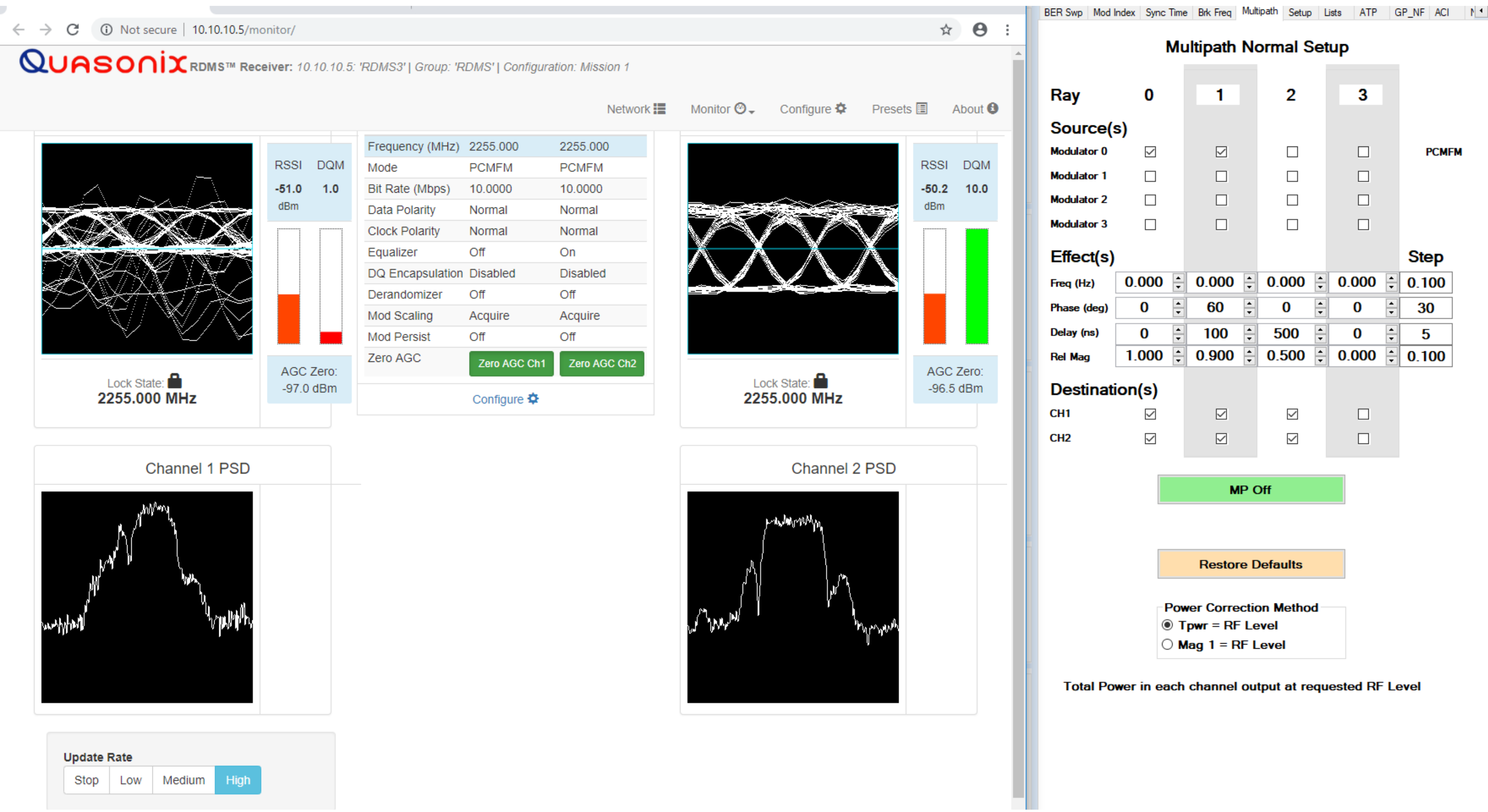
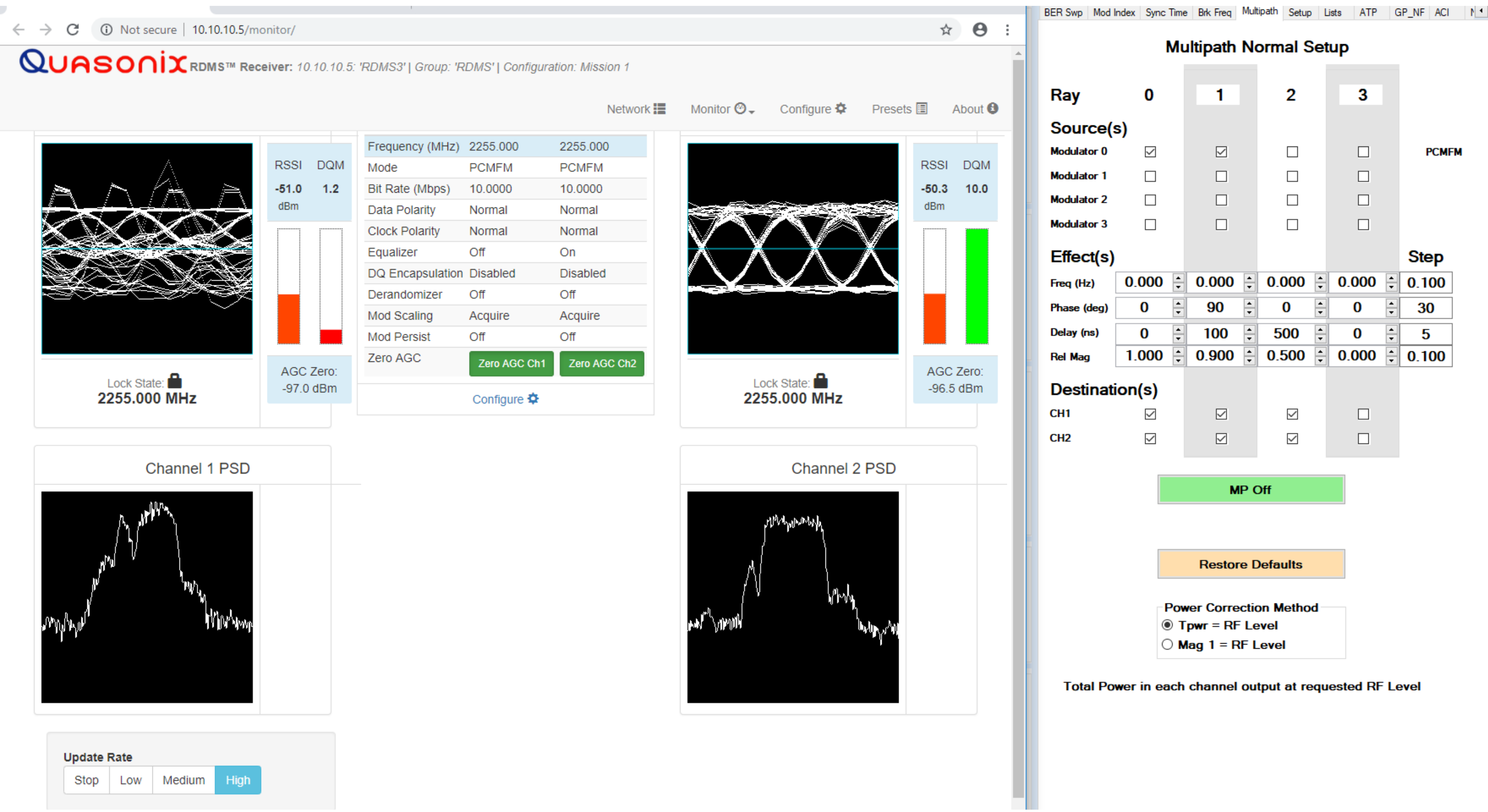
Terry Hill - thill@quasonix.com

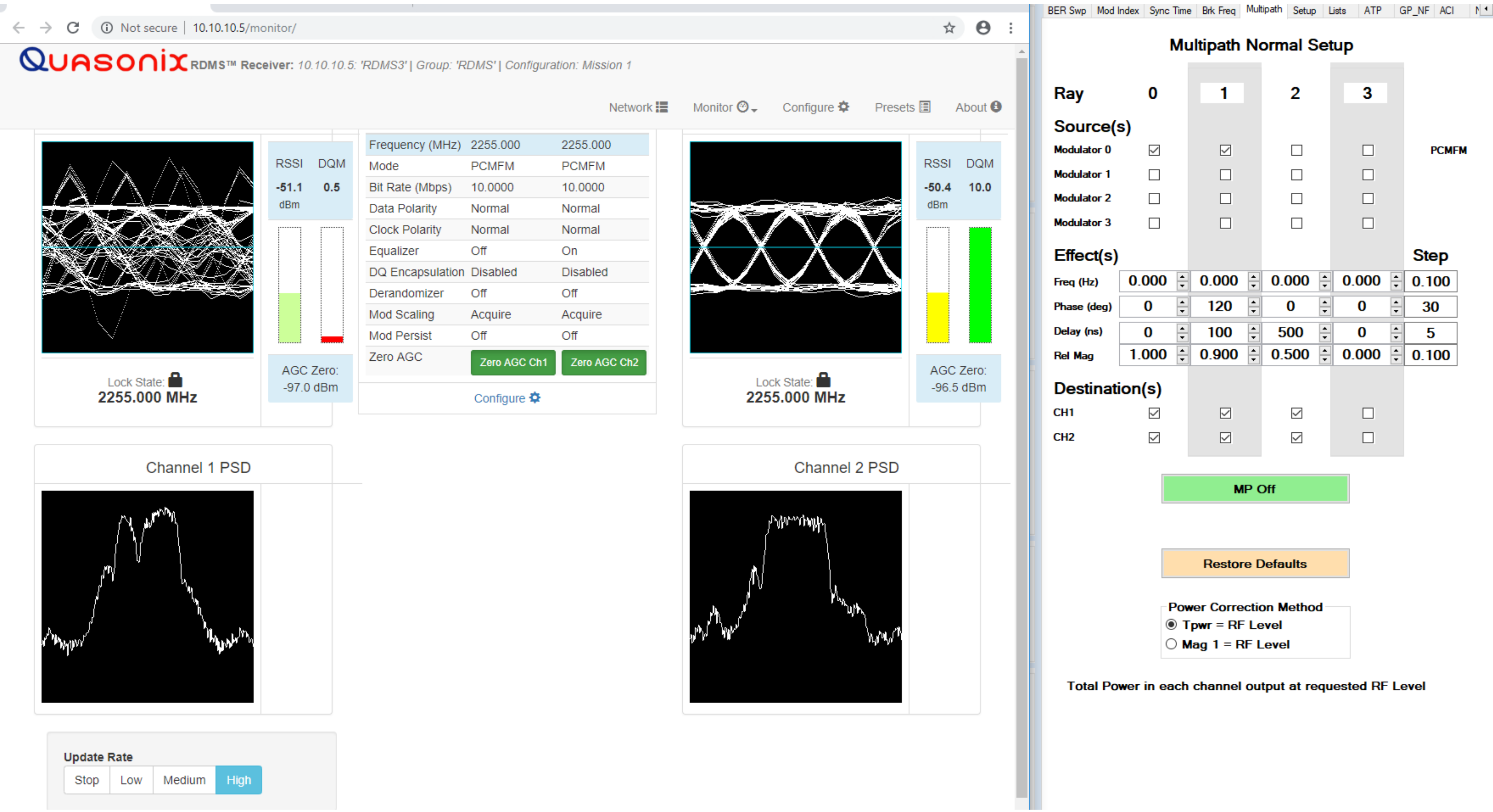
# 60-100-0.9


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 1.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 60 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 90-100-0.9

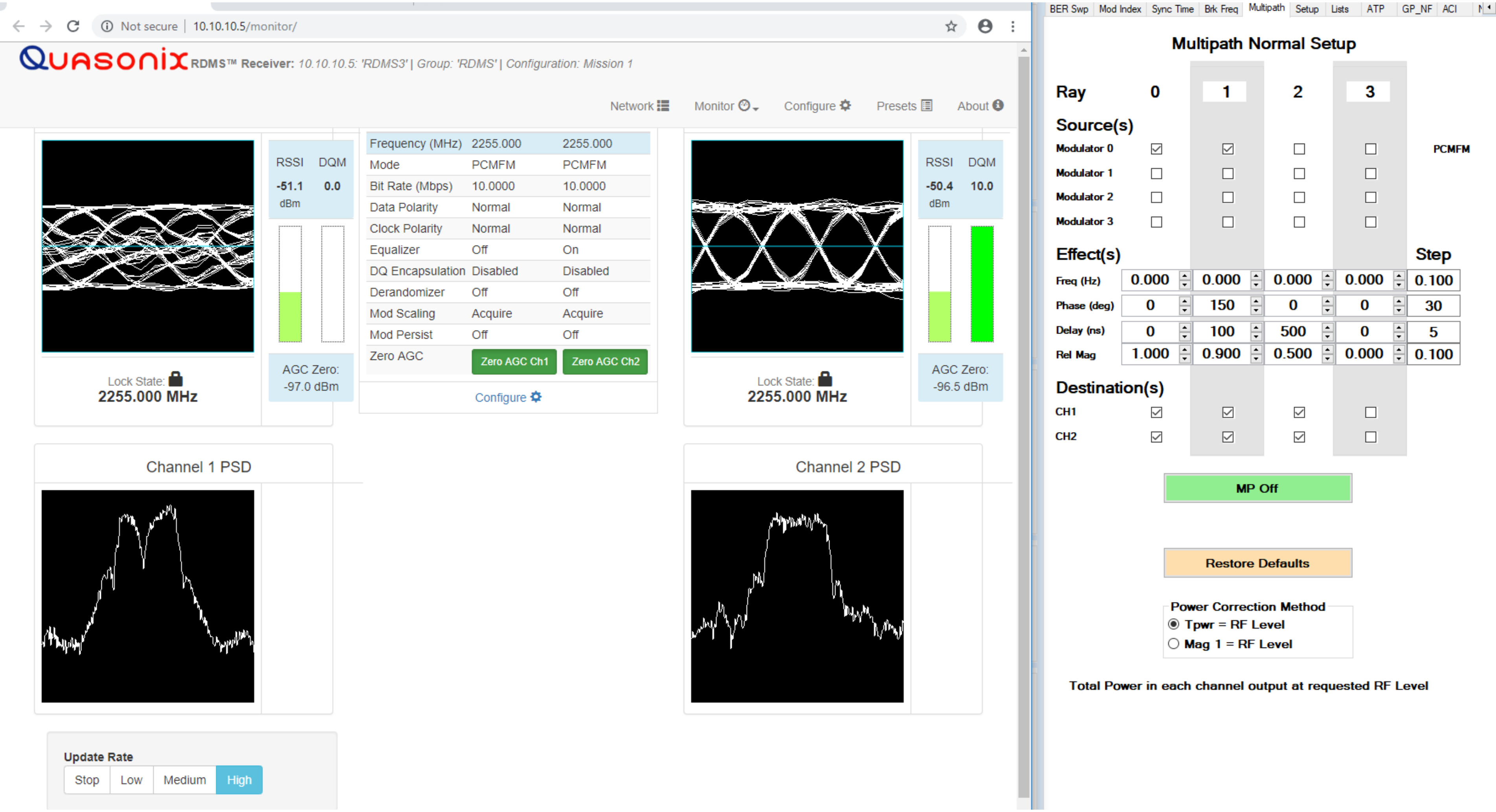

Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 1.2
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.3 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
PCMFM
Modulator 1
Modulator 2
Modulator 3
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 90 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 120-100-0.9

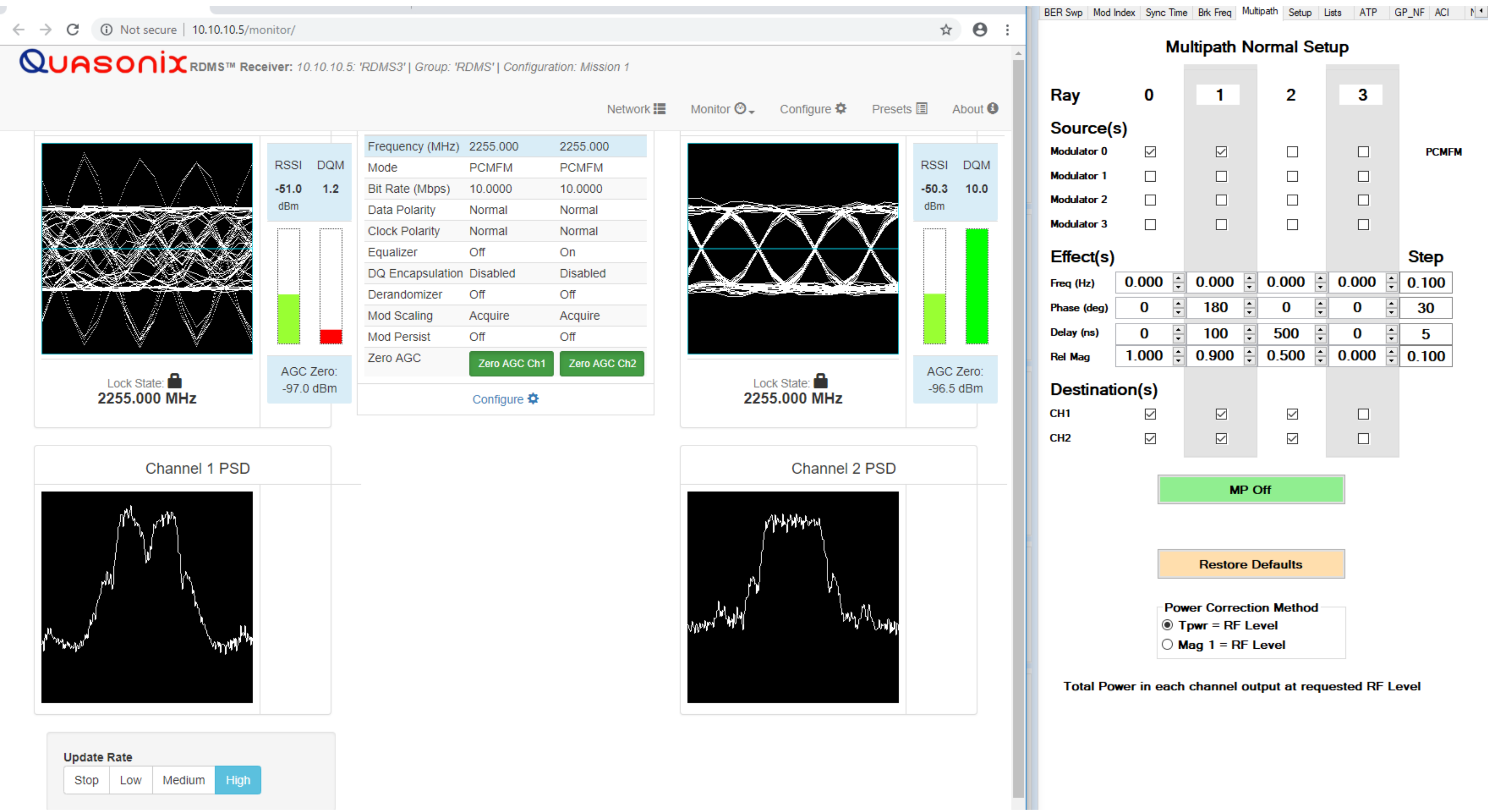


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.1 0.5
dBm
AGC Zero:
-97.0 dBm
Lock State:
2255.000 MHz
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.4 10.0
dBm
AGC Zero:
-96.5 dBm
Lock State:
2255.000 MHz
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 120 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

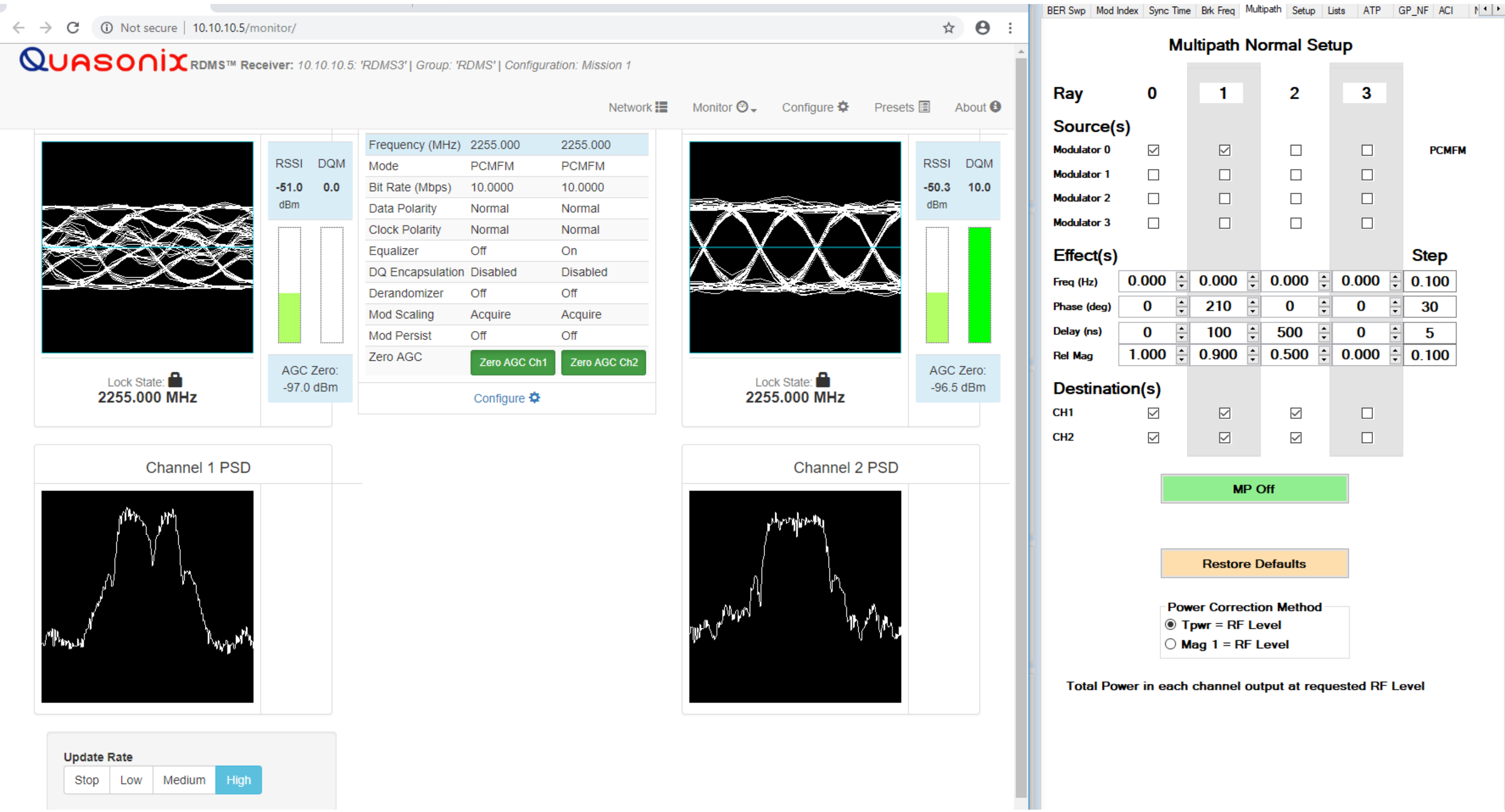
# 150-100-0.9


Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.1 0.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.4 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 150 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-100-0.9

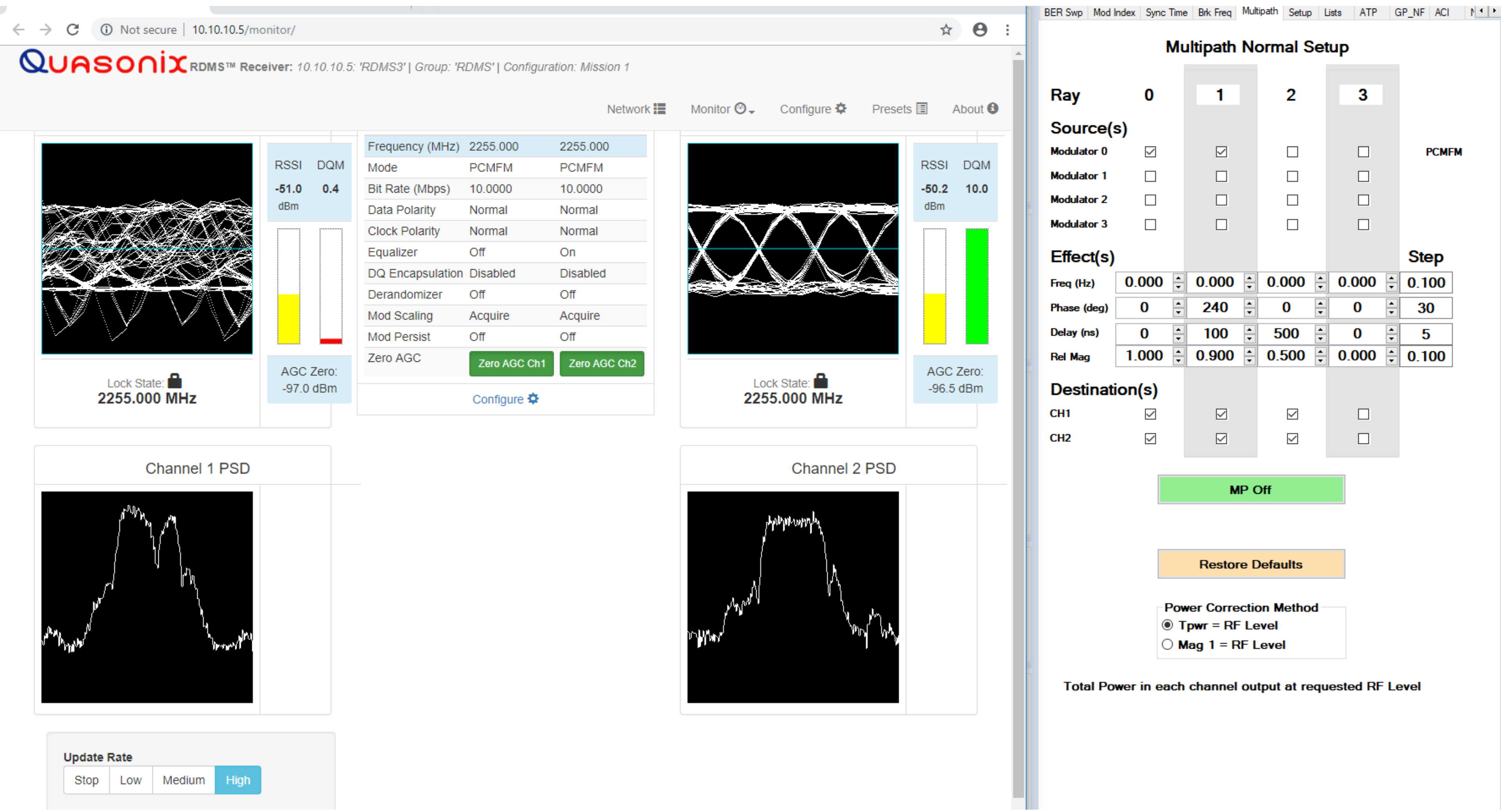

Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network Monitor Configure Presets About
RSSI DQM
-51.0 1.2
dBm
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC Zero AGC Ch1 Zero AGC Ch2
Configure
RSSI DQM
-50.3 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero: -96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s) Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 210-100-0.9

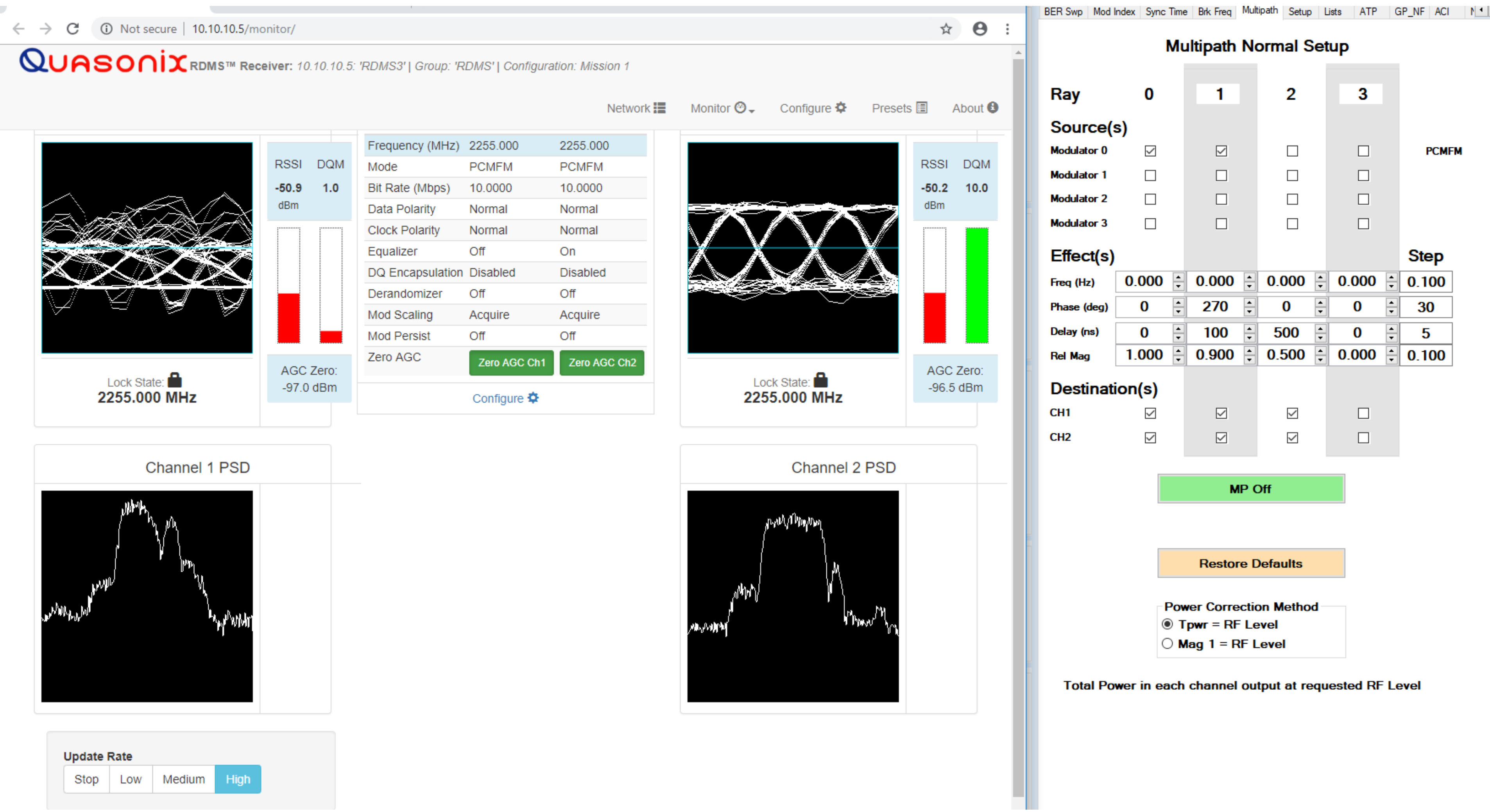


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network Monitor Configure Presets About
RSSI DQM
-51.0 0.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC Zero AGC Ch1 Zero AGC Ch2
Configure
RSSI DQM
-50.3 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s) Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 210 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

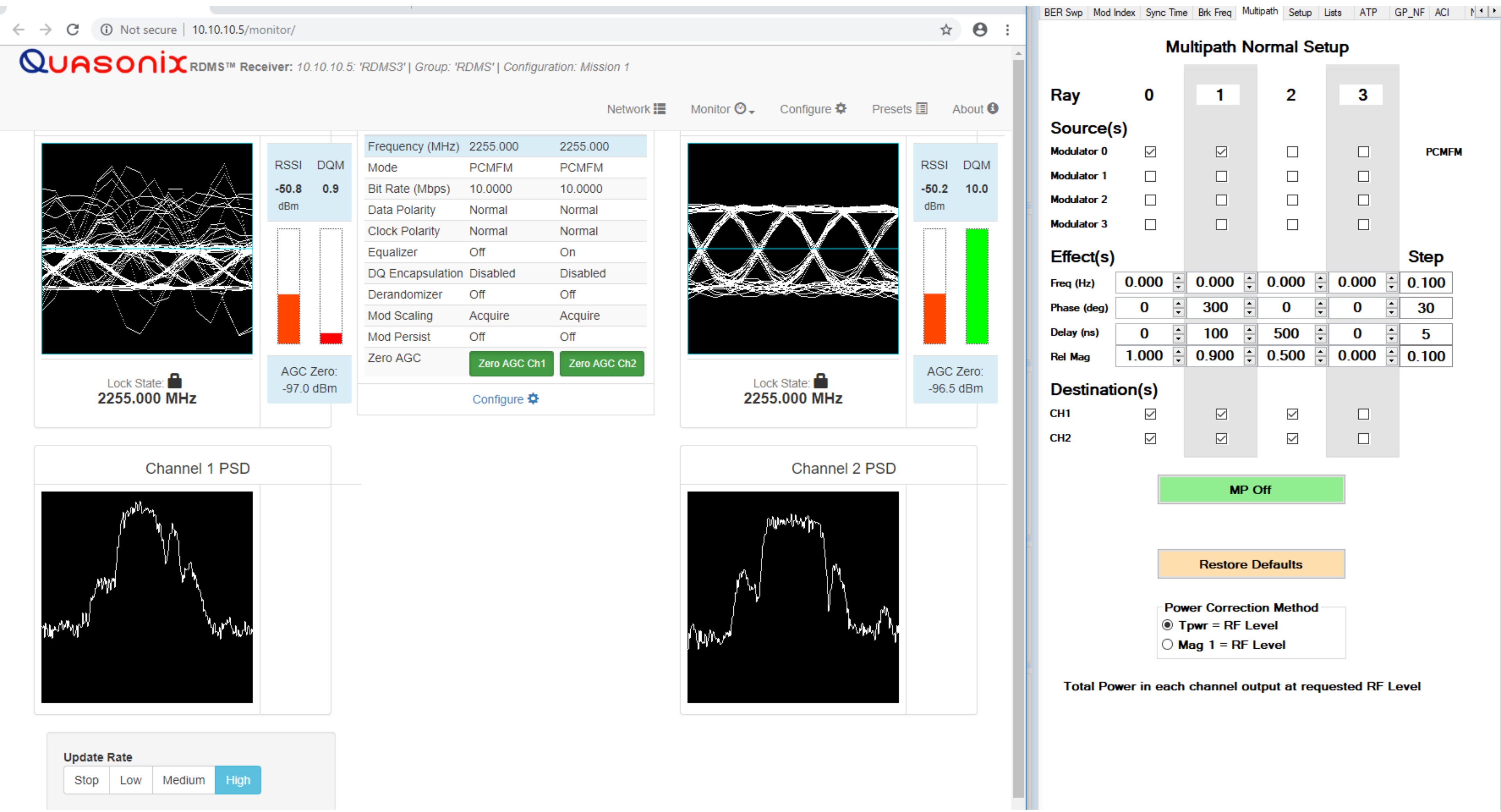
# 240-100-0.9


Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 dBm 0.4
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 dBm 10.0
Lock State:
2255.000 MHz
AGC Zero: -96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s) Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 240 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

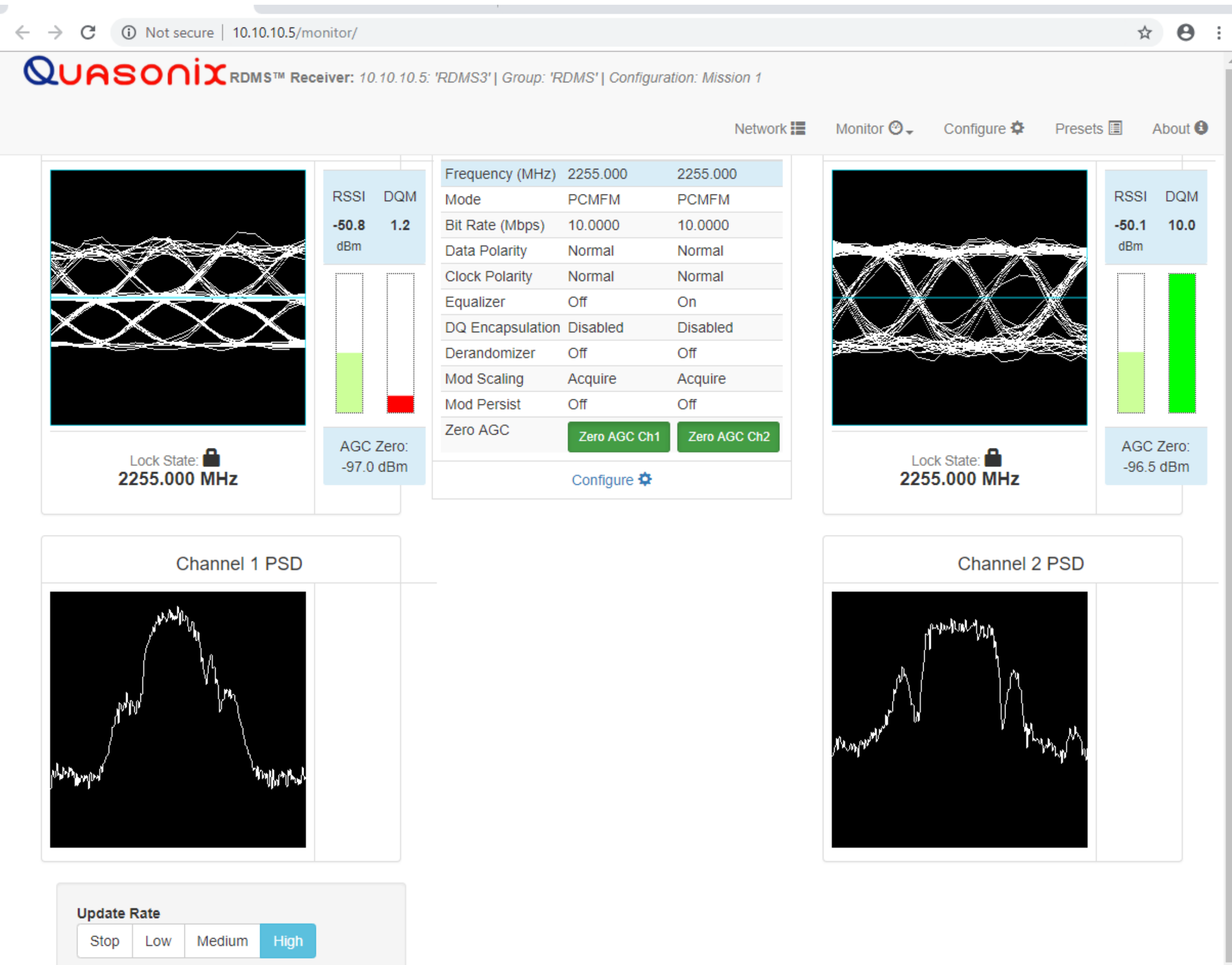
# 270-100-0.9

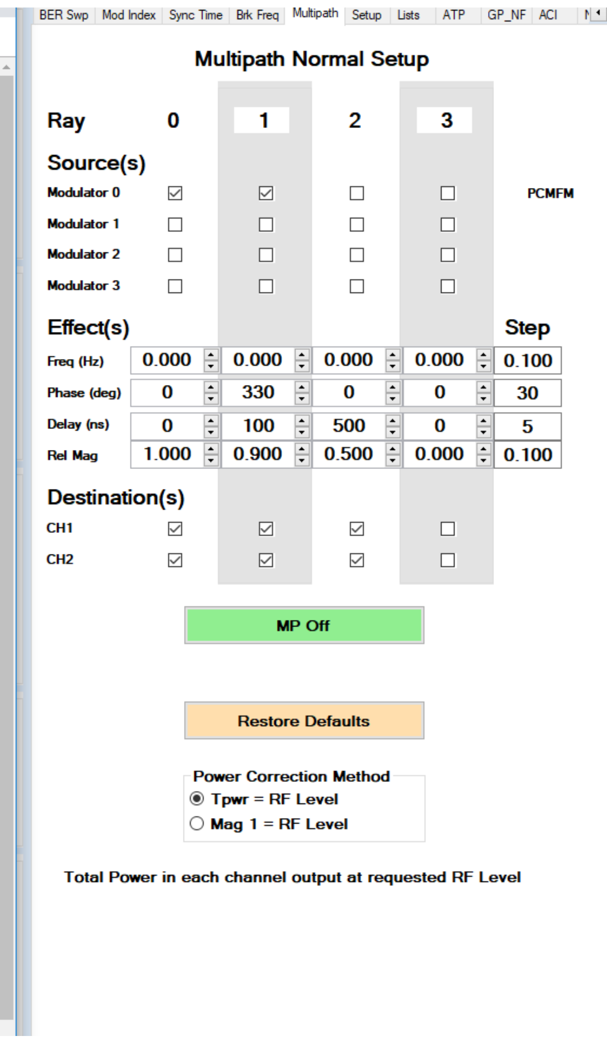

Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.9 1.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 270 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 300-100-0.9

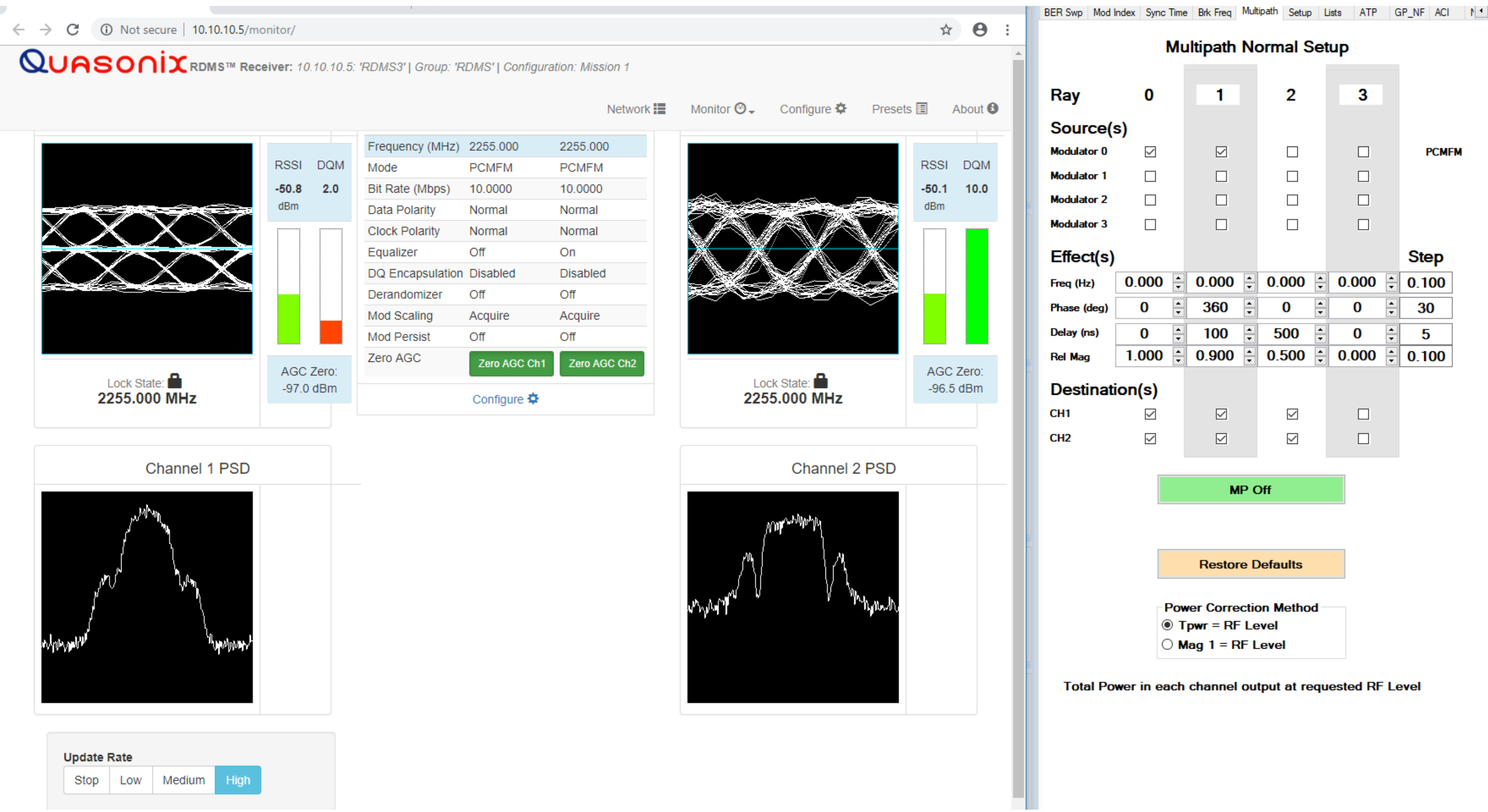

Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.8 0.9
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 300 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 330-100-0.9


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.8 1.2
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.1 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High

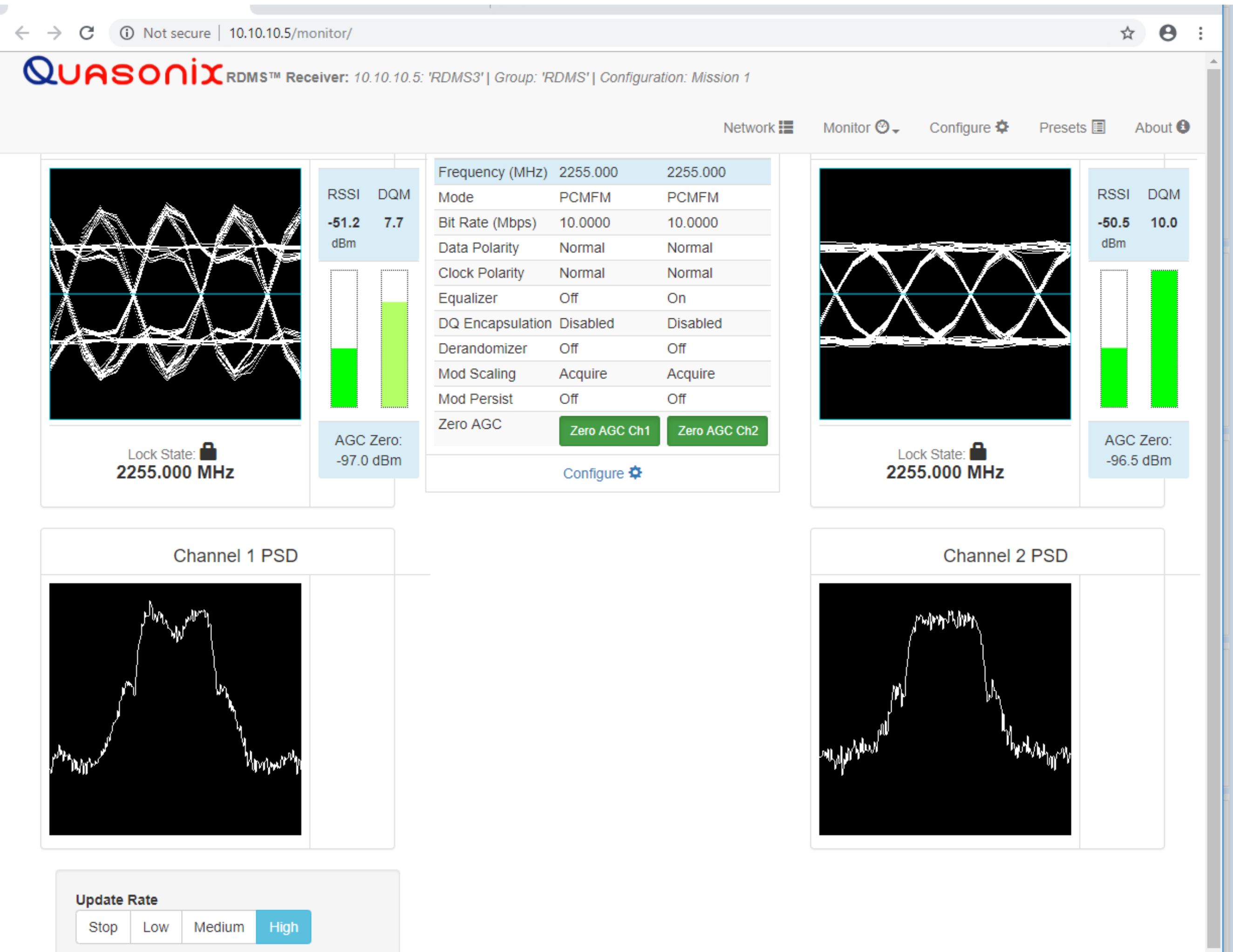

BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 330 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 360-100-0.9

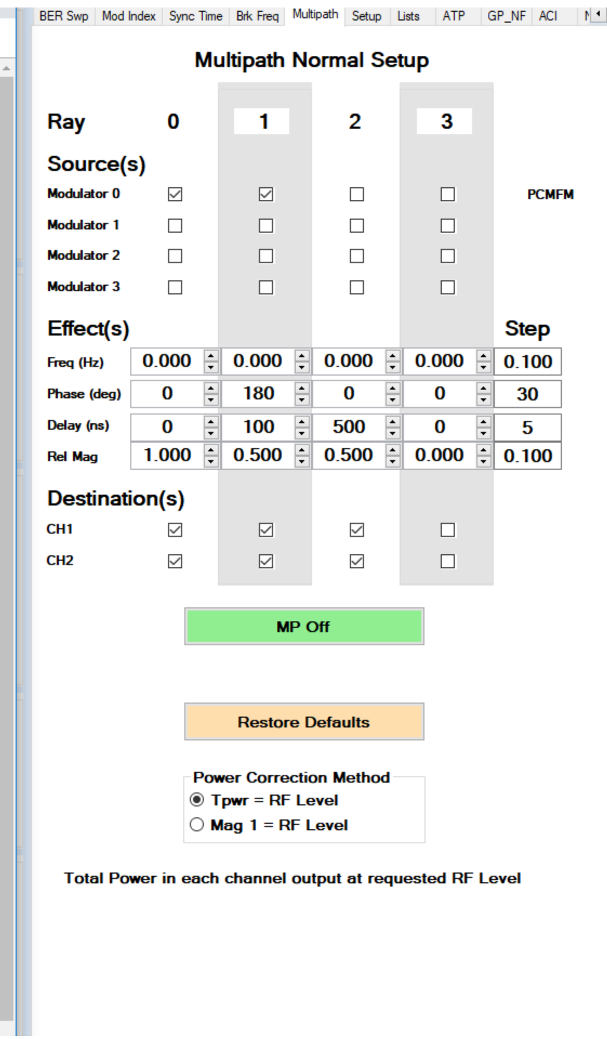


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.8 2.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.1 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 360 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-100-0.5

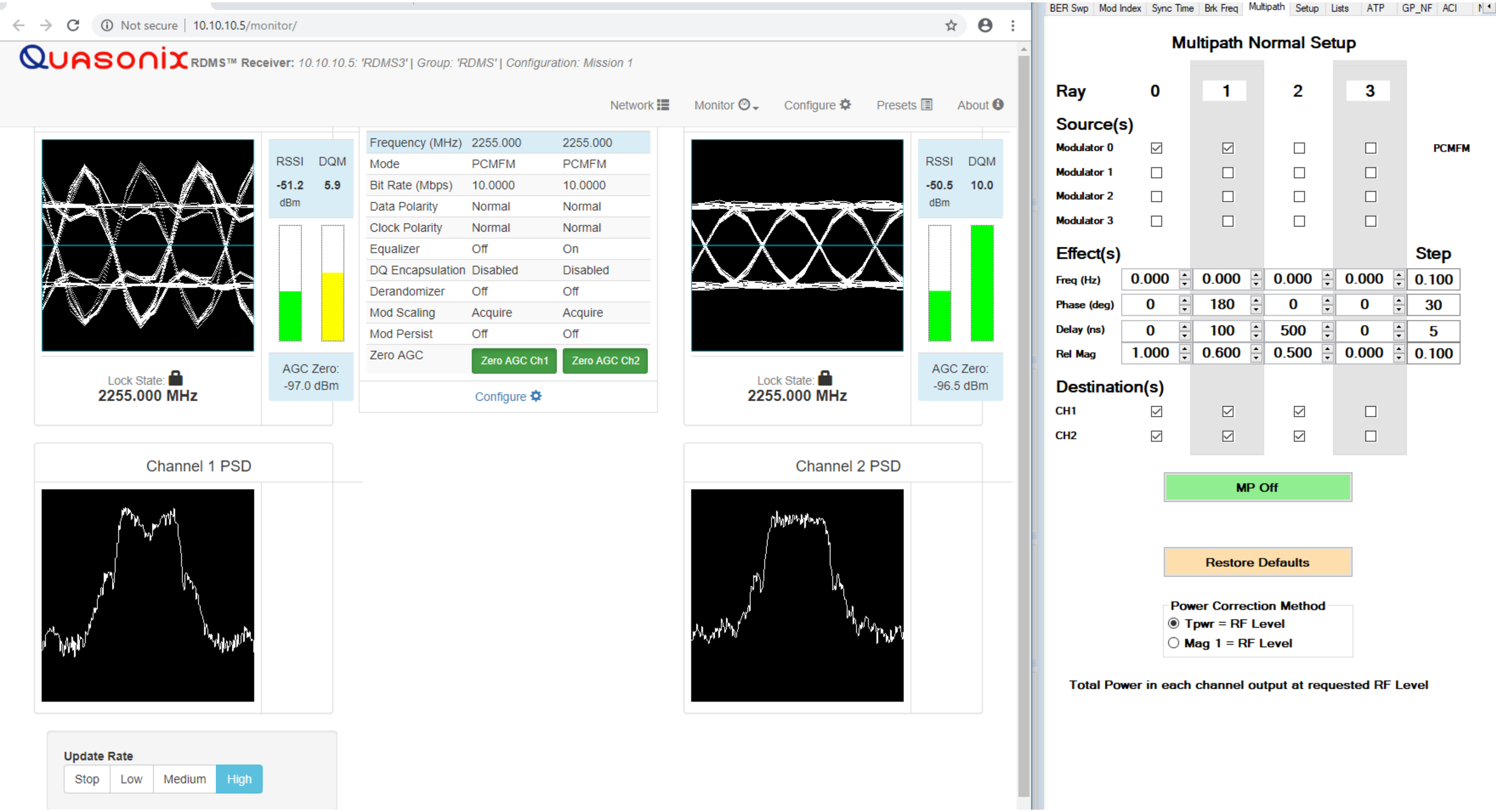


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.2 7.7
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.5 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High

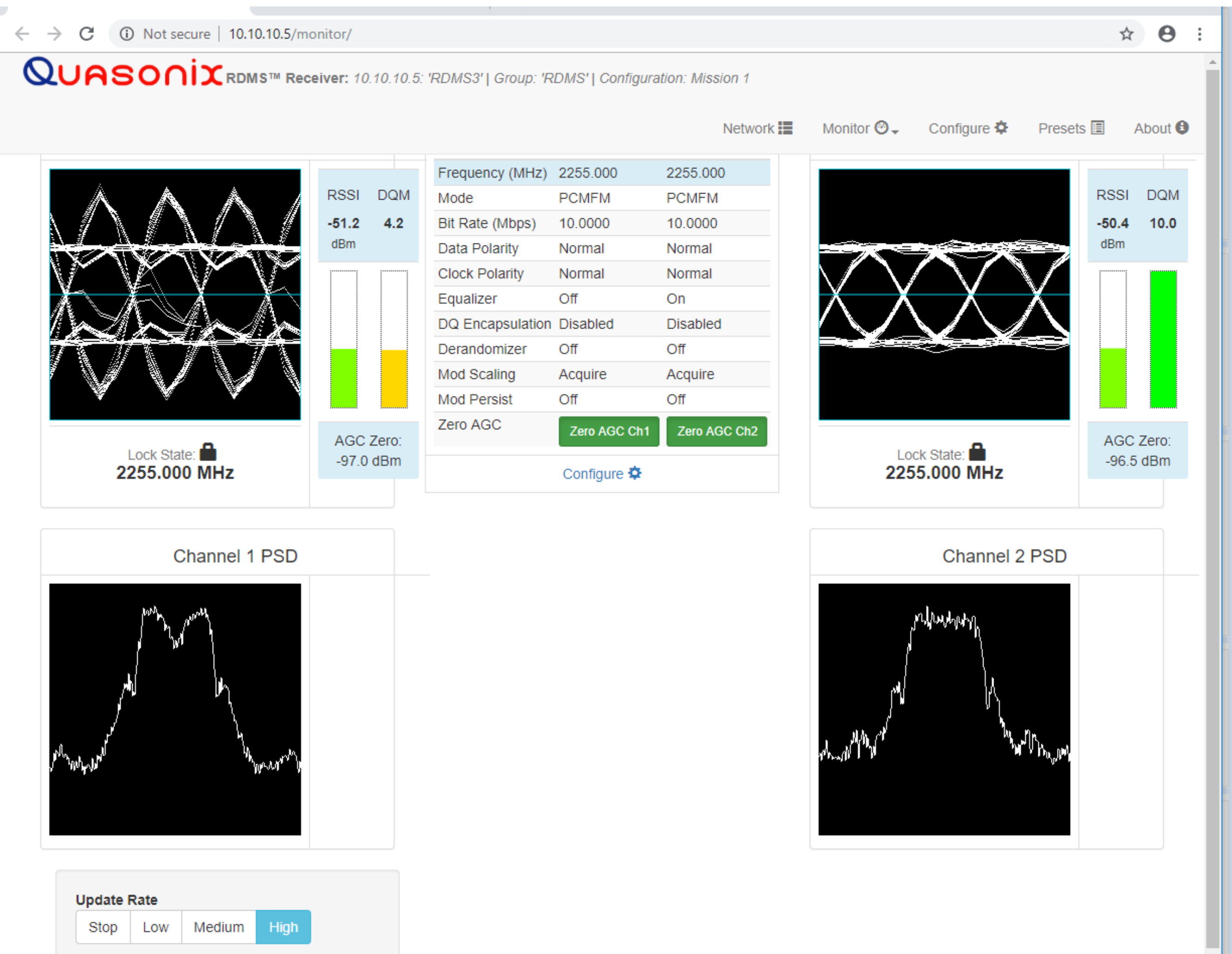



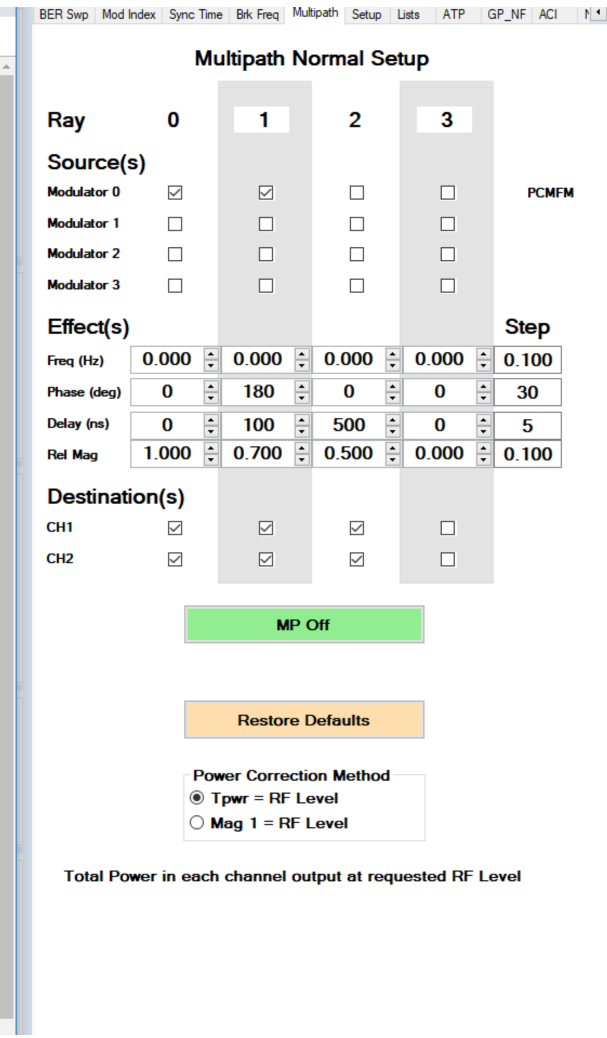
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
PCMFM
Modulator 1
Modulator 2
Modulator 3
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.500 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-100-0.6


Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.2 5.9
dBm
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.5 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero: -96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.600 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-100-0.7







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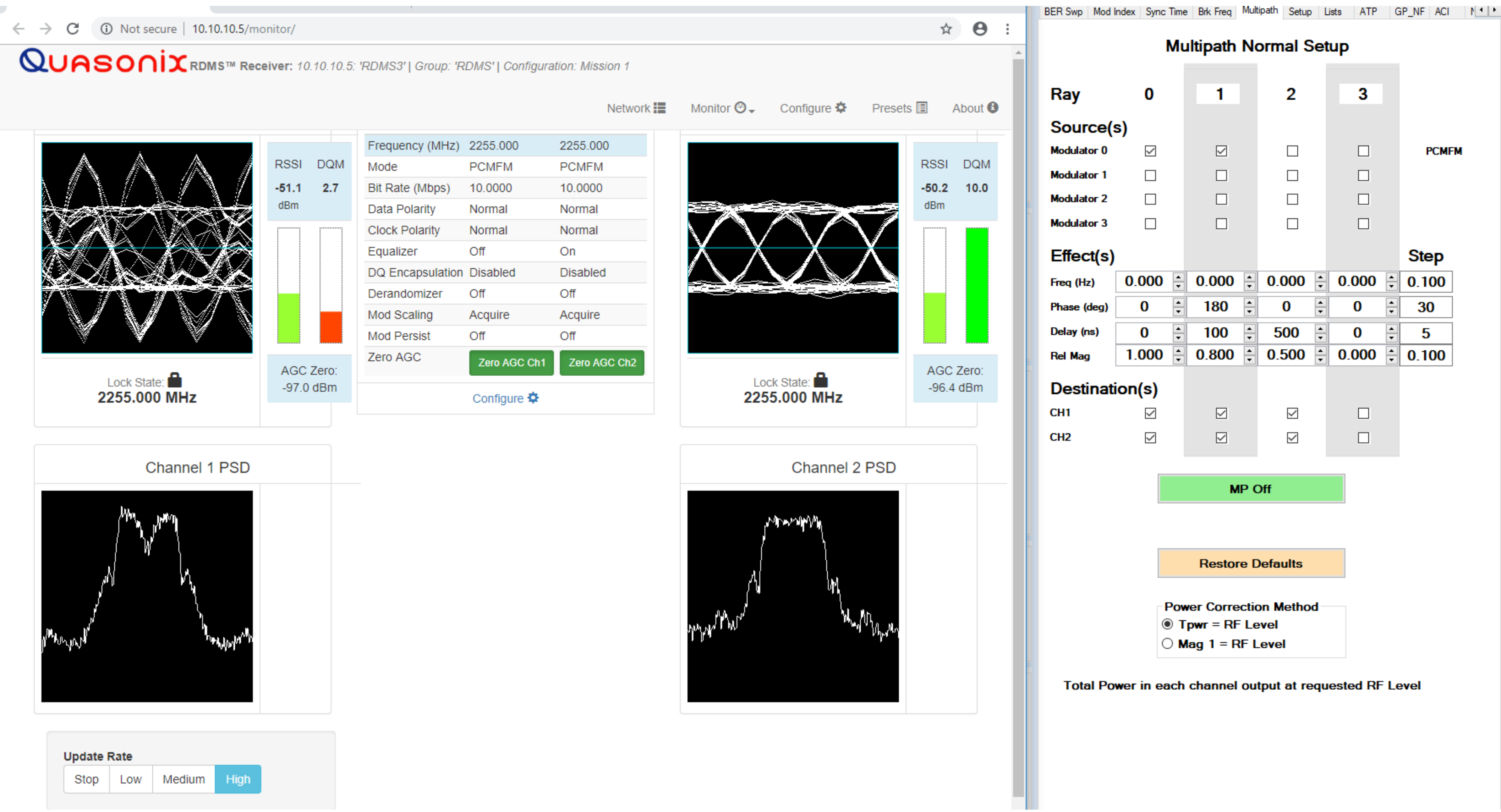
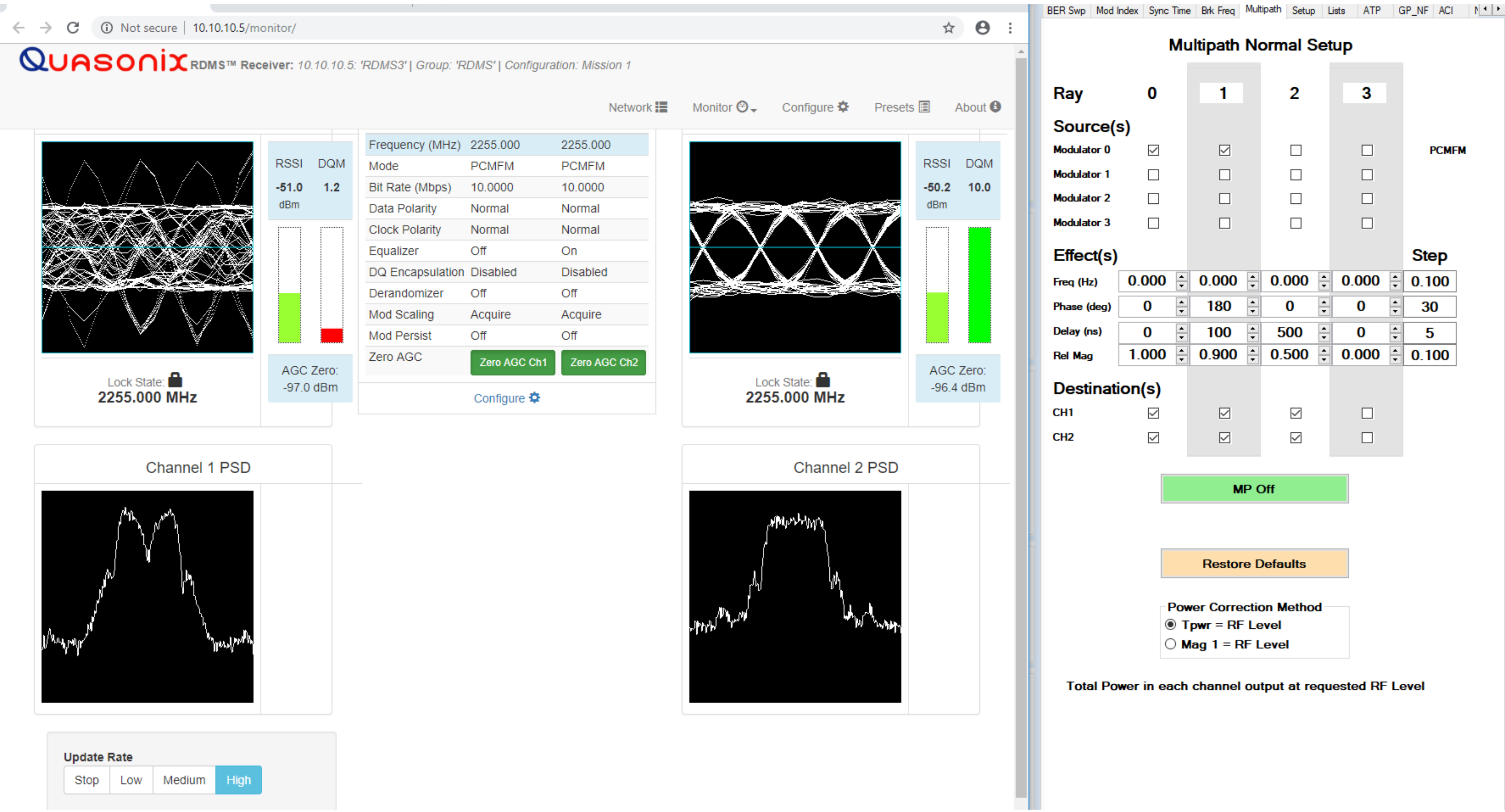
# 180-100-0.8

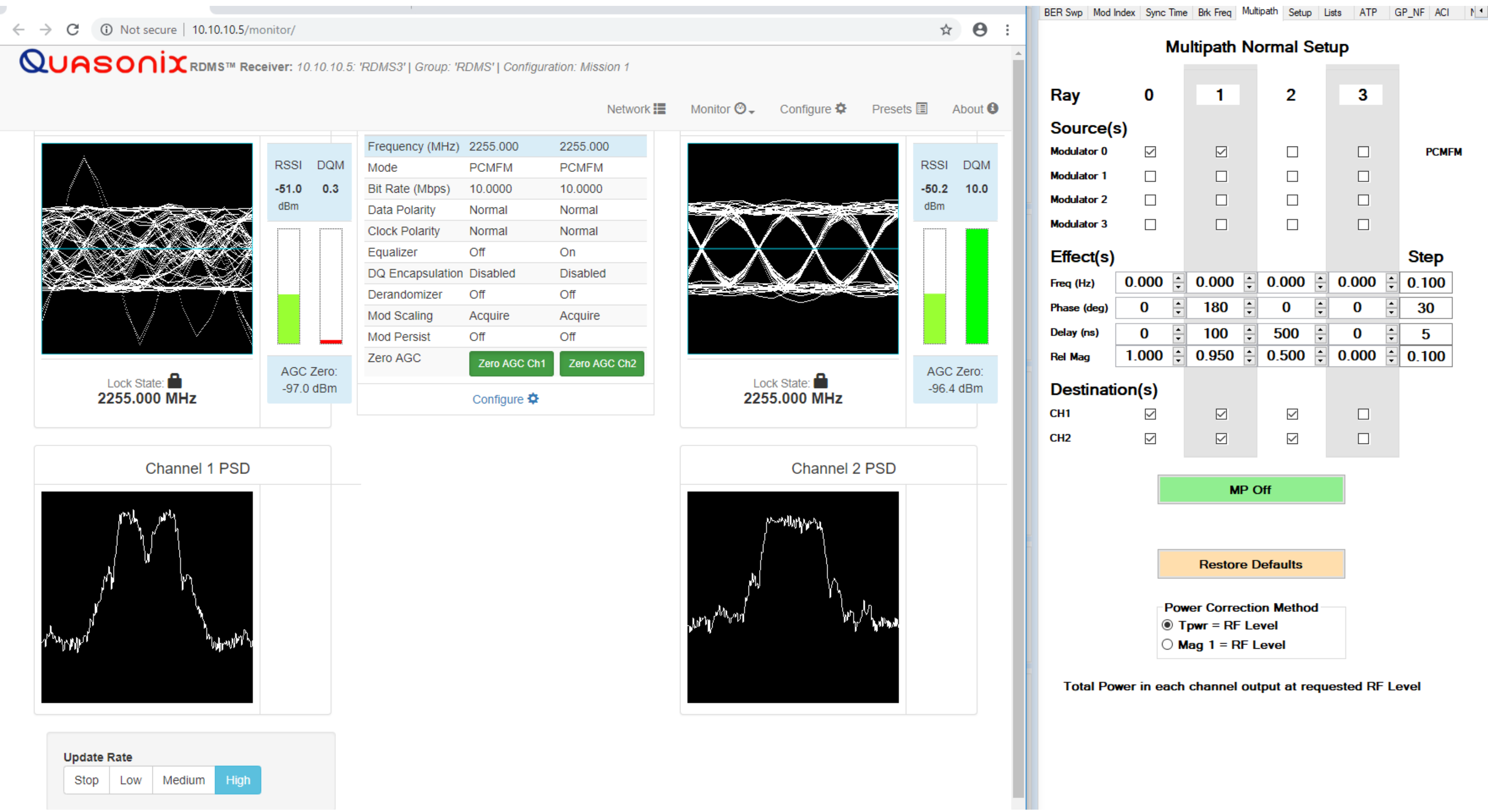


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.1 2.7
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.4 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
PCMFM
Modulator 1
Modulator 2
Modulator 3
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.800 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

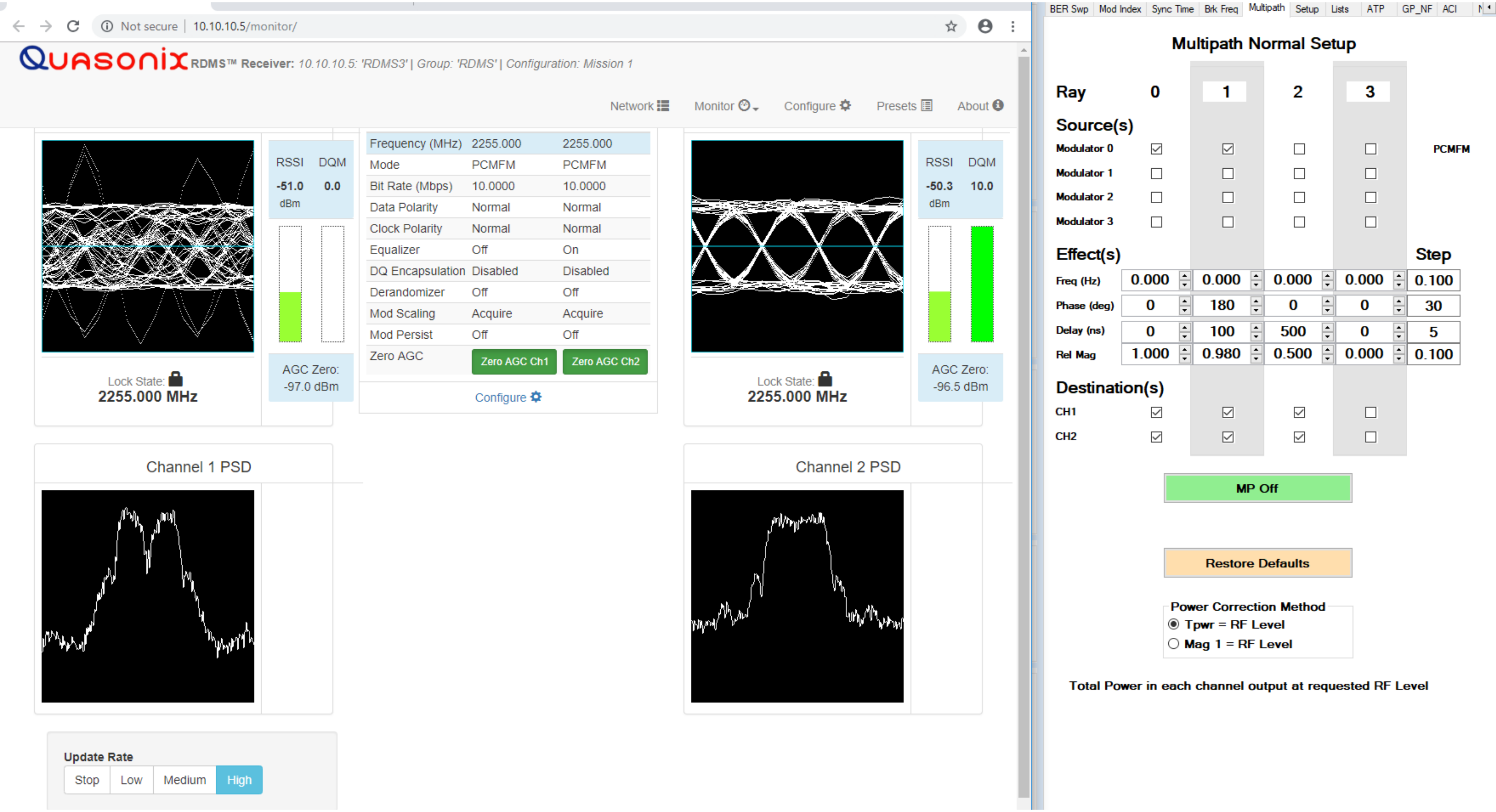
# 180-100-0.9


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 1.2
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.4 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-100-0.95

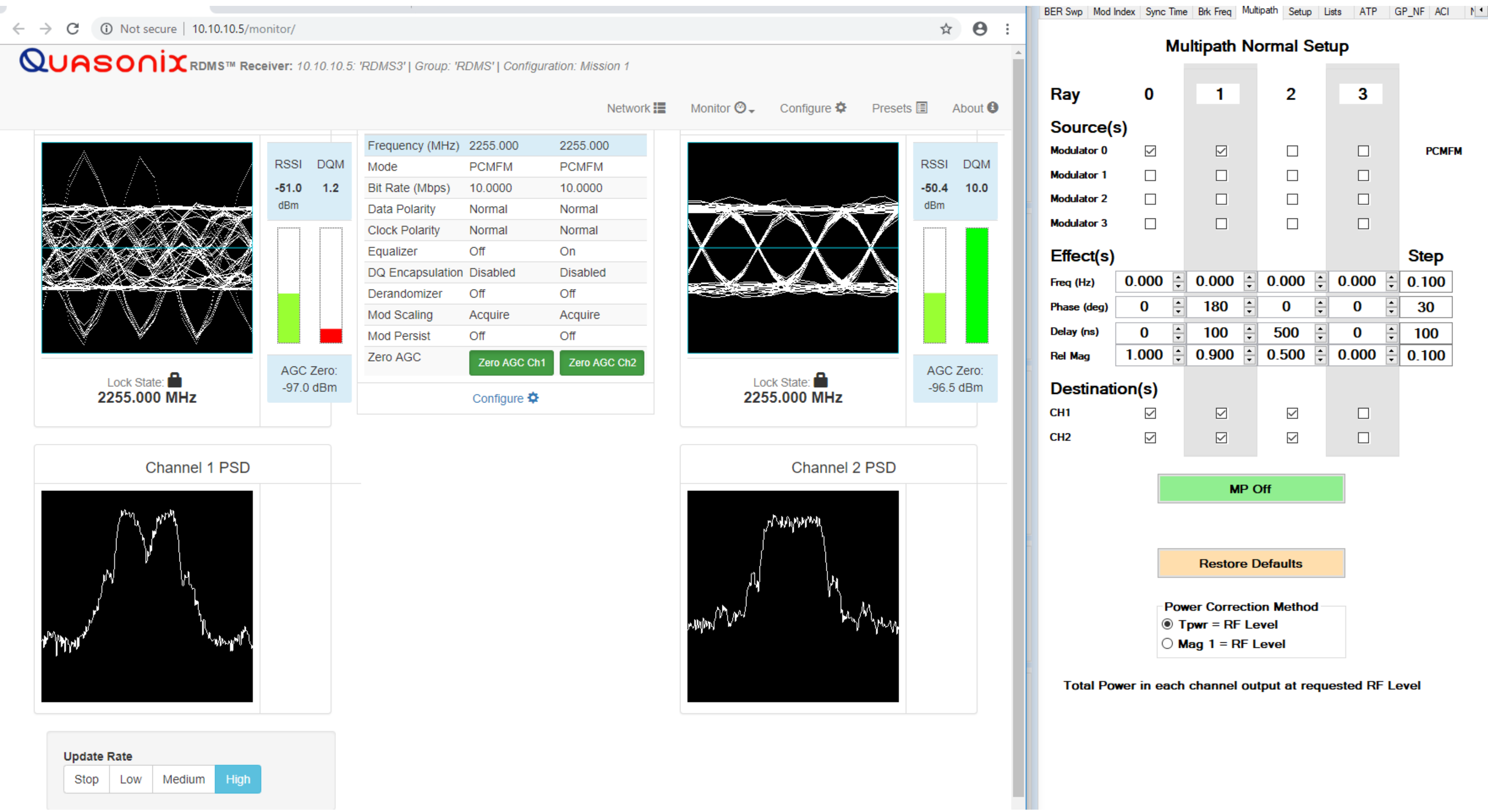

Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 0.3
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.4 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.950 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-100-0.98

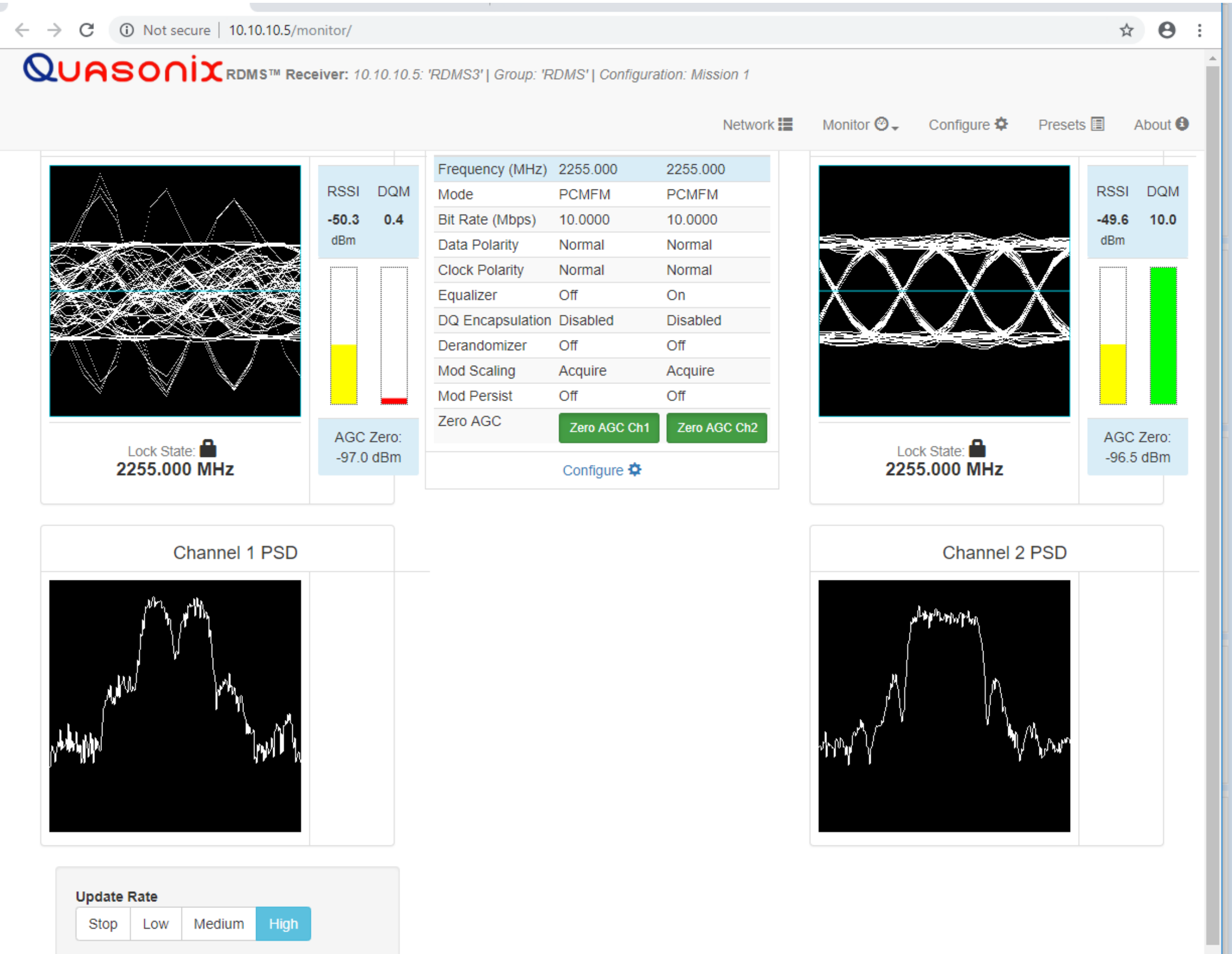


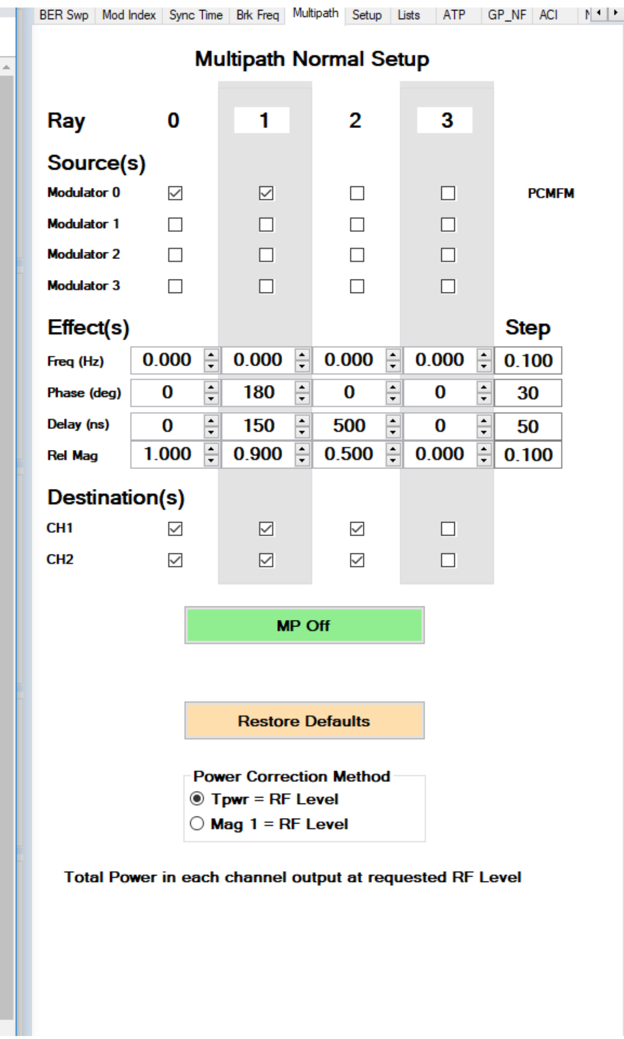
Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 0.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.3 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.980 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-100-0.9

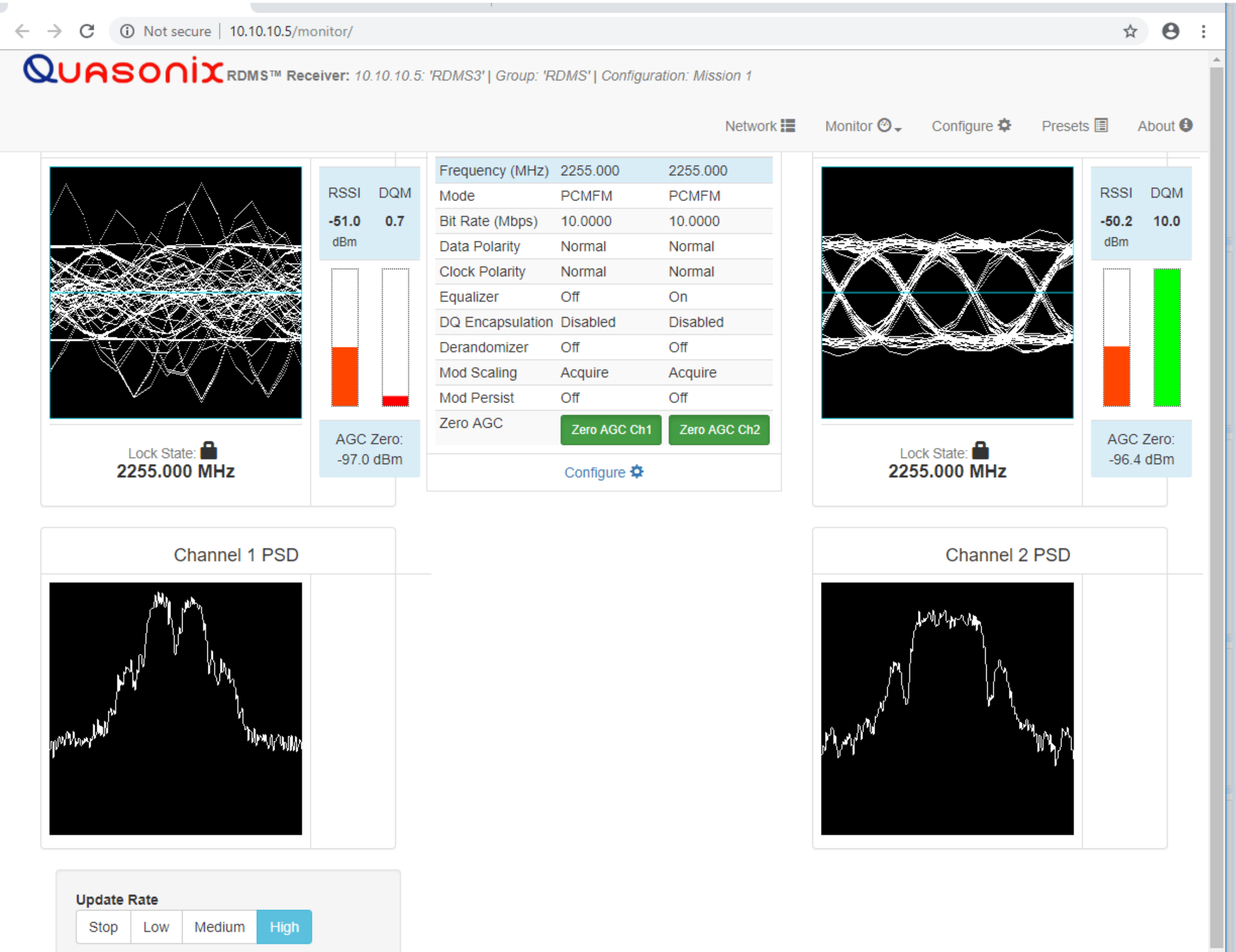

Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 1.2
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.4 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 100 500 0 100
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-150-0.9

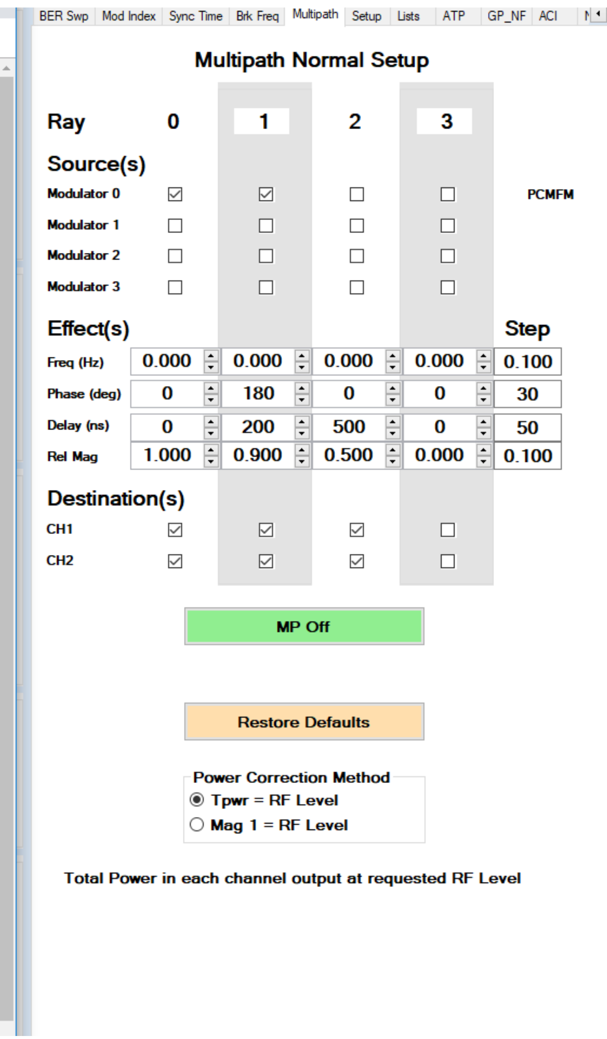

Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.3 0.4
dBm
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-49.6 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero: -96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High


BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 150 500 0 50
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-200-0.9

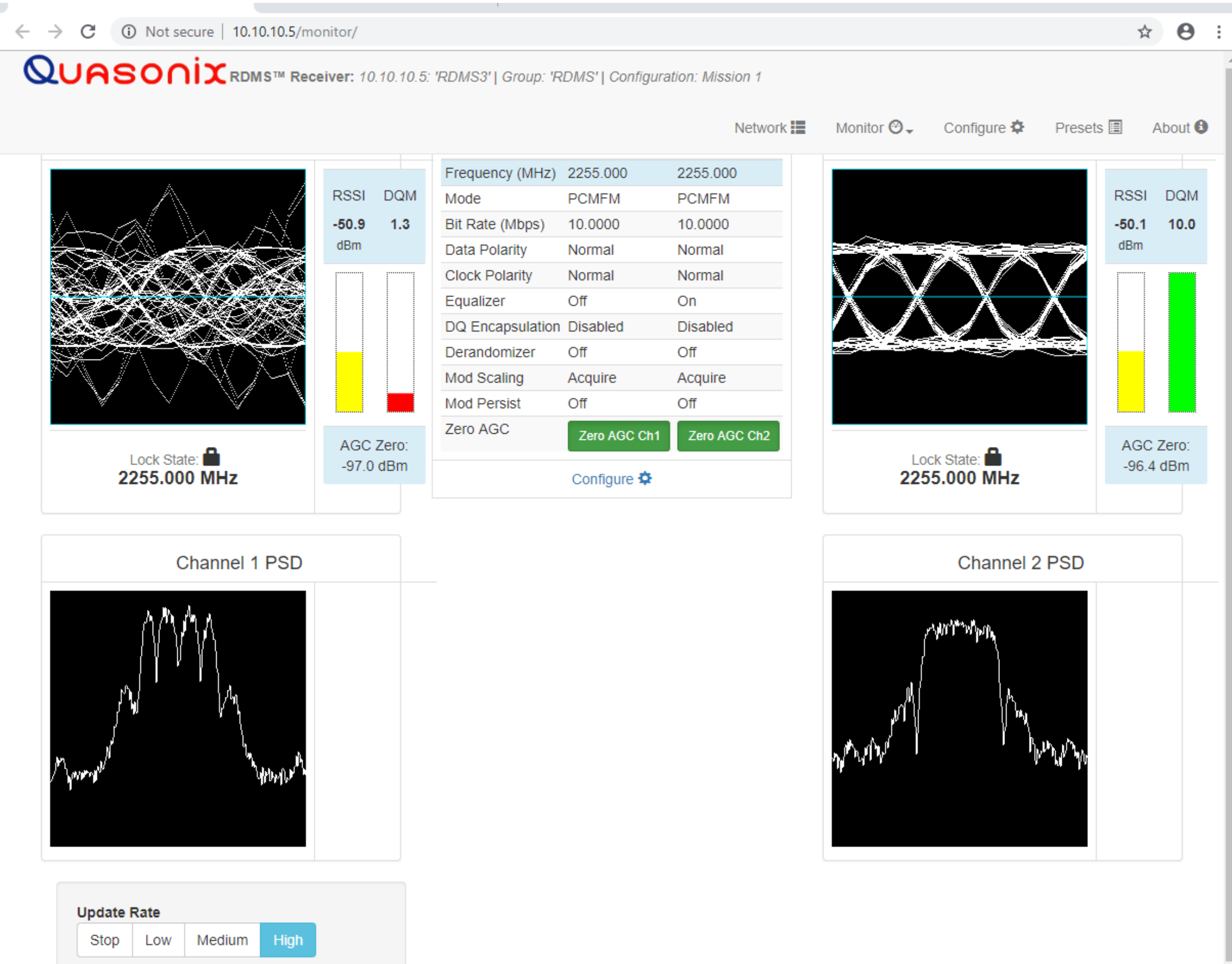


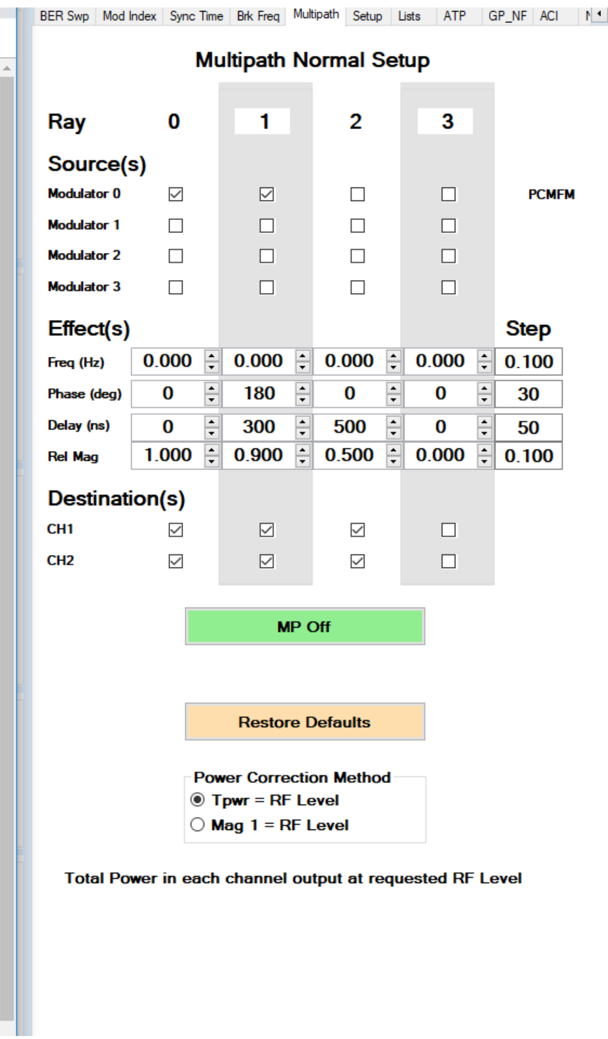
Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 0.7
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC Zero AGC Ch1 Zero AGC Ch2
Configure
RSSI DQM
-50.2 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.4 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High

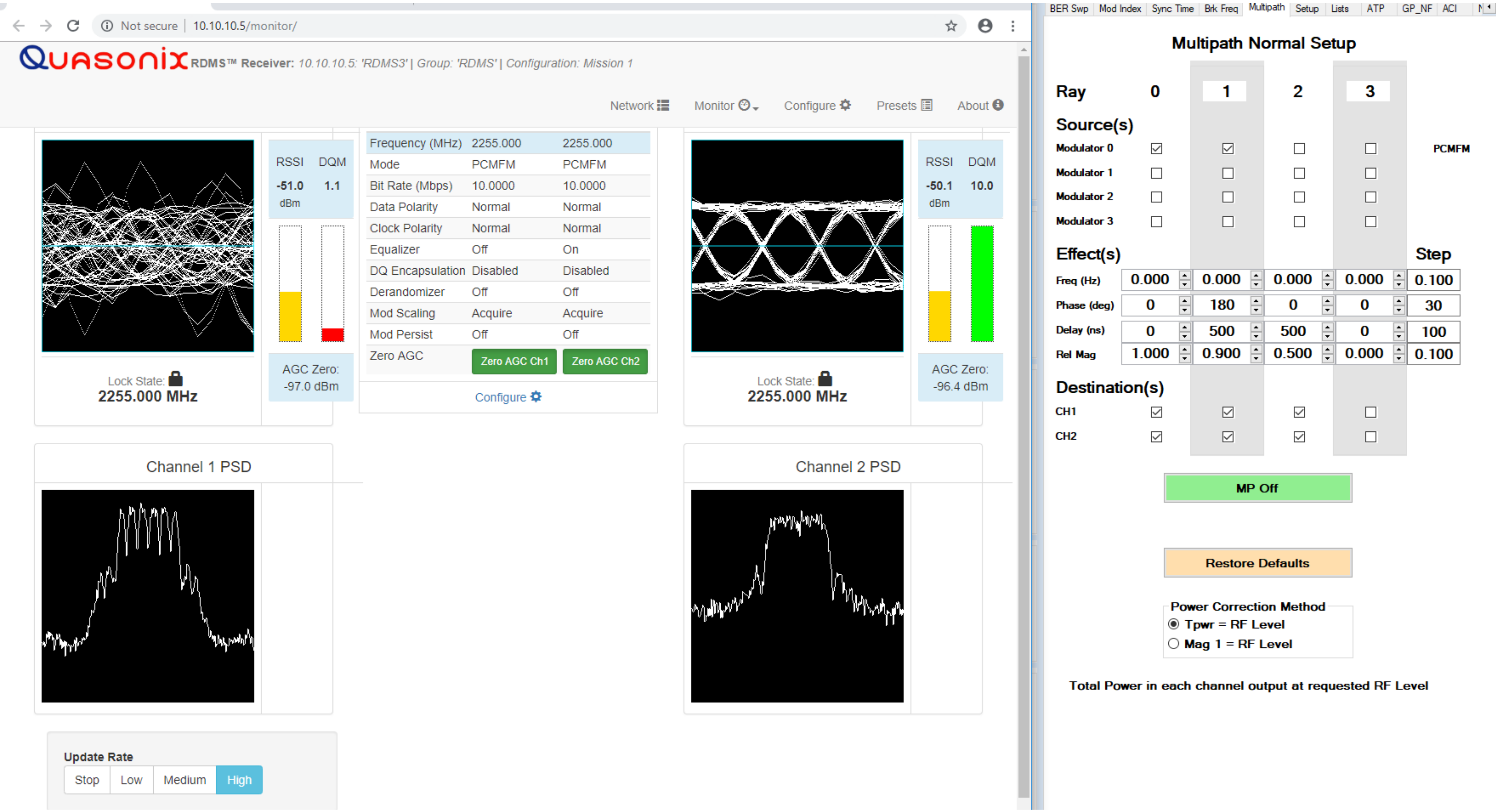
BER Swp
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 200 500 0 50
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-250-0.9


Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.9 1.3
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.1 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.4 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High

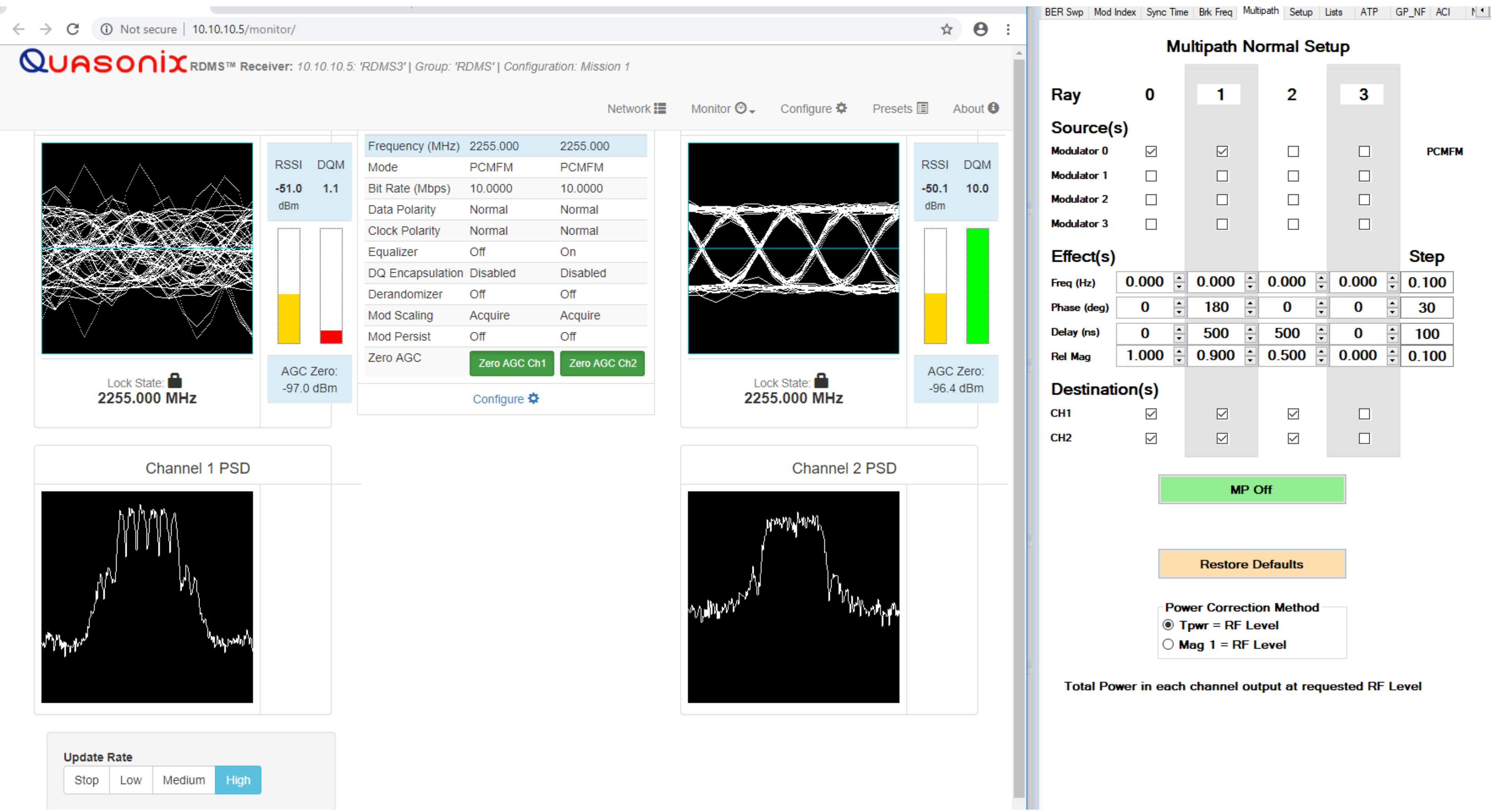

BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 300 500 0 50
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-300-0.9



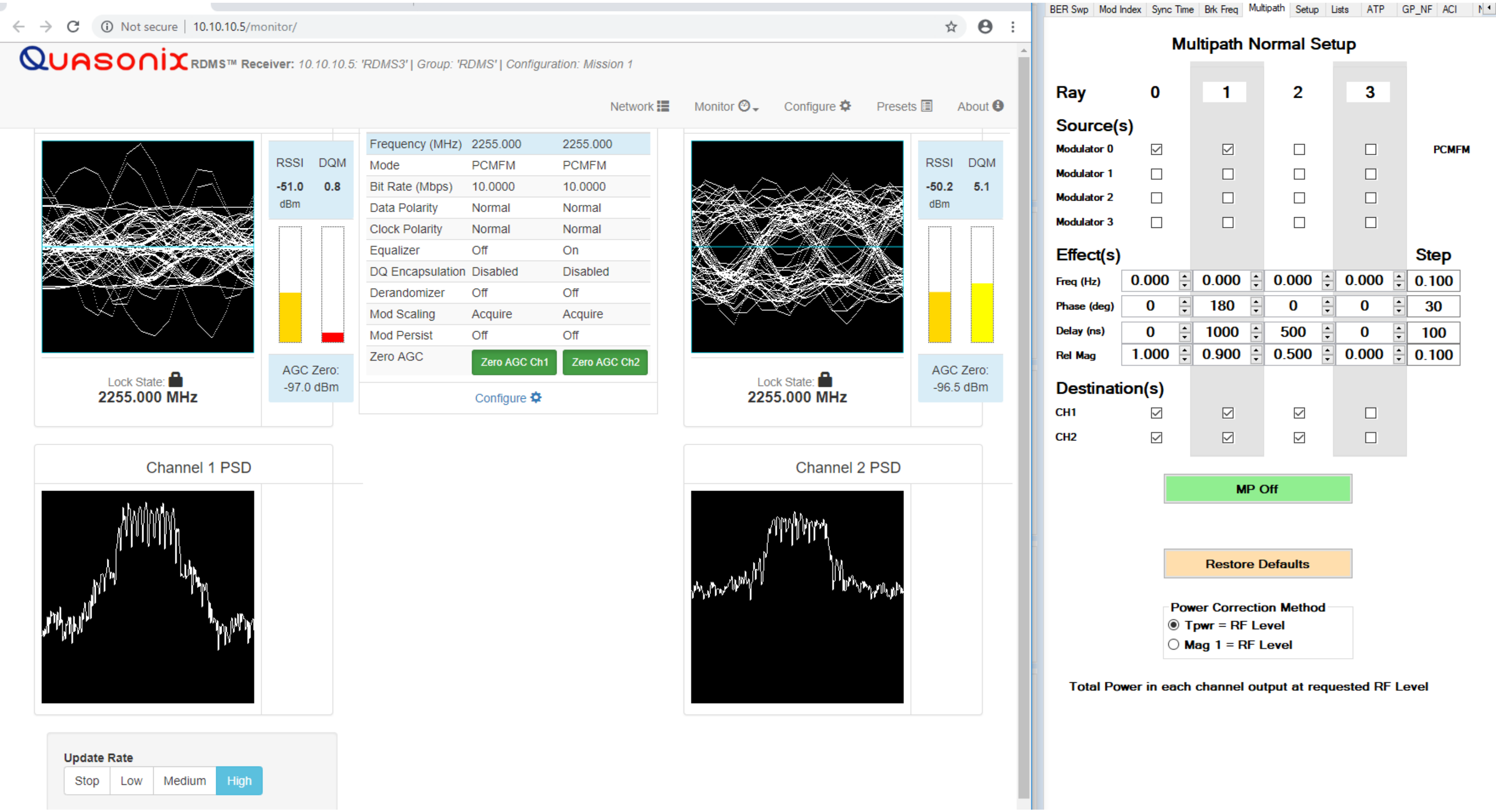
Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 1.1
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.1 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.4 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 500 500 0 100
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-500-0.9

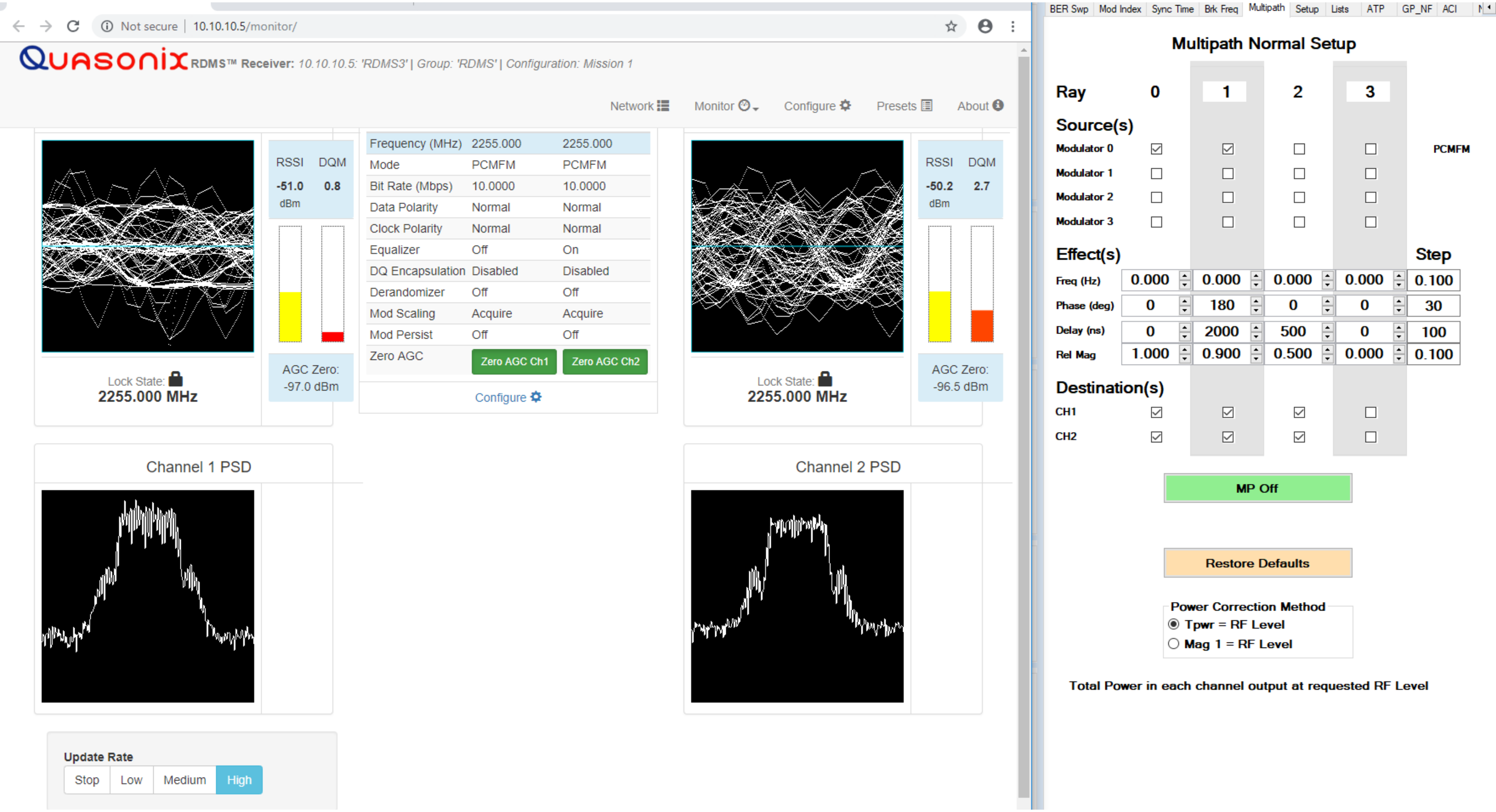


Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 1.1
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.1 10.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-96.4 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 500 500 0 100
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-1000-0.9


Not secure | 10.10.10.5/monitor/
QUASONIX RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 0.8
dBm
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.2 5.1
dBm
Lock State:
2255.000 MHz
AGC Zero: -96.5 dBm
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop Low Medium High
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 180 0 0 30
Delay (ns) 0 1000 500 0 100
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

# 180-2000-0.9



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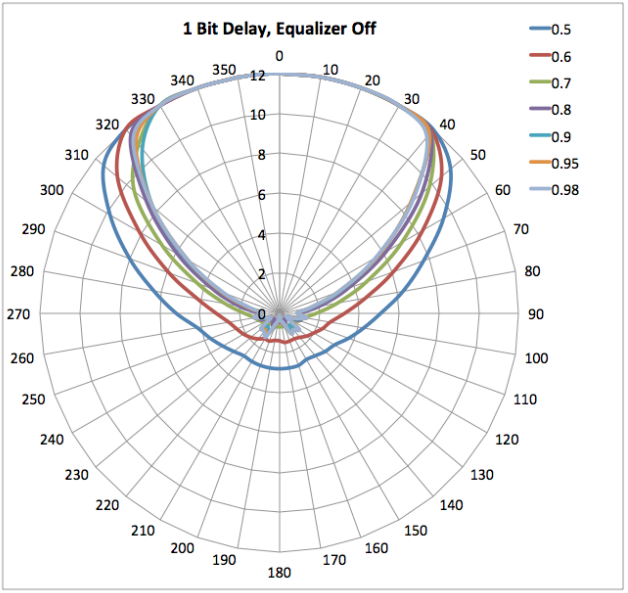
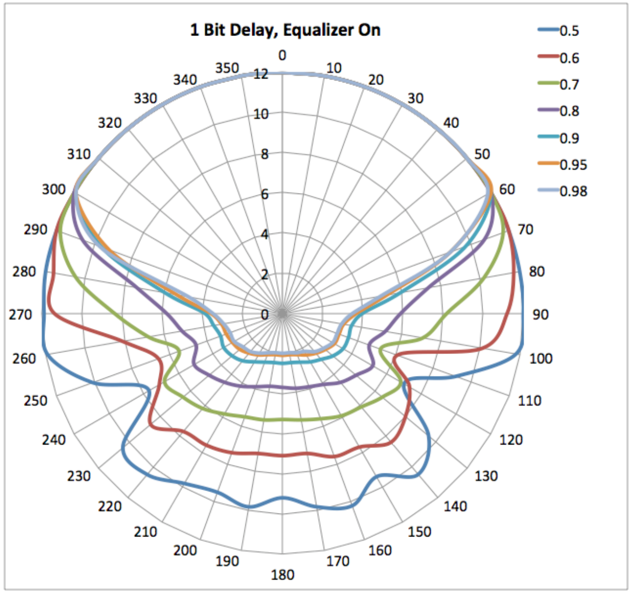
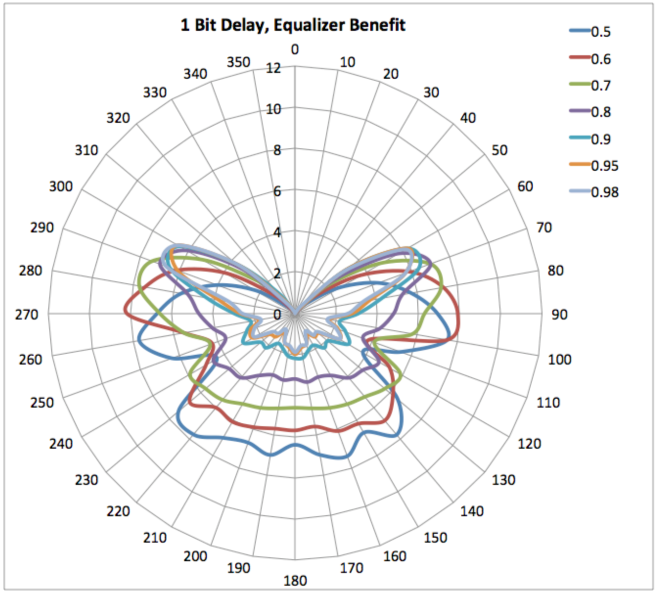
# Test Results Examples

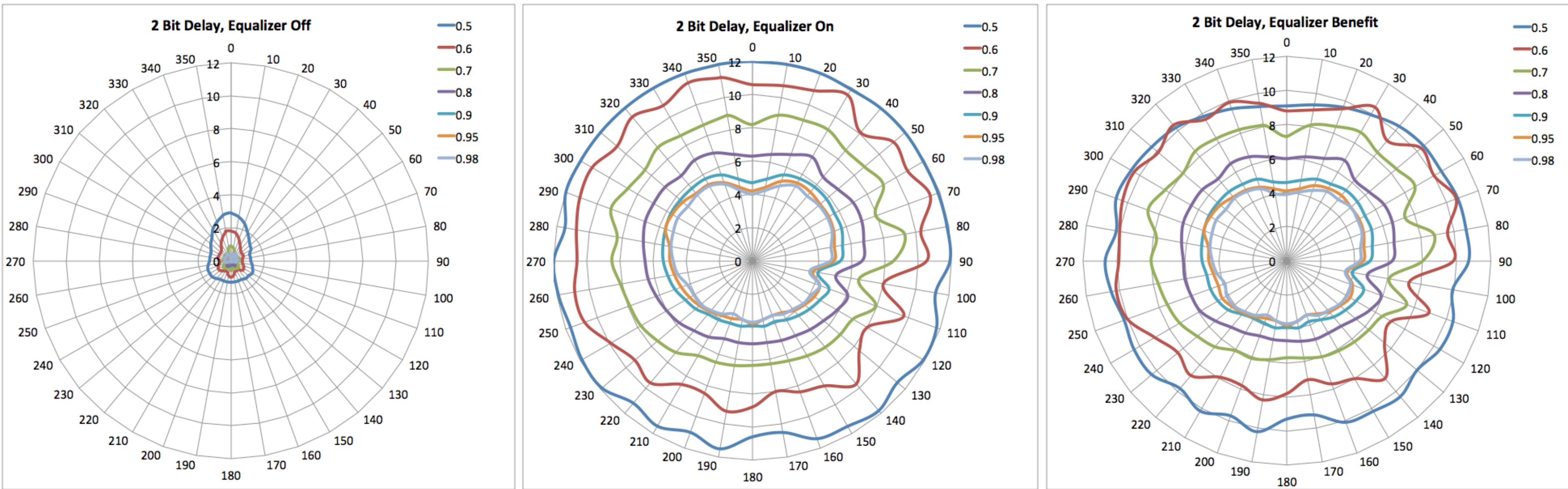
# 10 Mbps SOQPSK, 1 bit Delay



# 10 Mbps SOQPSK, 2 Bits Delay



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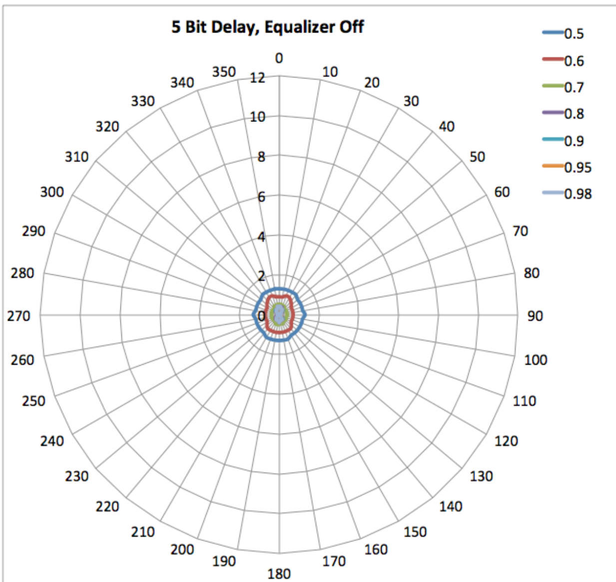
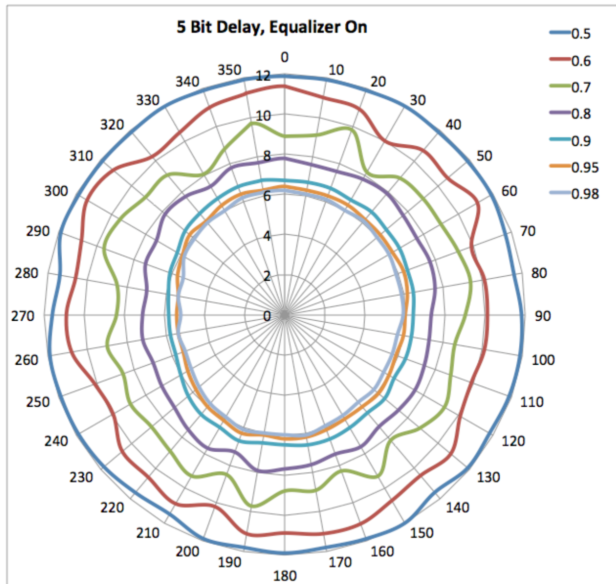
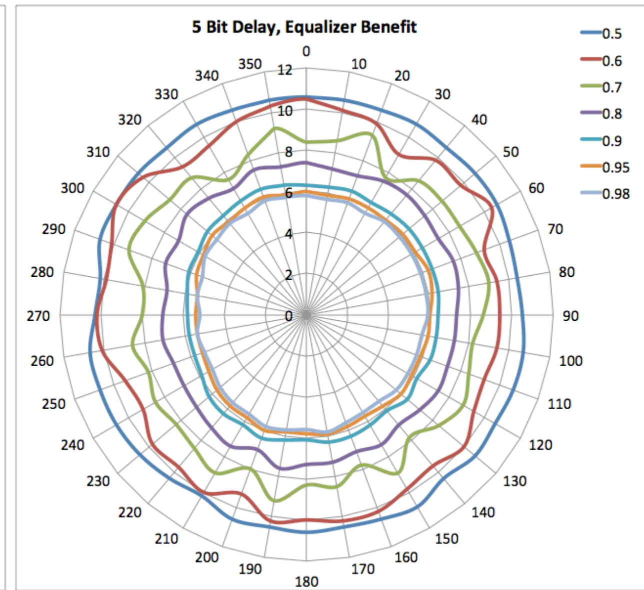
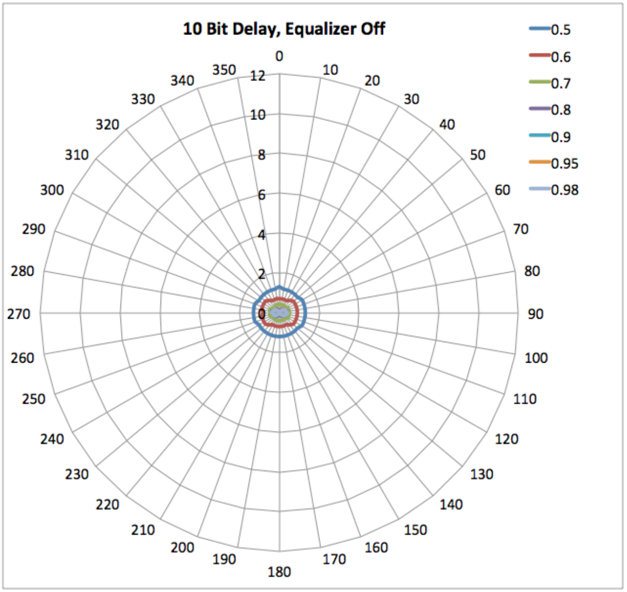
# 10 Mbps SOQPSK, 5 Bits Delay

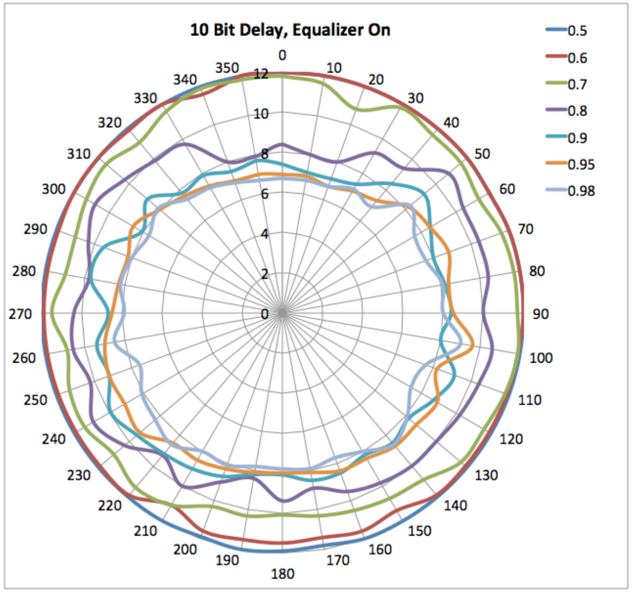


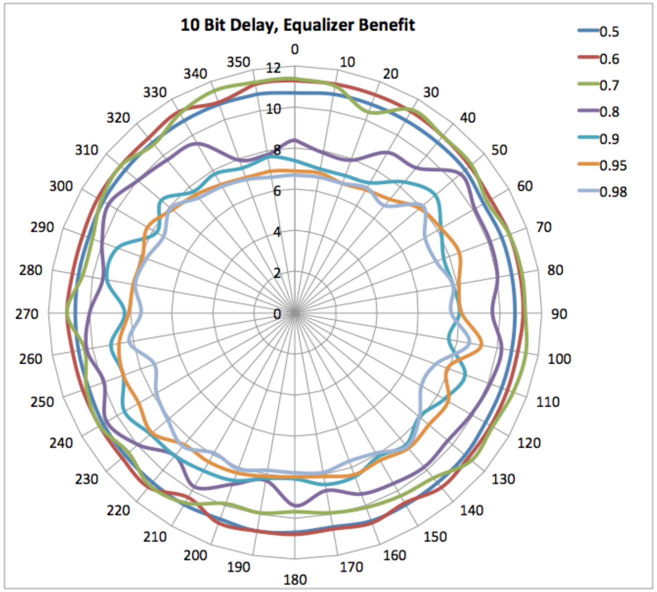



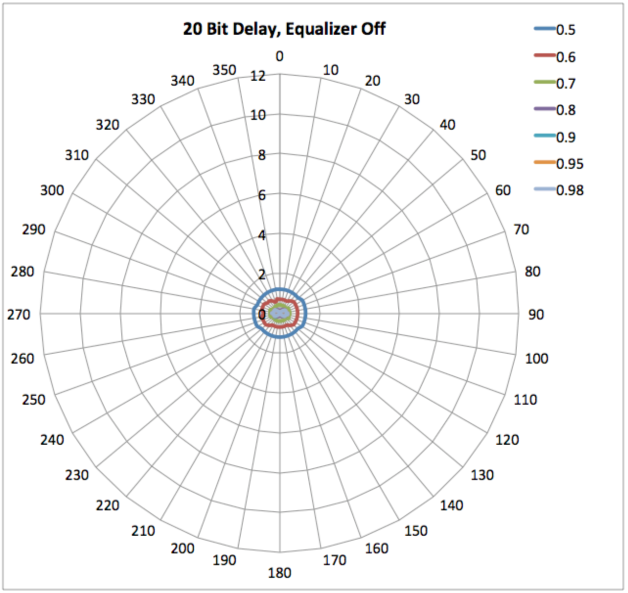
# 10 Mbps SOQPSK, 10 Bits Delay

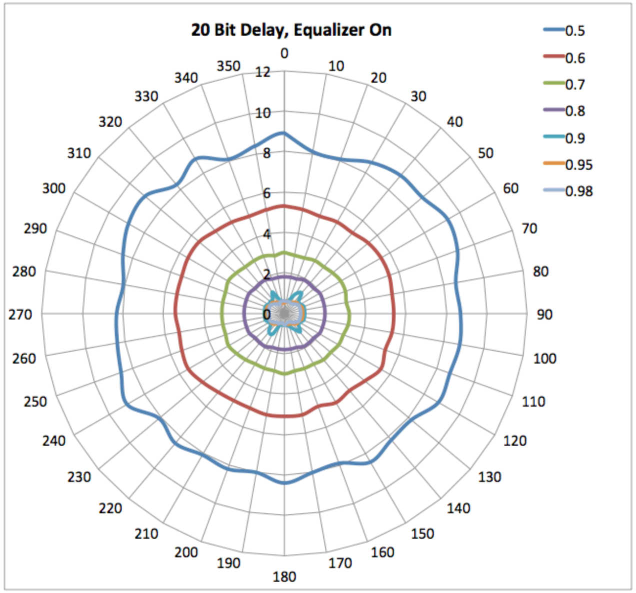


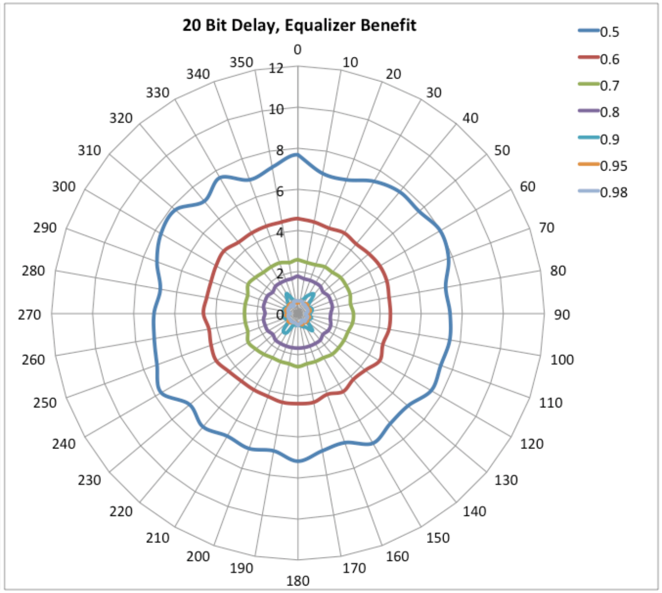



# 10 Mbps SOQPSK, 20 Bits Delay



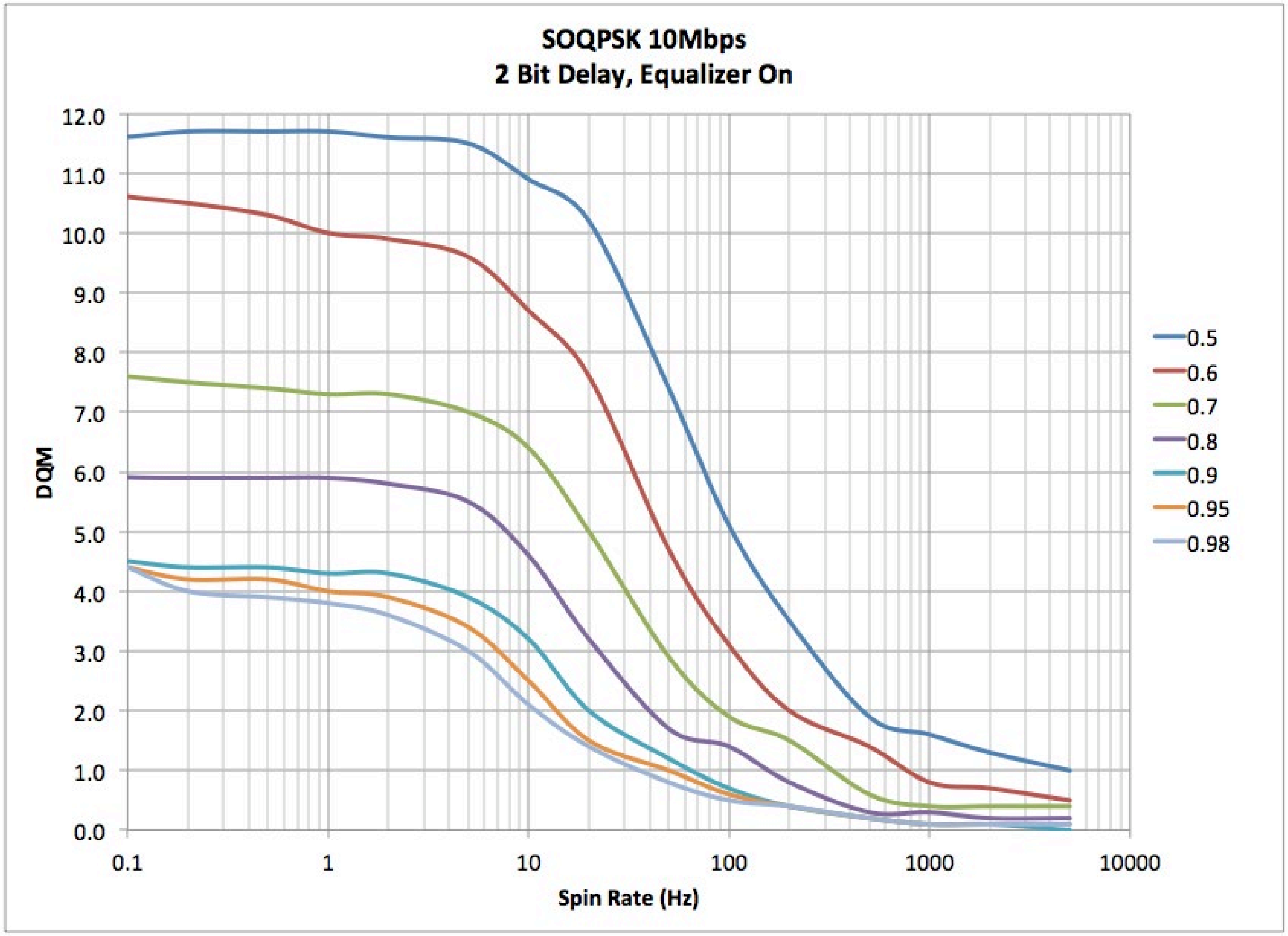
# What About Dynamics?

- Most pronounced effect of target motion is variation in phase of the reflected path
  - Manifests as spectral nulls sweeping through spectrum
- Proposal:
  - Stress the equalizer by sweeping the null faster and faster, until the EQ benefit starts to drop.
  - Similar to the Break Frequency test for combiners
- Figure of merit becomes the "Break Frequency" of the equalizer

# What Can we Measure?

- Measure the BER, averaged over all phases
  - Correlates with moving test article
  - Convert to DQM
  - Or measure DQM, but average it correctly (see next slide)
- For consistency with the static plots, plot DQM versus "spin rate"
- Plot multiple delay path amplitudes on one chart
- Separate charts for each delay value

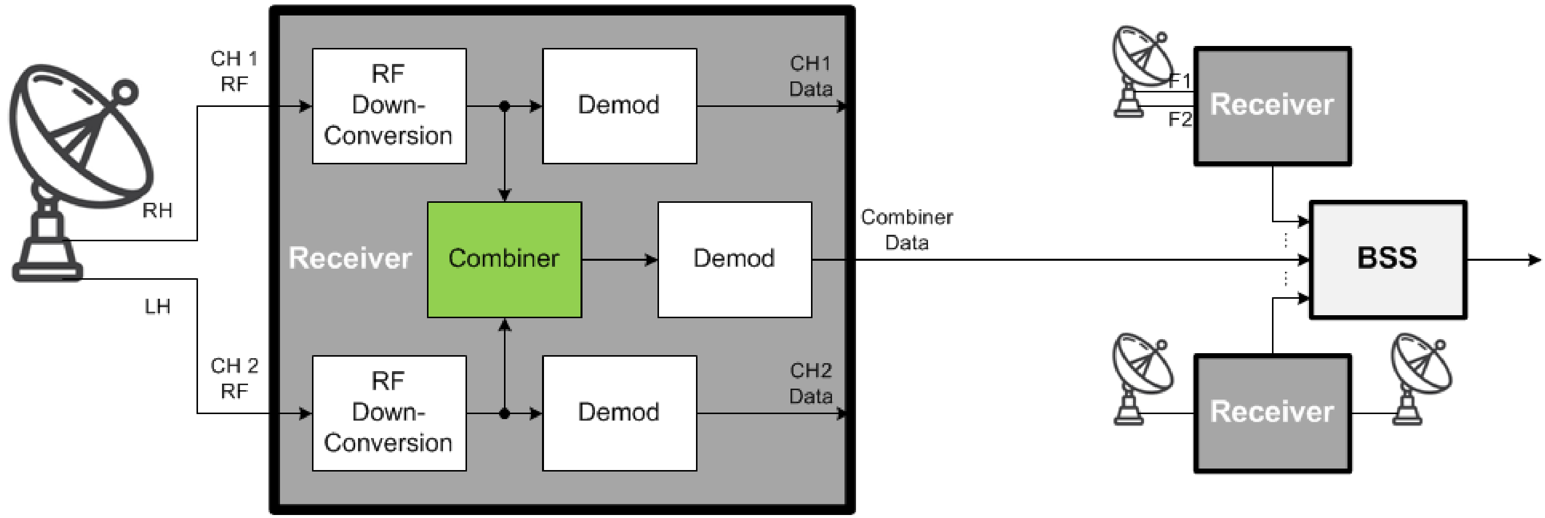
# Equalizer Break Frequency



# Best Channel Selector (BCS)

Handling the "Un-Combinable" Signals

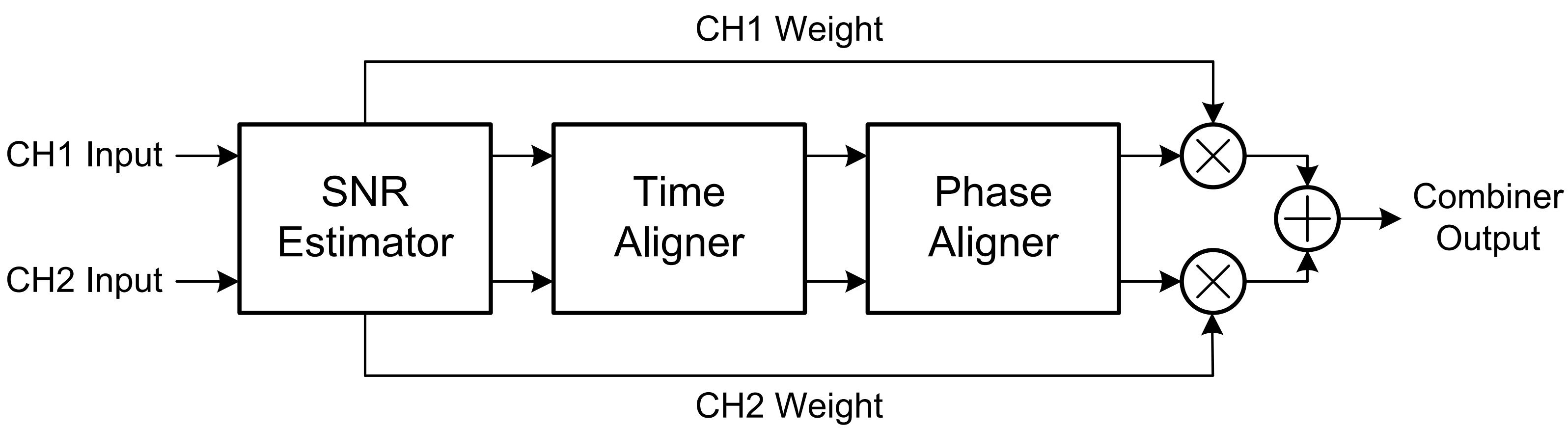
# Receive Diversity – Combiner




- Polarization, frequency, or short-range spatial diversity
- Maximal Ratio Combiner sums input channels proportional to their SNR
  - Optimal in additive white Gaussian noise (AWGN) – up to 3 dB gain
  - Use as only receiver output?

# Combiner Structure

- Maximal ratio combining



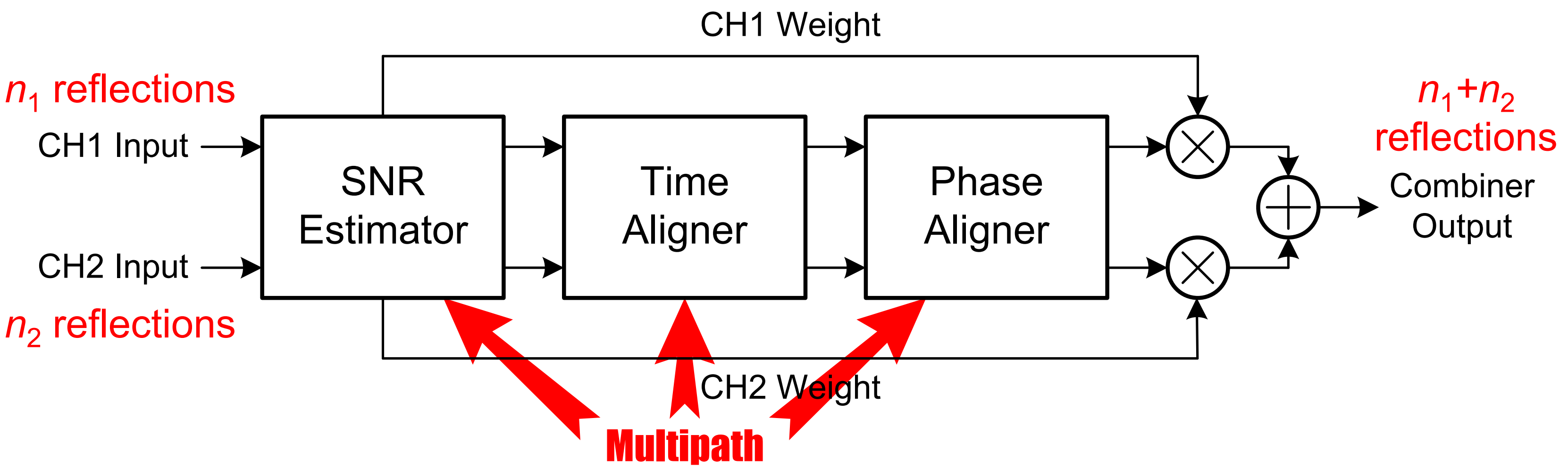

how good?

make sure we can sum coherently

sum (more of the better, less of the worse)

# Combiner Performance

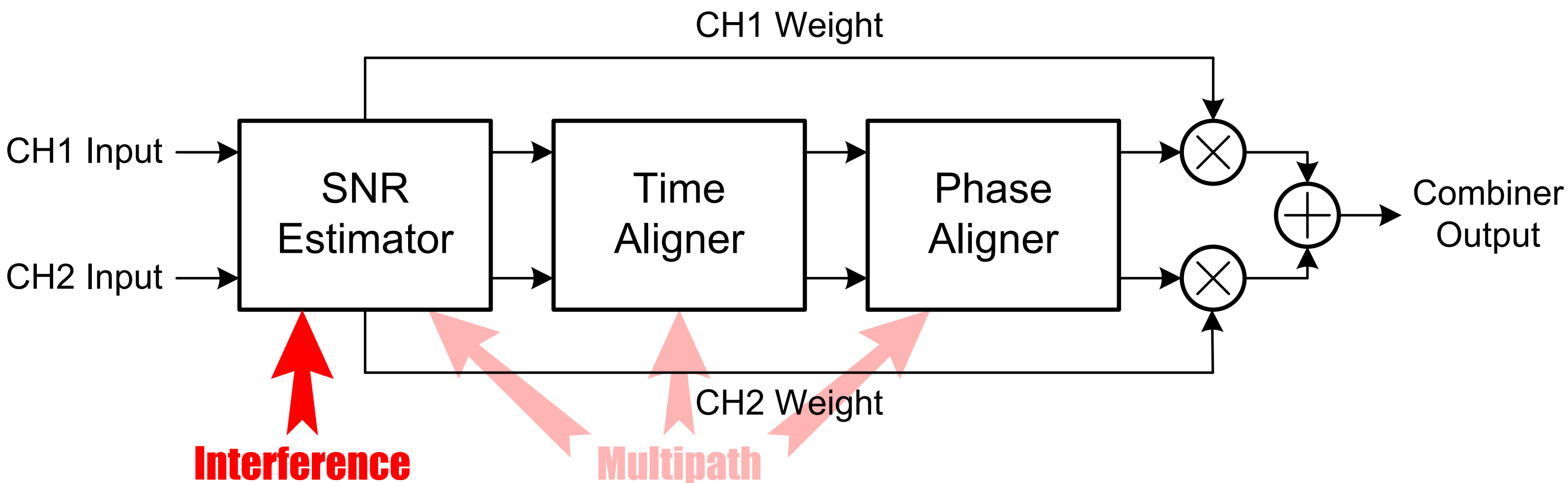
- Maximal ratio combining issues




  - Inaccurate SNR estimation: multiple signal copies, little or no noise
  - Degraded time and phase alignment
  - *Downstream demodulator must deal with **all** received reflections*

# Combiner Performance

- Maximal ratio combining issues




- Inaccurate SNR estimation: overwhelm estimator with strong *undesired* signal



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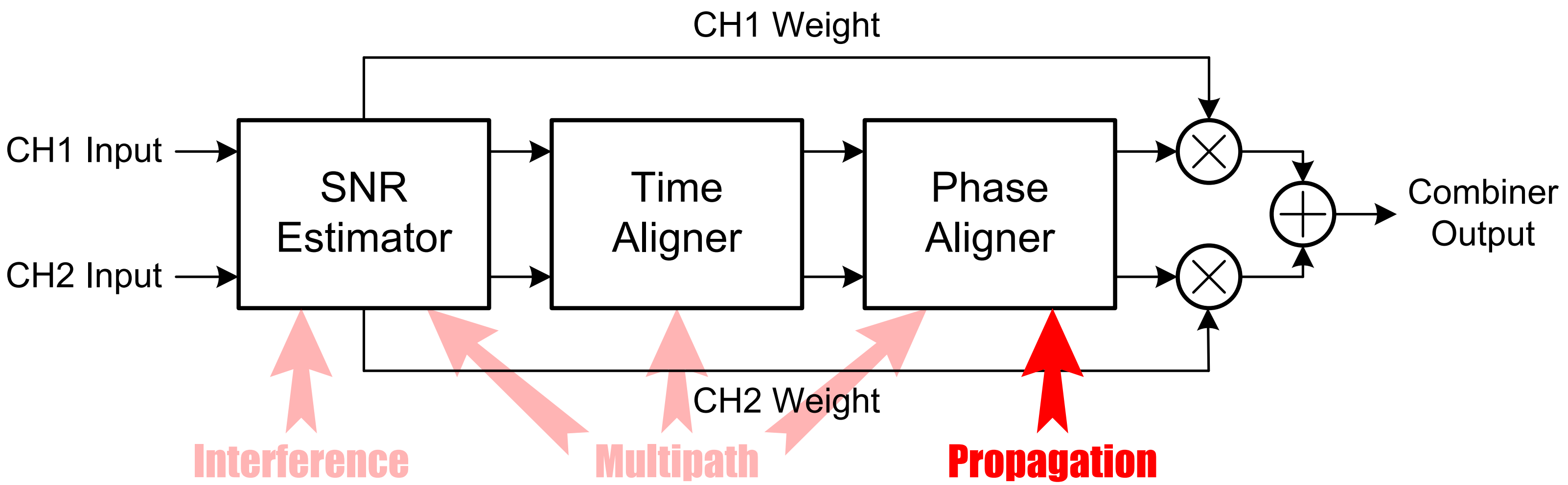
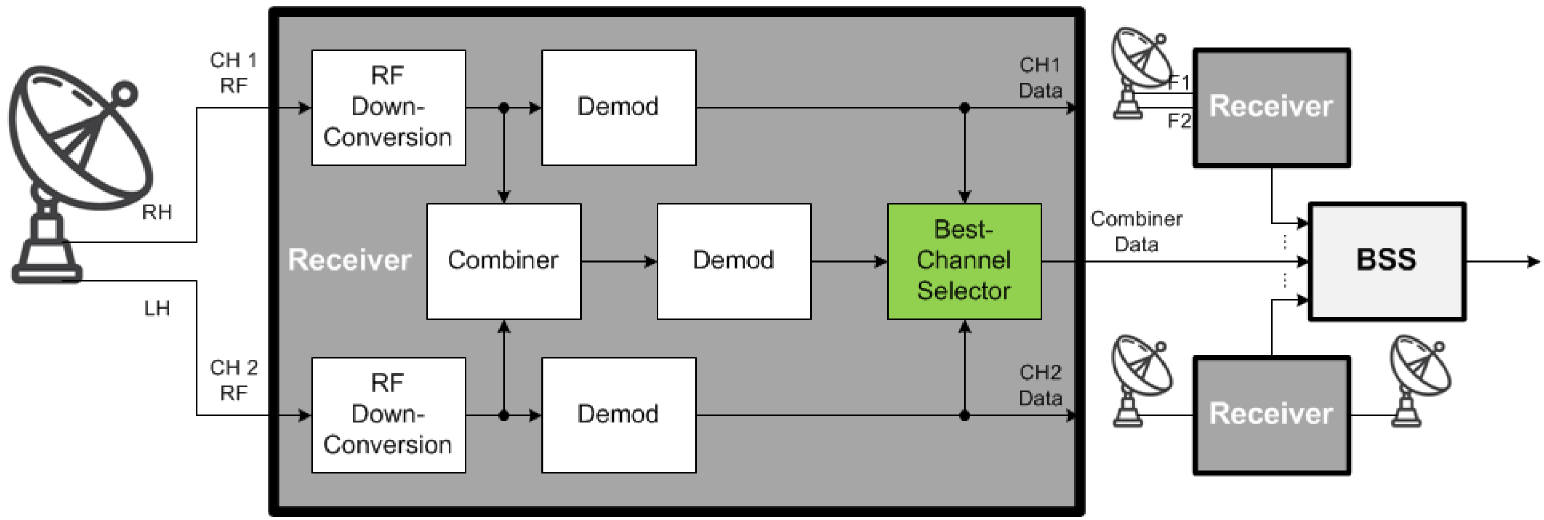
# Combiner Performance

- Maximal ratio combining issues




  - Propagation effects may result in non-combinable signals

# Receive Diversity – BCS

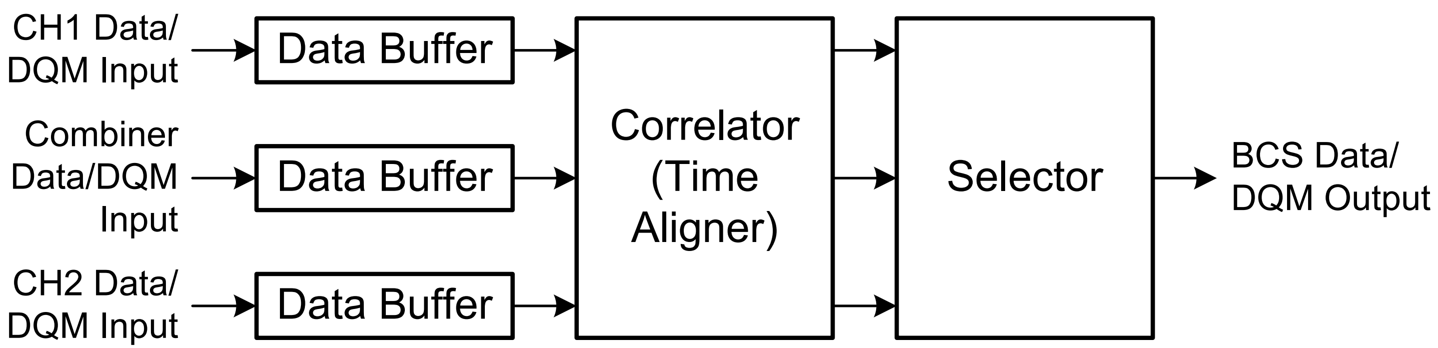



- Like a mini-BSS *inside the receiver*
- Selects and outputs best data from just three sources (Channel 1, Channel 2, and Combiner)
- Optimized for this narrowly scoped role

# BCS Structure

- 3-channel correlating selection

"hit-less" – no dropped or duplicated bits

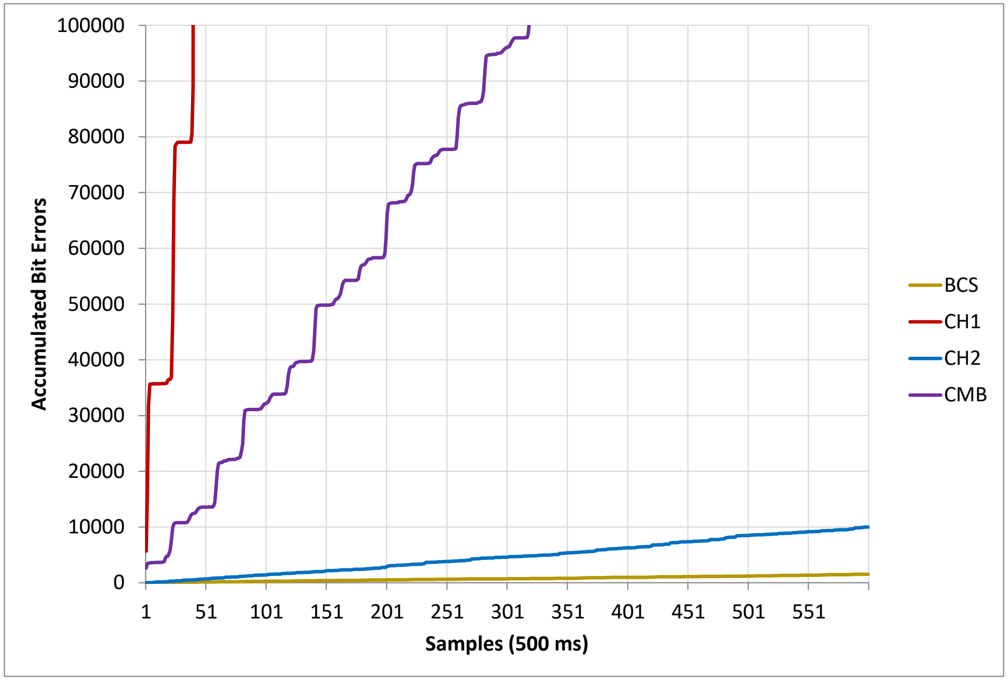



line up bits from all channels

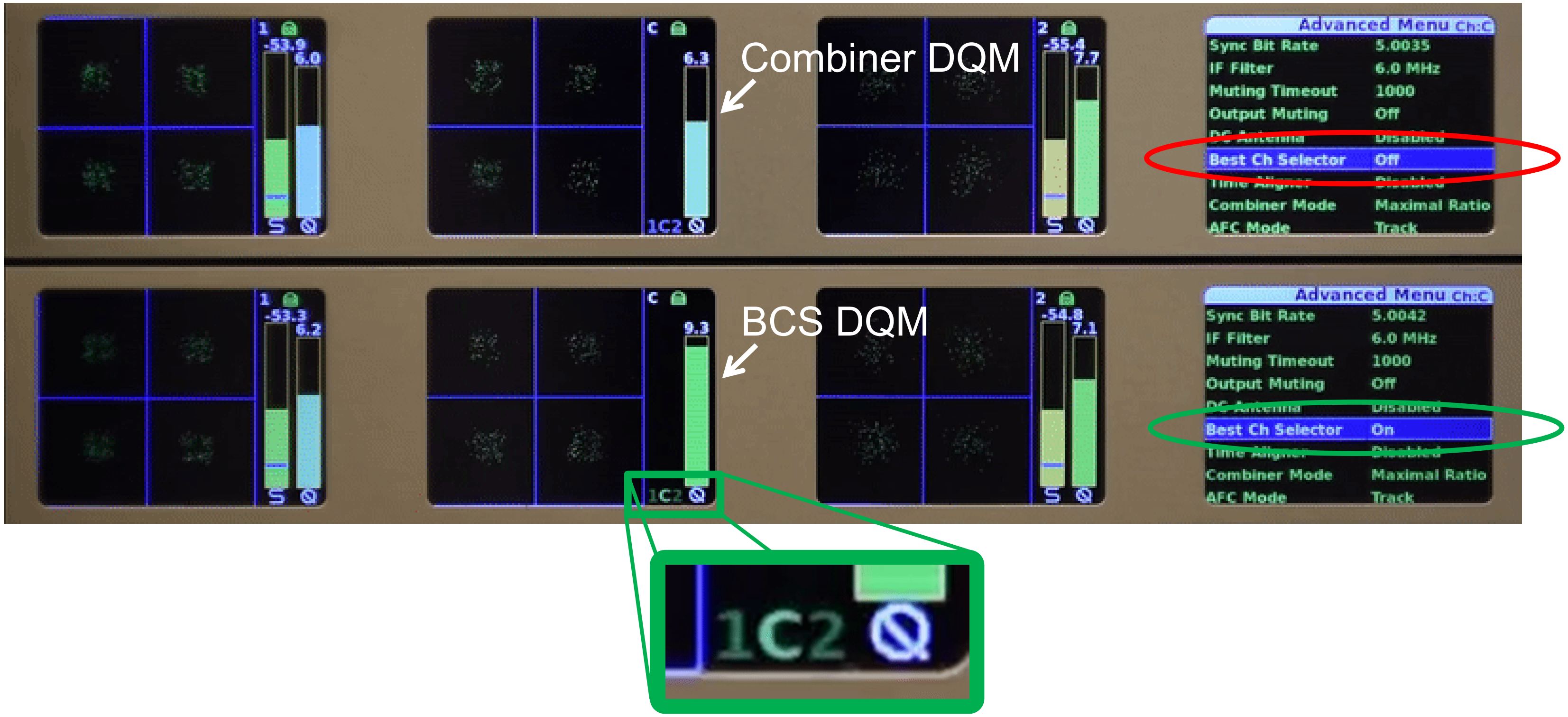
select best bit
based on
best DQM

# BCS Test – Multipath

- Apply severe multipath, engage adaptive equalization
- BCS outperforms all channels



# BCS Test – Multipath

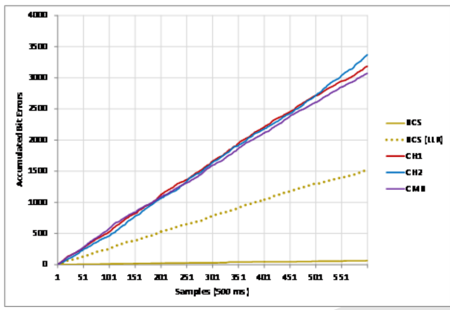



- DQM reduction of 1 = BER increase of 10x (!)
- BCS selection > 1000x faster than display

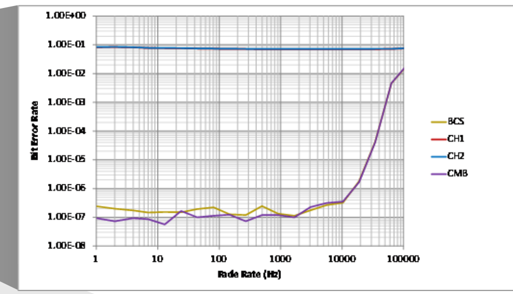
# BCS Test – Summary

- Uniformly equals or exceeds best channel's performance

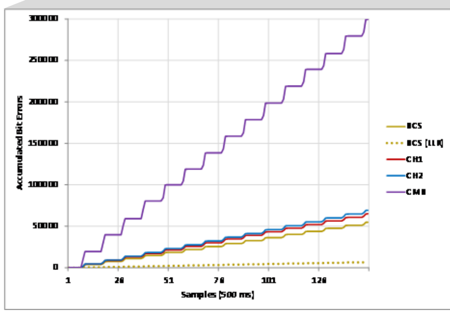
BCS



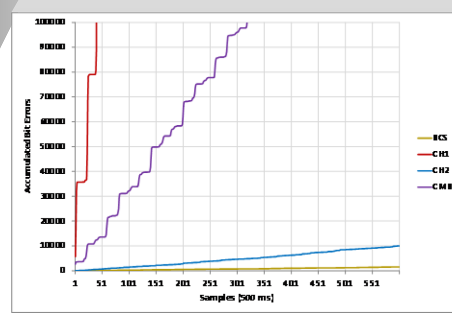

AWGN



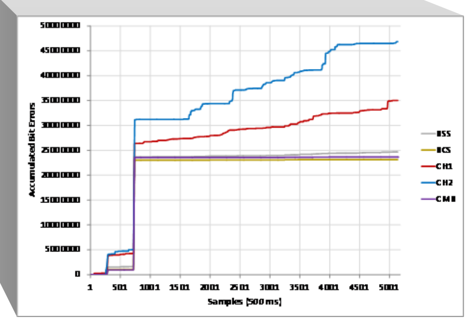

Break Frequency




STC polarization




Multipath




Flight Recording



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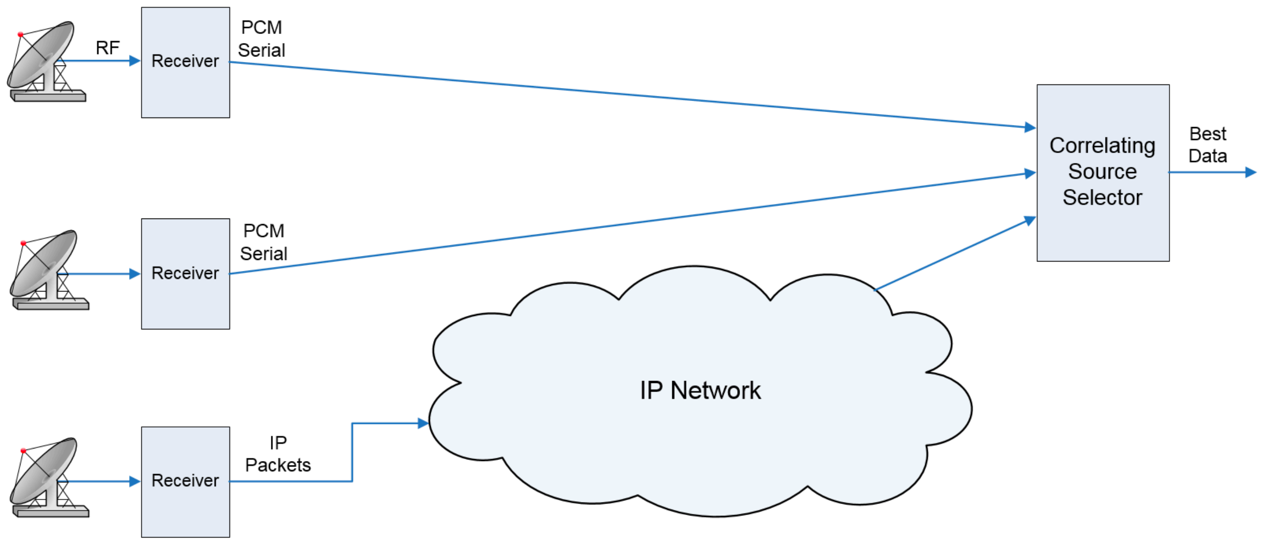
# Conclusions

- Combiner best most of the time, but not always
- BCS mitigates cases where Combiner falls short
  - Uses DQM to form reliable selection criterion
  - Dynamically selects best data from Channel 1, Channel 2, or Combiner
    - Preserves combiner gain in AWGN
    - Supplements combiner in multipath, interference, etc.
  - Generates output with accurate composite DQM
  - **Provides single output from dual-channel receiver that reliably supplies data superior to best channel, including Combiner**
- BCS does not replace BSS
  - BCS has great performance local to one receiver
  - BSS extends performance range-wide with multiple receive sites

# Best Source Selection

# Combining Multiple Sources

- Receive and demodulate the same signal at multiple receive sites
- Funnel all the demodulated data to one central location
- Time align the multiple data streams
- Build a better output stream from the multiple input streams



# Selection Algorithms

- Majority vote
  - Reasonably effective with three or more sources
  - Reduces to guesswork with only two sources
  - Sub-optimal for any number of sources
- PCM frame header accuracy
  - Uses only a small fraction of the bits to make an estimate
  - Poor resolution (BER is typically measured as Num_errors ÷ 32)
  - Useless with encrypted data
- Log-likelihood ratio
  - Uses all the bits
  - Works with encrypted data
  - Max-likelihood (optimal) combining scheme
    - Rice, Michael and Perrins, Erik. *"Maximum Likelihood Detection From Multiple Bit Sources"*, Proceedings of the International Telemetering Conference, Las Vegas, NV, USA, 2015.

# Why Measure Data Quality?

- Telemetry links suffer from a wide range of impairments
  - Noise
  - Interference
  - Multipath
  - Shadowing
  - Loss of antenna track
- We need a way to asses the impact of *all* these impairments
- We need to compute $p_n$
  - Quickly
  - Accurately

$$
\begin{aligned}
\hat{x} = 0 \iff & \prod_{n\in\mathcal{N}_0} p(y_n|x=0) \prod_{n\in\mathcal{N}_1} p(y_n|x=0) > \prod_{n\in\mathcal{N}_0} p(y_n|x=1) \prod_{n\in\mathcal{N}_1} p(y_n|x=1) \\
\iff & \prod_{n\in\mathcal{N}_0} (1-p_n) \prod_{n\in\mathcal{N}_1} p_n > \prod_{n\in\mathcal{N}_0} p_n \prod_{n\in\mathcal{N}_1} (1-p_n) \\
\iff & \log\left(\prod_{n\in\mathcal{N}_0} (1-p_n) \prod_{n\in\mathcal{N}_1} p_n\right) > \log\left(\prod_{n\in\mathcal{N}_0} p_n \prod_{n\in\mathcal{N}_1} (1-p_n)\right) \\
\iff & \sum_{n\in\mathcal{N}_0} \log(1-p_n) + \sum_{n\in\mathcal{N}_1} \log(p_n) > \sum_{n\in\mathcal{N}_0} \log(p_n) + \sum_{n\in\mathcal{N}_1} \log(1-p_n) \\
\iff & \sum_{n\in\mathcal{N}_0} \log(1-p_n) - \sum_{n\in\mathcal{N}_0} \log(p_n) > \sum_{n\in\mathcal{N}_1} \log(1-p_n) - \sum_{n\in\mathcal{N}_1} \log(p_n) \\
\iff & \sum_{n\in\mathcal{N}_0} \log\left(\frac{1-p_n}{p_n}\right) > \sum_{n\in\mathcal{N}_1} \log\left(\frac{1-p_n}{p_n}\right).
\end{aligned}
$$

Rice, Michael and Perrins, Erik. "Maximum Likelihood Detection From Multiple Bit Sources", Proceedings of the International Telemetering Conference, Las Vegas, NV, USA, 2015.

# Terminology

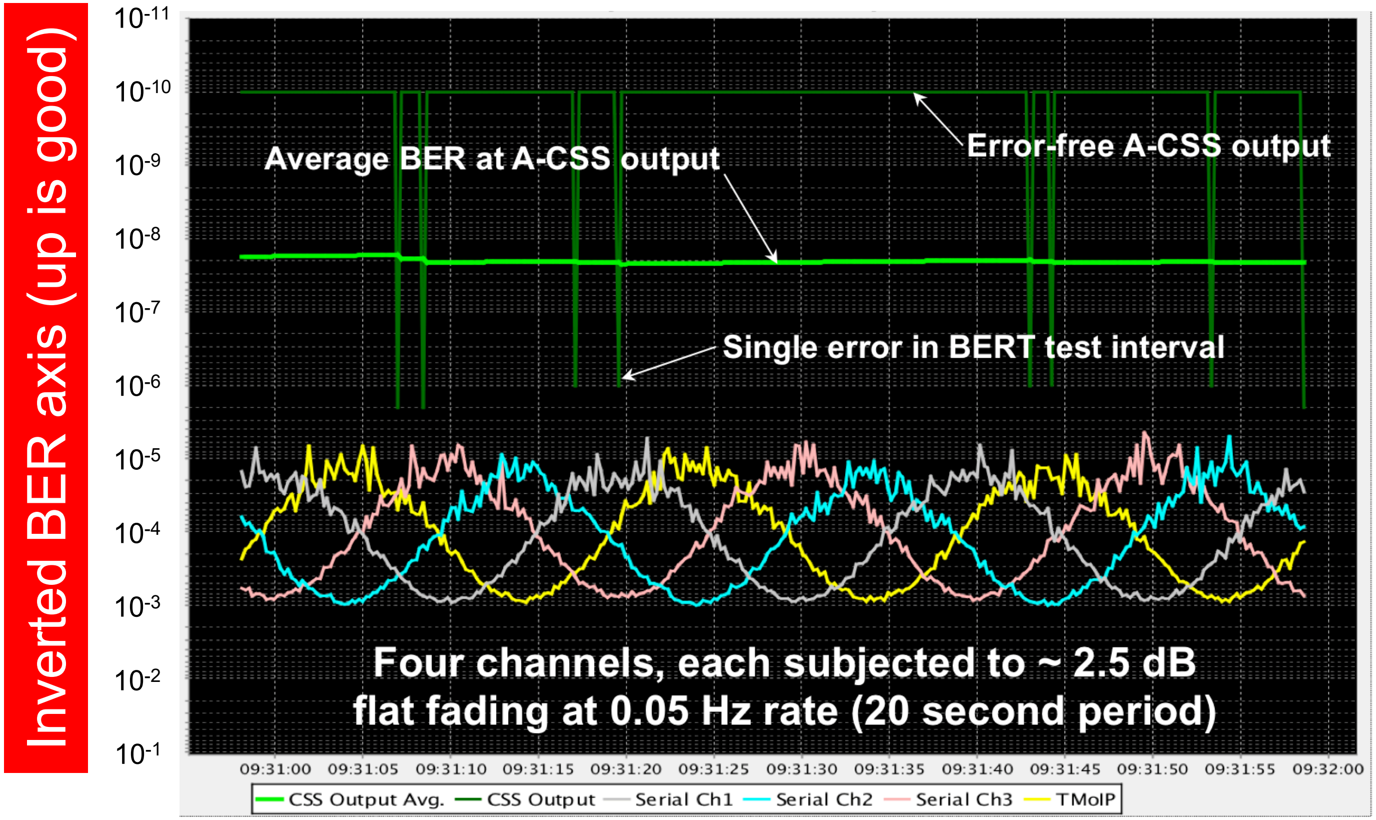
- BER (Bit Error Rate)
  - *Measured* as (number of errors / number of bits)
  - Assumes you know the data in advance
  - Measuring very low BER requires a long time
  - Converges to BEP if test runs long enough, *and channel is static*
- BEP (Bit Error Probability)
  - *Calculated* likelihood that a bit is in error
  - Even very low BEP can be determined from only a few bits
- DQM (Data Quality Metric)
  - Derived directly from BEP
  - Expressed as a 16-bit integer
- DQE (Data Quality Encapsulation)
  - Process of “bundling” DQM words and payload data
  - Includes a sync word to identify the start of the DQE frame

# Data Quality Encapsulation

- Payload data is bundled with its DQM, to give Best Source Selectors a valid basis for “best”
- Interoperability among vendors requires standards
  - DQM calibration against multiple signal impairments
  - DQE packet structure
- Quasonix has developed and shared an open DQM/DQE format
  - Published at ITC 2015
  - License-free, royalty-free
  - RCC standard as of IRIG 106-17, Chapter 2, appendix G
- Includes test procedures to evaluate DQM accuracy

# Does it work?

- Four “poor” channels for input to BSS
- One nearly error-free output from BSS



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# BSS Summary

- Correlating (time-aligning) source selectors deliver output data that is better than any single input stream
- Combats *all* forms of signal impairment
  - Noise
  - Multipath
  - Interference
  - Shadowing
  - Loss of antenna track
- Diversity can be in any form
  - Polarization
  - Frequency
  - Spatial
- DQE / DQM equip the BSS to make optimal decisions

# Rx/TX DSP Techniques

# Rx/Tx DSP Techniques

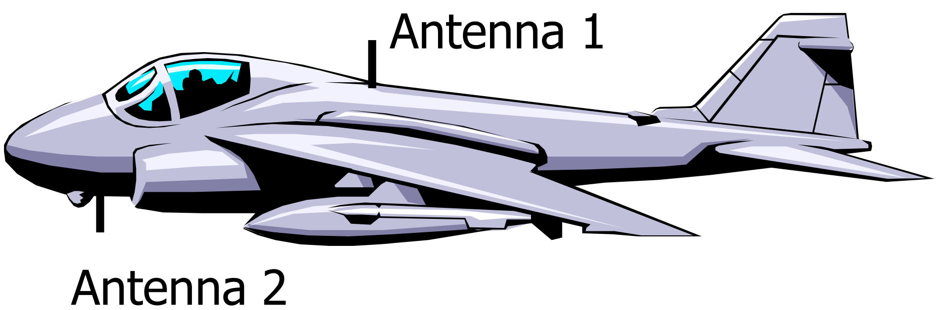
- If you can choose your transmitter…
- Space-time coding (STC)
  - Mitigates “built-in” multipath from dual TX antennas
  - Requires dual transmitters
- Forward error correction
  - Spending bandwidth to buy link margin
  - Requires encoder implemented in transmitter

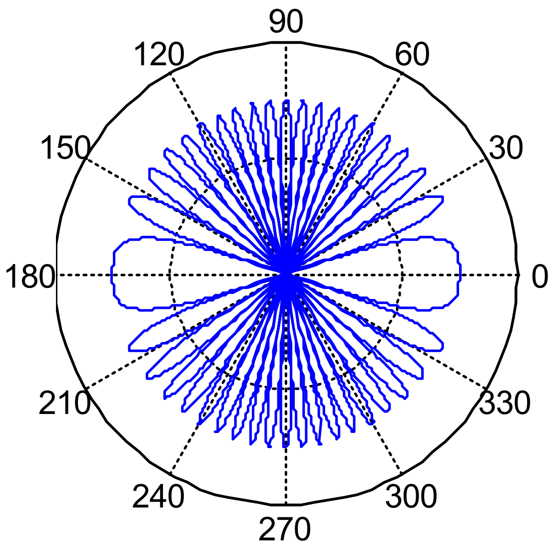
# Space-Time Coding

**Eradicates Porcupines!**

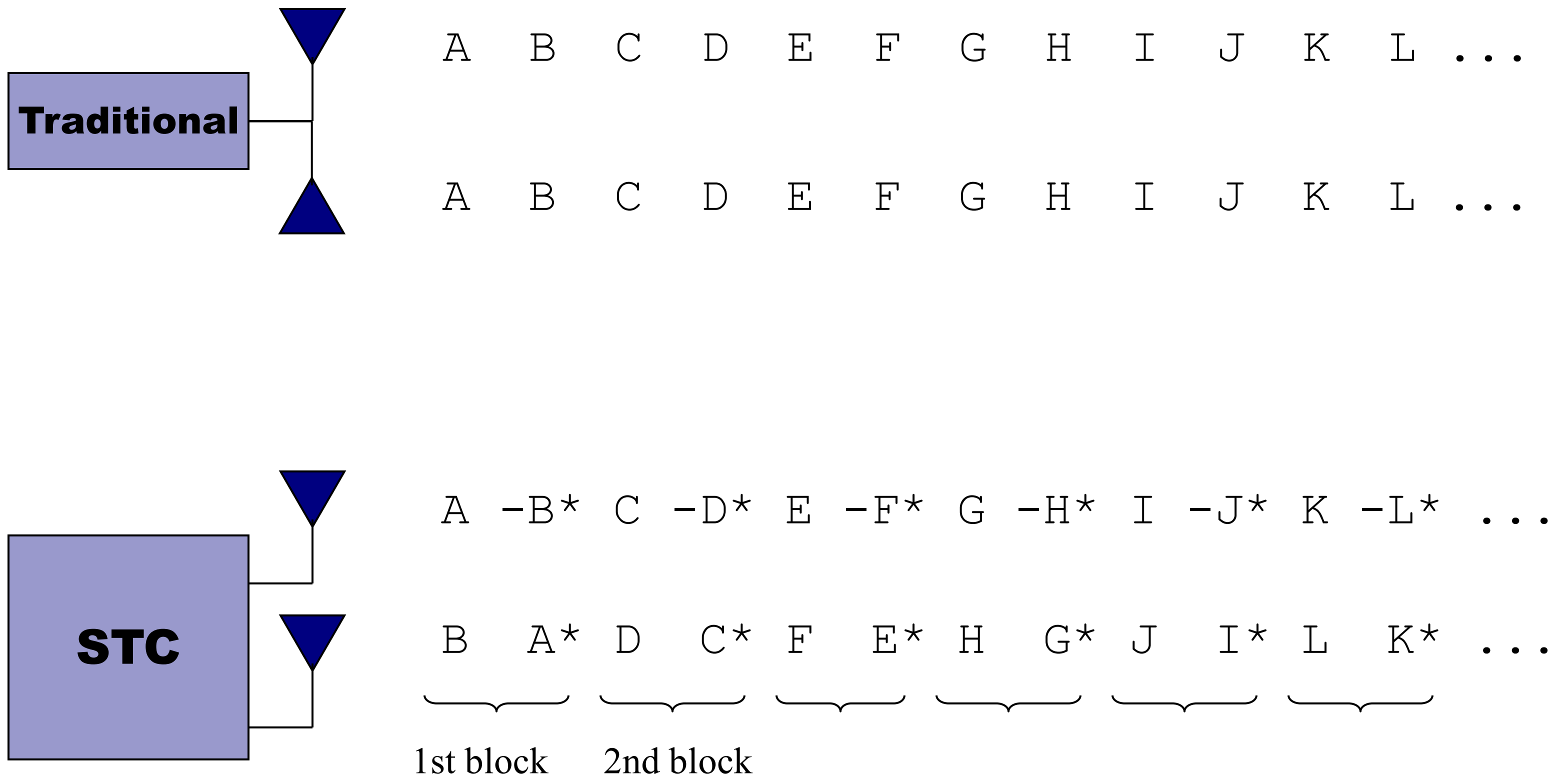
# Difficulties with TX Diversity

**Spatially Separated Antennas Create Interference Pattern**



# Alamouti Space-Time Coding (STC)



# Symbol Error Rate - QPSK

## Traditional signaling

$$P(E\mid\theta)=\frac{1}{2\pi}\int_0^{2\pi}2Q\left(\sqrt{\frac{E_s}{N_o}\frac{\left|h_1(\theta,\phi)+h_2(\theta,\phi)\right|^2}{2}}\right)d\phi$$

Addition of transfer functions leads to reduction in effective SNR

## For Alamouti signaling

$$P(E\mid\theta)=\frac{1}{2\pi}\int_0^{2\pi}2Q\left(\sqrt{\frac{E_s}{N_o}\frac{\left|h_1(\theta,\phi)\right|^2+\left|h_2(\theta,\phi)\right|^2}{2}}\right)d\phi$$

Only magnitudes of transfer functions used in sum

# Antenna Pattern Interpretation

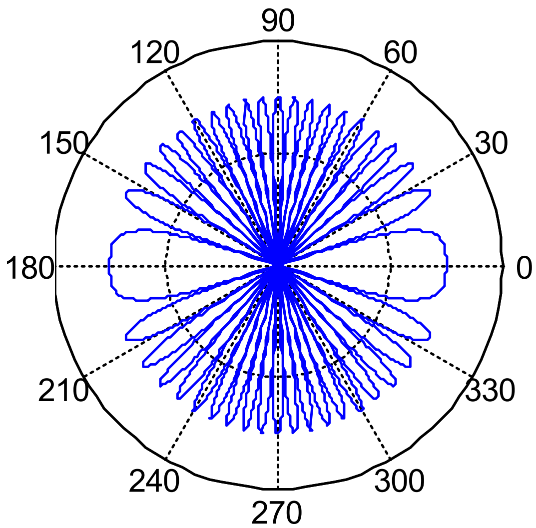
**Consider BPSK Signaling and Assume** $s_1 = s_2 = 1$

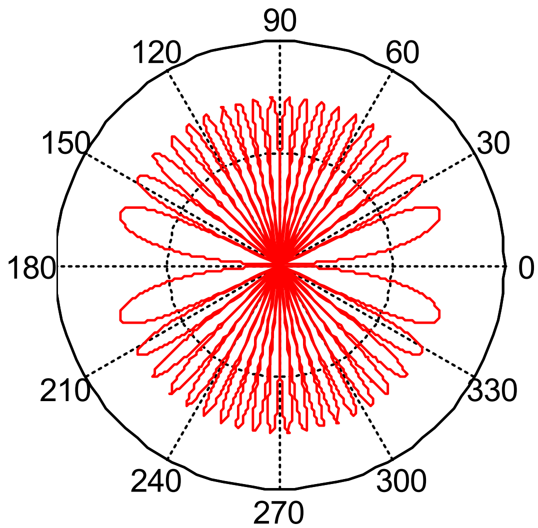
Time Slot 1:

Gain Pattern: $$G_{t1}(\phi) = 2\cos^2\left[\frac{kd}{2}\cos\phi\right]$$

Time Slot 2:

Gain Pattern: $$G_{t2}(\phi) = 2\sin^2\left[\frac{kd}{2}\cos\phi\right]$$







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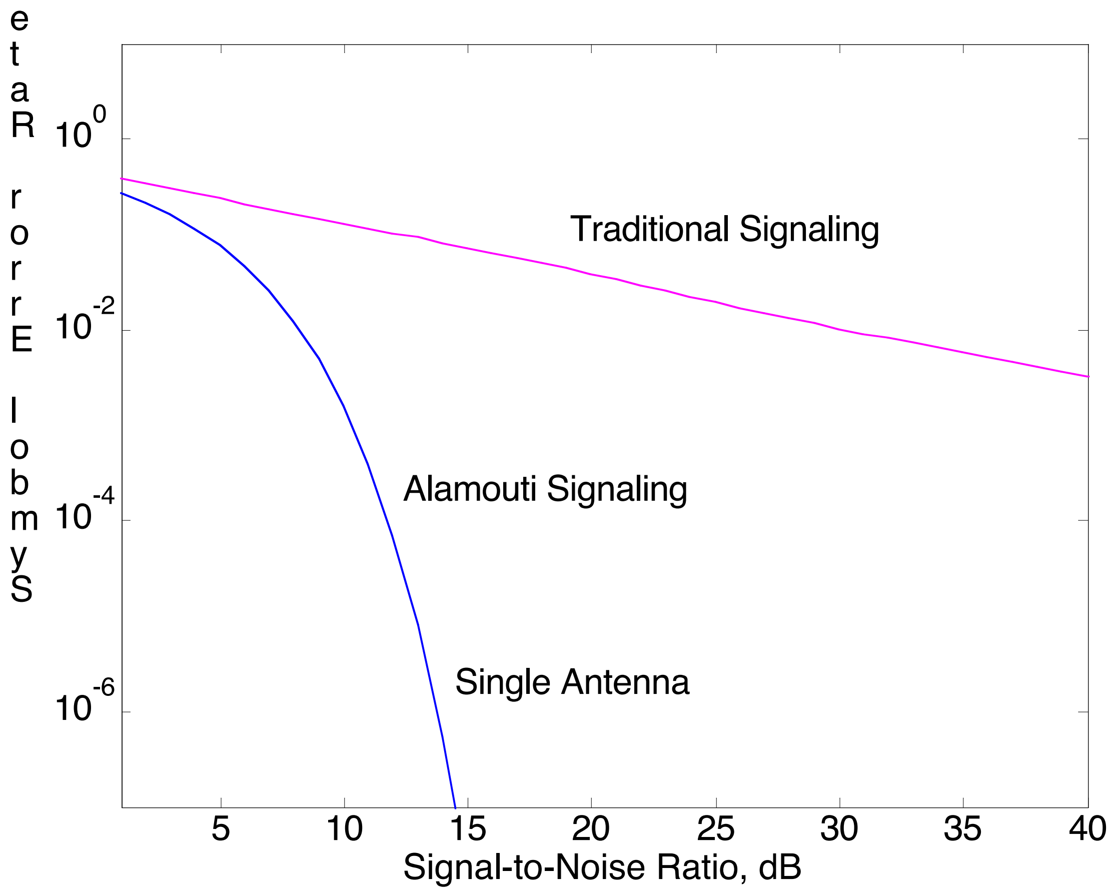
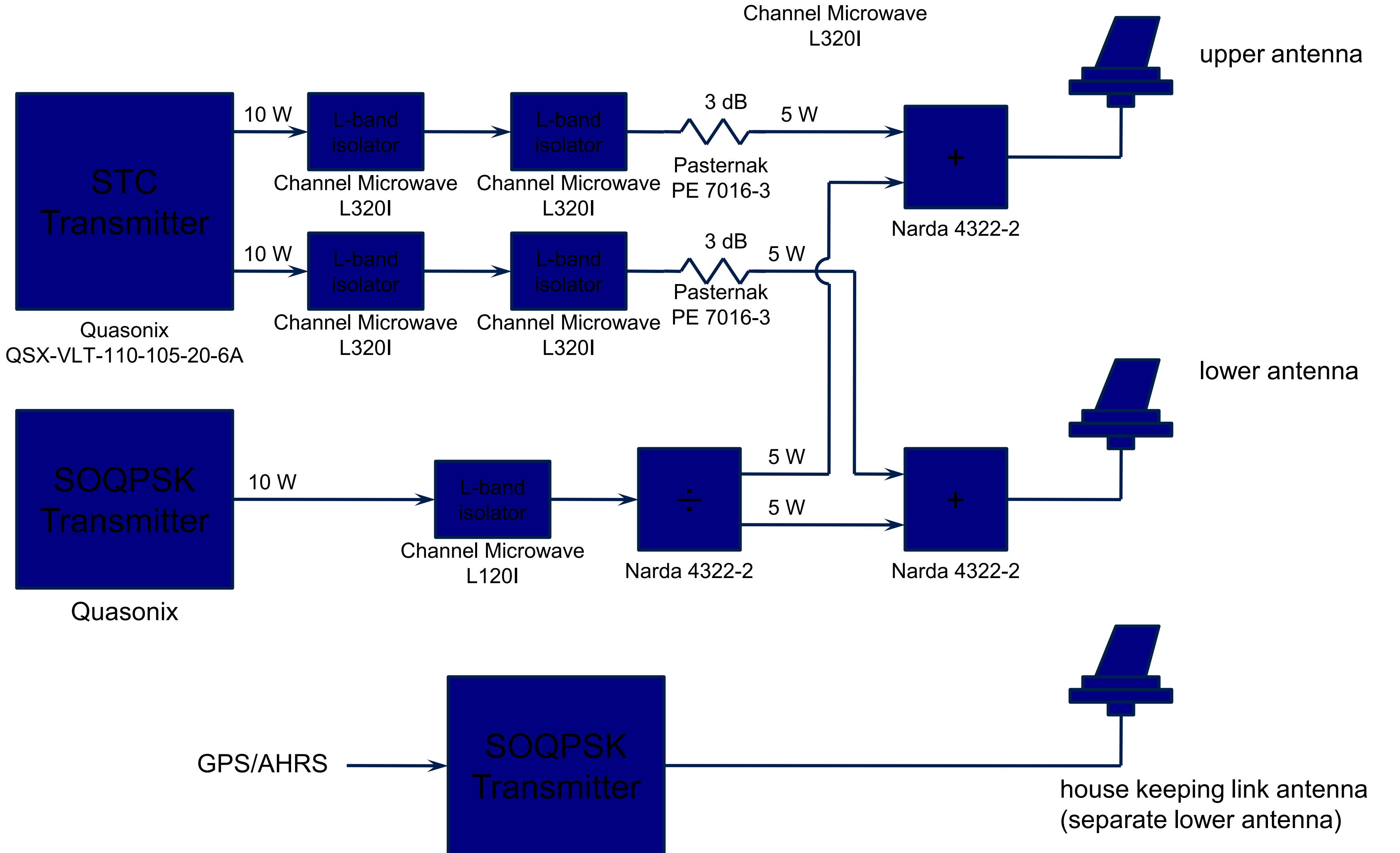
# SER Simulations




**Circular Polarization Diversity Reception**

**Results Identical to Single Receive Antenna System**

# Flight Tests: Airborne Configuration

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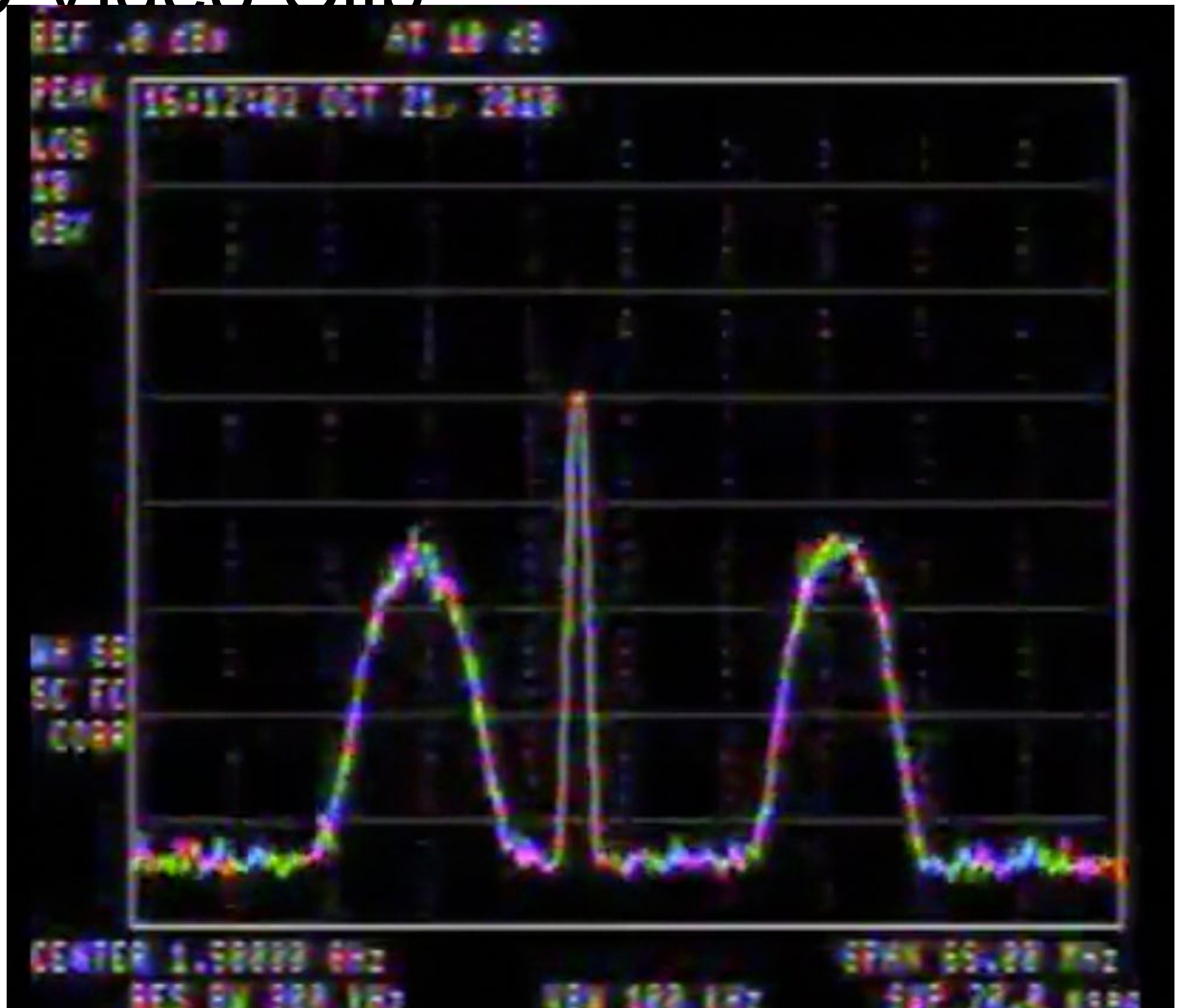
# C-12 Beechcraft: Airborne Platform

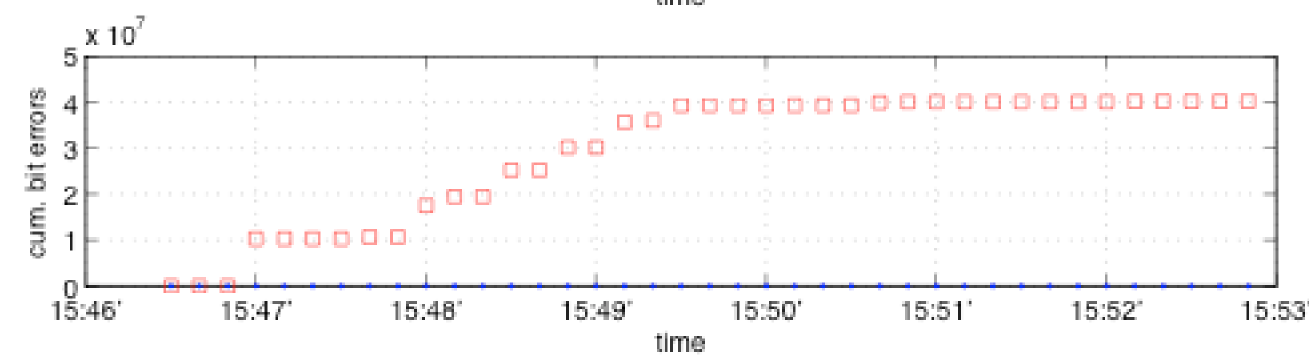
# STC Video Clip



# STC Summary

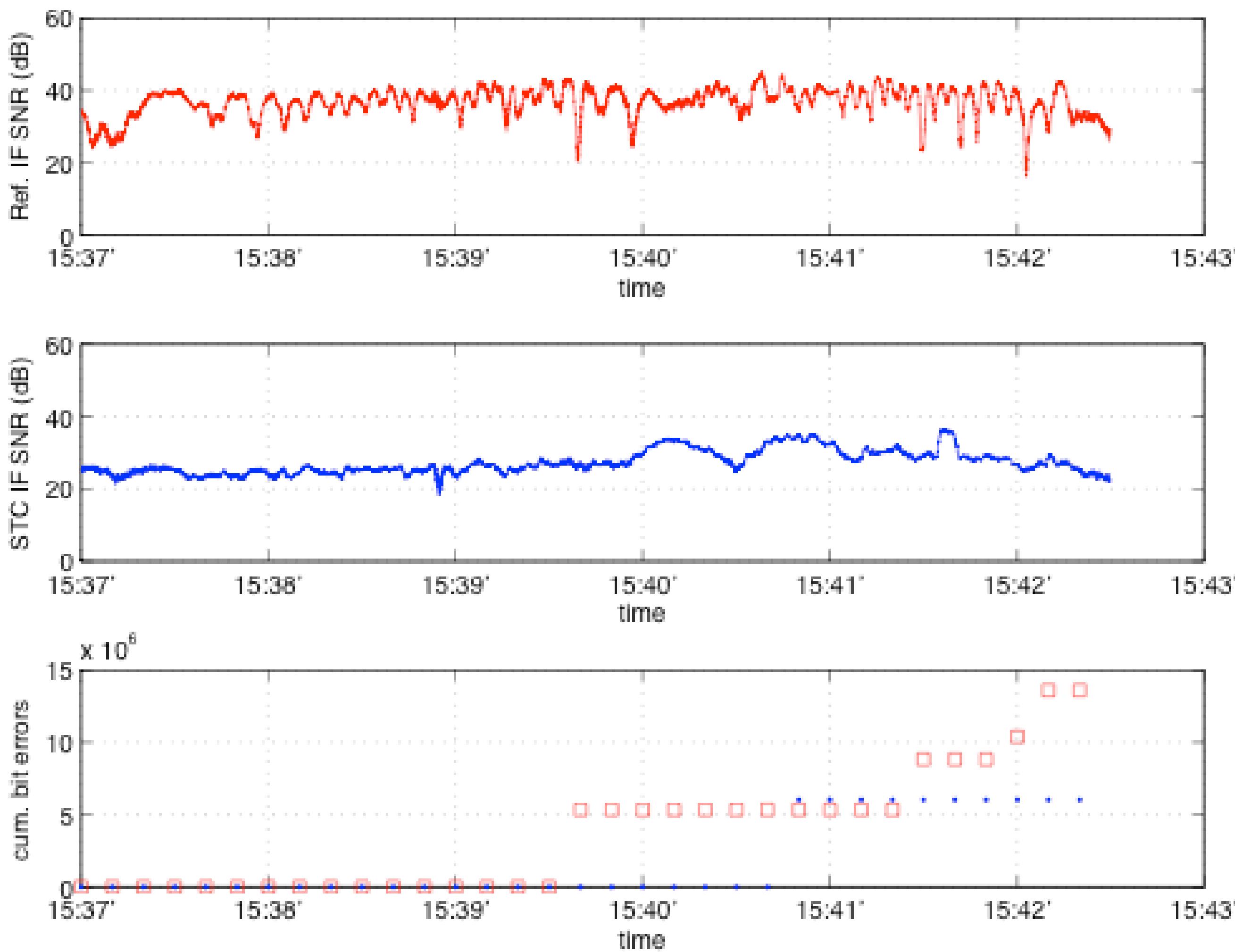
- Dual-Antenna Diversity Scheme
- Removes dropouts created by multiple transmit antennas
  - SNR equivalent to single antenna transmission
  - Multi-antenna scheme alleviates masking during maneuvering
  - Can be used with diversity reception
- Realtime hardware flight tested at Edwards AFB and showed substantial performance benefit

# M1: Test Results

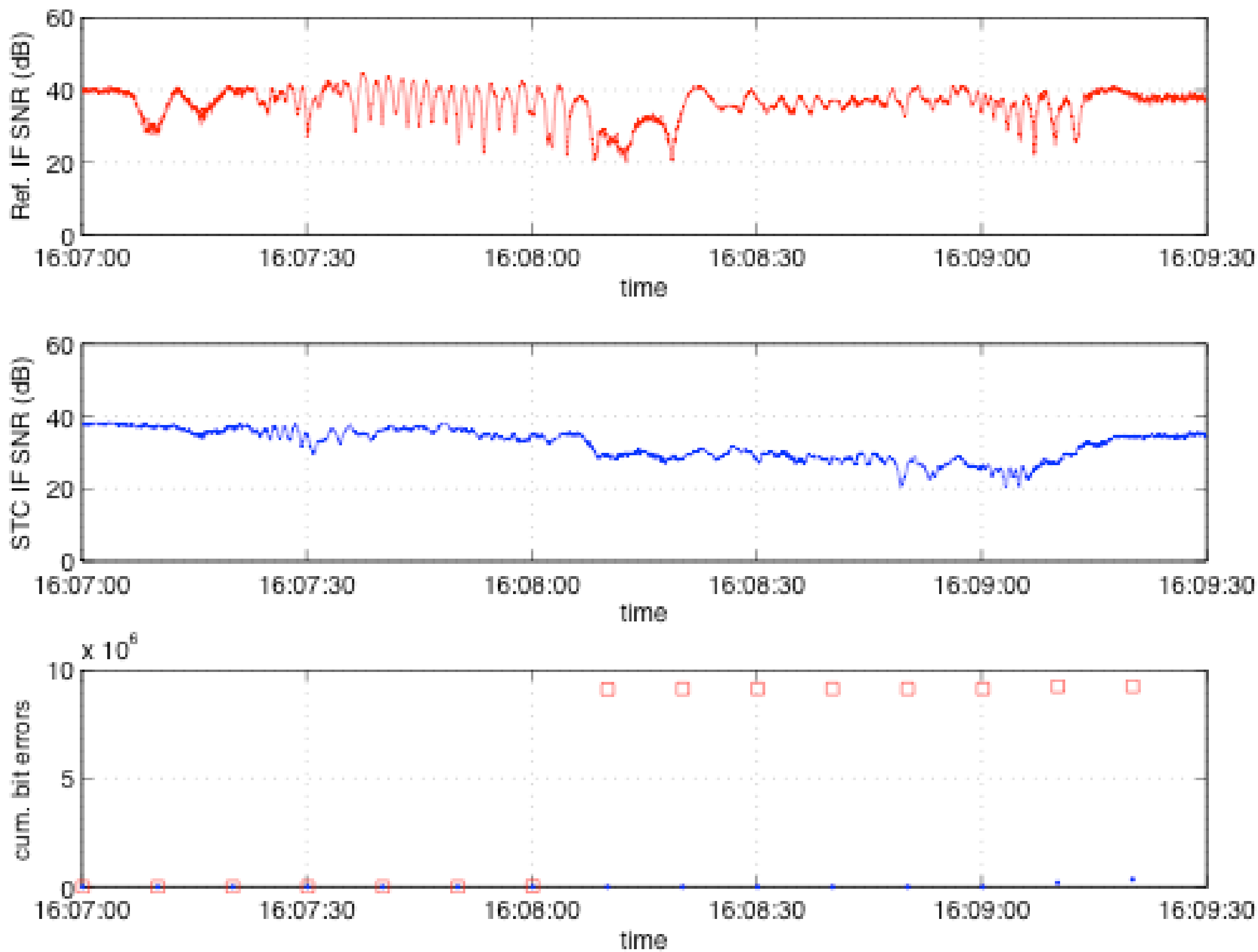



QUASONIX

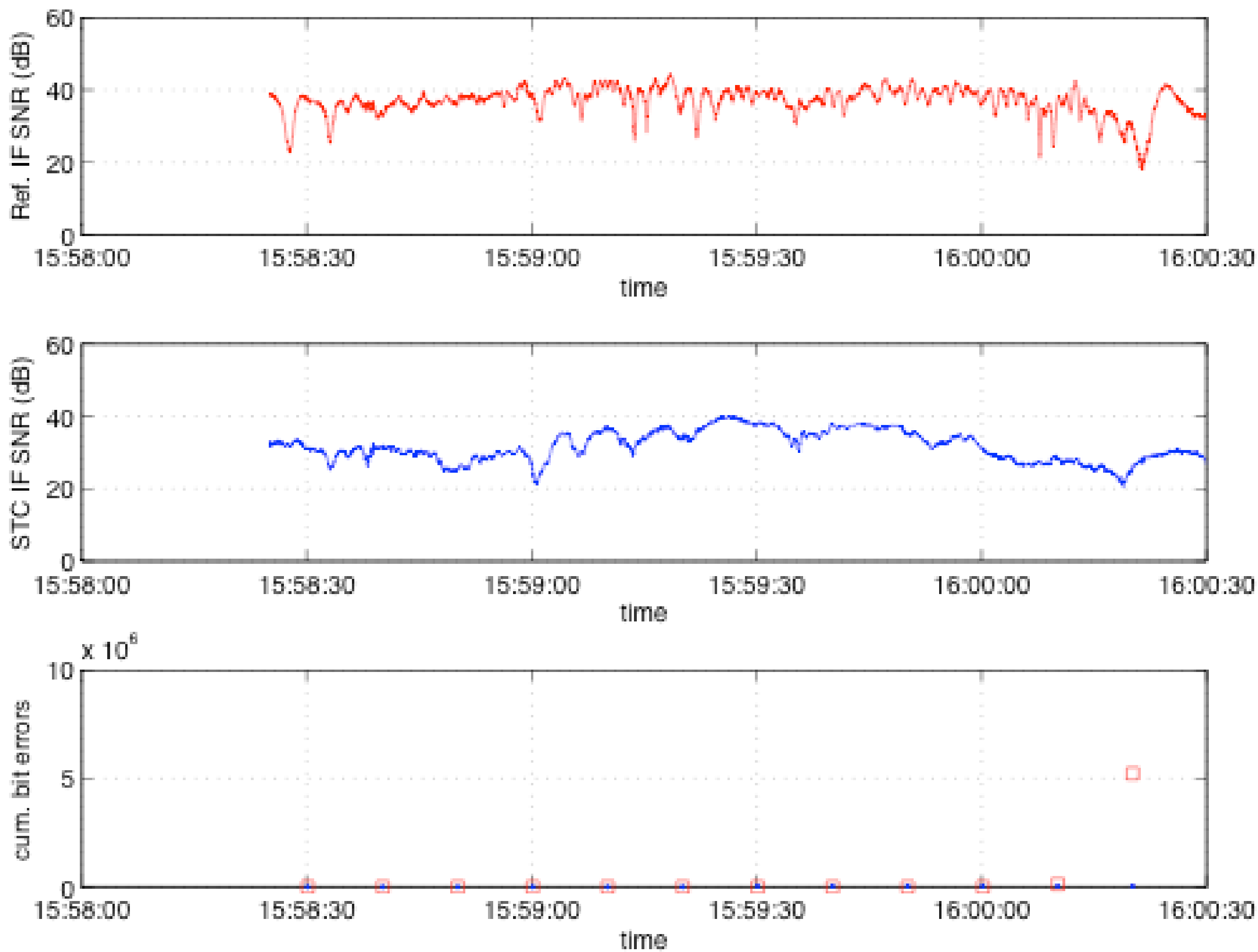
# M2: Test Results



# M3: Test Results



# M4: Test Results







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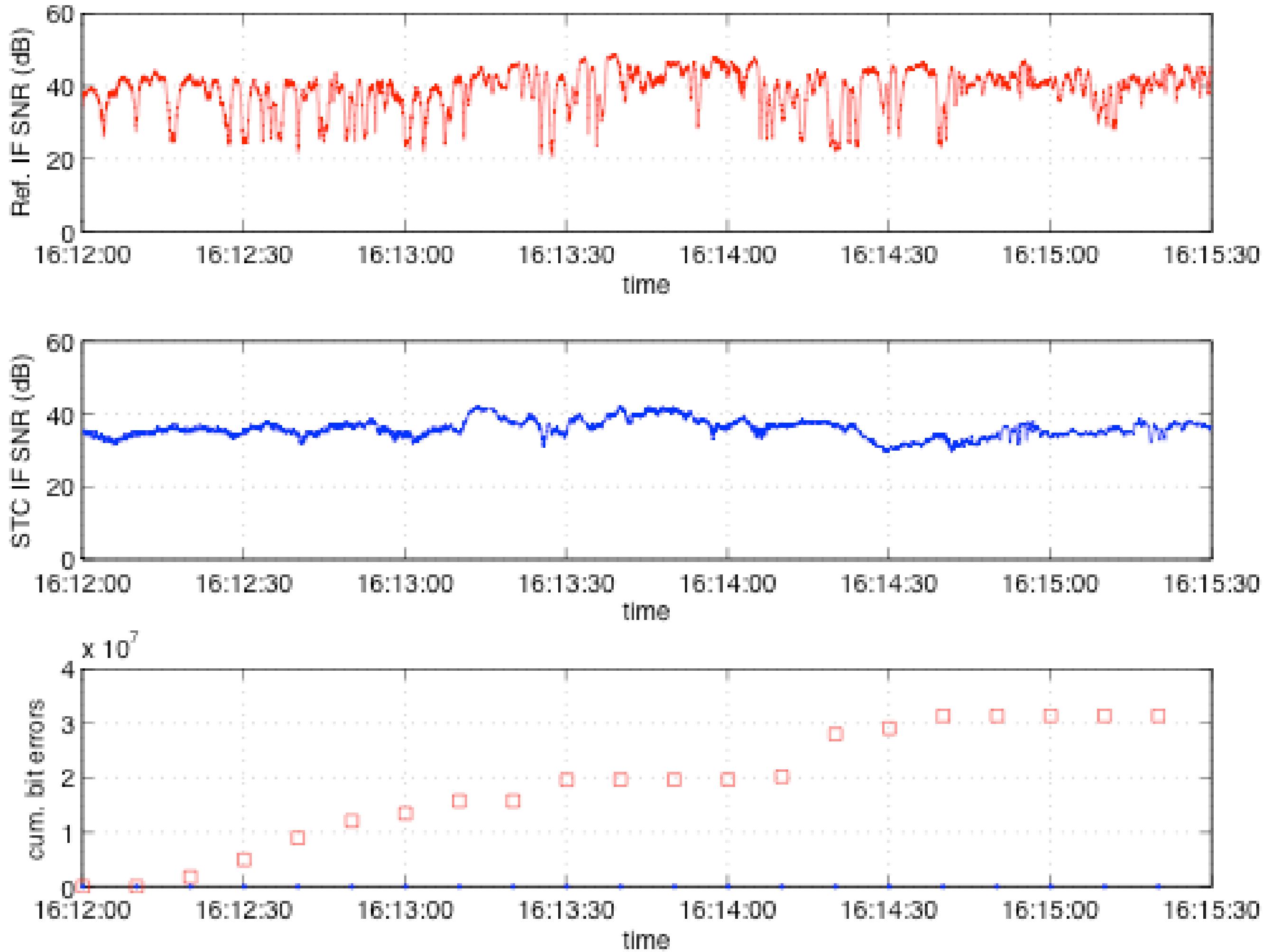
# M3 to C2 Transition Test Results



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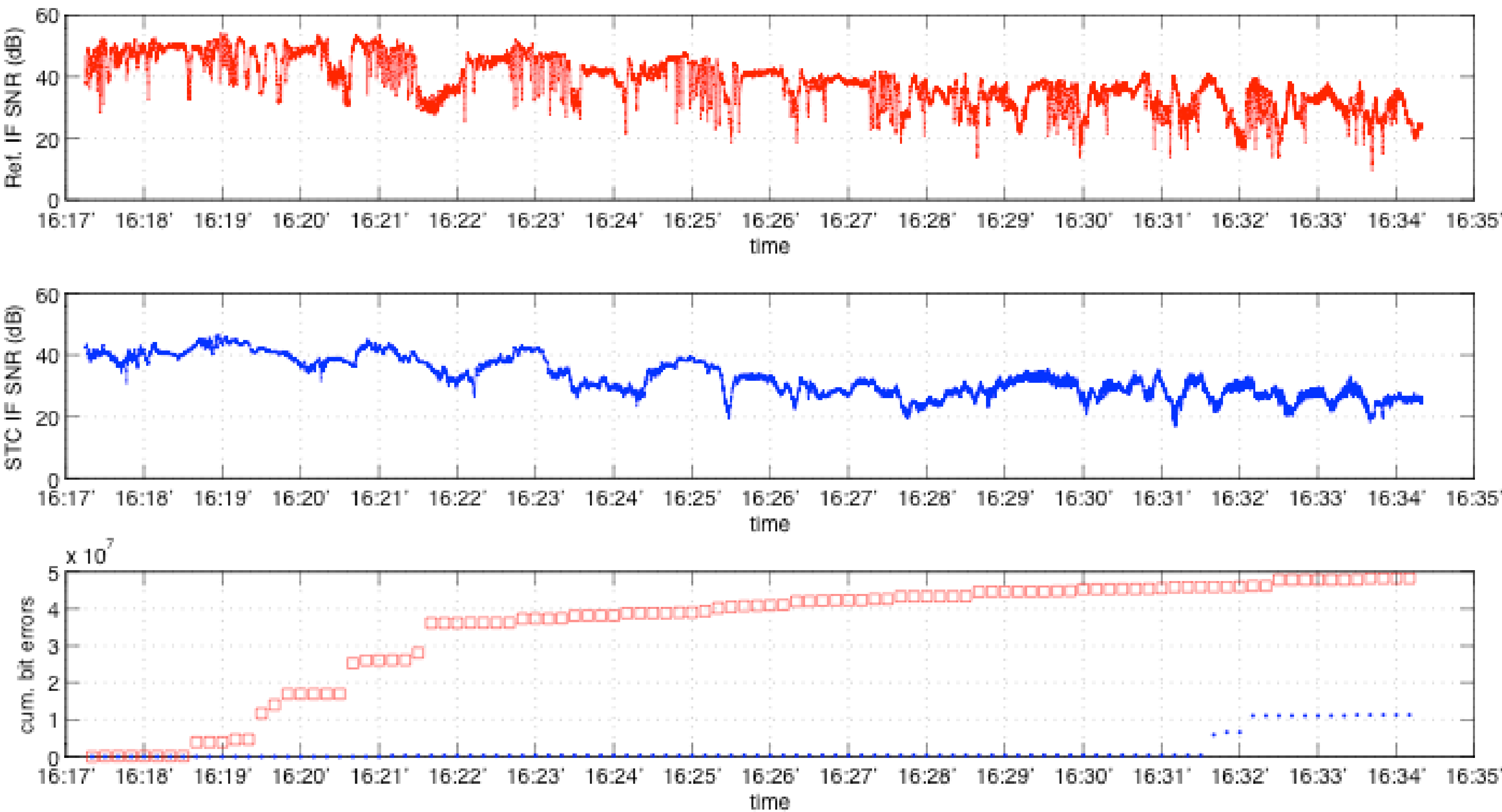
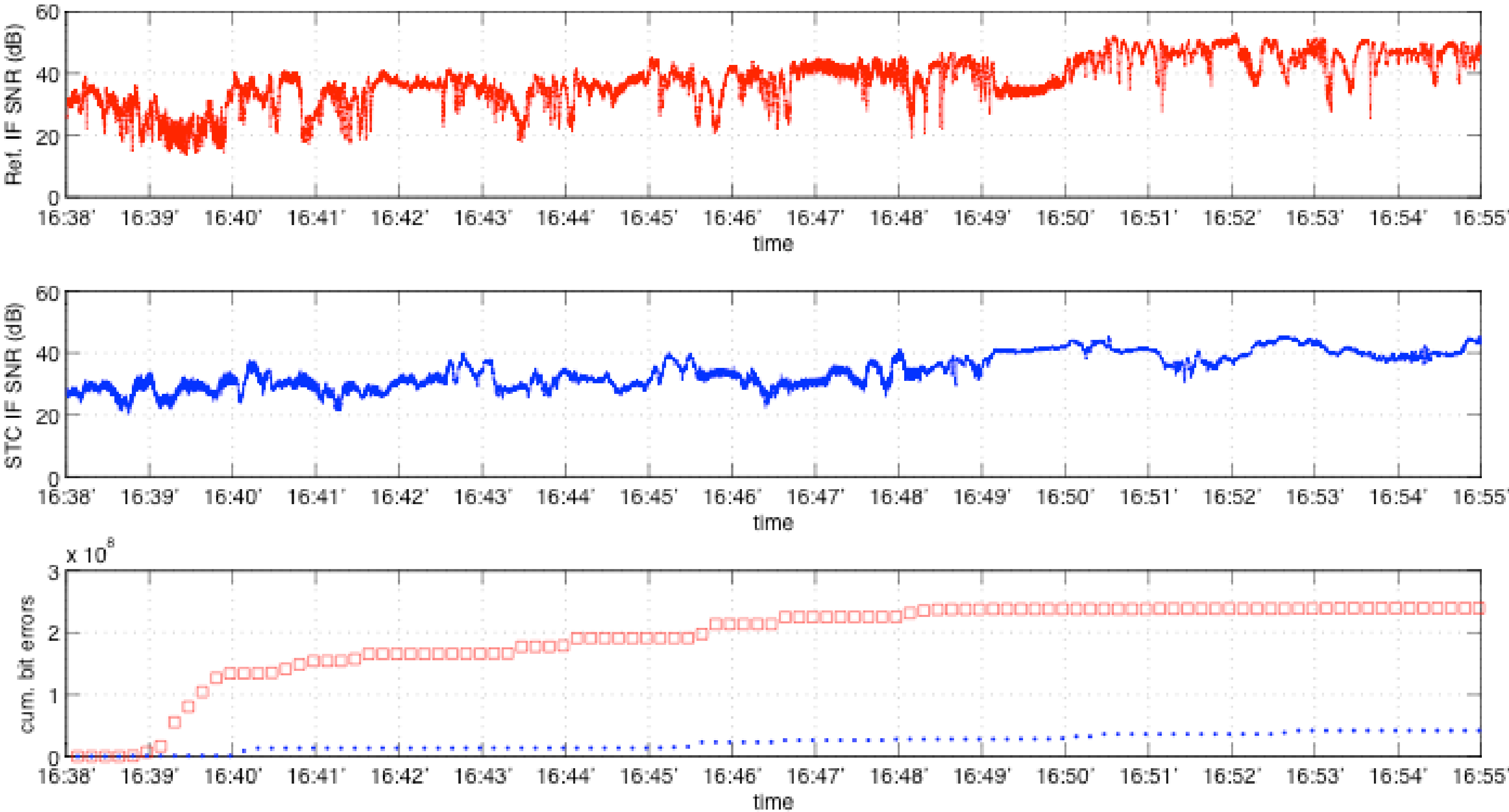
# C2: Test Results



# D2: Test Results



# STC Summary

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  - Can be used with diversity reception
- Realtime hardware flight tested at Edwards AFB and showed substantial performance benefit

# Forward Error Correction

# Forward Error Correction

- Basic premise
  - Insert redundant bits into transmitted stream
  - Use known relationships between bits to correct errors
- Countless schemes have been developed
  - Convolutional code / Viterbi decoder
  - Block codes
    - BCH
    - Reed-Solomon
  - Concatenated codes
    - RS / Viterbi
    - Turbo product codes (TPC)
  - Low Density Parity Check (LDPC)

# LDPC Codes - History

- LDPC: Low Density Parity Check
- Linear block codes
  - Some are systematic
- Developed by Robert G. Gallager at M.I.T. in 1960
  - Published by the M.I.T Press as a monograph in 1963
- No practical implementations at that time
- Re-discovered by David J.C. MacKay in 1996
  - Began displacing turbo codes in the late 1990s
- Recent history
  - 2003: LDPC code selected for the new DVB-S2 standard for the satellite digital TV
  - 2006: LDPC code selected for 10GBase-T Ethernet (10 Gbps over twisted-pair cables)
  - 2007: LDPC codes published by CCSDS as an “Orange Book”
  - 2008: LDPC code selected for the ITU-T G.hn standard
  - 2009: LDPC codes adopted for Wi-Fi 802.11 High Throughput (HT) PHY specification
  - 2012: LDPC code selected for integrated Network Enhanced Telemetry (iNET)

# LDPC AR4JA Codes

- AR4JA: Accumulate-Repeat-4-Jagged-Accumulate
- Published by CCSDS as an “Orange Book”
  - Low Density Parity Check Codes For Use in Near-Earth and Deep Space Applications
- Defines a family of systematic LDPC codes

| Information block length $k$ | Code block length $n$ | | |
|---|---|---|---|
| | rate 1/2 | rate 2/3 | rate 4/5 |
| 1024 | 2048 | 1536 | 1280 |
| 4096 | 8192 | 6144 | 5120 |
| 16384 | 32768 | 24576 | 20480 |

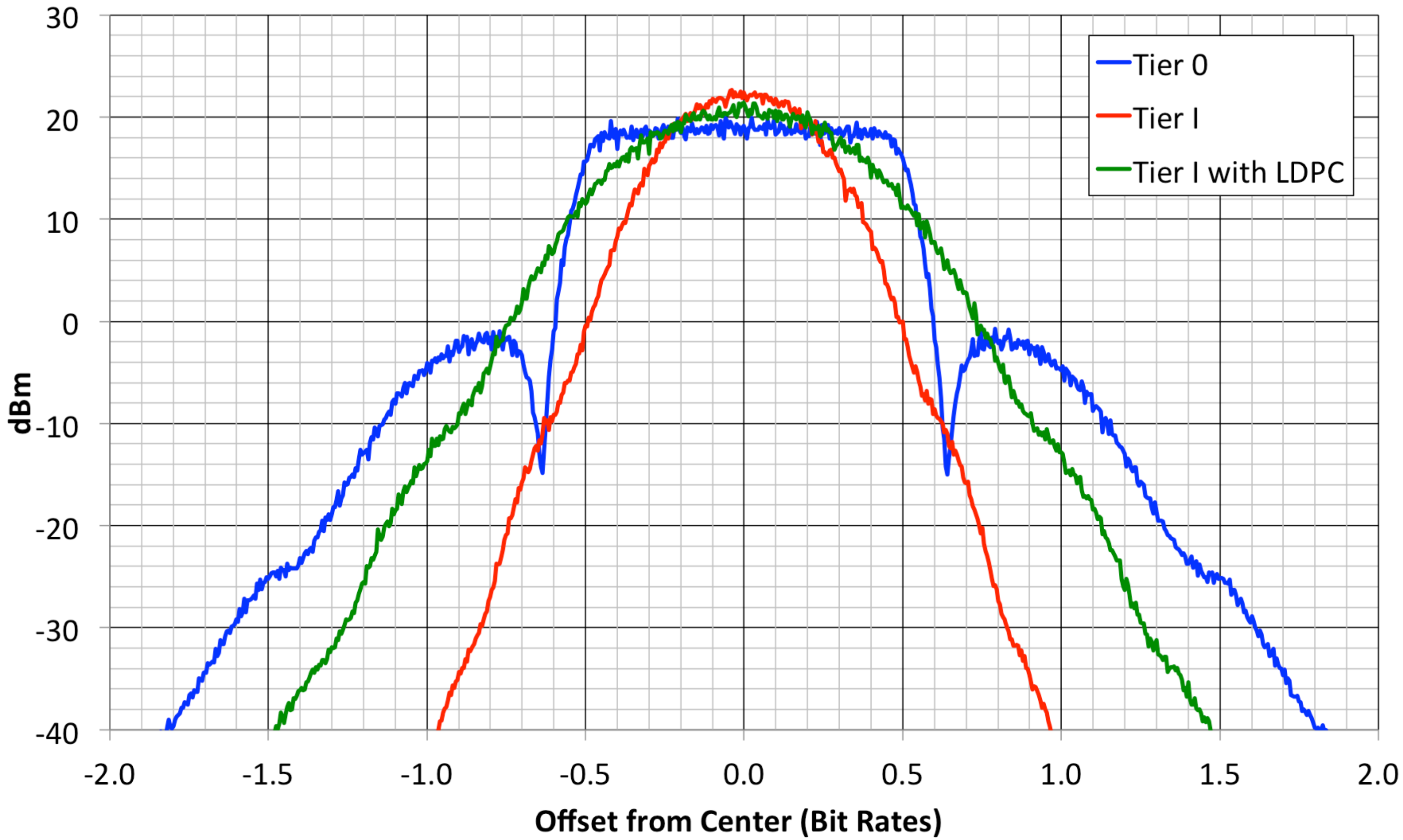
- Defines attached sync markers (ASM)
  - Specified in section 6 of CCSDS Recommended Standard CCSDS 131.0-B-1
- Present work based on the (6144, 4096) code

# Packet Assembly

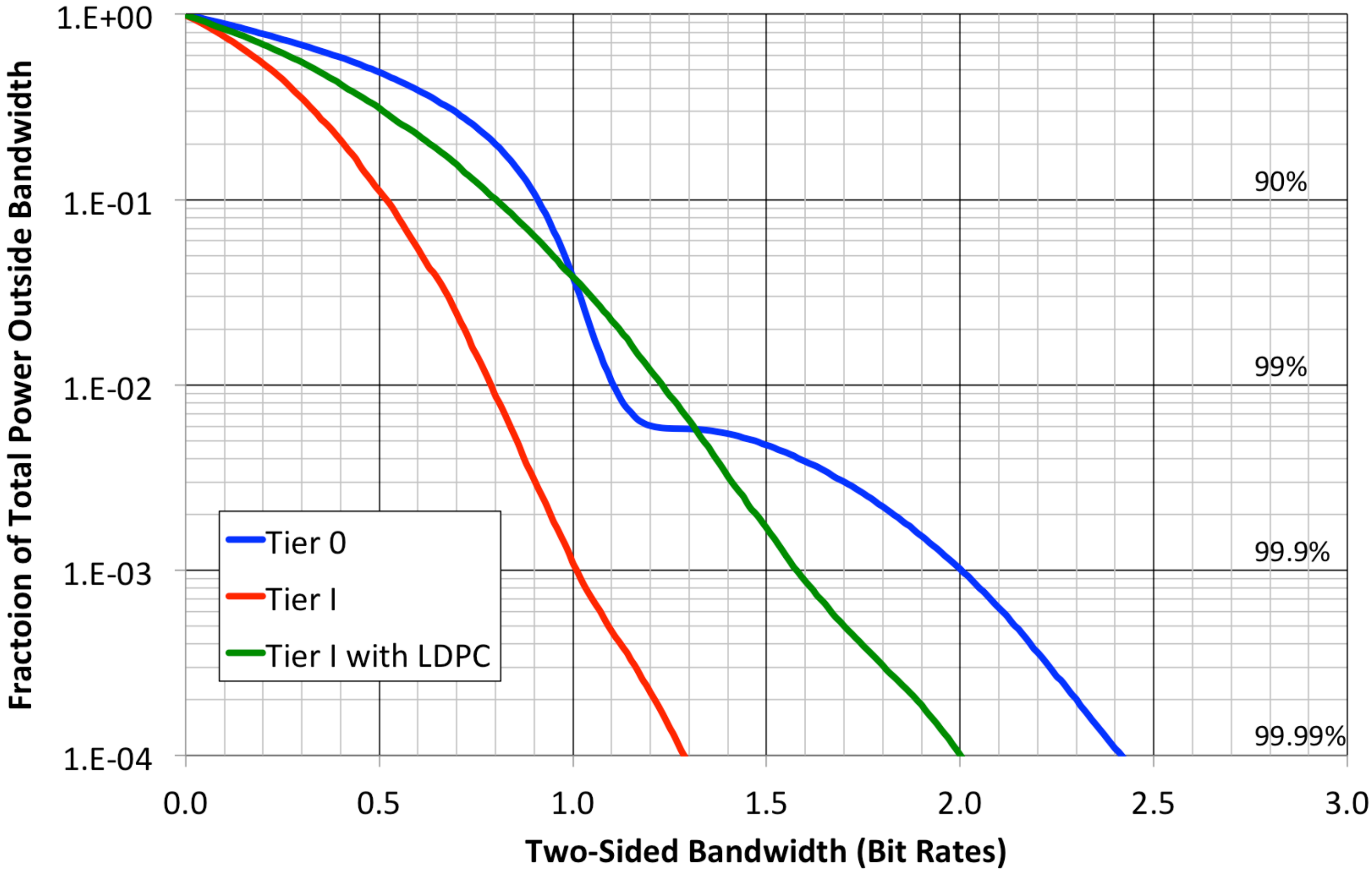
- Input 4096 data bits
  - Randomize prior to encoding, if necessary
- Compute and append 2048 parity bits
- Prepend 256-bit attached sync marker (ASM)
  - Yields a 6400-bit packet
  - Each and every code word carries the ASM:  A, A, Ā, A
    - A = FCB88938D8D76A4F
    - Ā = 034776C7272895B0
  - Synchronization requires at most one code word

| | | | | | |
|---|---|---|---|---|---|
| A | A | Ā | A | 4096 Data Bits | 2048 Parity bits |

# Spectral Characterization



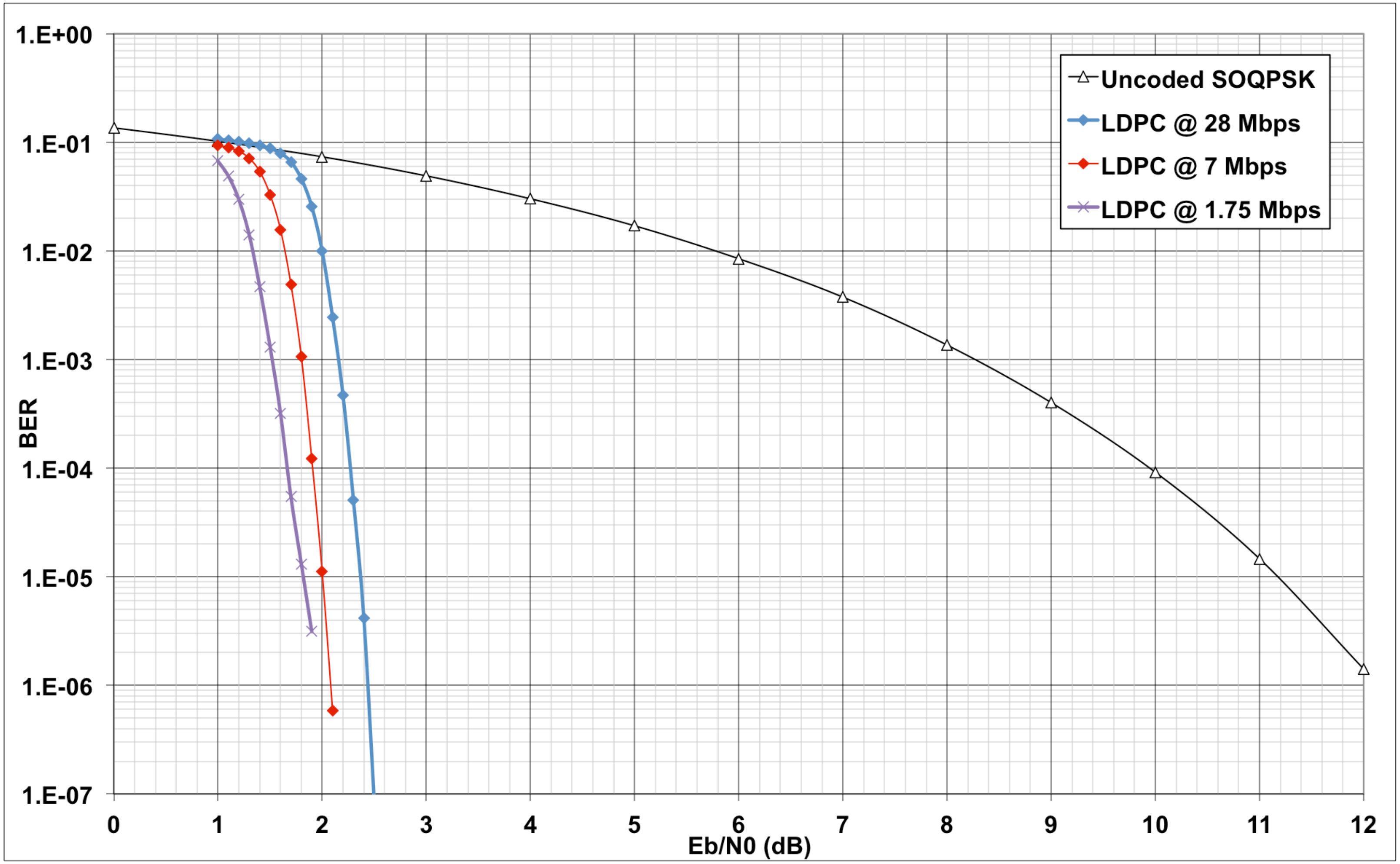
# Fractional Out-of-Band Power



# Decoder

- Demodulate SOQPSK with soft decisions
  - Implemented 8-bit decisions
    - Iterative decoders work best with high resolution soft decisions
  - Estimate $E_b/N_0$ for soft decision scaling
- Correlate for ASM with hard decisions
  - Resolves the 4-ary phase ambiguity in SOQPSK
  - Virtually certain sync at $E_b/N_0 = 0$ dB
- Initialize decoder
- Execute decode iterations until next code word
  - Coding gain varies with bit rate

# Measured BER Results



# LDPC from Appendix 2-D

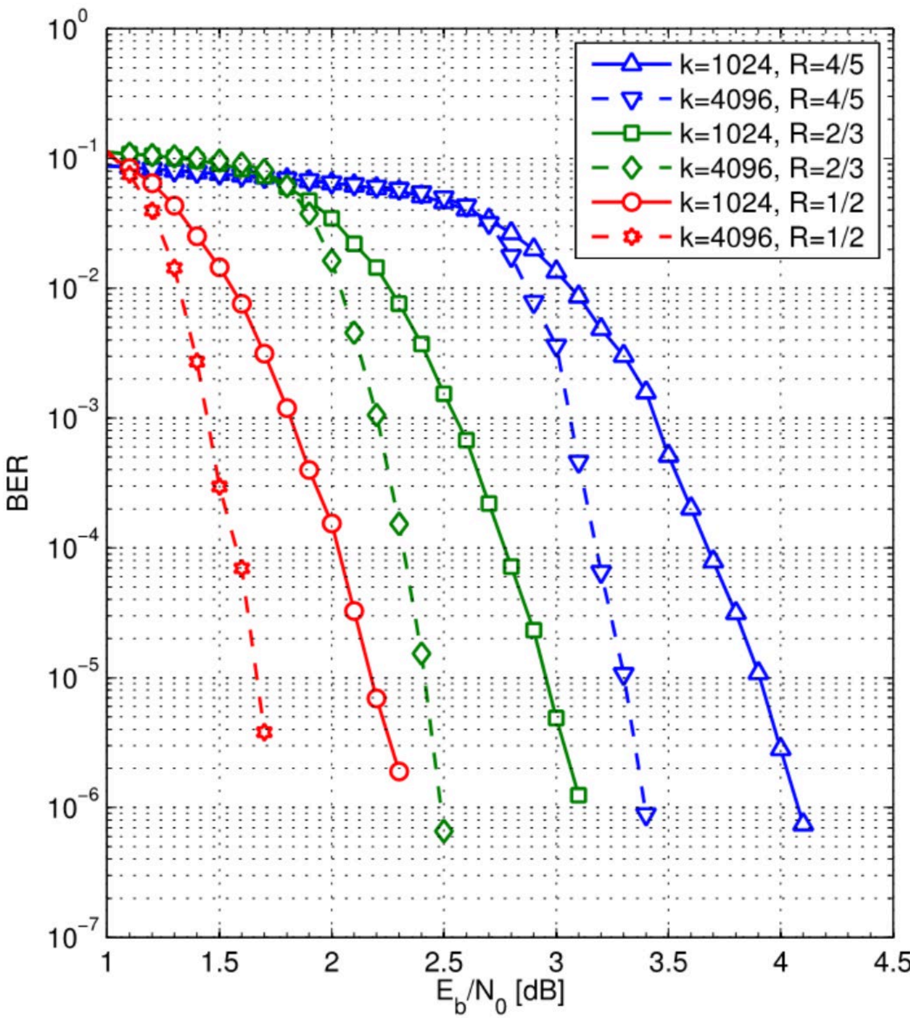
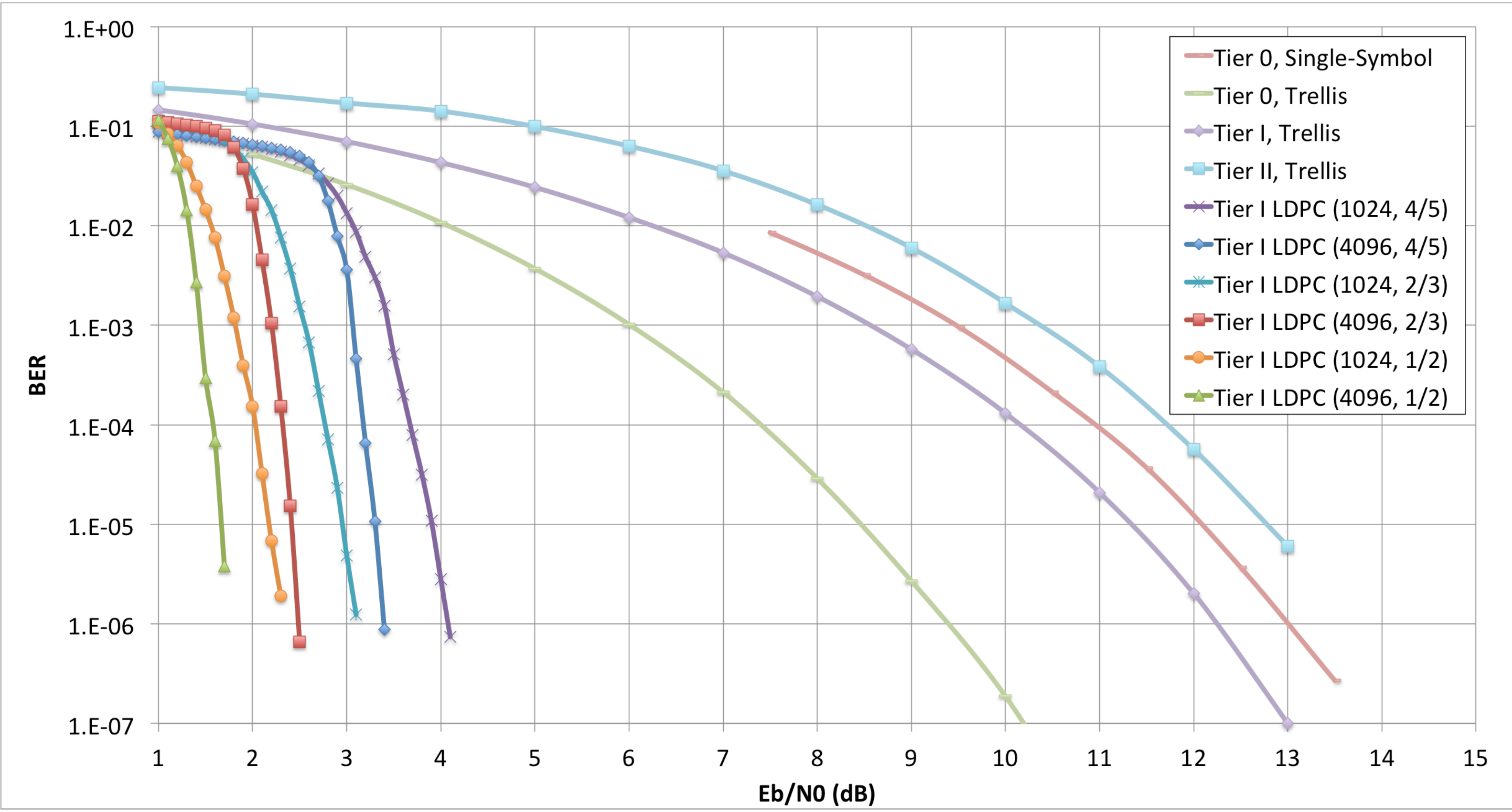



**Table D-11. Bandwidth Expansion Factor**

| Information Block Length, *k* | Bandwidth Expansion Factor | | |
|---|---|---|---|
| | Rate 1/2 | Rate 2/3 | Rate 4/5 |
| 1024 | 33/16 | 25/16 | 21/16 |
| 4096 | 33/16 | 25/16 | 21/16 |

# BER – All Modes



# Conclusions

- Rate 2/3 LDPC code yields ≈9 dB coding gain relative to uncoded SOQPSK
  - ±0.5 dB, depending on data rate
- 256-bit ASM provides reliable, fast synchronization at Eb/N0 < 0 dB
  - Synchronization is consistently achieved in < 4096 data bits
- Bandwidth expansion of 25/16
  - Still 22% less bandwidth than legacy PCM/FM
- SOQPSK with LDPC offers a reasonable trade of spectral efficiency for a significant gain in detection efficiency
- 5 other LDPC codes offer similar trade of bandwidth for BER performance

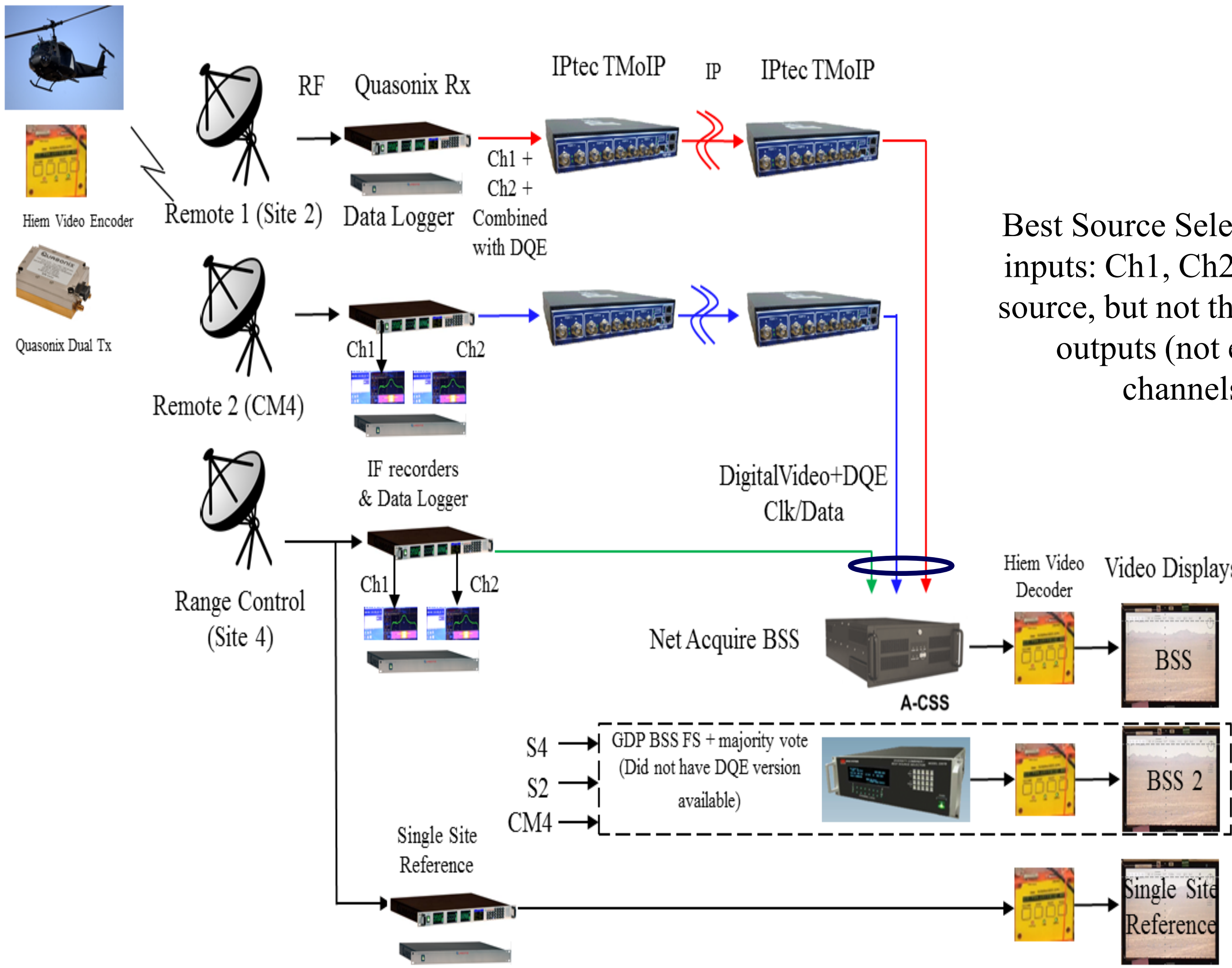
# How Well Does It All Work Together?

**Yuma Proving Grounds, AZ**
**Feb 8-11, 2016**

# Recipe for Delivering Every Bit

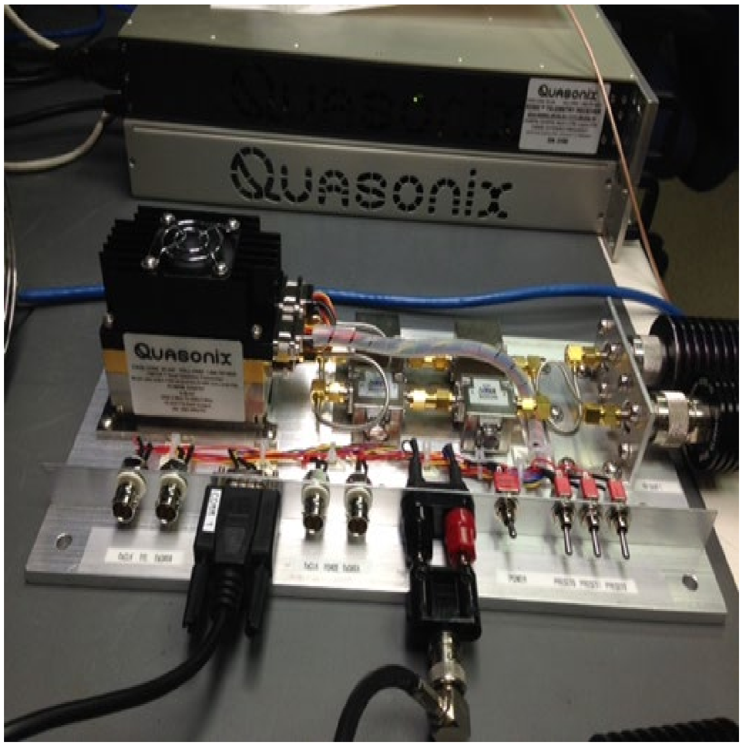
- Space Time Coding (STC)
  - Eliminates aircraft pattern nulls
- Low Density Parity Check (LDPC) coding
  - Improves margin, stops “dribbling errors”
- Adaptive Equalization (for non-STC signals)
  - Mitigates multipath
- Spatial diversity with correlating source selection
  - Eliminate coverage-based dropouts
  - Requires DQE/DQM for optimal operation
  - TMoIP makes delivery easy

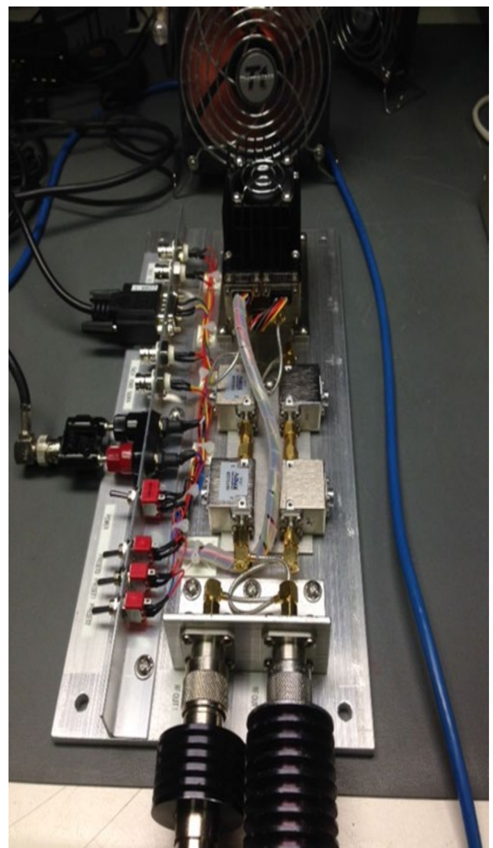
# Multiple Receiving Sites




Best Source Selector used 6 inputs: Ch1, Ch2 from each source, but not the combiner outputs (not enough channels).

# Dual Transmitter – S band – 10 W each output



Installed in UH-1 (Huey) helicopter with top and bottom blade antennas

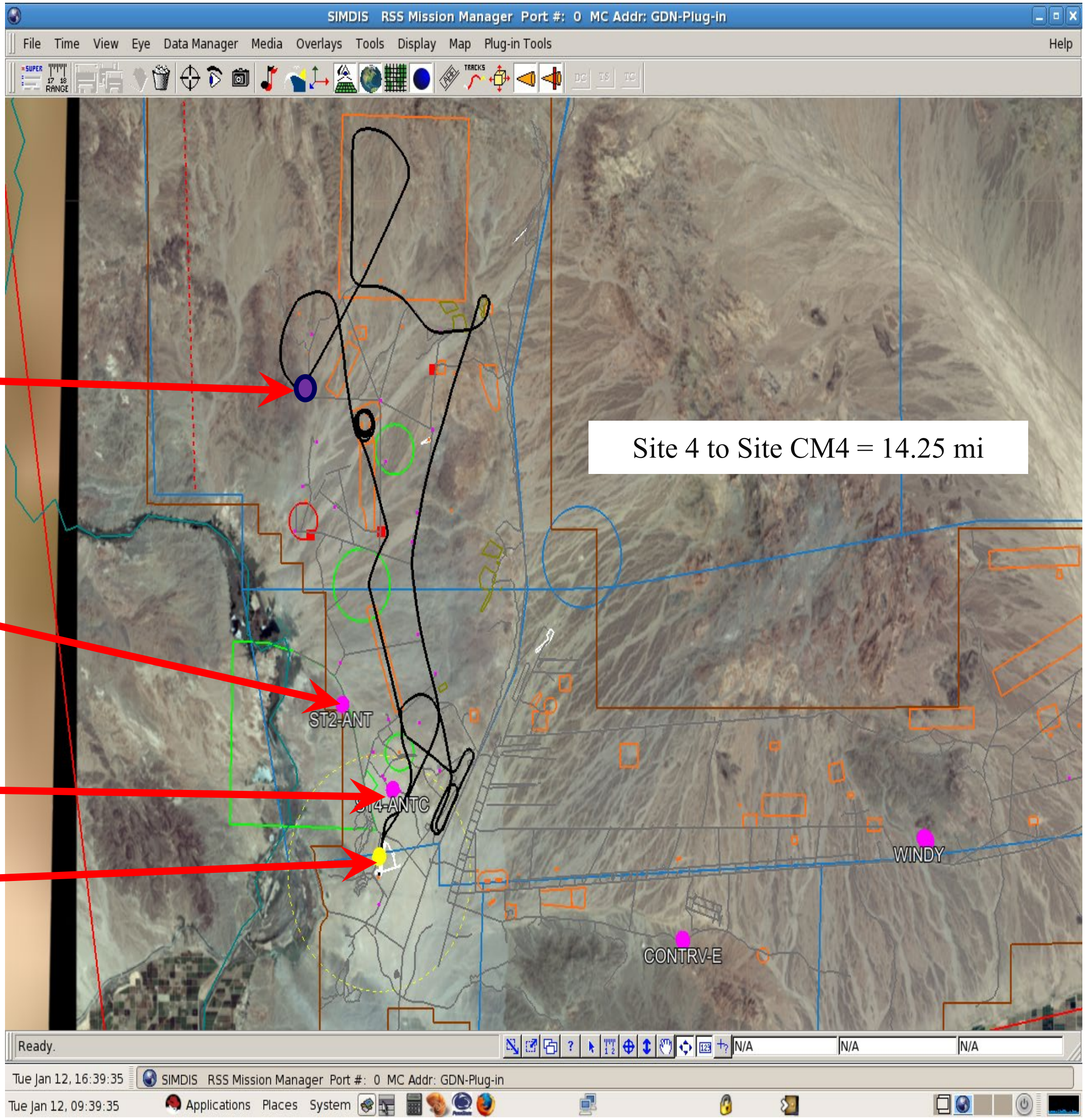
# YPG Test Sites

Site CM4

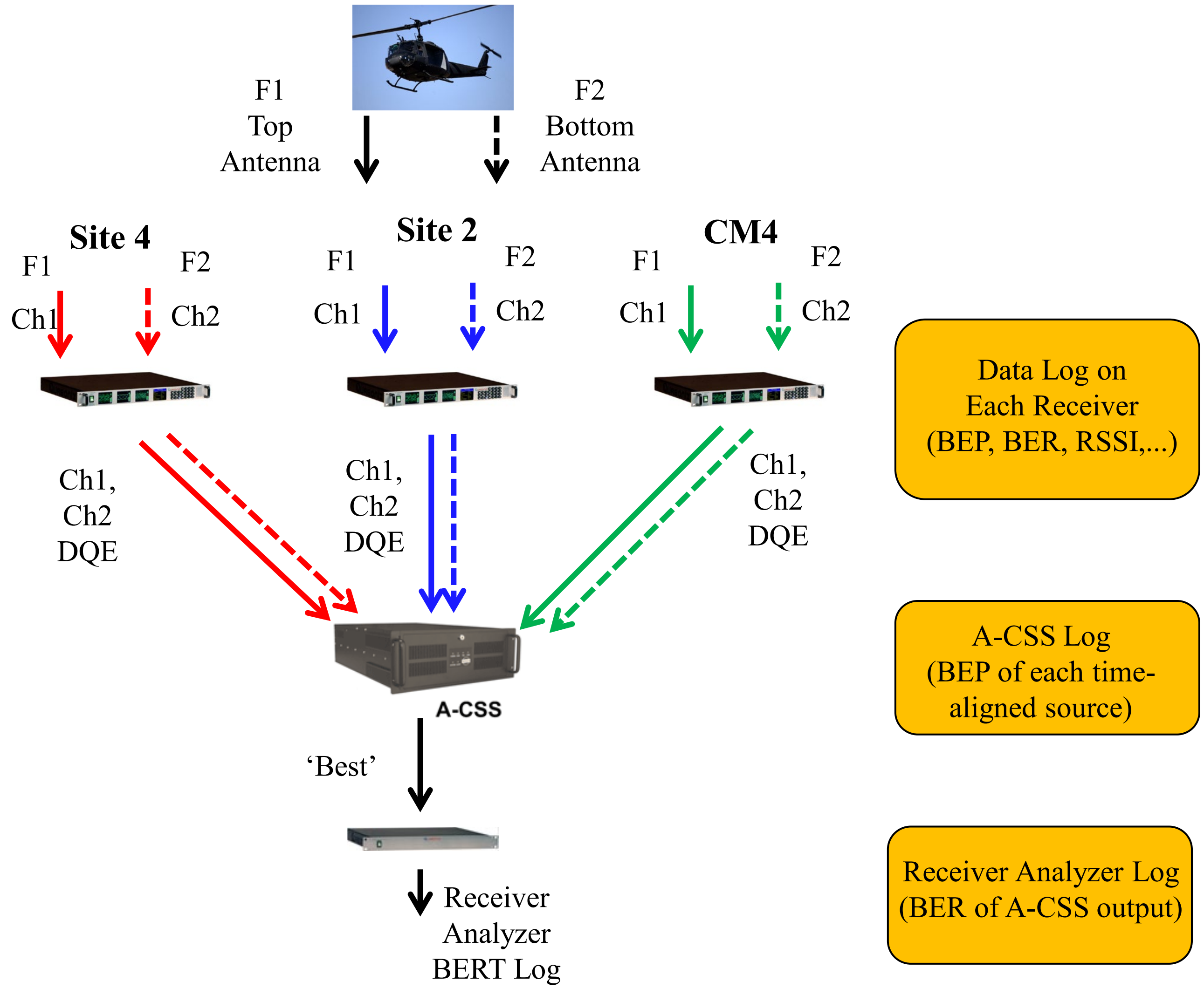
Site 2

Site 4

Laguna Airfield

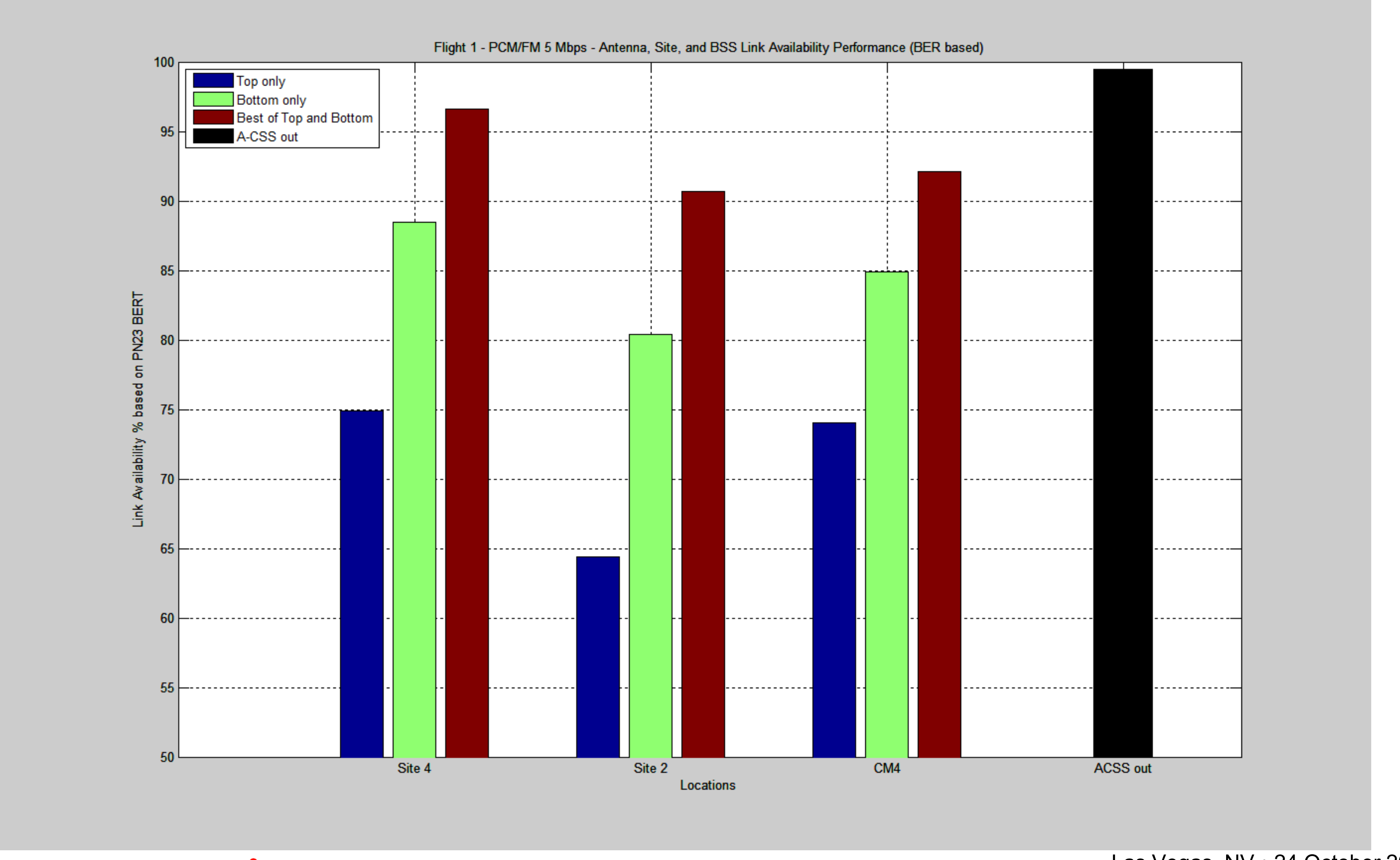


# Analysis using Data Logs

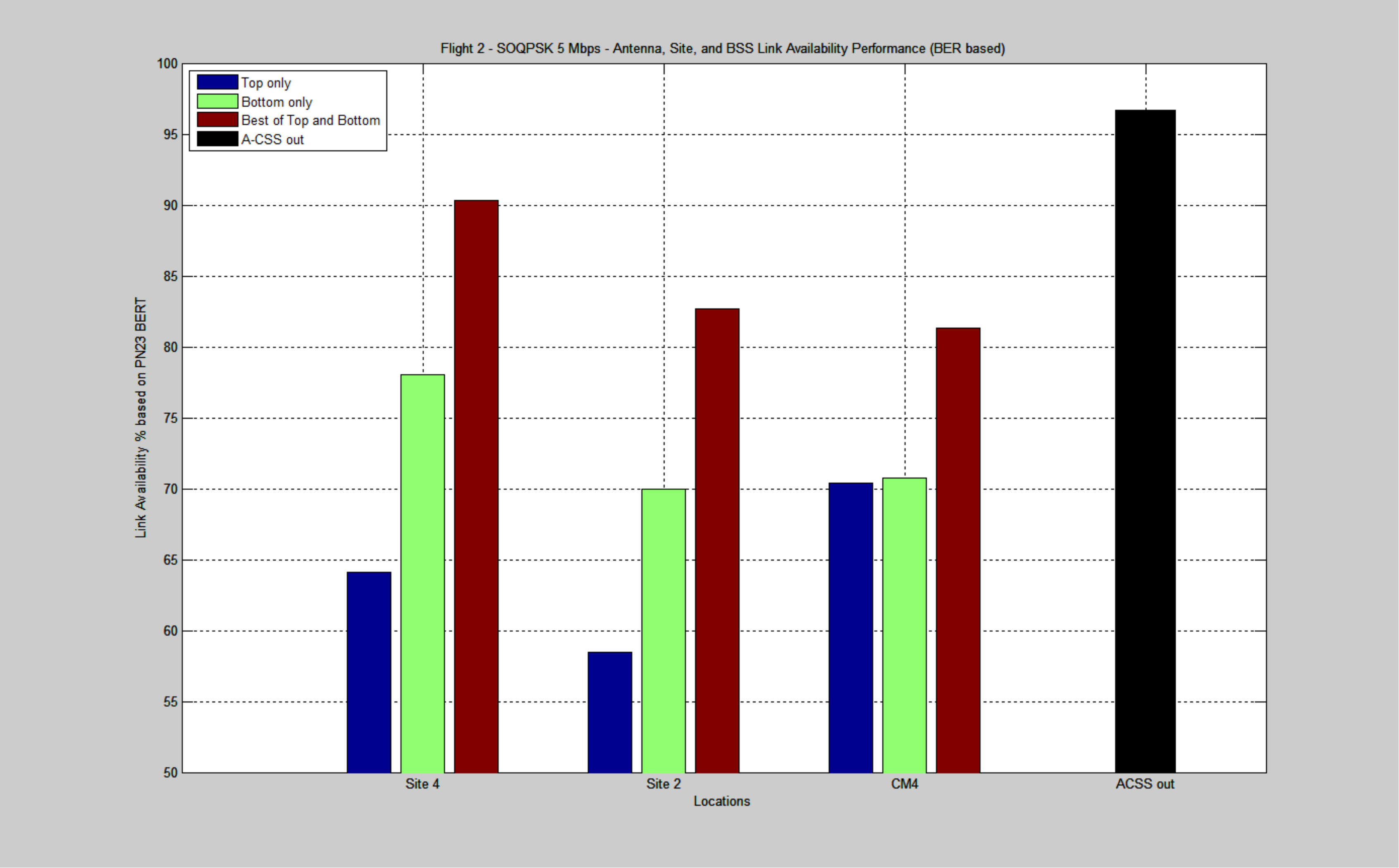



- Transmit F1-Top, F2-Bottom
- 3 Receive Sites
- 6 Clock & Data streams provided to A-CSS with Data Quality Encapsulation (DQE)
- DQE = Receiver inserts periodic estimate of instantaneous BEP
- Items of interest
  - Top vs Bottom Antenna
  - Individual Site Performance
  - Source Selector Performance

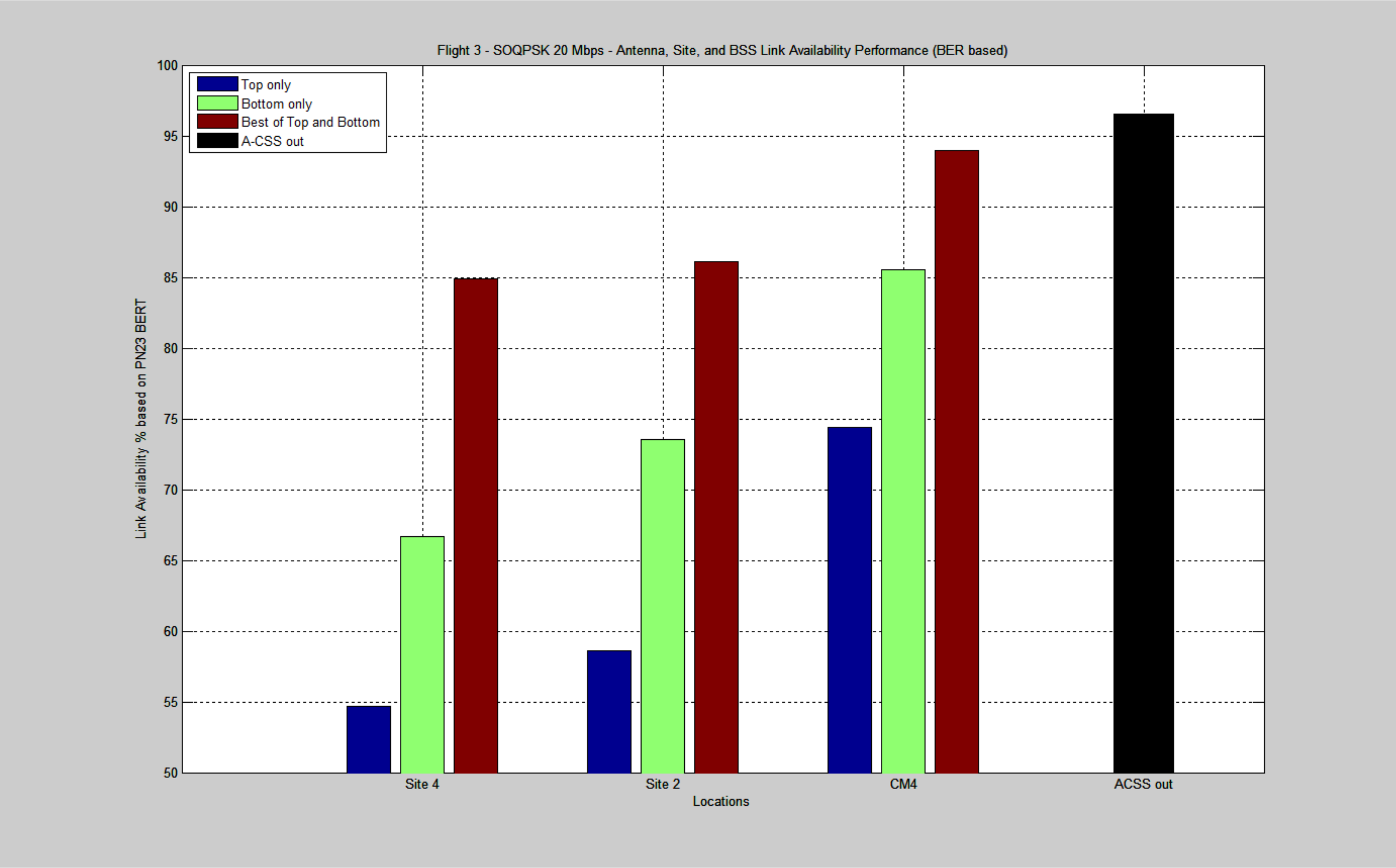
# Flight 1 – PCM/FM 5 Mbps Link Availability Summary (PN23 BER)



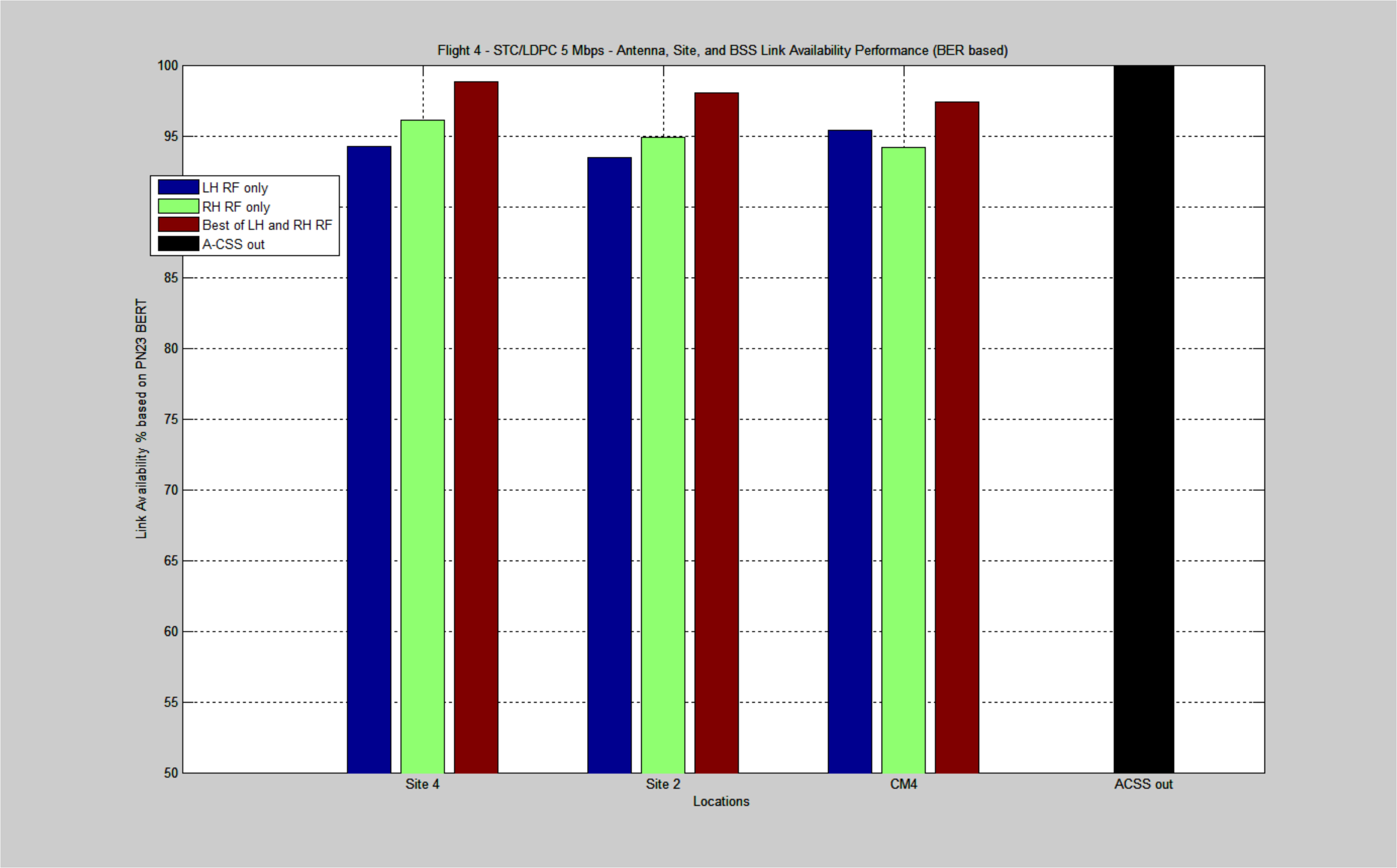
# Flight 2 – SOQPSK 5 Mbps Link Availability Summary (PN23 BER)



# Flight 3 – SOQPSK 20 Mbps Link Availability Summary (PN23 BER)

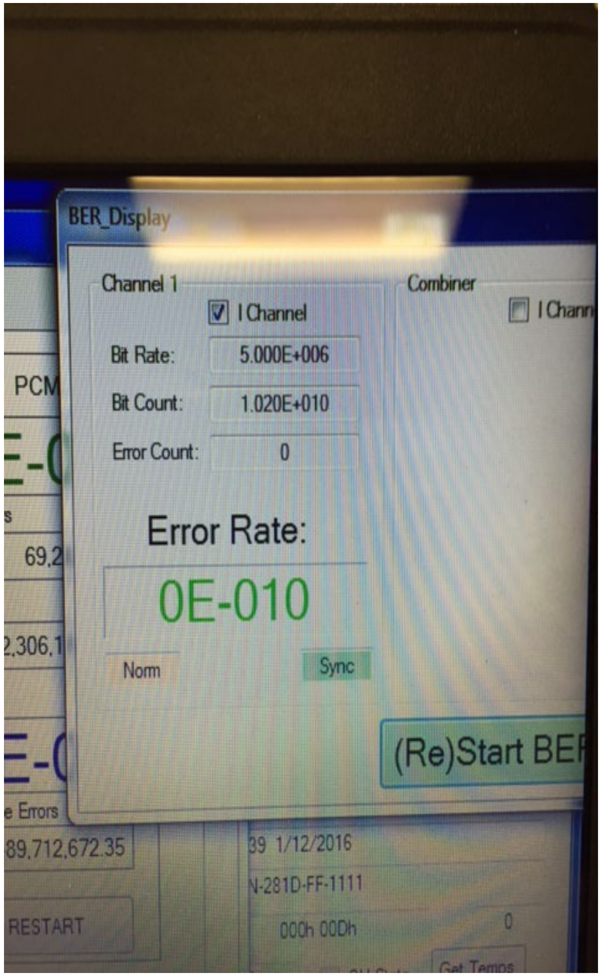


# Flight 4 – STC/LDPC 5 Mbps
# Link Availability Summary (PN23 BER)



# The elusive zero-error link.....

- STC/LDPC from 3 sites at 5 MBPS
- 1st pass PN23 -- 34 minutes of helicopter flight across YPG…
- Error-free!
- 2nd pass video with no freeze ups or blackouts!



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- Kip Temple, ARTM, Edwards AFB
- Gene Law, NAWCWD, Pt. Mugu
- Vickie Reynolds, White Sands Missile Range

# Questions/Comments

# Thank You!