Diversity Performance Gains Achieved by a WBHF Waveform in Simulated WBHF Channels

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WideBand HF (WBHF) Background

- In early 2009, the MIL-STD-188-110B/141B revision Technical Advisory Committee (TAC) began definition of WBHF, contiguous HF frequencies providing HF bandwidths up to 24 kHz
- Over the summer of 2009, Rockwell Collins (RCI) developed two WBHF waveform prototypes, a 6 kHz and a 12 kHz WBHF waveform
- RC prototype waveforms, not compliant with current WBHF waveform standard definitions, based upon MS-188-110B App C; prototype waveform performance expected similar to final standard
- Prototype 12 kHz WBHF waveform highest surface wave data rate is 64 kbps, highest skywave rate is 48 kbps (requires high SNR channel)

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Prototype WBHF Characteristics

- Prototype waveforms use constraint length 9 convolutional coding punctured to various rates
- Four interleaver options, 7.68, 1.92, 0.48 and 0.12 seconds
- Short initial preamble and interleaver for supporting voice services
- Preamble reinserted every 7.68 s to facilitate late entry
- Highest data rate waveforms are only suitable for surface wave channels (256 QAM)
- At 12 kHz, 48 kbps may be possible for mid-latitude paths
  - 64QAM modulation
  - Low delay spread capability

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Diversity Combining

- Diversity can be used to improve reception in a fading channel if the fading of multiple receptions is not strongly correlated
- Several types of diversity combining are possible
  - Frequency diversity
  - Spatial diversity
  - Polarization diversity
  - Pattern diversity
  - Angle diversity
- Transmit diversity is also possible with equalized serial tone waveforms
- Use of transmit and receive diversity is particularly attractive where a ground station (with diversity) services mobile users (one antenna)

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WBHF Spatial Receive Diversity Theory

- There are many well-known methods of accomplishing receive diversity
  - Switching diversity
  - Maximal ratio combining
  - Soft decision combining
  - Combining within the equalizer
- For the WBHF waveform, combining is done within the equalizer
- Spatial separations as small as 1 wavelength have been shown to provide significant de-correlation of fading on an NVIS link (Nieto)
- To be useful, SNR on the received signals have to be comparable

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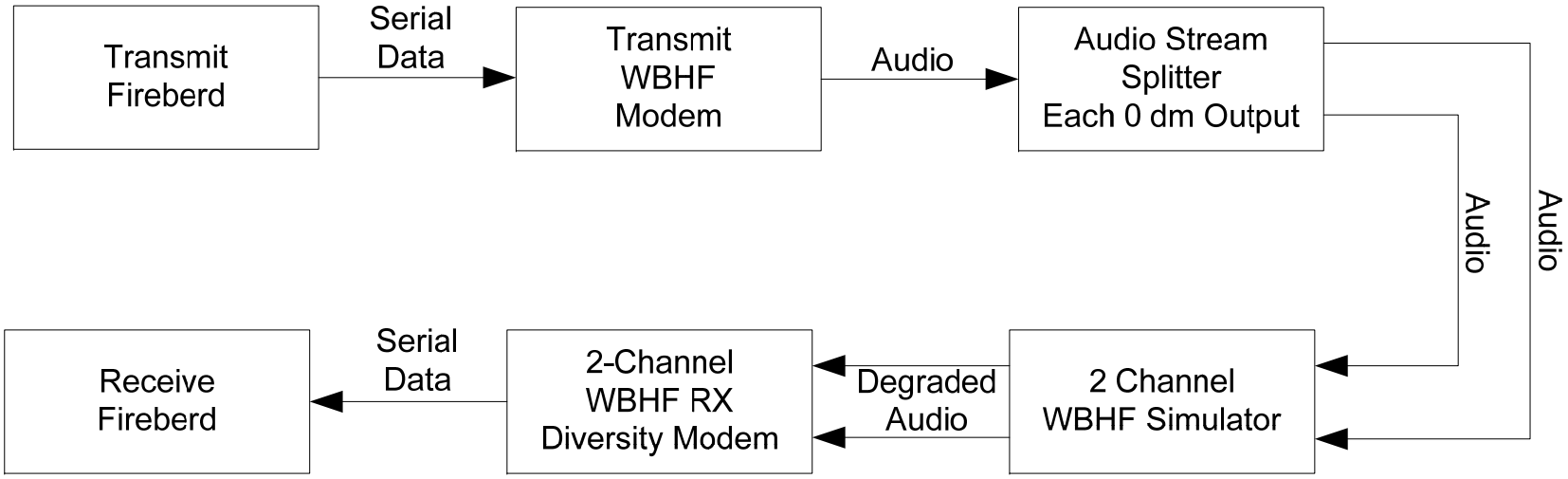
WBHF Spatial RX Diversity Simulation Test Bed

- RCI developed WBHF channel simulator supporting channel simulations up to 24 kHz bands
- Prototype WBHF modems capable of 2nd order transmit and receive diversity combining
- A single transmitting WBHF modem audio output split into two identical audio streams with same power (0 dBm)
- Each WBHF audio stream routed through a two-channel WBHF baseband channel simulator
- Each WBHF channel simulator output audio stream passed to a 2-channel WBHF modem set up for 2nd order diversity combining
- Fireberds used for transmitting and receiving data platform

WBHF Simulator Channels Independent

WBHF Waveform RX Diversity Test Bed Diagram



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WBHF RX Diversity Simulation Gains Summary

- 12 kHz WBHF 2nd order receive diversity performance gains 2 dB to 4 dB better than similar test trials with 3 kHz HF waveforms
- To maintain synchronization beyond 5 to 10 minutes, 12 kHz WBHF 48 kbps data rate requires unrealistically high SNR for multipath, fading channel simulations
- Employing 2nd order receive diversity, 48 kbps rate (12 kHz channel) achieves BER of 1E-5 with 22 dB CCIR Poor channel, requires 23 dB SNR for CCIR Moderate channel (1E-5 BER)
- 12 kHz WBHF 48 kbps data rate can support short data bursts (up to a few minutes) in skywave channel simulations
- A potential solution has been identified to enhance the prototype 48 kbps WBHF rate to improve skywave performance

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WBHF Simulation Summary (No Diversity)

- Channel simulator test results with prototype 6 kHz and 12 kHz WBHF waveforms suggest similar performance as 3 kHz HF waveforms for non-diversity WBHF channel simulations
- 12 kHz WBHF 64 kbps rate only tested in AWGN (single path, no Doppler spread) channel simulations
- AWGN channel simulations with 64 kbps rate suggest 26 to 27 dB surface wave channel needed for low bit error transmissions
- AWGN channel simulations using 48 kbps rate requires 20 to 22 dB surface wave channel for low bit error transmissions

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Future WBHF Channel Characterization Activities

- WBHF Over-The-Air (OTA) transmit and receive diversity trials via Iowa-Texas WBHF channel links
- WBHF channel simulator testing using video applications
  - Serial data interface video application (limited to 64 kbps)
  - UDP data interface video application (all WBHF rates supported)
- Subnet Relaying, HFIP, and STANAG 5066 WBHF OTA trials
- WBHF channel simulations for transmit diversity
- Channel characterization testing for WBHF channels greater than 12 kHz (OTA and WBHF channel simulator)

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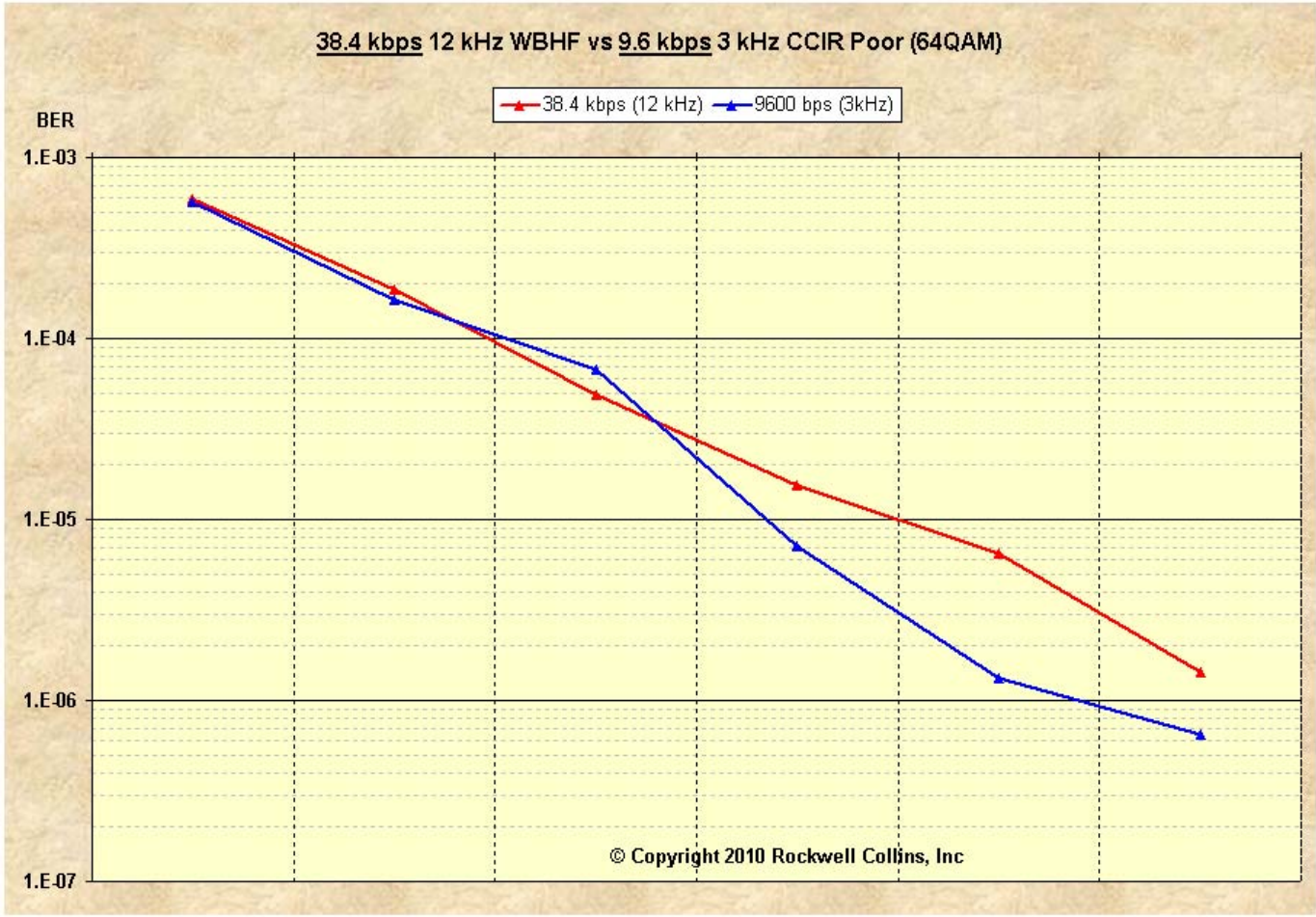
Backup WBHF Diversity Performance Charts

The following slides graphically illustrate:

- WBHF 12 kHz channel performance simulations versus MIL-STD-188-110B Appendix C performance simulations

- WBHF diversity performance gain simulations

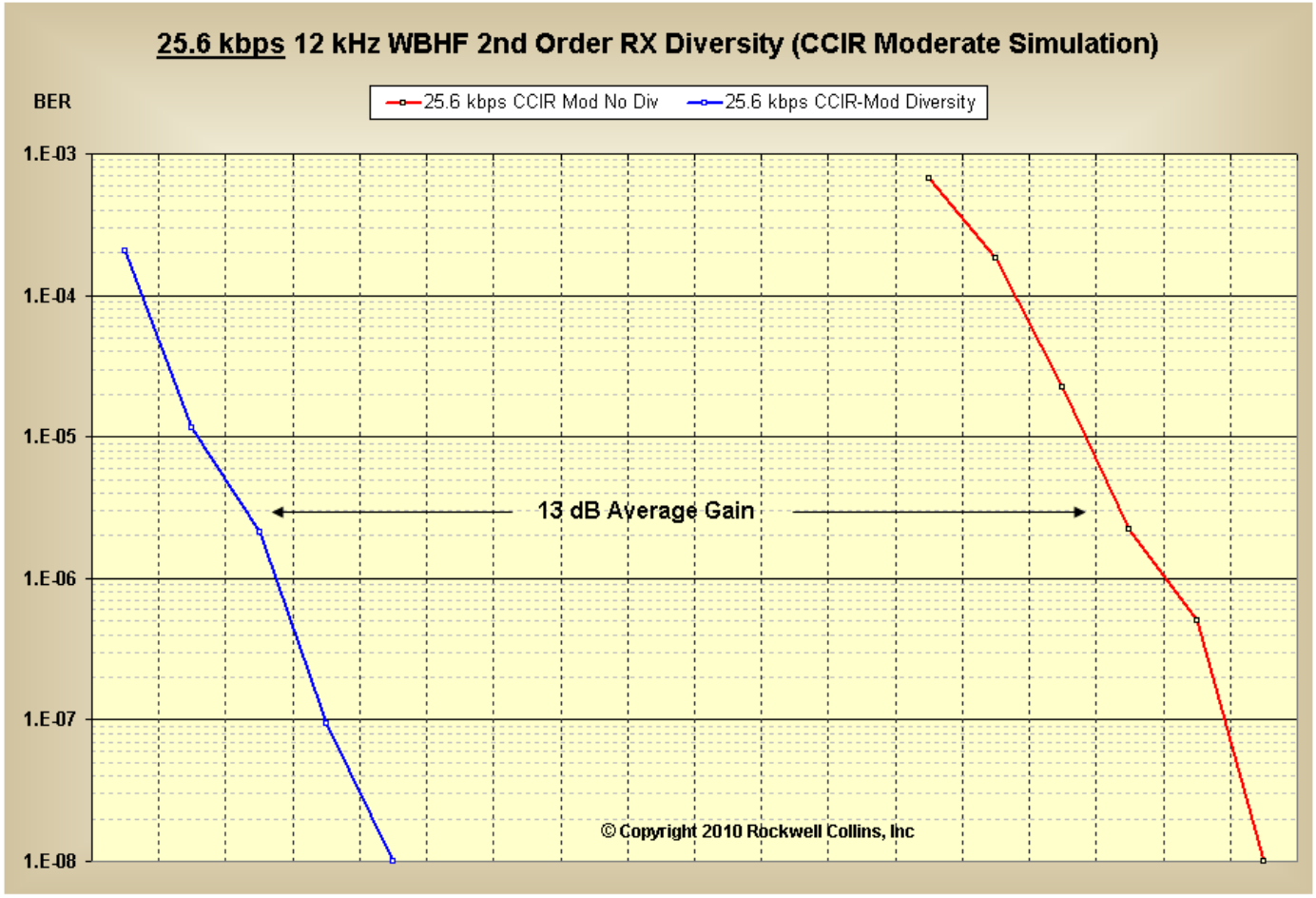
12 kHz WBHF-3 kHz CCIR-Poor Comparison (64 QAM)



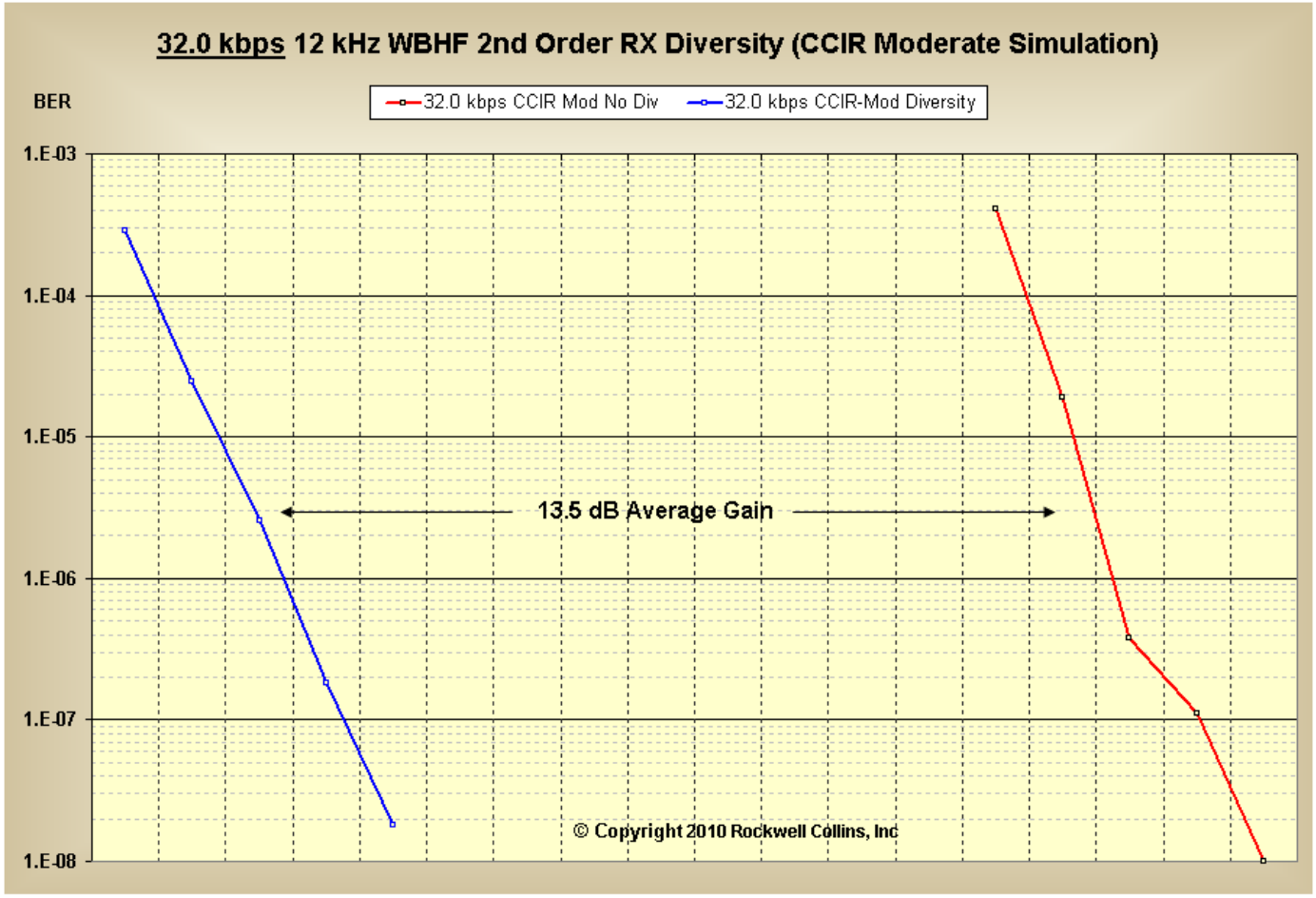
12 kHz WBHF-3 kHz CCIR-Poor Comparison (32 QAM)

12 kHz WBHF-3 kHz CCIR-Poor Comparison (16 QAM)

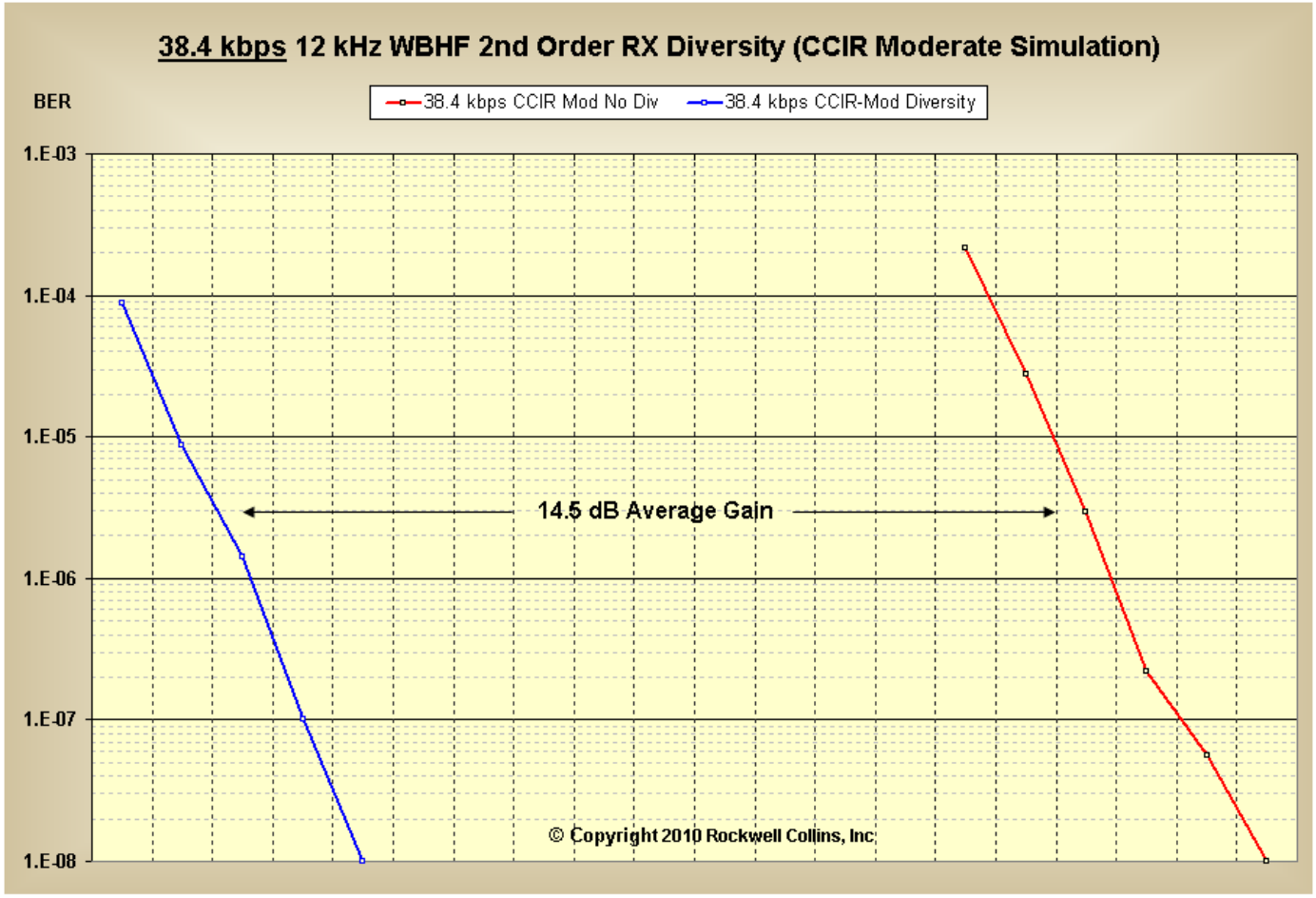
12 kHz WBHF CCIR-Moderate Diversity Gains (25.6 kbps)



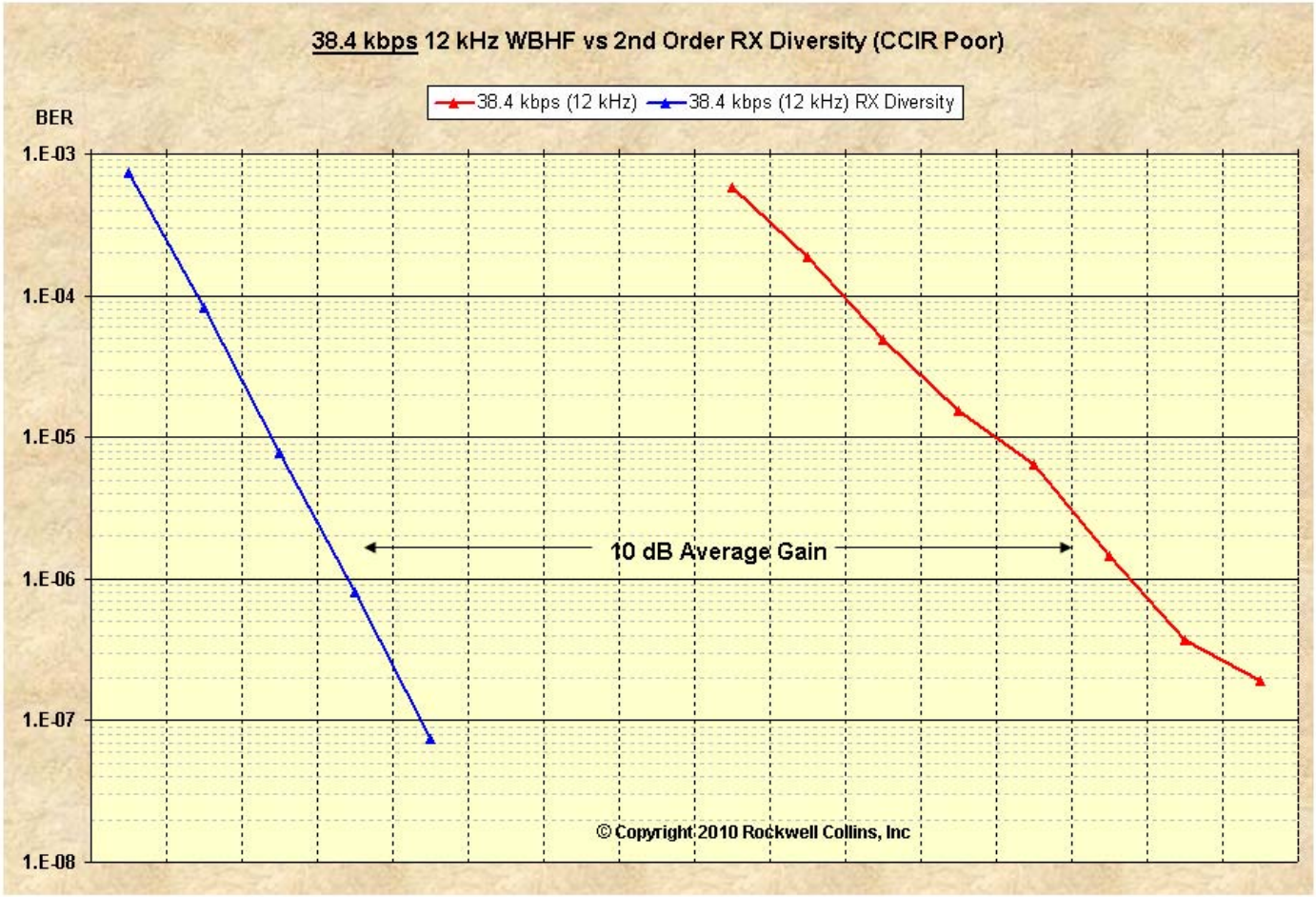
12 kHz WBHF CCIR-Moderate Diversity Gains (32.0 kbps)



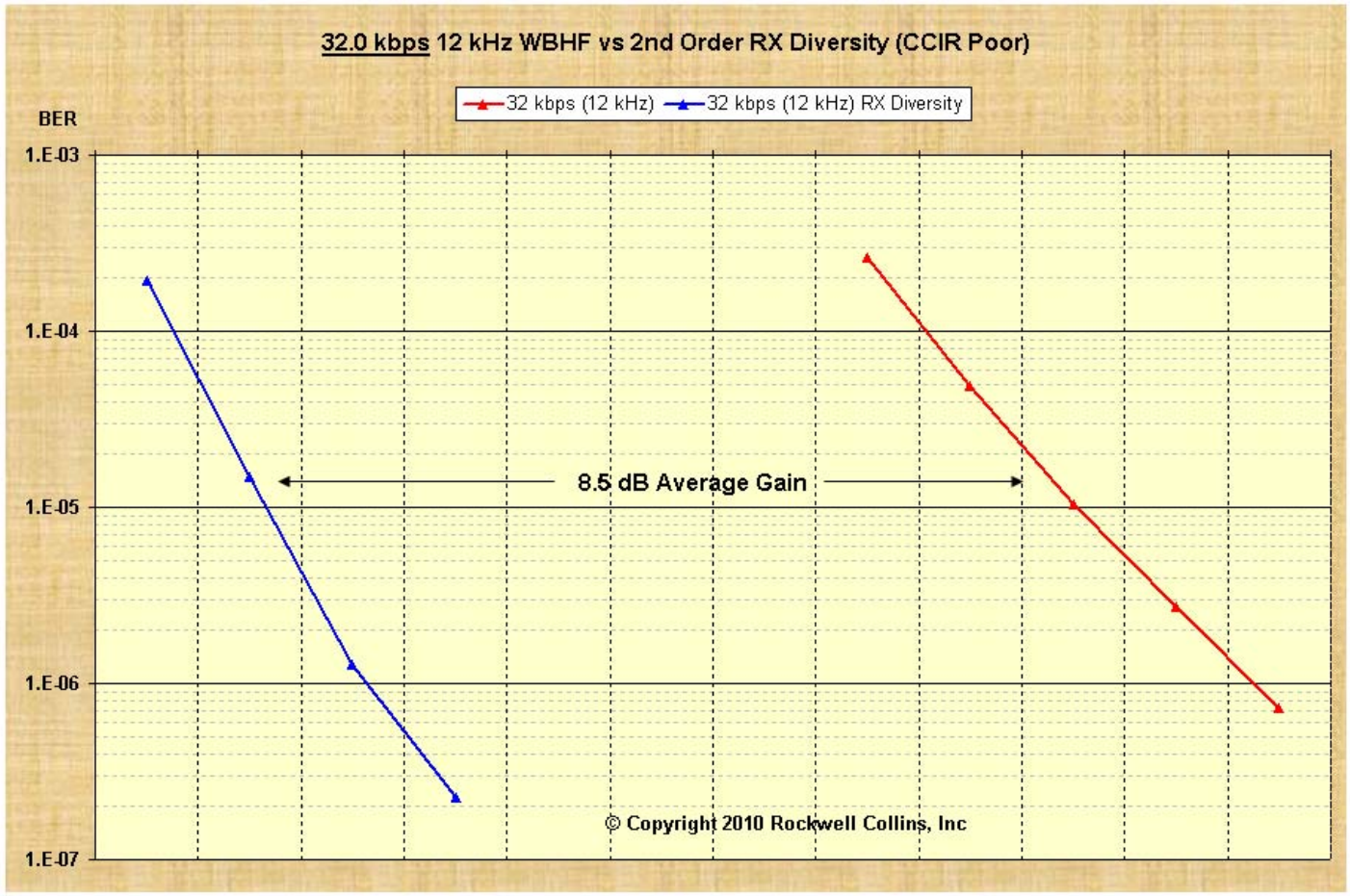
12 kHz WBHF CCIR-Moderate Diversity Gains (38.4 kbps)



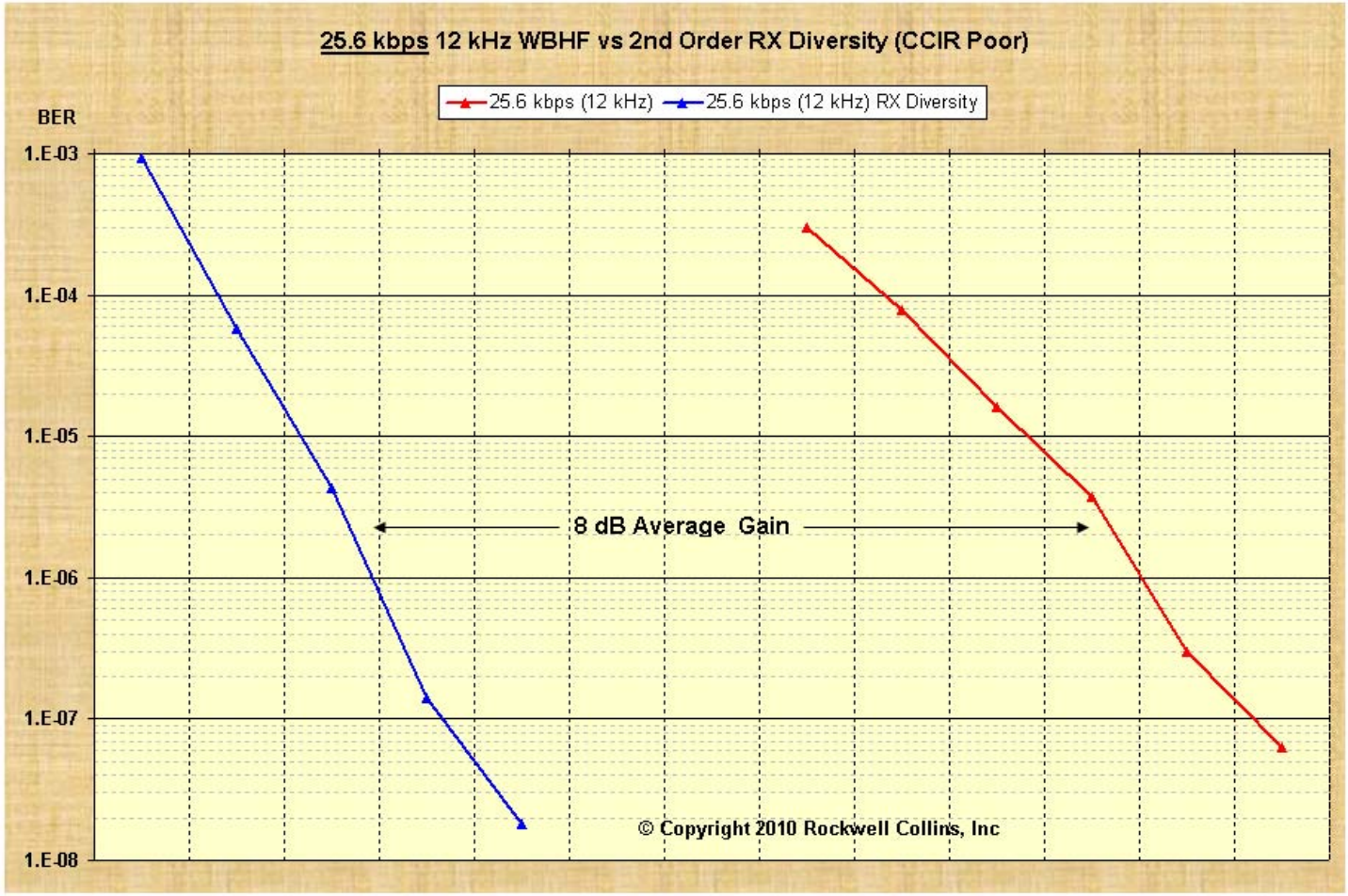
12 kHz WBHF CCIR-Poor Diversity Gains (38.4 kbps)



12 kHz WBHF CCIR-Poor Diversity Gains (32.0 kbps)



12 kHz WBHF CCIR-Poor Diversity Gains (25.6 kbps)



WBHF RX Diversity Simulation Gains Summary

- **Simulated CCIR Poor Diversity Gains (12 kHz)**
  - 10 dB average gain for 64 QAM (38.4 kbps)
  - 8.5 dB average gain for 32 QAM (32.0 kbps)
  - 8 dB average gain for 16 QAM (25.6 kbps)

- **Simulated CCIR Poor Diversity Gains (3 kHz channels)**
  - 6.5 dB average gain for 64 QAM (9.6 kbps)
  - 5.5 dB average gain for 32 QAM (8.0 kbps)
  - 6 dB average gain for 16 QAM (6.4 kbps)

WBHF RX Diversity Simulation Gains Summary

- **Simulated CCIR Moderate Diversity Gains (12 kHz)**
  - 14.5 dB average gain for 64 QAM (38.4 kbps)
  - 13.5 dB average gain for 32 QAM (32.0 kbps)
  - 13 dB average gain for 16 QAM (25.6 kbps)

- **Simulated CCIR Moderate Diversity Gains (3 kHz)**
  - 10.5 dB average gain for 64 QAM (9.6 kbps)
  - 11.5 dB average gain for 32 QAM (8.0 kbps)
  - 10 dB average gain for 16 QAM (6.4 kbps)

WBHF Diversity Combining Performance Gains

QUESTIONS?