Over Air Test Results of Highest Mil-Std-188-110C App D WBHF Waveform Data Rates

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Wideband HF (WBHF) Data Waveform Overview

- New MIL-STD-188-110C Appendix D Data Waveform Suite
  - Comprised of eight data waveforms for eight HF bandwidths, 3 kHz through 24 kHz in 3 kHz bandwidth increments
  - All eight waveforms fully autobaud, 12 to 14 data rates, four interleaver options per waveform
- This discussion focuses upon the 32, 64, and 256 symbol QAM data rates over sky wave WBHF using 24 kHz bandwidths
  - 1320 km link between Cedar Rapids Iowa (US) and Ottawa Canada
  - Impact of PA average output power on high order QAM performance
  - Impact of interleaver lengths (four options) for successful WBHF data transport with larger payloads
    - Long interleaver: 7.68 seconds
    - Medium interleaver: 1.92 seconds
    - Short interleaver: 0.48 seconds
    - Ultra-short interleaver: 0.12 seconds

110C Appendix D 24 kHz Waveform Characteristics

Data Rate (bps)	Modulation Type	Code Rate	Frame Data Symbols	Frame Known Symbols
600	Walsh	1/2	N/A	N/A
1200	BPSK	1/8	272	272
2400	BPSK	1/4	272	272
4800	BPSK	1/3	816	272
9600	BPSK	2/3	816	272
12800	BPSK	3/4	2176	272
25600	QPSK	3/4	2176	272
38400	8PSK	3/4	2176	272
51200	16QAM	3/4	2176	272
64000	32QAM	3/4	2176	272
76800	64QAM	3/4	2176	272
96000	64QAM	8/9	1920	128
120000	256QAM	5/6	1920	128

110C App D QAM Proposed Performance Points

110C Appendix D QAM Performance Specs (24 kHz Band)

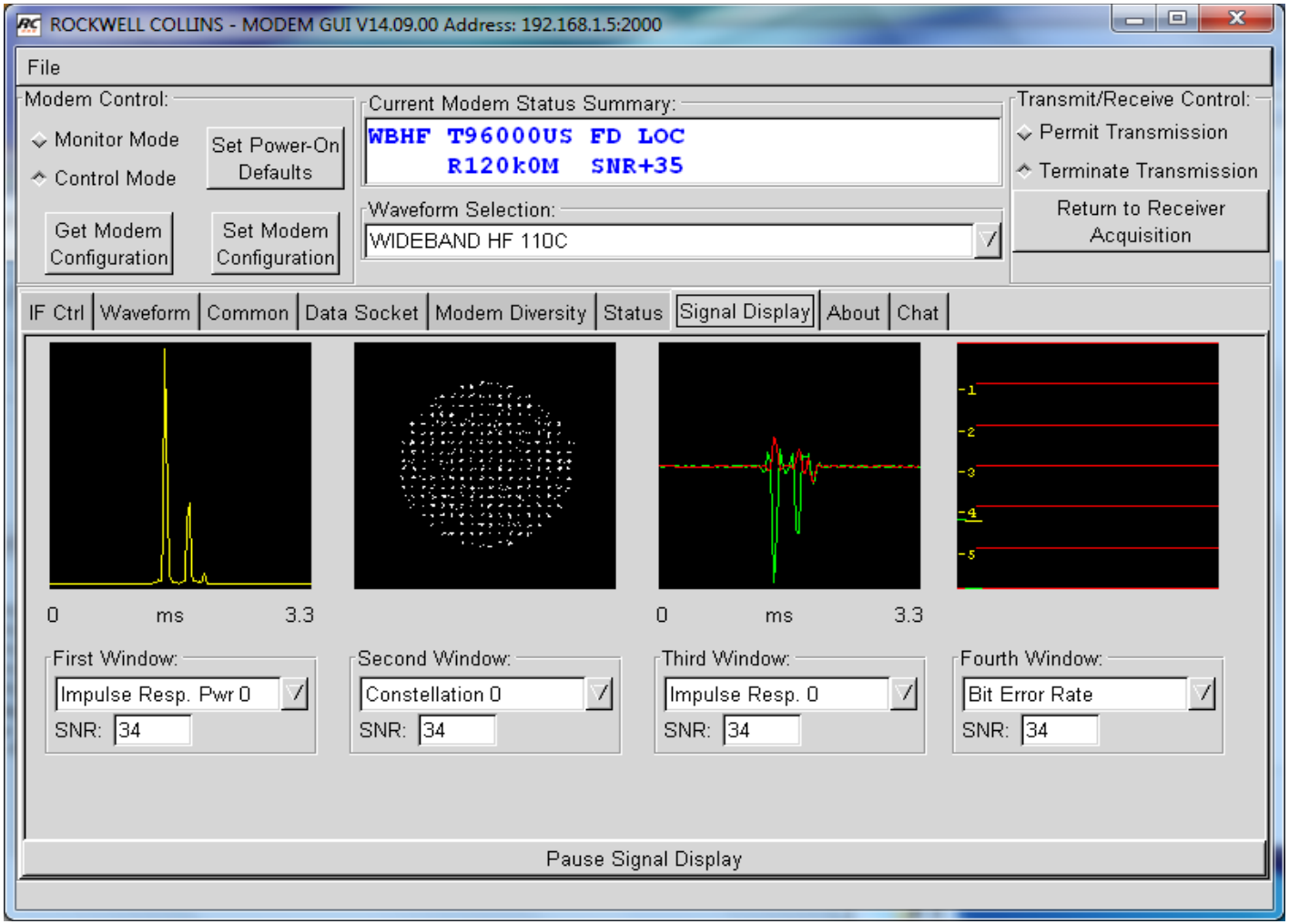
Data Rate (kbps)	Coding Rate	AWGN Channel (SNR)	Minimum BER	"Poor" Channel (SNR)	Minimum BER
51.2 16QAM	3/4	16 dB	1E-5	23 dB	1E-5
64.0 32QAM	3/4	19 dB	1E-5	27 dB	1E-5
76.8 64QAM	3/4	21 dB	1E-5	33 dB	1E-4
96.0 64QAM	8/9	24 dB	1E-5	NA	NA
120.0 256QAM	5/6	30 dB	1E-5	NA	NA

110C App D QAM Performance Comments

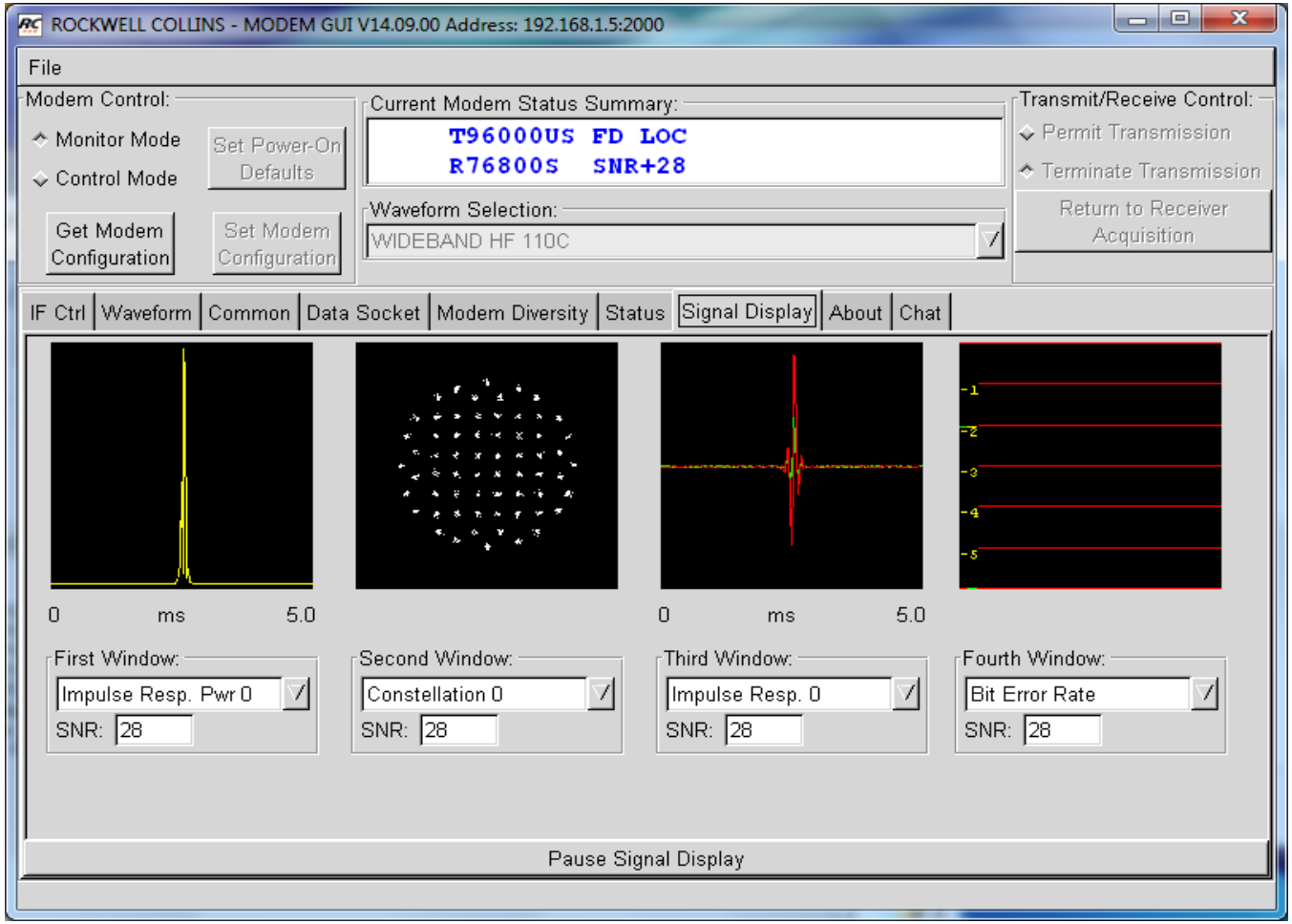
- Note the 256 symbol QAM (120 kbps) and the coding rate 8/9 64 symbol QAM (96 kbps) data rates lack requirements for the CCIR Poor channel
  - These modulations do not perform well using Watterson model channel simulator (CCIR Poor) and are intended for surface wave data transport
  - Actual sky wave over-the-air trials with these data rates suggest they are usable when ionosphere propagation is strong
- 110C Appendix D performance requirements also include static multipath for selected bandwidths, including the 24 kHz channel
  - Three tries, 10 minute duration, less than 1E-5 BER

Data Rate	Static Multipath (msec)	SNR
76.8 kbps	4-Path (0.0, 1.5, 3.0,5.0)	50 dB
120.0 kbps	2-Path (0.0, 1.5)	50 dB

256 QAM: 120 kbps, Iowa->Ottawa (1KW Average Power)



64 QAM: 76.8 kbps, Iowa->Ottawa (62W Average Power)



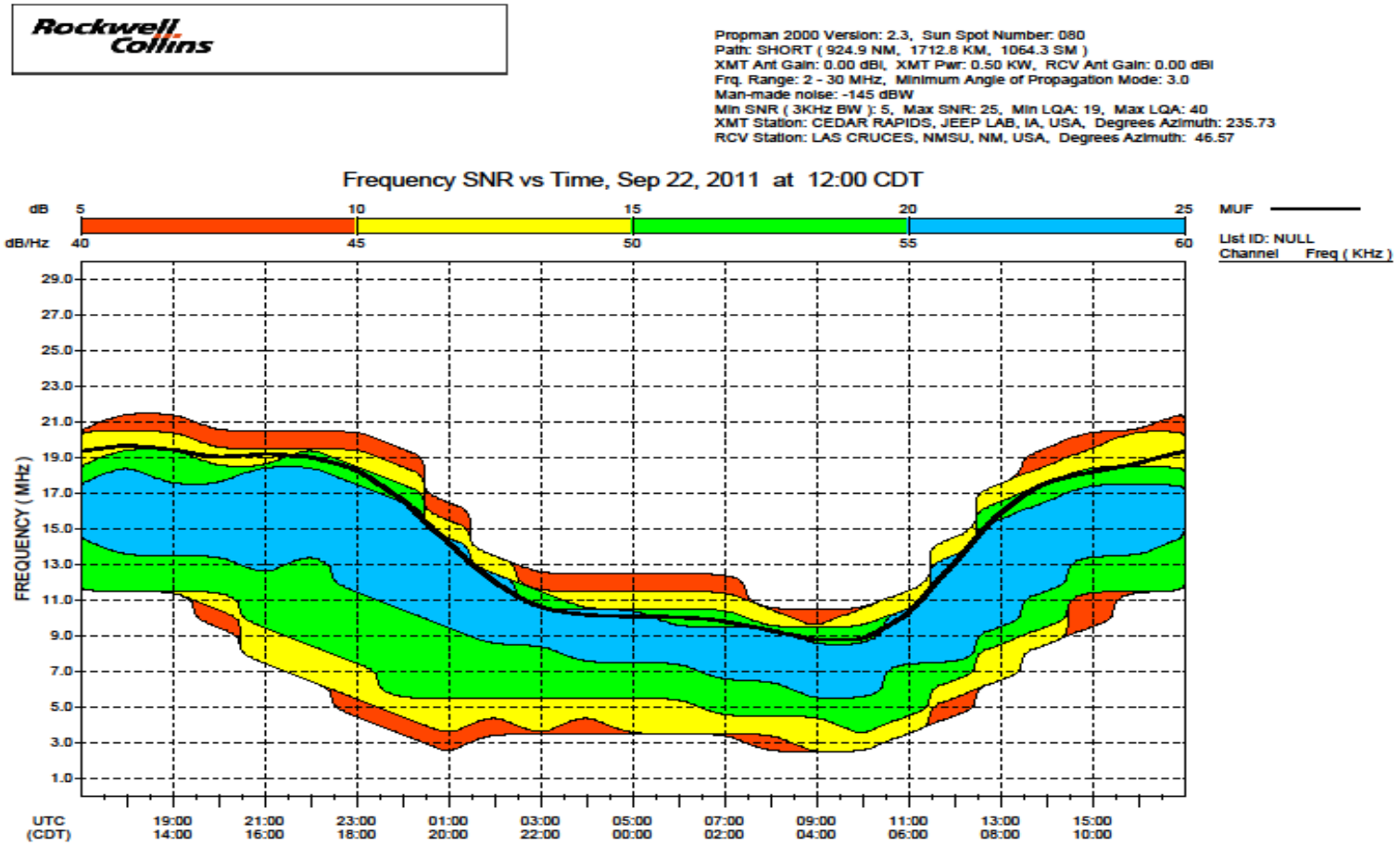
WBHF Over-the-Air Test Bed Details

- Rockwell Collins WBHF Test Environment
  - Modified Rockwell Collins VHSM-5000 Platform
  - Standard Off-The-Shelf Rockwell Collins 1 KW URG III power amplifier
  - Standard Off-The-Shelf Band-pass (co-site) Filter (1U chassis)
  - Data sources: Bit Error Rate Tester (BERT) and H.264 video application scaled for WBHF data rates
- All transmissions from Iowa (USA) to Ottawa Canada
  - Iowa antenna a directional log periodic, Ottawa receive antenna at Communications Research Centre is a sloping V (1320 km link distance)
  - Power amplifier average output power variable from 30 to 1000 watts
  - Transmit frequencies in the 10 MHz to 11 MHz range

WBHF Over-the-Air Pre-Transmission Setup Details

- HF frequency propagation predictions generated daily providing the optimal frequencies based upon time of day in conjunction with transmit and receive station locations
  - Other parameters are used for frequency selection include TX & RX antenna gains, antenna takeoff angles, and local noise floor
  - Propagation prediction plot example in following slide
- Candidate dial frequencies evaluated for presence of energy (existing traffic) within the bandwidth of interest
- Local noise floors are determined and probes are transmitted to characterize channel propagation quality
- The optimal frequency with respect to available bandwidth and channel quality is selected and test trials begin

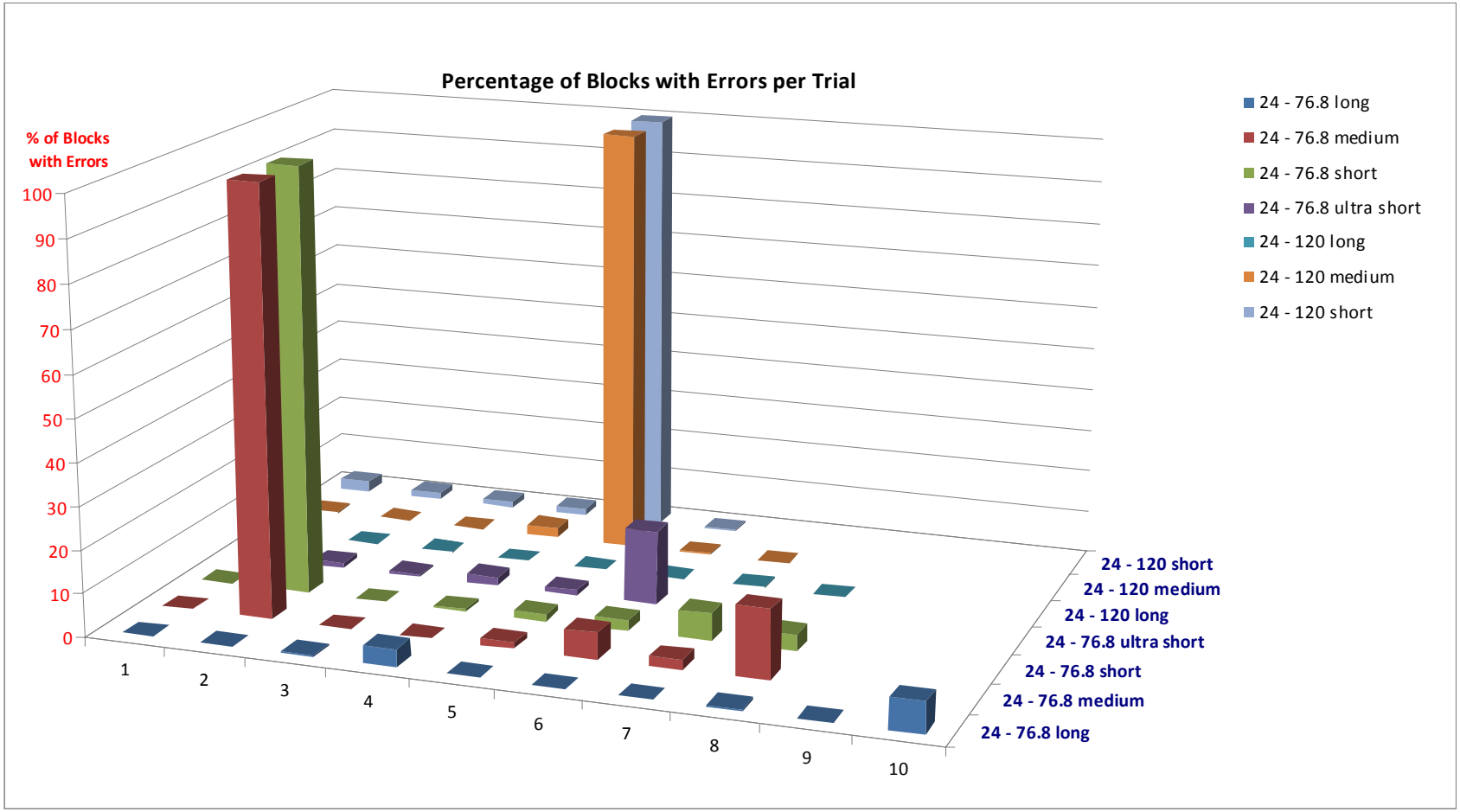
Frequency Propagation Prediction Plot Example



WBHF Block Error Results, varied Interleaver Lengths

- The following slide graphically illustrates the percentage of block errors during 76.8 kbps and 120 kbps transmissions from Iowa to Ottawa
  - Percentage calculated per (blocks with errors)/(total blocks transmitted)
  - Included are two trials with no acquisition, designated by two bars touching the highest horizontal grid line
  - Trials ranged from 10,000 blocks to over 64,000 blocks (1000 bits per block)
  - Data collected during three days of testing (August 31 – September 9, 2011)
- Long interleaver (7.68 seconds) yielded eight trials, out of seventeen total, with no block errors over the duration of the transmission
- Medium interleaver (1.92 seconds) with four of twelve trials having no block errors
- Short interleaver (0.48 seconds) provided surprising results with two of eleven trials with no block errors
- Ultra-short interleaver (0.12 seconds) tests at 76.8 kbps & 120 kbps all had block errors, although only 1% blocks transmitted with PA power greater than 60 watts
- Useful block error rates were observed with all interleavers and with transmitted powers as low as 31 Watts

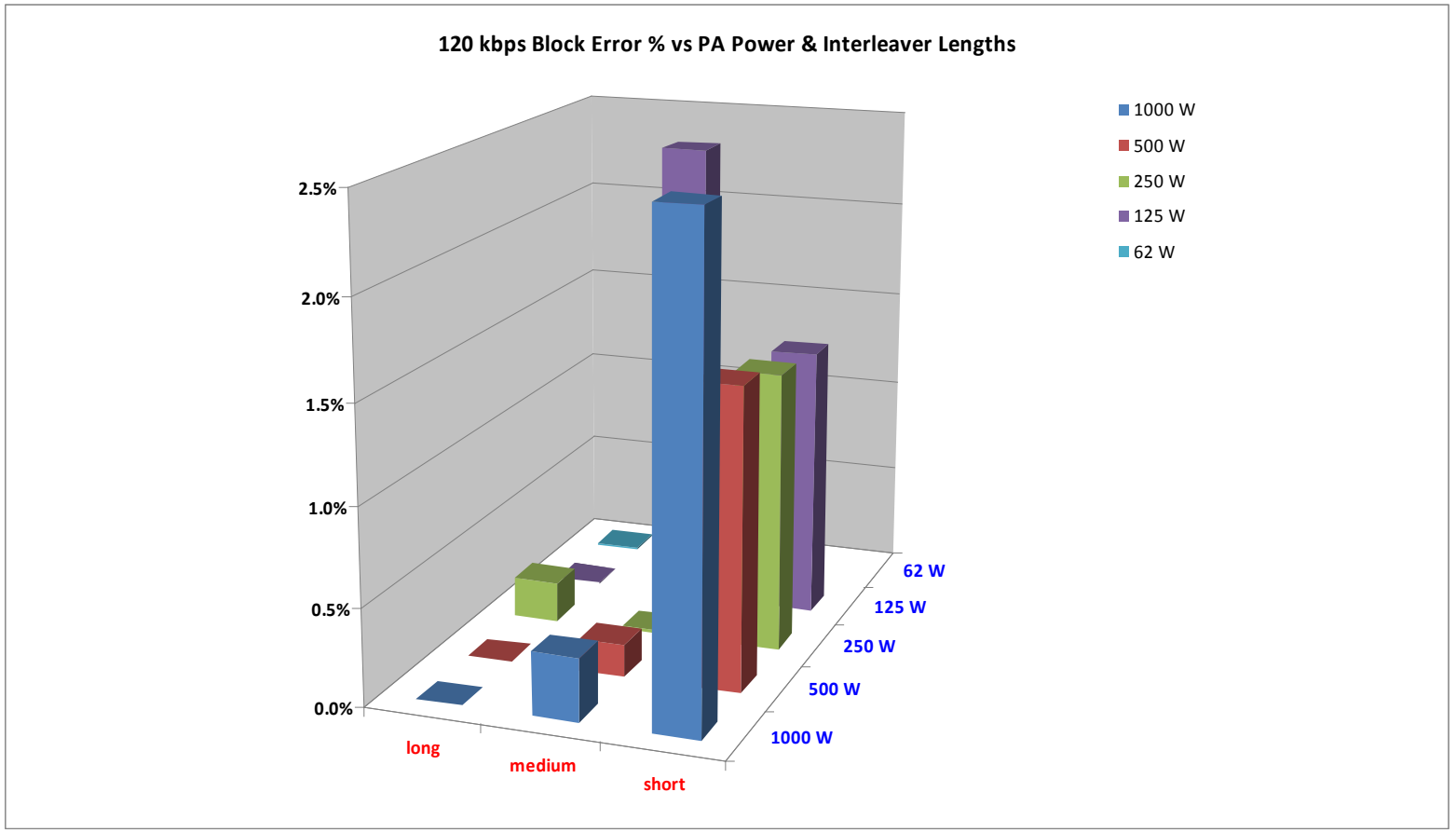
Block Error Percentages per Trial: Iowa -> Ottawa



Block Error % Function of PA Power / Interleaver (120 kbps)

- The following slide graphically illustrates the percentage of errored blocks received versus PA average output power and interleaver length for **120 kbps** data rate
- For the 256QAM rate, the short interleaver (0.48 seconds) percentage of errored block was significantly higher than the longer interleavers regardless of transmitter average power
  - At 62 watts of PA power, a sustained link at 120 kbps with short or ultra-short interleaver not achieved
  - Signal-to-Noise-Ratio (SNR) range over the three days of 120 kbps testing varied from 27 dB up to 44 dB
    - In all cases, SNR postings over 40 dB achieved with 1000 watt average power
  - Multipath during the 120 kbps trials between Iowa and Ottawa was normally less than 0.5 msec, rarely more than two paths, with several examples of no multipath regardless of average RF power levels

120 kbps Block Error % as Function of PA Output Power



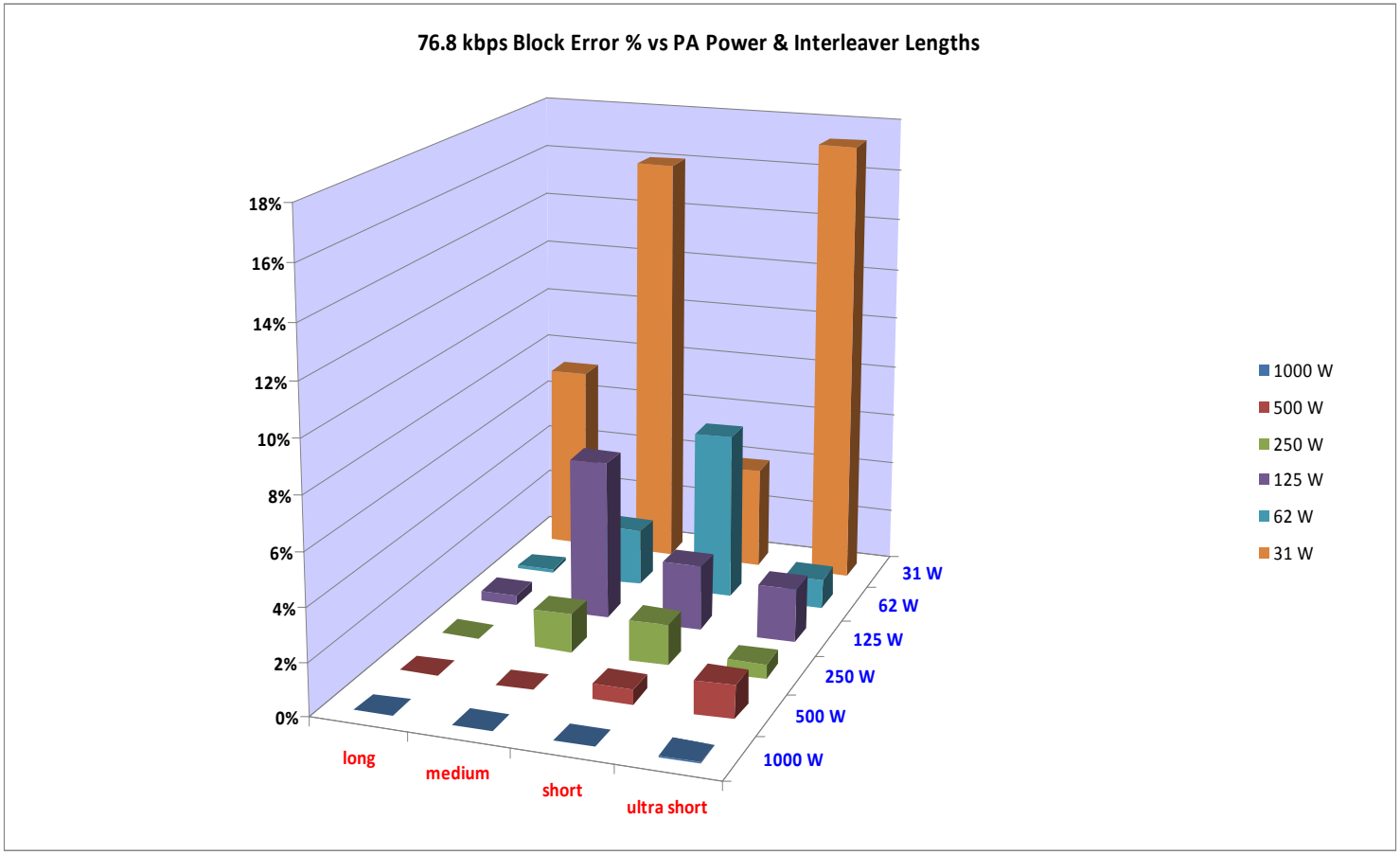
Block Error % as Function of PA Power & Interleavers

- The next slide graphically illustrates the percentage of errored blocks received versus PA average output power and interleaver length for **76.8** kbps data rate (64QAM, rate ¾ coding)

- Sample size for each data point (bar column) combination is small, in many cases a single OTA trial of 10,000 blocks (1000 bits per block) minimum
  - In the coming months, additional trials to be conducted for each interleaver-PA power combination

- As expected, PA power and interleaver lengths important factors in performance metrics
  - Interleaver length requirements of less than one second for power limited platforms will likely limit the use of the highest order QAM data rates on fading sky-wave channels

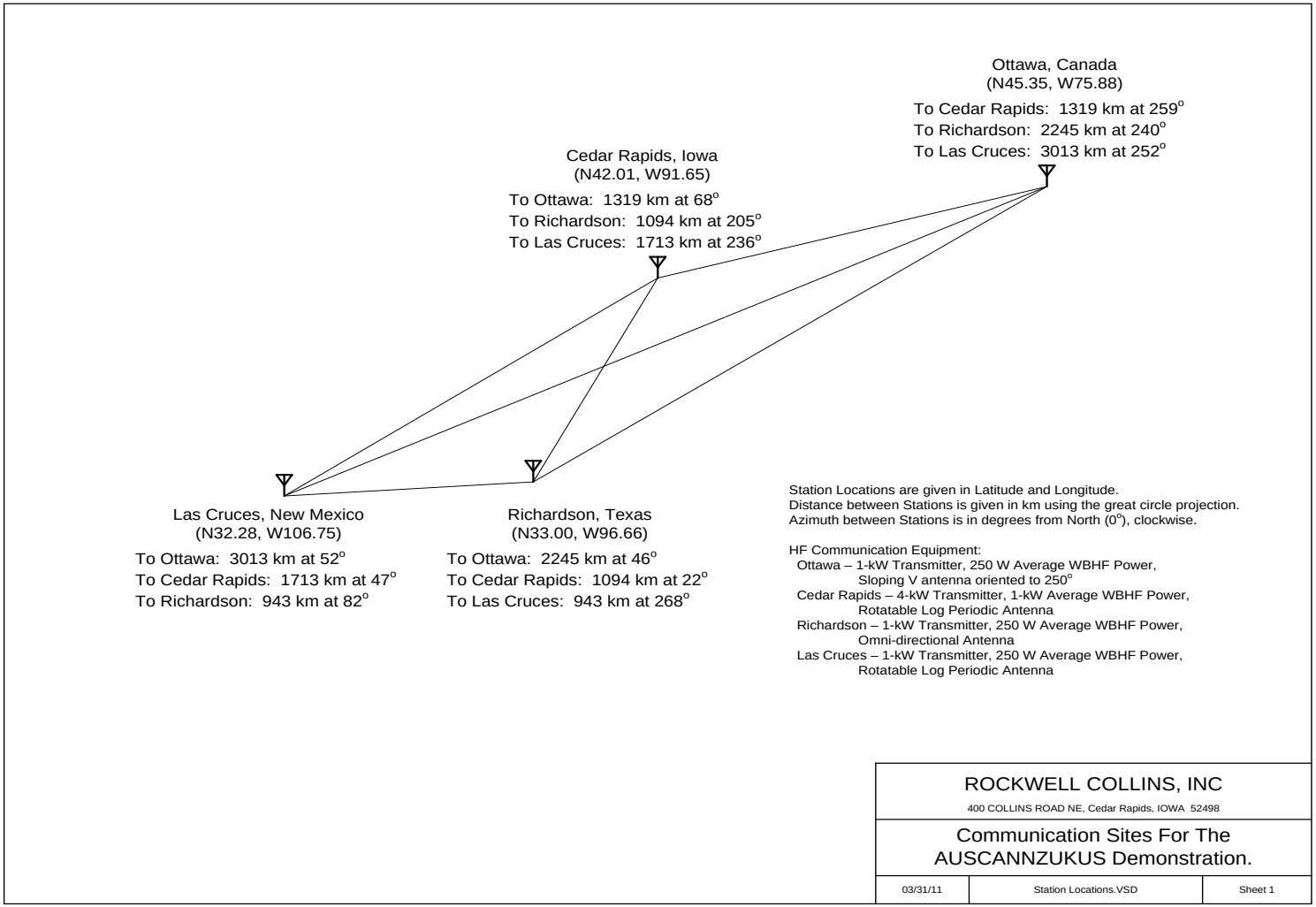
76.8 kbps Block Error % as Function of PA Output Power



WBHF Networking over Sky Wave Circuits

- WBHF participated in the 2011 AUCANNZUKUS (AZ) trials (March) with SPAWAR San Diego facilitating the trials
- Four WBHF fixed site nodes located in Richardson Texas, Las Cruces New Mexico, Cedar Rapids Iowa, and Ottawa Canada participated in trials utilizing sky wave links
- HF bandwidths were limited to 18 kHz due to radio filter width restrictions at the time of the trials
- Primary focus was evaluating the HFIP protocol at higher data rates over sky wave circuits
- Over a two day period, numerous applications were evaluated using HFIP with encouraging results
- The next slide illustrates the locations of the four nodes used in the AZ trials

Node Locations for WBHF AZ Trials (March 2011)



Highlights of WBHF AZ Trials using HFIP

- Two-node HFIP network sky wave link with sustained data rates up to 72 kbps in an 18 kHz channel.
- Four-node HFIP network sky wave link with sustained data rates of 19.2 kbps to 38.4 kbps (18 kHz channel)
  - Some nodes operated at lower data rates with the other nodes operating at the higher data rates.
- Transmission of a FTP server program (FileZilla Server, 1.6 MB in size) over an 18 kHz HF channel using HFIP.
  - Program transferred from Las Cruces to Ottawa (3013 km link)
  - File executed successfully following its reception and installation.
  - Several file type transfers exchanged between the two sites using the FTP server application.
- Demonstrated split-frequency operation with HFIP
  - Operating frequencies optimized for bi-directional transmission

Other WBHF OTA Activities

- Transatlantic WBHF link (6800 km) between Iowa (USA-Rockwell Collins) and Netherlands (MoD: Wim Ketel & Jerry Doms)
  - 12 kHz bandwidth with data rates up to 32 kbps (32QAM)
- Demonstrated full motion-color H.264 video over HF
  - 15 frames per second, frame size scaled to data rate
  - Data rate range from 19.2 kbps to 120 kbps
  - Sustained streaming video at 38.4 kbps (18 kHz band) from New Mexico to Iowa (1700 km) for 75 minutes without sync loss
- Demonstrated WBHF 2nd order receive diversity
  - Iowa to Texas (1100 km) with 250 watt average power
  - Particularly effective for higher order QAM data rates
  - Current processing resources limit diversity combining to 12 kHz bandwidths with 64 kbps the highest data rate

WBHF Studies in the Future

- Collaboration with frequency authorization agencies to determine HF spectrum allocations in support of WBHF
- Future OTA testing will include focus upon shorter interleaver lengths for characterizing networking and ARQ protocol performance
- Establish additional WBHF station nodes for studying performance of node link distances 80 km to 400 km apart
- WBHF performance evaluation of ground and sea wave circuits
- Establish WBHF ALE standards for automating bandwidth, frequency, and data rate selection
- Investigate WBHF performance on airborne platforms

Special Thanks…..

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- Rockwell Collins engineers Brad Butikofer (Iowa), David Church (Iowa), Nick Mailloux (Ottawa), Brent McMillan (Ottawa), and Gary Pepper (Ottawa) for their skillful efforts in selecting frequencies, data collection and, data organization during the WBHF 24 kHz band test trials

Questions, Comments, Suggestions?

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