Telemetry Smorgasbord

A Little Taste of Everything

Terry Hill, Quasonix

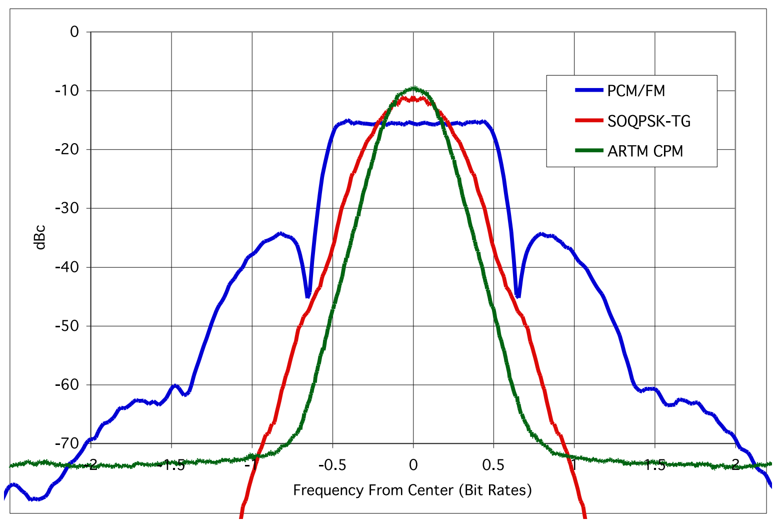
Spring 2020

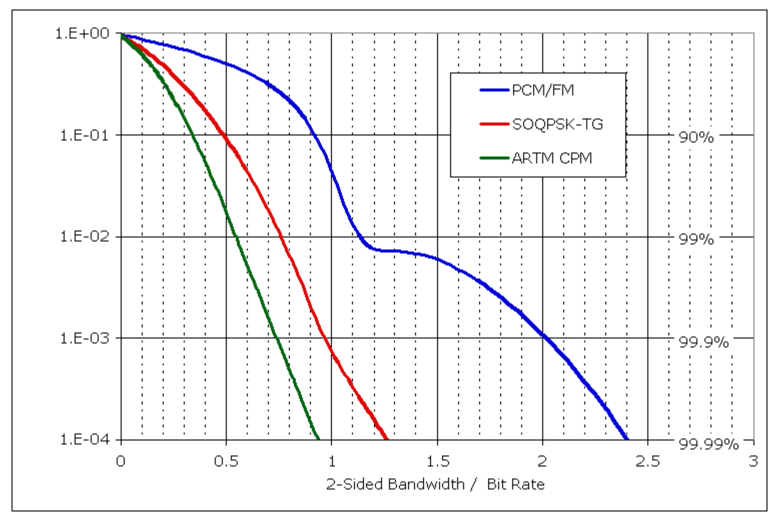
Course Outline – Day 2

- Demodulation
  - Trellis vs. Single-Symbol
  - Data Quality Metric
  - Diversity Combining
  - Synchronization
- Channel Impairments
  - Adjacent Channel Interference
  - Multipath Propagation
- Impairment Mitigation Techniques
  - Adaptive Equalization
  - Best Source Selection

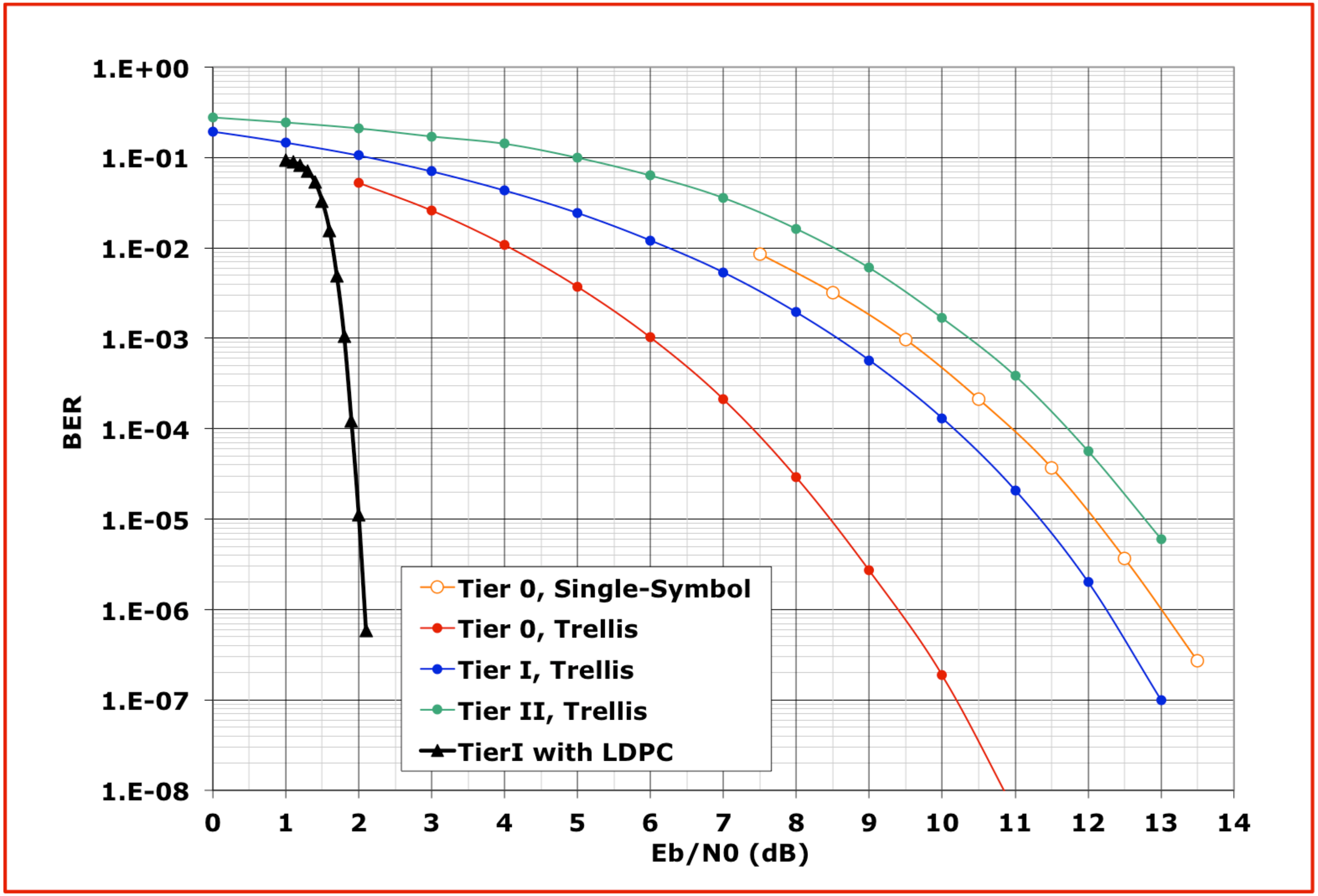
Side by Side Summary

Tier	M	α_i	h	g(t)	99.9% BW
0	2	{-1, +1}	0.7	Normalized impulse response of a high order Bessel filter with 3 dB bandwidth = 0.7 * bit rate	2.03
I	3	{-1, 0, +1}	0.5	Normalized windowed impulse response of a spectral raised cosine, 8 bits long	0.98
II	4	{-3, -1, +1, +3}	{4/16, 5/16}	Normalized raised cosine, 3 symbols (6 bits) long	0.75

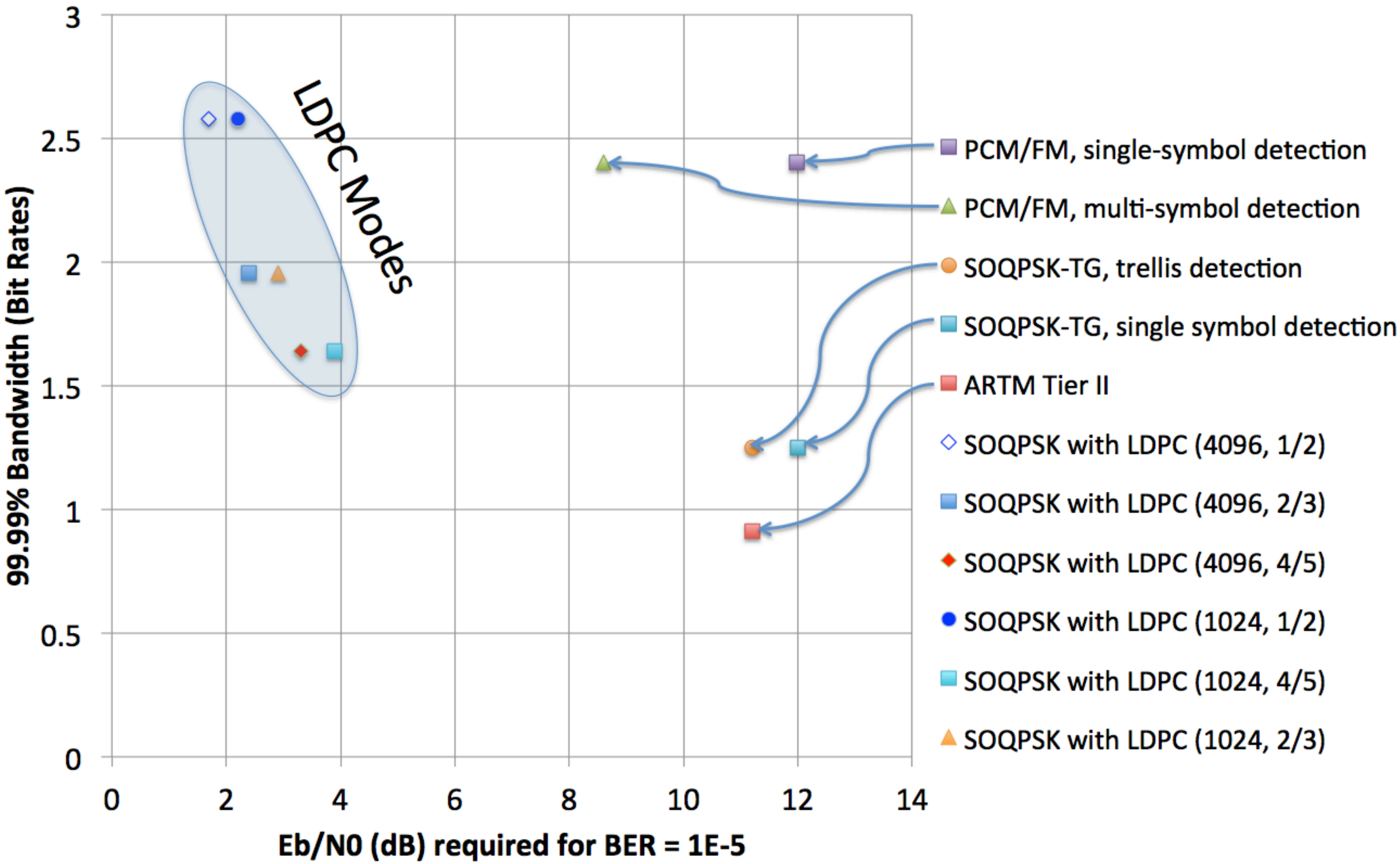




BER Performance Comparison



Today's Modulation Tour



Quasonix

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

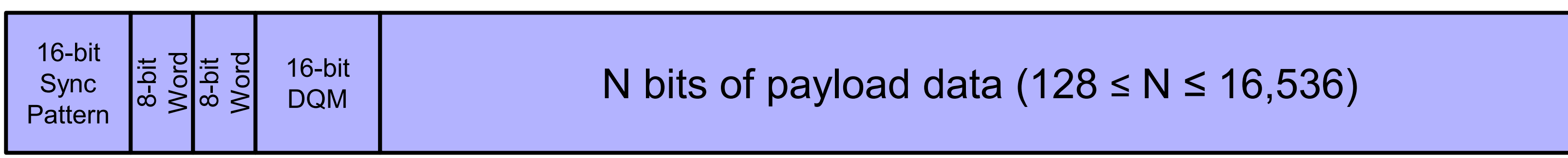
Definition of DQM

- 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, $(128 \leq N \leq 16{,}536)$
  - Defaults to 4096

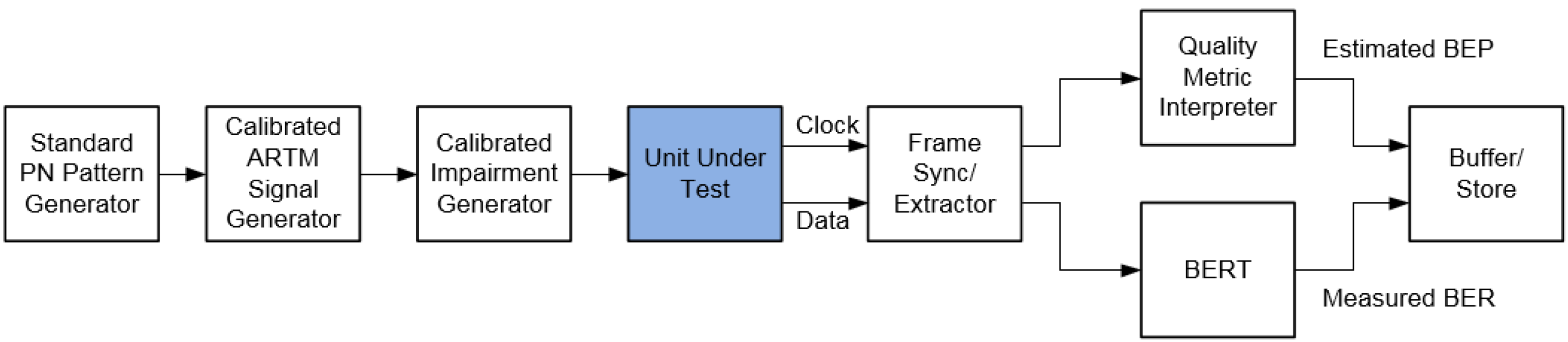


Calibration of DQM

- 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

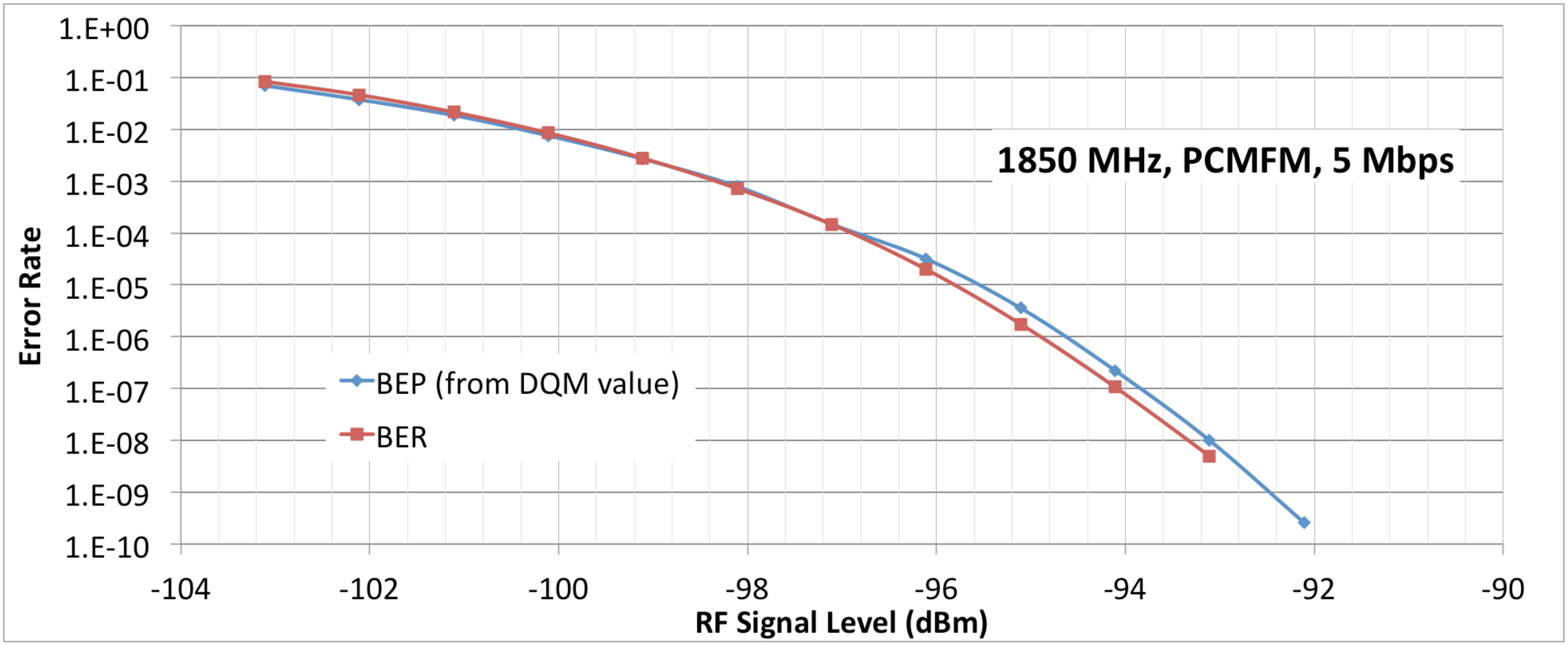
DQM Calibration Fixture

- 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



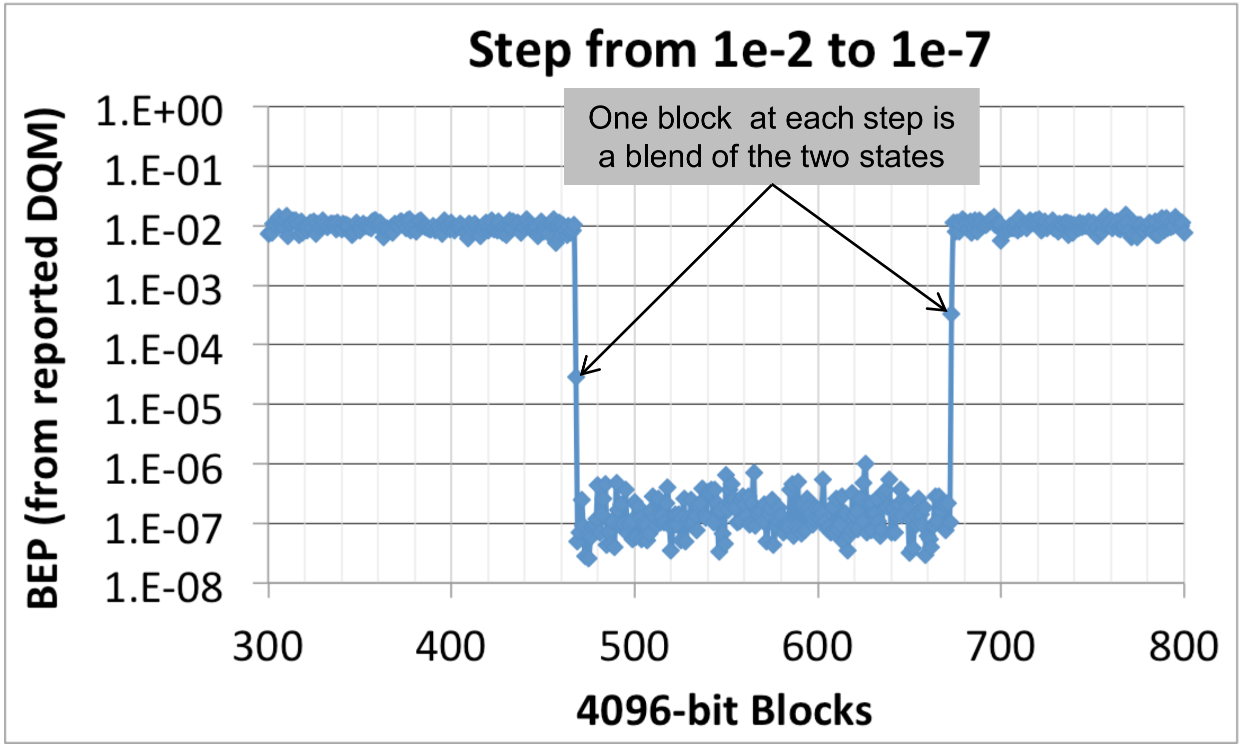
DQM Calibration in AWGN

- Required as a baseline for all other tests



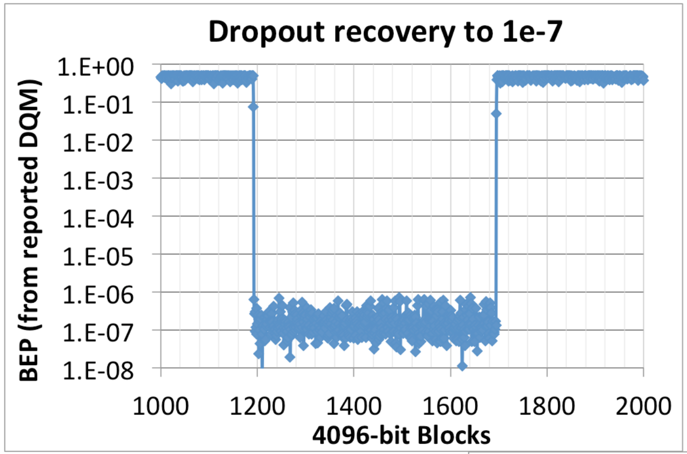
DQM Step Response

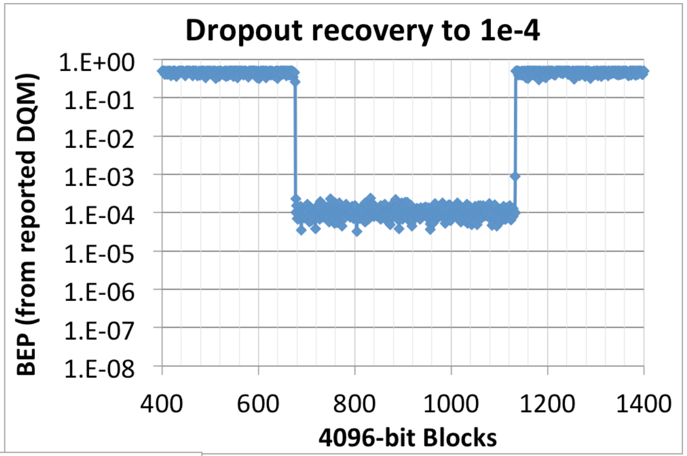
- Assesses timeliness of DQM values
- UUT stays synchronized during test

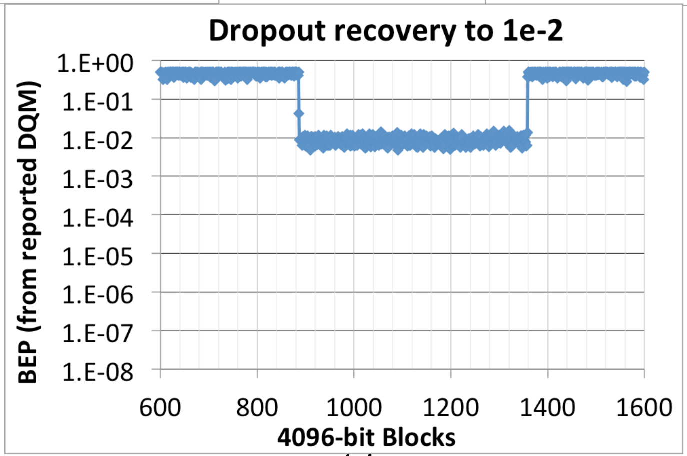


DQM Fade Recovery

- Includes UUT synchronization time

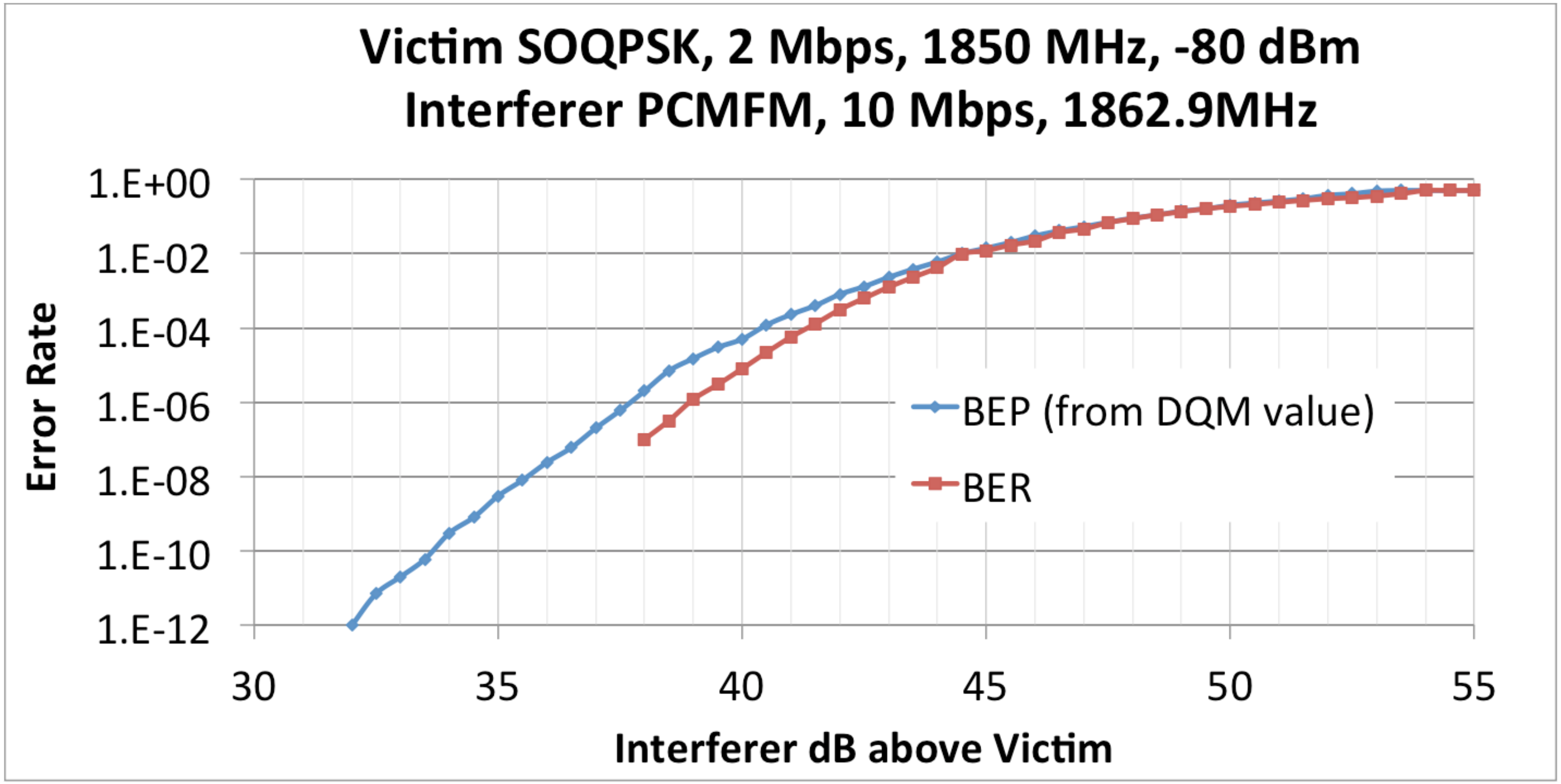






DQM Interference Test

- Interference is not AWGN, but it causes bit errors

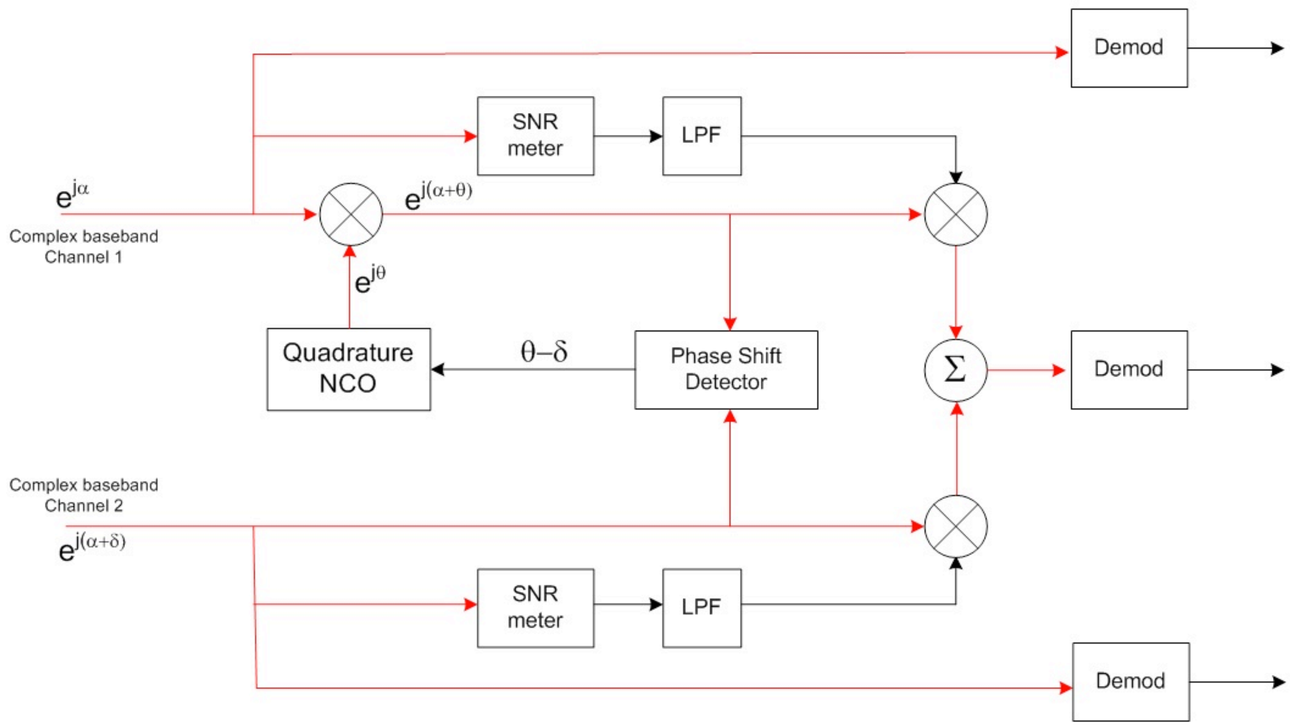


Diversity Combining

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

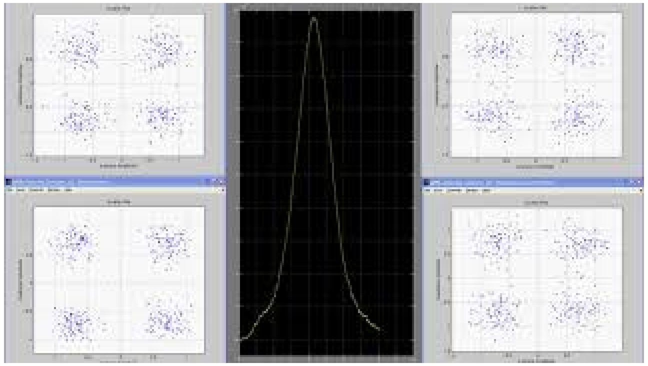
Maximal Ratio Combining



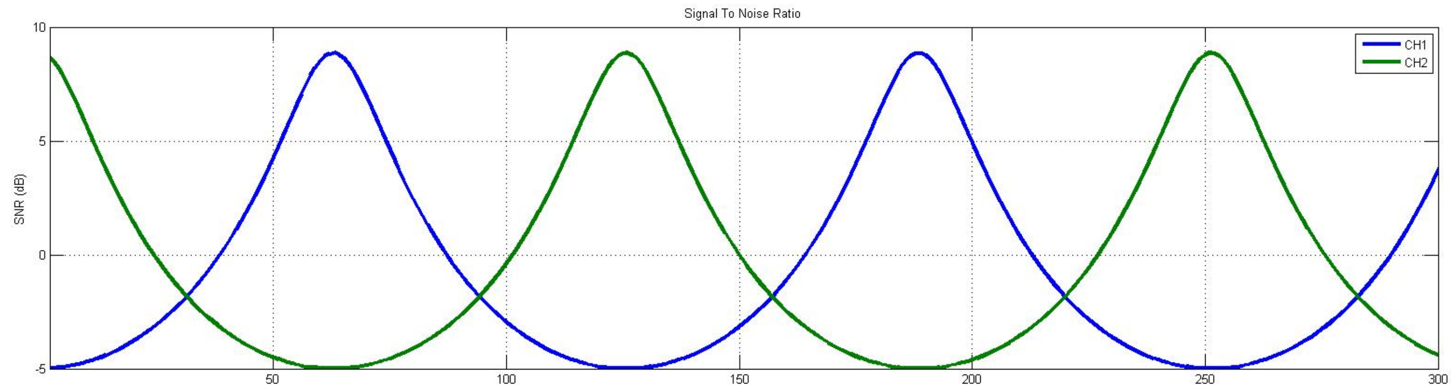
- Weight each signal in proportion to its SNR and add
- Yields optimum SNR on combined channel **in AWGN**
- $SNR_{combined} = SNR_a + SNR_b$

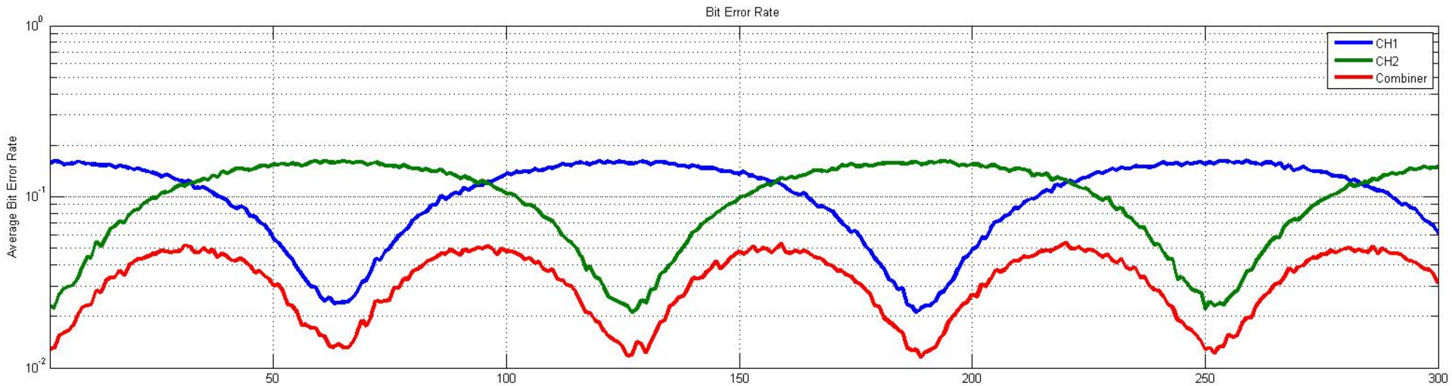
Maximal Ratio Combining

- Jump to file: diversity-combiner-video.mp4
  - Or, click to view on our website: Combining Video

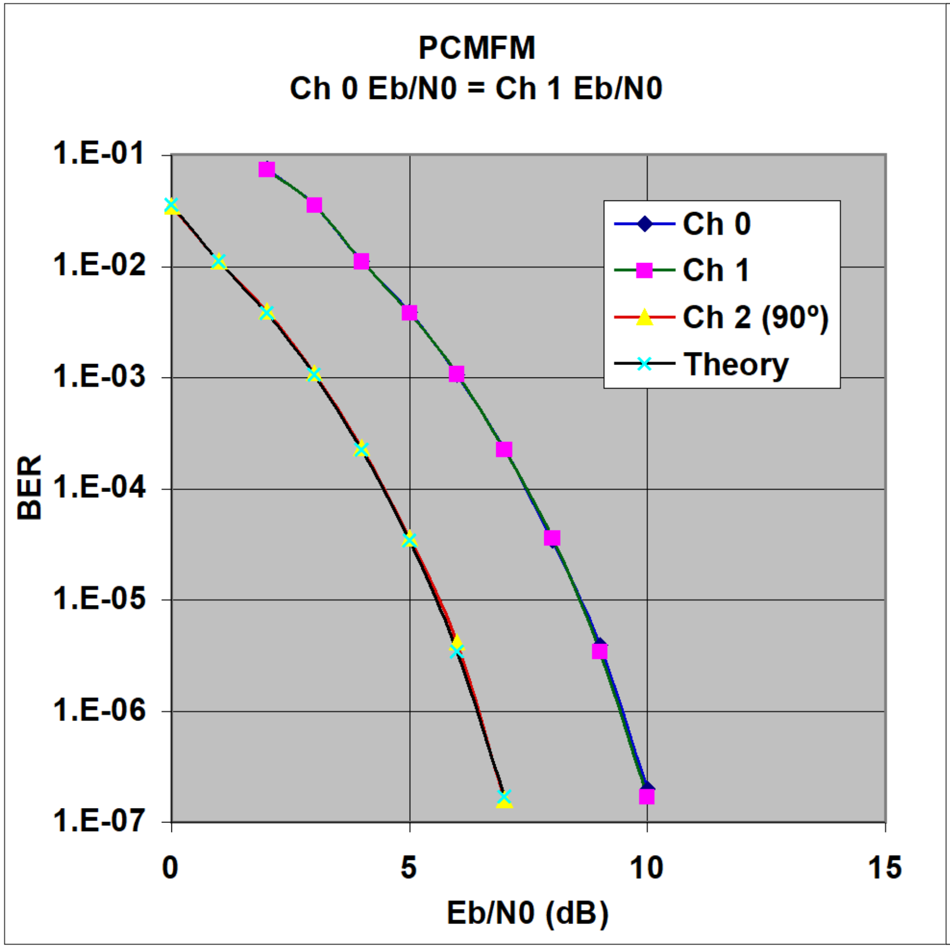


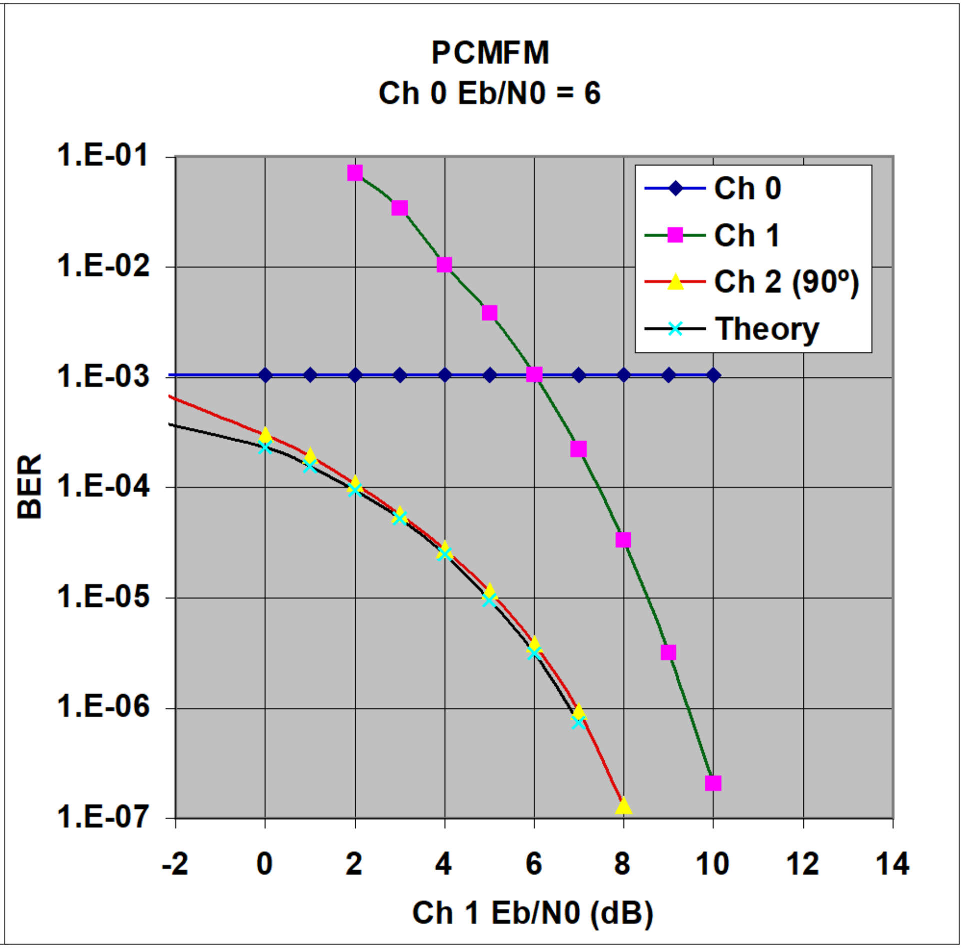
BER Results - Fading Signals



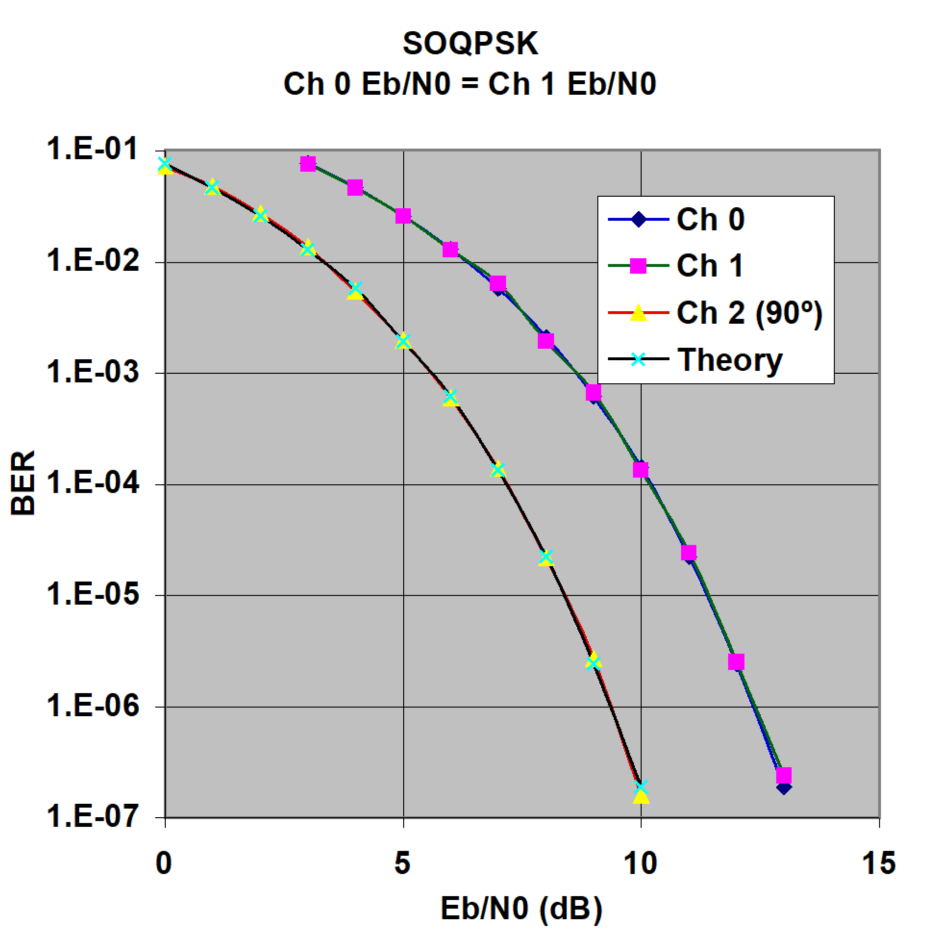


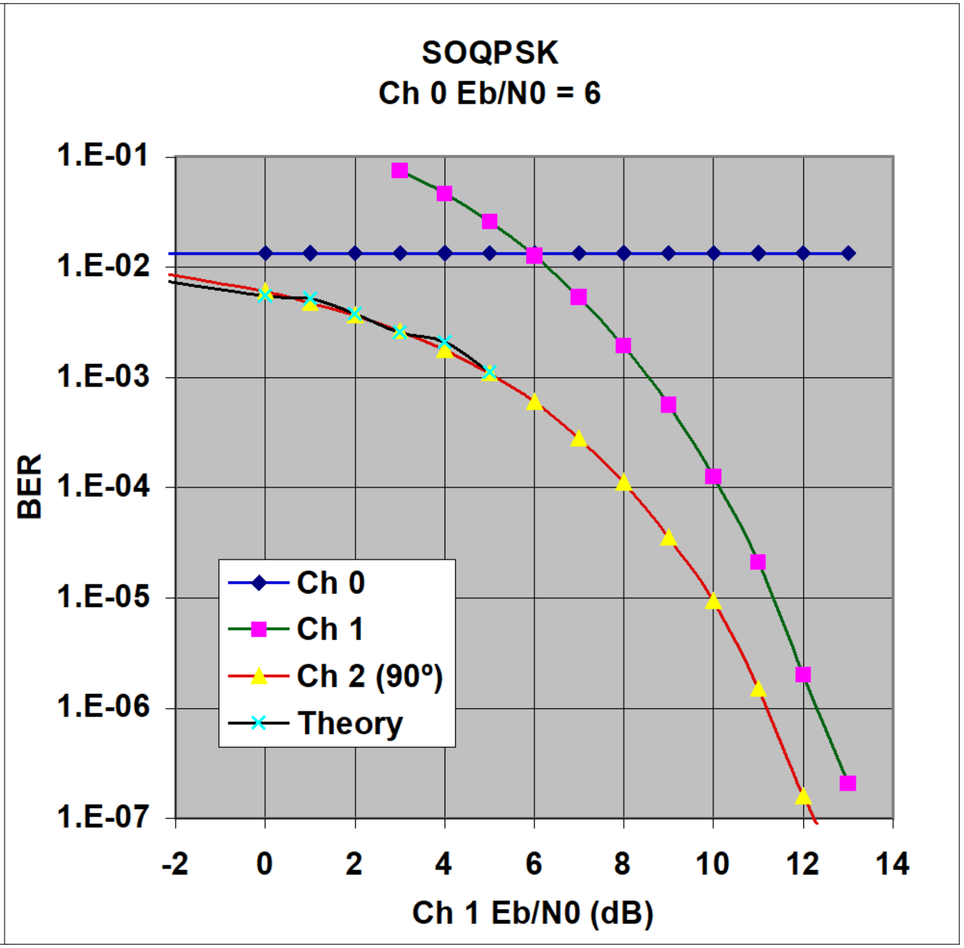
Measured Combiner BER - Tier 0



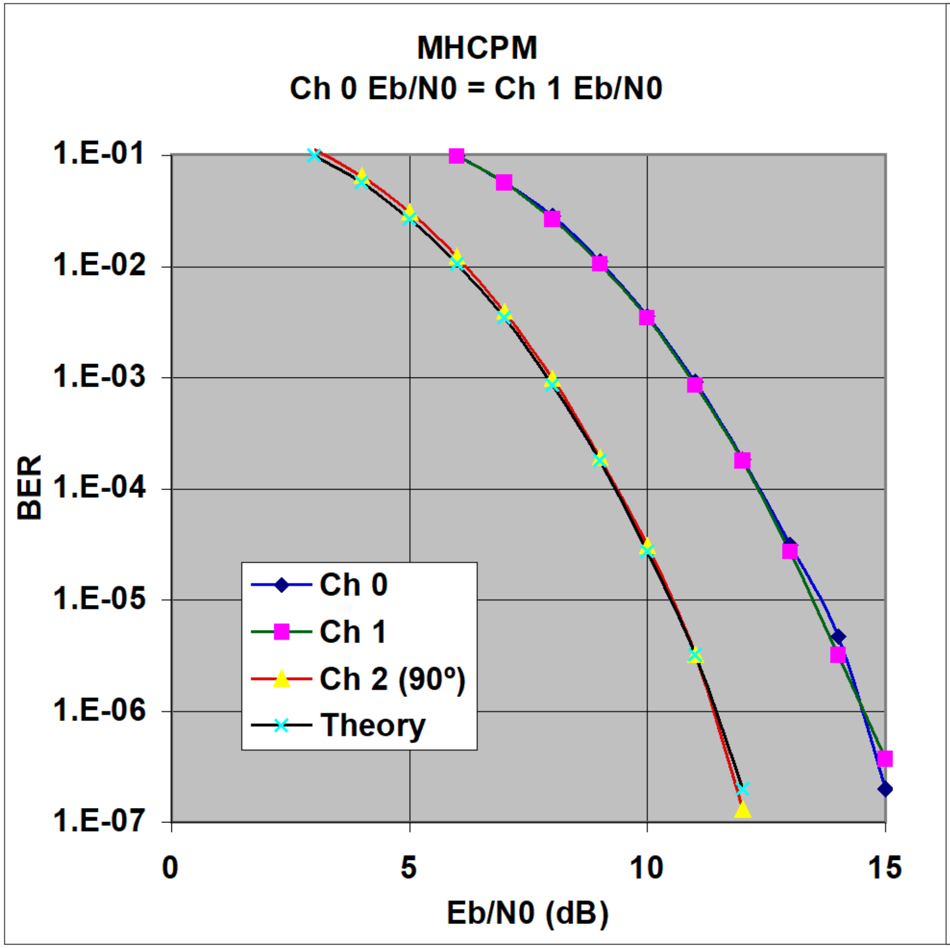


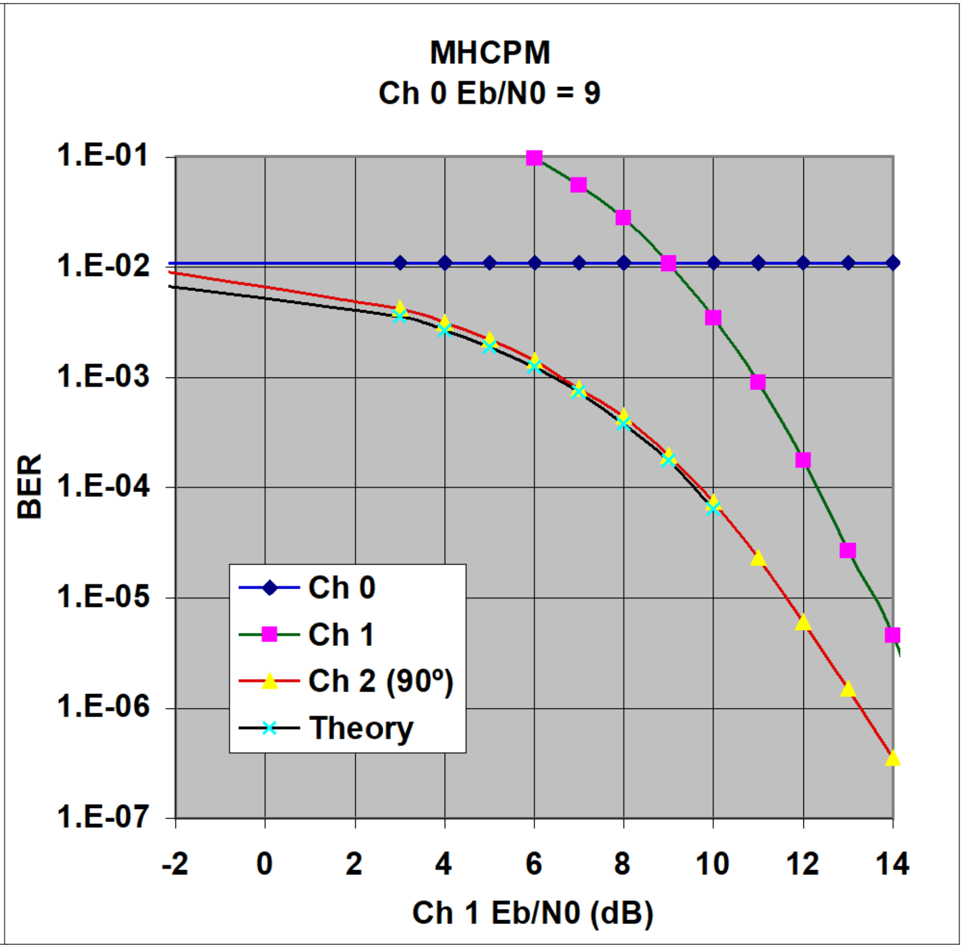
Measured Combiner BER - Tier I





Measured Combiner BER - Tier II





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!

Synchronization

Telemetry Channels are Bursty

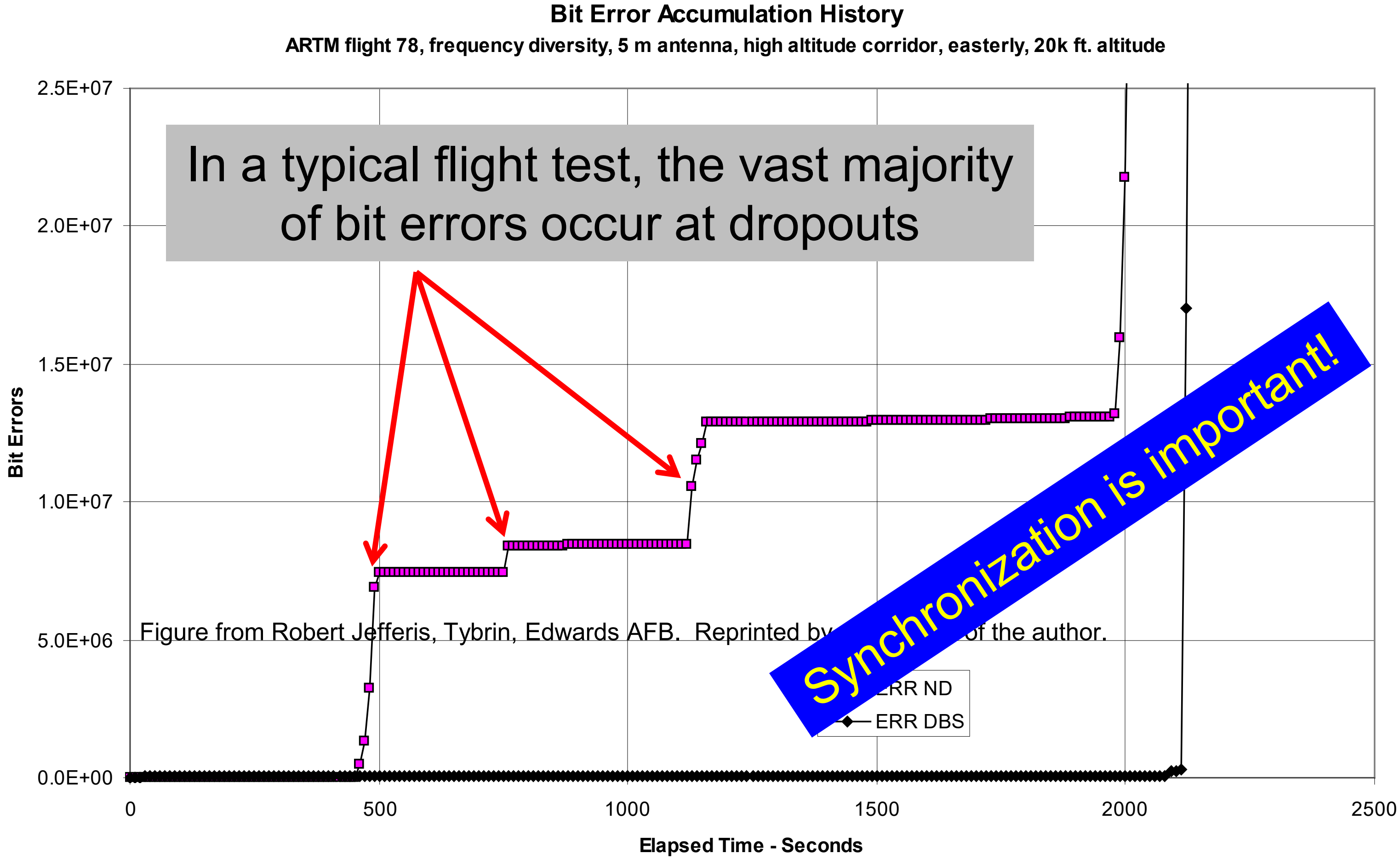
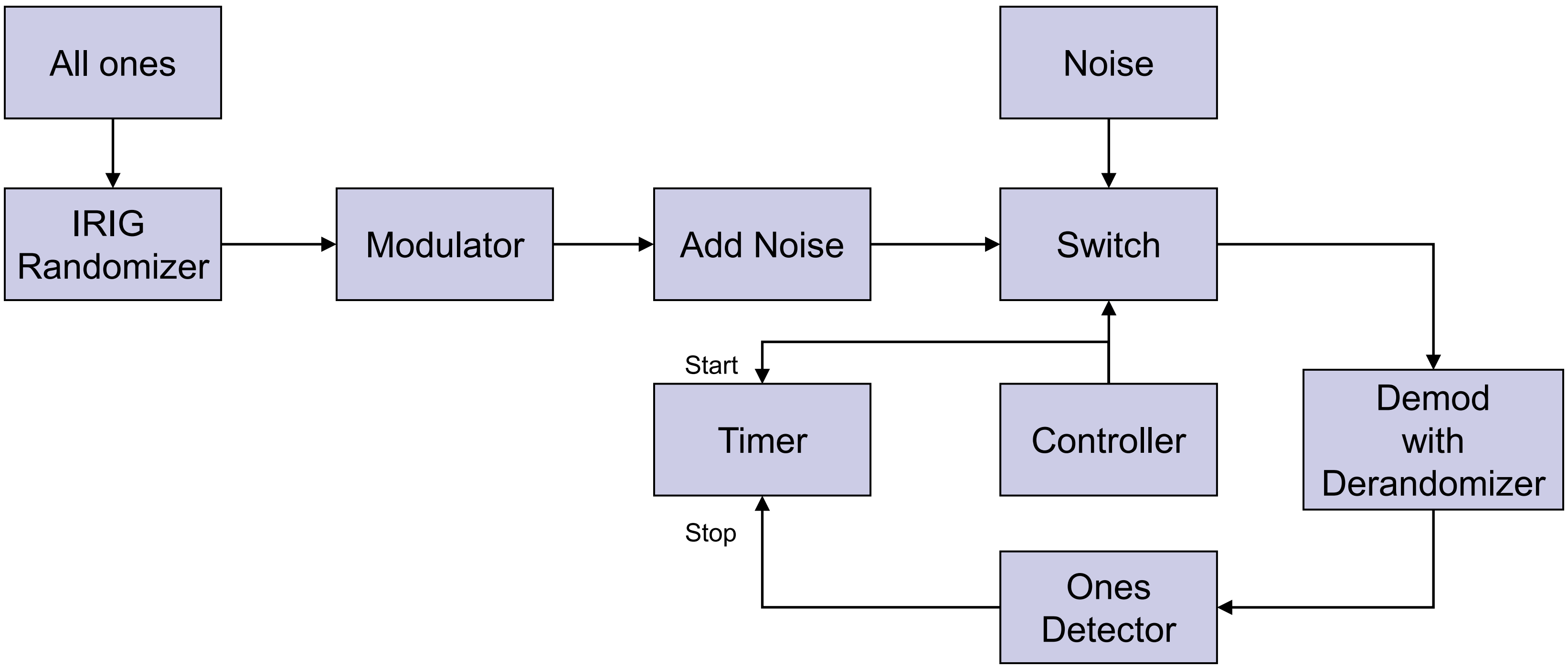


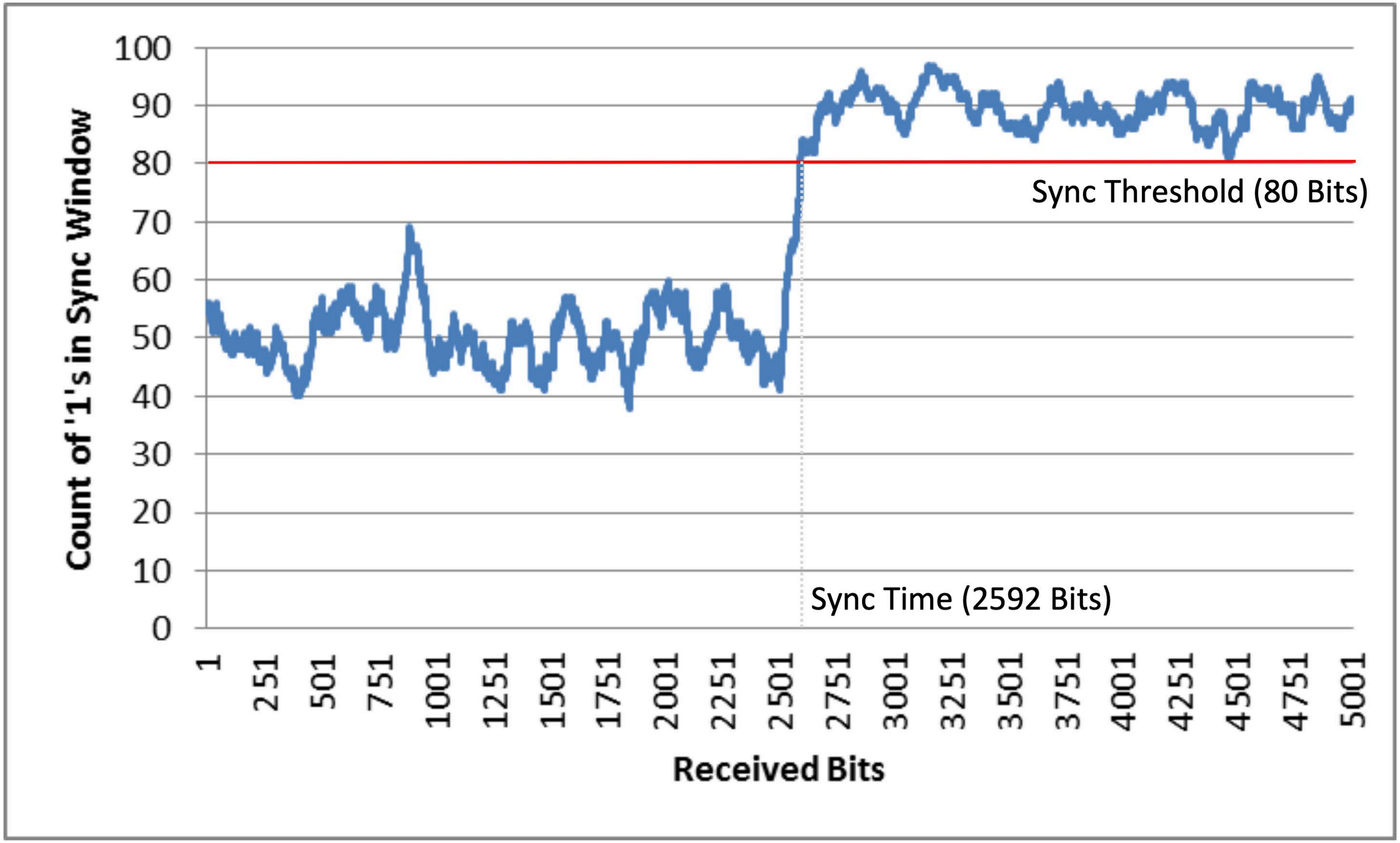
Figure from Robert Jefferis, Tybrin, Edwards AFB. Reprinted by … of the author.

Synchronization Test

- IRIG 118-12, Procedure 7.4 (Flat Fade Recovery Test)
- Transmit randomized ones pattern
- Measure time at which output becomes “all (or mostly) ones”



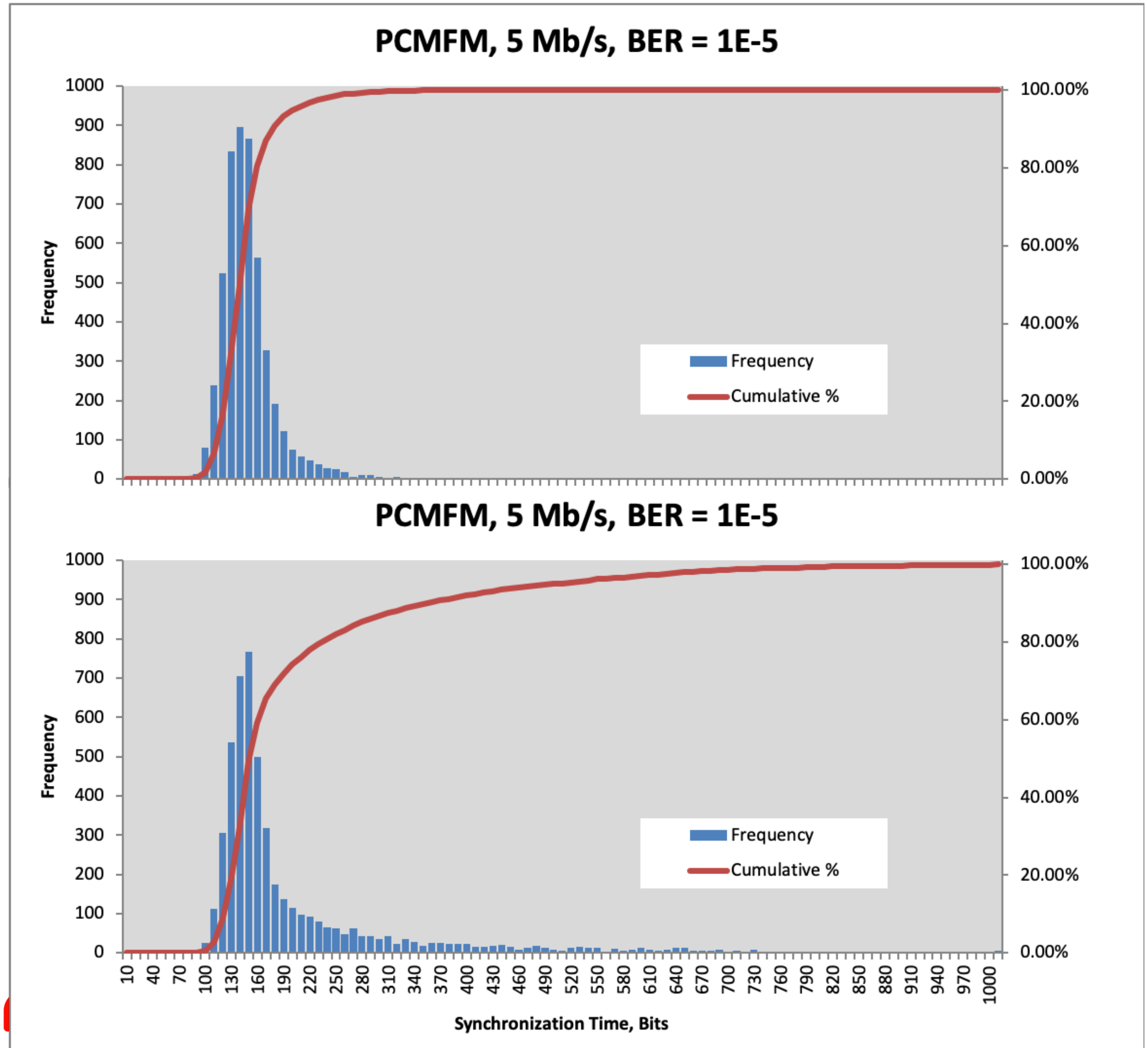
Typical Sync Test



Synchronization Parameters

- Modulation technique
  - Tier 0 uses more bandwidth – easier to synchronize to
  - Tier I is spectrally compact, making it slippery – synchronization is more difficult
    - Trellis demodulation helps achieve sync
  - Tier II is even more compact – synchronization takes longer
- Bit rate
  - Fixed-duration tasks amount to more bits at high bit rates
- Signal to noise ratio
  - Sync times will be longer at low SNR
- Synchronization threshold
  - SNR at which the demodulator can *acquire* sync
- Sync loss threshold
  - SNR at which a synchronized demodulator will *drop* sync

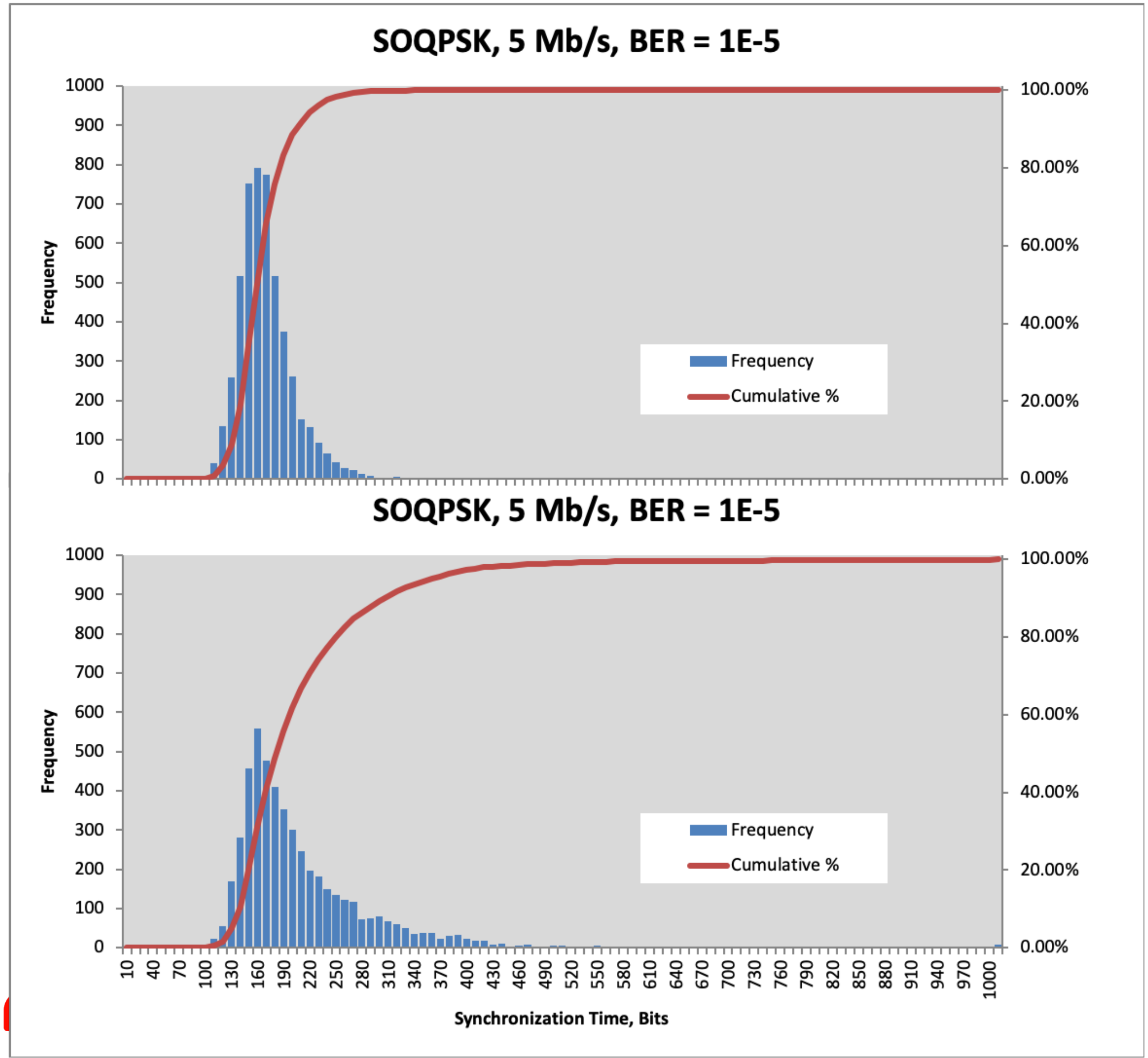
Tier 0 Synchronization



Channel 1, 2

Combiner

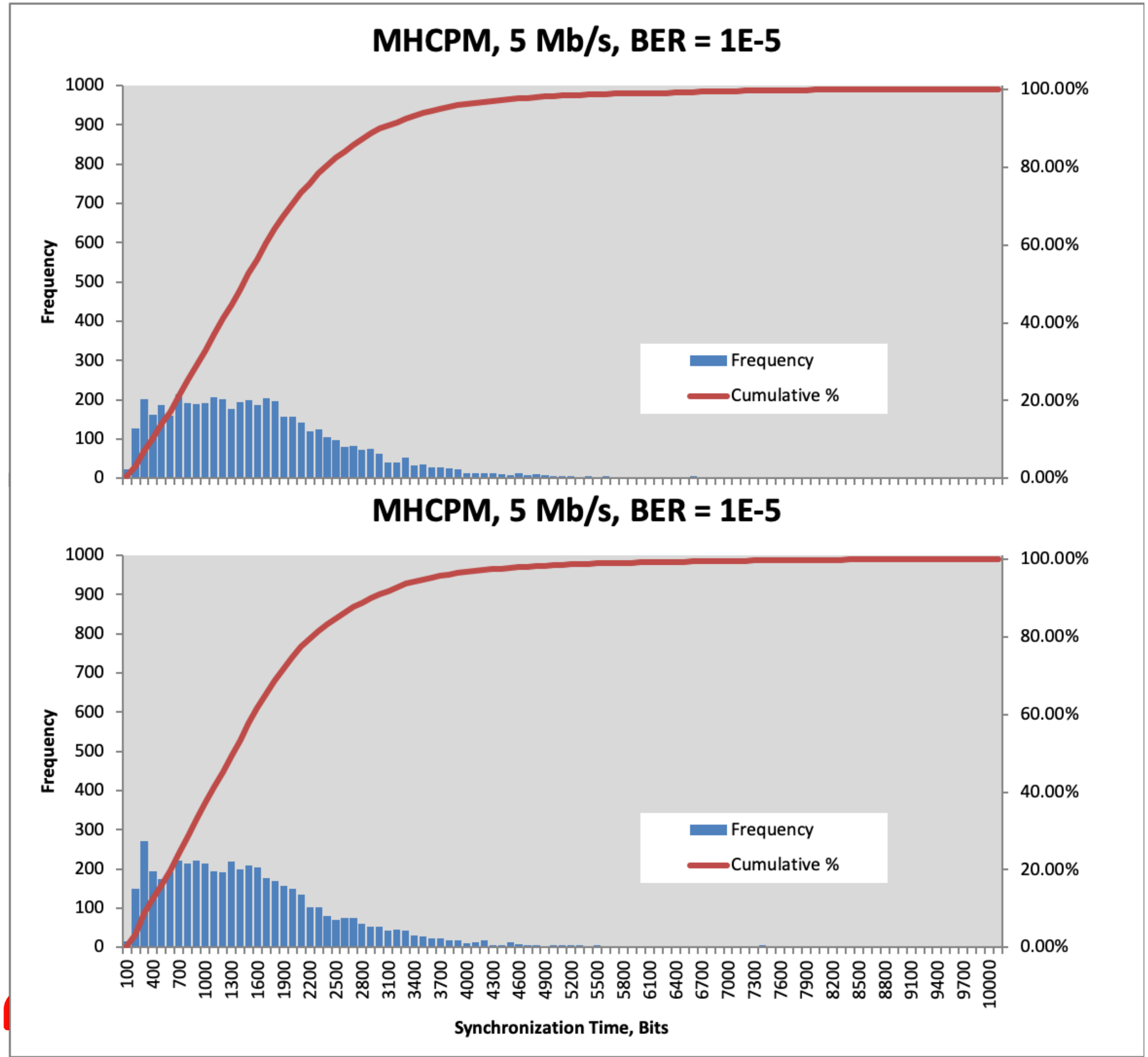
Tier I Synchronization



Channel 1, 2

Combiner

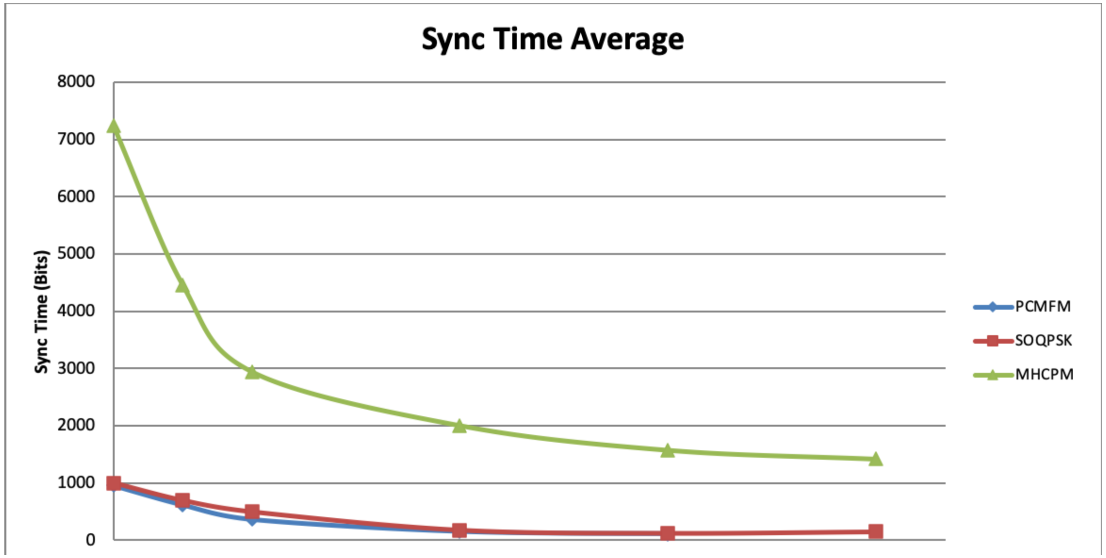
Tier 0 Synchronization

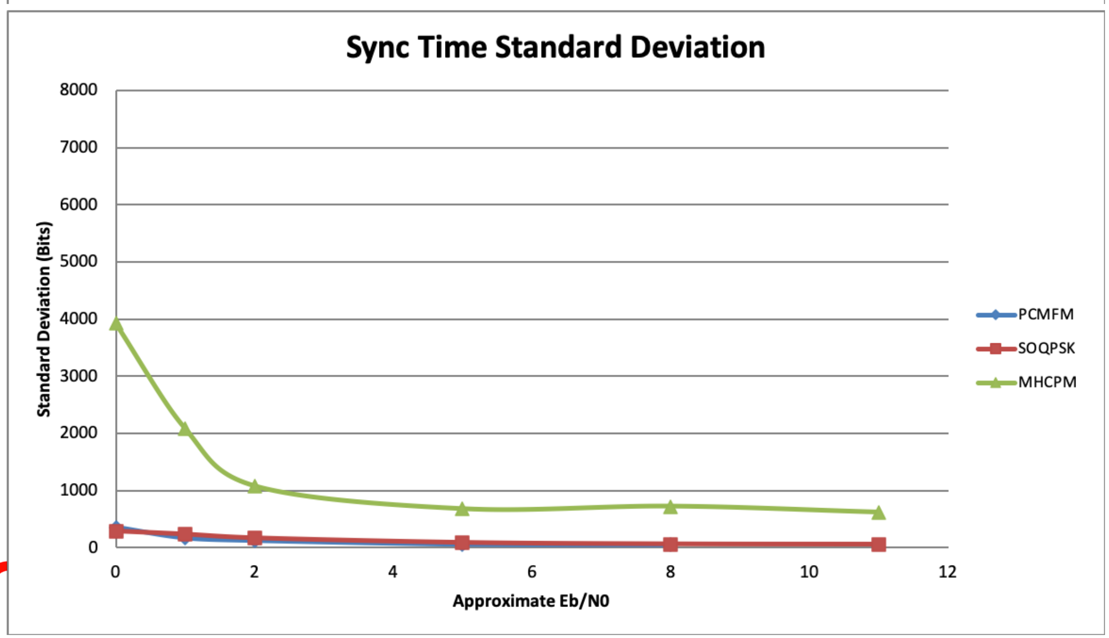


Channel 1, 2

Combiner

Low SNR Synchronization





Synchronization Summary

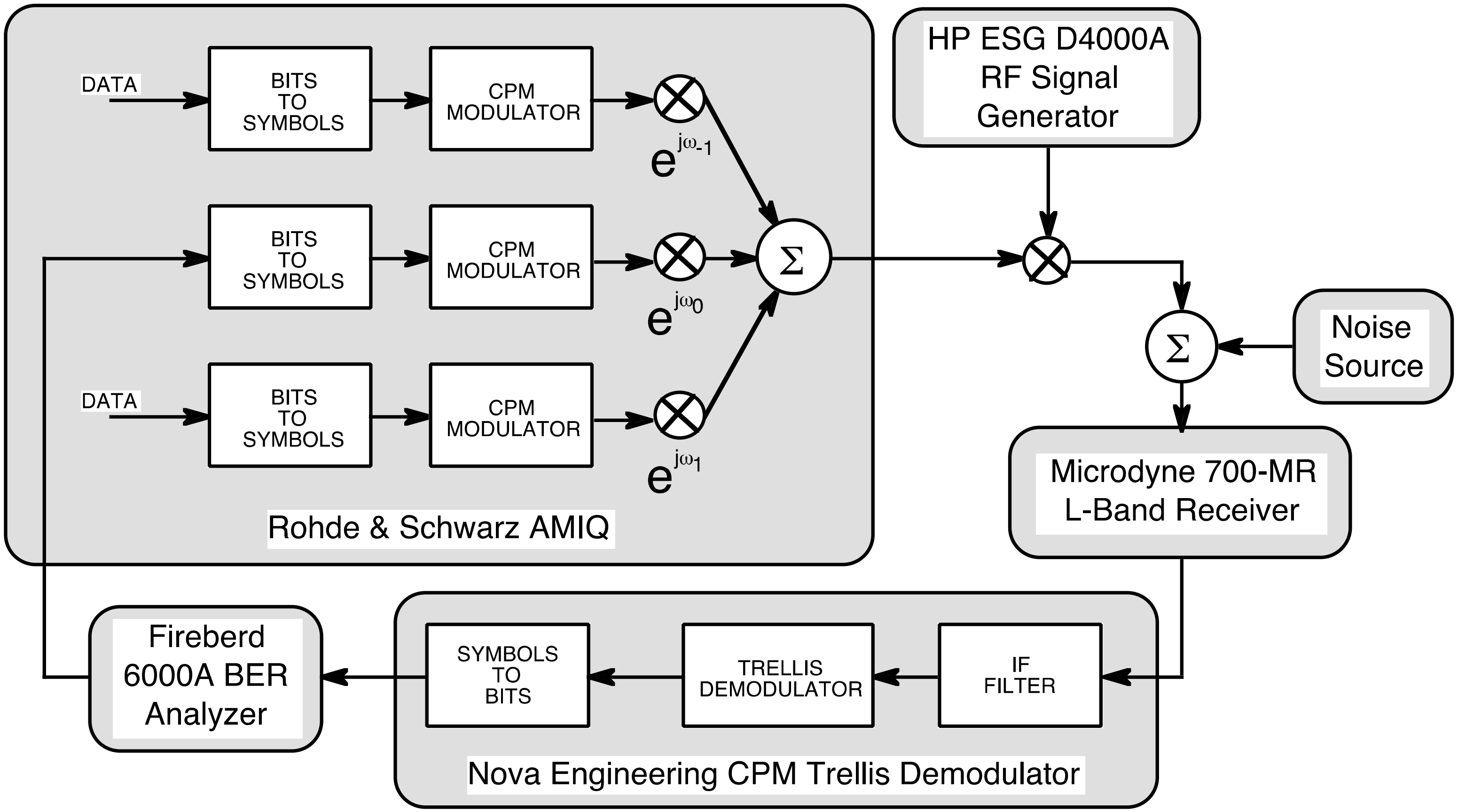
- The aeronautical telemetry channel is plagued with dropouts
- Rapid synchronization, and synchronization at low SNR, is the best means of minimizing the impact of these dropouts
- IRIG 118 defines test procedures for measuring sync time and sync thresholds
- Pay attention to synchronization performance!

Adjacent Channel Interference

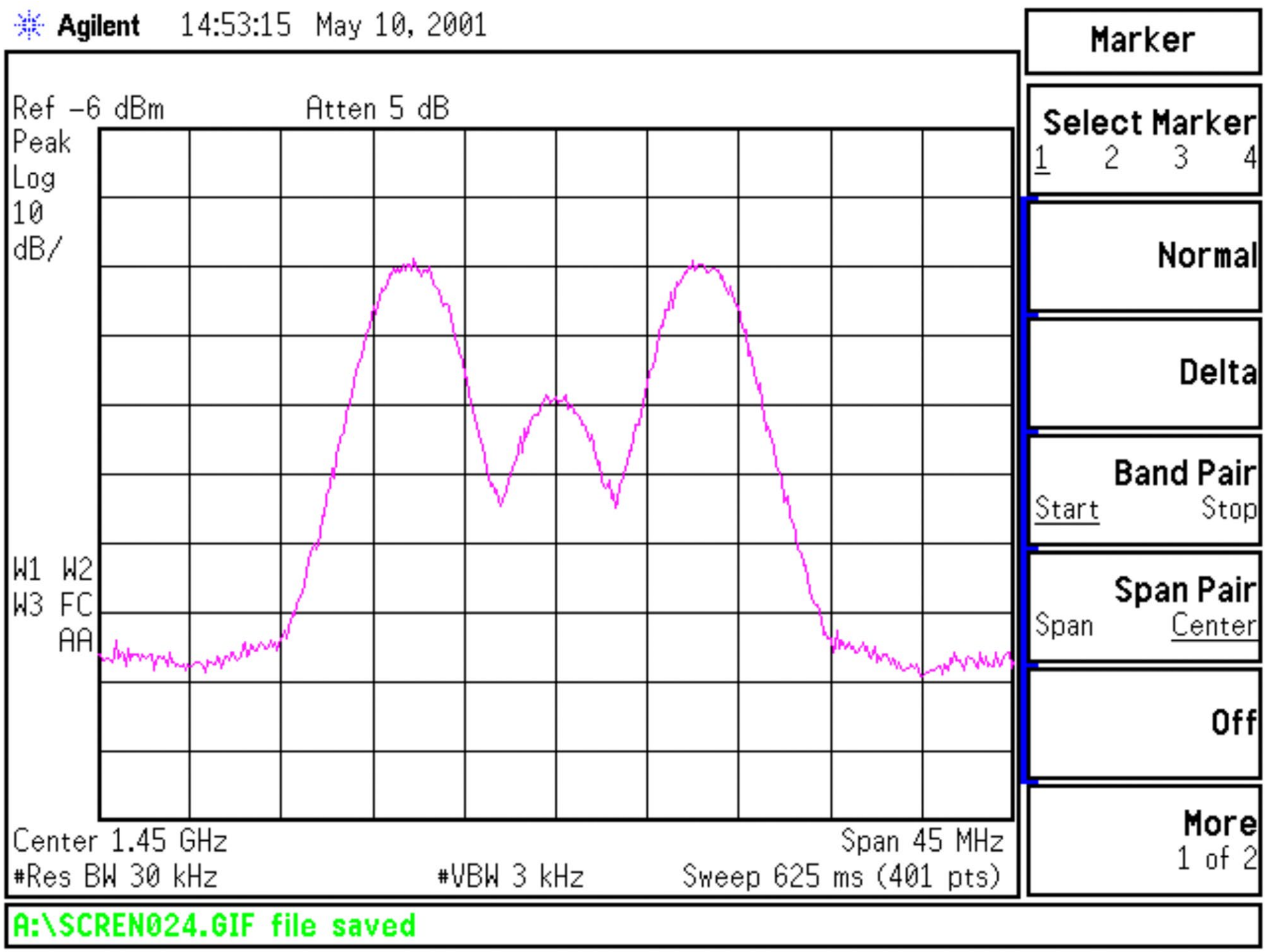
PSD is Half the Story

- Overall spectral efficiency is determined by spacing between channels
- Receiver selectivity affects channel spacing
- A valid comparison must account for both transmitted spectrum and “tolerable” receiver filtering
- Not all modulations are equally “tolerant” of IF filtering and interference
- **Multi-channel testing accounts for these factors**

Multi-channel ACI Test Set

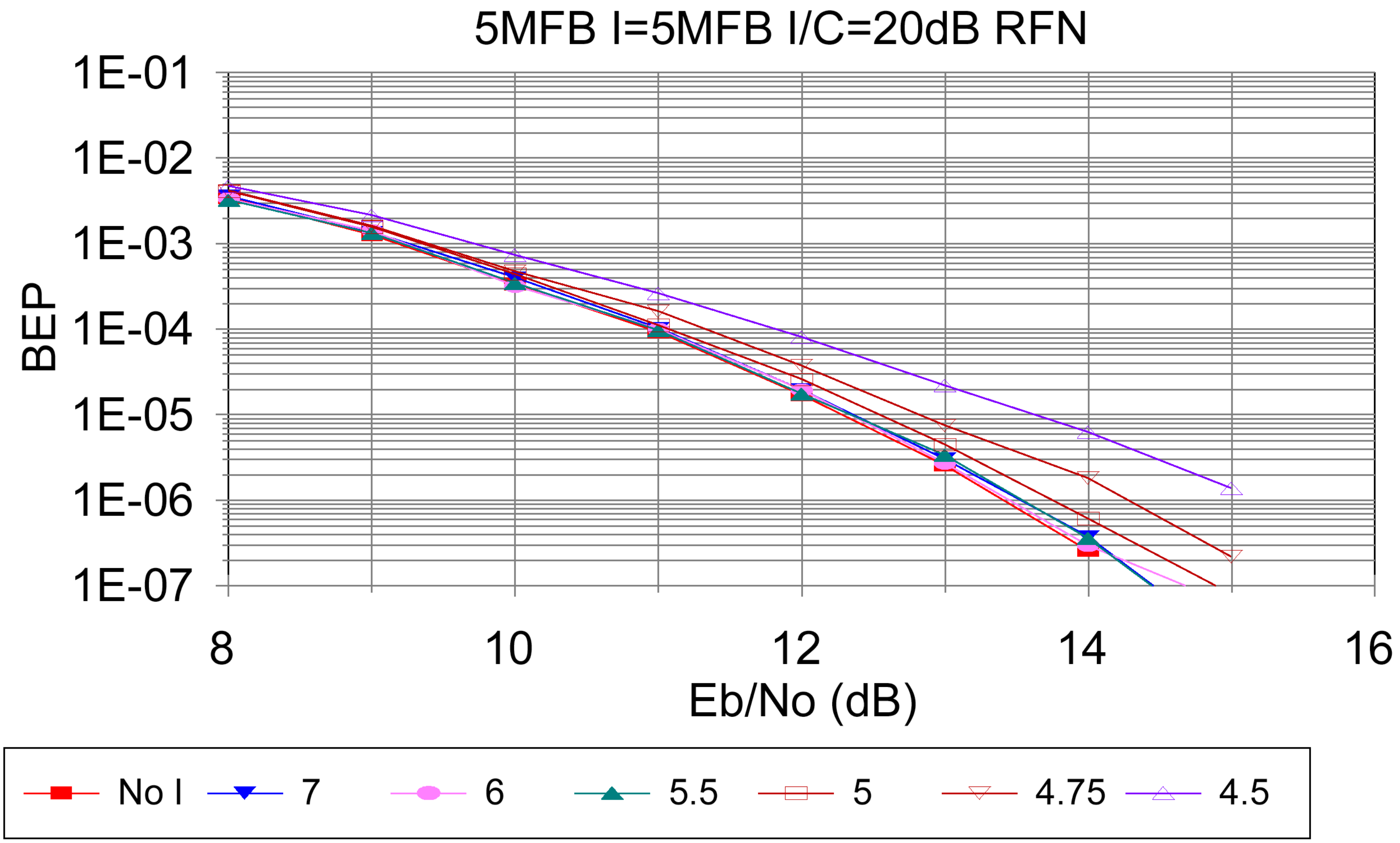


9 Mbps Multi-h CPM, Multichannel



BER as a Function of ΔF

From Gene Law, "Recommended Minimum Telemetry Frequency Spacing With CPFSK, CPM, SOQPSK, and FQPSK Signals", ITC 2003



Degradation as a Function of ΔF

From Gene Law, "Recommended Minimum Telemetry Frequency Spacing With CPFSK, CPM, SOQPSK, and FQPSK Signals", ITC 2003

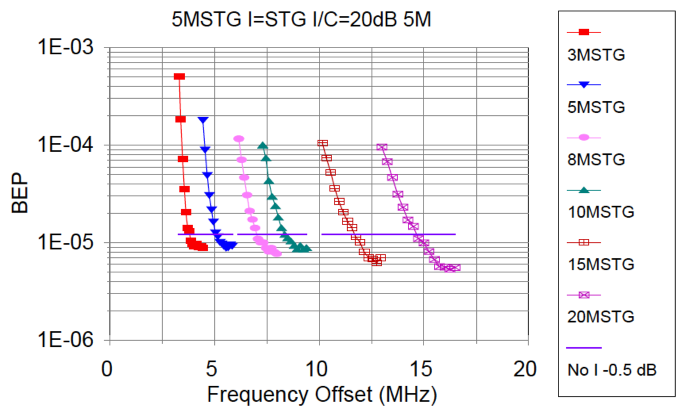


Figure 5. 5 Mbps SOQPSK-TG.

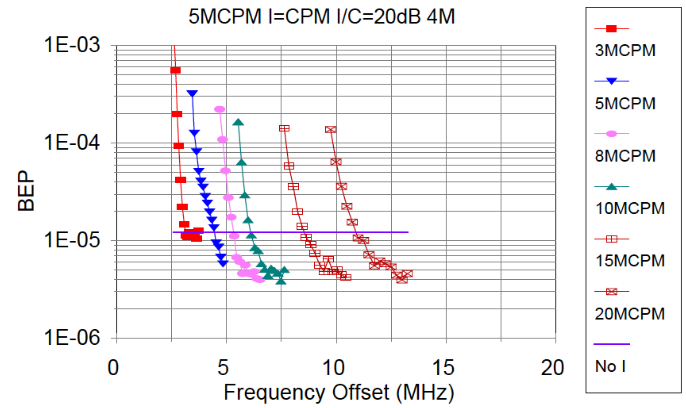


Figure 6. 5 Mbps multi-h CPM.

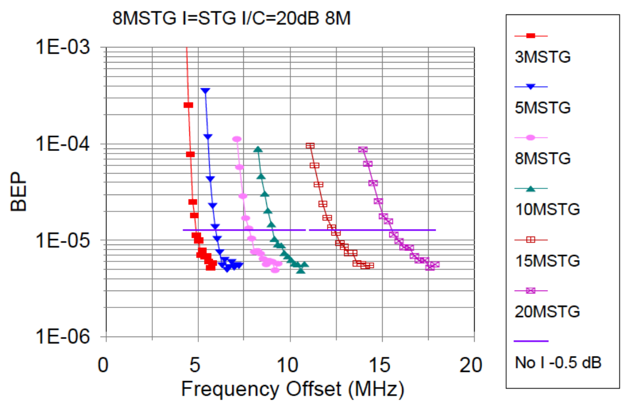


Figure 7. 8 Mbps SOQPSK-TG with 8 MHz IF BW.

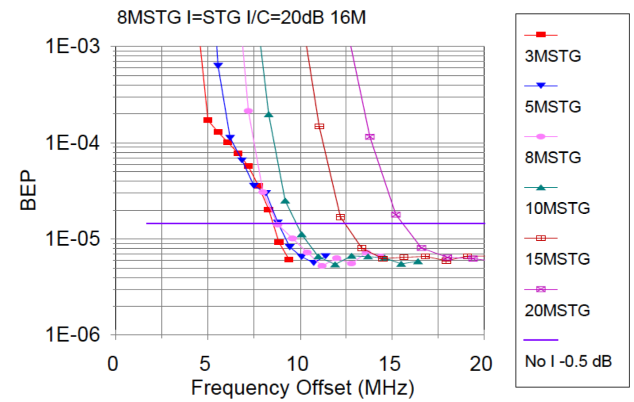
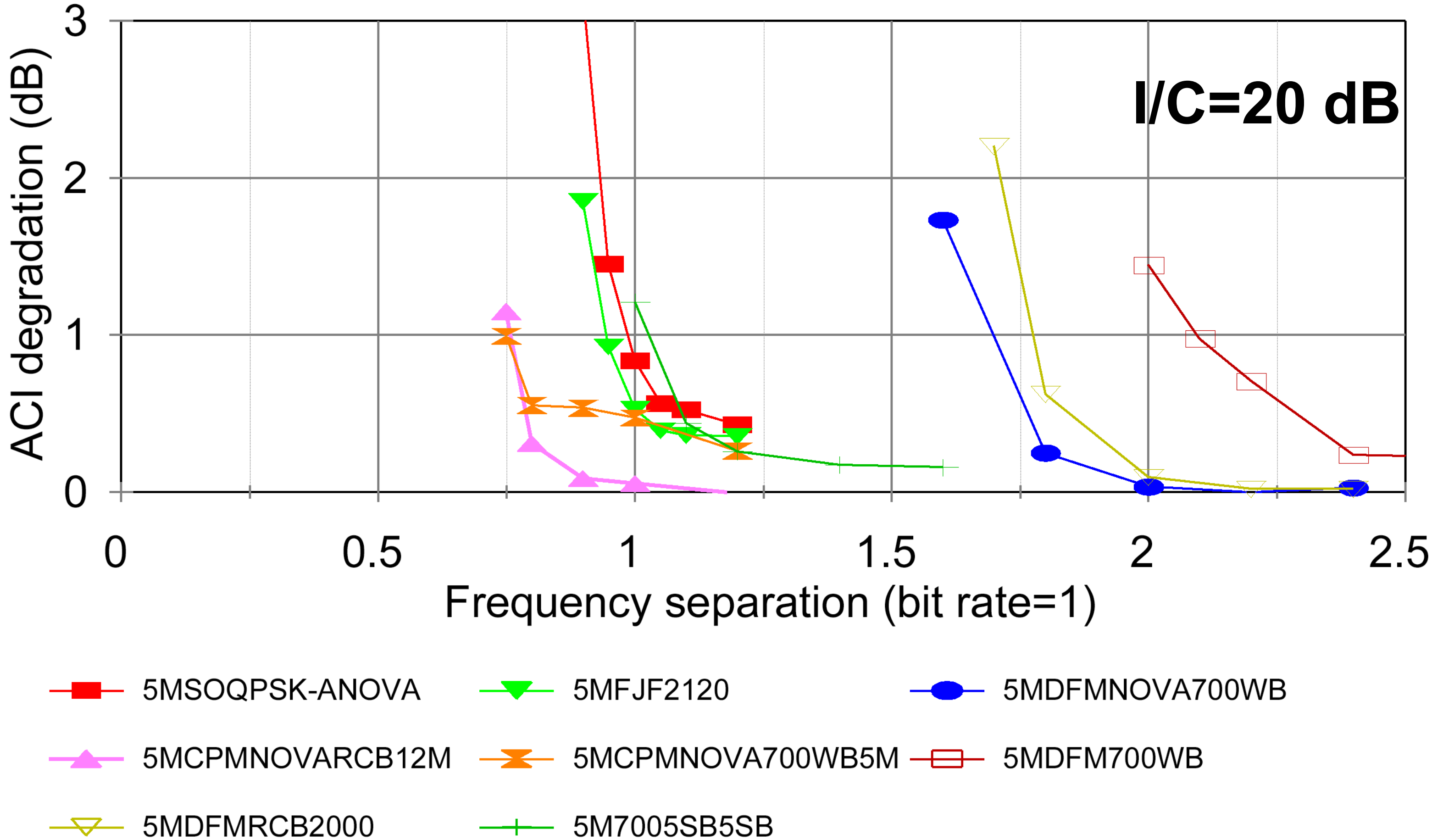


Figure 8. 8 Mbps SOQPSK-TG with 16 MHz IF BW.

ACI Summary



From Gene Law, "Recommended Minimum Telemetry Frequency Spacing With CPFSK, CPM, SOQPSK, and FQPSK Signals", ITC 2003

Frequency Separation Rule

$$\Delta F_0 = a_s{*}R_s + a_i{*}R_i$$

where:

- ΔF_0 = the minimum center frequency separation in MHz
- R_s = bit rate of desired signal in Mb/s
- R_i = bit rate of interfering signal in Mb/s

Modulation Type	a_s		a_i	Rs = Ri
NRZ PCM/FM	1	for receivers with RLC final Intermediate Frequency (IF) filters	1.2	2.2
	0.7	for receivers with Surface Acoustic Wave (SAW) or digital IF filters	1.2	1.9
	0.5	with multi-symbol detectors (or equivalent devices)	1.2	1.7
FQPSK-B, FQPSK-JR, SOQPSK-TG	0.45		0.65	1.1
ARTM CPM	0.35		0.5	0.85

- The NRZ PCM/FM signals are assumed to be premodulation filtered with a multi-pole filter with 3 dB point of 0.7 times the bit rate and the peak deviation is assumed to be approximately 0.35 times the bit rate.
- The receiver IF filter is assumed to be no wider than 1.5 times the bit rate and provides at least 6 dB of attenuation of the interfering signal.
- The interfering signal is assumed to be no more than 20 dB stronger than the desired signal.
- The receiver is assumed to be operating in linear mode; no significant intermodulation products or spurious responses are present.

Multipath Propagation

Brace yourself!

Greek symbols ahead!

Multipath Propagation

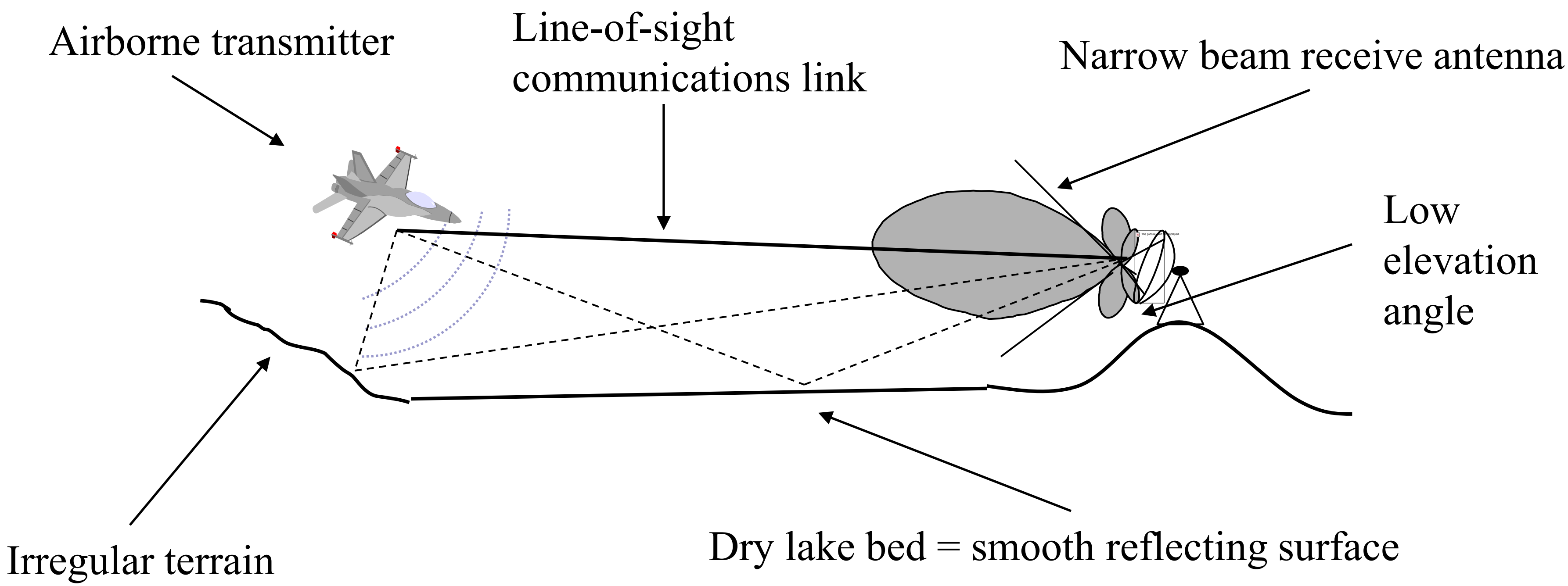


Figure from Dr.Michael Rice, BYU Telemetry Laboratory, Provo, Utah. Reprinted by permission of the author.

Assumptions

- Channel can be modeled as a linear time-invariant (LTI) system over "short enough" time interval

Complex-valued path loss

$$h(t) = \sum_{k=0}^{L-1} \Gamma_k e^{-j\omega_c \tau_k} \delta(t - \tau_k)$$

$$= \delta(t) + \sum_{k=1}^{L-1} \Gamma_k e^{-j\omega_c \tau_k} \delta(t - \tau_k)$$

Line-of-sight propagation path

L-1 multipath propagation paths

Figure from Dr.Michael Rice, BYU Telemetry Laboratory, Provo, Utah. Reprinted by permission of the author.

2-Ray Transfer Function

- Magnitude of first multipath reflection: Γ_1
- "sweep rate" of multipath null ~ $\omega_c \dot{\tau}_1 + \dot{\theta}_{\Gamma_1}$

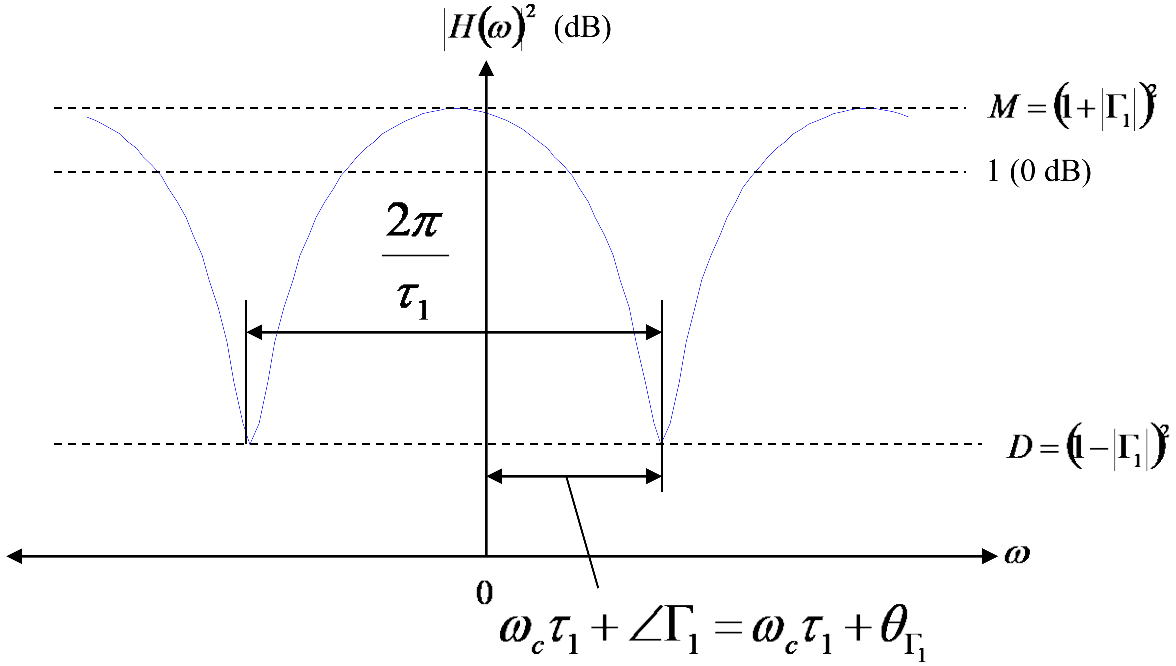
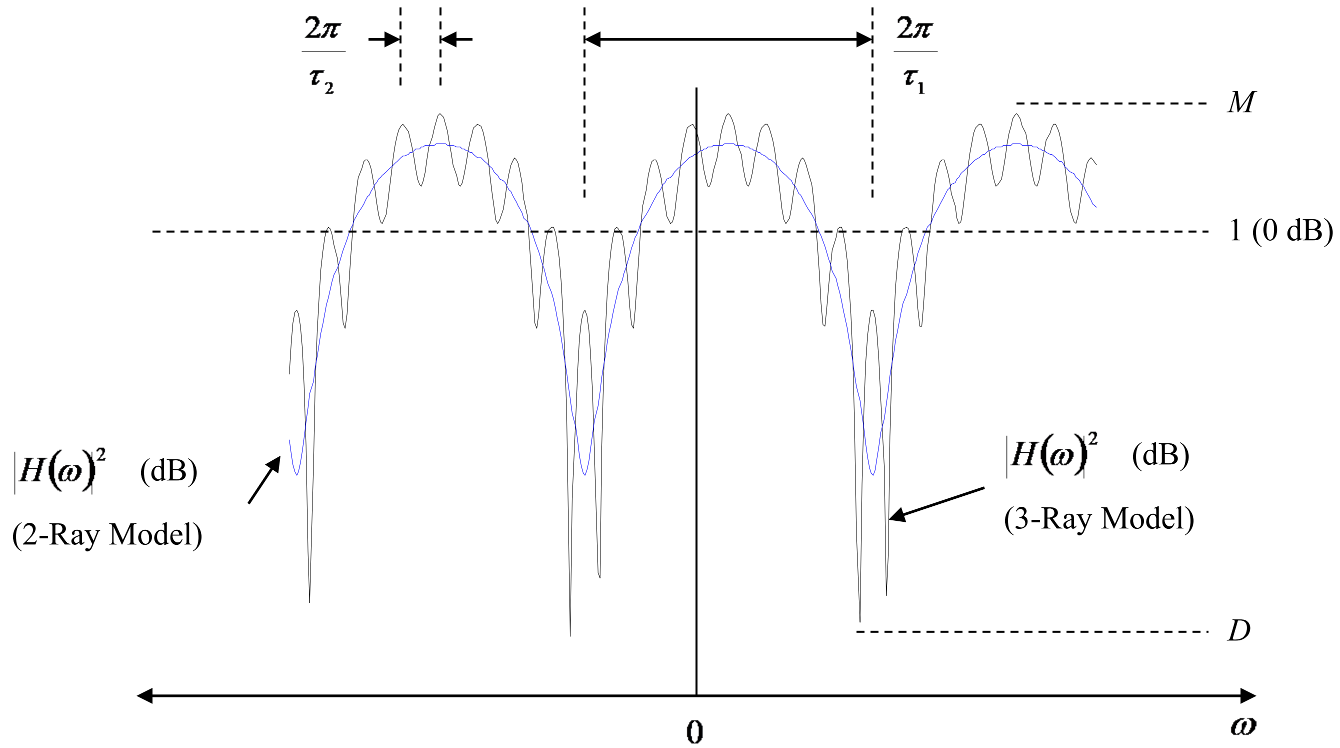


Figure from Dr.Michael Rice, BYU Telemetry Laboratory, Provo, Utah. Reprinted by permission of the author.

3-Ray Transfer Function

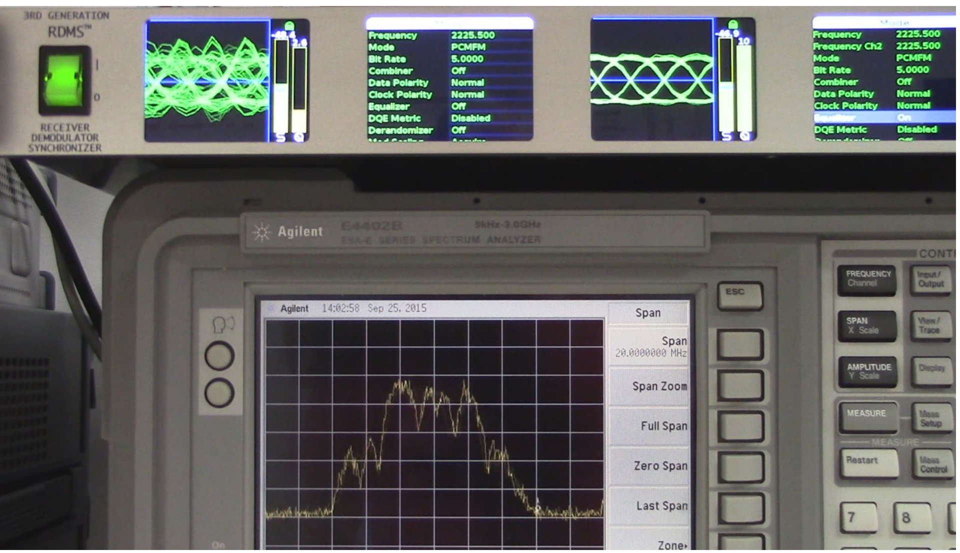


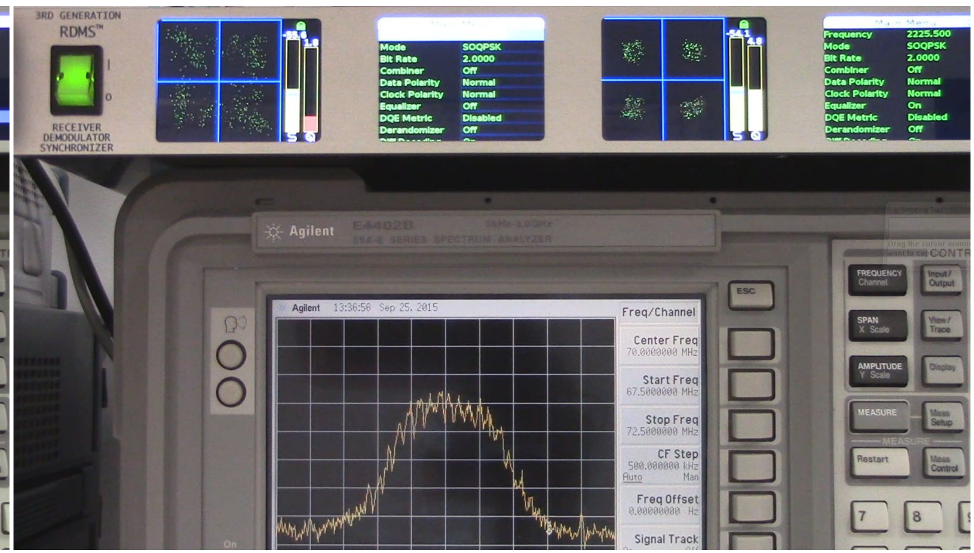
$$\text{Assumes } \tau_1 < \tau_2 \text{ and } |\Gamma_1| > |\Gamma_2|$$

Figure from Dr.Michael Rice, BYU Telemetry Laboratory, Provo, Utah. Reprinted by permission of the author.

Multipath on the Tarmac

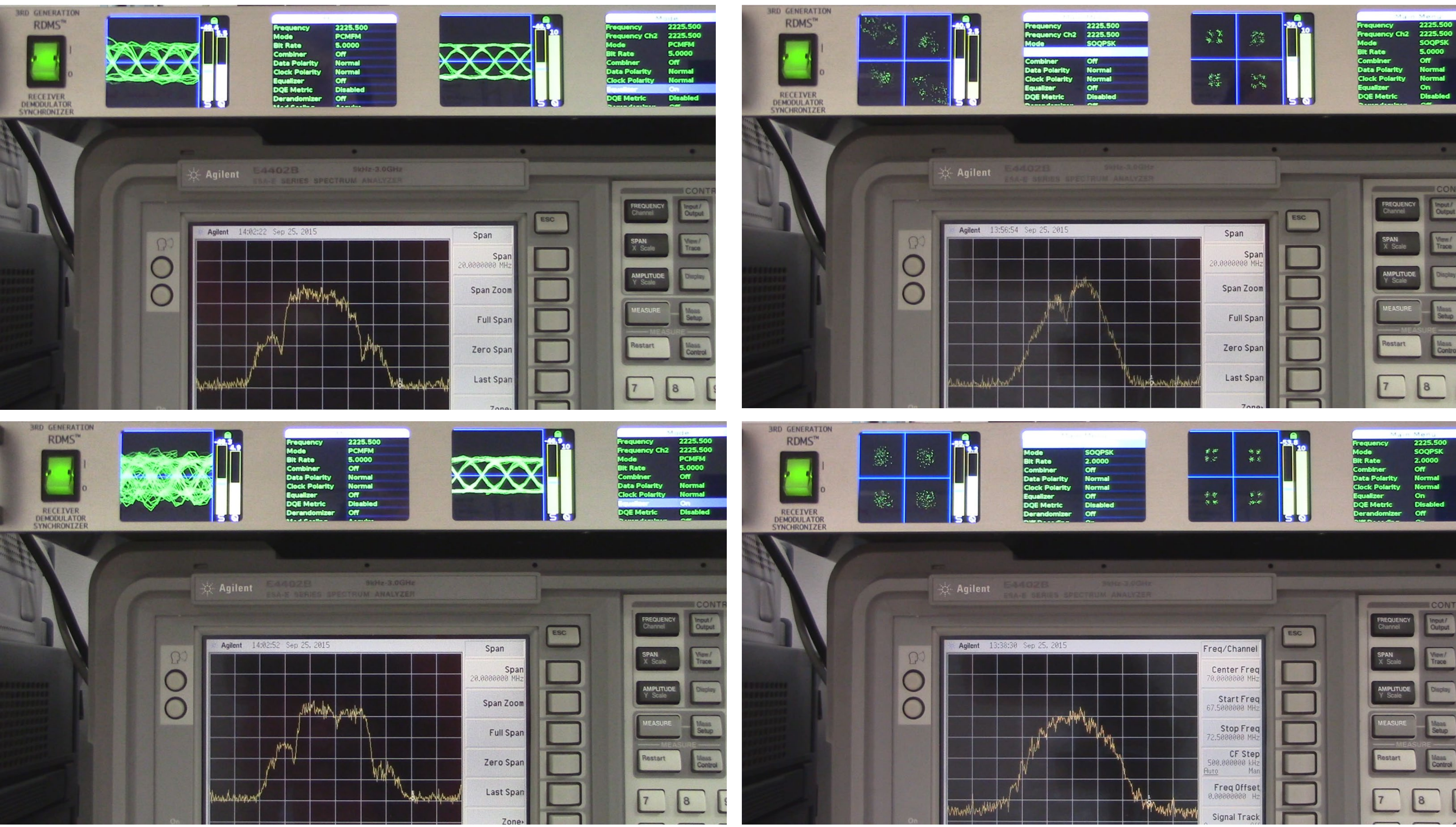
- Nearly static, frequency selective, long delays





Multipath in Flight

- Dynamic, frequency selective and flat fading, various delays



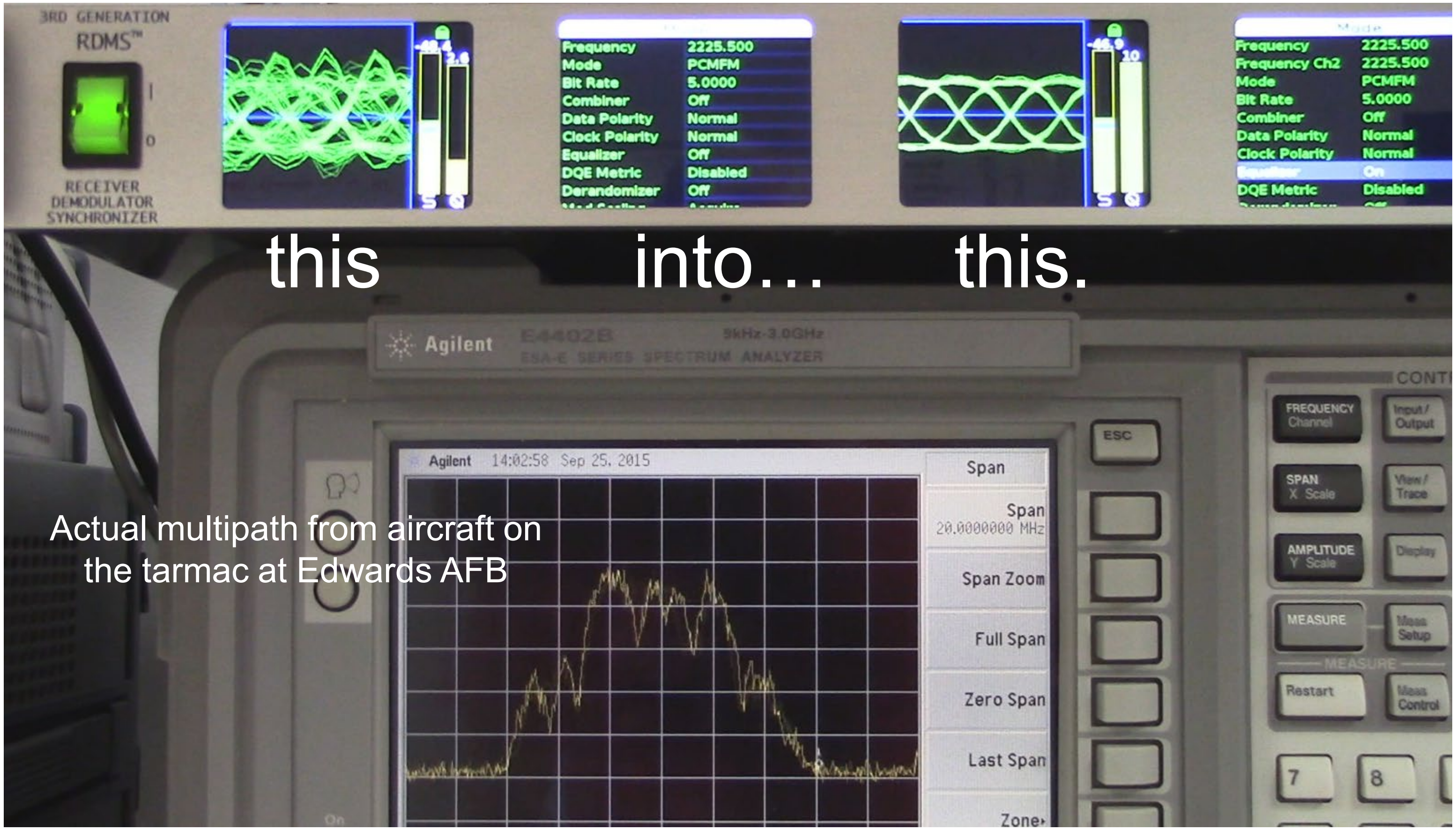
Multipath Summary

- If your test article operates near the ground, you are quite likely experiencing multipath.
- If so, there will be intervals during which no useful data is recovered.
- Loss of bit count integrity is likely
  - Encrypted links will lose crypto sync
- What to do?
- Stay tuned for the “Adaptive Equalizer” discussion

Adaptive Equalization

Multipath is Ugly

- Equalization can turn



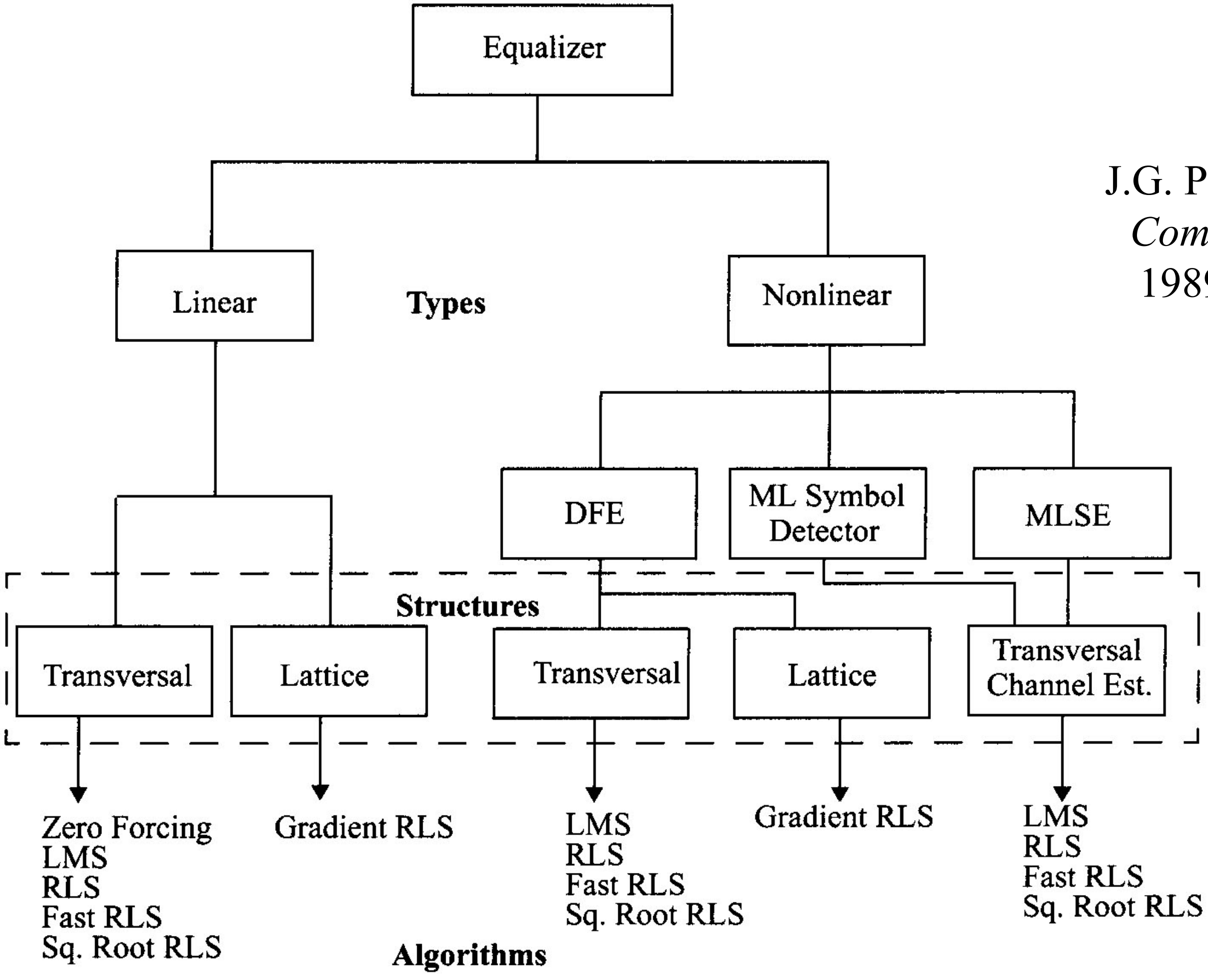
- this into… this.

Actual multipath from aircraft on the tarmac at Edwards AFB

Adaptive Equalization

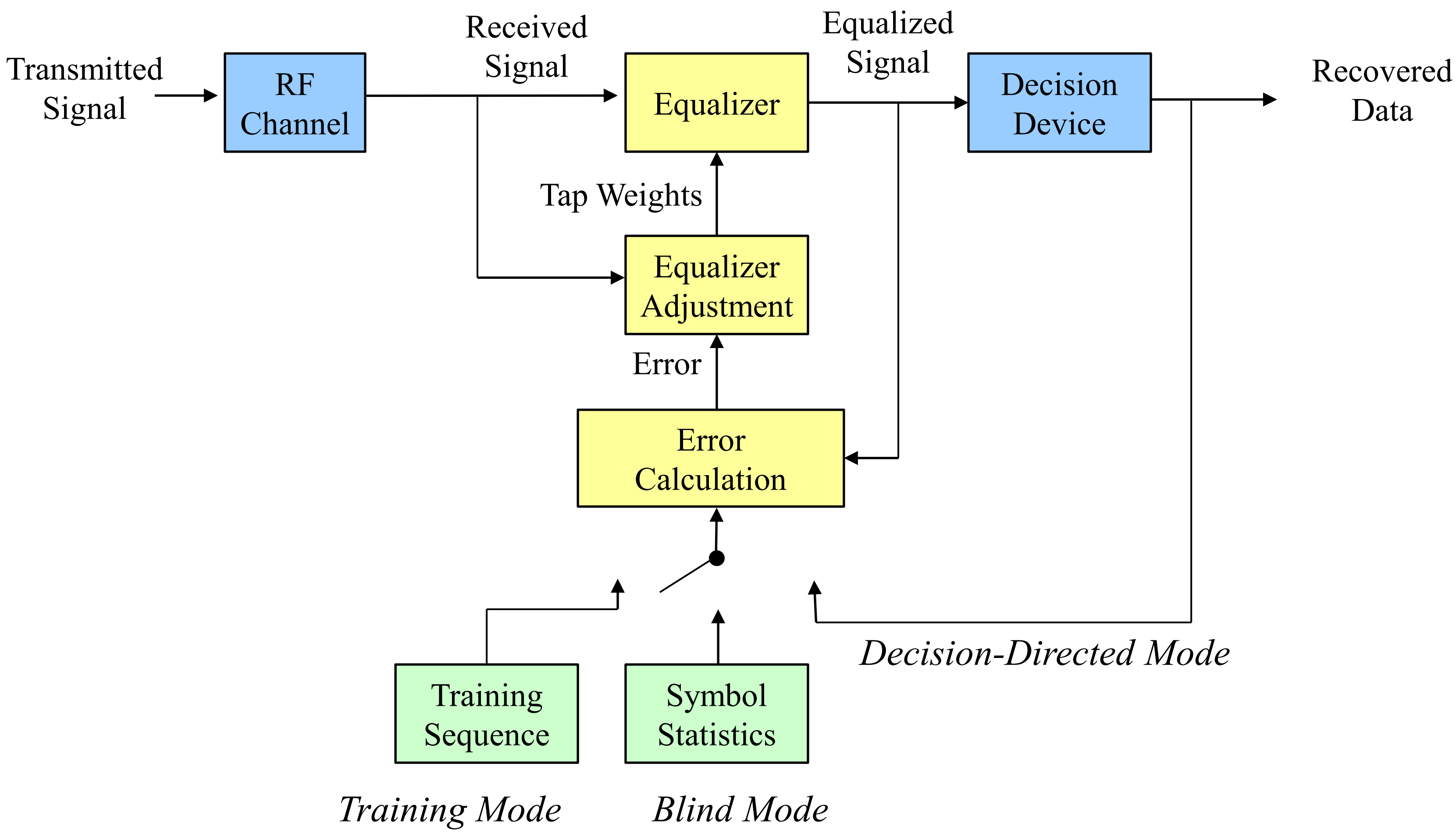
- Consider the multipath channel to be a filter
  - Varies over time
- Consider building a filter which “undoes” the filtering imposed by the channel
  - Let it keep track of the the channel and continuously adapt itself to the channel
- Presto! You have an adaptive equalizer
  - Can repair damage done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

Equalizer Techniques



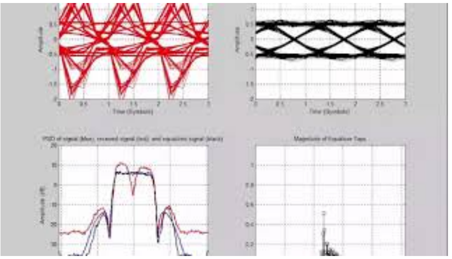
J.G. Proakis, *Digital Communications*. 1989 2nd Edition

Generic Adaptive Equalizer

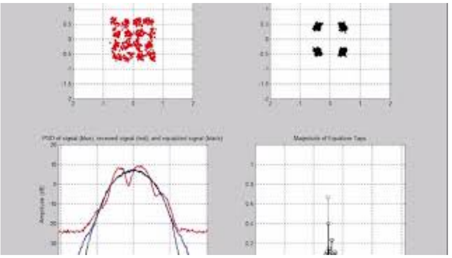


Adaptive EQ - Adapting

- Jump to file: equalizer-out-pcmfm-3ray-dynamic-video.mp4
  - Or, click to view on our website: PCMFM Adaptive Equalizer Video



- Jump to file: equalizer-out-soqpsk-3ray-dynamic-video.mp4
  - Or, click to view on our website: SOQPSK Adaptive Equalizer Video



Adaptive Equalizer in Action

- Jump to file: rdms-rackmount-receiver-adaptive-equalizer-demonstration-video.mp4
  - Or, click to view on our website: [Adaptive Equalizer Demonstration Video]

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?

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Proposed *Static* Channels

- Channel response depends on
  - Carrier frequency, ω_c
  - Delay, τ_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?

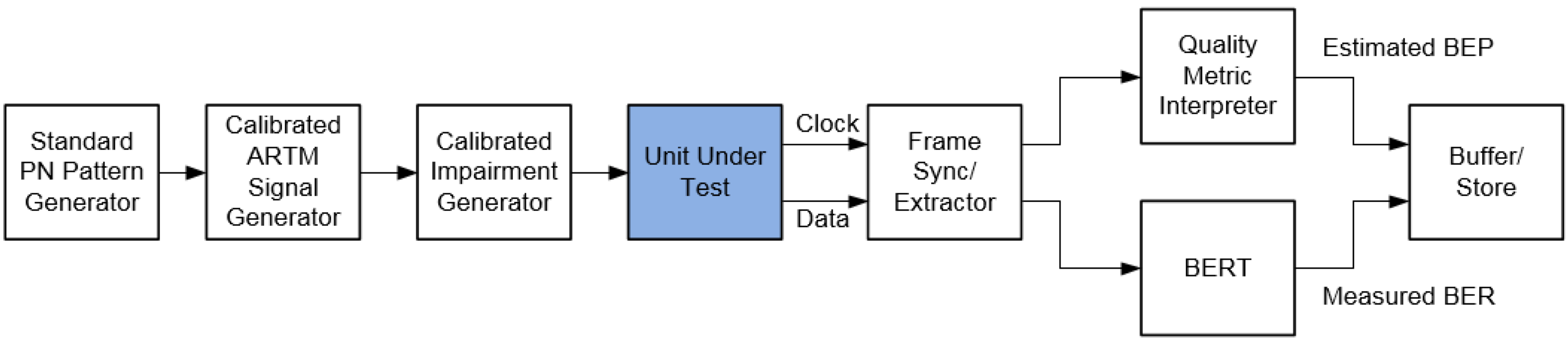
Definition of DQM (a.k.a. Q)

- 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

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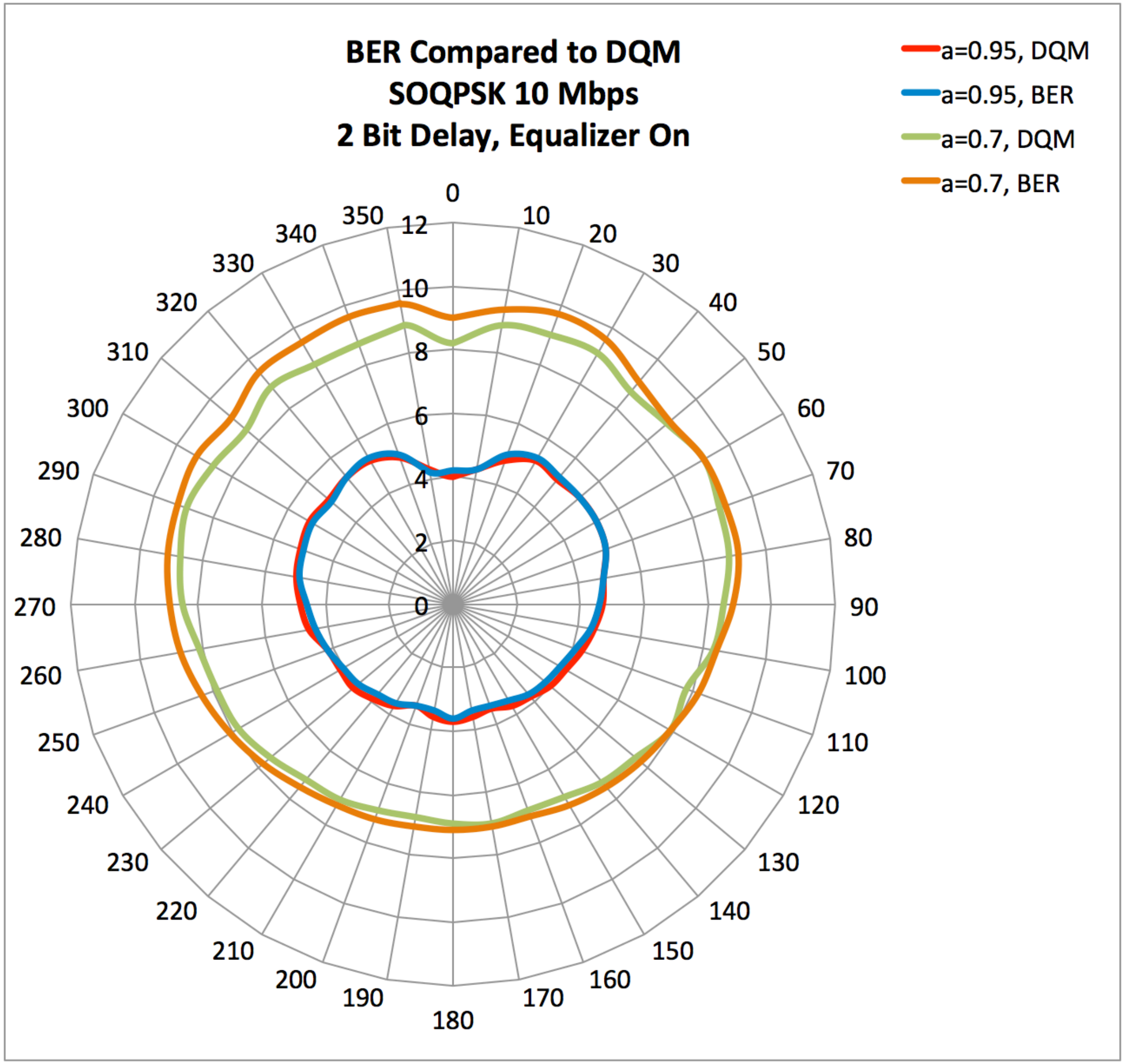
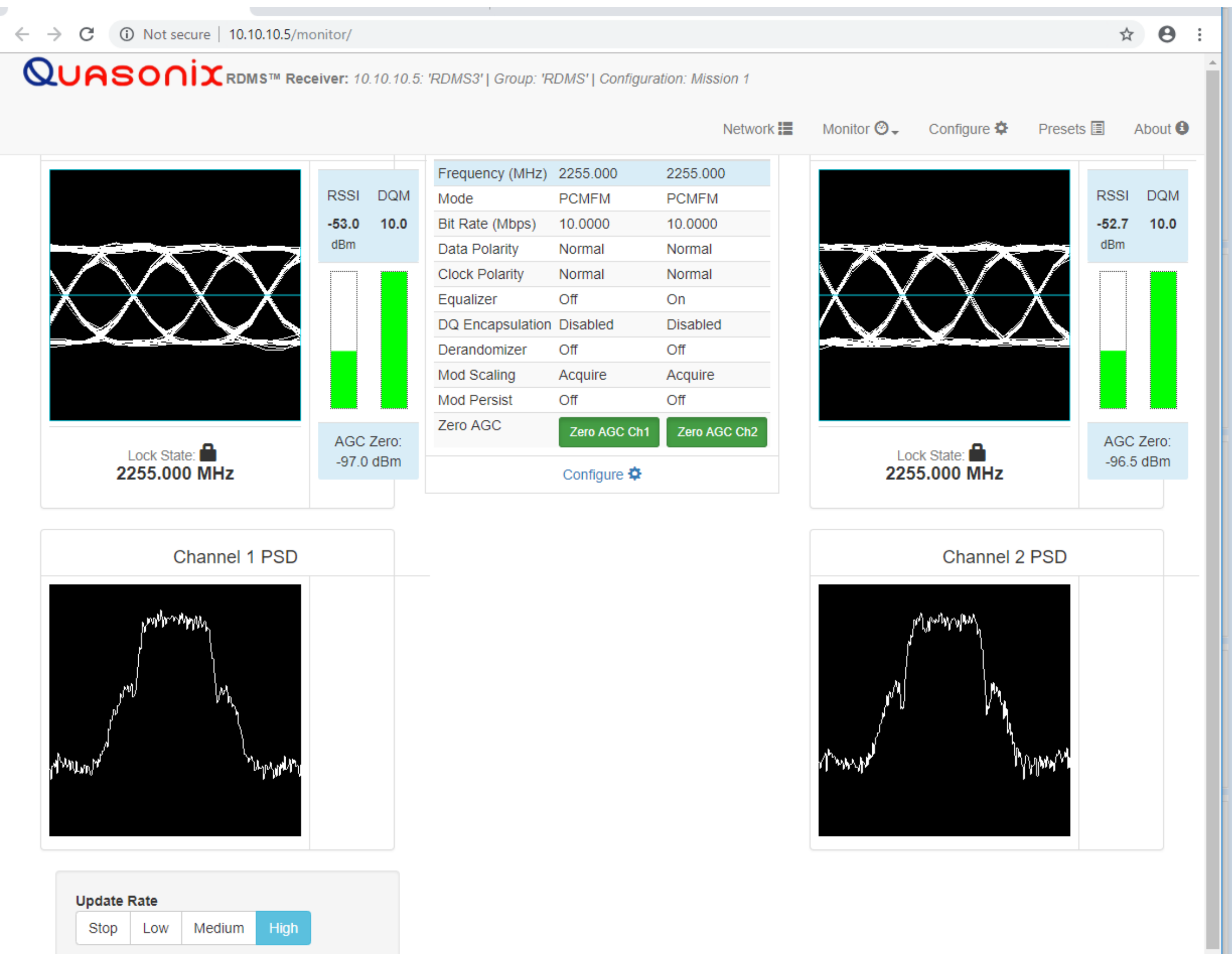
Grading the Tests

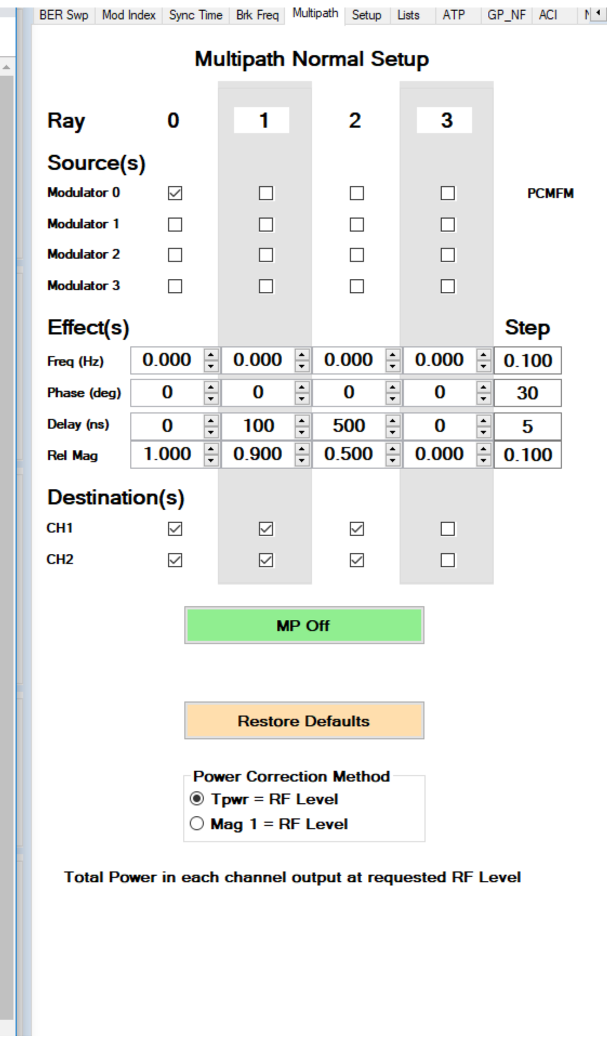
- Measure BER with EQ on and off, then compute DQM
  - If your DQM is well calibrated, measure DQM directly
- Plot DQM vs. delay path phase, in polar form
  - Radius = DQM
  - Angle = phase of delayed path
- Result will be a distorted “hoop”
  - Bigger radius is better
  - Some angles will be worse than 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

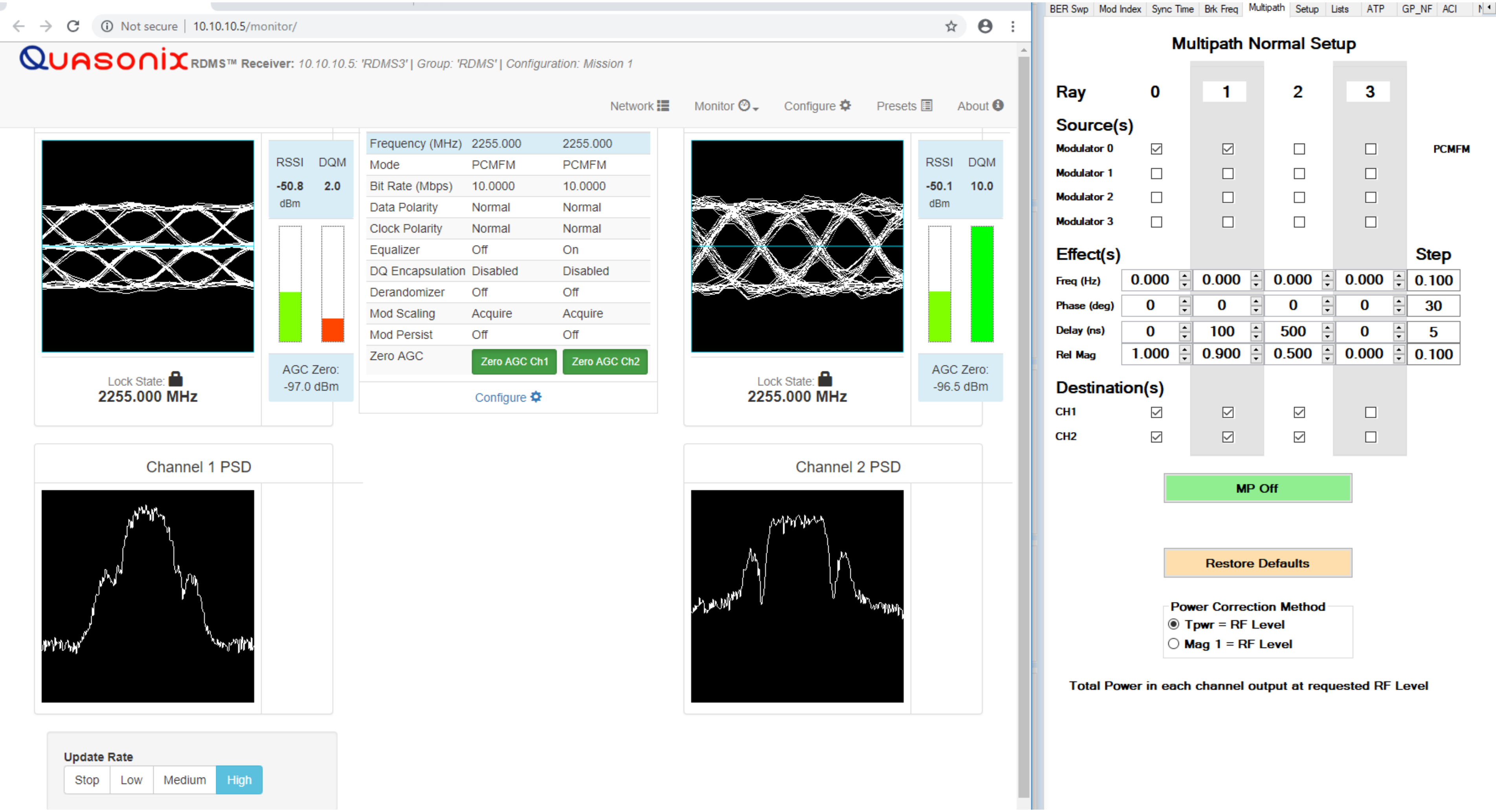


No Multipath, No Problem





0-100-0.9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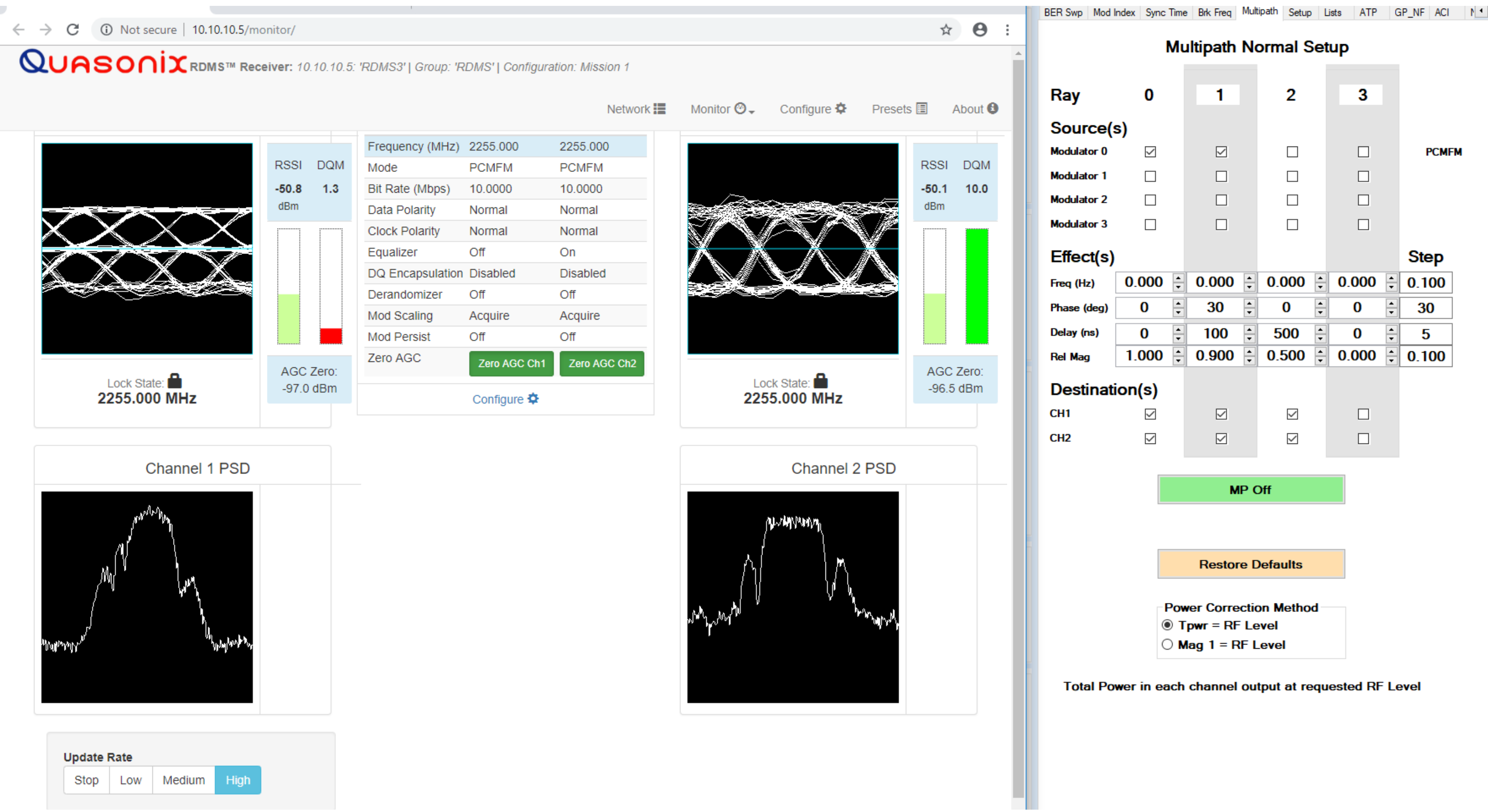
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.8 dBm 2.0
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.1 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 0 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

30-100-0.9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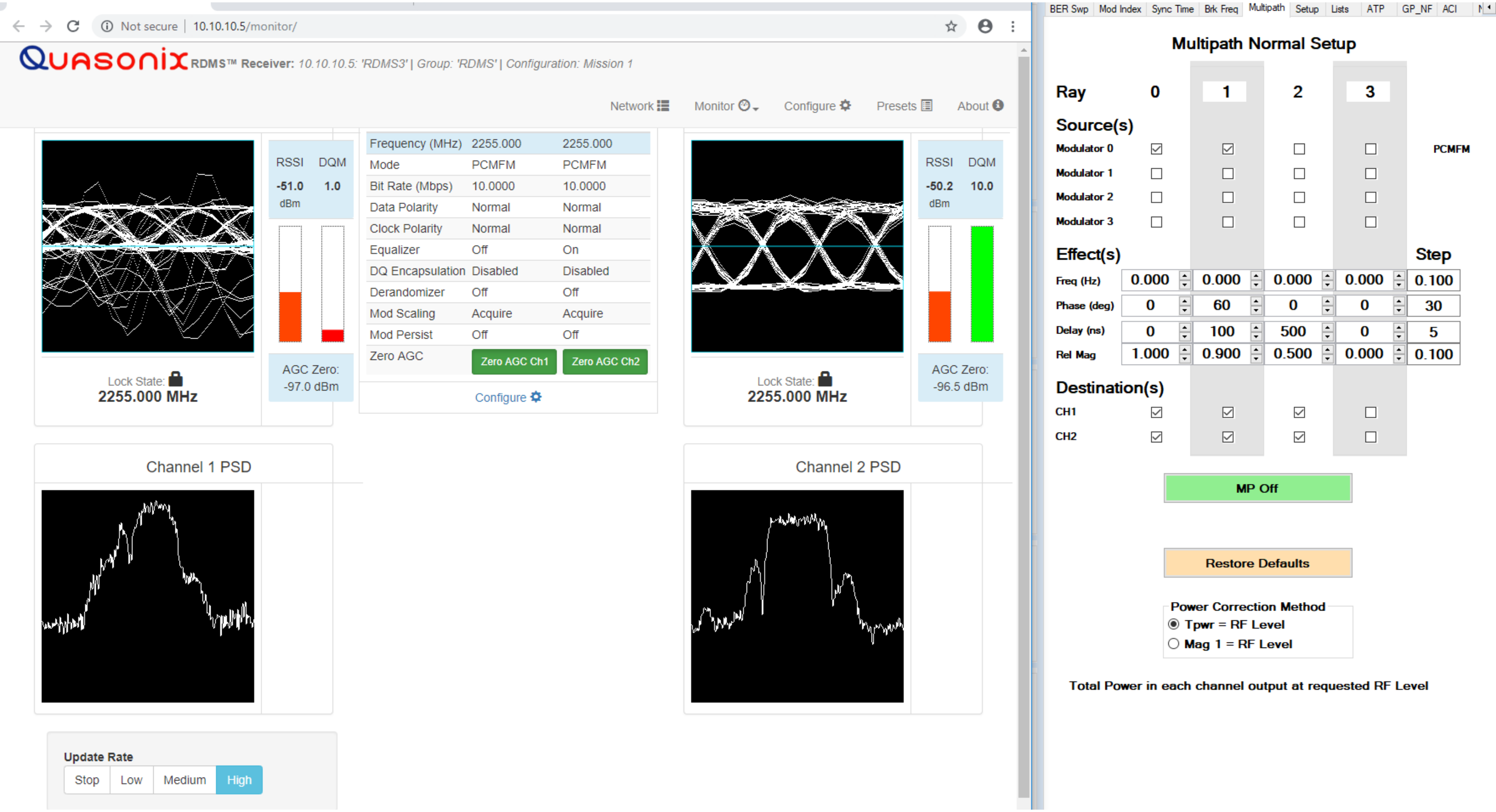
RSSI DQM
-50.8 1.3
dBm
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire 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: -96.5 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 30 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

60-100-0.9



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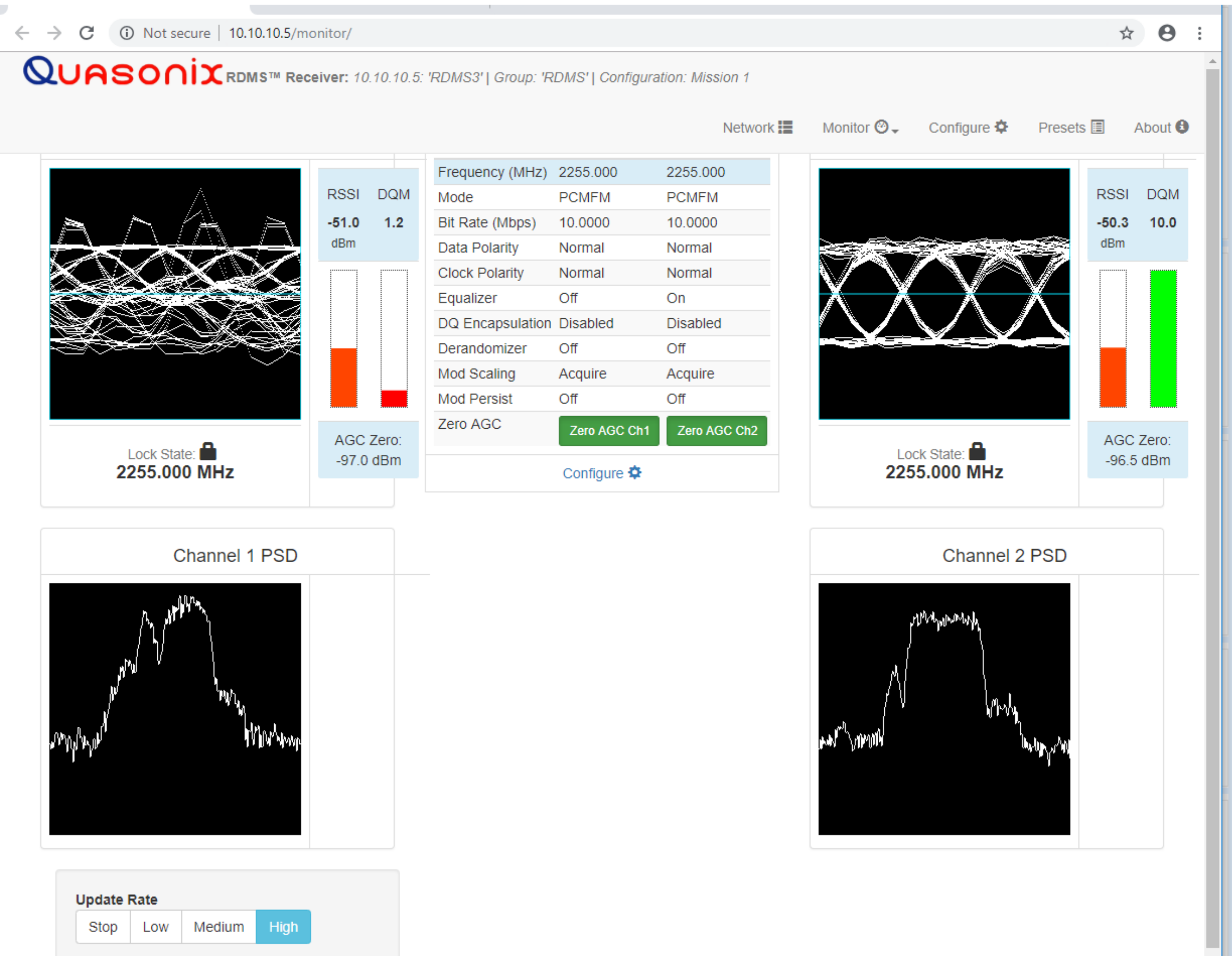
Network Monitor Configure Presets About
RSSI DQM
-51.0 1.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer 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 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 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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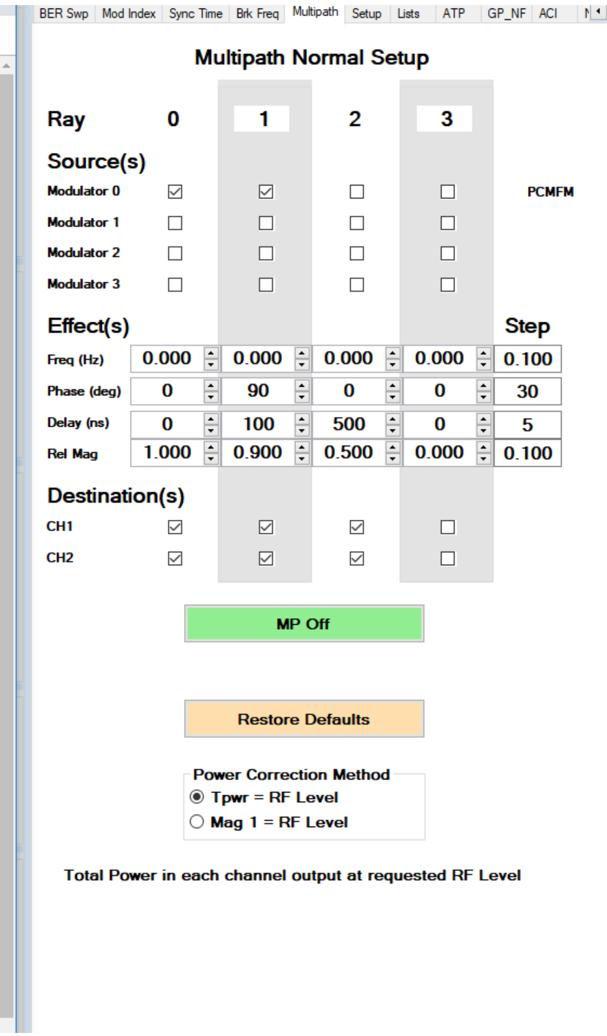
Monitor
Configure
Presets
About
RSSI DQM
-51.0 1.2
dBm
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer 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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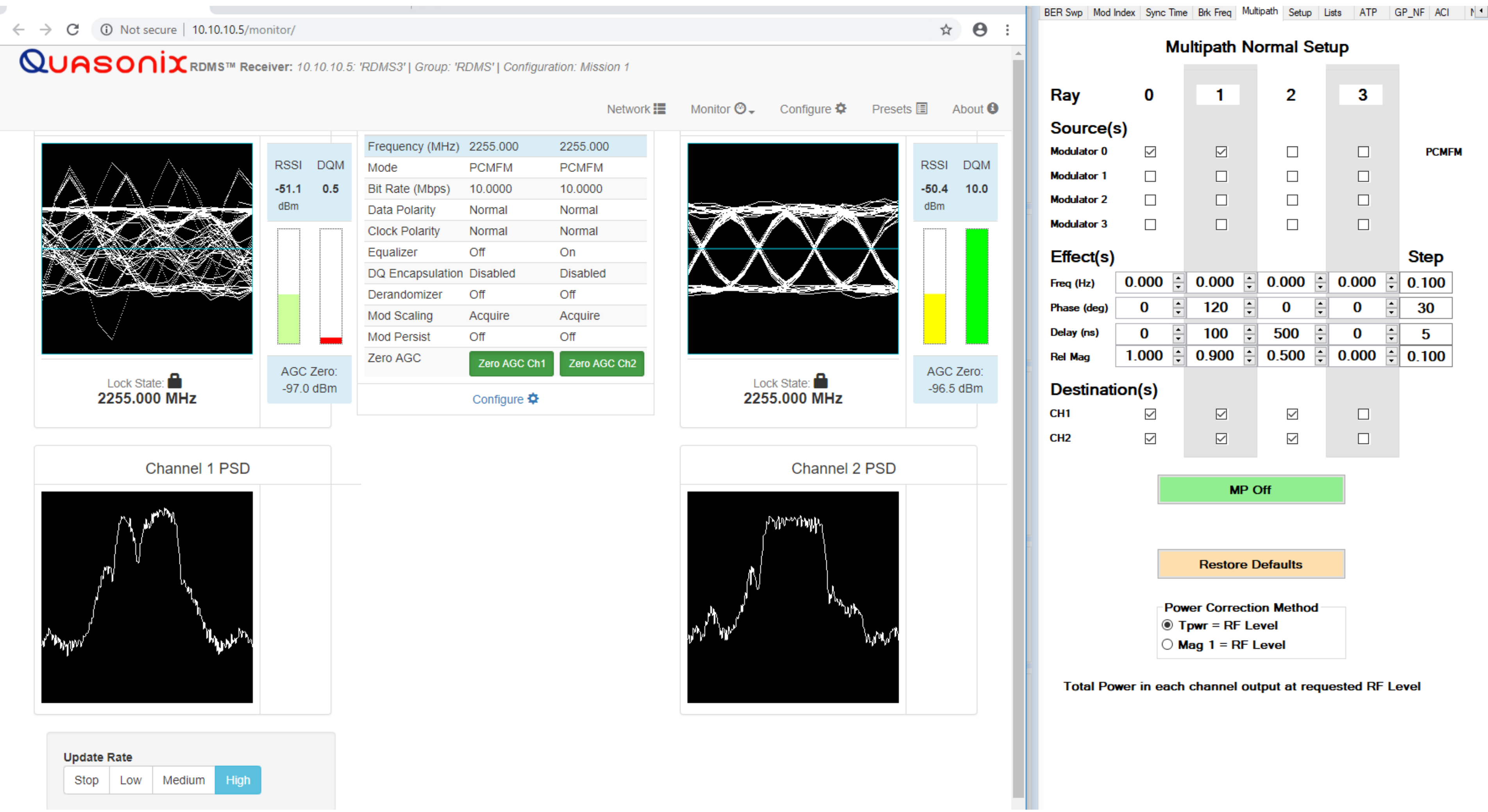
Mod Index
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 90 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
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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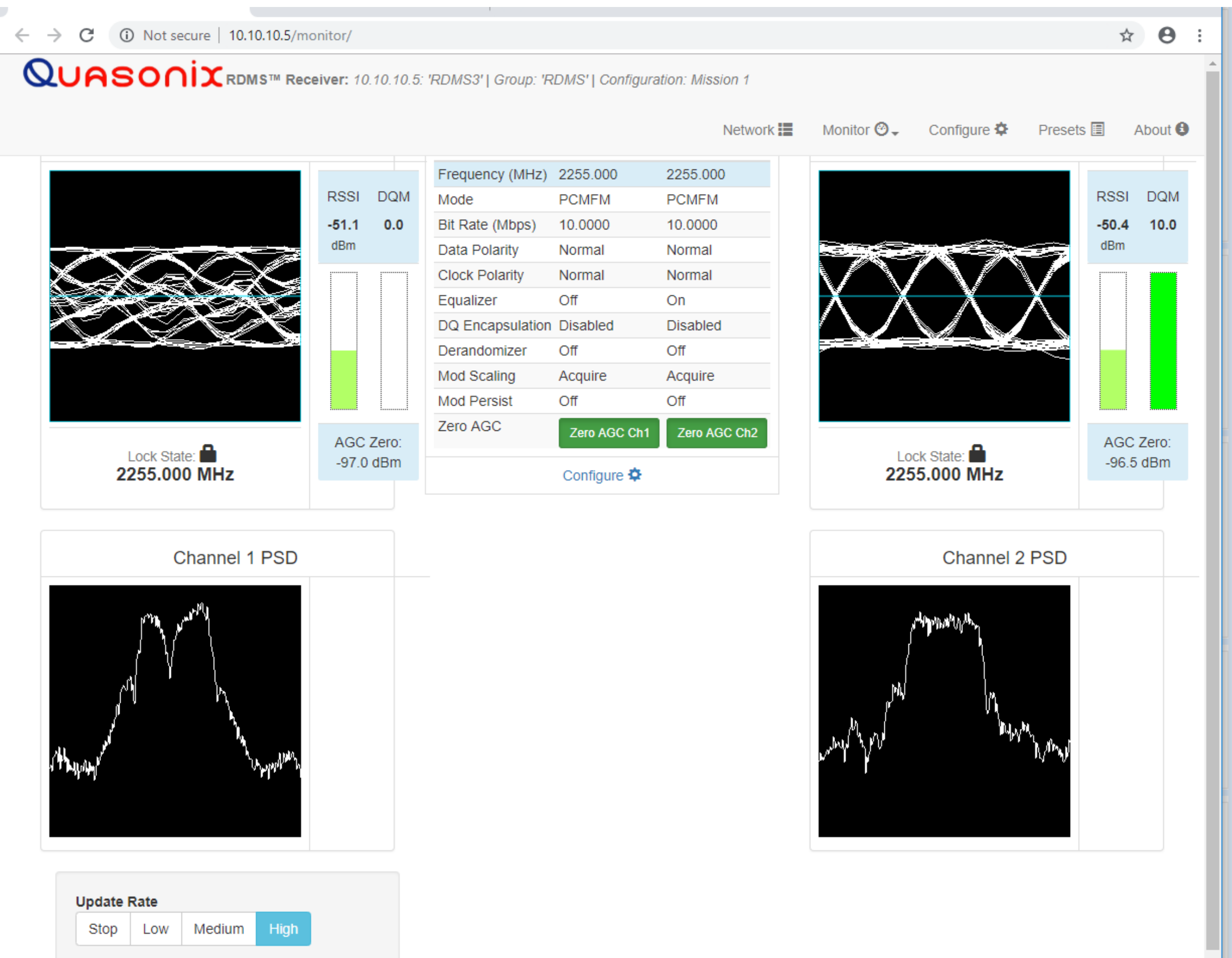
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.1 0.5
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer 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) 0 120 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



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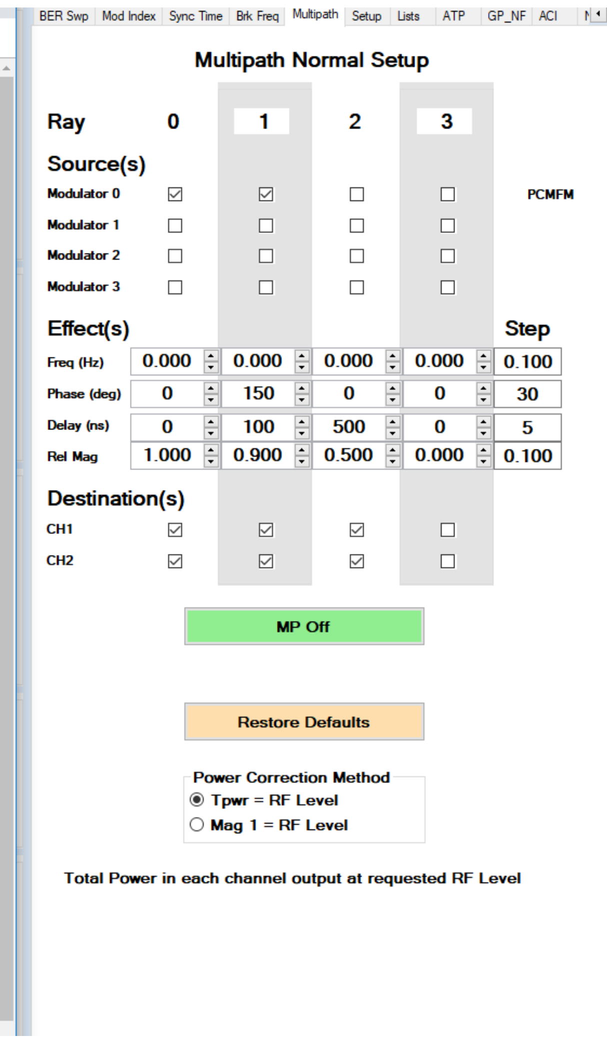
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.1 0.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer 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



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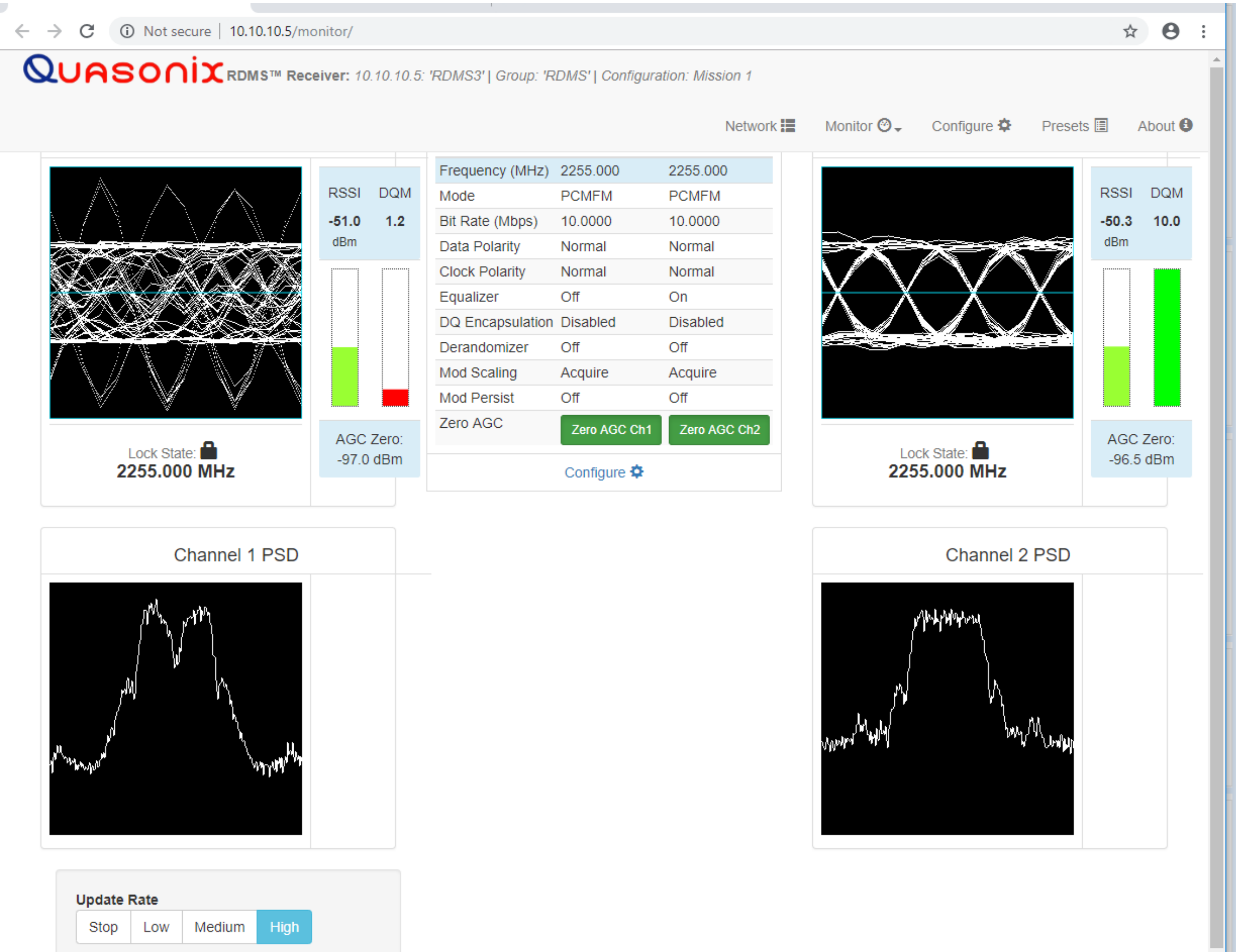
Sync Time
Brk Freq
Multipath
Setup
Lists
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 150 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
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



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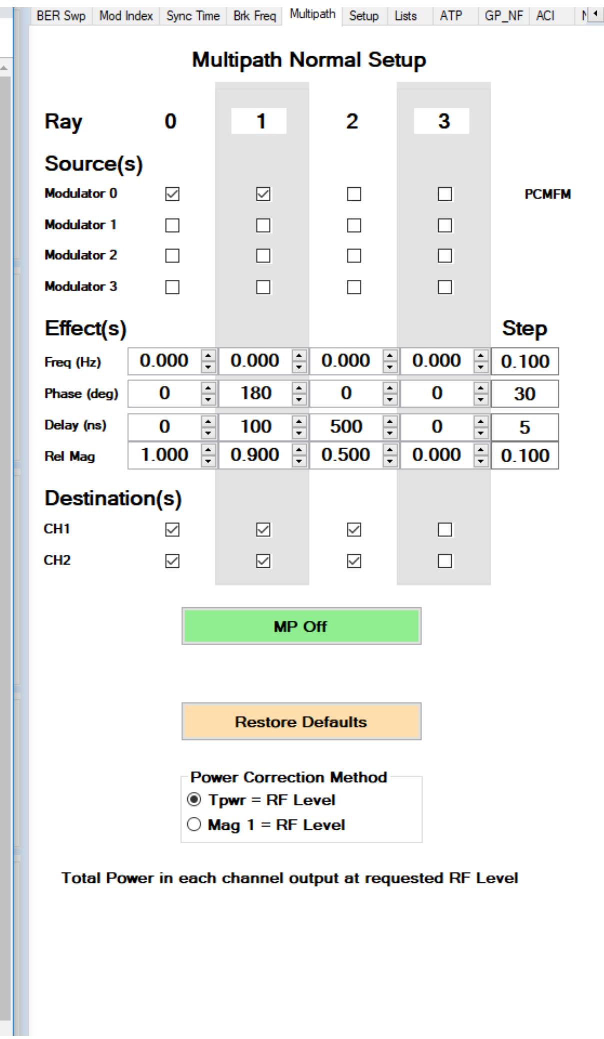
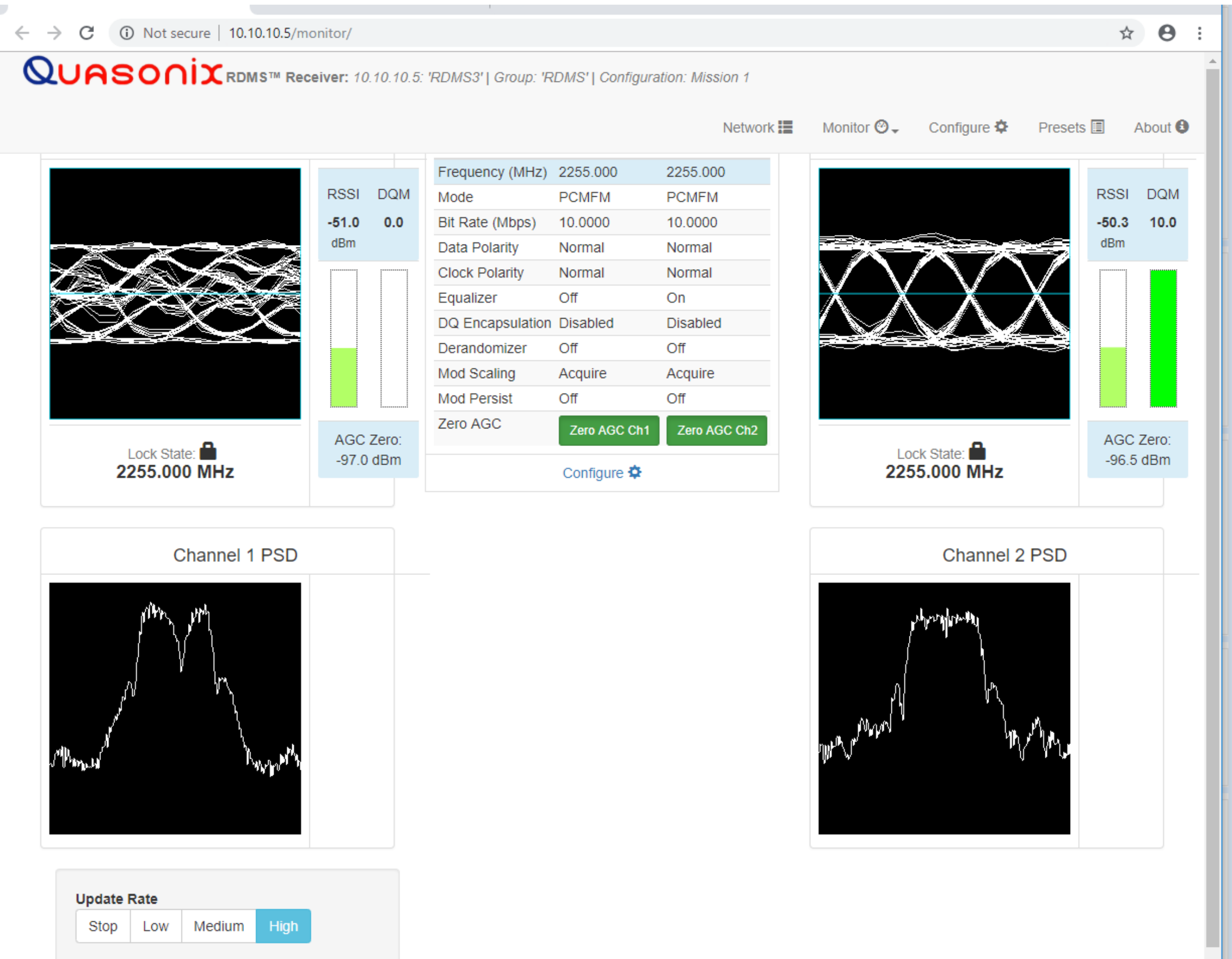
Network
Monitor
Configure
Presets
About
RSSI DQM
-51.0 dBm 1.2
Lock State:
2255.000 MHz
AGC Zero: -97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
Data Polarity Normal Normal
Clock Polarity Normal Normal
Equalizer Off On
DQ Encapsulation Disabled Disabled
Derandomizer Off Off
Mod Scaling Acquire Acquire
Mod Persist Off Off
Zero AGC
Zero AGC Ch1
Zero AGC Ch2
Configure
RSSI DQM
-50.3 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) 0 180 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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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
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AGC Zero:
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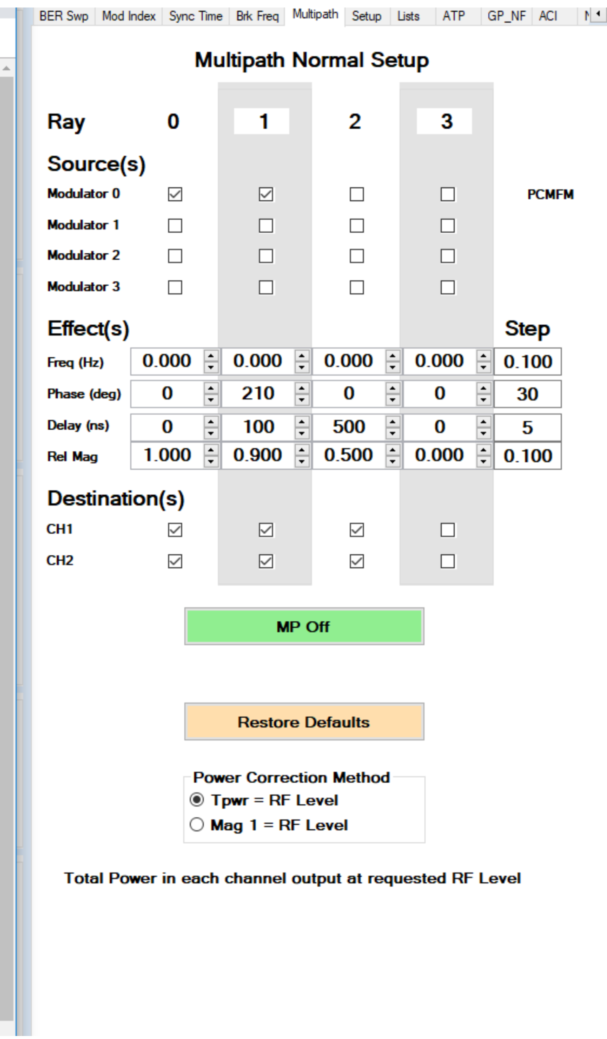
Channel 1 PSD
Channel 2 PSD
Update Rate
Stop
Low
Medium
High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Mod Index
Sync Time
Brk Freq
Multipath
Setup
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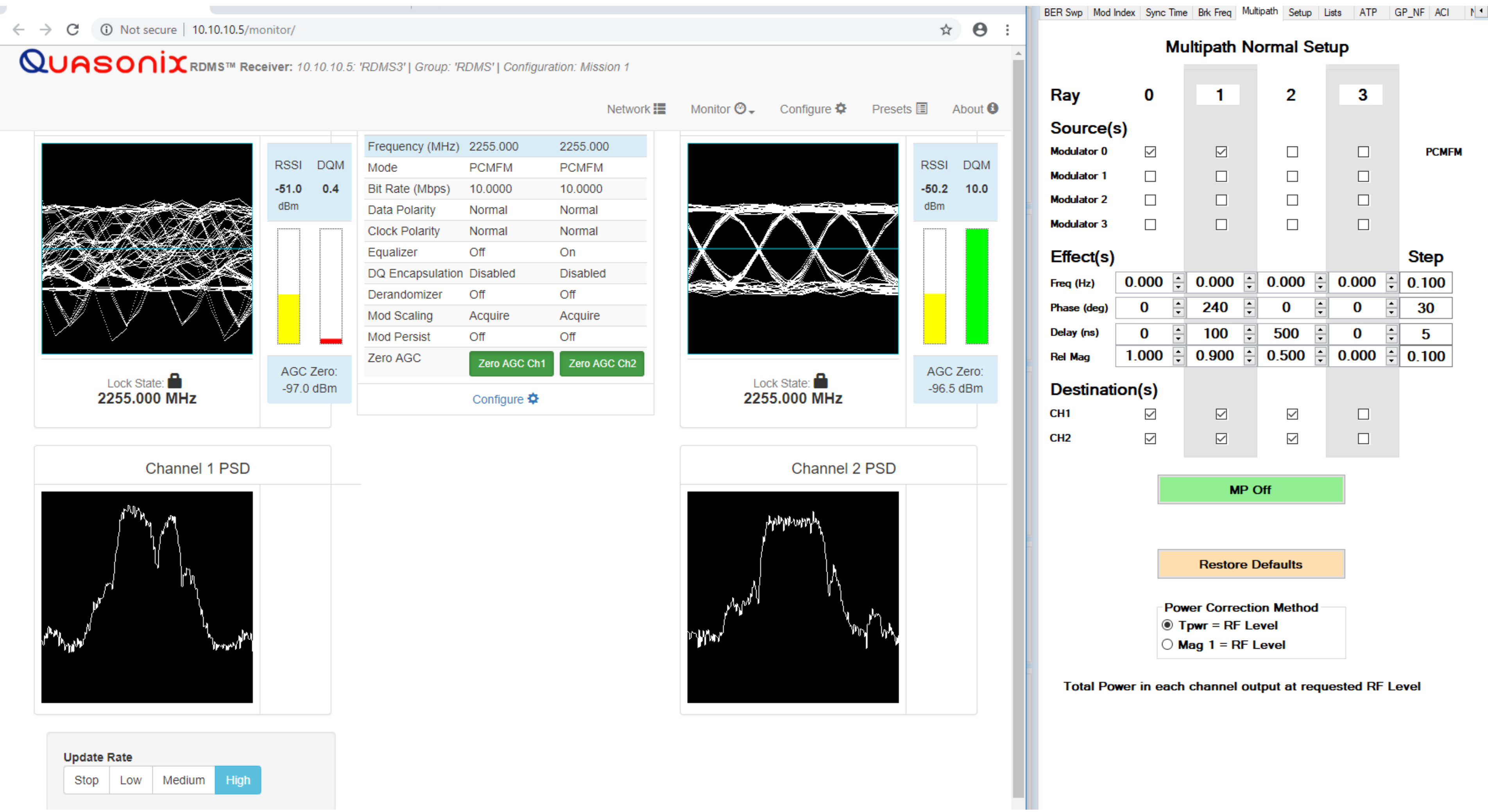
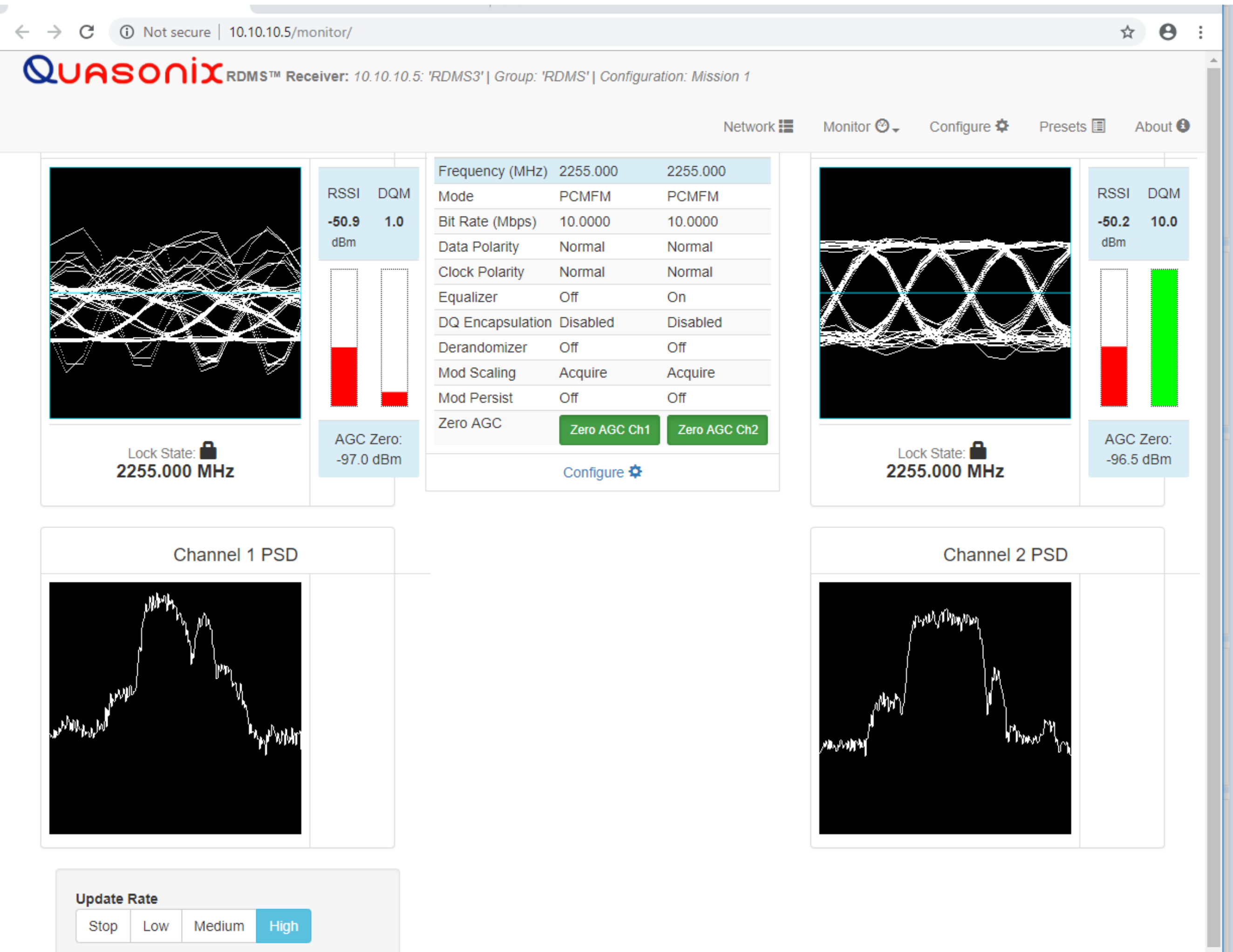
ATP
GP_NF
ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s)
Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 210 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 0.000 0.100
Destination(s)
CH1
CH2
MP Off
Restore Defaults
Power Correction Method
Tpwr = RF Level
Mag 1 = RF Level
Total Power in each channel output at requested RF Level

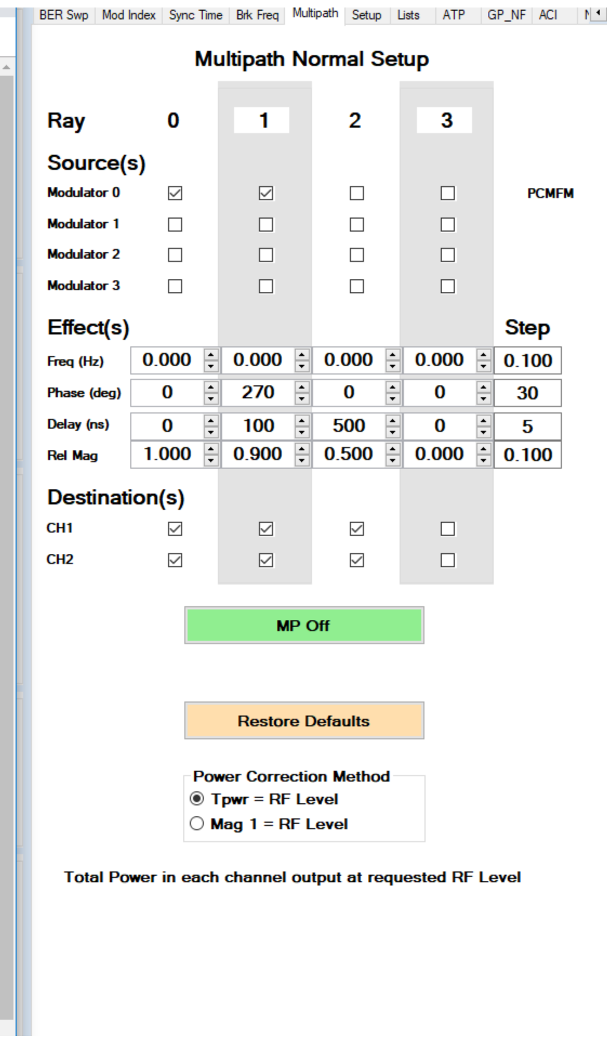
240-100-0.9



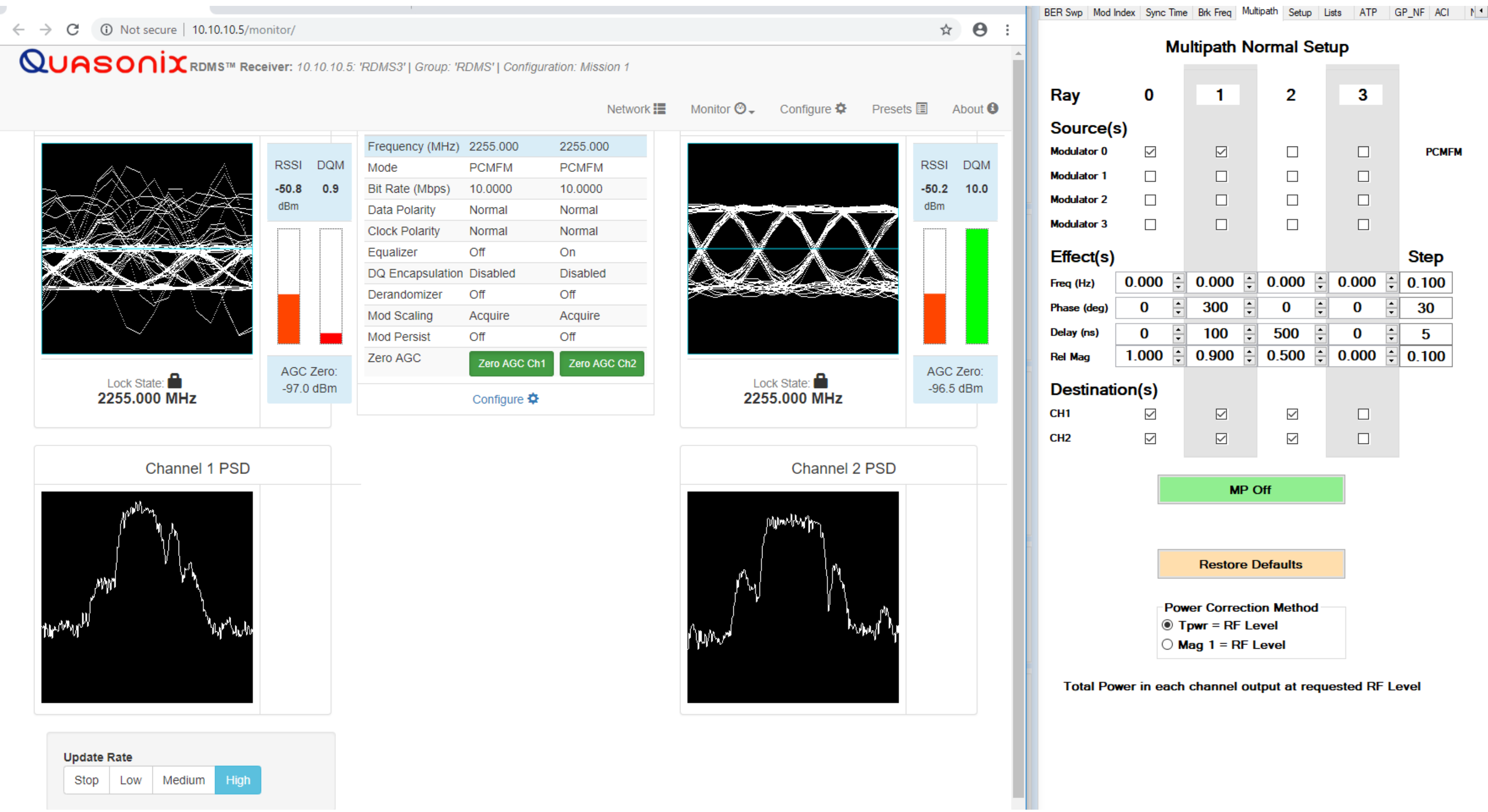
April 2020 TM Smorgasbord
Terry Hill - thill@quasonix.com

270-100-0.9

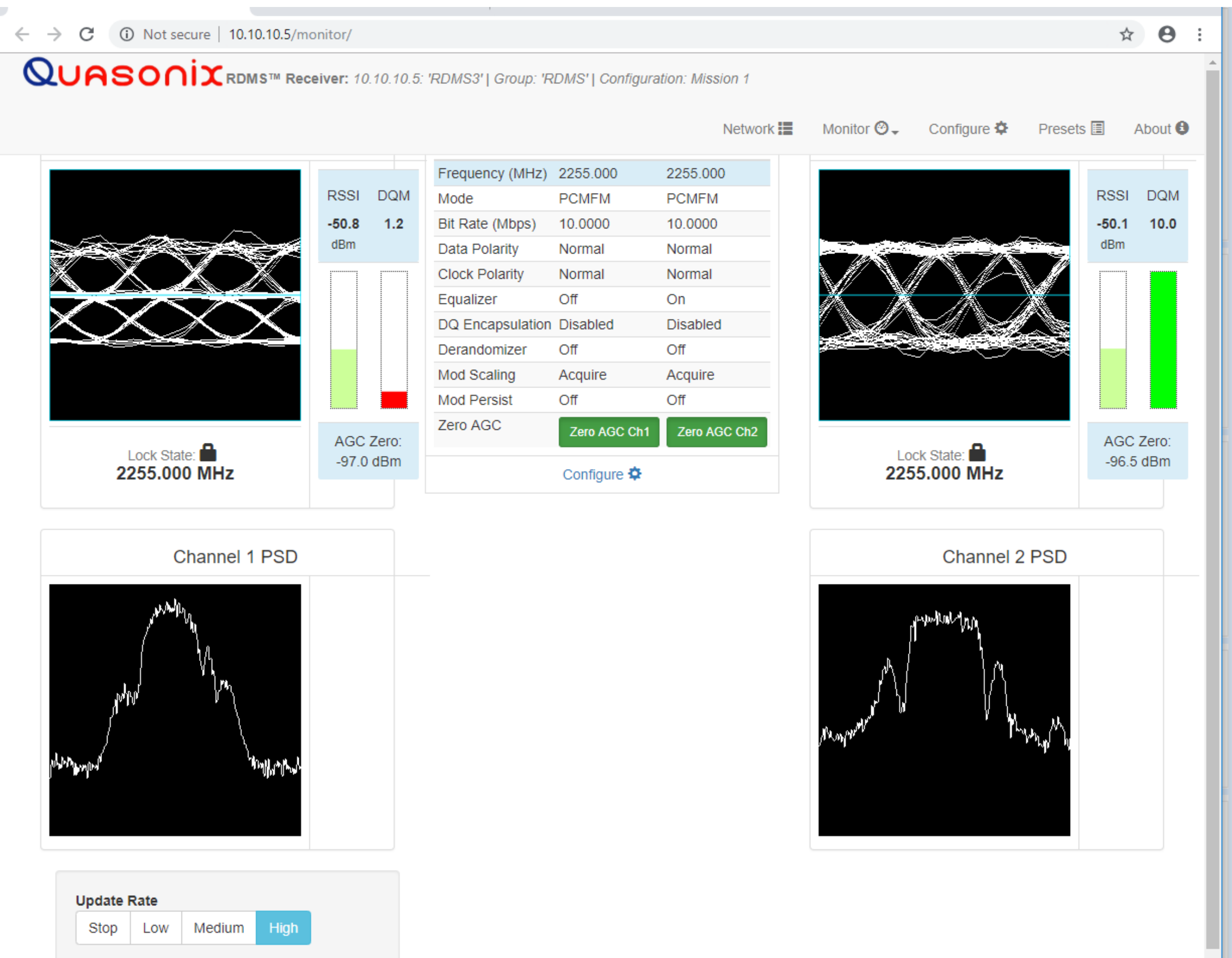

Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.9 1.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
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

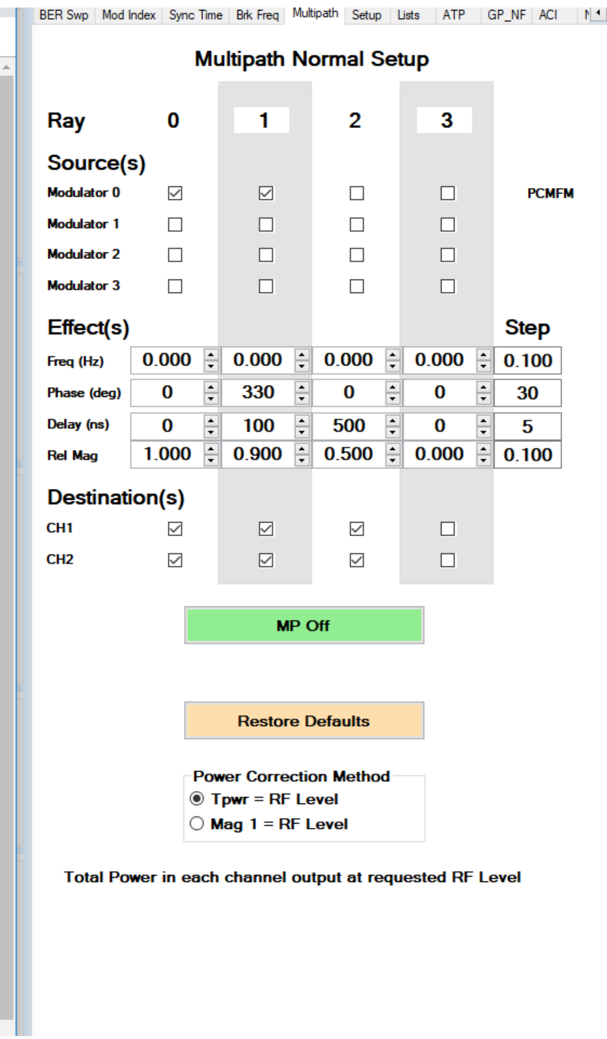
300-100-0.9


Not secure | 10.10.10.5/monitor/
QUASONIX 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

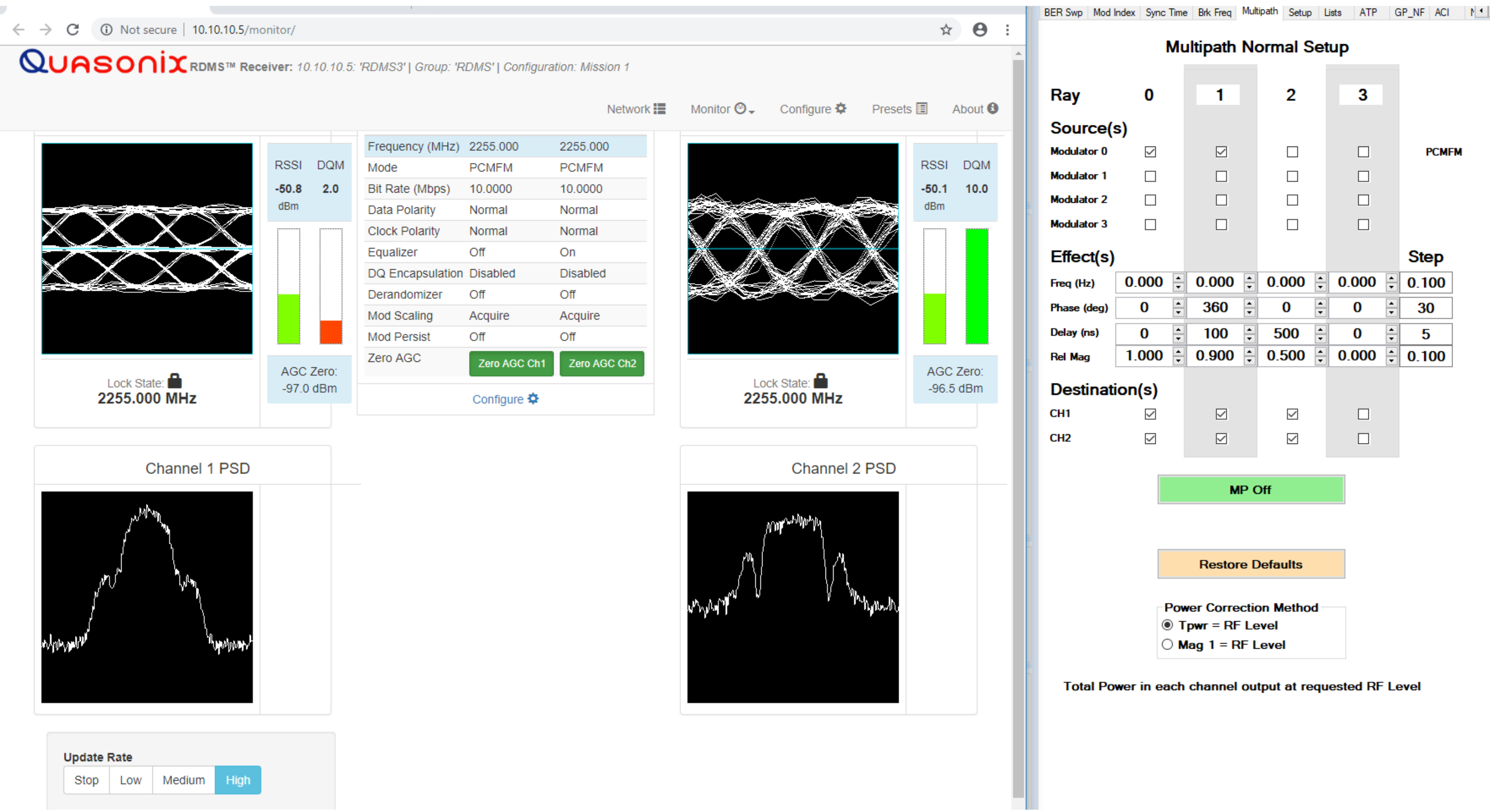


Not secure | 10.10.10.5/monitor/
RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network Monitor Configure Presets About
RSSI DQM
-50.8 1.2
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 10.0000
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



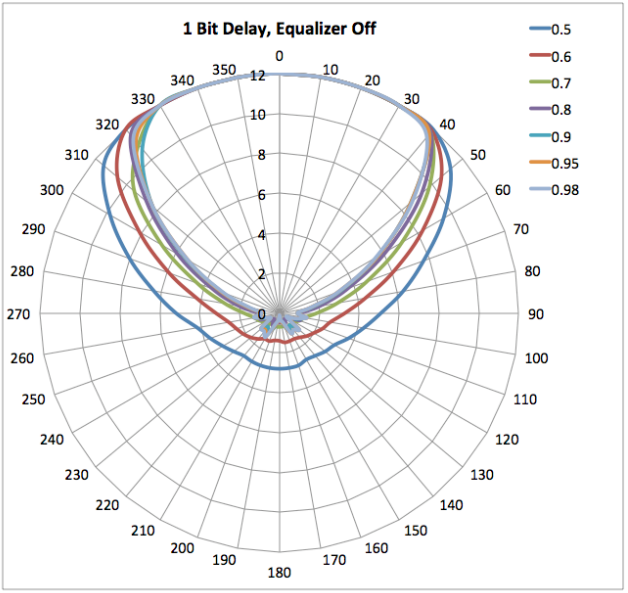
BER Swp Mod Index Sync Time Brk Freq Multipath Setup Lists ATP GP_NF ACI
Multipath Normal Setup
Ray 0 1 2 3
Source(s)
Modulator 0
Modulator 1
Modulator 2
Modulator 3
PCMFM
Effect(s) Step
Freq (Hz) 0.000 0.000 0.000 0.000 0.100
Phase (deg) 0 330 0 0 30
Delay (ns) 0 100 500 0 5
Rel Mag 1.000 0.900 0.500 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

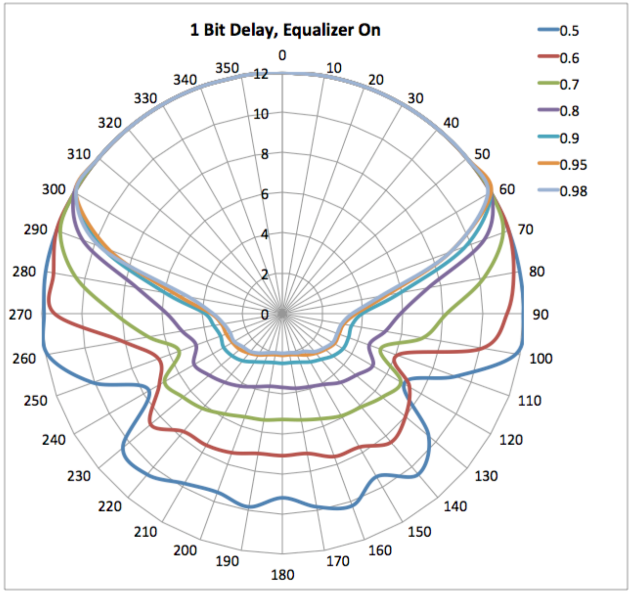
360-100-0.9

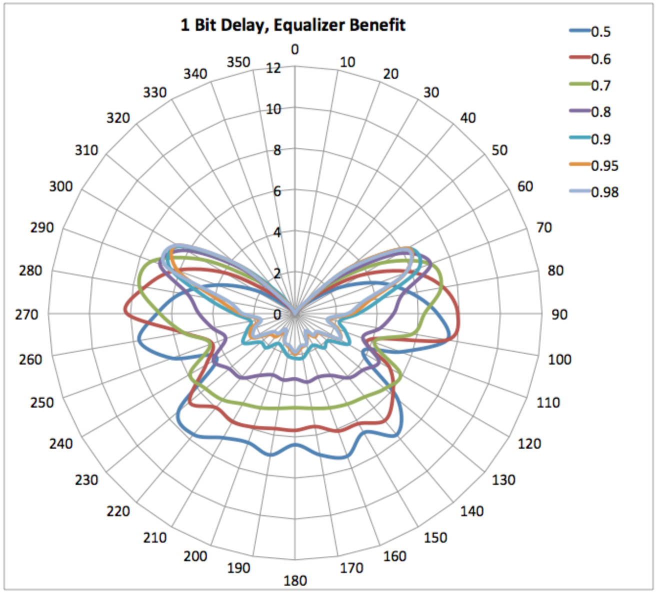

Not secure | 10.10.10.5/monitor/
Quasonix RDMS™ Receiver: 10.10.10.5: 'RDMS3' | Group: 'RDMS' | Configuration: Mission 1
Network
Monitor
Configure
Presets
About
RSSI DQM
-50.8 2.0
dBm
Lock State:
2255.000 MHz
AGC Zero:
-97.0 dBm
Frequency (MHz) 2255.000 2255.000
Mode PCMFM PCMFM
Bit Rate (Mbps) 10.0000 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

Test Results Examples

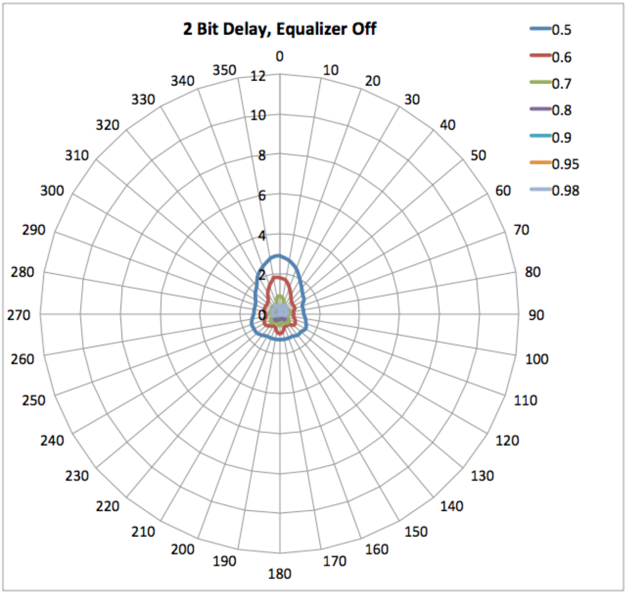
10 Mbps SOQPSK, 1 bit Delay

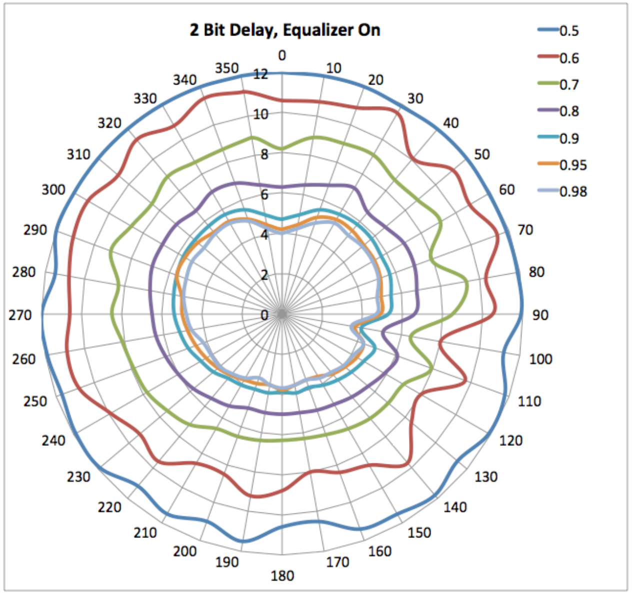


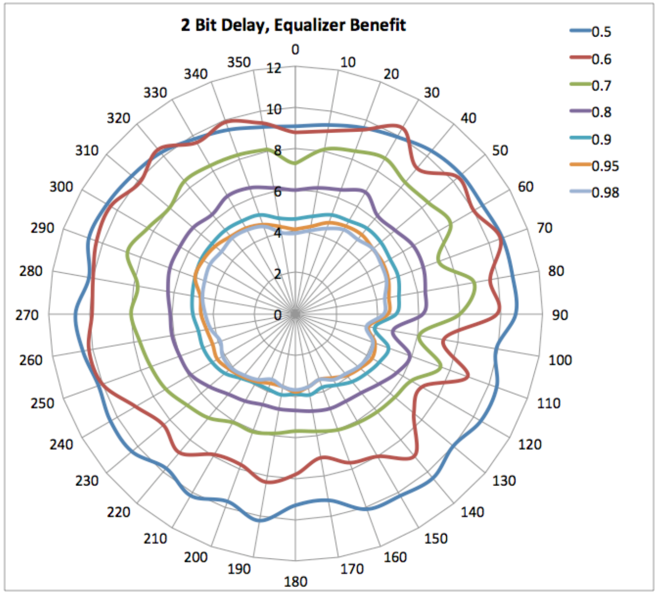




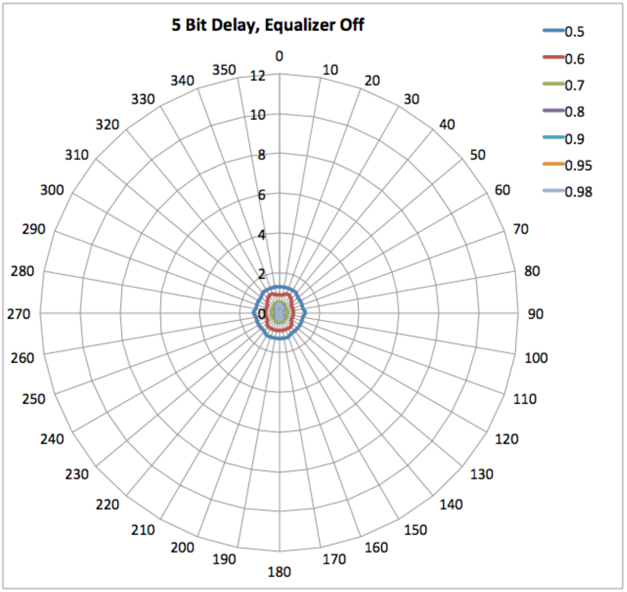
10 Mbps SOQPSK, 2 Bits Delay

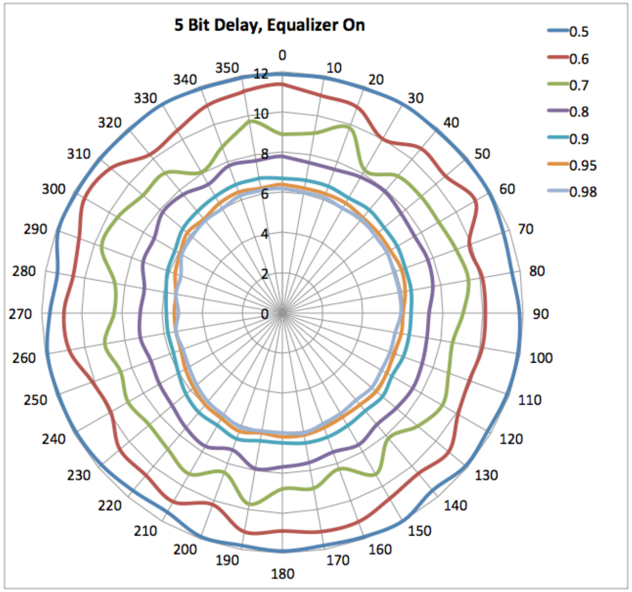


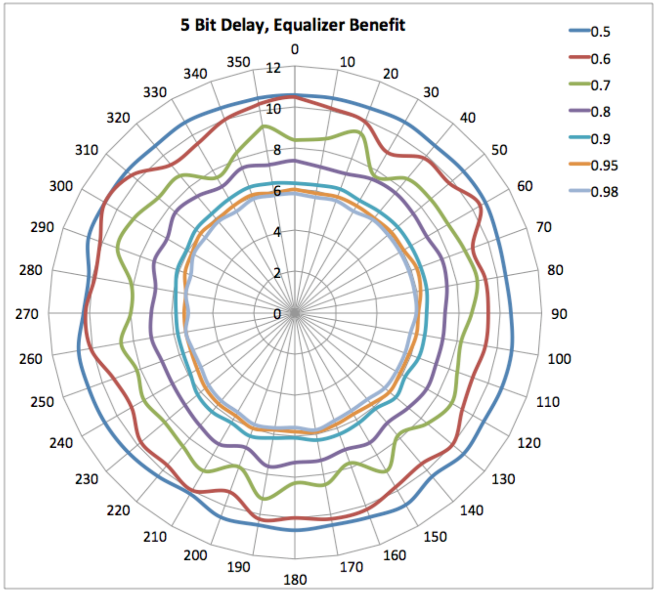




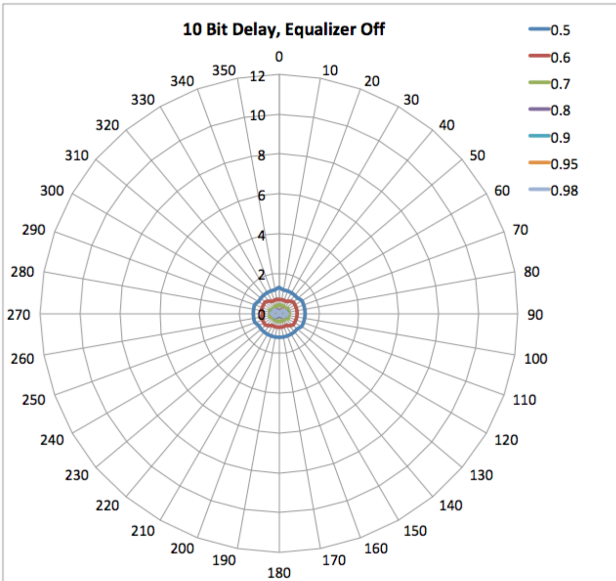
10 Mbps SOQPSK, 5 Bits Delay

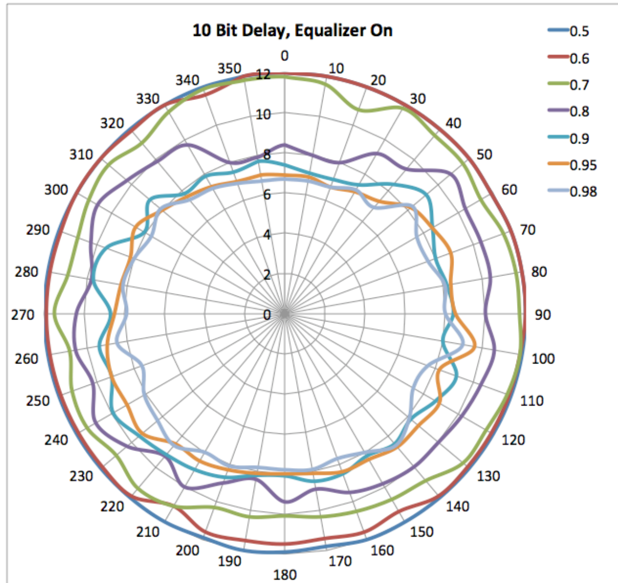


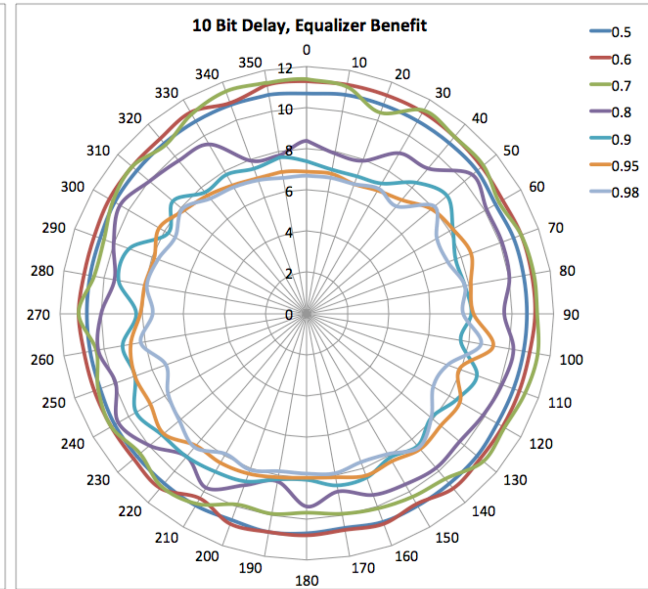




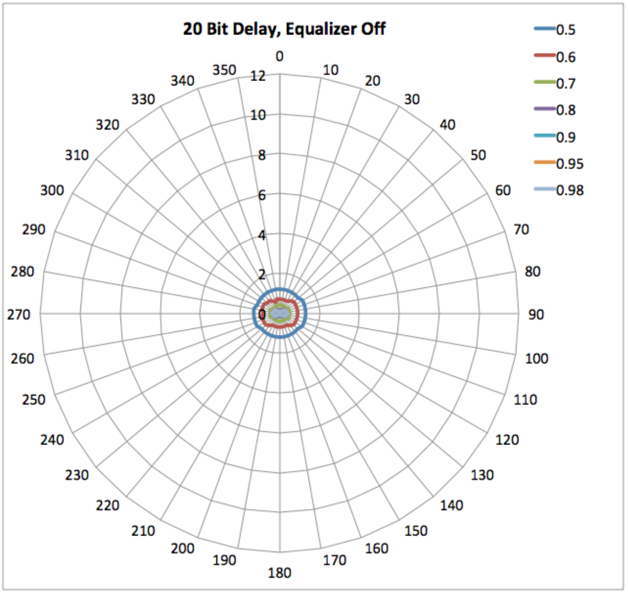
10 Mbps SOQPSK, 10 Bits Delay

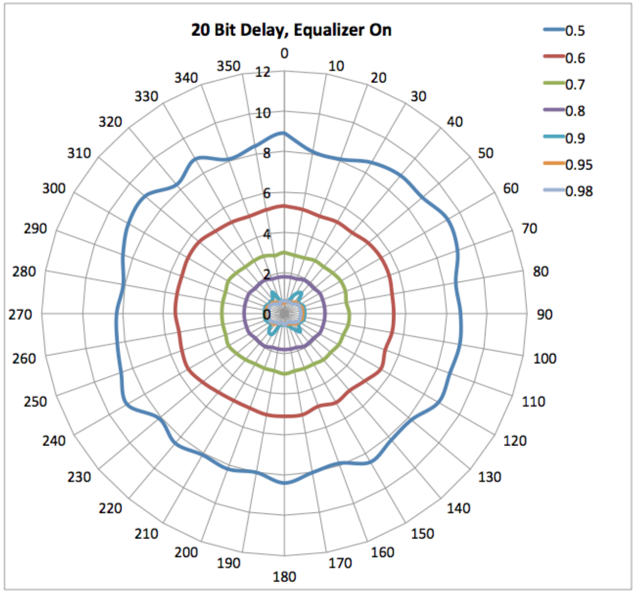


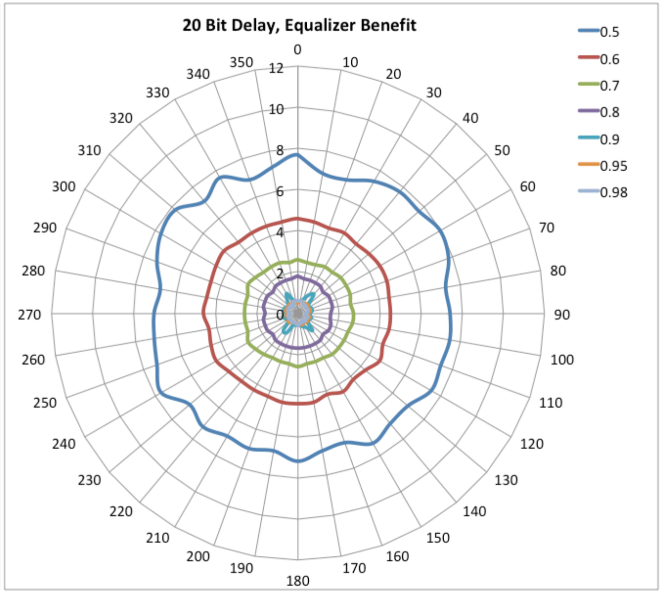




10 Mbps SOQPSK, 20 Bits Delay







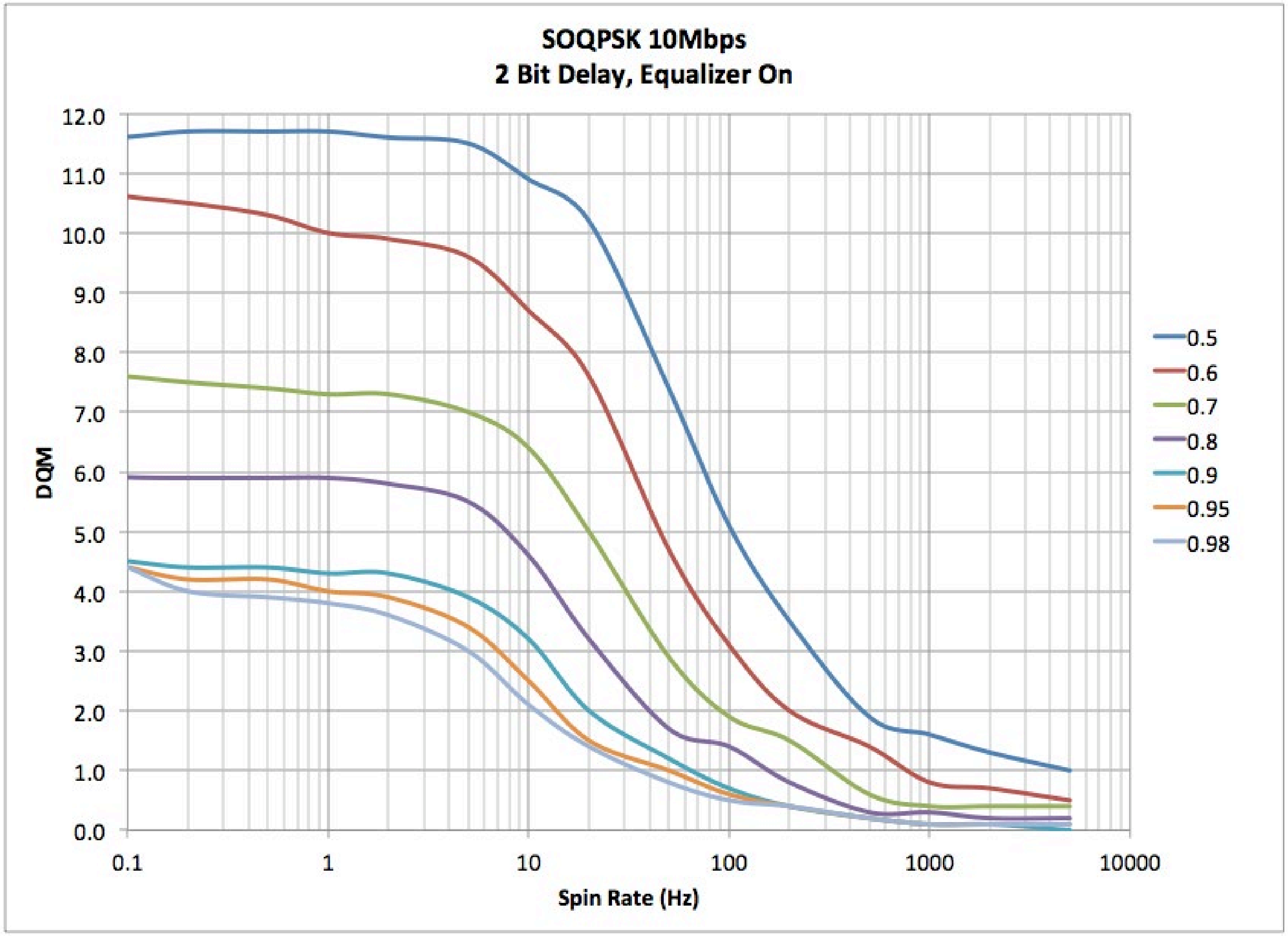
What About Dynamics?

- 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



Course Outline – Day 3

- Impairment Mitigation Techniques
  - Adaptive Equalization
  - Best Source Selection
  - Best Channel Selection
  - Space-Time Coding (STC)
  - Low Density Parity Check (LDPC) Coding
- Using All the Tools Together
- Performance Comparison & Summary
- Link Budgets