Assessing Telemetry Receiver Data Quality Metrics using RCC 118-22 Test Procedures

ITC 2024

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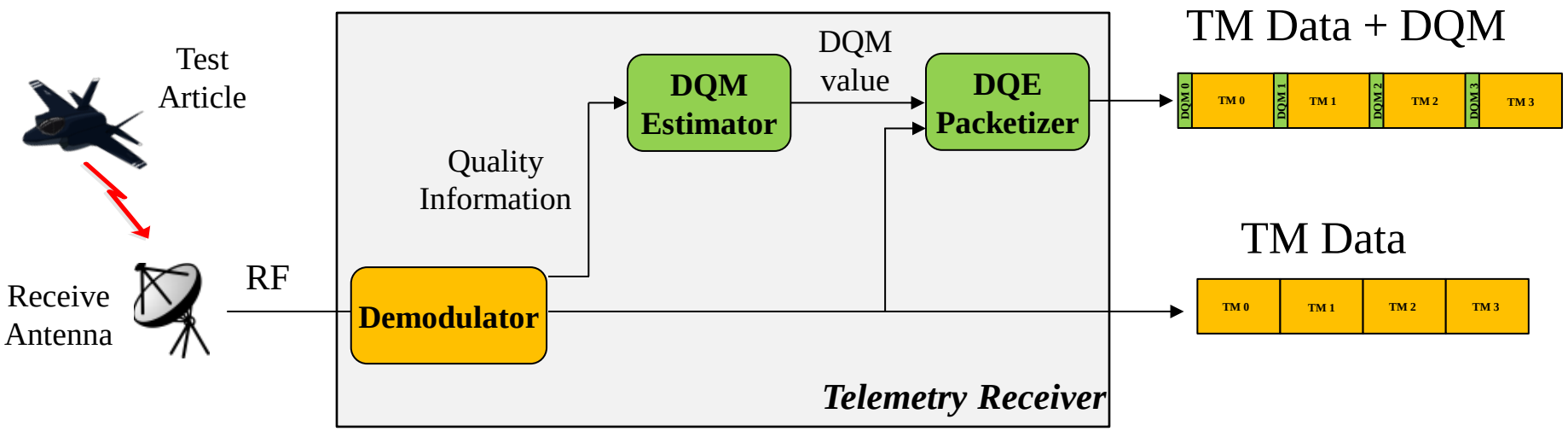
Presentation Outline

- DQE/DQM background
- DQE/DQM RCC 118-22 Testing Methods
- Test Results (11.1-11.6)
  - AWGN, Step & Dwell, ACI, 3/2 Ray Multipath, Resync
- Testing Observations/Recommendations
- Industry Day 2 – DQE/DQM characterization
- Conclusions

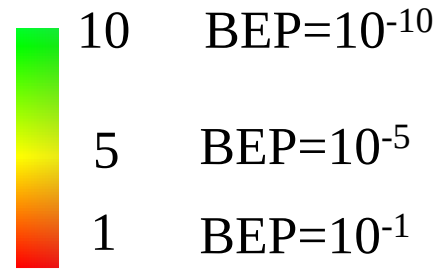
Data Quality Metric (DQM)

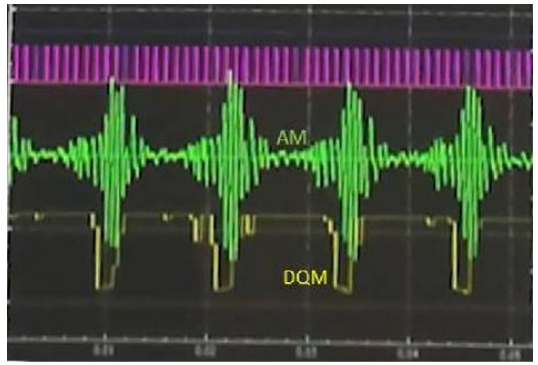
- 16 bit value that indicates the BEP for a ‘single’ block of TM data bits
- Periodically inserted in TM data output stream

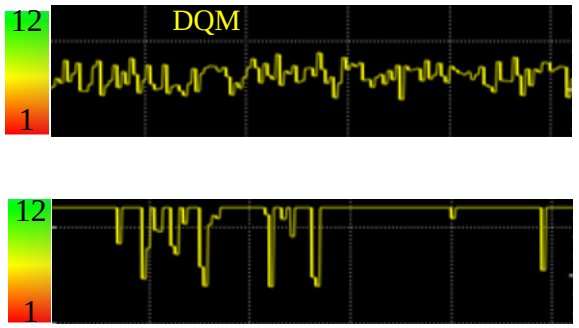


DQM Telemetry Applications

- Provides estimate of TM quality without a priori knowledge of data.
- Provides real-time indication of the TM channel.





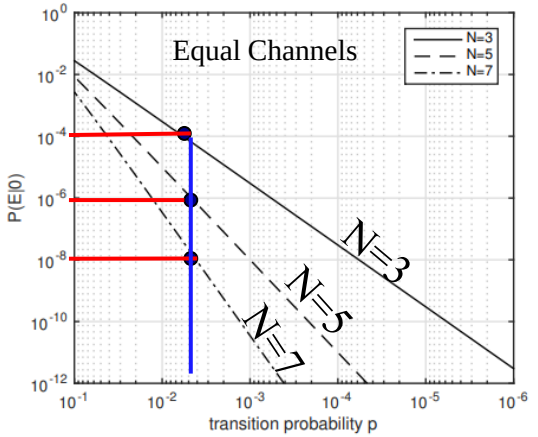


Noise
BEP=10^{-5}

Interference
BEP=10^{-5}

Which one would you choose?

- Doesn't get fooled by other signals or interferers like traditional RSSI or SNR indicators
- Provides sufficient information for optimal multi-channel telemetry reception.
  - *Potential for virtually 'error-free' telemetry*.



DQE/DQM Background

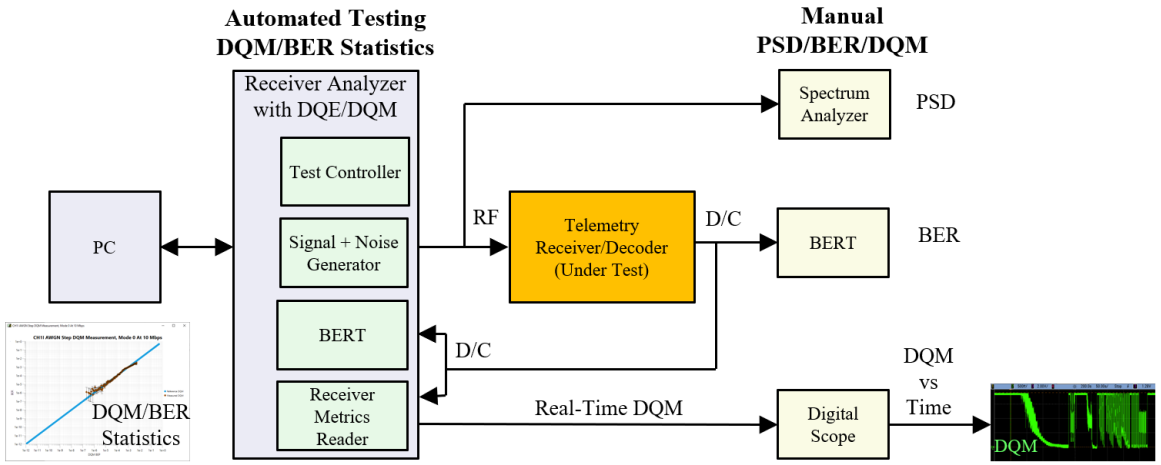
Milestones	Contributions
2015 Hill ITC Paper - “Metrics and Test Procedures for Data Quality Estimation in the Aeronautical Telemetry Channel”	DQE/DQM transport protocol to support efficient multiple source TM combining
2015 Rice/Perrins ITC Paper -“Maximum Likelihood Detection from Multiple Bit Sources”	Optimal combining recipe and performance analysis - Maximum Likelihood Bit Detection (MLBD)
IRIG 106-22 Chapter 2, Appendix 2-G - “Standards for Data Quality Metrics and Data Quality Encapsulation”	Standardized in IRIG 106-22
2022 Temple ITC Paper - “Some Thoughts on Testing the Data Quality Metric”	Proposed DQE/DQM verification test methods
IRIG 118-22 Release 2 Volume 2., Chapter 11, 2022 -“Test procedures for assessing telemetry receiver data quality metrics”	DQE/DQM verification test methods standardized in IRIG 118-22
Industry Day on DQE/DQM assessment 10/28/22	Initial multi-vendor DQE/DQM performance/compatibility testing
2023 Geoghegan ITC Paper -“Data Quality Metric (DQM) – How accurate does it need to be?”	Determined relationship between worst case system MLBD performance loss and DQM estimation error
****** Industry Day 2 on DQE/DQM assessment 10/25/24 ******	Multi-vendor DQE/DQM performance/compatibility testing (all tests with real-time results)

DQE/DQM verification test methods standardized in IRIG 118-22 V2 R2

- Test Matrix
  - 6 Tests

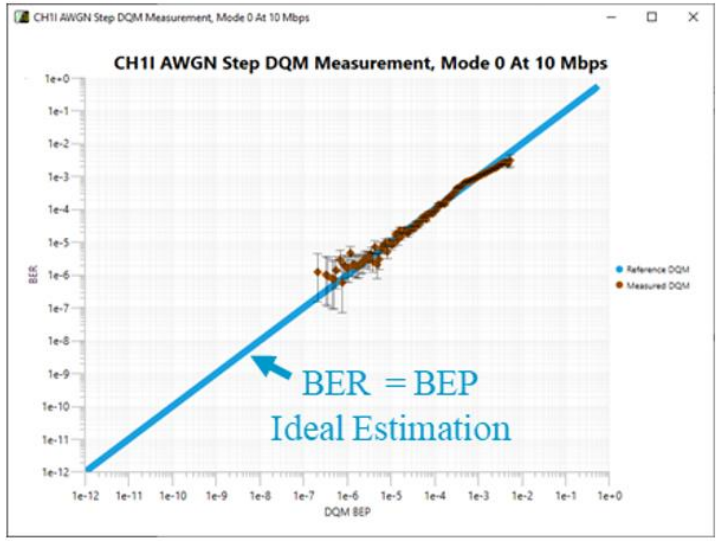
Table 11-2. Test Matrix for Data Quality Metric Testing	
Test Number	**Test Description**
11.1	BER vs BEP with Additive Noise
11.2	DQM (BEP) Step and Dwell Response
11.3	BER vs BEP with Adjacent Channel Interference
11.4	BER vs BEP for Static 3-Ray Multipath Channel Conditions
11.5	BER vs BEP for Static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

- Testing Setup
  - Runs all 6 tests sequentially

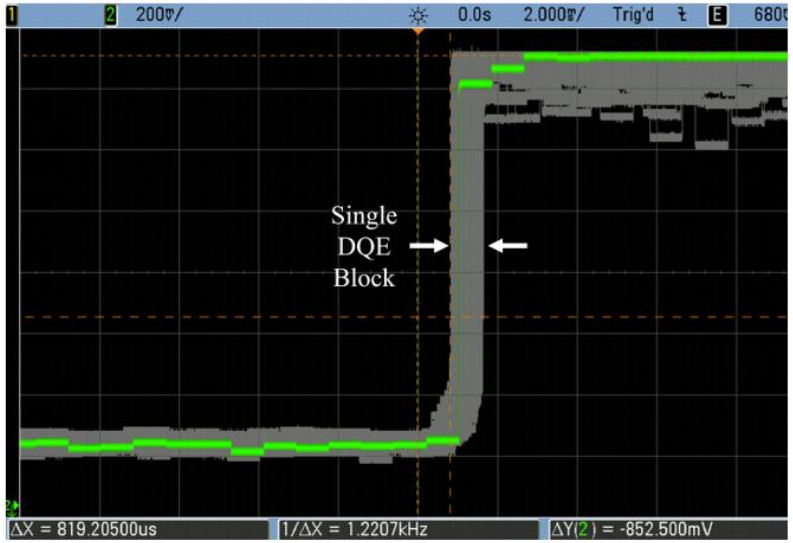


Data Reduction

- DQM/BEP Correlation Plot
  - Actual measured BER vs Estimated BEP(DQM)
- DQM Step Response
  - Shows ability of DQM to quickly reflect change in channel



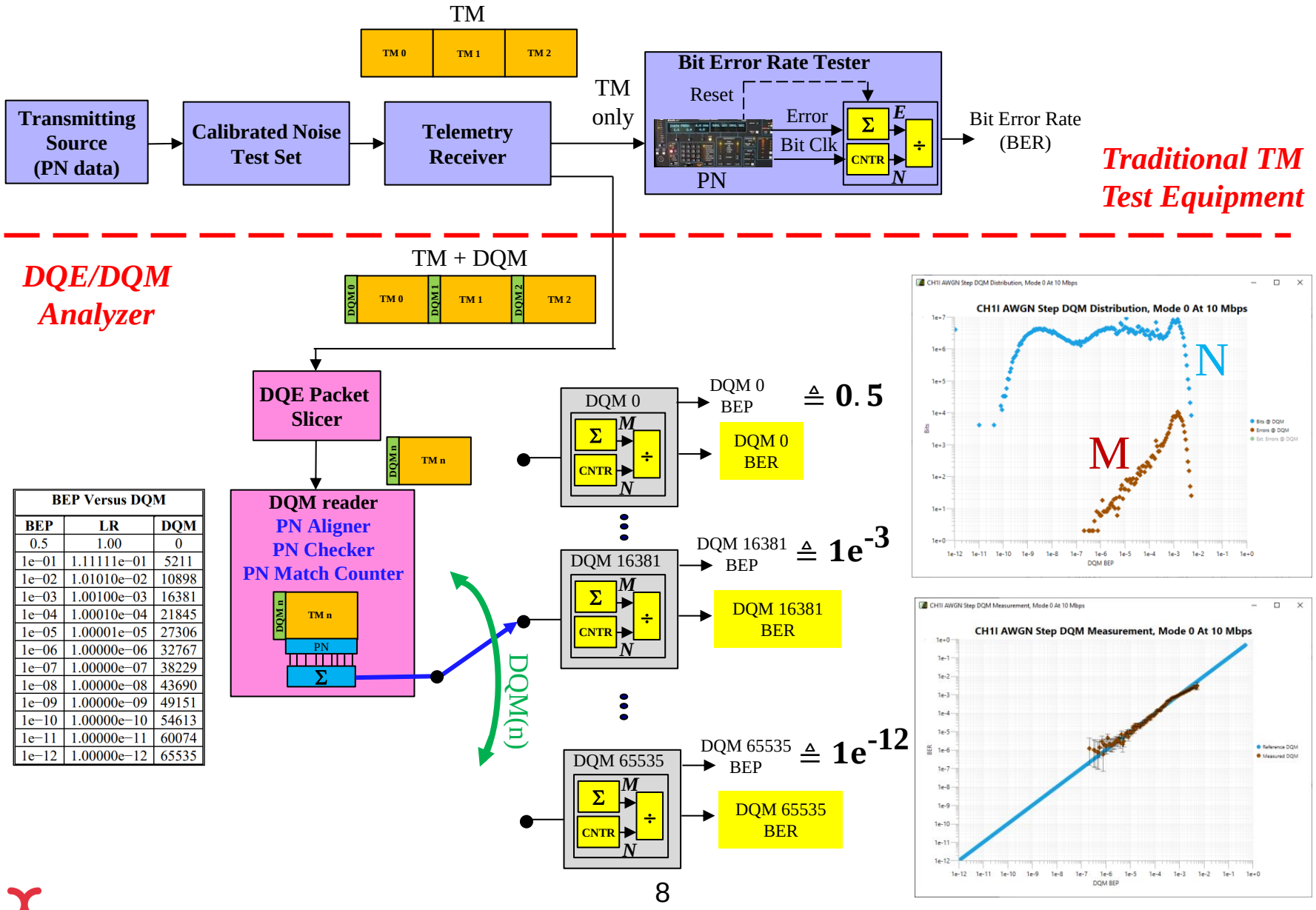
A) DQM/BEP Correlation



B) DQM Step Response

Figure 3: Primary Data Reduction Results – DQM Correlation and Step Response

Calculation of DQM (BEP) and BER values



BEP Versus DQM		
BEP	LR	DQM
0.5	1.00	0
1e−01	1.11111e−01	5211
1e−02	1.01010e−02	10898
1e−03	1.00100e−03	16381
1e−04	1.00010e−04	21845
1e−05	1.00001e−05	27306
1e−06	1.00000e−06	32767
1e−07	1.00000e−07	38229
1e−08	1.00000e−08	43690
1e−09	1.00000e−09	49151
1e−10	1.00000e−10	54613
1e−11	1.00000e−11	60074
1e−12	1.00000e−12	65535

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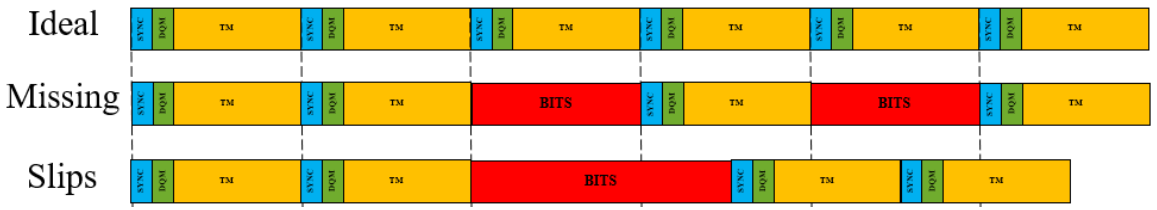
DQM correlation assessment

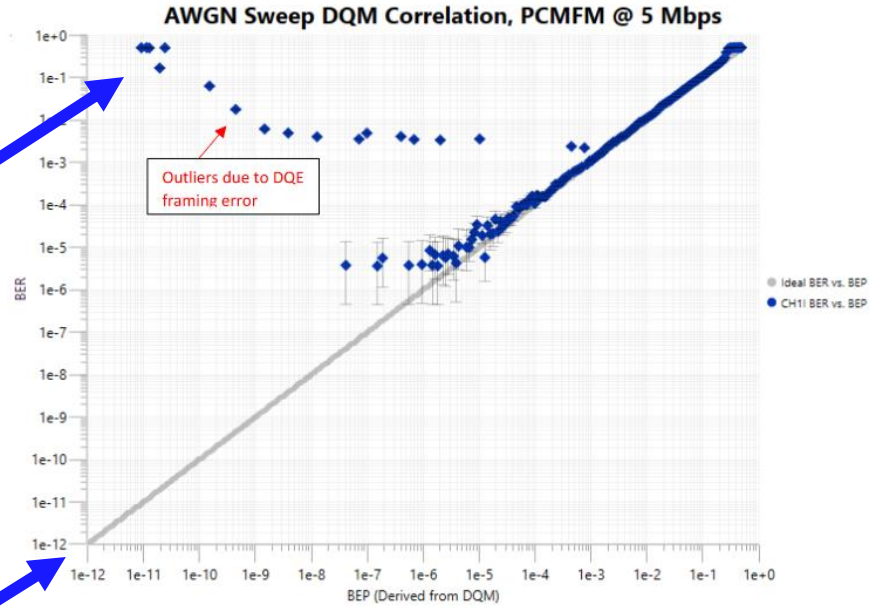
- DQM correlation plots reflect both
  - ***DQM Accuracy*** – how well the quality is estimated
  - ***DQE Framing*** – structure of DQE block

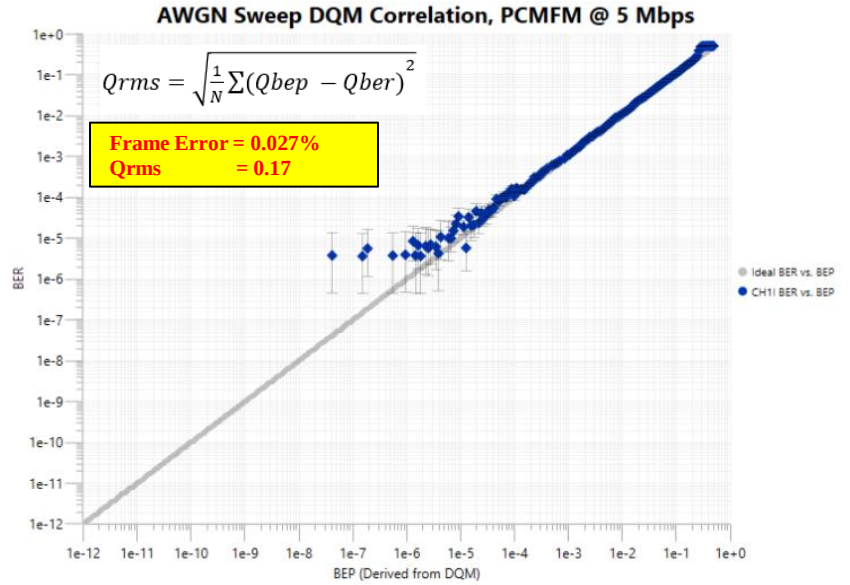
- DQE framing errors (jitter, missing, or wrong format) can produce very large errors (outliers)



- DQM accuracy errors typically result in points slightly above or below the reference line

- Recommended scoring approach
  - Indicate the presence of framing errors while capturing DQM accuracy from valid frames
  - $Qrms = \sqrt{\frac{1}{N}\sum(Qbep - Qber)^2}$





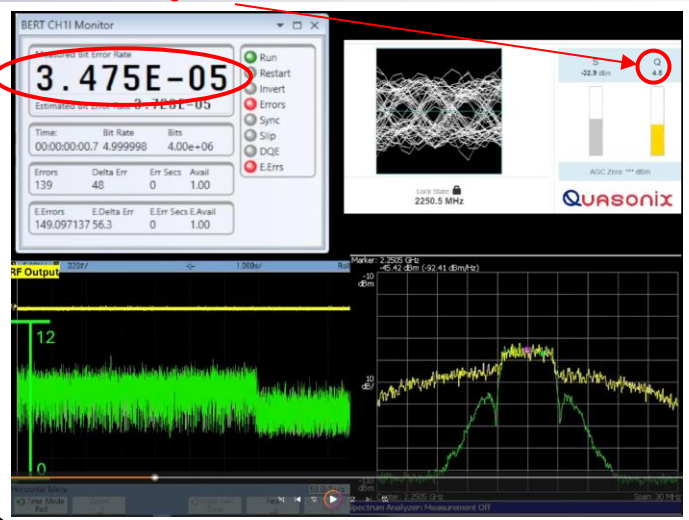
DQM Accuracy and DQE Framing Errors are mixed together

Framing Errors are captured while DQM Accuracy is preserved

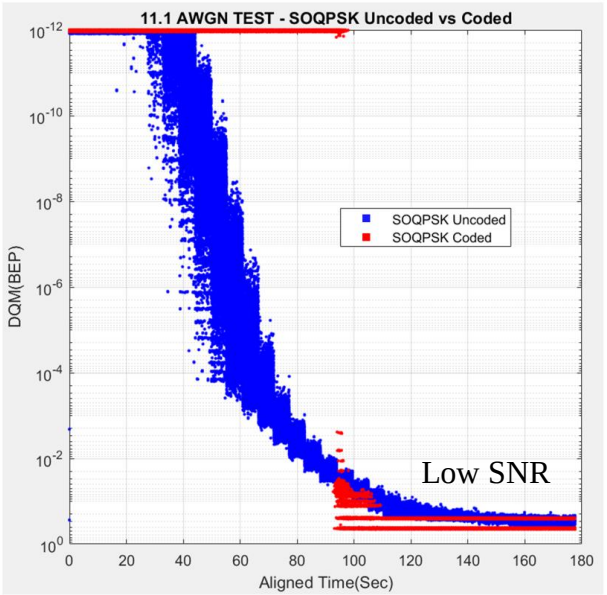
11.1 AWGN

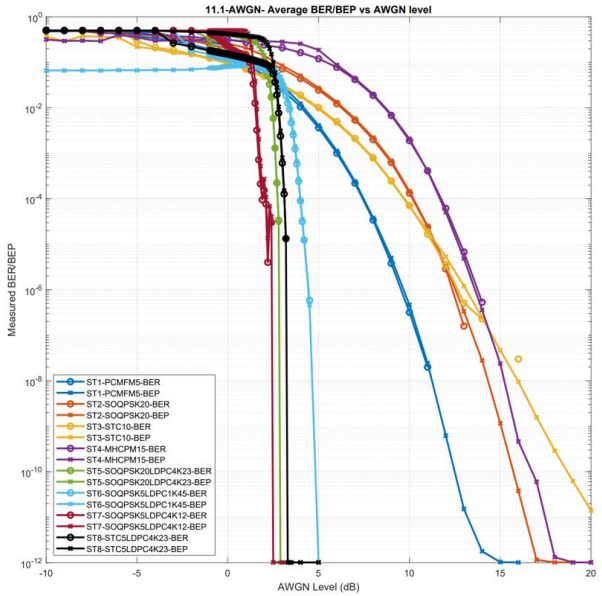
- BER vs BEP/DQM in AWGN
- DQM correlation is tight (Worst case Qrms = 0.38)
- Averages values match very well
- All 8 Signal Types are shown

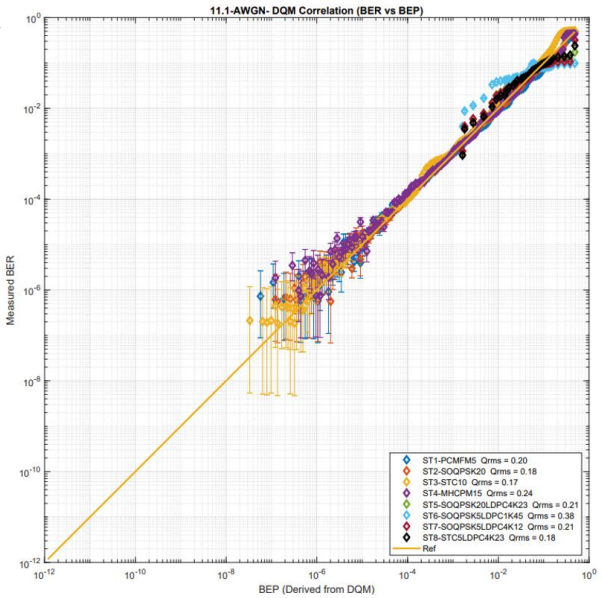
Q=4.5 => $10^{-4.5}$ =>BEP=3.16e-5



High SNR







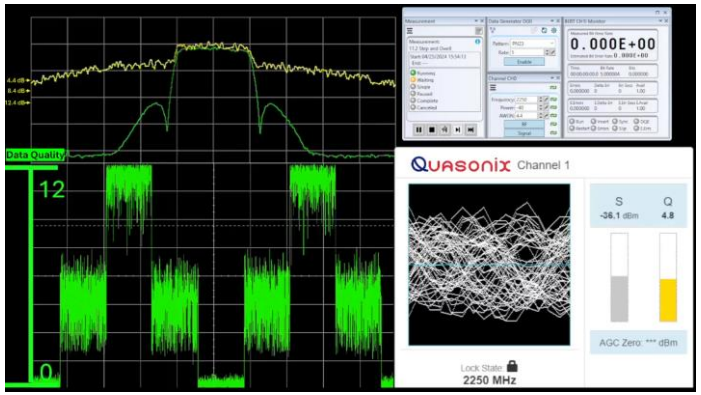
A) DQM/BEP vs Time

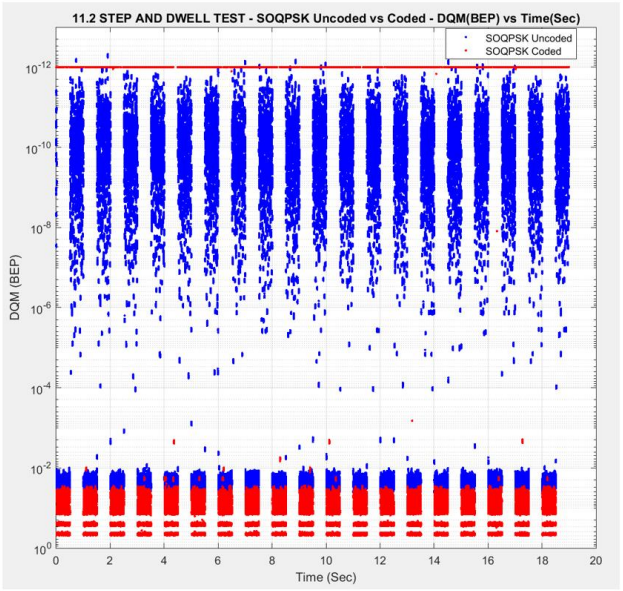
B) Average BER/BEP vs AWGN

C) DQM Correlation

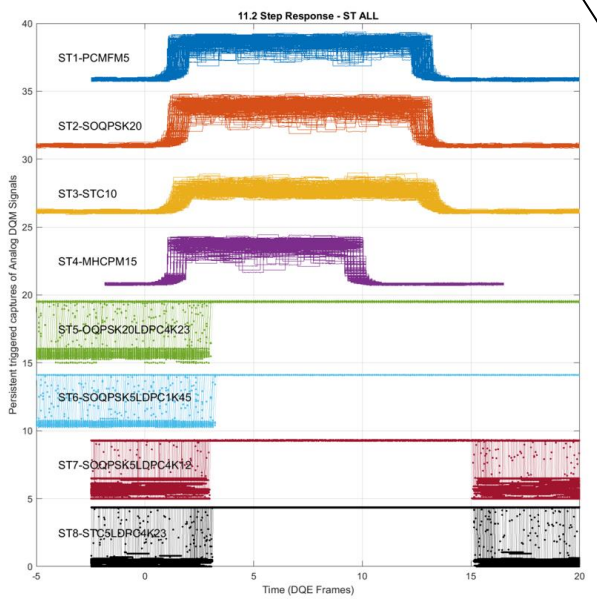
11.2 Step & Dwell

- BER vs BEP/DQM in dynamic AWGN
- DQM correlation is tight (Worst case Qrms = 0.43)
- Step response quickly indicates changes in channel (≈1 DQE frame)
- All 8 Signal Types are shown

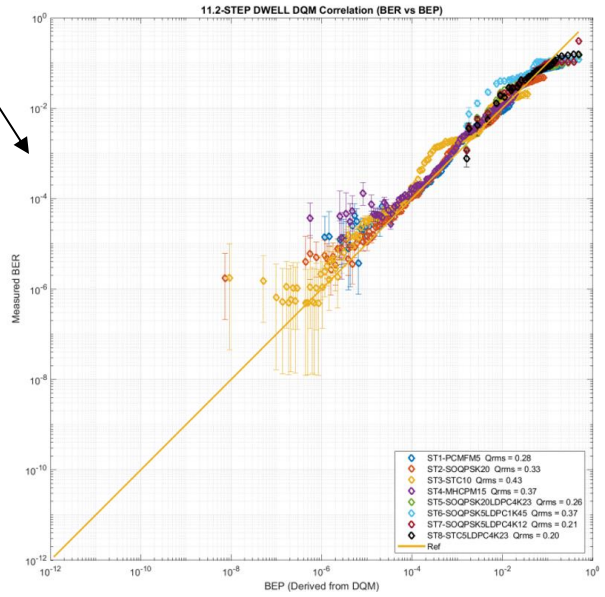




A) DQM/BEP vs Time



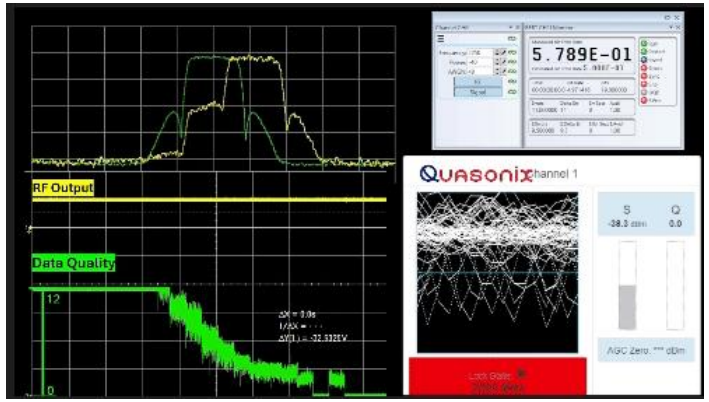
B) DQM Step Responses

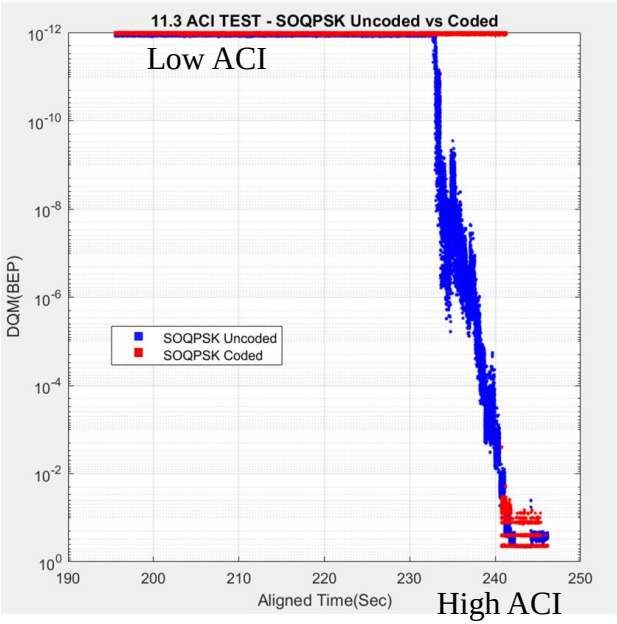


C) DQM Correlation

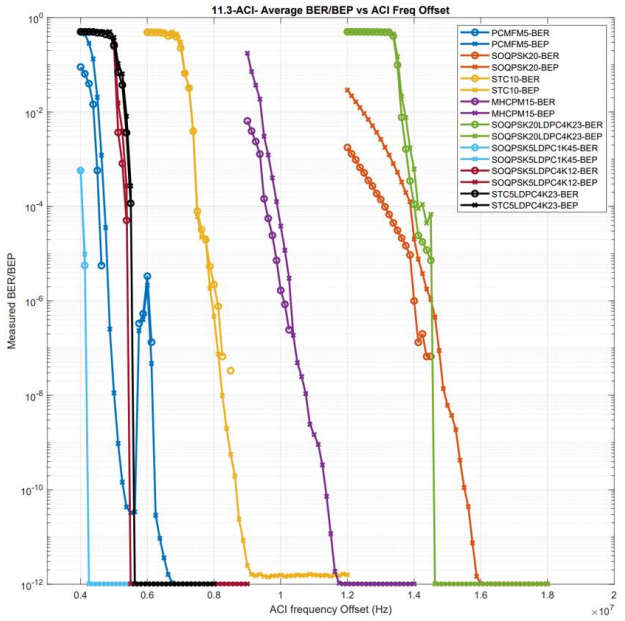
11.3 ACI (Interferer 5 Mbps SOQPSK)

- BER vs BEP/DQM with adjacent channel interference
- DQM correlation error is larger, but still following ideal line (Worst case Qrms = 1.48)
- Averages values match fairly well, but curves are steep with ACI
- All 8 Signal Types are shown

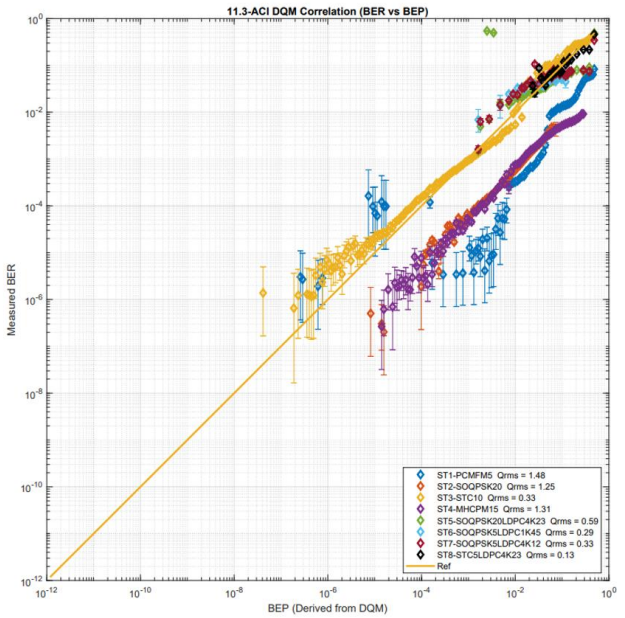




A) DQM/BEP versus Time



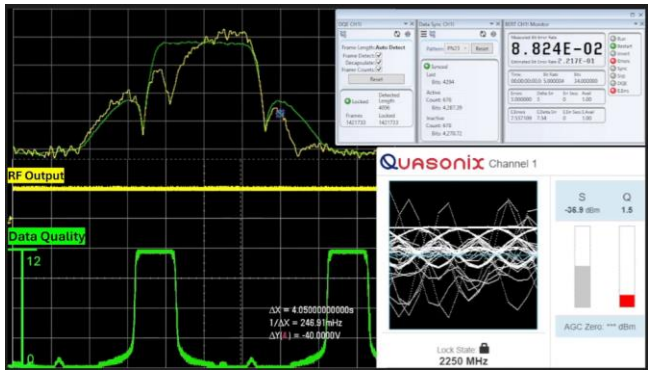
B) BER/BEP vs ACI Freq Offset



C) DQM Correlation

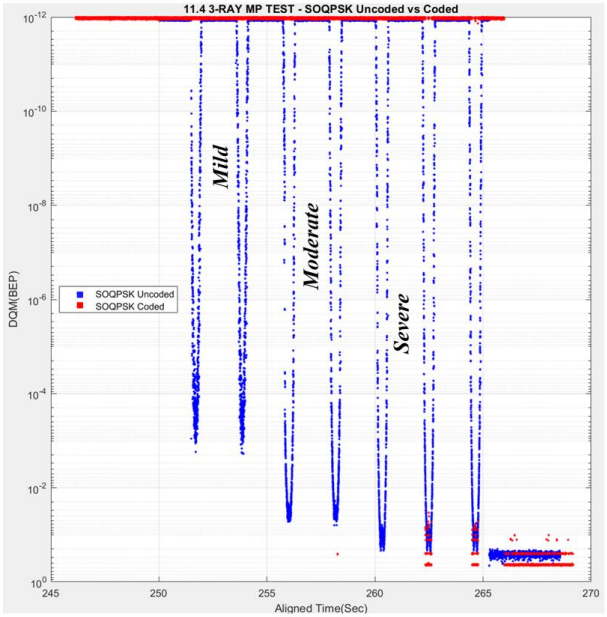
11.4 3-Ray Multipath

- BER vs BEP/DQM with 3-Ray Multipath
- DQM correlation is pretty good (Worst case Qrms = 1.00)
- Modulation type and data rate influence sensitivity to multipath
- All 8 Signal Types are shown

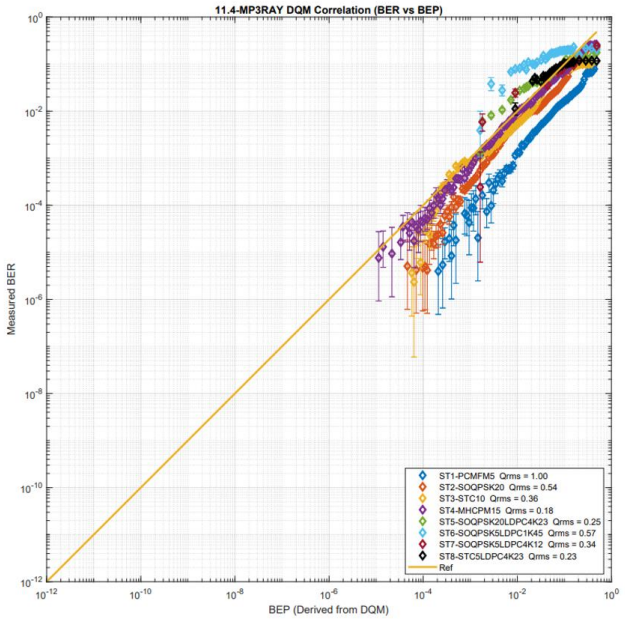


3-Ray MP	Mild	Moderate	Severe
Γ1 (dB)	-3	-1.5	-1
τ1 (ns)	50	50	50
γ1 (deg)	0-360	0-360	0-360
Γ2 (dB)	-20	-20	-20
τ2 (ns)	155	155	155
γ2 (deg)	90	90	90

A) 3-Ray Parameters



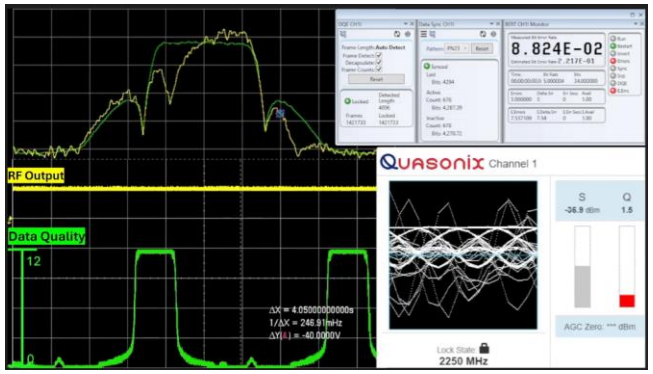
B) DQM/BEP versus Time



C) DQM Correlation

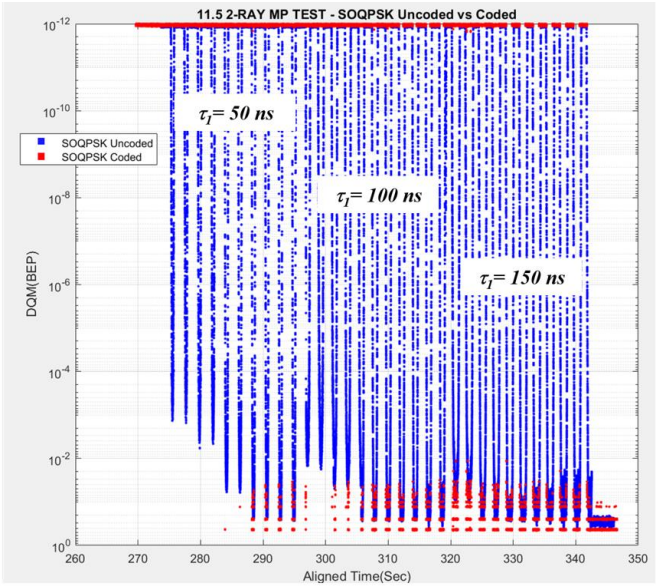
11.5 2-Ray Multipath

- BER vs BEP/DQM with 2-Ray Multipath
- DQM correlation is pretty good (Worst case Qrms = 1.07)
- Modulation type and data rate influence sensitivity to multipath
- All 8 Signal Types are shown

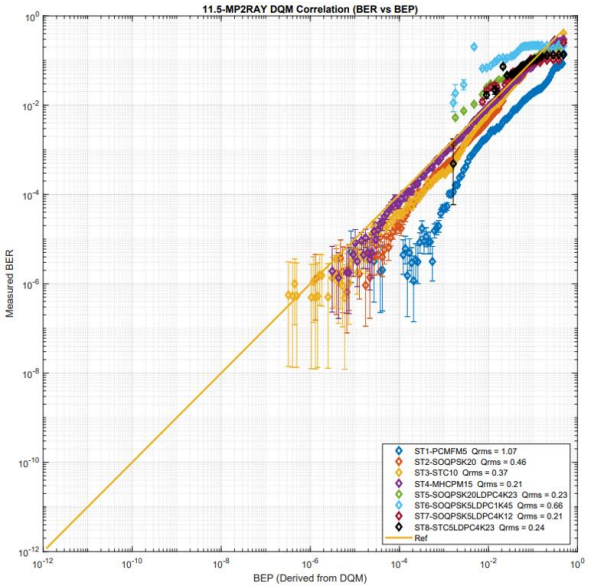


2-Ray MP	Mildest to Worst
Γ1 (dB)	-3,-2.5,-2,-1.5,-1,-0.5
τ1 (ns)	50,100,150
γ1 (deg)	0-360

A) 2-Ray Parameters



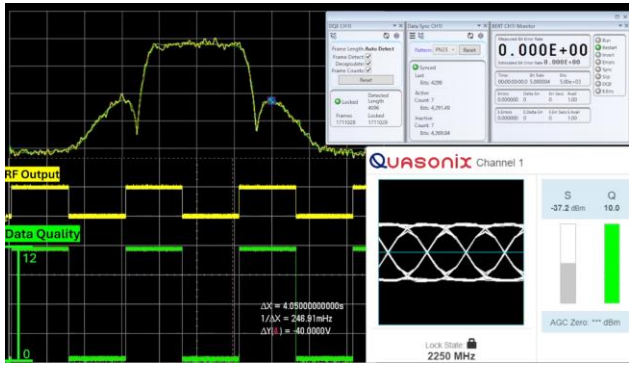
B) DQM/BEP versus Time

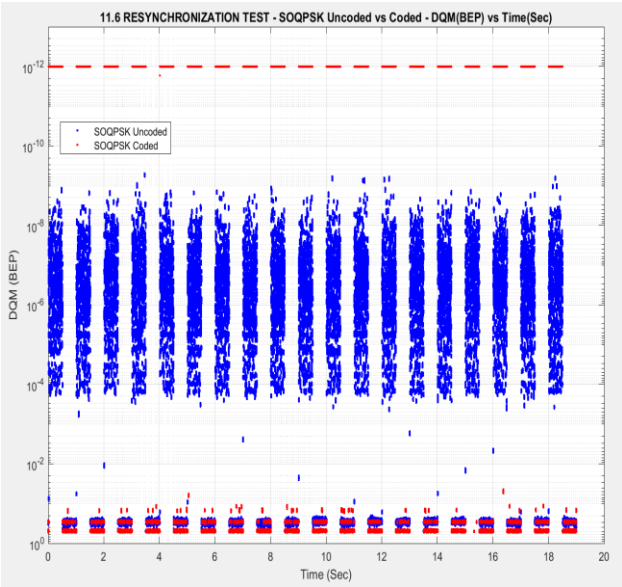


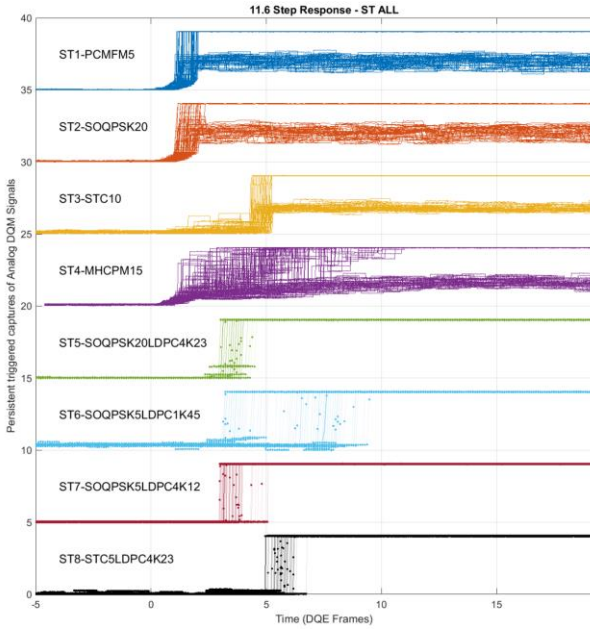
C) DQM Correlation

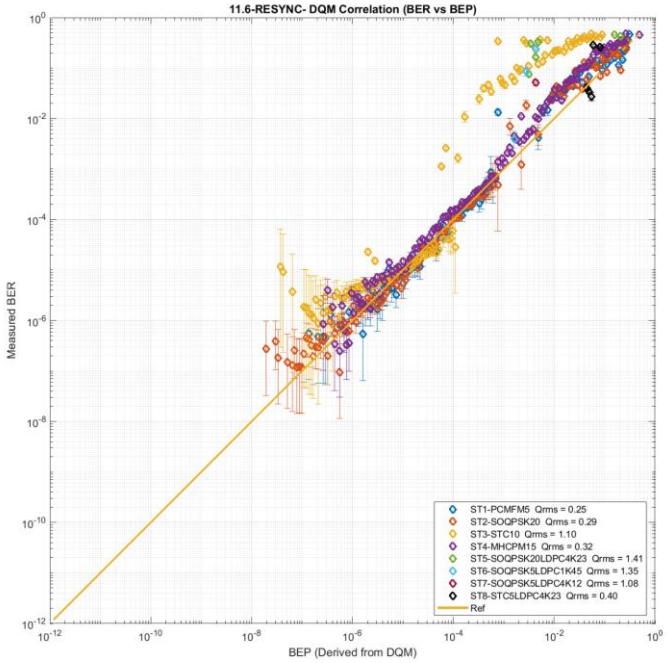
11.6 Resync

- BER vs BEP/DQM during resynchronization
- DQM correlation is tight (Worst case Qrms = 0.43)
- Step response quickly indicates changes in channel (≈1 DQE frame)
- All 8 Signal Types are shown

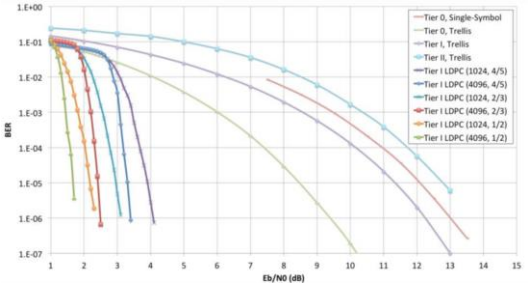








Individual Test Comments



- 11.1 AWGN
  - Eb/N0 resolution <1 dB uncoded, <0.1 dB coded
  - Run long enough for DQM correlation plots to show roughly 10^{-6} level
  - Resolution and Eb/N0 range are different between uncoded and coded signal types
- 11.2 Step & Dwell
  - Don't want DQM values of different channel conditions to overlap visually
  - Eb/N0 values that result in around 10^{-2} and 10^{-7} are good choices
  - Good strategy is to start at 10^{-2} (noisy) and reduce Eb/No by around 6 dB (less noisy)
  - Switching period - Rising edge vs both edges – should not cause resynchronization
- 11.3 ACI
  - "Narrowband" cases work best – desired and interferer fit within about a 40 MHz bandwidth
  - Use highest data rates with narrower modulations to keep ACI synthesis bandwidth reasonable
  - Resolution and offset range are different between uncoded and coded signal types

3-Ray MP	Mild	Moderate	Severe
Γ1 (dB)	-3	-1.5	-1
τ1 (ns)	50	50	50
γ1 (deg)	0-360	0-360	0-360
Γ2 (dB)	-20	-20	-20
τ2 (ns)	155	155	155
γ2 (deg)	90	90	90

- 11.4 3-Ray MP (5 Mbps => T_b=200ns)
  - LOS + specular + diffuse (strength, delay, phase)
  - Mild, Moderate, Severe
  - Recommend letting phase slowly rotate over multiple cycles
- 11.5 2-Ray MP (5 Mbps => T_b=200ns)
  - LOS + specular (strength, delay, phase)
  - Many channel combinations (5x3x21=315)
  - Recommend letting phase slowly rotate over multiple cycles

2-Ray MP	Mildest to Worst
Γ1 (dB)	-3,-2.5,-2,-1.5,-1,-0.5
τ1 (ns)	50,100,150
γ1 (deg)	0-360

- 11.6 Resynchronization
  - Resynchronization DQM response is modulation/coding dependent
  - DQM values may be degraded due to partial noise-only payload frames

RCC 118-22 DQE/DQM Observations

- ***The RCC 118-22 DQE/DQM test framework is sufficient for DQE/DQM characterization.***
- ***Modification to test parameters have been recommended based on the conducted testing (details in paper).***
- ***Example test results have been presented to serve as an achievable performance baseline.***
- ***The 11.2 (step and dwell) and 11.6 (resynchronization) tests dynamic transitions between channel conditions. Performance varies with the modulation type and coding scheme.***
- ***Testing should include enough modes to verify the DQE format adheres to variations based on different IRIG modulation and coding alternatives as well as other operational settings.***
- ***Automated testing should be used as much as possible for repeatability and accuracy.***
- ***Minimum levels of performance should be determined and included like other RCC 118 tests such as the diversity combiner operation or transmitter spectral mask compliance.*** *The 11.1-2 tests are well suited for adding minimum Pass/Fail thresholds in the form of a mask or RMS error of the exponent differences.*

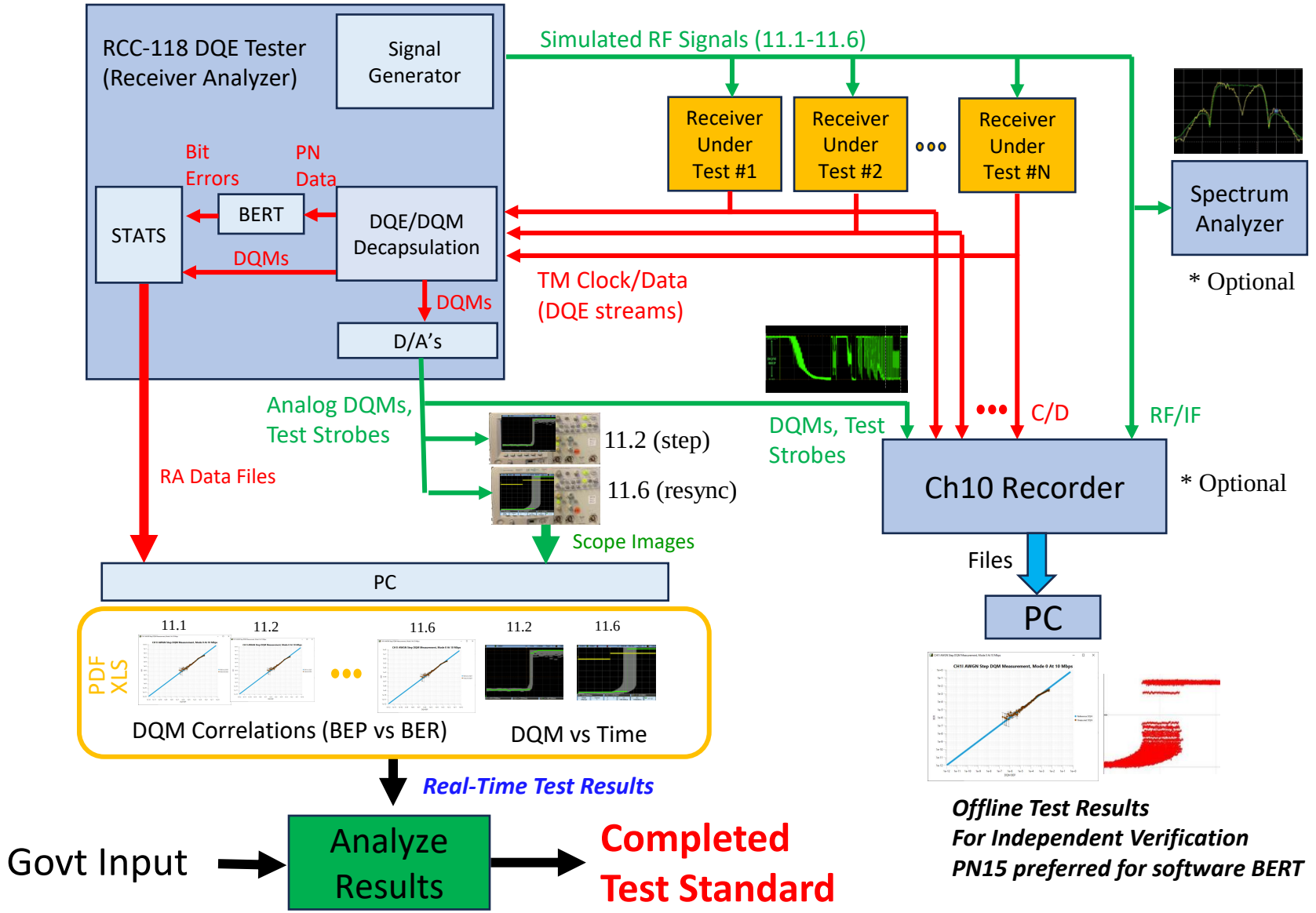
Industry Day 2

DQE/DQM Assessment Testing

Friday Oct 25th, 2024

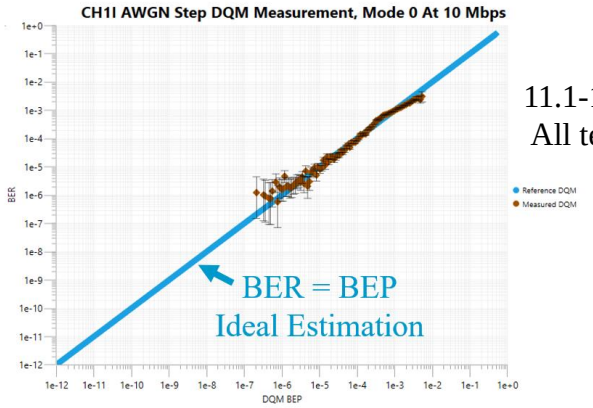
Meeting room Cascade B (Renaissance Hotel)

Industry Day 2 Test Setup



Testing Outputs

- Two types of results
  - DQM correlation plot – Measured BER vs Estimated BEP
    - DQM accuracy – How well estimated quality matches measured quality over each DQE frame
  - Step Response plot – DQM vs Time
    - DQM responsiveness – How quickly the estimated quality reflects a change in actual quality
    - For modulation/coding selections that synchronize much faster than the DQE block size, the change should only take a single DQE frame
- Supporting Data
  - DQM correlation and step response plots
  - Recordings of testing outputs



11.1-11.6
All tests

11.2 (step) &
11.6 (resync)

Signal Types / DQE Tests

- Cannot verify all modulation/coding/block size/bit rate combinations (objective is functional interoperability NOT design verification)
- After meeting with vendors and Govt personnel, 8 representative signal types were agreed upon for DQE/DQM testing

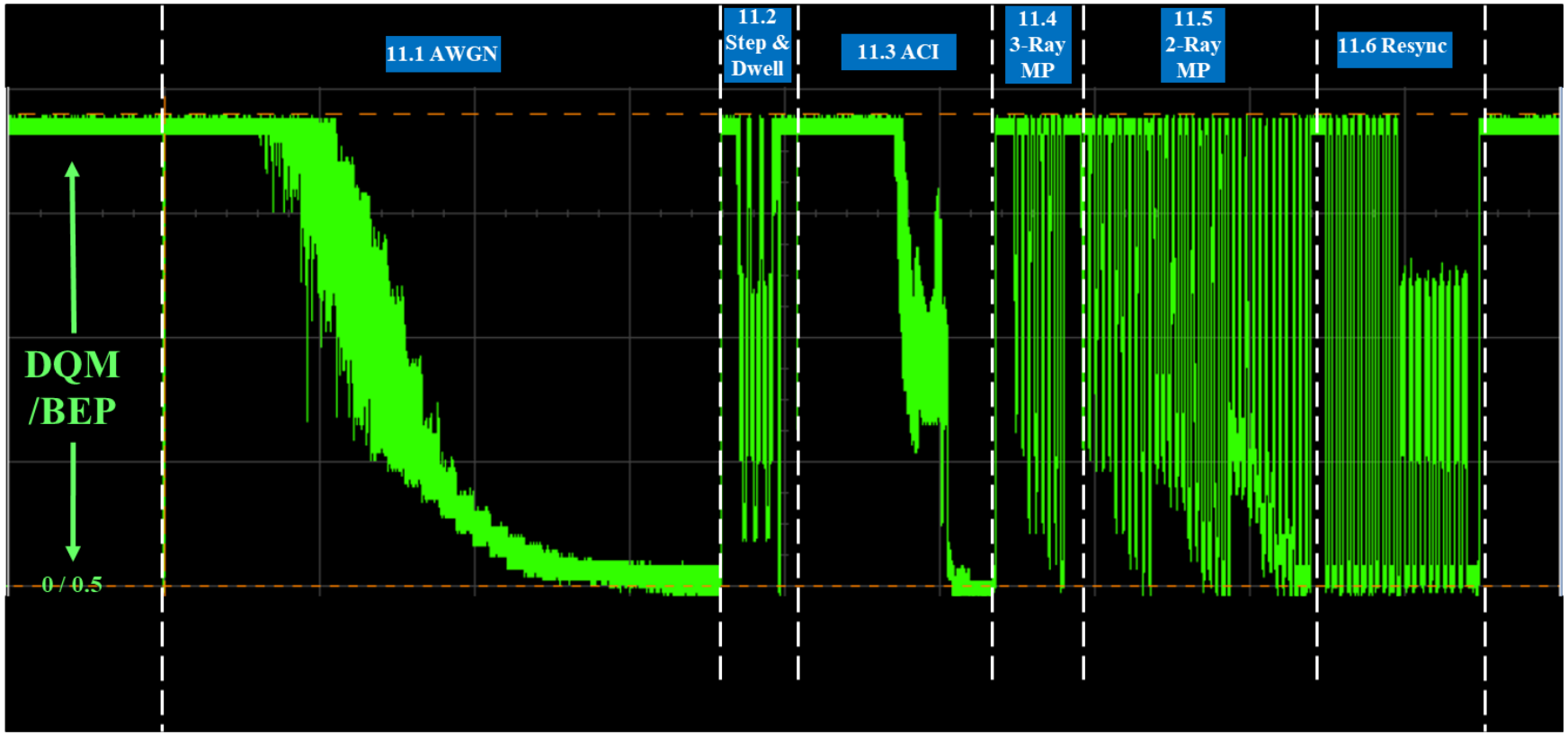
DQE Test
11.1 AWGN
11.2 Step & Dwell
11.3 ACI
11.4 MP 3 Ray
11.5 MP 2-Ray
11.6 Resync

Signal Types	DQE Block Size (bits)	Bit Rate (Mbps)	Signal Type ID
PCM/FM	4096	5	ST1
SOQPSK	4096	20	ST2
STC	3200	10	ST3
ARTM-CPM	16384	15	ST4
SOQPSK-LDPC (r=2/3 k=4096)	4096	20	ST5
SOQPSK-LDPC (r=4/5 k=1024)	1024	5	ST6
SOQPSK-LDPC (r=1/2 k=4096)	4096	5	ST7
STC-LDPC (r=2/3 k=4096)	4096	5	ST8

6 Tests x 8 Signal Types → 48 Combinations

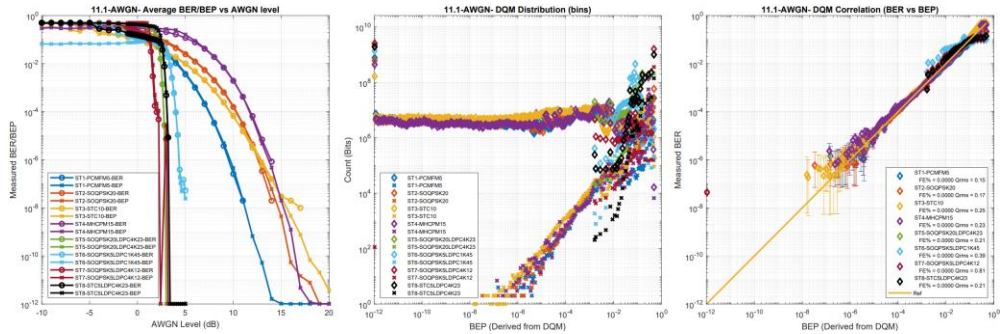
Real-Time DQM output

- RA decapsulates streams and outputs analog version of DQM
  - Very helpful for verifying all sources are ready and test is proceeding as expected

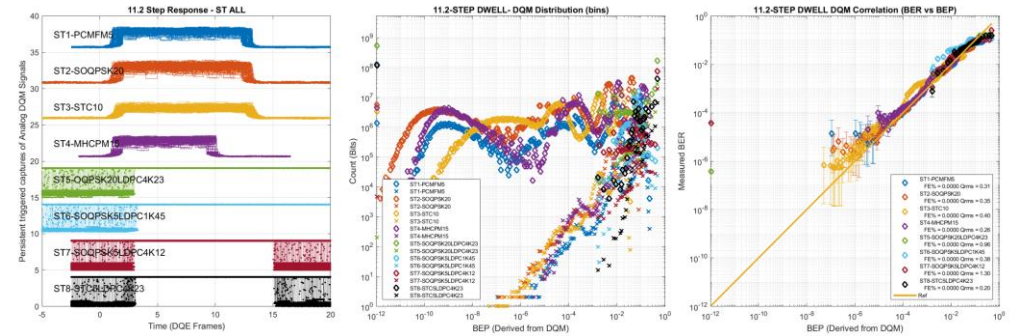


Test Output Example (6 page summary report)

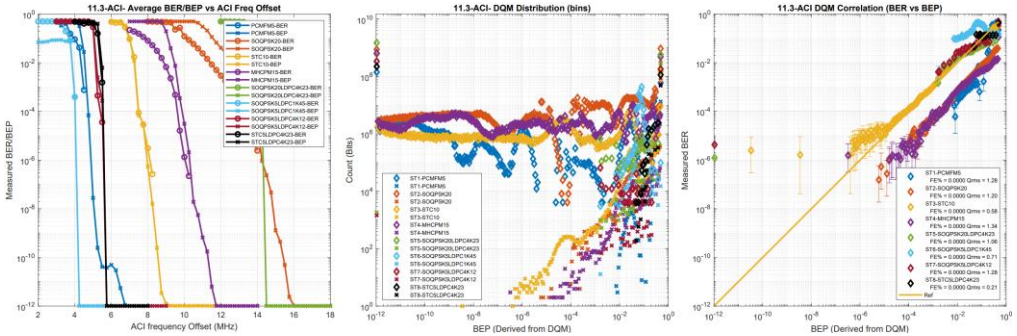
11.1 - AWGN



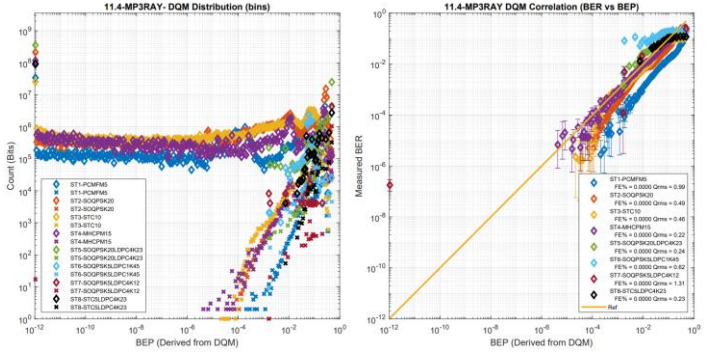
11.2 – Step & Dwell



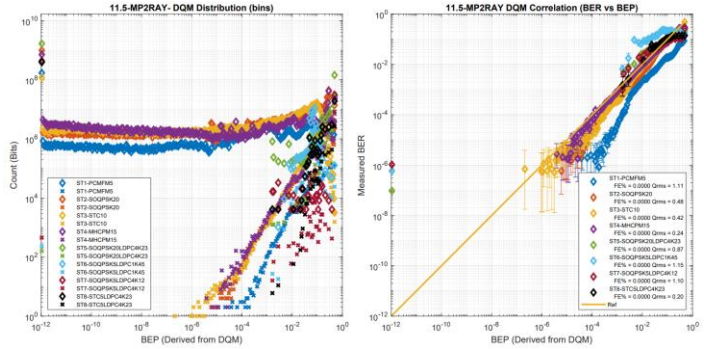
11.3 – ACI



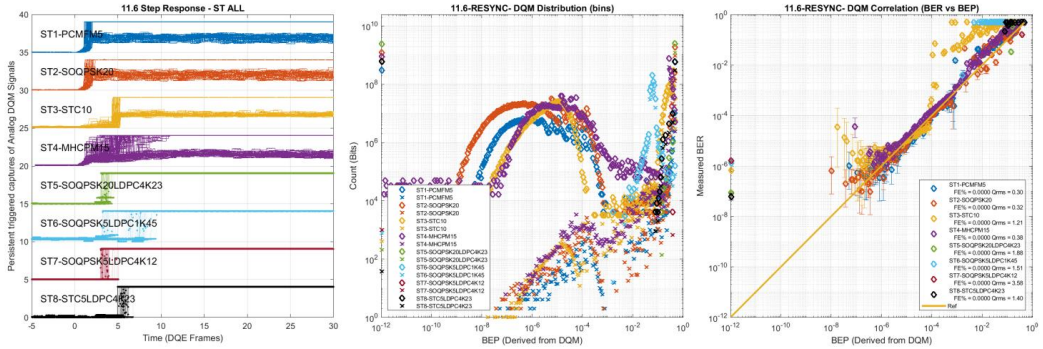
11.4 – 3 Ray MP



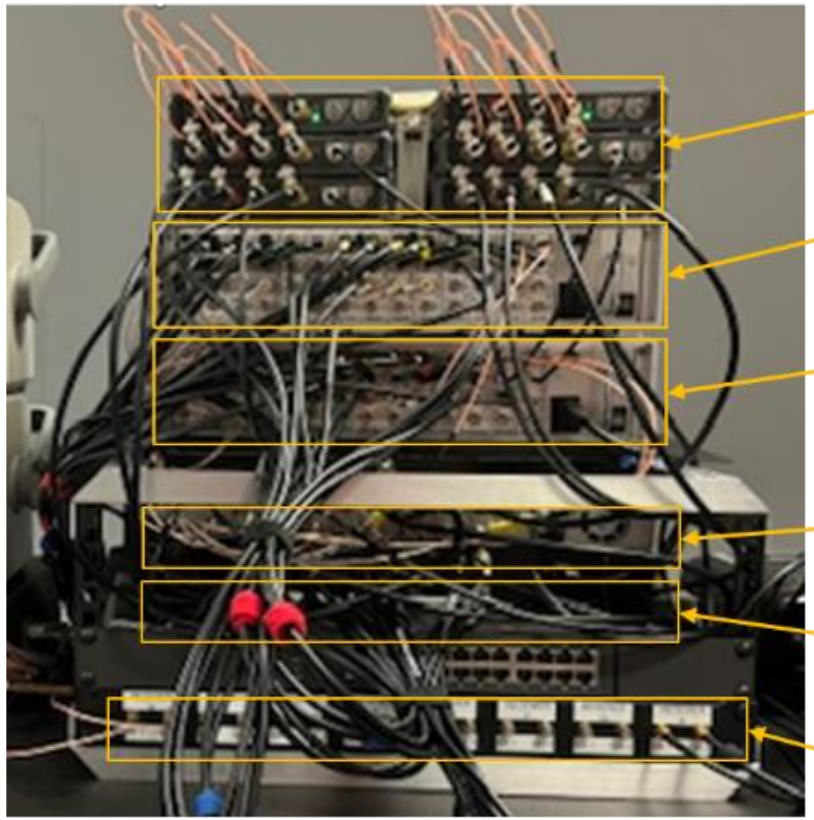
11.5 – 2 Ray MP



11.6 – Resync

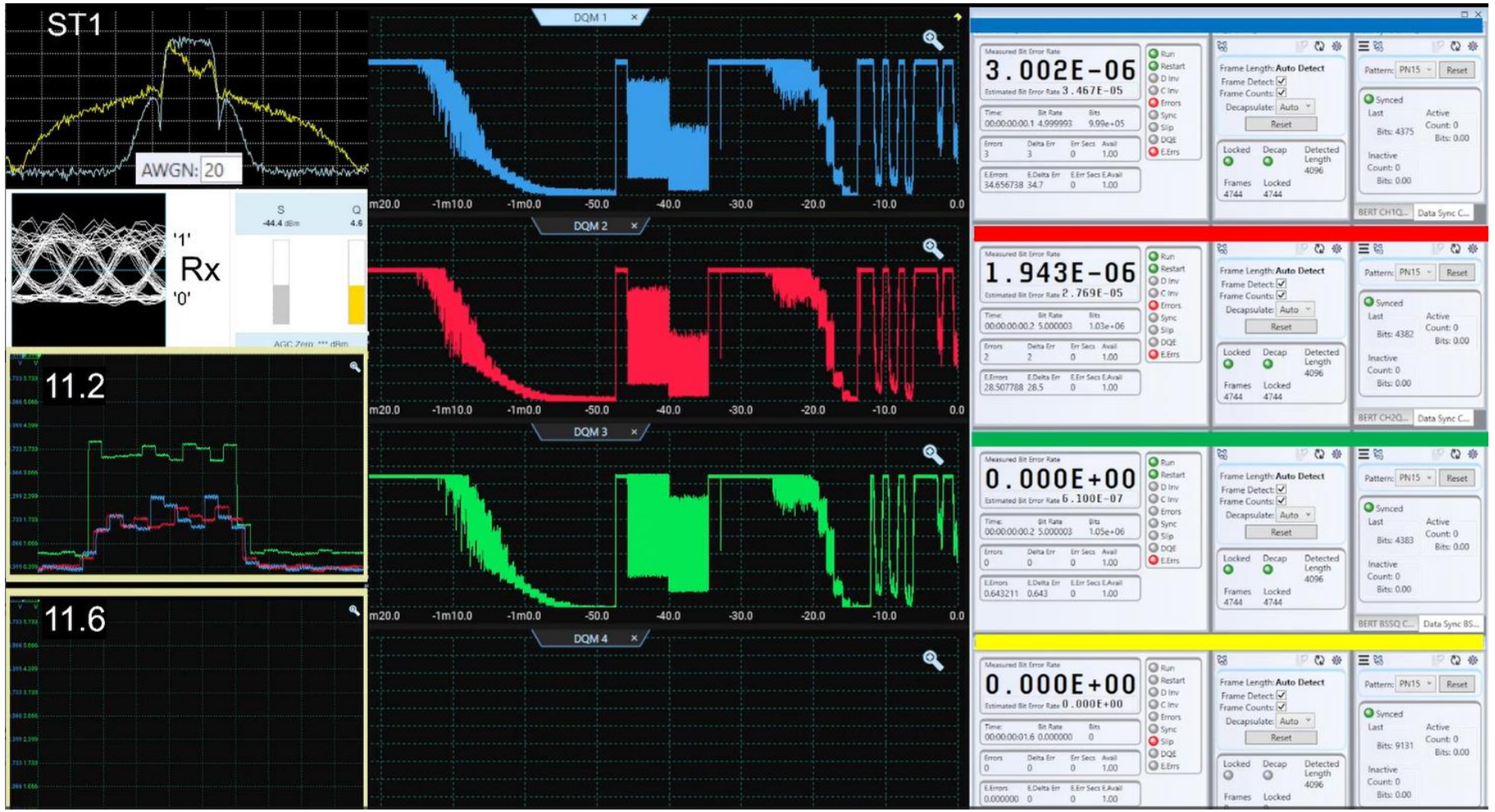


Equipment Diagram



Device		Description
Single Channel 1 (I)	Combiner 3 (Q)	
Picoscope	Picoscope	Analog DQM Monitor
Picoscope	Picoscope	Analog DQM 11.2 Step Response
Picoscope	Picoscope	Analog DQM 11.6 Step Response
Clock and Data Distribution		Receiver3&4 Clock and Data Distribution
Clock and Data Distribution		Receiver1&2 Clock and Data Distribution
Receiver Analyzer		Signal Source, DQM BERT
Receiver Analyzer DAC		DQM Analog Outputs
RF Splitter		RF Signal Distribution

Example Video of Testing



Conclusions

- DQE/DQM provides new tools for improving telemetry
  - Embedded Data Quality status
  - Data stream steering for support equipment
  - Metrics for optimal Best Source Selection (BSS) to improve TM BER
- Standards and test procedures in place
- Efficient DQE/DQM test and measurement equipment
- TM community has collaborated on interoperability testing

Questions / Comments

???

Thank you!

BACKUP SLIDES

Data Reduction Discussion (11.2 Step and Dwell example)

11.2.8 Data Reduction. There are three results from this testing.

* The first result is how DQM reacts to a step in Eb/N0, or alternately how quickly after a step change in Eb/N0 did the receiver/decoder take to settle on a DQM (BEP) value.

* The second result is whether the DQM estimate corresponds to the payload in the DQE frame.

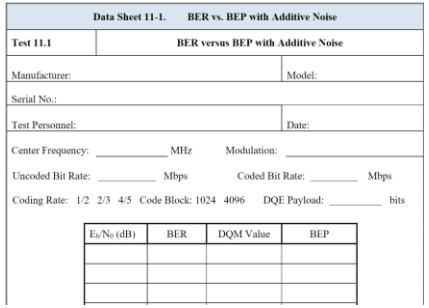
* The third result is the accuracy of the BEP estimate for a dynamic channel condition.

In the logged files, convert the captured DQM values to estimated BEP using the above equations. To illustrate the DQM step response, plot the BEP estimates with BER values for each Eb/N0 setting using a linear-logarithmic X-Y scale with a running total of test time, total payloads captured, or total number of bits captured during the test on the X-axis.

Implies recorder (DQM vs Time)

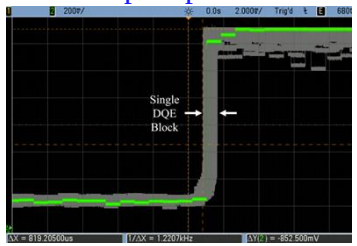
To illustrate the DQM accuracy/applicability to the DQE frame, plot and compare the BEP with the measured BER by plotting the data on a logarithmic-logarithmic X-Y scale.

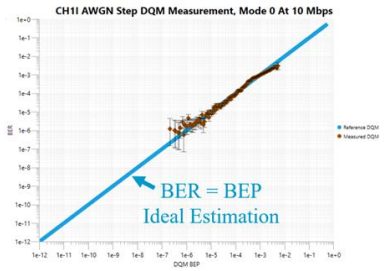
DQM Correlation Plot



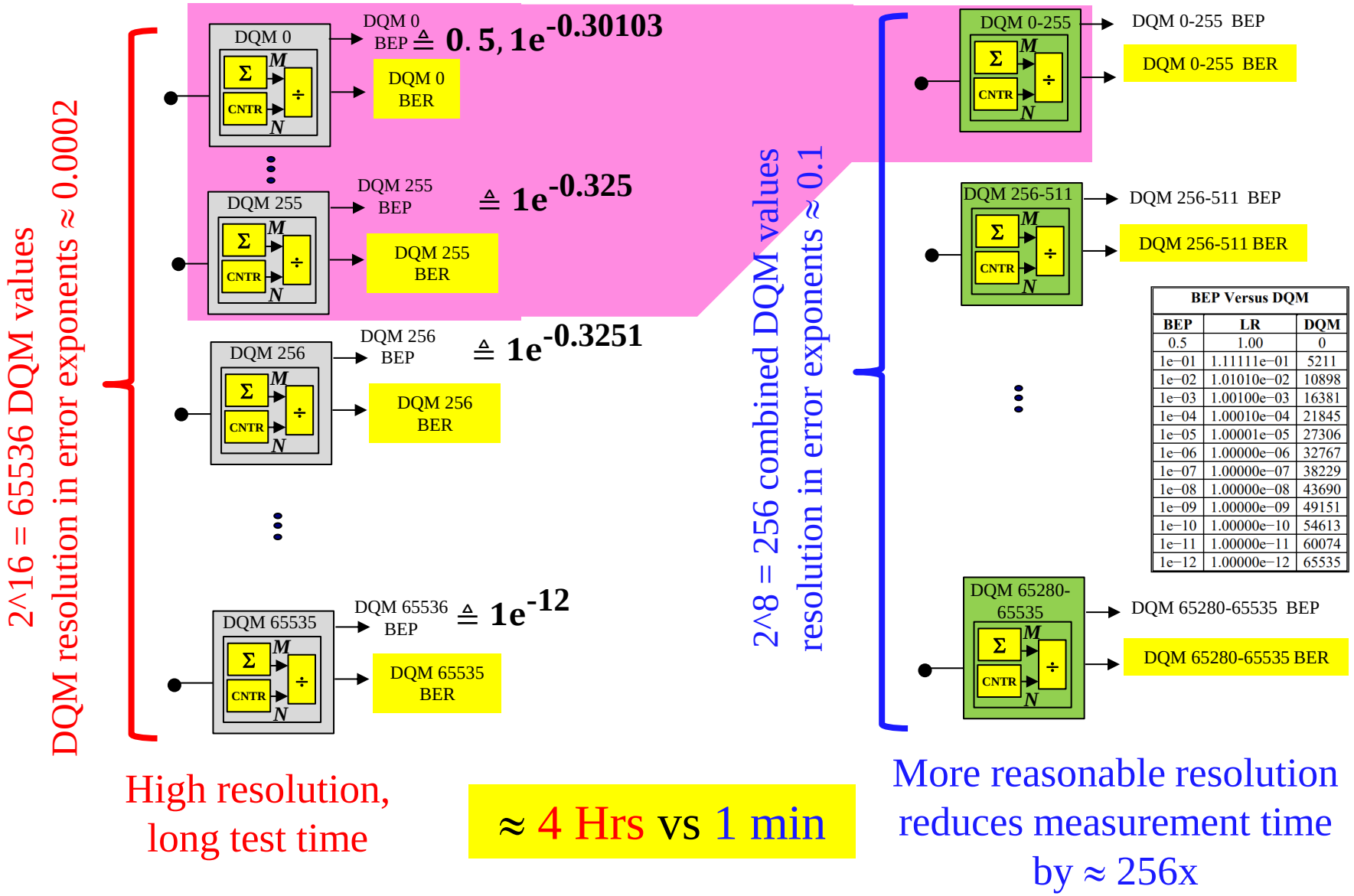
Data Sheet 11-1. BER vs. BEP with Additive Noise			
Test 11.1	BER versus BEP with Additive Noise		
Manufacturer:		Model:	
Serial No.:			
Test Personnel:		Date:	
Center Frequency: _____ MHz		Modulation: _____	
Uncoded Bit Rate: _____ Mbps		Coded Bit Rate: _____ Mbps	
Coding Rate: 1/2 2/3 4/5 Code Block: 1024 4096		DQE Payload: _____ bits	
E_b/N_0 (dB)	BER	DQM Value	BEP

Recommend persistent scope capture for real-time step response





DQM BER resolution vs measurement time (“binning”)



BEP Versus DQM

BEP	LR	DQM
0.5	1.00	0
1e−01	1.11111e−01	5211
1e−02	1.01010e−02	10898
1e−03	1.00100e−03	16381
1e−04	1.00010e−04	21845
1e−05	1.00001e−05	27306
1e−06	1.00000e−06	32767
1e−07	1.00000e−07	38229
1e−08	1.00000e−08	43690
1e−09	1.00000e−09	49151
1e−10	1.00000e−10	54613
1e−11	1.00000e−11	60074
1e−12	1.00000e−12	65535

High resolution, long test time

≈ 4 Hrs vs 1 min

More reasonable resolution reduces measurement time by ≈ 256x

DQE/DQM Testing Observations

Item	Subject	Observations
A	DQM Test Terminology	BER is used to indicate a measured value where BEP is estimated from the DQM value.
B	DQM testing is not about receiver sensitivity	DQM is all about accurately estimating the recovered TM quality – not about the receiver sensitivity performance. Whether the TM quality is good or bad, the accuracy of the DQM indication is what is being tested.
C	Distribution of DQM values	For AWGN channels, the DQM values should follow a binomial probability distribution instead of a single averaged value. For example, using 4096 bits at an average BER of 10^{-5}, the DQM values should be spread over a range of around 10^{-3} to 10^{-7}. As the block size or average BER increases, the spread of the DQM distribution narrows.
D	DQM Correlation	The confidence interval of the DQM correlation bin values should contain the ideal BEP=BER line. Indicators of poor DQM correlation performance include points with a large estimation error (particularly measured errors at mimimum BEP), horizontal or vertical segments, or significant gaps not related to the test stimulus.
E	DQM Step Response	If the modulation step response is fast relative to the period of a DQE frame, the new DQM value should accurately reflect the actual BER level within a single DQE frame. Timing misalignment or DQM averaging can smear the response over multiple frames causing slow convergence and poor correlation with the actual BER.
F	Selection of TM Signal Types	It is impossible to test all TM modes and channel conditions. Select test parameters that exercise modulation/coding/system options that verify the various DQE formats.
G	Automated Real-Time Testing	DQE/DQM testing requires dynamic signal generation, precise data capture, and specialized equipment. Automating the test execution, data collection, and results reduction to the maximum extent possible is highly recommended for efficiency, accuracy, and repeatibility. Real-time results can be checked using TM recordings and off-line processing if desired.
H	Receiver Operating Modes	Testing of both single-channel and combiner operation is recommended as well as any other speciality modes such as adaptive equalization.
I	Test Time/Resolution	Measuring DQM correlation results at low error rates can require long run times. A practical approach is to first run through all the tests in a reasonable time frame with longer runs reserved for individual tests based on the results. Resolutions of 1 dB are sufficient for uncoded modulations while steps of 0.1 dB over a narrower range are recommended for coded modes.

DQE/DQM Testing Observations

Item	Subject	Observations
J	Uncoded vs Coded Testing	A starting point for appropriate Eb/N0 ranges and step sizes can be determined from theoretical values for each particular modulation/coding mode. Adjust the ranges as required.
K	Multipath Generation	The standard lists discrete phase difference values (γ) for the multipath parameters. A signal generator capable of implementing a slow phase rotation (frequency offset) that exercises all phase differences is simpler, more complete, and is recommended.
L	DQE Block Size	The standard does not call out a specific block size. At a minimum, it is recommended to test 1K, 3200, and 4K bit block sizes as these are the most commonly used settings.
M	Average DQM/BEP vs Frame-by-Frame DQM/BEP	Unlike the dynamic tests, 11.1 AWGN and 11.3 ACI are suitable for comparing the average BER to the average BEP at each individual channel setting. The results should agree reasonably well since they represent the means of a large sample size. If not, this may indicate a bias in the receiver processing approach.
N	11.2 Step and Dwell	The current suggestion of 8,10,12 Eb/N0 levels in the 11.2 step and dwell test produce DQM distributions with overlapping values. Eb/N0 levels that produce a BER corresponding to $1e^{-2}$ and $1e^{-7}$ make the SNR transitions clearly discernable.
O	11.6 Resynchronization Artifacts	Resynchronization artifacts may be present in the resynchronization test and are more prevelant with advanced modulations, coding, and shorter DQE block sizes. Be aware that DQM estimation is degraded prior to demodulator lock. This test should be conducted with both long and short outage periods to understand DQM behavior. Be aware that the step response could validly span multiple DQE frames if the receiver synchronization is slow or unsteady.
P	Pass/Fail Criterion	There is currently no Pass/Fail criterion. It is recommended to adopt a minimum level of performance as is done with diversity combiner operation (5.16, 5.26) or transmitter spectral mask compliance (9-7). *The 11.1-2 tests are well suited for adding minimum Pass/Fail thresholds in the form of a mask or RMS error of the exponent differences.*