Simulation Requirements for fading multipath channel conditions

William N. Furman / John W. Nieto
Harris Corporation
RF Communications Division

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Overview

- Problem statement
- Previous study
- Experiment organization
- Results
- Observations / Conclusions

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Problem Statement

- How long should a modem Bit Error Rate (BER) test be run for consistent results and what variation can be expected ?
- Factors to consider
  - Channel model
  - Waveform Definition: modulation, coding and interleaving
  - Modem Implementation, tracking loops, equalization, estimation.
  - Error mechanisms

Previous Study

- McRae / Perkins – “Digital HF modem performance measurements using HF link simulators” IEE 1988
- Mathematical analysis based on number of uncorrelated BER samples required so that their variance about the mean is sufficiently small that there is adequate confidence that the observed value is within a specified range of the true value (90% confidence i.e. factor of 2)
- Based on:
  - channel memory – reciprocal of Doppler spread
  - modem memory time – tracking loop time constants, coding interleaving effects
  - effective order of diversity - modem specific constant.

Previous study

- Based on some assumptions and analysis the paper stated the following:
- "…It can be seen that the test time required can be several hours for a single valid BER measurement. Such test times tend to be longer than the messages to be transmitted. In light of this is there any practical significance to such bit error rate measurements? The answer is yes, since the actual behavior of the modem for shorter intervals is clearly related to the average bit error rate, even if this true average is hard to obtain."

- Historical Perspective – Circa 1988 modem HW testing had to be done real time or less than real time. Hard to validate analysis performed in this paper.
- It is easier now due to dramatic increase in PC simulation speed (10bps – 100,000bps for 2400bps).

Experiment Organization

- Waveforms tested: 2400S (0.6s), 2400L (4.8s), 9600S(1.07), 9600L (4.3), 9600VL(8.61)
- Channel models considered:
  - 2ms, 1 Hz (Mid Latitude Disturbed / Poor)
  - 0.5ms, 0.1 Hz (Mid Latitude Quiet / Good)
  - 2ms, 2Hz(path 2 only) (Rician)
- BER operating points 1e-3 , 1e-5
- Method
  - Run N multi-hour (6/20) simulations for each waveform, channel, BER combinations.
  - Each simulation initializes the random noise and random fading mechanisms independently

Channel Profiles

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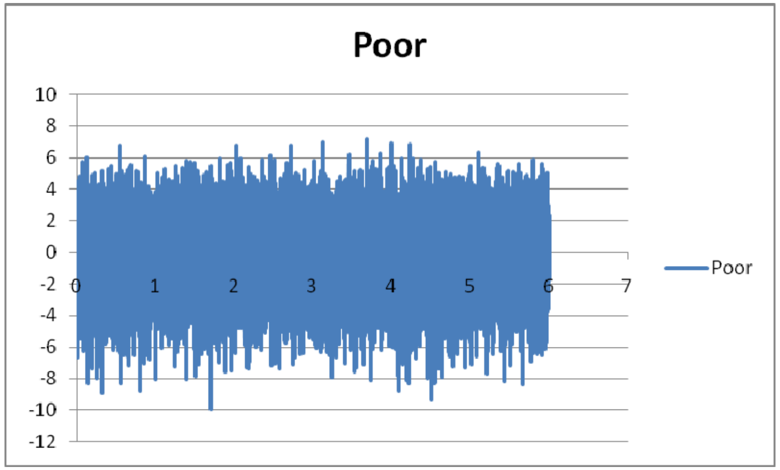
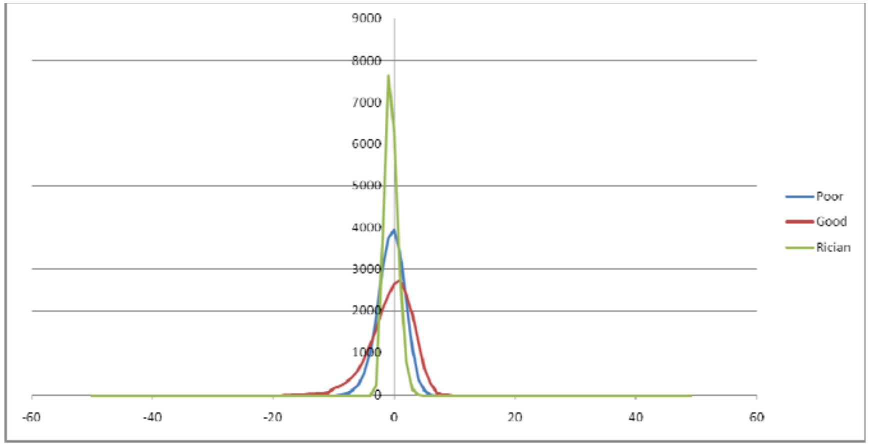
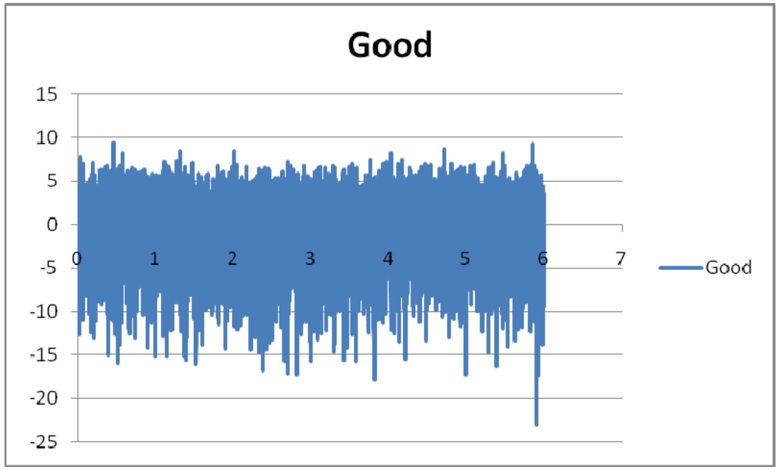
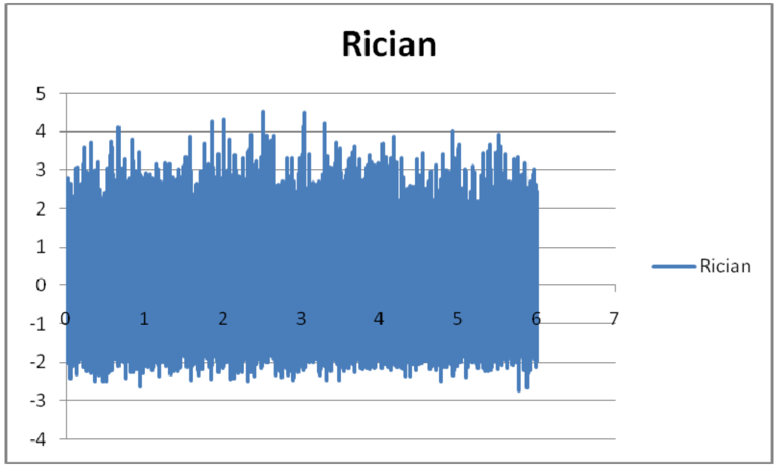
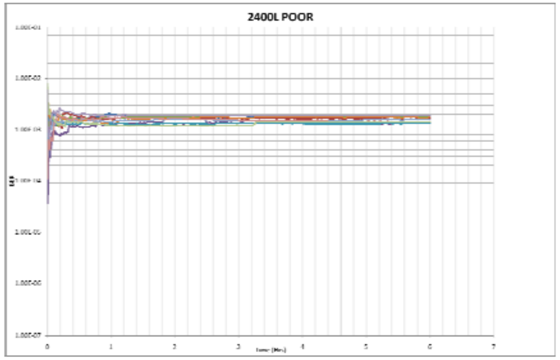


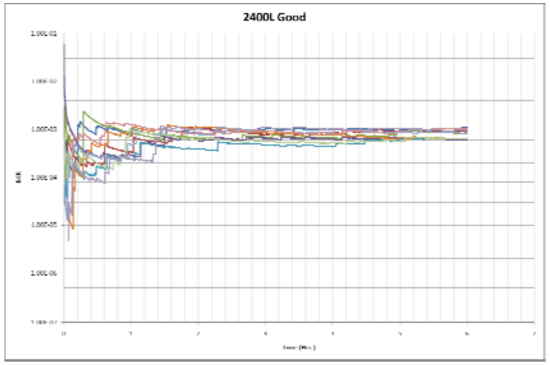


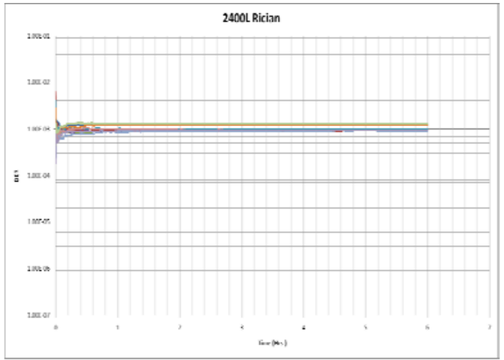




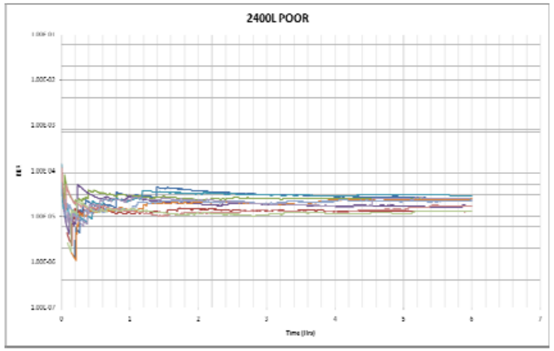
$1e^{-3}$

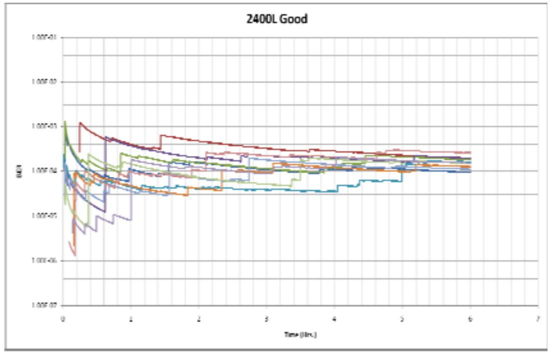

2400L POOR

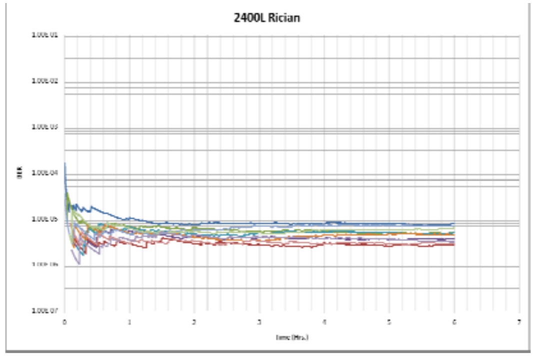

2400L Good


2400L Rician

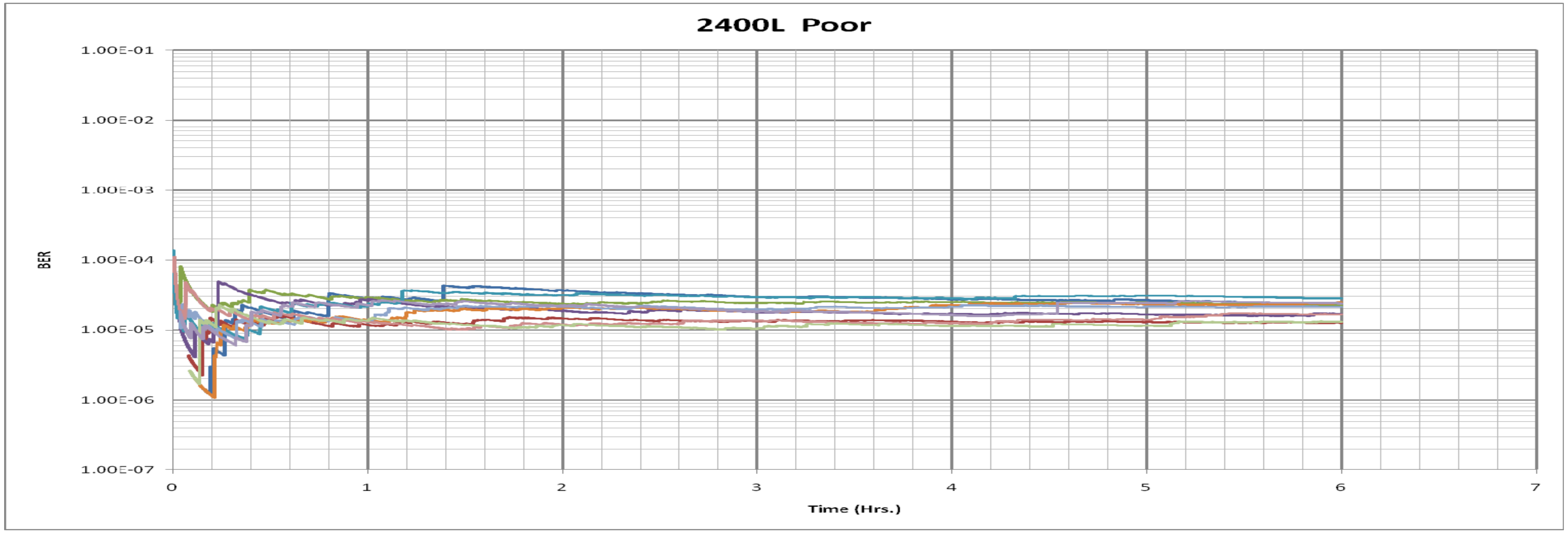
$1e^{-5}$


2400L POOR

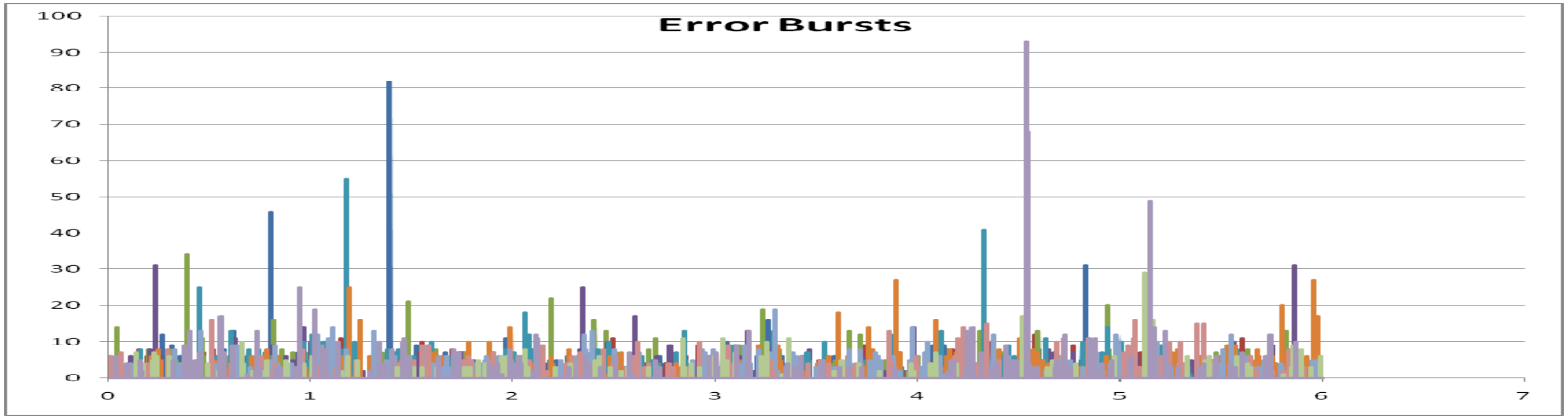

2400L Good


2400L Rician

2400L Poor

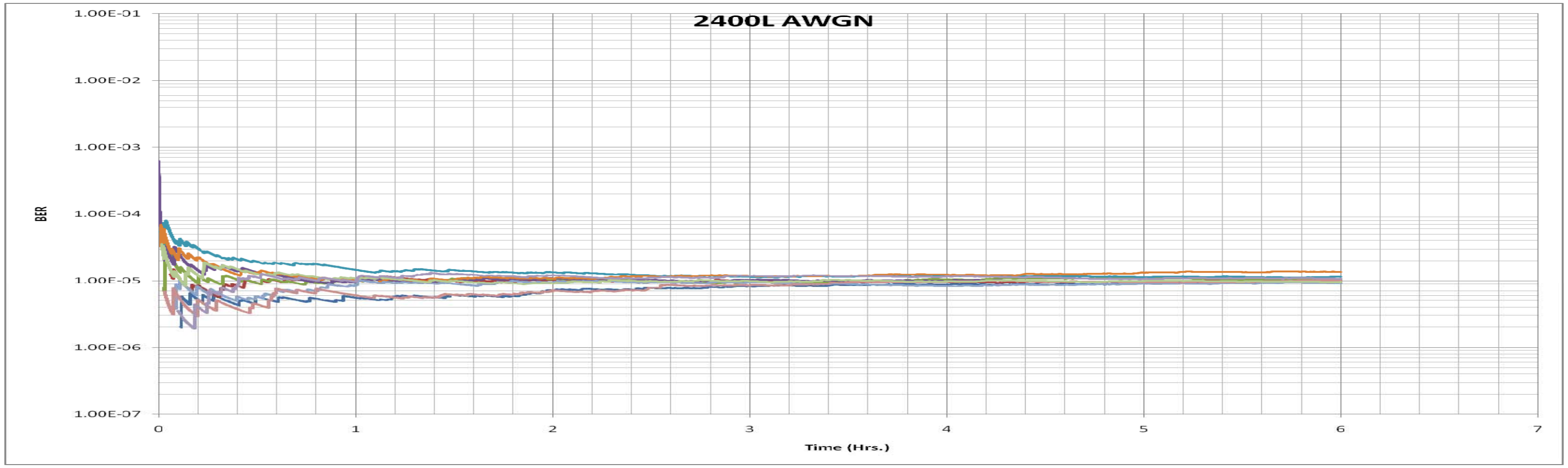


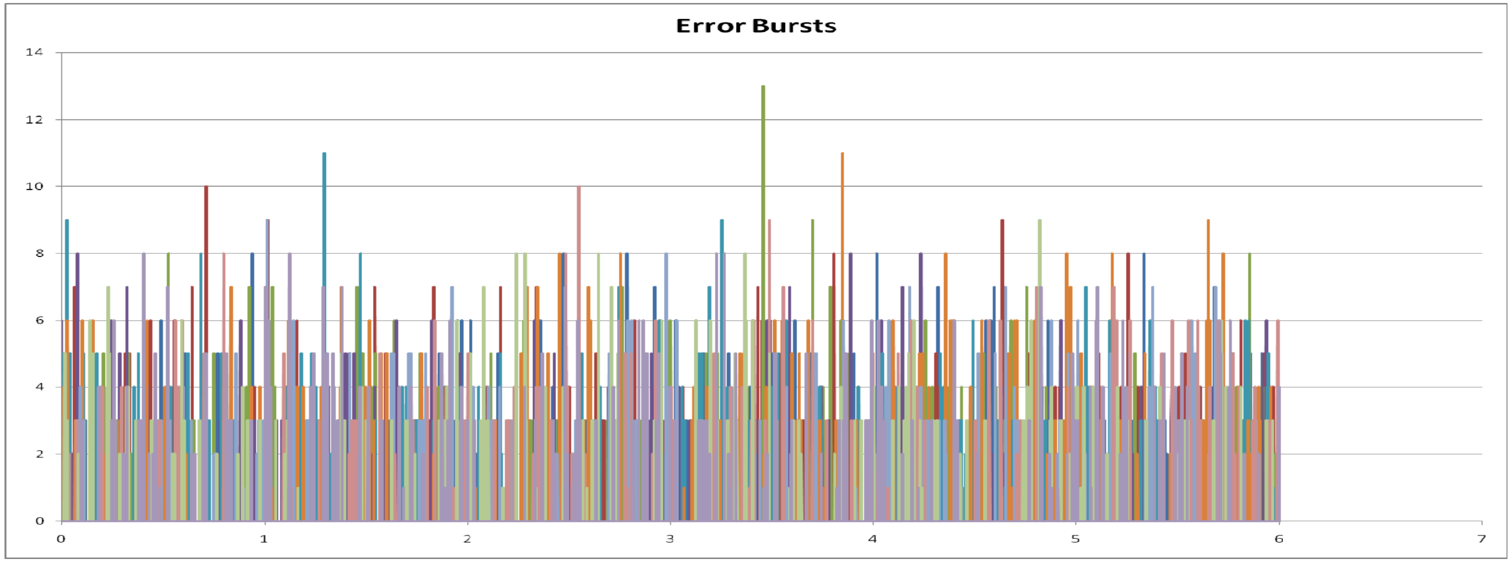
2400L Poor
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
BER
0
1
2
3
4
5
6
7
Time (Hrs.)



Error Bursts
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7

2400L - AWGN

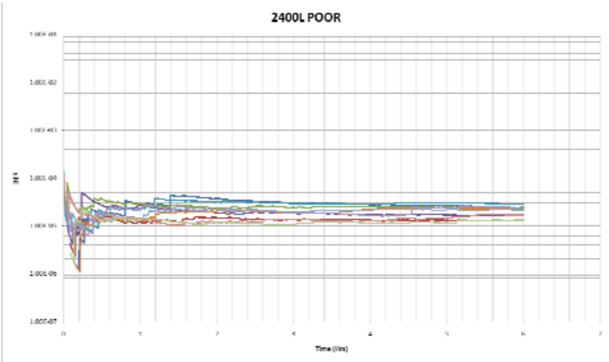

2400L AWGN
BER
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
0
1
2
3
4
5
6
7
Time (Hrs.)

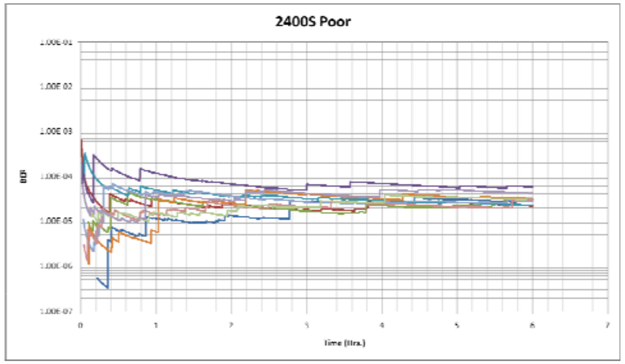

Error Bursts
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7

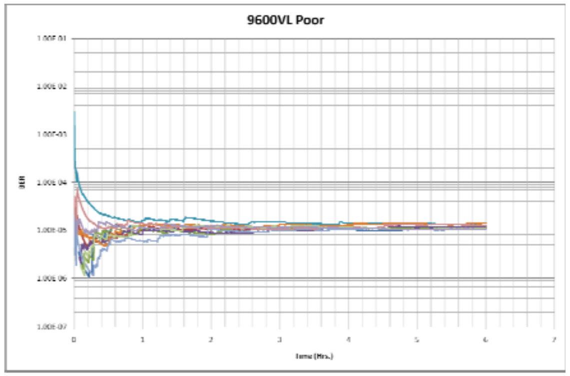
Observations 2400L

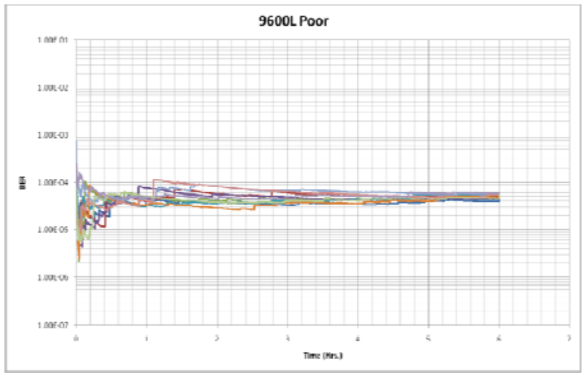
- Final BER variance is greater for 1e-5 than 1e-3
- All tests show higher variance in first two hours
- BER profiles suggest Poor requires 4-5 hrs, Good longer
- Error bursts drive BER deviations and final variance of BER
- Additive White Gaussian Noise
  - Variance less, but not zero
  - Burst errors much less

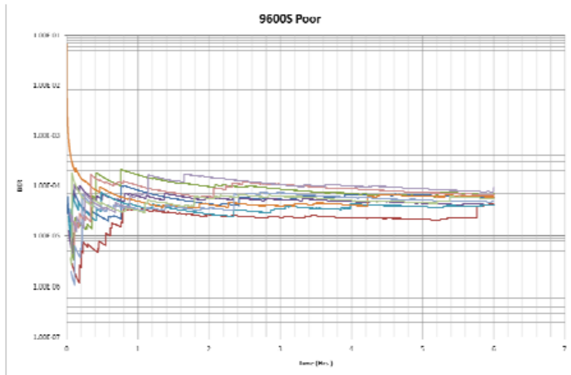
All Waveforms (Poor $1e^{-5}$)











All Waveforms (Poor)

- Role of interleaver depth is highlighted. The longer the interleaver, the tighter the variance
- 9600VL, with longest interleaver structure has the smallest variance

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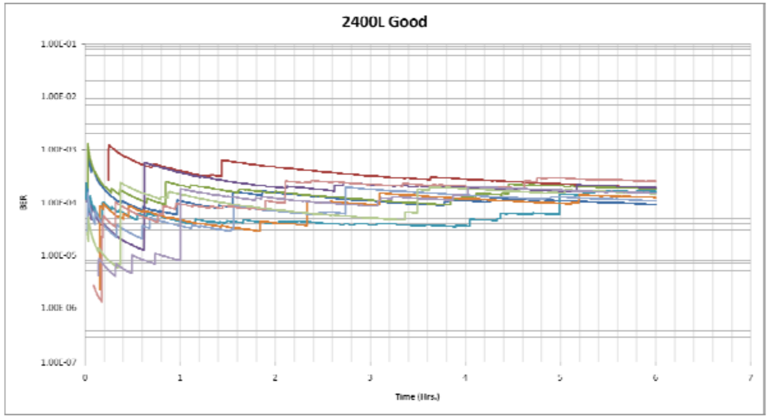
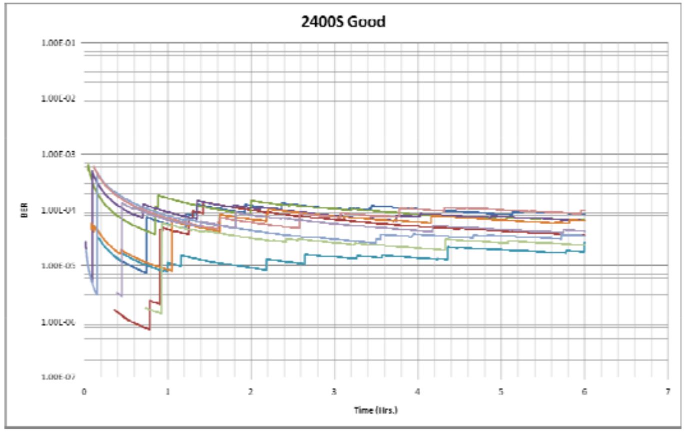
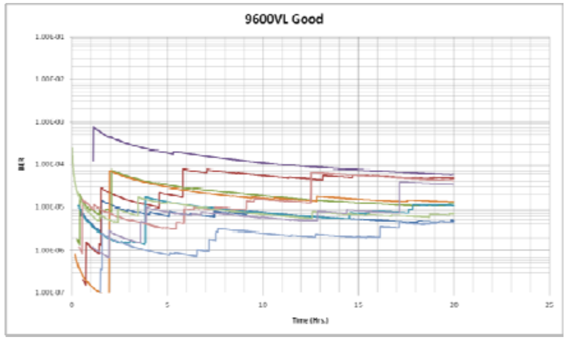
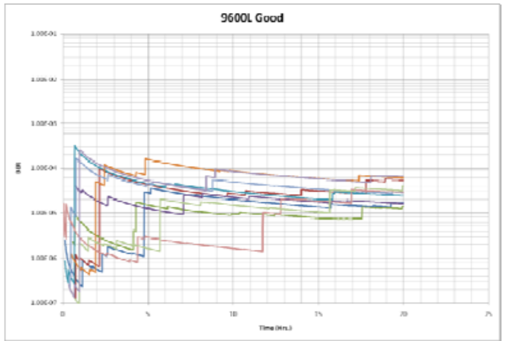
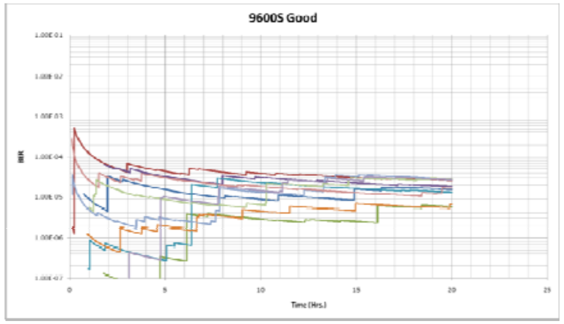
All Waveforms (Good $1e^{-5}$)











All Waveforms (Good)

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- Effect of interleaver length is much less obvious, even with the 20 Hr 9600 bps simulations as all of the interleavers are too short relative to the 0.1 Hz fade rate of the Good channel.
- Since the fade rate is 10X slower than the Poor channel we expect variance to be higher and the tests should be 10X longer to get variances equivalent to those in the Poor case.

Conclusions

- HF modems are complex signal processing machines that contain many mechanisms that can lead to performance variations
- Test durations of 4-5 hours are necessary to reduce variation of the measured BER for Poor and Rician channels. Much longer test durations are required for the Good channel.
- Averaging of multiple tests should be considered to further reduce variance
- Performance specifications should factor in the expected variation, and guidelines on making the measurements

Way Ahead

- Examine other error metrics such as packet error rate and error free seconds.
- Examine averaging techniques to reduce measurement variance.
- Compare results against recommendations in ITU RF1487, which appears to be too optimistic
- Examine HF waveform standards to validate recommended test times versus performance.