Application of Spectrum Sensing toward a Wideband HF ALE Solution

William Furman, Eric Koski, John Nieto

Harris Corporation / RF Communications

Presentation overview

- Wideband HF waveforms
- Wideband ALE concept
- The need for spectrum sensing
- Wideband ALE spectrum sensing requirements
- Spectrum sensing prototype
- Spectrum sensing: field test observations
- Contribution to use of wideband HF waveforms
- Caveats
- Conclusions and future work

Wideband HF waveforms

- New appendix in MIL-STD-188-110C that defines
  - Suite of waveforms from 3 kHz to 24 kHz at intervals of 3 kHz
  - Bit rates of 75bps to 120000bps
  - Many modes
    - 8 bandwidths
    - 13 waveform modulations
    - 4 Interleaver settings
    - Adjustable preamble length
- Standard created collaboratively between Harris and Rockwell Collins
- Benefits
  - Higher capacity/throughput when conditions allow
  - More robustness when there is a performance advantage to going with a wider bandwidth and simpler constellation

Wideband ALE concept

- Establish links suitable for use of the wideband waveforms
- Use 3 kHz signaling of existing ALE systems
  - For ease and cost-effectiveness of implementation and adoption
- Must coordinate selection of wider bandwidth to be used for data transmission
  - Waveforms lack any auto-bandwidth capability
- Support adaptive selection of other waveform parameters (modulation, coding)

The need for spectrum sensing

- We can apparently get frequency allocations of up to 24 kHz
- In practice, these are often at least partially occupied
  - Allocations are often provided for use on a ‘non-interfering basis’
- The multiple bandwidths of the WBHF waveform family can allow us to effectively use *part of* an allocated channel
- A spectrum sensing capability would allow us to identify the usable portion of an occupied wideband channel

Precedents for 'spectrum sensing'

- "Listen Before Transmit" has been a feature of the 2G and 3G ALE standards
- In both cases, it's intended for collision avoidance as part of a Media Access Control (MAC) function
- LBT makes a binary determination (busy/not-busy) for an entire 3 kHz channel

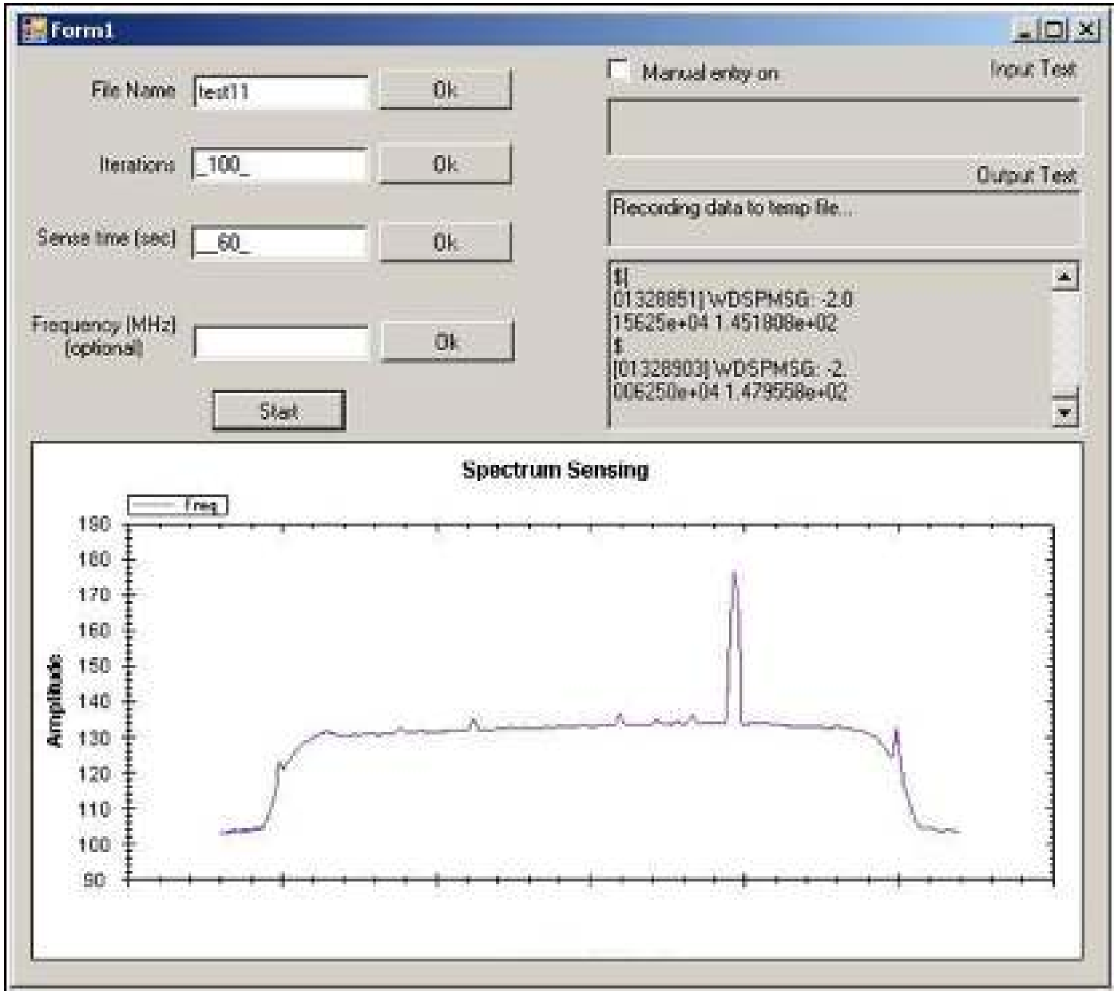
Waveform	AWGN 3 kHz SNR (dB)	Minimum Required Detection Probability
2G-ALE	0	50%
	6	90%
Robust LSU (BW0)	-9	50%
	-6	95%
HDL (BW2)	0	30%
	6	70%
single sideband (SSB) Voice	6	50%
	9	75%
MIL-STD-188-110 or	0	30%
FED-STD-1052 PSK modem	6	70%
STANAG 4285 or	0	30%
STANAG 4529 PSK modem	6	70%

Wideband ALE spectrum sensing requirements

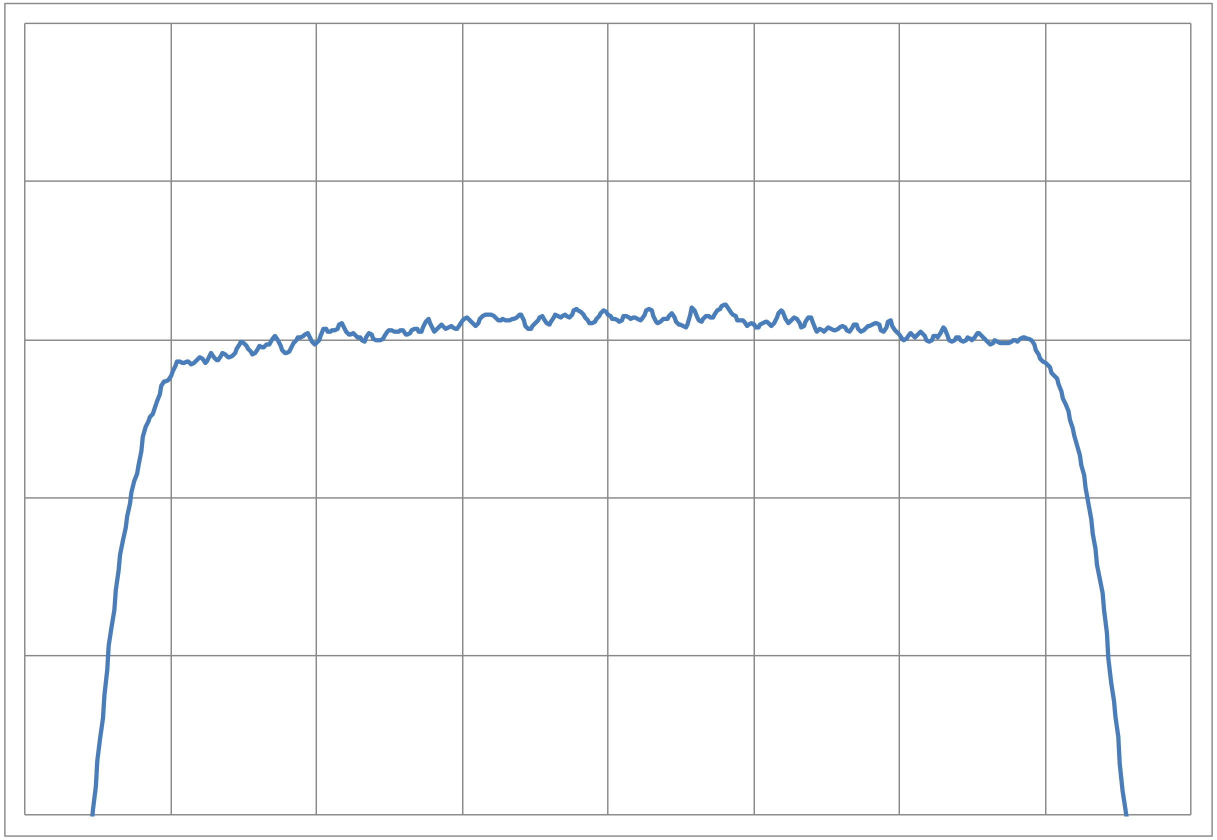
- Capable of examining a band of at least 24 kHz width
- Detect presence of interference in the band that might preclude effective use of the wideband waveforms
- Determine specific frequencies within the band at which interference is present
- Identify a clear sub-band (if present) of the allocated band, within which data transmission can be more effectively achieved
- Support prediction of SNR achievable within a portion of the band, for selection of waveform parameters as part of adaptive selection of modulation and coding
- Be suitable for incorporation into a ‘4G’ ALE protocol
  – Timing characteristics suitable for use while scanning

Spectrum sensing prototype

- Part of the prototype radio system Harris has used for WBHF waveform on-air testing
- Prototype radio is commanded to compute energy spectrum of received RF signal
- Spectrum dumped to PC application for display
- Can compute spectrum while receiving WBHF transmission

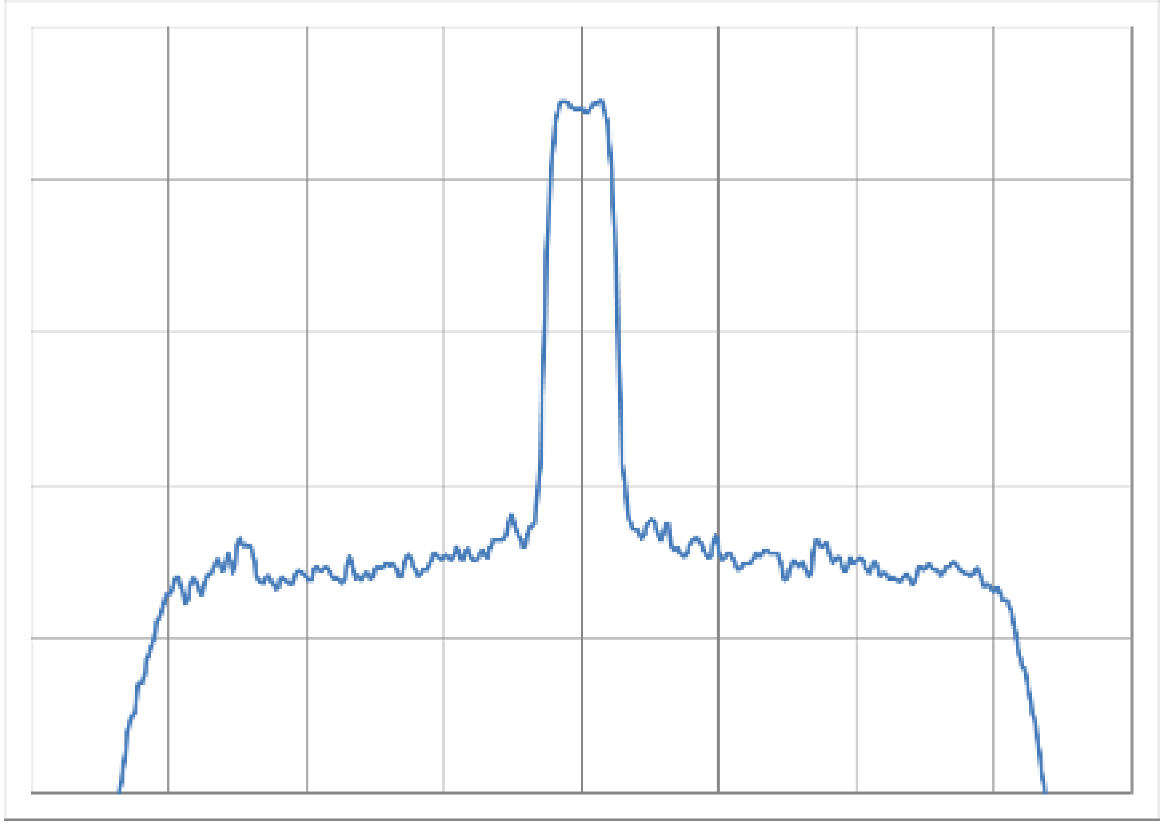


Spectrum sensing field test observations – channel noise floor



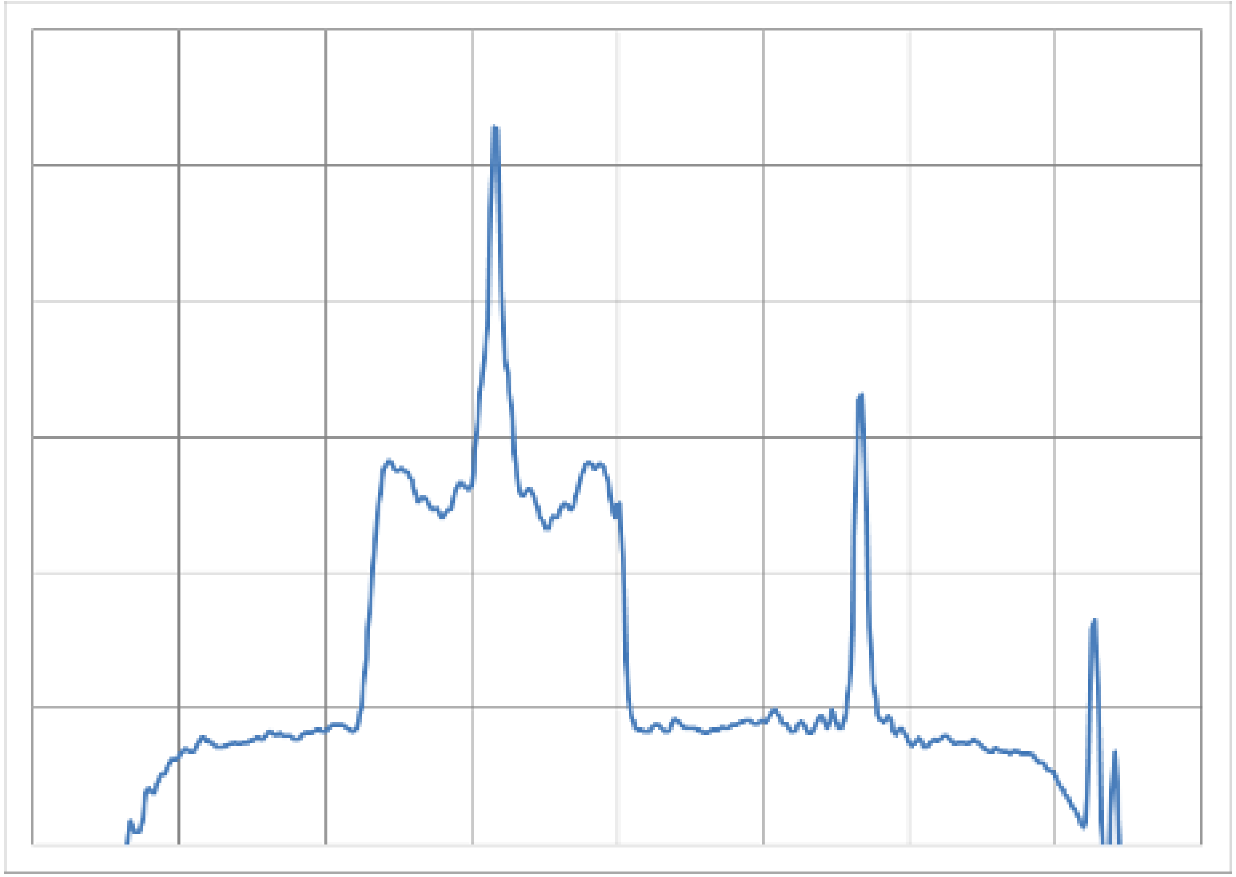
- Channel noise floor without interference

Field test observations – channel noise w/ 3 kHz probe



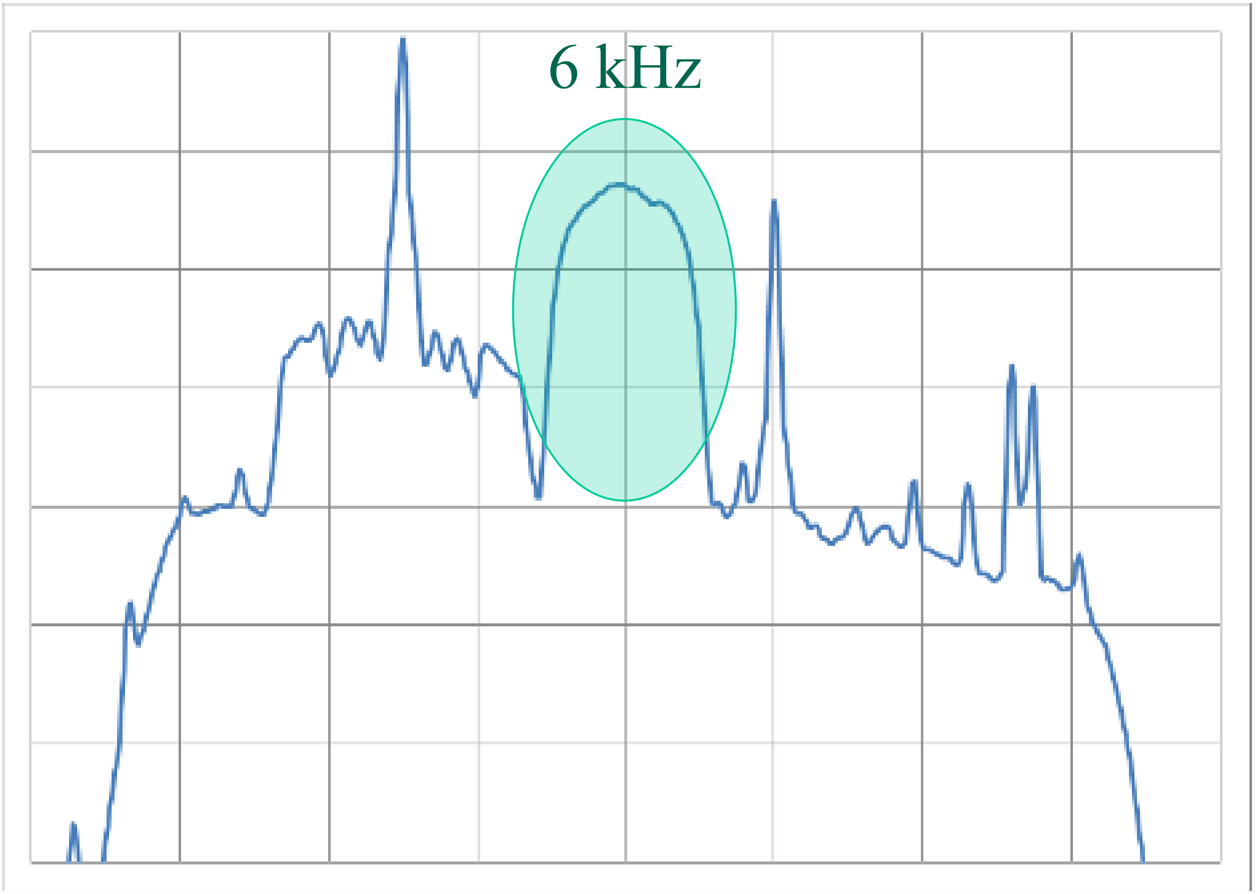
- Visual comparison provides a rough estimate of SNR; adjust for bandwidth to predict SNR with transmissions of different bandwidths – or estimate based on Received Signal Strength measurements

Field test observations – channel interference



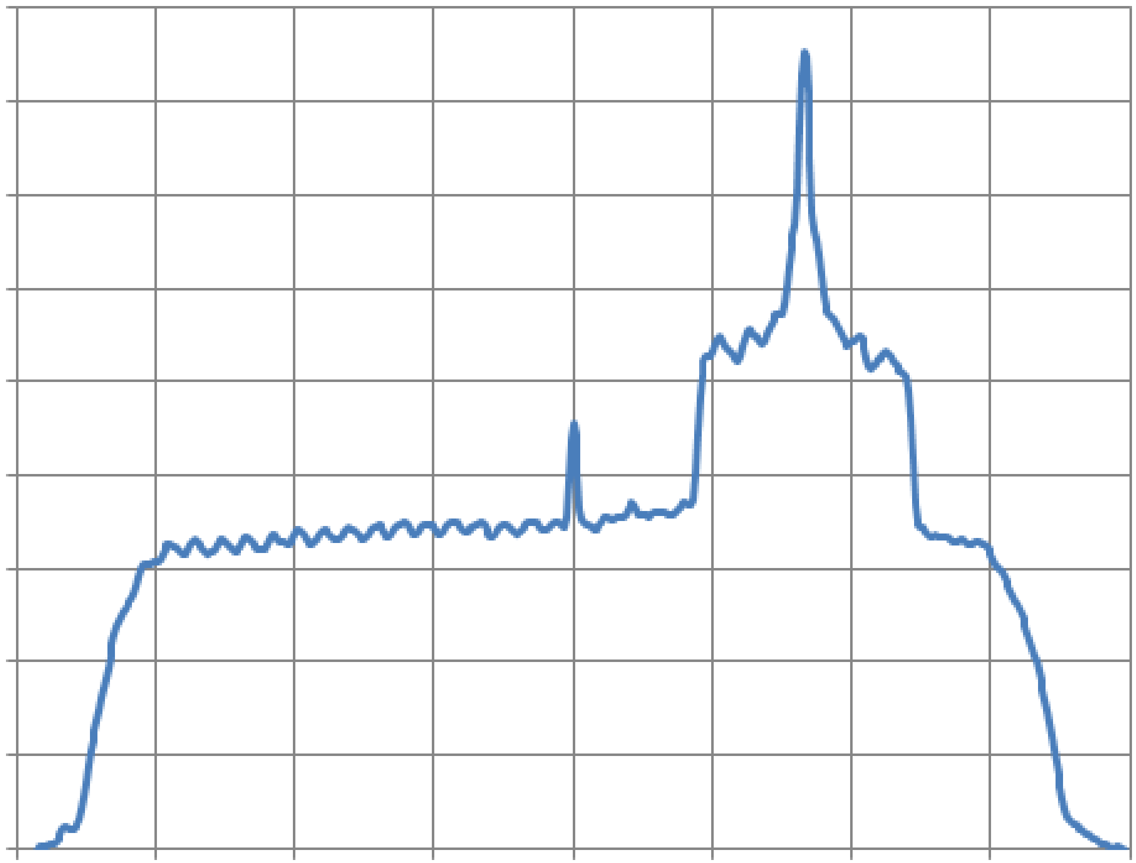
- Prominent AM broadcast interferer with other narrowband interference

Contribution to use of HF wideband waveforms



- Avoiding the AM broadcast interferer allowed us to transmit at 12800 bps error-free

Another interferer ...



- Spectrum sense of assigned frequency 6060
- AM broadcast signal is CFRX 1kW Toronto talk radio AM broadcast
- Modem experienced 50% BER for 24 kHz 64000 bps

... avoided!

- We retuned carrier frequency to 6054, reduced bandwidth to 12kHz
- Achieve error-free data transfer at 32000bps
- Spectrum above shows our signal and the AM broadcast

Caveats

- Need to combine probing with spectrum sensing to be able to predict SNR
- Spectrum sensing for WB-ALE will be subject to the well-known *hidden node problem* (**and** *'exposed node problem'*) affecting media access control protocols
  - May motivate incorporating some sort of cooperative technique …
  - … which might significantly impact the complexity of the ALE protocols …
  - … so it would be great to know how important these problems are for us!

Conclusions and future work

- The introduction of the new HF wideband waveforms will give rise to needs for new ALE capabilities
  - Establish links of different bandwidth in a coordinated manner
  - For a given allocated channel, determine in real time what portion of the allocated band is usable
  - Support adaptive selection of waveform parameters
- The new ALE system will need a spectrum sensing capability having particular features
  - Identify interference-free portion of an allocated wideband channel
  - Provide estimate of achievable SNR
- Harris has developed a prototype of a spectrum sensing capability and demonstrated its utility for WBHF traffic on real-world HF skywave links

- In future work, we hope to
  - Further elaborate the use of spectrum sensing as a component of a wideband ALE solution
  - Further investigate the significance of the spectrum sensing *hidden-node problem* through additional field testing and analysis

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

Mark Jorgenson & Randy Nelson

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

Rockwell Collins

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)

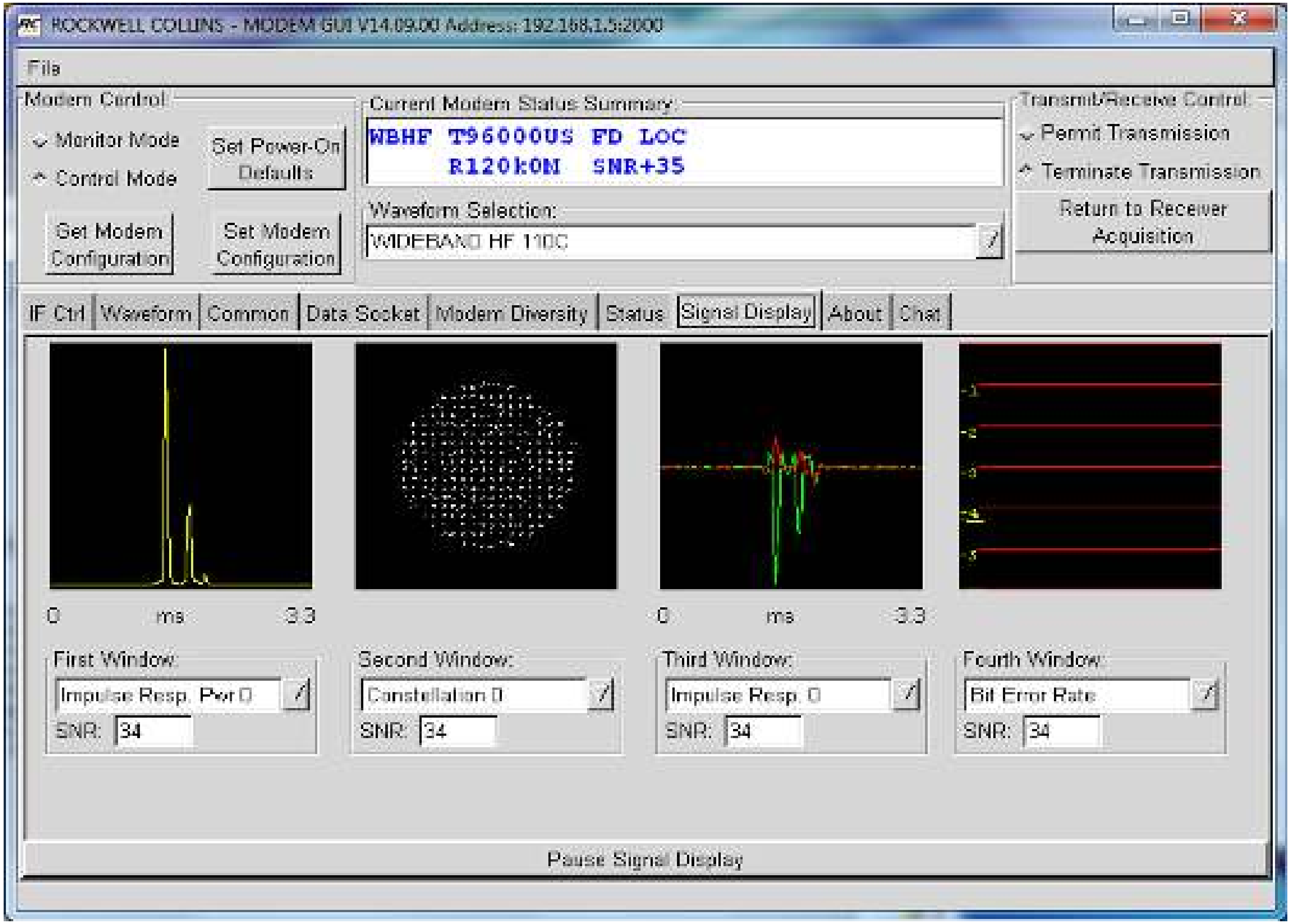
Data Rate (kbps)	Coding Rate	AWGN Channel (SNR)	Minimum BER	"Poor" Channel (SNR)	Minimum BER
51.2 16QAM	3/4	16 dB	1E-5	23 dB	1E-5
64.0 32QAM	3/4	19 dB	1E-5	27 dB	1E-5
76.8 64QAM	3/4	21 dB	1E-5	33 dB	1E-4
96.0 64QAM	8/9	24 dB	1E-5	NA	NA
120.0 256QAM	5/6	30 dB	1E-5	NA	NA

110C App D QAM Performance Comments

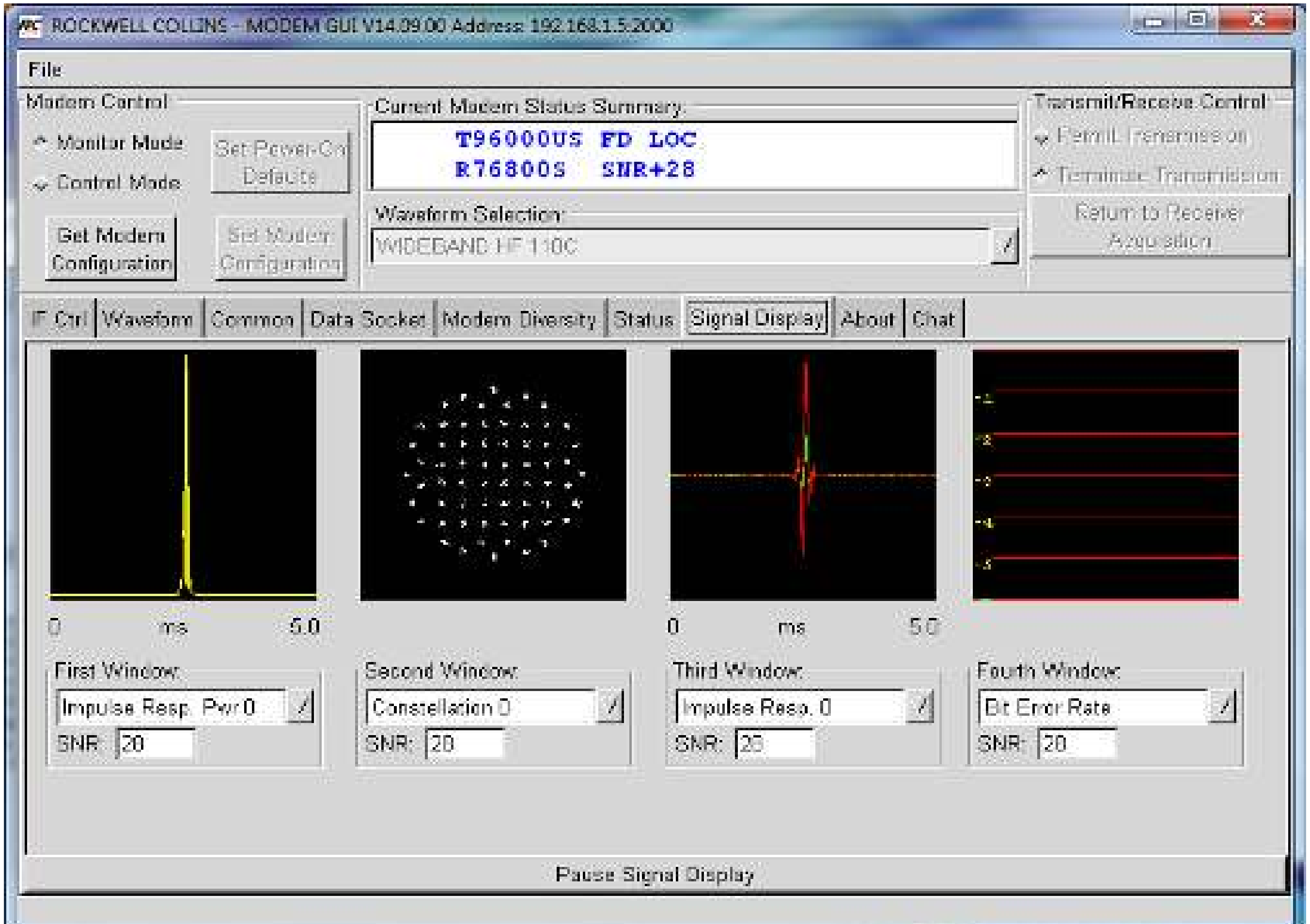
- Note the 256 symbol QAM (120 kbps) and the coding rate 8/9 64 symbol QAM (96 kbps) data rates lack requirements for the CCIR Poor channel
  - These modulations do not perform well using Watterson model channel simulator (CCIR Poor) and are intended for surface wave data transport
  - Actual sky wave 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

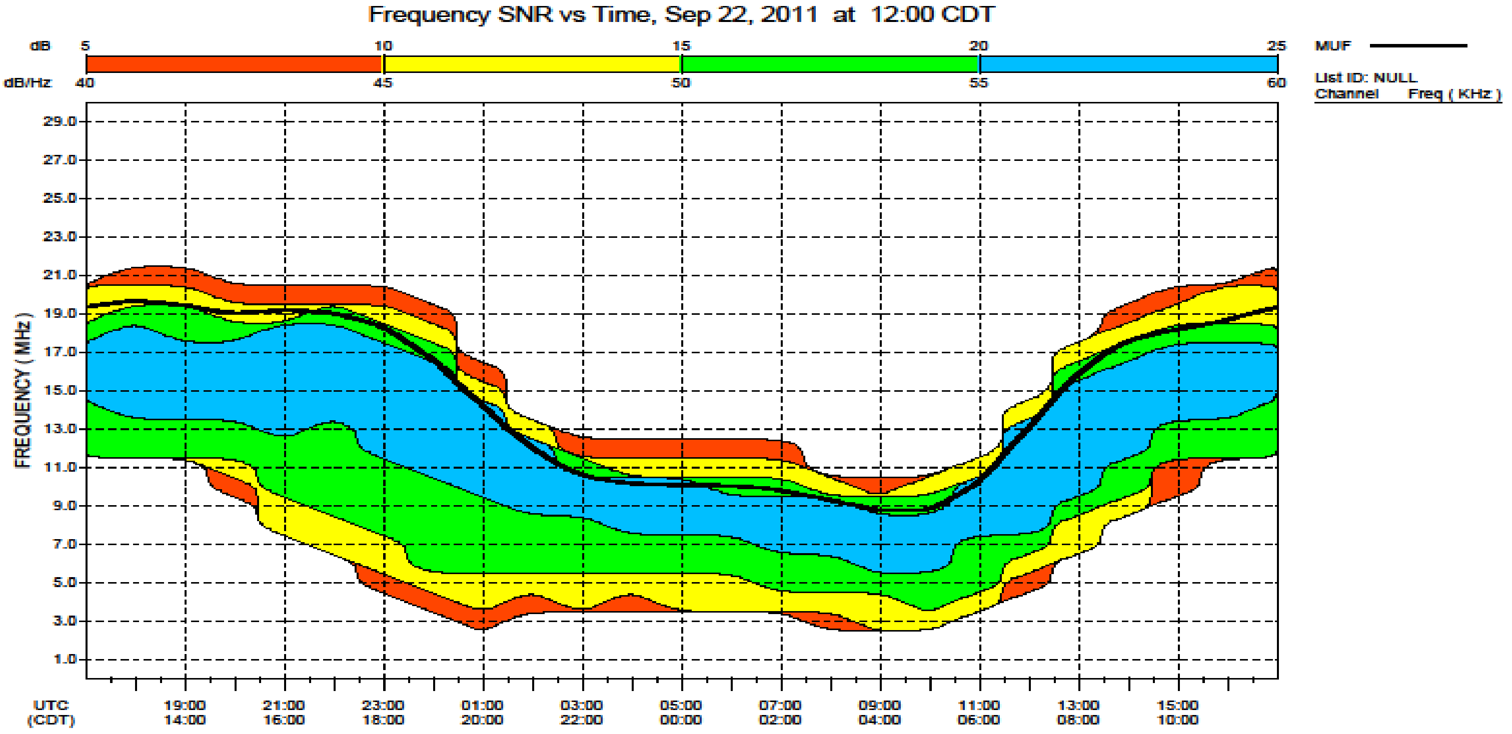
- Rockwell Collins WBHF Test Environment
  - Modified Rockwell Collins VHSM-5000 Platform
  - Standard Off-The-Shelf Rockwell Collins 1 KW URG III power amplifier
  - Standard Off-The-Shelf Band-pass (co-site) Filter (1U chassis)
  - Data sources: Bit Error Rate Tester (BERT) and H.264 video application 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

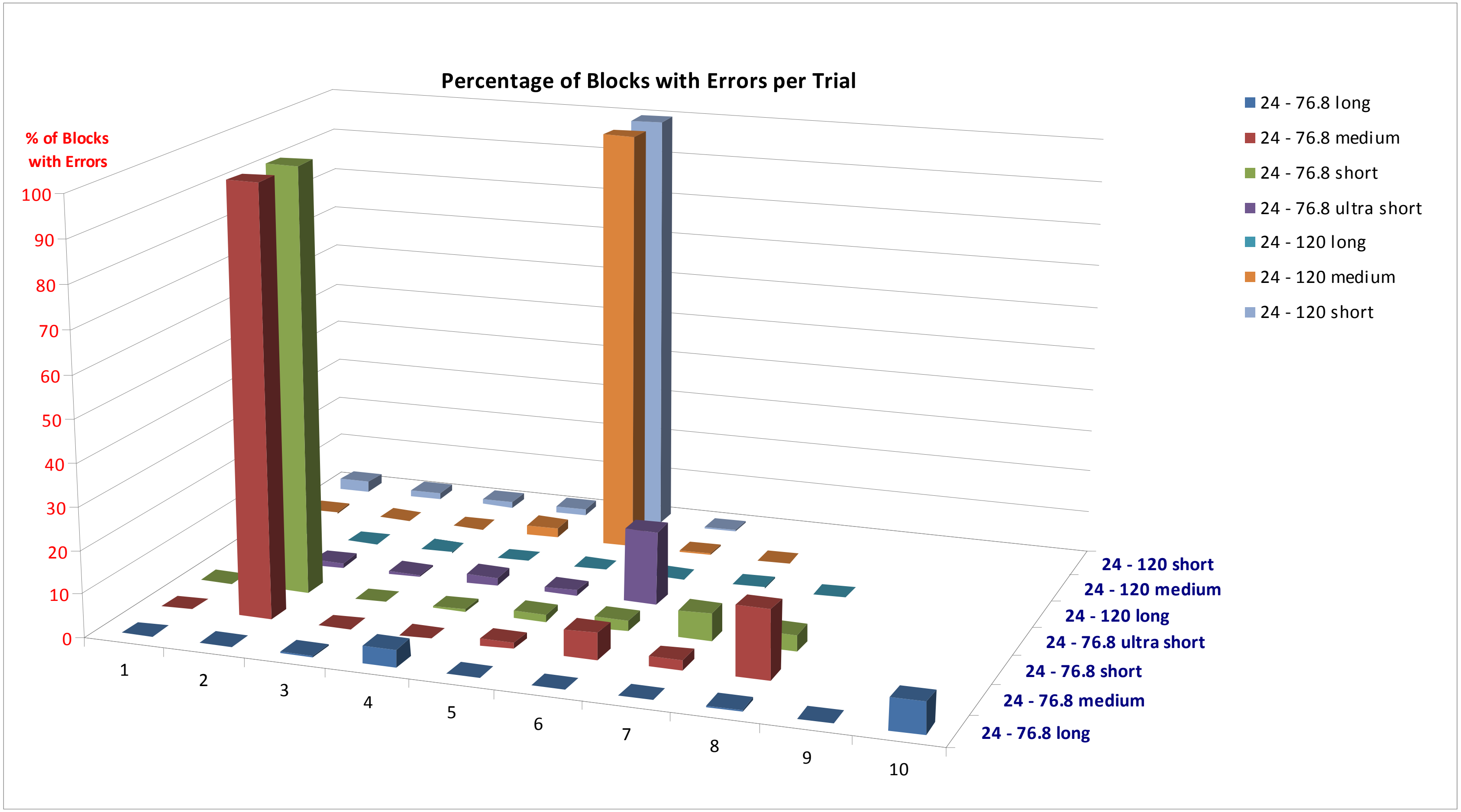
Propman 2000 Version: 2.3, Sun Spot Number: 080
Path: SHORT (924.9 NM, 1712.8 KM, 1064.3 SM)
XMT Ant Gain: 0.00 dBi, XMT Pwr: 0.50 KW, RCV Ant Gain: 0.00 dBi
Frq. Range: 2 - 30 MHz, Minimum Angle of Propagation Mode: 3.0
Man-made noise: -145 dBW
Min SNR (3KHz BW): 5, Max SNR: 25, Min LQA: 19, Max LQA: 40
XMT Station: CEDAR RAPIDS, JEEP LAB, IA, USA, Degrees Azimuth: 235.73
RCV Station: LAS CRUCES, NMSU, NM, USA, Degrees Azimuth: 46.57



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

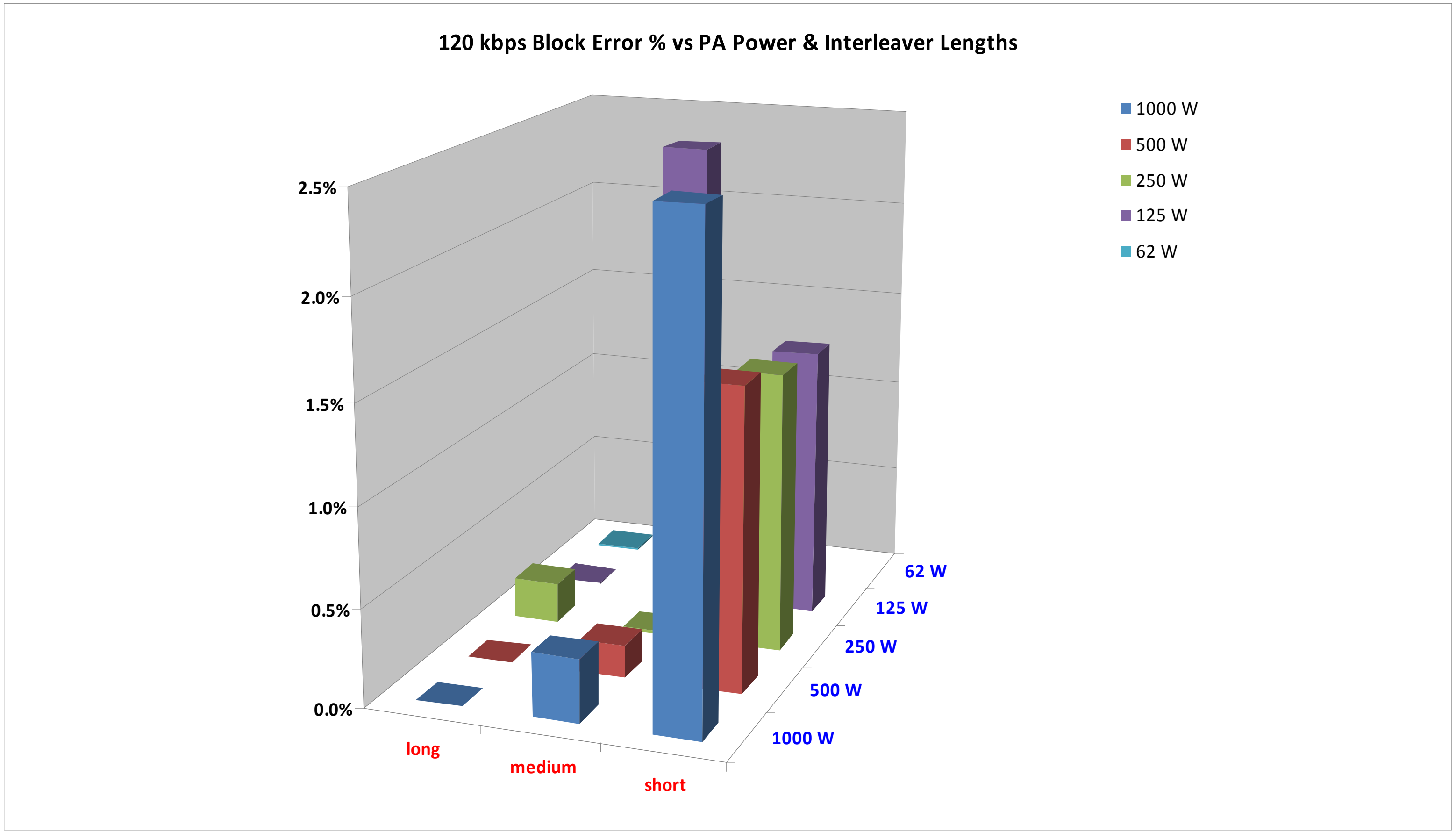
Block Error Percentages per Trial: Iowa -> Ottawa



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



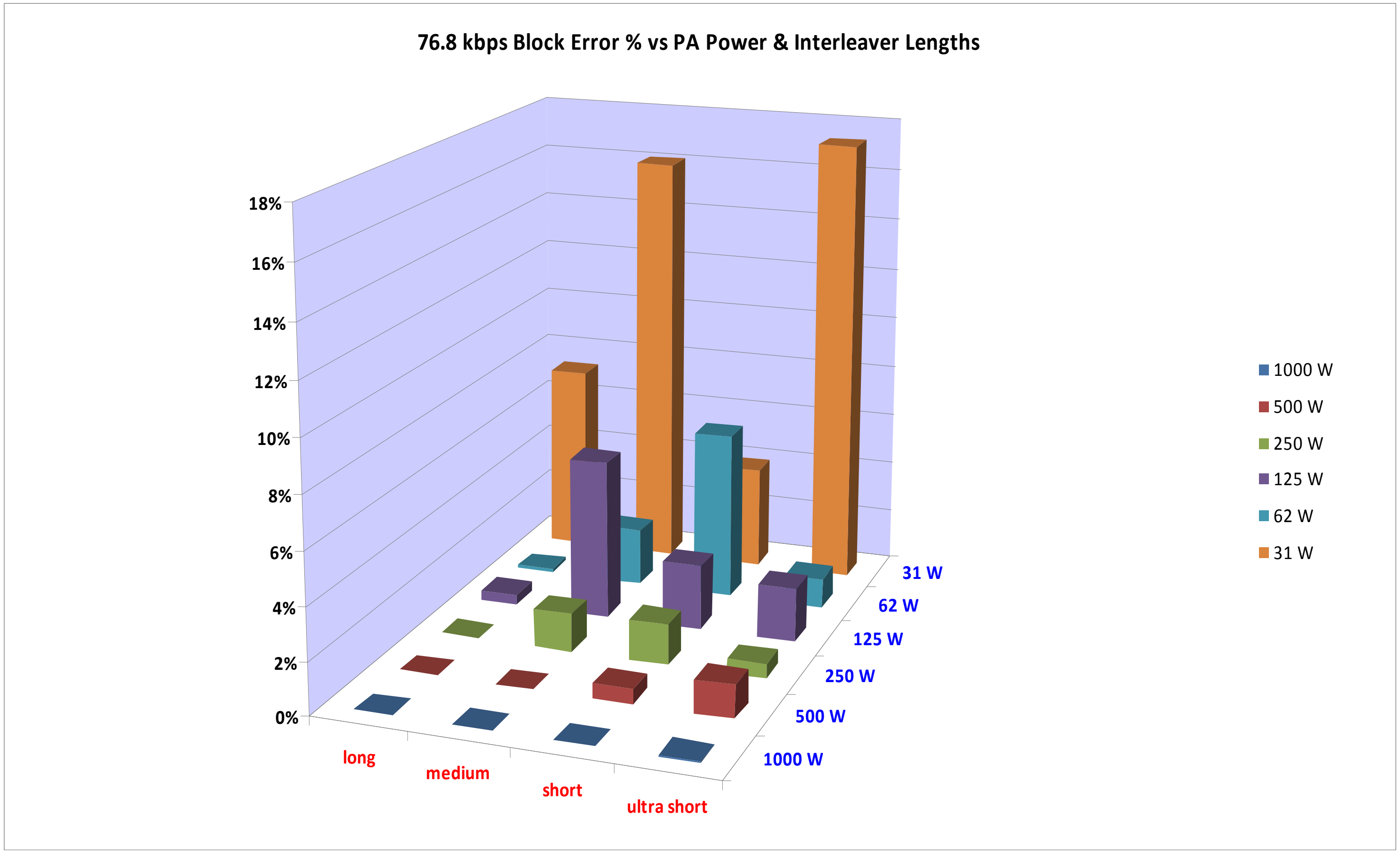
Block Error % as Function of PA Power & Interleavers

- 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

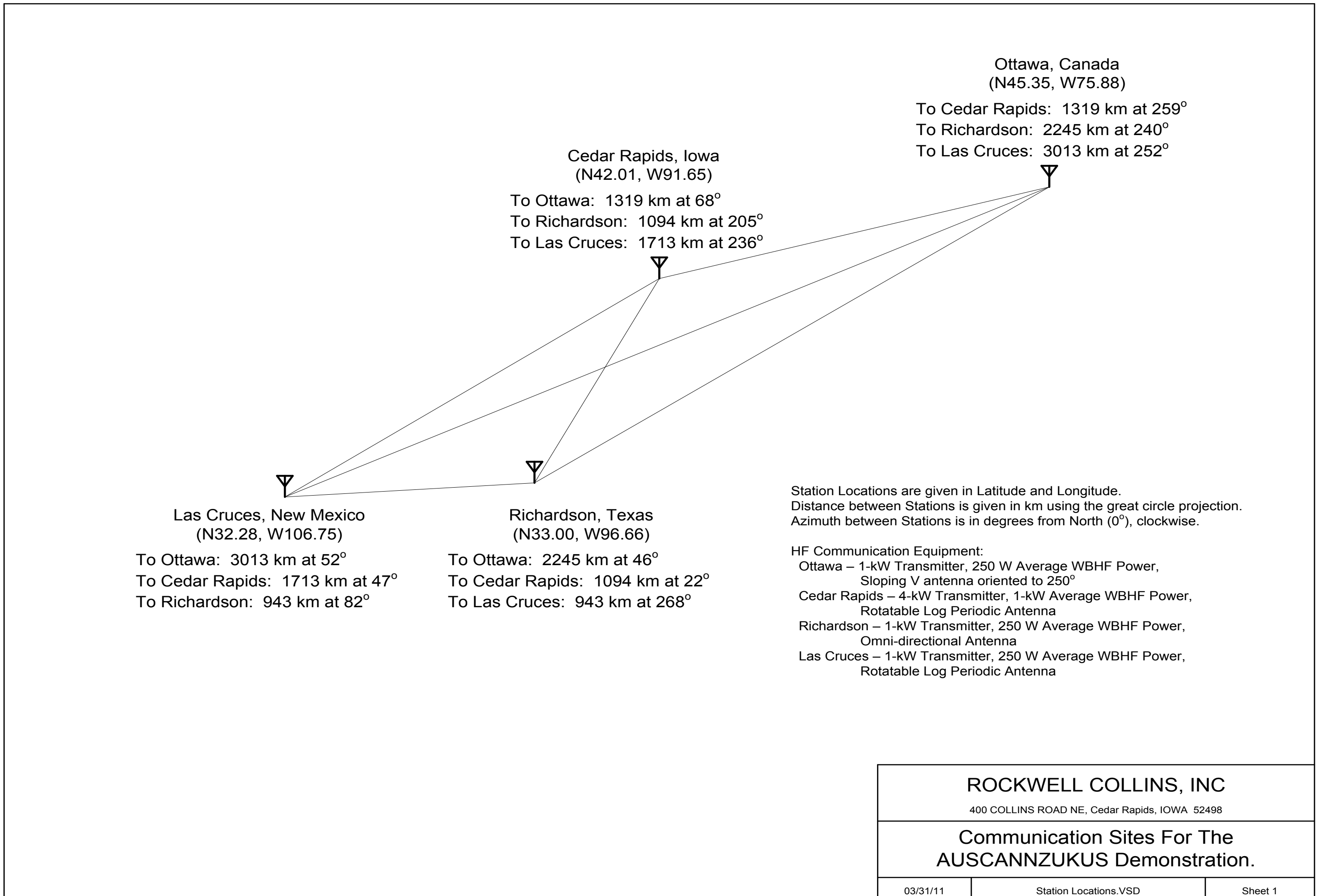
76.8 kbps Block Error % as Function of PA Output Power



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.....

- Communications Research Centre (CRC) in Ottawa for support and the use of their HF antennas
- 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?

?

Summary of Wideband HF On-Air Testing for Calendar Year 2011

Authors: William N. Furman, Eric N. Koski, John W. Nieto

Presenter: John W Nieto

Overview

- Background
- US MIL-STD-188-110C Wideband HF (WBHF) Data Modem
- Summary of on-air testing for calendar year 2011
  - Goals
  - Equipment
  - Link Details
  - Test Procedure
  - Test Results
- Conclusions

Background

- US MIL-STD-188-110B has been updated to US MIL-STD-188-110C
  - New revision includes Appendix D defining a wideband HF (WBHF) data modem with bandwidths of 3, 6, 9, 12, 15, 18, 21 and 24 kHz
    - 13 different waveforms for 3 kHz
    - 12 different waveforms for all other bandwidths
- Harris has implemented a prototype of the new wideband data modem that is fully compliant with Appendix D
- Harris has performed on-air testing over a 167 km East to West Near Vertical Incidence Skywave (NVIS) path between Rochester, NY and Stockbridge, NY
- Harris has performed on-air testing over a 1700 km North to South link between Rochester, NY and Melbourne, FL

US MIL-STD-188-110C WBHF Data Modem

- Standard defines a point to point HF data modem without any ARQ or ALE functionality
- General design is very similar to the serial tone modems of 110B
  - Symbol rate is increased as bandwidth increases
  - Known/Unknown ratio adjusted to preserve good Doppler spread and multipath spread performance
  - Convolutional FEC rate adjusted to provide convenient data rates supported by DTE interfaces
  - Rounded constellations for good peak power to average power properties (i.e. 16-QAM, 32-QAM, 64-QAM, 256-QAM)
  - A low rate Walsh mode is defined, similar to STANAG 4415 waveform
  - Robust preamble defined, in bandwidth of data

US MIL-STD-188-110C WBHF Data Modem

- Bandwidth, modulation, bit rate options

WID	3 kHz	6 kHz	9 kHz	12 kHz	15 kHz	18 kHz	21 kHz	24 kHz
0 - Walsh	75	150	300	300	300	600	300	600
1 - 2-PSK	150	300	600	600	600	1200	600	1200
2 - 2-PSK	300	600	1200	1200	1200	2400	1200	2400
3 - 2-PSK	600	1200	2400	2400	2400	4800	2400	4800
4 - 2-PSK	1200	2400	-	4800	4800	-	4800	9600
5 - 2-PSK	1600	3200	4800	6400	8000	9600	9600	12800
6 - 4-PSK	3200	6400	9600	12800	16000	19200	19200	25600
7 - 8-PSK	4800	9600	14400	19200	24000	28800	28800	38400
8 - 16-QAM	6400	12800	19200	25600	32000	38400	38400	51200
9 - 32-QAM	8000	16000	24000	32000	40000	48000	48000	64000
10 - 64-QAM	9600	19200	28800	38400	48000	57600	57600	76800
11 - 64-QAM	12000	24000	36000	48000	57600	72000	76800	96000
12 - 256-QAM	16000	32000	48000	64000	76800	90000	115200	120000
13 - 4-PSK	2400	-	-	-	-	-	-	-

- Two major real time optimizations available
  - If conditions and SNR allow it, increase bandwidth to achieve higher data rates
  - If conditions are marginal, increase bandwidth and reduce modulation complexity to achieve same data rate with increased robustness
    - Most effective when modulation complexity used in marginal condition utilizes 8-PSK or higher

Goals of On-Air Testing

- Goals:
  - Test and evaluate operation of a fully compliant implementation of the new wideband HF data modem defined in US MIL-STD-188-110C Appendix D
  - Gain experience operating a wideband HF system over a short range NVIS path (167 km), representative of tactical military links
  - Gain experience operating a wideband HF system over a long range link (1700 km), representative of strategic military links

Equipment for NVIS Link

Rochester, New York	Stockbridge, New York
Harris RF-5800H man-pack radio system	Harris RF-5800H man-pack radio system
Harris RF-5834 400 Watt mobile power amplifier, typical transmit power 200 Watts average power.	Harris RF-5833 150 Watt power amplifier Harris RF-382 coupler Harris RF-5245 pre / post selector
Harris prototype wideband HF System	Harris prototype wideband HF System
Radiant Broadband Dipole	Harris RF-1912 antenna

Equipment for 1700 km Link

Rochester, New York	Melbourne, Florida
Harris RF-5800H man-pack radio system	Harris RF-5800H man-pack radio system
Harris RF-5834 400 Watt mobile power amplifier, typical transmit power 200 Watts average power.	Harris RF-5833 150 Watt power amplifier
Harris prototype wideband HF System	Harris prototype wideband HF System
Log-Periodic Antenna	Log-Periodic Antenna

Test Procedure

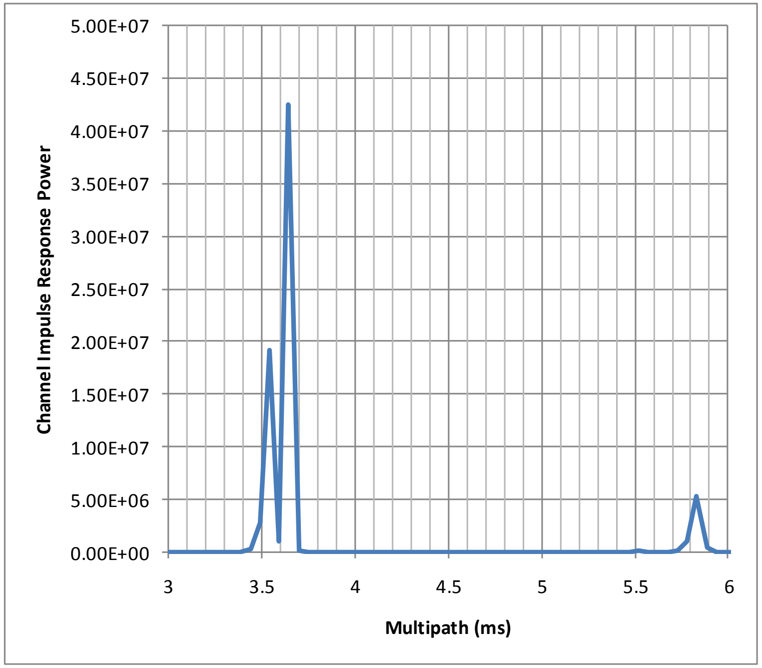
- 3G ALE LQA performed between RF-5800H systems
- Channel selected based on SNR, multipath, fading
- Spectrum Sensing performed, Bandwidth and offset selected
- (Rochester) RF-5800H keyed, input to 400 W PA disconnected from RF-5800H, connected to prototype wideband transmitter
- RX Antenna feed connected to wideband receiver
- BER, 1000 bit PER, and channel characteristics recorded.
- Test repeated with periodic LQAs

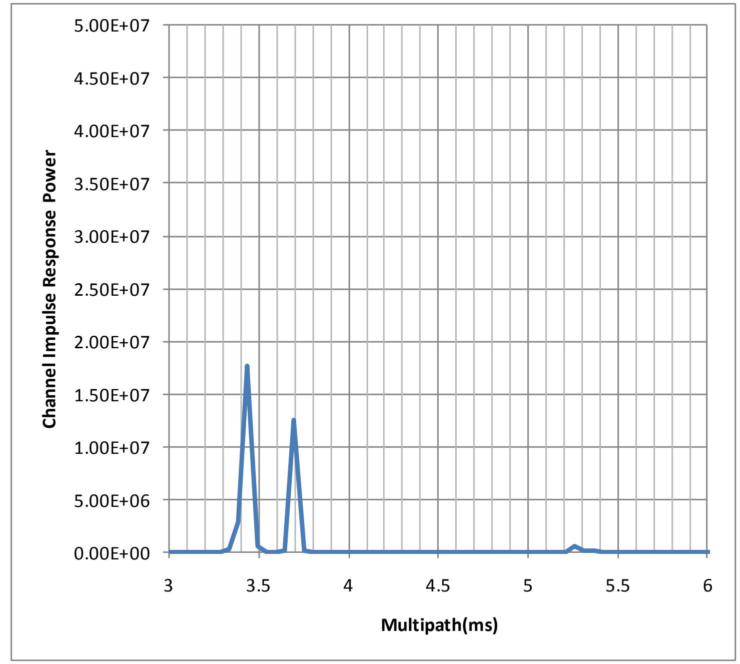
Test Results NVIS Link

- On-air NVIS testing (Rochester, NY to Stockbridge, NY)
  - April 14-15, 2011
    - Summarized for two days of testing
    - Total seconds, error free seconds, error free %, and MB transferred for each mode tested.
    - Results are summed for all tests
    - No diversity reception

Bandwidth (kHz)	Bit rate (bps)	Total Seconds (secs)	Error Free Seconds (secs)	Per-cent Error Free (%)	Error Free Data Transferred (MB)
12	32000	826	826	100	3.3
12	38400	720	662	92	3.2
21	38400	620	620	100	3.0
18	48000	586	566	96.6	3.4
24	51200	6100	6007	98.5	38.4
24	64000	9596	8272	86.2	66.2
24	76800	1919	1080	56	10.4
Total		20367	18033	88.5	127.9

Test Results NVIS Link

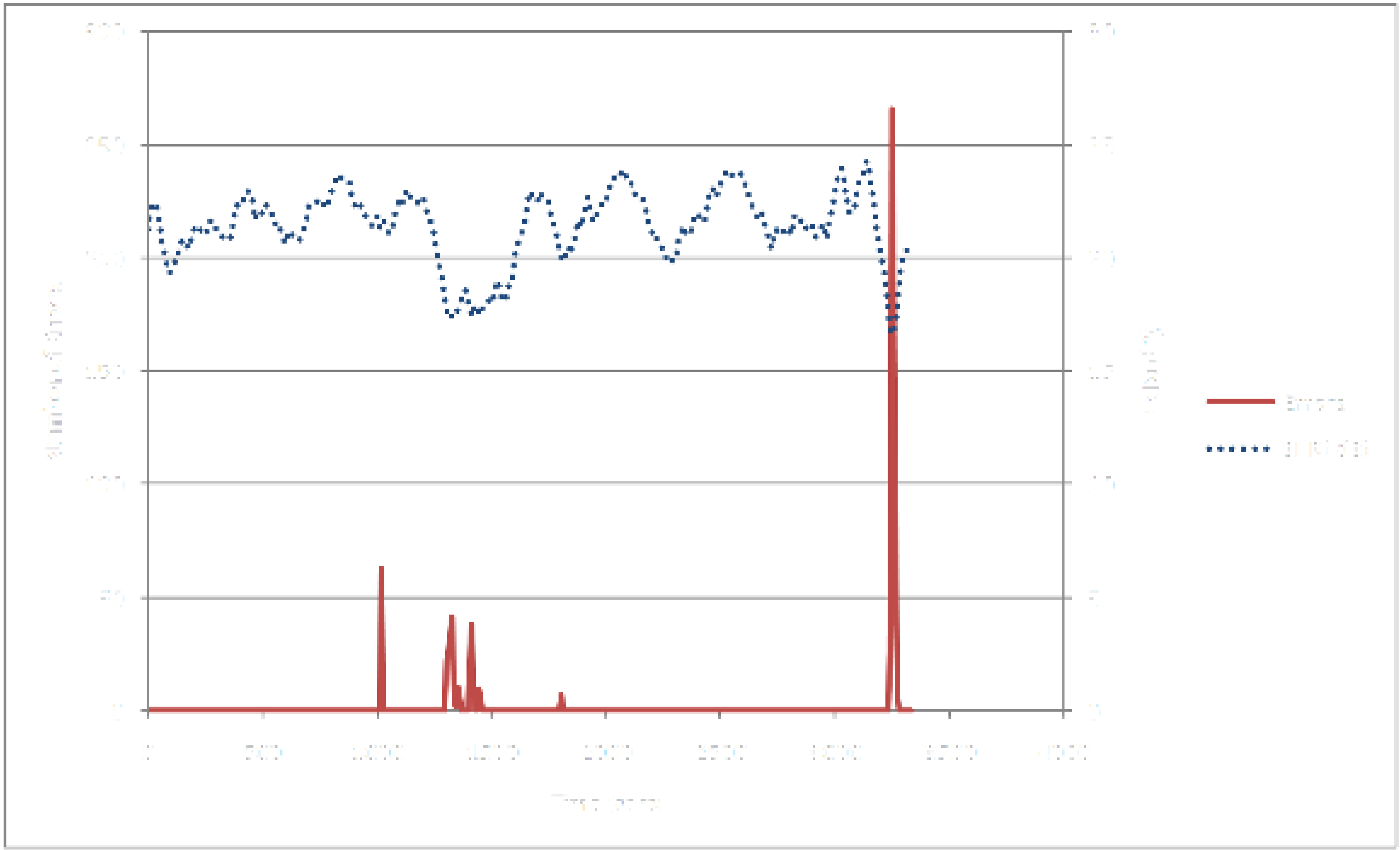




- Multipath Profile consistent over two days, main path, weaker second path (0.15ms) and even weaker third path(2ms). This is a single snapshot, all paths fade up and down.

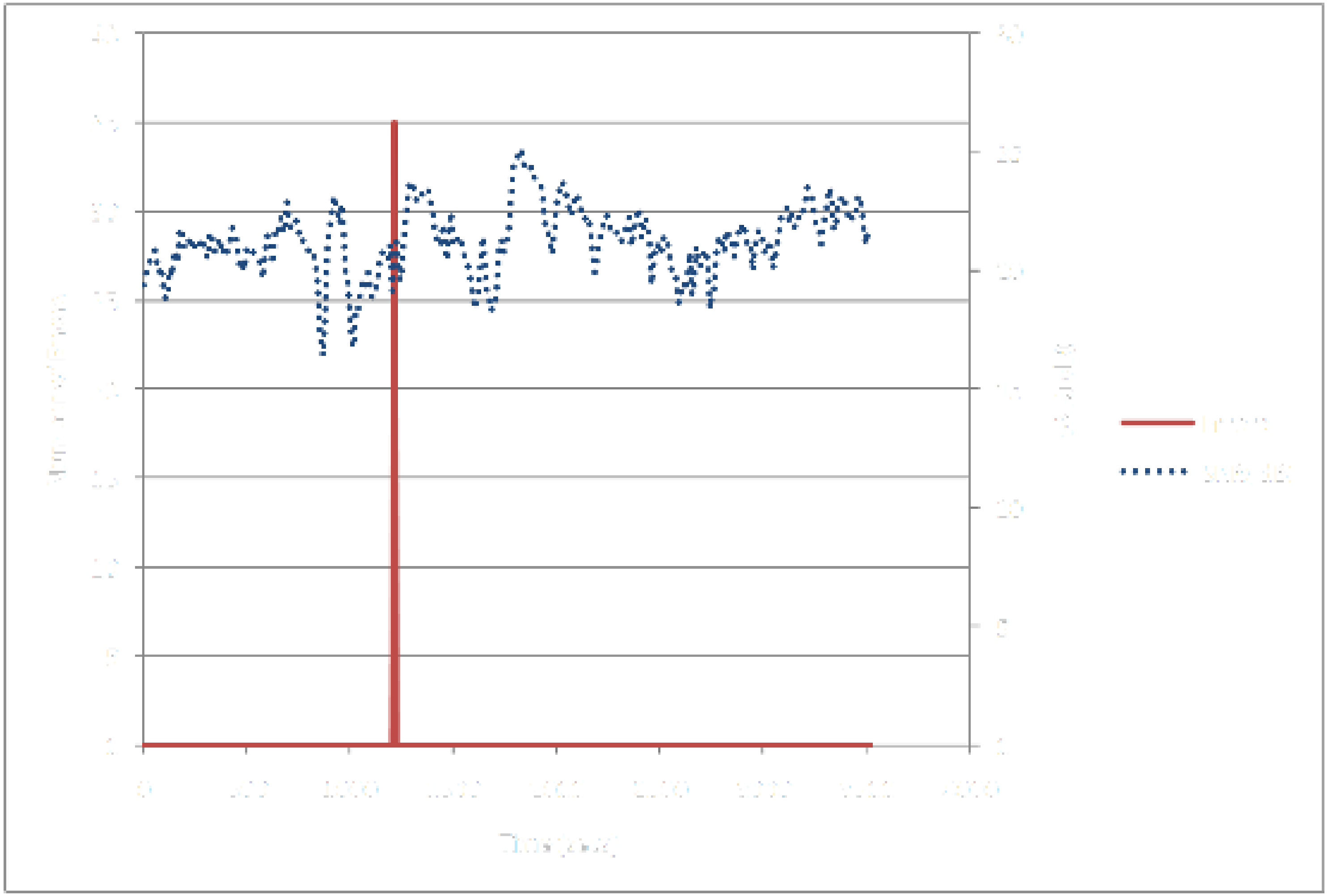
Test Results NVIS Link

Lunch time run: 24 kHz 64,000 bps

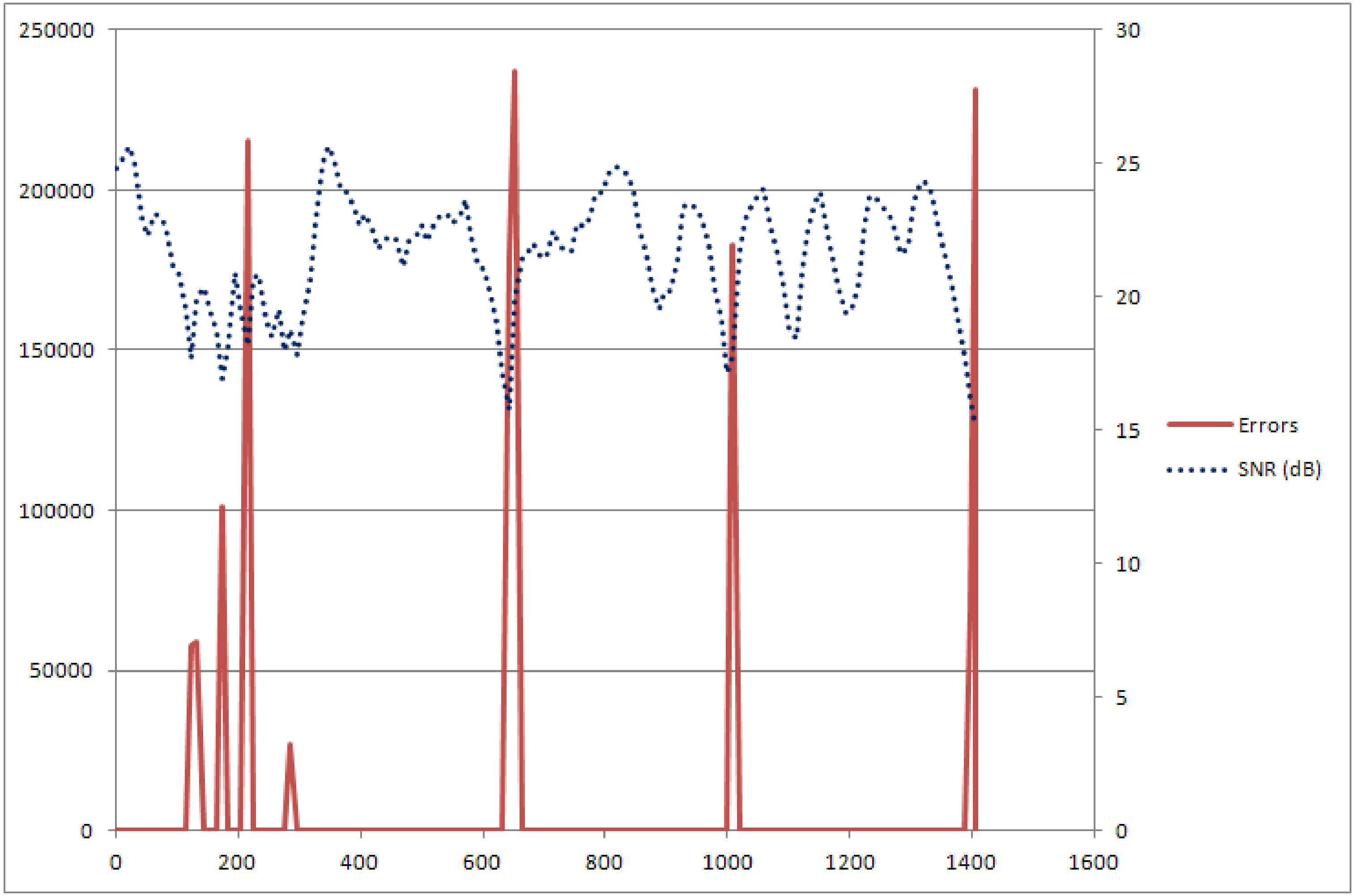


Test Results NVIS Link

Lunch time run: 24 kHz 51,200 bps

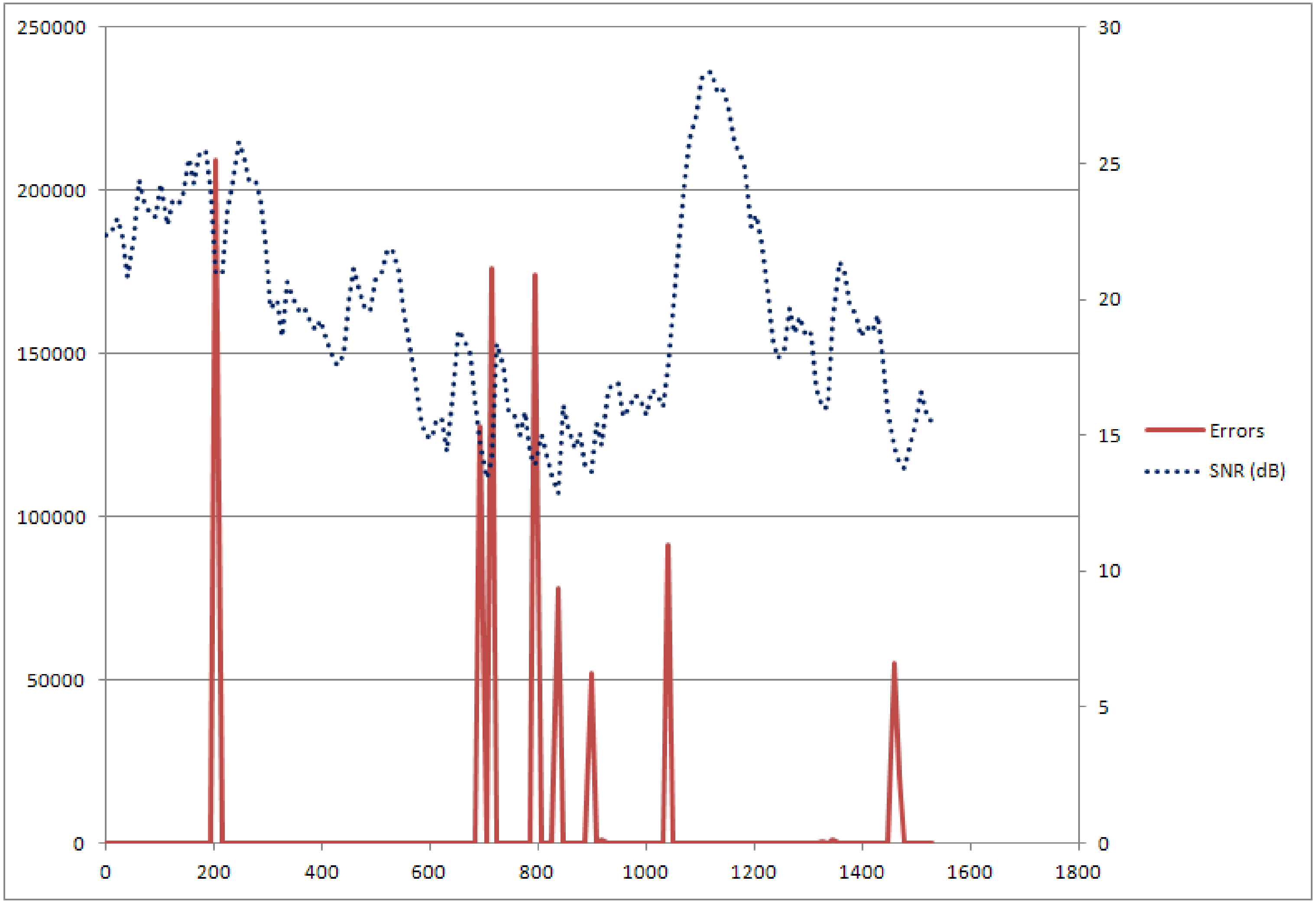


20 Minute Run: 24 kHz 64,000 bps (87% Error Free, 23/8/2011)



Test Results NVIS Link

20 Minute Run: 24 kHz 51,200 bps (83% Error Free, 23/8/2011)



Channel Estimate movie: 20x real-time

animation_17_m2.avi

Channel Estimate movie: 20x real-time

animation_test2m1.avi

Channel Estimate movie: 20x real-time

animation_14_m2.avi

Test Results 1700 km Link

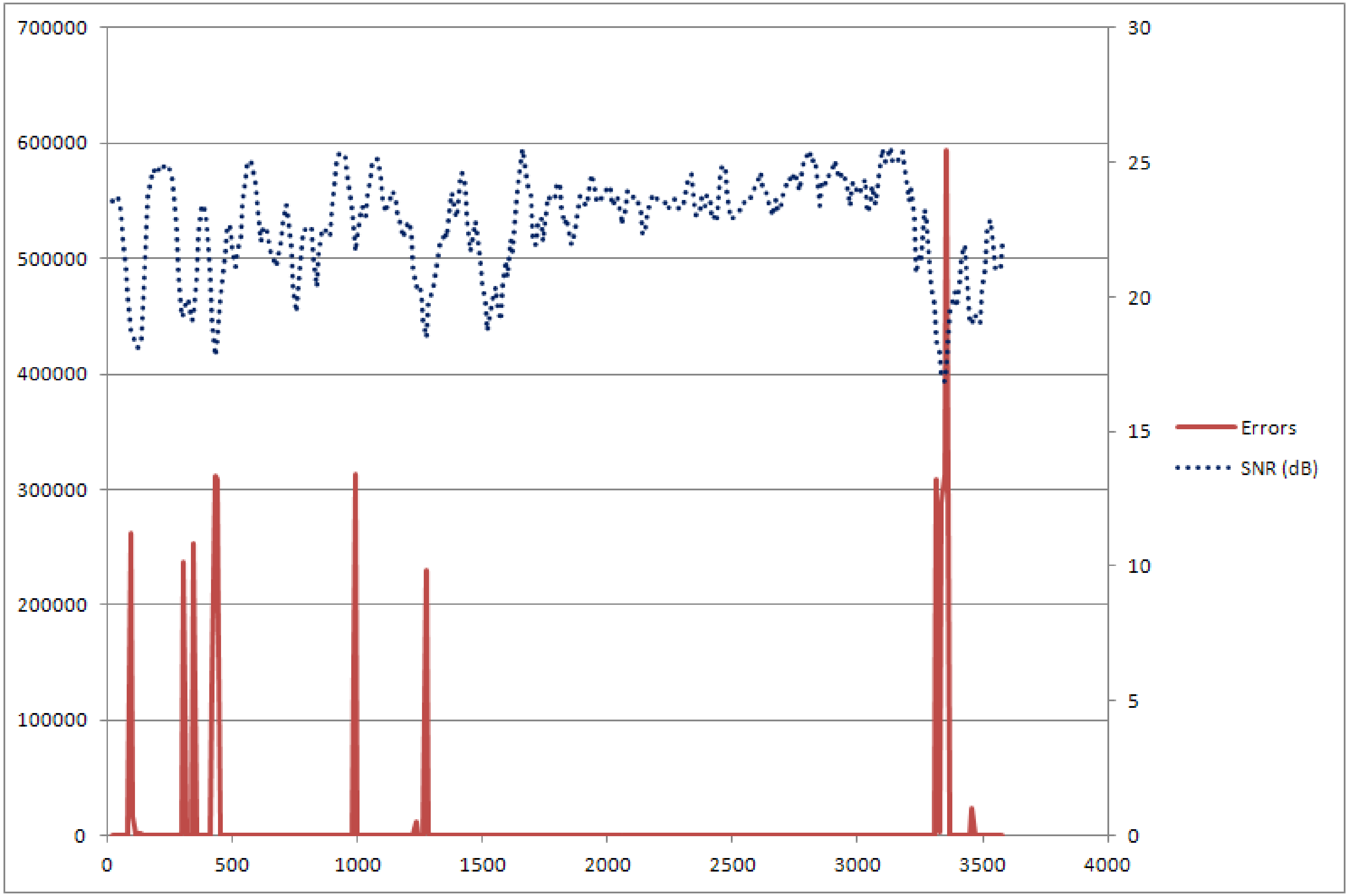
- On-air 1700 km testing (Rochester, NY to Melbourne, Fl)
  - April 25-27, 2011
    - Table summarizes the three days of testing
    - Total seconds, error free seconds, error free %, and MB transferred for each mode tested
    - Tests performed at different frequencies and with different interference environments
    - 324.759 Mbytes of data transferred error free
    - No diversity reception
    - 400 Watt Mobile PA used at transmitter

Test Results 1700 km Link

Bandwidth (kHz)	Bit rate (bps)	Total Seconds (secs)	Error Free Seconds (secs)	Per-cent Error Free (%)	Error Free Data Transferred (MB)
24	12800	622	622	100	0.995
3	16000	51	38	75	0.076
6	24000	1179	854	72.4	2.55
24	25600	296	296	100	0.94
24	38400	660	611	92.6	2.94
12	48000	595	489	82.2	2.93
24	51200	5904	4794	81.2	29.488
18	57600	261	95	36.4	0.69
24	64000	12525	11597	92.6	95.32
24	76800	9583	7330	76.5	70.366
24	**96000**	**11874**	**9868**	**83.1**	**118.464**

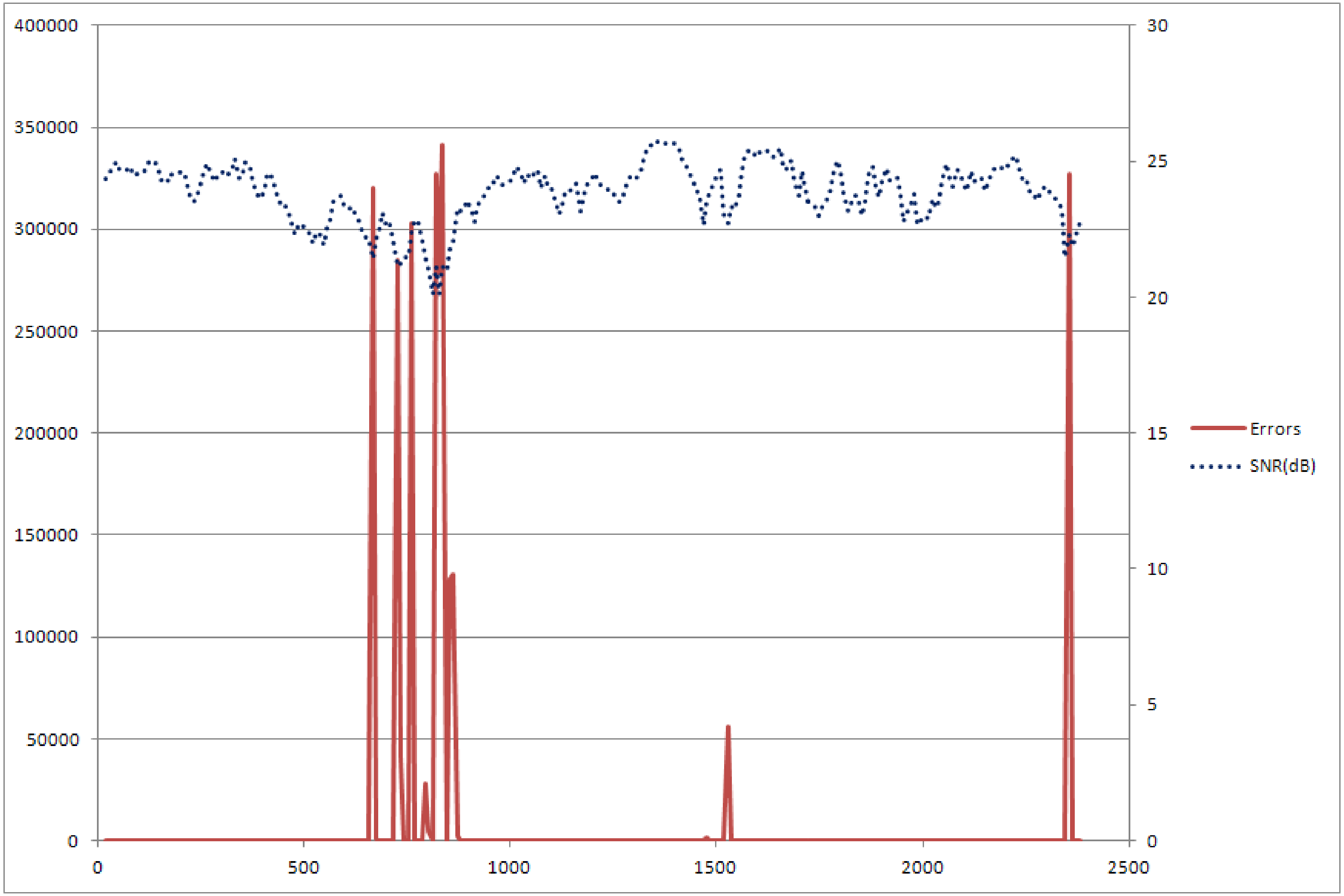
Test Results 1700 km Link

60 Minute Run: 24 kHz 76,800 bps



Test Results 1700 km Link

40 Minute Run: 24 kHz 96,000 bps



Channel Estimate movie: 20x real-time (96000 bps)

animation_10_m6.avi

Test Results 1700 km Link

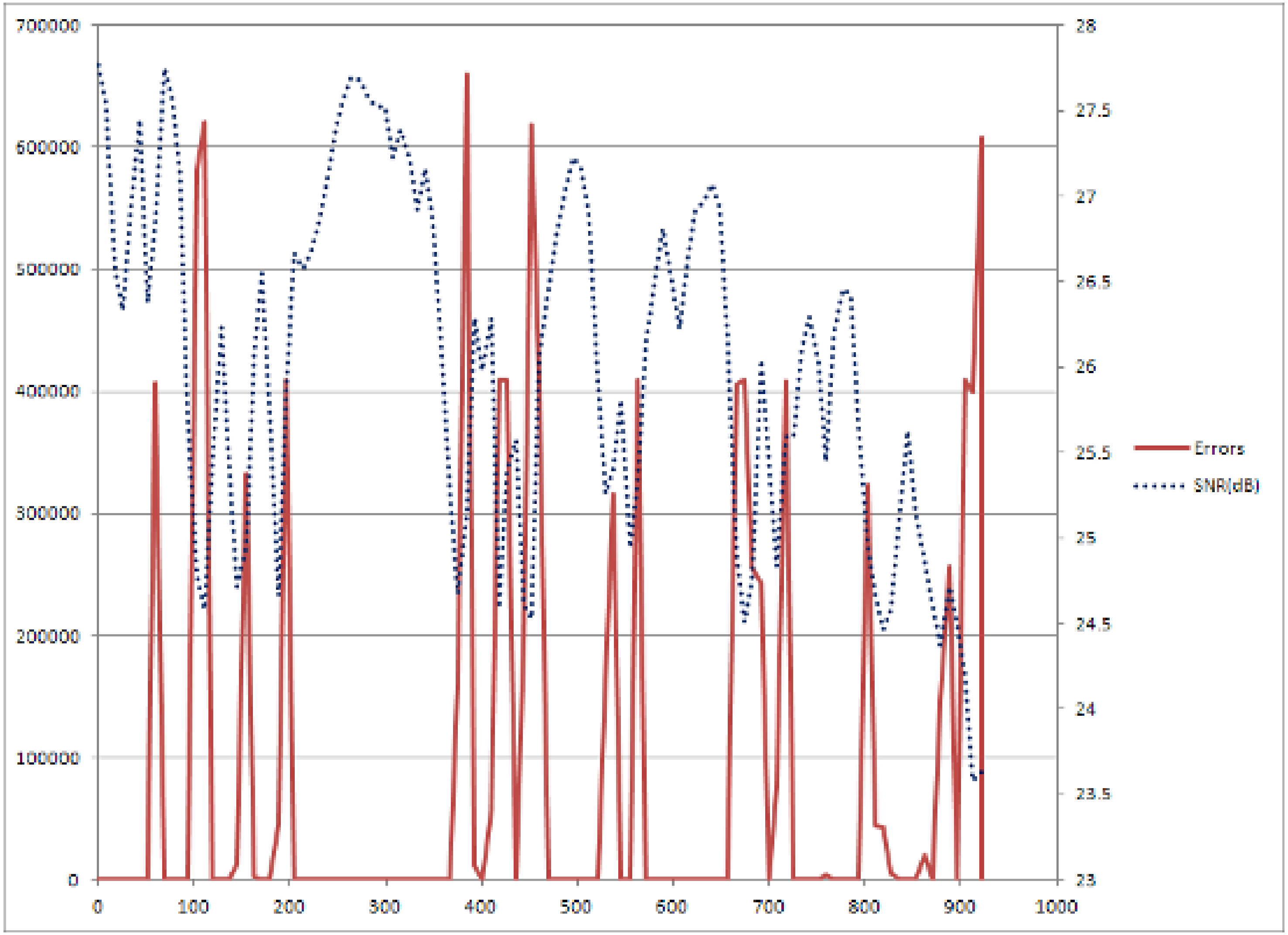
- On-air 1700 km testing (Rochester, NY to Melbourne, Fl)
  - June 20-22, 2011
    - No diversity reception
    - 400 Watt Mobile PA used at transmitter
    - Portion of 3 days dedicated to testing 120000 bps
      - Table lists all 120000 bps attempts
      - Total seconds, error free seconds, error free %, and MB transferred for test
      - A Total of 34 MB transferred at 120000 bps

Test Results 1700 km Link

Bit rate (bps)	Total Seconds (secs)	Error Free Seconds (secs)	Per-cent Error Free (%)	Error Free Data Transferred (MB)
120000	1109	8	0.7	0.12
120000	1049	375	36	5.625
120000	878	60	7	0.9
120000	674	128	19	1.92
120000	2423	1066	44	15.99
120000	921	477	52	7.155
120000	1280	145	11	2.175

Test Results 1700 km Link

15 Minute Run: 24 kHz 120,000 bps



Channel Estimate movie: 20x real-time (120,000 bps)

animation_11m1.avi

Test Results 1700 km Link

- On-air testing of 120,000 bps looks very promising
- 1000 Watt PA (instead of a 400 Watt PA) would have improved results significantly
- Highest data rates of 110C WBHF are possible on some well engineered HF links

Conclusions

- Harris has demonstrated the following:
  - A wideband HF data modem capability fully compliant with MIL-STD-188-110C Appendix D
  - Transfer of data at 51,200 bps, 64,000 bps and 76,800 bps over a fading multipath NVIS link typical of tactical military communications
  - Transfer of data at 76,800 bps, 96,000 bps and 120,000 bps over a 1700 km fading multipath link typical of strategic military communications
- US MIL-STD-188-110C is a promising new standard which can transform HF into a competitive alternative to some VHF, UHF and satellite systems

Wideband (WBHF) Update

Eric E. Johnson

Professor Emeritus
Klipsch School of Electrical and Computer Engineering
New Mexico State University, USA

Wideband HF in 110C

- Technical discussion that follows is from final **DRAFT** MIL-STD-188-110C.
- This document has been reviewed; publication expected by end of October.
- Technical parameters unlikely to change.

Wideband HF in 110C

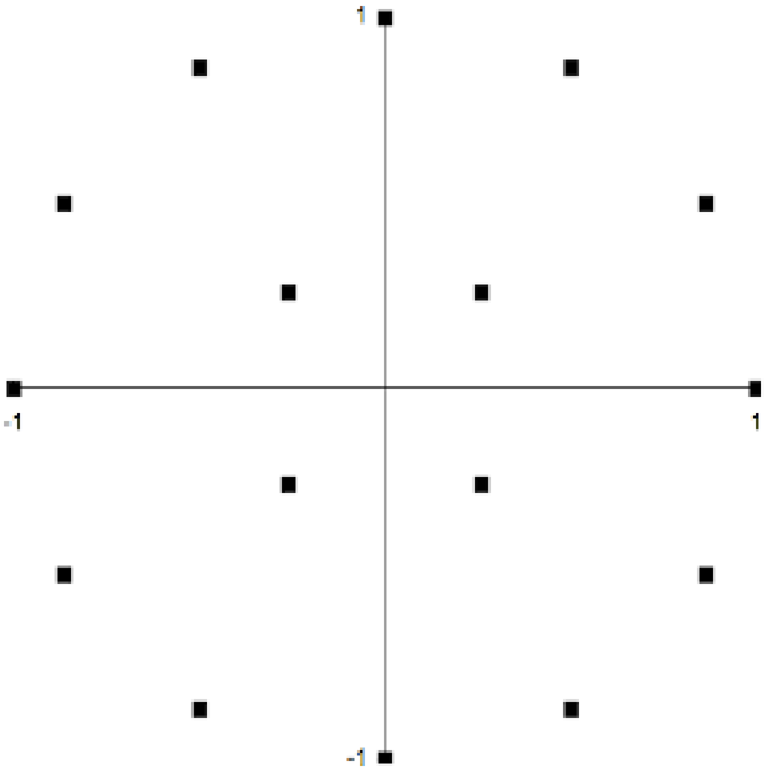
- Natural evolution of 110B waveform to wider channel bandwidths:
  - Up to 24 kHz
  - 3 kHz steps
- Same family of modulations and coding
- 4 interleavers from 120 ms to 10.24 s

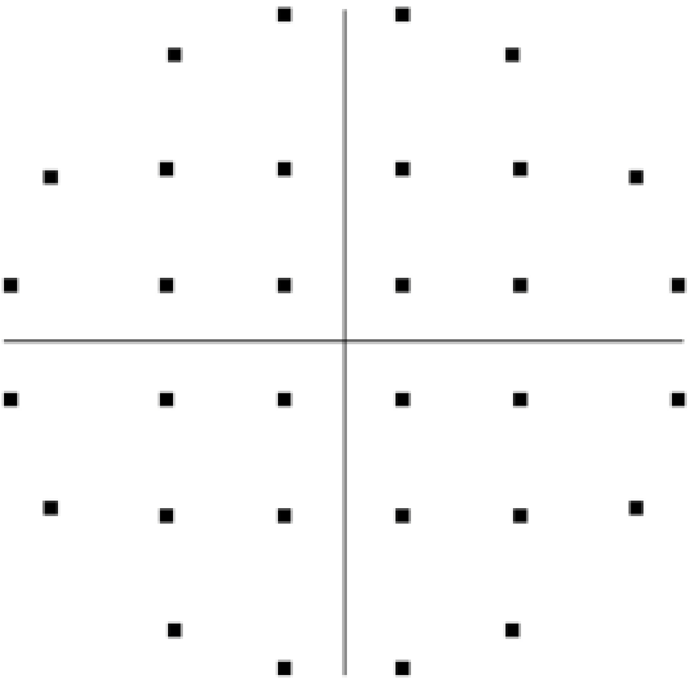
WBHF Data Rates

Waveform Number	Modulation	Data Rate 3 kHz	6 kHz	12 kHz	18 kHz	24 kHz
0	Walsh	75	150	300	600	600
1	BPSK	150	300	600	1,200	1,200
2	BPSK	300	600	1,200	2,400	2,400
3	BPSK	600	1,200	2,400	4,800	4,800
4	BPSK	1,200	2,400	4,800	-	9,600
5	BPSK	1,600	3,200	6,400	9,600	12,800
6	QPSK	3,200	6,400	12,800	19,200	25,600
7	8PSK	4,800	9,600	19,200	28,800	38,400
8	16QAM	6,400	12,800	25,600	38,400	51,200
9	32QAM	8,000	16,000	32,000	48,000	64,000
10	64QAM	9,600	19,200	38,400	57,600	76,800
11	64QAM	12,000	24,000	48,000	72,000	96,000
12	256QAM	16,000	32,000	64,000	90,000	120,000
13	QPSK	2,400				

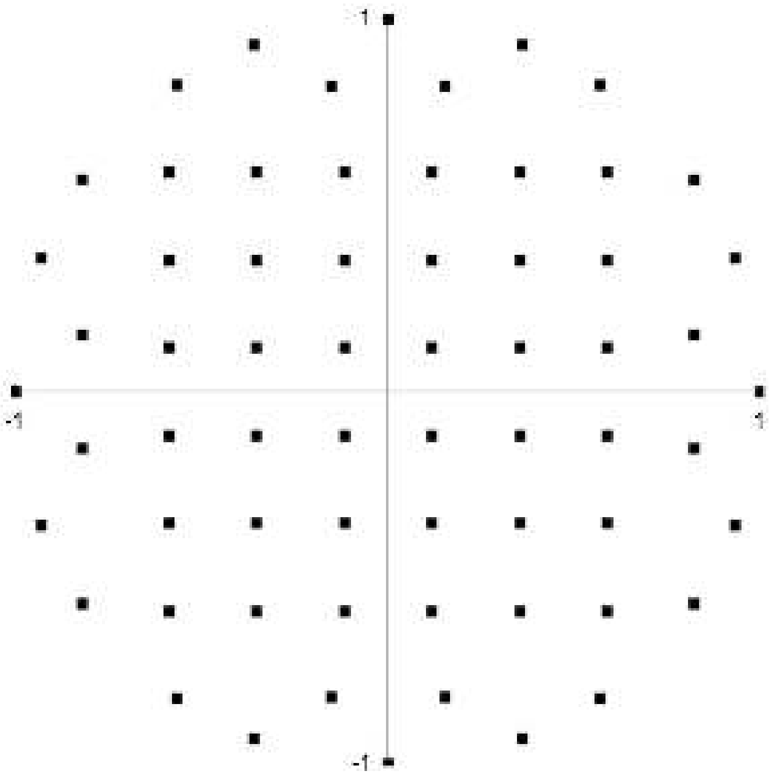
NM STATE UNIVERSITY

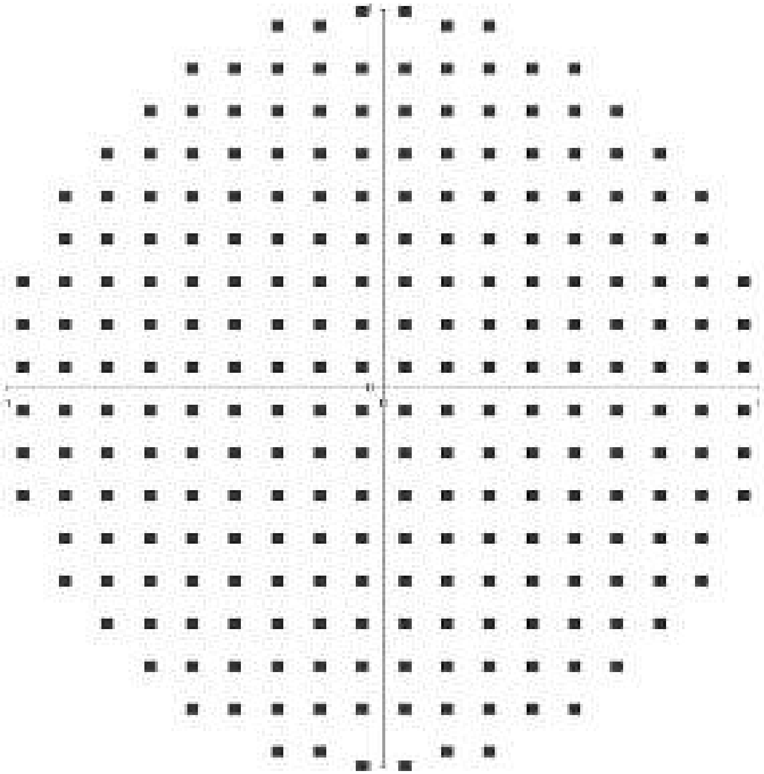
QAM Constellations



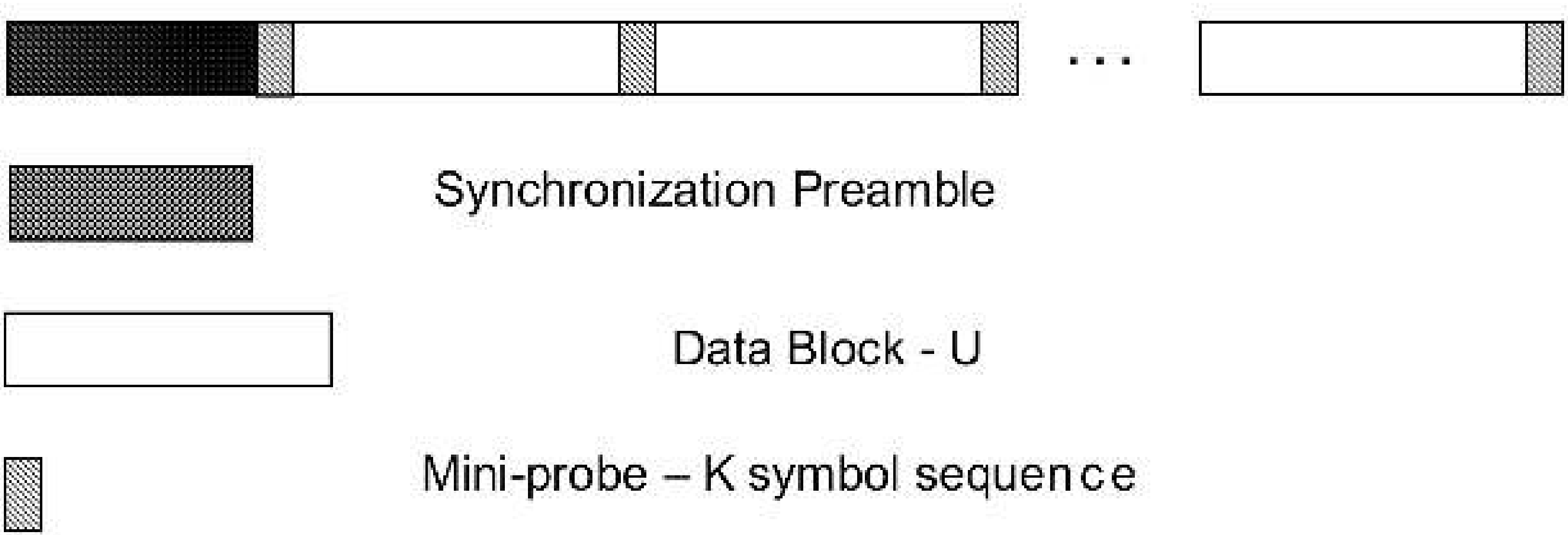


QAM Constellations



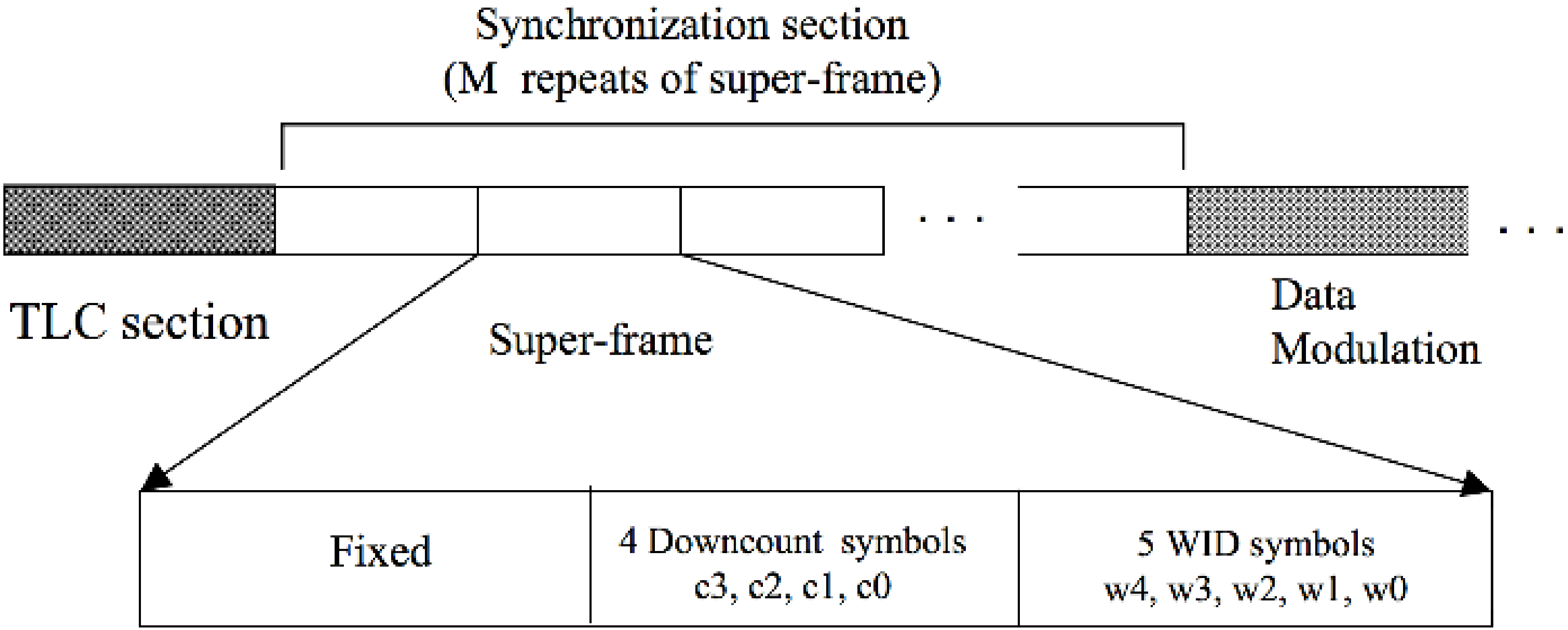


WBHF Frame Structure



- No reinserted preambles

WBHF Sync Preamble



* Downcount: 5 count bits plus 3 for parity

Waveform ID Symbols

- w4, w3 identify the waveform
- w2 specifies interleaver
  - Ultrashort, short, medium, long
- w1 (msb) identifies constraint length (7 or 9)
- w1 (lsb) & w0: 3 parity check bits

WBHF Mini-Probes

- Inserted following preamble and each data block in non-Walsh waveforms
- 14 different mini-probe sequences
- Cyclically-rotated version sent after penultimate block of long interleaver frame (independent of interleaver in use)

WBHF Interleavers

Interleaver	Depth
Ultrashort	0.16 s
Short	0.64 s
Medium	2.56 s
Long	10.24 s

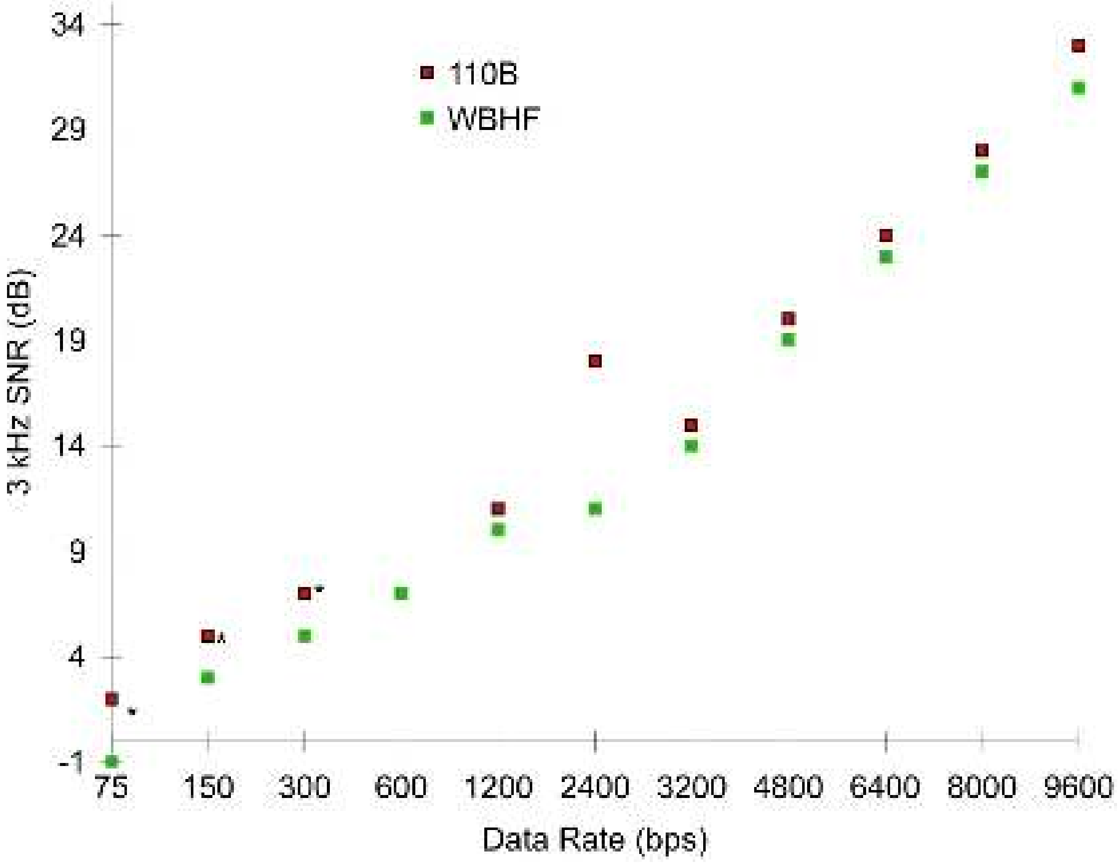
WBHF Coding

Waveform Number	Modulation	Data Rate 12 kHz	Code Rate	Probes	SNR (dB) for BER ≤ 1.0E-5 AWGN	Poor
0	Walsh	300	1/2		-6	-1
1	BPSK	600	1/8	1/2	-3	3
2	BPSK	1,200	1/4	1/2	0	5
3	BPSK	2,400	1/3	1/4	3	7
4	BPSK	4,800	2/3	1/4	5	10
5	BPSK	6,400	3/4	1/9	6	11
6	QPSK	12,800	3/4	1/9	9	14
7	8PSK	19,200	3/4	1/9	13	19
8	16QAM	25,600	3/4	1/9	16	23
9	32QAM	32,000	3/4	1/9	19	27
10	64QAM	38,400	3/4	1/9	21	31
11	64QAM	48,000	8/9	1/16	24	-
12	256QAM	64,000	8/9	1/16	30	-

3 kHz WBHF *vs* 110B

3 kHz Data Rate	WBHF Waveform					110B Waveform				
				SNR (dB) for BER≤1E-5					SNR (dB) for BER≤1E-5	
	Modulation	Code Rate	Probes	AWGN	Poor	Modulation	Code Rate	Probes	AWGN	Poor
75	Walsh	1/2	-	-6	-1	Walsh	1/2	-		2*
150	BPSK	1/8	1/2	-3	3	BPSK	1/8	1/2		5*
300	BPSK	1/4	1/2	0	5	BPSK	1/4	1/2		7*
600	BPSK	1/3	1/4	3	7	BPSK	1/2	1/2		7
1,200	BPSK	2/3	1/4	5	10	QPSK	1/2	1/2		11
1,600	BPSK	3/4	1/9	6	11					
2,400	QPSK	9/16	1/9	6	11	8PSK	1/2	1/3	10	18
3,200	QPSK	3/4	1/9	9	14	QPSK	3/4	1/9	9	14
4,800	8PSK	3/4	1/9	13	19	8PSK	3/4	1/9	13	19
6,400	16QAM	3/4	1/9	16	23	16QAM	3/4	1/9	16	23
8,000	32QAM	3/4	1/9	19	27	32QAM	3/4	1/9	19	27
9,600	64QAM	3/4	1/9	21	31	64QAM	3/4	1/9	21	31
12,000	64QAM	8/9	1/16	24	-					
16,000	256QAM	8/9	1/16	30	-					

3 kHz WBHF *vs* 110B



Questions?