# Status Report on NATO BLOS Comms Experts Group

6 September 2012

Eric E. Johnson

New Mexico State University (USA)
Klipsch School of Electrical and Computer Engineering
and Physical Science Laboratory

eejohnson @ ieee.org

# Meeting of 5 Sept 2012

- Status within NATO
  - BLOS Comms experts group not currently recognized as a Capability Team (new term for Working Group)
  - NATO support now limited to maintaining our web site and submitting our work to CaP 1 (CIS Capability Panel)
  - Efforts underway to achieve recognition as a CaT

# Briefings of 5 Sep 2012

- WRC 2012 actions
- NLD/GBR WBHF Demo Invitation
- CAN Forces HF Conference Invitation

# Briefings of 5 Sep 2012

- STANAG updates
  - STANAG 4203 revision for WBHF
  - STANAG 4415 touch-up
  - STANAG 4444 (in ratification)
  - STANAG 4538
  - STANAG 4539
  - STANAG 5030 (VLF) is now STANAG 4724
  - STANAG 5066 (in ratification)

# Program of Work

- STANAG 4203: revision for wideband
- STANAG 4415: robust WF headed for ratification
- STANAG 4539: new NILE waveforms
- STANAG 4724: VLF headed for ratification
- New STANAG for wideband waveforms
- Revise channel simulator specs for WBHF
- Authentication and authorization over HF

Next Meeting

January 2012
San Diego

Defence R&D Canada

# Experimental Wide Band HFIP System SkyNet

Nur Serinken
Communications Research Centre
Ottawa, Canada
NATO HF-BLOS
Sept 2012 York, UK

# Outline

Defence R&D Canada

- Motivation
- SkyNet System description
- Experimental setup
- Future plans
- Questions

# Motivation for HFIP link

Defence R&D Canada

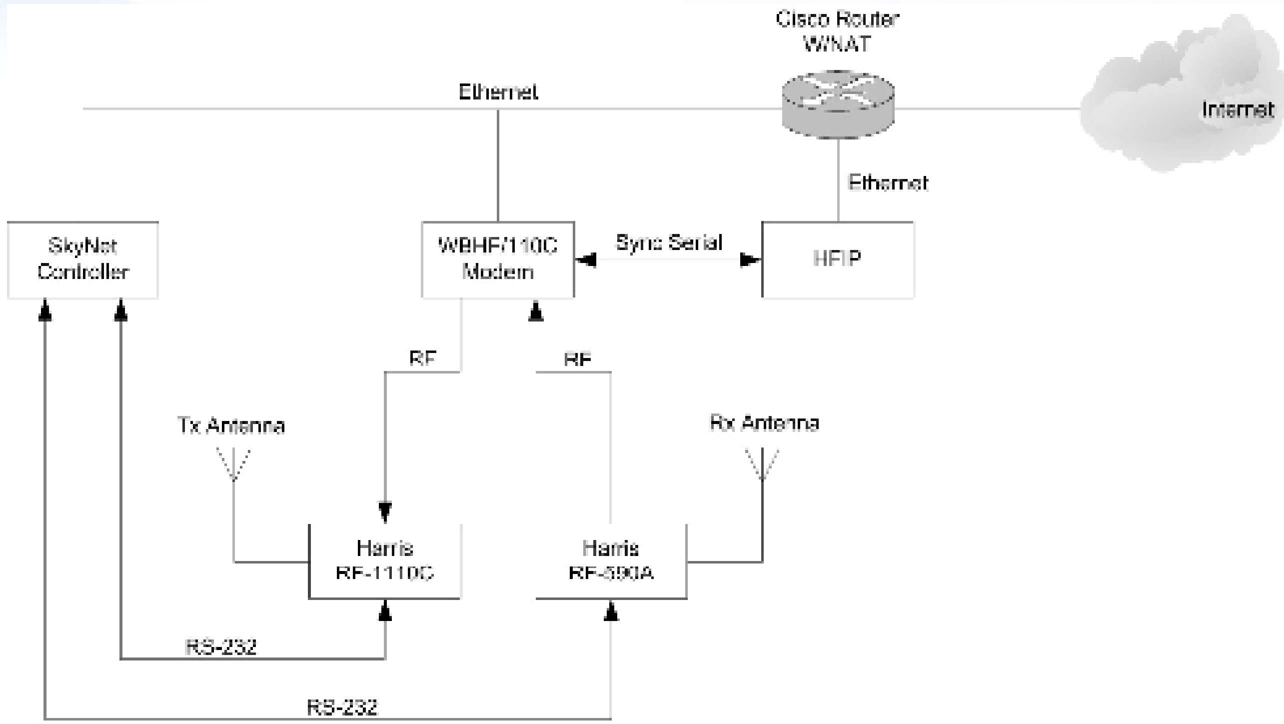
- Provide alternate data communication paths for BLOS links
- Operate in space denied environments
- Demonstrate Internet extension
- Long term evaluation of MIL-STD-188-110C wide band waveform

**Key system features**

- More like a mobile system
- Ease of operation provides reduced user training requirement

# SkyNet System Node

Defence R&D Canada



# HFIP Description

Defence R&D Canada

- Office of Naval Research, SPAWAR, NATO C3 agency
- STANAG 5066 with Annex L for Naval applications (ground wave)

Capabilities:

- A method for exchanging general IP data for TCP and UDP based applications over radio channels.
- Error free automatic delivery of e-mail messages, ASCII text files, and binary files (such as images and graphics), and other TCP/UDP based applications with packet compression.
- An at-sea Wide Area Network (WAN) IP capability.
- Maximum use of standard infrastructure, which includes HF radios, antenna assets, and KG-84C or KIV-7 cryptos.
- Network connectivity from ships to shore in support of litoral operations and terrestrial LAN infrastructure extension.
- Hub-spoke secure communications, whereby the station can send/receive IP traffic to/from a ship and/or shore equipped with HFIP system and interface to command secure networks.

# SkyNet Controller

Defence R&D Canada

- Controls the receiver, transmitter and data modem.
- Sets the radio frequency, bandwidth, data rate and data format.
- Frequency management is predetermined predicted frequencies (hour, month and year) read from a schedule text file.
- Adjusts the transmission bandwidth if some of the frequency assignments do not accommodate 24 kHz wide band signals.

# Summary



- Automated self configuring masterless network
- Delivery of error free IP packets
- Interface for smart phone or tablet computer devices

# Future Plans

Defence R&D Canada

## Exploring Collaborative Activities with Canadian Forces:

- Evaluation over sky wave paths from CRC to Atlantic  Coast
- Testing in the Arctic,  Possible sites Resolute, Iqaluit, Alert, Yellowknife
- Testing to/from ships,
- Inclusion in future exercises (AUSCANNZUKUS)

# Questions ?

Defence R&D Canada

Nur Serinken

(Canada) 613-998-2289

E-mail: nur.serinken@crc.gc.ca

# Wide Band High Frequency Communications

## 2012 UK Trials Summary

James Alexander

*HF Industry Association, York, September 2012*

Rockwell Collins

# Introduction

- This presentation describes trials conducted under the UK MOD Enabling Secure Information Infrastructure (ESII) programme, as follows:
  - This research was commissioned by the Defence Science and Technology Laboratory (DSTL) and funded by the Ministry of Defence (MOD) Research and Development budget through the MOD's Chief Scientific Advisor.
  - The aim was to investigate and demonstrate Commercial off the Shelf (COTS) alternatives to providing Beyond Line of Sight (BLOS) and reach-back capability at lower cost than extant maritime and land-based reach-back systems in a Satellite Communications (SATCOM) denied and/or bandwidth constrained environment.

# Context of UK Trials

- UK trial effort followed on from 2 significant initiatives:
  - Over The Air (OTA) trials conducted by Rockwell Collins Inc, culminating in AUSCANZUKUS Trident Warrior 11 (March 2011):
    - First ever four node HFIP network established over HF skywave circuits between Cedar Rapids, Richardson, Las Cruces, & Ottawa
  - Previous UK MOD ESII Task 7 trialled IP over HF and proved the limited utility of a standard (non-WBHF) channels for IP.
- A team of ESII consortium partners led by RCUK was contracted by UK MOD in September 11 to run WBHF trials in European environment – this became ESII Task 23.

# ESII Task 23 Trials - Organisation

## Phase 1 – Application Integration

- ACP 142 – STANAG 5066 (HF Messenger) Integration
- SIS and IP layer connectivity
- 3 kHz test environment
- IP Client Integration

## Phase 2 – Over The Air Ground Wave (13-17 Feb 2012)

- Land Systems Reference Centre (LSRC) Blandford – QinetiQ Portsdown

## Phase 3 – Over The Air  Sky Wave (22 Feb to 2 Mar 2012)

- Royal Marines (RM) Condor Arbroath – QinetiQ Portsdown

## Phase 4  - Bowman Integration

- Lab demonstration of Reachback and Range Extension potential

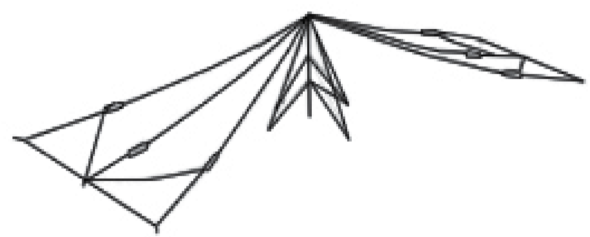
# Radio and Modem Hardware Employed

1kW HF Amplifier and Power Supply (standard product line item)

An HF Pre/Post Selector (standard product line item)

A modified VHSM-5000 modem and associated Pre-Amp (acting as HF Receiver Exciter)

Inverted “V”, Standard Biconical and Tactical Fanlite HF Antennas



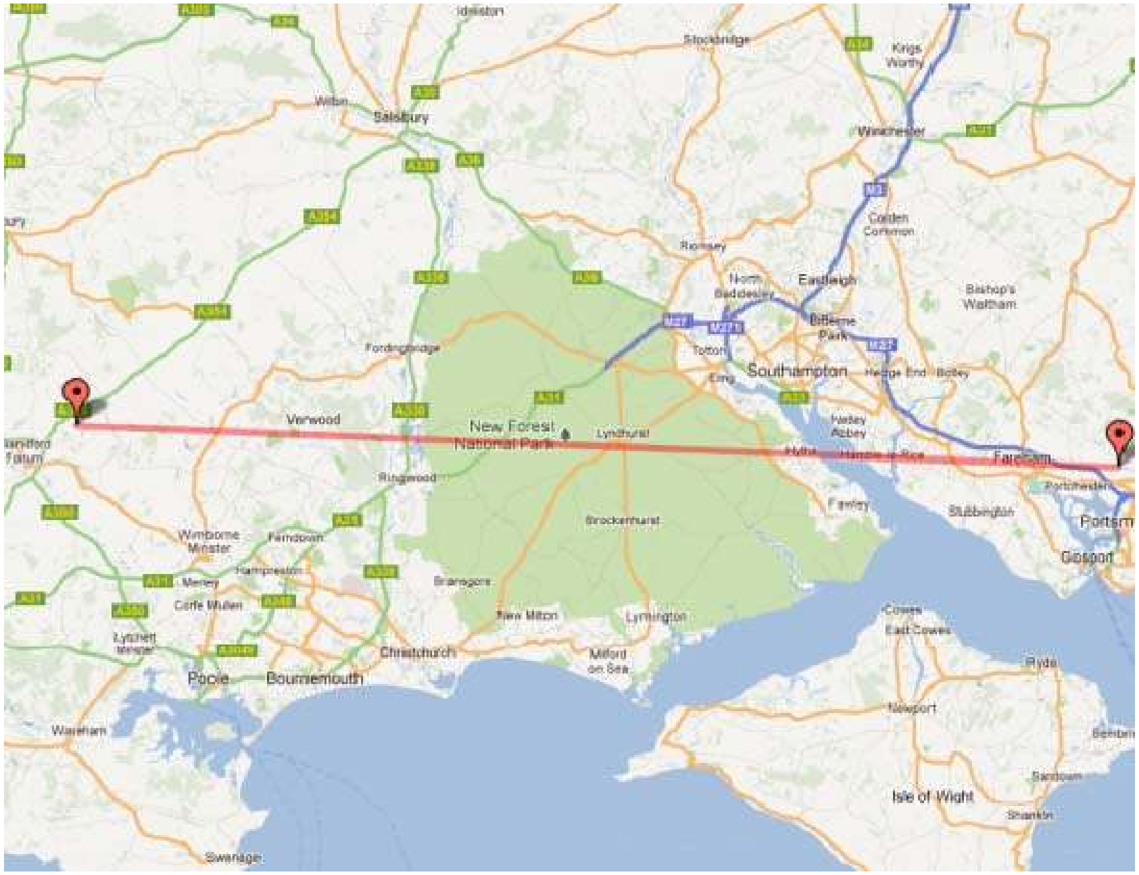
# Over The Air Trial Conditions

- Frequencies:
  - OFCOM granted a temporary non-operational licence to use 24 kHz bandwidths at:
    - 3.613 MHz
    - 6.390 MHz
    - 7.975 MHz
    - 13.047 MHz

- Transmit Power limitations were imposed by site and/or power supply limitations
  - 125W maximum at Portsdown (site limitation)
  - 400W maximum at Arbroath (PSU limit)

# Ground Wave Trial

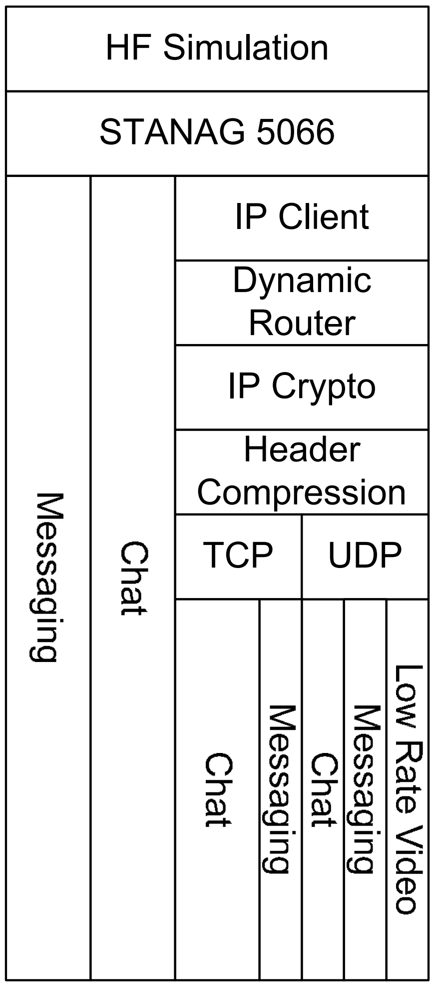
Blandford – Portsmouth (Approx 40 miles)



# Sky Wave Trial

## Arbroath – Portsmouth (Approx 400 miles)

# ESII Task 23 Protocol Stack



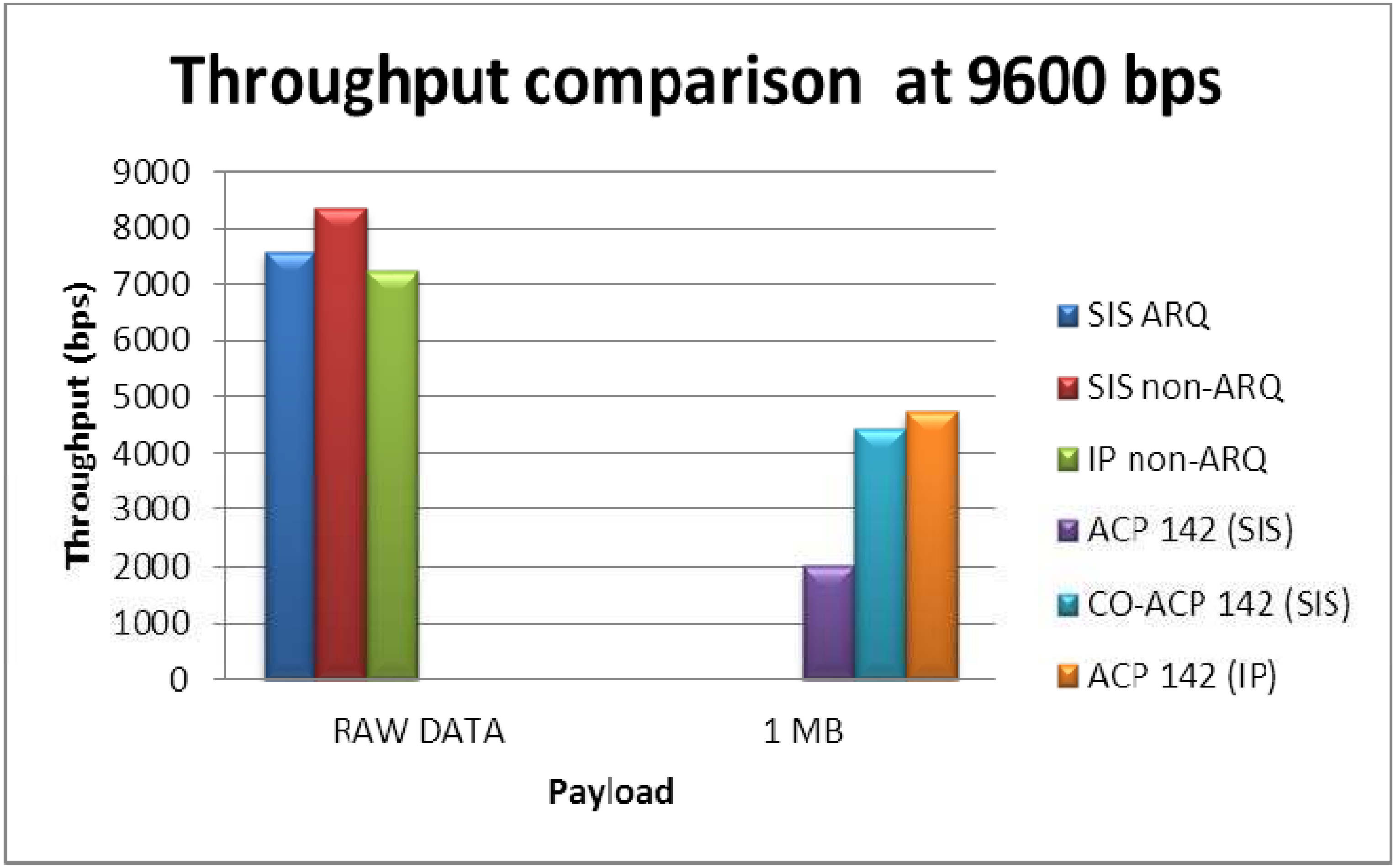

- Third party technologies integrated to demonstrate provision of:

- XMPP Chat
- X.400/SMTP Messaging (email)
- H.264 Low rate video
- FTP

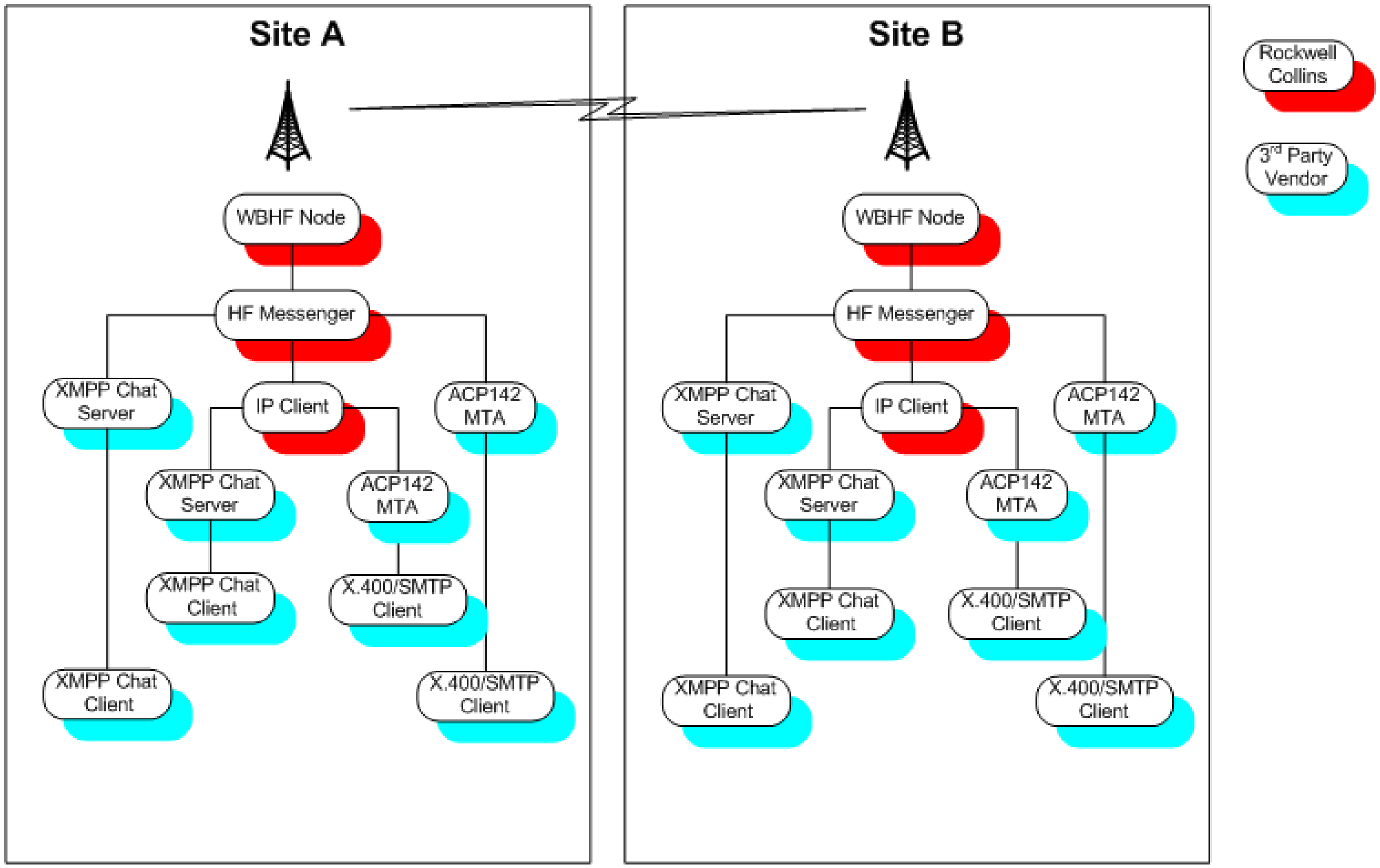
# Test Findings

- Phase 1 (Lab Trials)
  - IP Client is resilient and can support IP Encryption
  - ACP142 works well with STANAG 5066 – Areas for potential further development identified
  - Demonstrated Increased throughput and performance when compared to TCP
  - Utilisation of 92% of raw modem data rate
  - IP traffic added 17% overhead for UDP traffic
  - CO-ACP142 achieved 3 fold improvement over SMTP
  - ACP142 achieved 2 fold improvement over SMTP
  - XMPP Chat latency of 7s average @ 4800 bps

# LAB - Throughput



# ESII Task 23 OTA Architecture



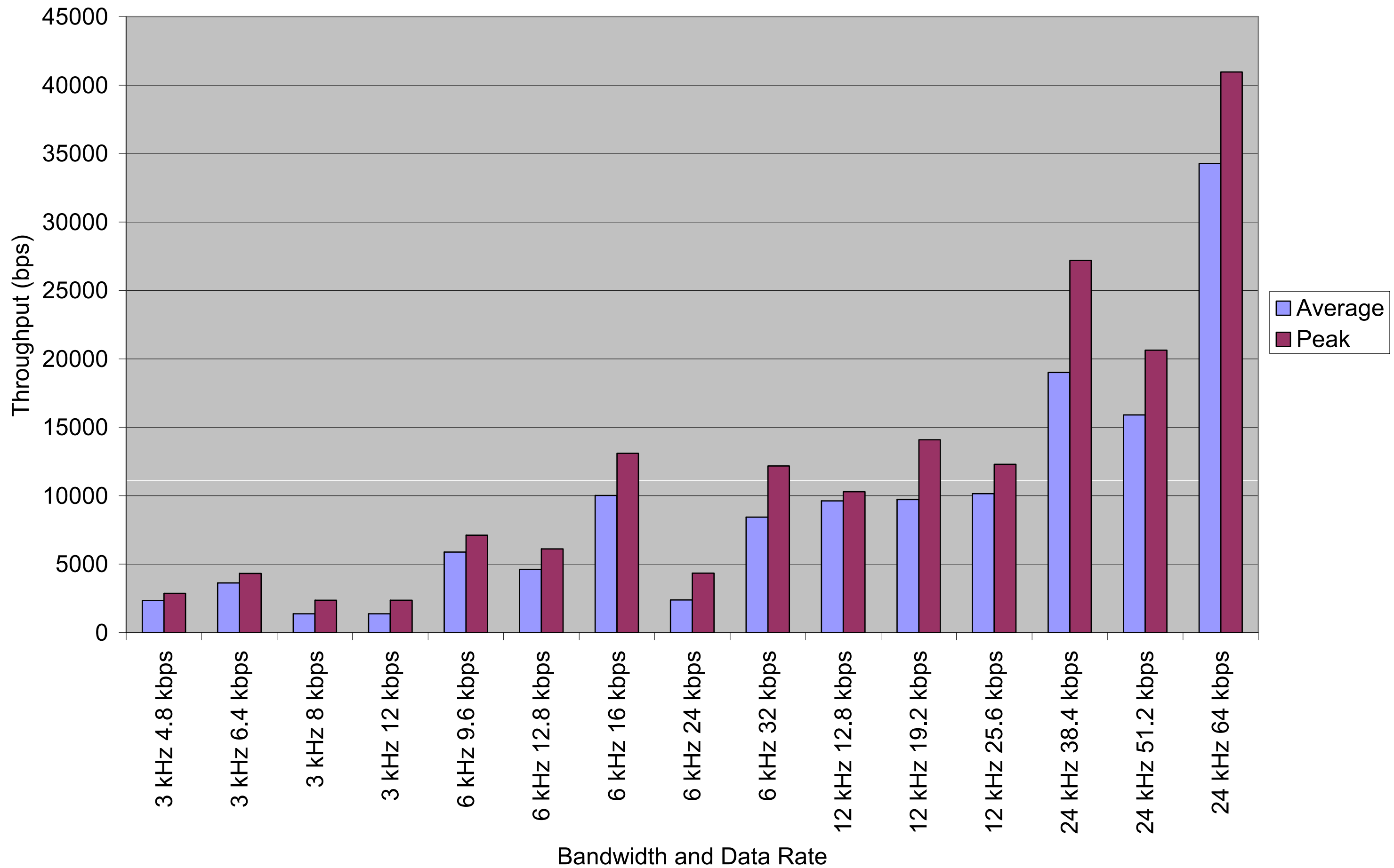

- WBHF radio / modem hardware integrated with protocol stack proven in the lab to enable full OTA trials.

# Over The Air Test Findings

- Phase 2 (Ground Wave Trial)
  - 3, 6 and 7 MHz channels were employed, with best results on 6 MHz
  - Signal to Noise Ratios (SNRs) achieved were typically low, but we were able to achieve:
    - Maximum Data Rate 64 kbps
    - 64 QAM Modulation
    - Maximum throughput 40.96 kbps
    - Utilisation of 66.67 %

- Phase 3 (Sky Wave Trial)
  - All channels were employed, with best results on 6 and 7 MHz
  - Better SNRs were obtained, allowing:
    - Maximum Data Rate 120 kbps
    - 256 QAM Modulation
    - Maximum throughput 57.7 kbps @ 120kbps
    - Utilisation of 48.08 % @120 kbps
    - Peak Utilisation 72% @ 48 kbps
    - MCR – 1400/hour @10 kB Payload = 14 MB

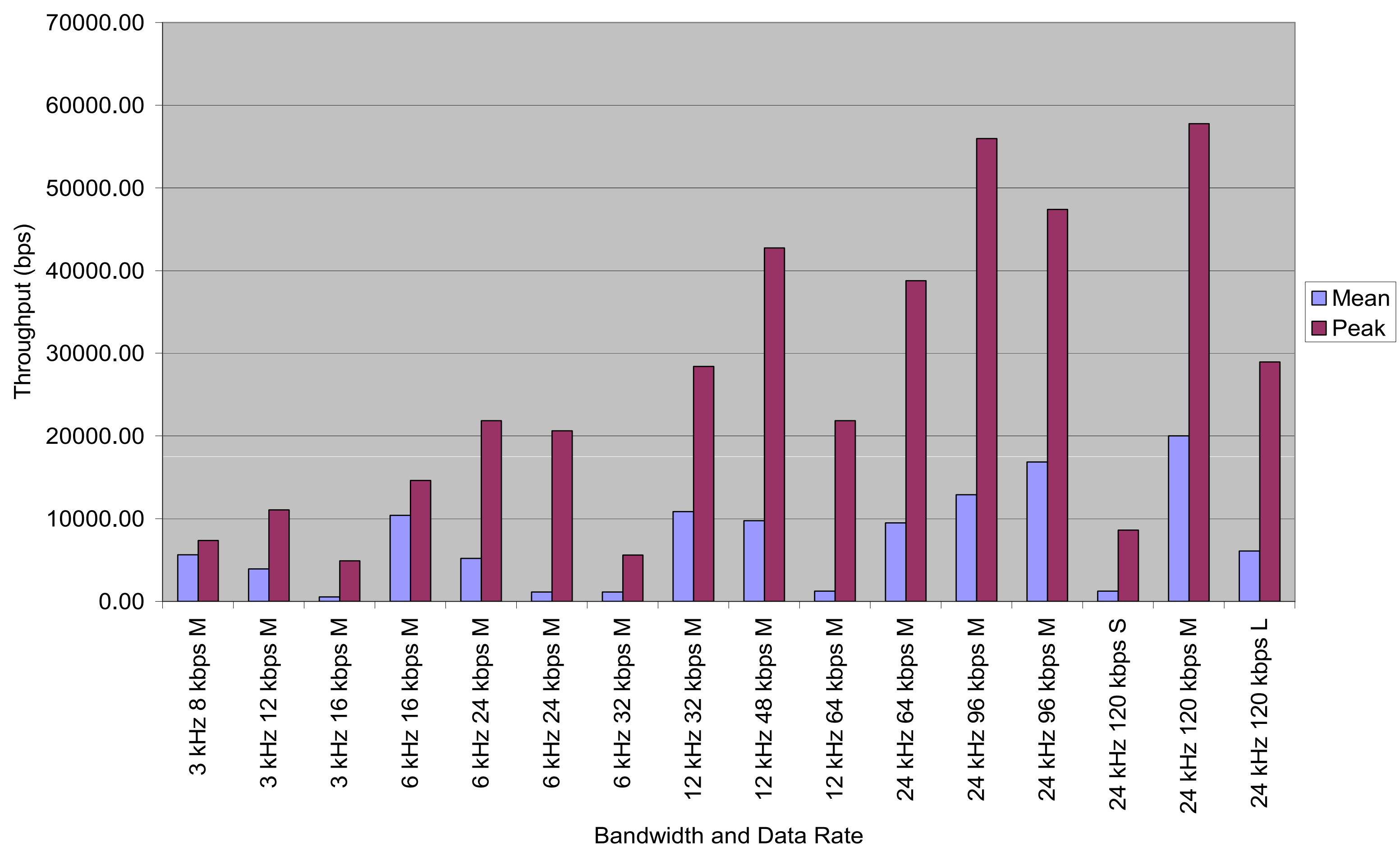
# OTA – S5066 Raw Data Throughput



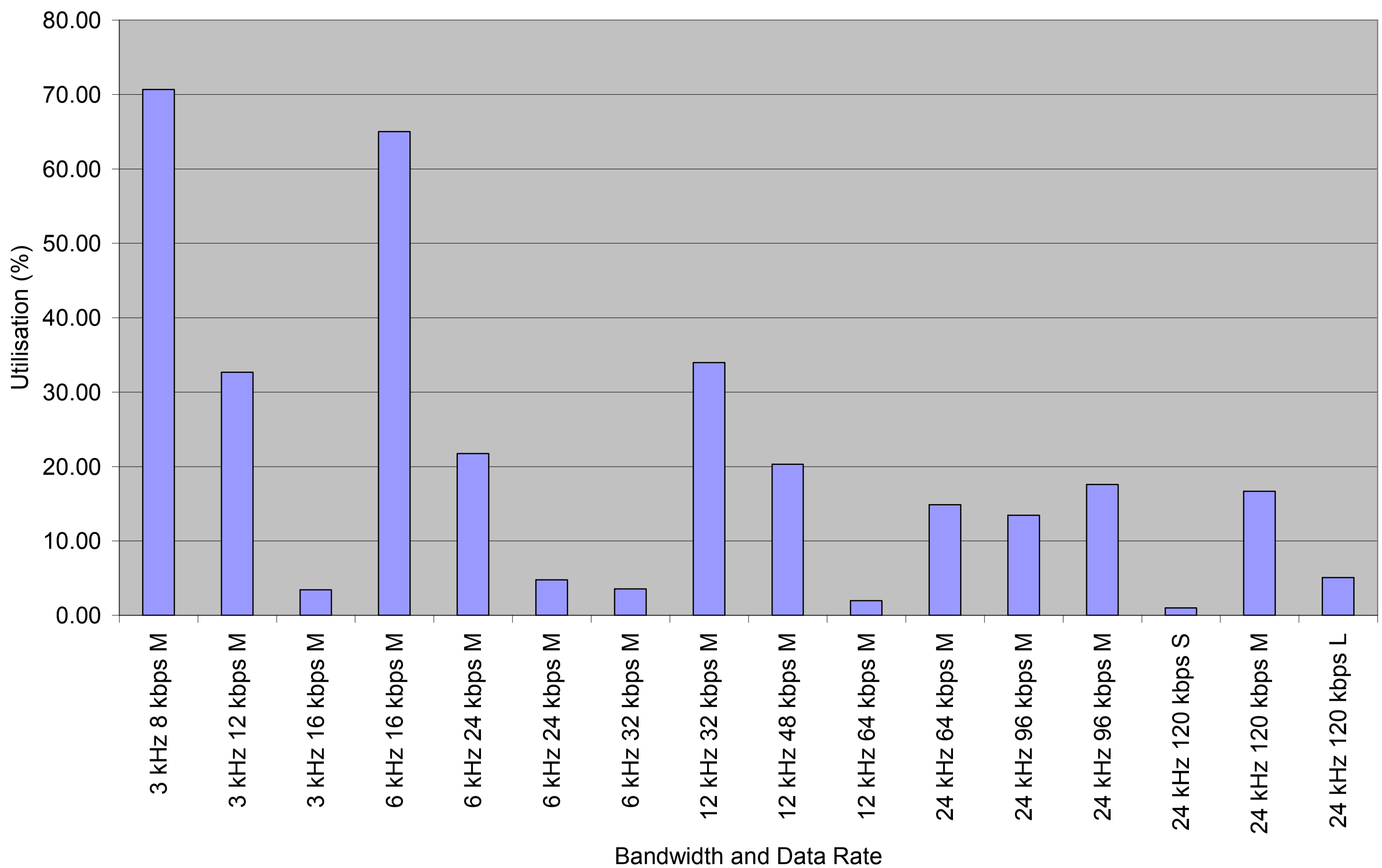



Proprietary Information

# OTA – IP Data (Non-ARQ) Throughput



# OTA – IP Data (Non-ARQ) Throughput



# OTA – ACP142 Messaging

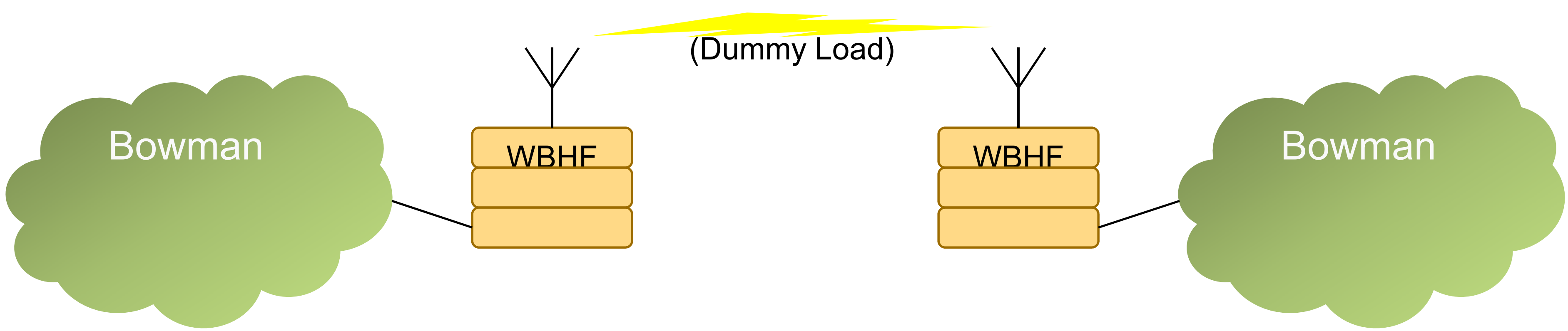
- CO-ACP142
- S5066 ARQ SIS connection
- 100 messages with 10 kByte payload

| **Test Description** | **Test Duration (mins:secs)** | **Average Message Duration (secs)** | **Throughput (bps)** |
|---|---|---|---|
| **120 kbps** | 4:09 | 2.5 | **33 kbps** |
| **9.6 kbps** | **29:51** | **17.9** | **4.6 kbps** |

- *Maximum message rate of 1400/Hour @ 120kbps*
- *ARQ Retransmissions*
- *Limitations due to S5066 128 frame limit*

# Test Findings

- Phase 4 (Bowman Lab Trials)
  - Detailed architectures for Internal and External Bowman Messaging
  - ACP142 works well with Bowman – Further development required
  - Achieved 8 MB/hour payload Data Throughput
  - Minimum 2 x Order of Magnitude increase over standard Bowman HF



# Conclusions

- These trials represented the first UK over the air transmissions of MIL-STD-188-110C WBHF waveforms.
- Modem data rates of up to 120kbps (Sky Wave) were observed.
- STANAG 5066 as currently written limits higher data rate transmissions in ARQ mode – potential for improvement
- Higher mode modulations (64 and 256 QAM) require high (>24dB) SNR and are more susceptible to multi-mode propagation effects.
- Higher bandwidth transmissions with lower modulations schemes proved resilient to interferer's.
- Maintenance of a link sometimes required significant management:
  - Frequency changes
  - Bandwidth changes
  - Modulation scheme changes

  Work on automation of these elements is ongoing.

# Reccomendations

- Frequency Management and Allocation
  - Investigation into National and International availability
- Waveform Characterisation –
  - SNR
  - Delay Spread
  - Frequency Spread
- Automation of Link Set-Up and Management
  - WBHF ALE
- S5066 adaption
  - Modification of frame limit to permit transmissions from 75 bps up to 120 kbps

# Q & A

HFIA HIGH FREQUENCY INDUSTRY ASSOCIATION

# Summer Meeting
# September 6, 2012

National Railway Museum
York, UK

# Welcome & Introductions

- Welcome
- Current Officers
  - Randy Nelson – Chairman – Term: August 2009 - 2012
  - Steve Ruggieri – Secretary – Term: January 2012 – 2014
- Introductions around the room
  - Please pass around attendance sheet
- The charter, website, past presentations, etc
- Today's Agenda

# What is the HFIA?

- The High Frequency Industry Association (HFIA) provides an industry driven forum for the interactive exchange of technical ideas and information in the area of High Frequency Communications.

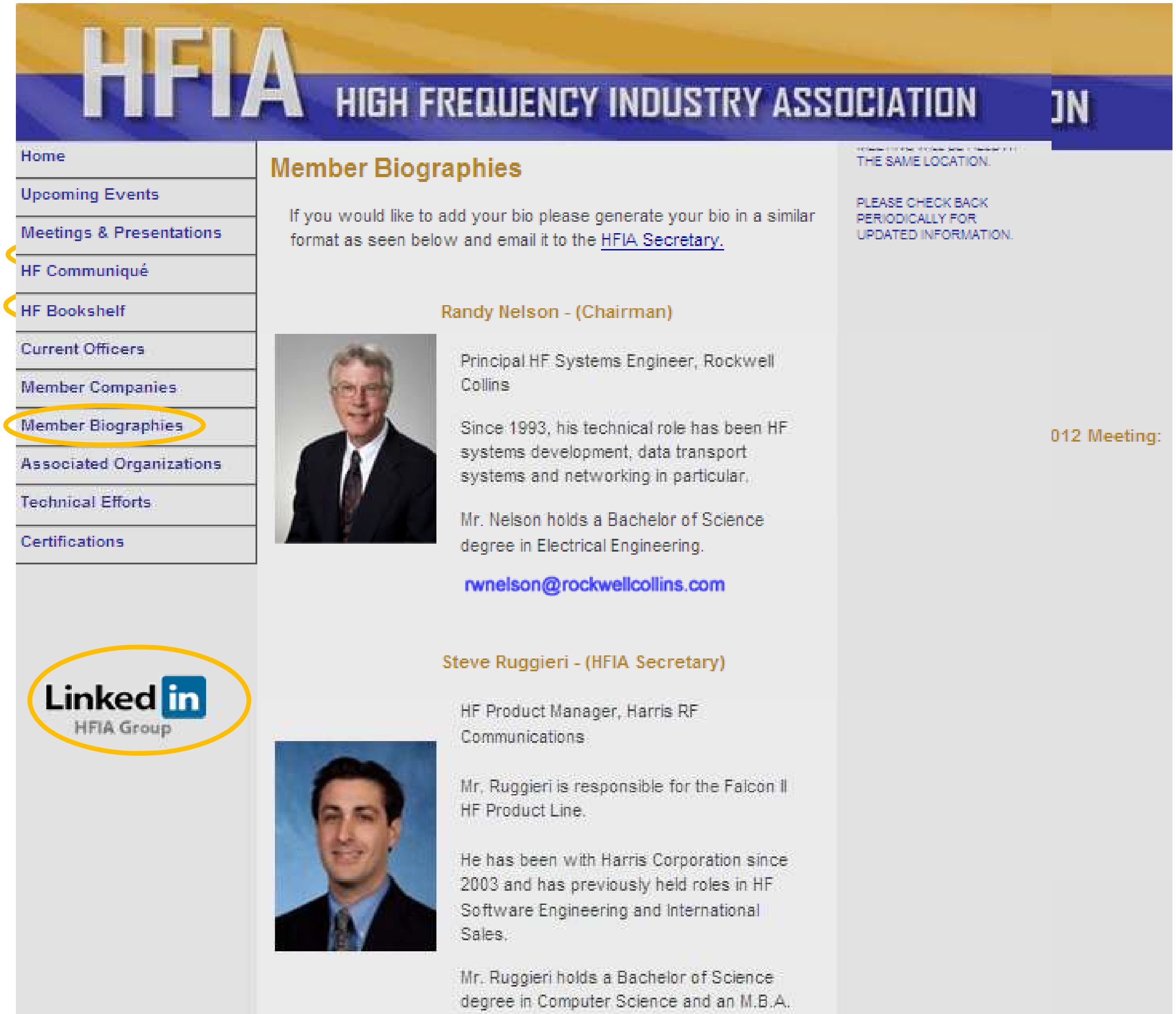
- The High Frequency Industry Association (HFIA) facilitates:

  - Introduction of new technical concepts and approaches to the HF community which might solve communication problems.
  - Forum for government to brief industry or standards, interoperability, and program related activities.
  - Forum for industry to disseminate views on standards, current and forthcoming technology, and interoperability concerns.
  - Mechanism to allow industry to directly contribute to the development of standards.
  - Recommendations and positions by industry to government on standards related issues

HFIA HIGH FREQUENCY INDUSTRY ASSOCIATION

# Upgraded Website

www.hfindustry.com



# Review of Last HFIA Meeting

- The last HFIA Meeting was held on January 26, 2012 in San Diego, California, USA
- Over 40 participants attended the meeting
- The agenda from that meeting follows:

# HFIA Key Agenda Items – January 26, 2012

- Status Report on Last NATO Working Group Meeting - Dr. Eric Johnson
- Status Report on the MIL-STD Technical Advisory Committee - Dr. Eric Johnson
- JITC High Frequency Test Facility – Sandra Maldonado, JITC
- Additional Wideband HF Mid-Latitude Over-the-Air Performance Results – Mark Jorgenson, Rockwell Collins
- Waveform Comparison based on Multipath and Doppler Spread Capability. John Nieto & William Furman, Harris Corporation

HFIA HIGH FREQUENCY INDUSTRY ASSOCIATION

# HFIA Agenda – January 26, 2012

- Are HF BLOS Circuits still a Viable Communications Medium in 2012? – Mark Allen, Antenna Products Corporation
- Wideband HF IP at Sea. Jeremy Mucha, SPAWAR
- Spectrum Sensing as Tool to Analyze Wideband HF Channel Availability. Bill Furman, John Nieto, Colleen Henry, Eric Koski – Harris
- HF XL: An Alternative 4G Solution. Eric Bader, Thales Defence & Security C4I Systems
- Election of HFIA Secretary – Marcelo De Risio term completed and Steve Ruggeri begins a 2 year term

HFIA HIGH FREQUENCY INDUSTRY ASSOCIATION

# Today’s HFIA Meeting

# HFIA Agenda – September 6, 2012

- 9:00 – Welcome, Introductions – Randy Nelson, HFIA Chairman
- 9:10 – Report on Last HFIA Meeting, Today's Agenda – Steve Ruggieri, HFIA Secretary
- 9:30 – Status Report on Last NATO Working Group Meeting – Dr. Eric Johnson
- 9:50 – Status Report on the MIL-STD Technical Advisory Committee – Dr. Eric Johnson
- 10:00 – Spectrum Issues for HF Wideband Communications – Catherine Lamy-Bergot, Thales Defence & Security C4I Systems
- 10:30 – Morning Break
- 10:45 – UK MOD WBHF Trails 2012 – Radio and Modem Performance – Jerry Frost - Rockwell Collins, UK
- 11:15 – Application and STANAG 5066 performance over WB HF – Steve Kille - Isode

# HFIA Agenda – September 6, 2012

- 12:00 – Working Lunch
- 12:15 – HF Spectrum Congestion & Availability for WBHF Data Transport – Mark Jorgenson, Rockwell Collins USA
- 12:45 – Effects of Interleaver Size and FEC Code Constraint OTA for 110C WB HF Waveforms – John Nieto - William Furman, Harris Corp
- 13:15 – Analysis of Chilton Ionosonde Critical Frequency Measurements during Solar Cycle 23 in the Context of Mid-altitude HF NVIS Frequency Predictions (Use of T-Index with VOACAP)
  – Dr. Marcus Walden – Plextek Limited
- 13:45 – Afternoon Break
- 14:00 – Remarks and Closing (group photo)

# Closing Remarks &
# Announcements

# Closing Remarks /Announcements

- Next HFIA Winter Meeting
  - Location – San Diego or Florida?
    - Next Slide has three potential Florida locations
  - Date – TBD

- HFIA Chairman - nominations to be accepted at Winter Meeting

# Closing Remarks /Announcements

Next HFIA Winter Meeting Location, Florida?

# Application and STANAG 5066 performance over Wide-Band HF

Steve Kille

CEO - Isode Ltd

# Overview

- ESII Maritime Wideband HF Project
- Applications Run over WBHF
  - The Headline Success
- Detailed Findings: not all good news
  - New capabilities needed
- STANAG 5066: performance implications
- STANAG 5066 enhancements needed for WBHF

# ESII Maritime Wideband HF Project

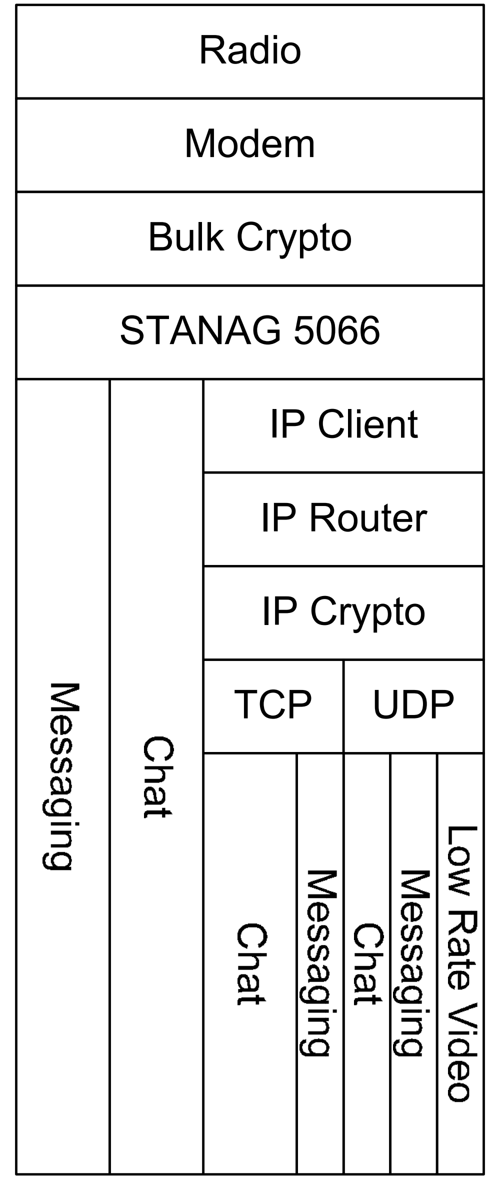
- Seven companies funded through ESII programme
- Research was commissioned by the Defence Science and Technology Laboratory (Dstl)
- Funded by the Ministry of Defence (MOD) Research and Development budget through the MOD's Chief Scientific Advisor.
- The aim was to investigate and demonstrate Commercial off the Shelf (COTS) alternatives to providing Beyond Line of Sight (BLOS) and reach-back capability at lower cost than extant maritime and land-based reach-back systems in a Satellite Communications (SATCOM) denied and/or bandwidth constrained environment.

# The Infrastructure

- Groundwave and Skywave
- Rockwell Collins VHSM 5000 Modems
- Up to 24 kHz band
- 128 kbps achieved
- 64 kbps maintained


# Applications Tested

- Demonstration was a Success
  - Looked good to observers
  - Will discuss things under the hood
- Isode Applications
  - Messaging
  - Directory Synchronization
  - XMPP (Chat)
- IP vs Direct
  - Setup was able to look at operation over IP vs Direct over STANAG 5066
- Low Rate Video
  - Rockwell Collins Demo
  - Observers liked this



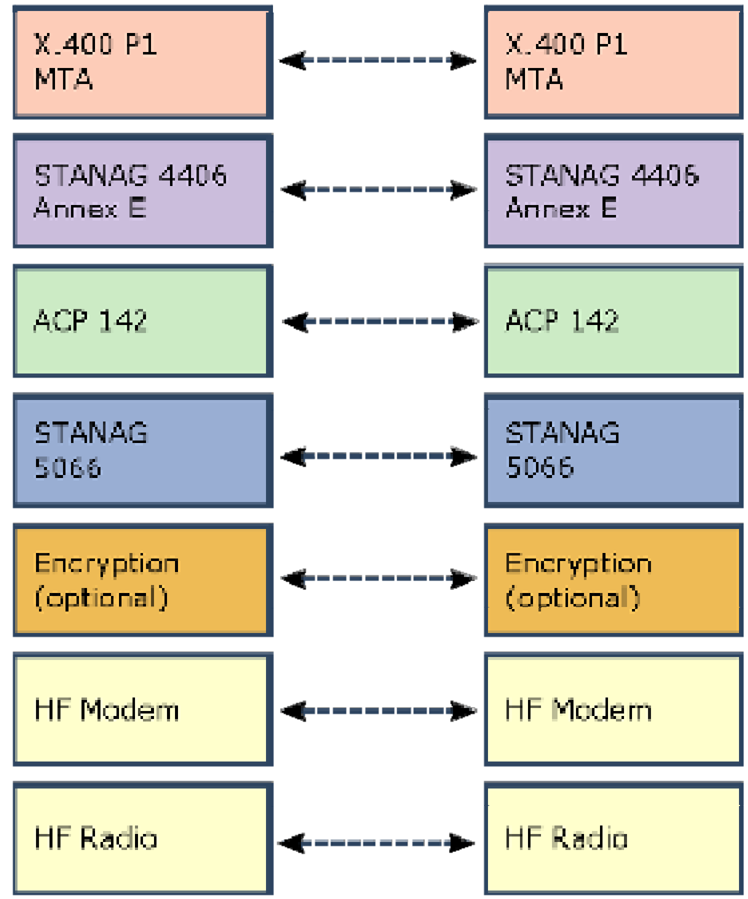
# Key Conclusion: Optimized Protocols

- Data there to support applications
  - There is little point in finely tuning Modem protocols, if your applications are inefficent
  - Even WBHF is slow compared to modern networks, so tuning applications is key
- Tests with Messaging and Chat demonstrated that protocols optimized for HF give vastly superior performance
- Previous tests with standard messaging protocols running over IP over HF had concluded that the approach was not viable

isode

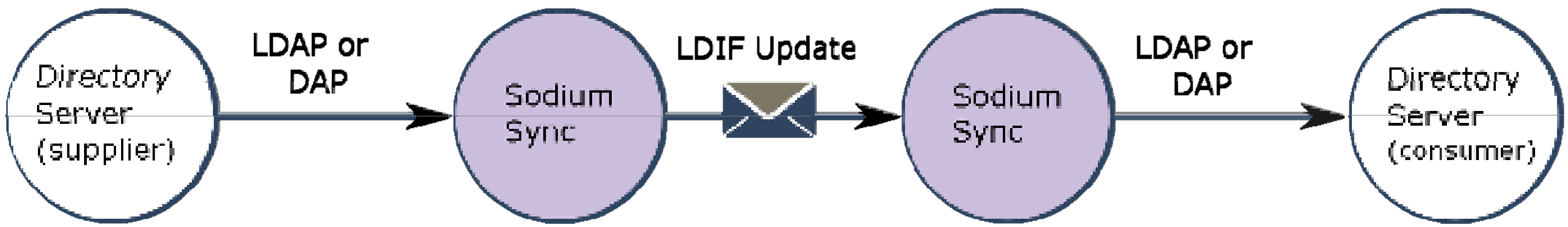
# ACP 142 & Messaging

- ACP 142 ("P-Mul") is a CCEB (five nations) protocol designed for multicast transfer of STANAG 4406 over constrained links
  - Can also be used for Internet email
- Operates over datagram protocol
  - UDP over IP; or
  - UDOP over STANAG 5066 (as shown)
- Gives effective utilization of up to 50%
  - This is seen as acceptable: MUCH better than previous results
  - Some tests gave lower results
  - Not all data clearly explained
- I would expect higher results to be achievable (70%)




isode

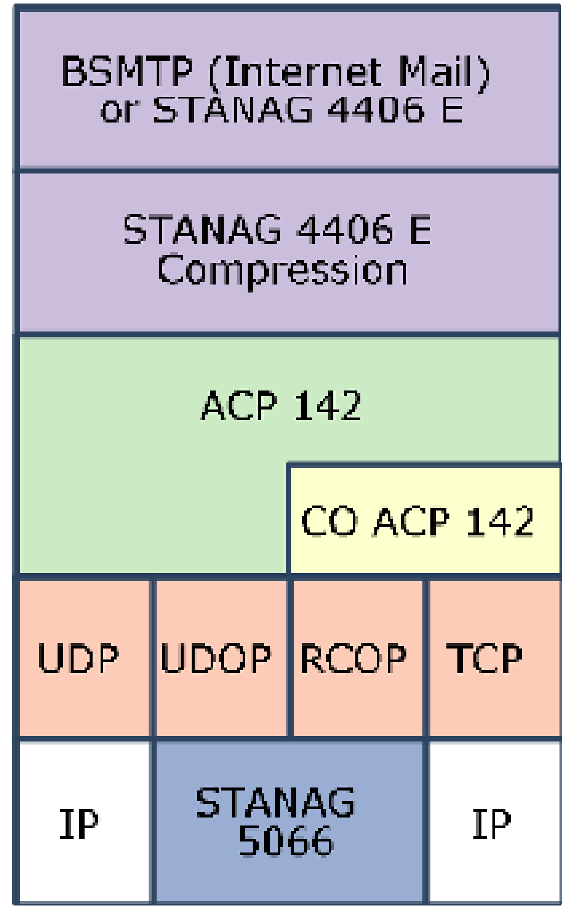
# Directory Synchronization



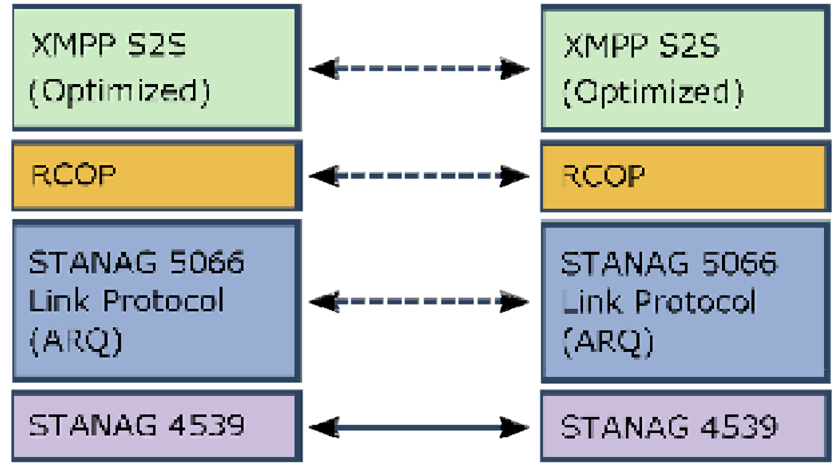

- Standard directory access (LDAP) and replication work badly over HF
- Isode's Sodium Sync approach allows incremental replication of directory over email
- Operationally can lead to massive cost savings (why it was in the demo)
- Uses messaging over HF, so protocol measurements are uninteresting

# ARQ Messaging

- ACP 142 is designed to operate over datagram (multicast)
- Datagram service naturally maps to non-ARQ
- Point to Point links can use STANAG 5066 ARQ
- Isode's Connection Oriented ACP 142 optimizes ACP 142 for ARQ links
- CO ACP 142 achieved trial utilization of up to 75% (as opposed to 50% for ACP 142)



# XMPP




- XMPP (eXtensible Messaging and Presence Protocol) is open standard being widely adopted by military, for 1:1 chat, multi-user chat and presence
- Instant messaging is relatively easy over HF
  - Data Volumes are low
  - Just need to avoid handshakes
- Standard XMPP has a lot of handshakes on startup
- General approach is to communicate Server to Server (S2S) over the slow link to isolate users from the network
- Isode's optimized S2S Protocol is zero handshake
- Good performance demonstrated in the trials
  - User delays tie to HF radio turnaround times

isode

# IP over HF

- Use of IP over HF appears “politically desirable”
- ACP 142 measurements were typically 10-20% worse when using IP
- The difference will be accentuated if:
  - Link speed varies (very likely with HF)
  - Error conditions or other applications
- We did not get much time for application testing when operating OTA
- Key problems:
  - Lack of flow control with IP makes it hard to optimize link utilization
  - Hard to benefit from STANAG 5066 ARQ
    - Unreliable Datagram (IP) is an architecturally poor choice over ARQ

# Application Conclusions

- Use application protocols optimized for HF to gain best performance
  - ACP 142 (Non-ARQ)
  - Connection Oriented ACP 142 (ARQ)
  - Optimised XMPP S2S (ARQ)
- Use ARQ whenever possible (and protocols optimized for ARQ)
- Avoid use of IP over HF

# STANAG 5066: Link Protocol is Key

- HF Modems (and Radios) present awkward characteristics to the layers above:
  - Variable speed (e.g., with STANAG 4539 or MIL-STD-110-110C)
  - Long turnaround times
- An optimized link protocol is vital.   Standardized choices:
  - STANAG 5066 (used here)
  - STANAG 4538
- Details of the implementation matter
  - This layer has at least as much impact on the performance as applications

# STANAG 5066 Performance Results

| | ESII Pilot | Isode Tests |
|---|---|---|
| Non-ARQ Raw | 90% | 90% |
| ARQ Raw | 80% | 85% |
| CO ACP 142 | 75% | 85% |

- "Raw" STANAG 5066 numbers tested using Isode STANAG 5066 Console
- Comparative Tests in Isode labs using RapidM RC66 STANAG 5066 Server
  - Believe that the STANAG 5066 Server was the only difference
- Suggests that details of STANAG 5066 server can significantly impact performance
- I suspect that a number of detailed anomalies in the pilot tests (performance much lower than expected) were down to STANAG 5066 issues
- STANAG 5066 Tracing is Important

isode

# STANAG 5066 Queue Length

- Queue Strategy & Queue Length is a key design decision for a STANAG 5066 server (stack) implementation
  - APDUs provided by S5066 Client are queued for transmission
  - When queue is full, S5066 server flow controls the application
  - Choice  of queuing approach left to implementer by the standard
- The ESII S5066 Server used very long queues (effectively infinite)
  - This made application tuning very difficult
  - Led to suboptimal applications performance
  - Would have caused many more problems in challenging radio conditions

# STANAG 5066: Why Short Queues?

- Application Timers
  - Applications need timers to deal with error situations
  - Short timers lead to better responsiveness
  - Timer need to allow for data in S5066 queues, so long queues are awkward
- Bandwidth Adaptation
  - HF Bandwidth can vary significantly (75 bps -128 kbps; outages; sharing with voice)
  - Application cannot determine effective bandwidth
  - STANAG 5066 Flow Control from Queue allows application to react to changes
- Priority Handling
  - If a FLASH message arrives, short queue allows the application to send the data out as quickly as possible

# STANAG 5066: DPDU Size Tuning

| | 4800 bps | 9600 bps |
|---|---|---|
| CO ACP 142 Utilization (ARQ) | 75% | 50% |

- Utilization at 9600 seemed very low
- Increasing DPDU size from 273 to 1023 (Max) led to better throughput at 9600 than 4800
- Analysis of max transmit time (constrained by 128 window) shows why

| | 4800 bps | 9600 bps |
|---|---|---|
| 273 byte DPDU | 58 seconds | 29 seconds |
| 1023 byte DPDU | 127.5 seconds ** | 109 seconds |

- With reduced transmit time, turnaround time is significantly impacting performance

isode

# STANAG 5066 degradation over WBHF: Theory

| | 9600 bps | 20 kbps | 64 kbps | 128 kbps |
|---|---|---|---|---|
| Max Transmit Time | 109 seconds | 52 seconds | 16 secs | 8 secs |

- STANAG 5066 Designed for Maximum Speed of 20 kbps
  - STANAG 5066 Annex G, Section 3.1
  - These max transmit times show why: because of long turnaround times you need long transmit time (1-2 minutes) to get good link utilization over HF
- We estimated that for WBHF at top speed, that performance for ARQ traffic would be significantly degraded by this, and that link utilization of 30-50% would be expected at 128 kbps
  - Exact utilization will be critically dependent on turnaround time

# STANAG 5066 degradation over WBHF: Observations

| | ARQ | Non-ARQ |
|---|---|---|
| Utilization at 128 kbps | 42% | 62% |

- Performance measurements made at STANAG 5066 Layer, using Isode STANAG 5066 Console tool
- Measurements made over Skywave link under good conditions
- ARQ number fits with the theory
- Non-ARQ number should be much higher
    - Perhaps an S5066 implementation issue

# STANAG 5066 enhancements needed for WBHF

- We need to update STANAG 5066 to efficiently support WBHF
- Changes straightforward, but backwards compatibility is not possible
- Two options:
  1. Increase Max DPDU Size.
  2. Increase Window Size
- It may make sense to do both
  - Useful to repeat tests on optimum DPDU size
    - 1992/93 Studies (Annex H Section 7 of STNAG 5066) suggest 100-200 bytes is the optmum
    - For higher speeds it is possible that a larger DPDU size is optimal
- Likely to be desirable to increase Window Size
  - Analogous to TCP Extended Window

isode

# STANAG 5066 Conclusions

- STANAG 5066 Server is as important as Application and Modem for performance tuning
- Recommend that future pilots measure using more than one STANAG 5066 server
- Good tracing and diagnostics are vital for performance analysis
- STANAG 5066 Servers should have short queues
- STANAG 5066 needs protocol modifications to support WBHF efficiently
  - NATO needs to take an Action here

# Isode Product Pre-Announcement

- We are building an Isode STANAG 5066 Server
  - Cross Platform
  - Client/Server Management (key for large systems)
  - Modem Independent:
    - RapidM Modems are initial target
  - Optimized for WBHF
  - STANAG 5066 ed3 support, including Annex L (WRTP)
    - Key for interoperable multi-node deployments
- Target 1: Ability to deploy Isode applications over any Modem set
- Target 2: Adoption as OEM product by Modem Vendors
- We are looking for partners

Any Questions?

Plextek

# Analysis of Chilton Ionosonde Critical Frequency Measurements During Solar Cycle 23 in the Context of Midlatitude HF NVIS Frequency Predictions (Use of T-Index with VOACAP)

Marcus C. Walden
marcus.walden@plextek.com

HFIA Meeting, York, UK
6 September 2012

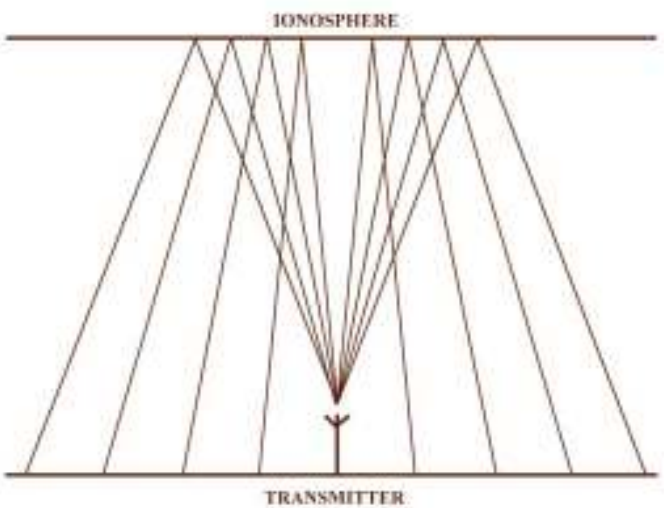
Plextek

# Overview of Presentation

- Introduction
- Motivation for this work
- MUF definitions
- HF propagation predictions
- Chilton ionosonde measurements
- Comparison methodology
- Results
- Summary

# Introduction

- NVIS: Near-Vertical Incidence Skywave
- HF ionospheric propagation technique
- Low HF frequencies (typically 2-10 MHz)
- High angle radiation
- Short ranges (up to 500 km)
- No skip zone
- Terrain insensitive



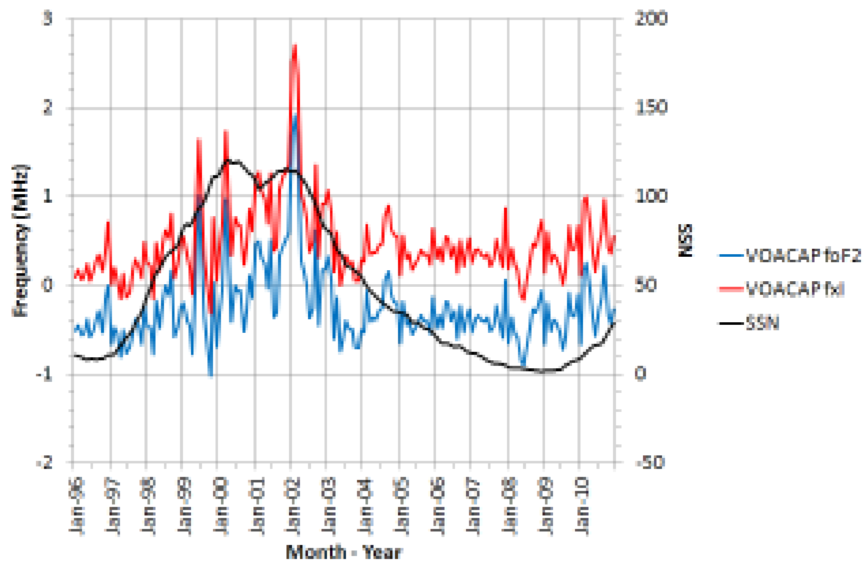
Plextek

# Motivation for this Work (1)

- Follow on from IET IRST 2009
  - Relevance (and limitations) of extraordinary-wave (x-wave) in NVIS propagation
  - HF monthly-median prediction software (e.g. ASAPS, VOACAP) considers x-wave for zero-distance MUF prediction
- Follow on from IET IRST 2012
  - Chilton ionosonde critical frequency measurements
  - ASAPS and VOACAP MUF predictions
  - Upper and lower decile predictions
  - Time period 1996-2010 (covering solar cycle 23)

# Motivation for this Work (2)

- IRST 2012 VOACAP Results
  - Vertical-incidence frequency predictions for Chilton conservative (particularly around solar maximum)
  - Predictions show significant errors during solar cycle maximum
  - Diverges from trends when T-SSN > ~15
- This work uses the Australian monthly T-index instead of SSN as input to VOACAP



# MUF Definitions (1)

- ITU-R Recommendation P.373-8
  - Definitions of maximum and minimum transmission frequencies
- MUF – Maximum useable frequency
- Basic MUF
  - Ionospheric refraction alone
- Operational MUF
  - Considers system parameters
    (e.g. transmit power, antenna gains, modulation, noise, etc.).
- Basic and operational MUF are median values

# MUF Definitions (2)

- Optimum working frequency (OWF)
  - Frequency exceeded by operational MUF during 90% of specified period (usually a month)
- Highest probable frequency (HPF)
  - Frequency exceeded by operational MUF during 10% of specified period (usually a month)
- ITU-R Rec. P.373 places emphasis on ‘operational’

# HF Prediction Software (1)

- ASAPS (Advanced Stand Alone Prediction System)
  - Version 5.4
  - GRAFEX predictions
  - Monthly T-index (effective sunspot number)

# HF Prediction Software (2)

- VOACAP (Voice of America Coverage Analysis Program)
  - Version 09.1208
  - Method 9 (HPF-MUF-FOT graph)
  - International smoothed sunspot number (SSN)
    - SSN is 12-month running mean value
    - Recommended by George Lane for use with VOACAP
  - Evaluate monthly T-index with VOACAP

# HF Prediction Software (3)

- Global *foF2* maps
  - Sunspot numbers of 0 and 100
  - Interpolation for different sunspot numbers
  - IPS-own *foF2* maps (ASAPS)
  - CCIR coefficients (VOACAP)
- Predictions for median, upper and lower decile frequencies
  - MUF, UD and OWF (ASAPS)
  - MUF, HPF and FOT (VOACAP)

# HF Prediction Software (4)

- ASAPS (GRAFEX) and VOACAP (Method 9) predictions relate to basic MUF
  - Not operational MUF
- Analysis presented here relates to basic MUF
- Knowledge of basic MUF does not guarantee successful link
  - Link budget analysis required

# Zero-Distance MUF

- Underlying theory behind ASAPS and VOACAP
  - ITU-R Rec. P.533 and IONCAP respectively
- Zero-distance MUF (i.e. vertical incidence)

$$MUF \approx foF2 + \frac{f_H}{2}$$

  - $f_H$ is electron gyrofrequency
- Approximation for extraordinary wave critical frequency *fxF2*
  - Approximation not valid for long distance links
  - Refer to literature for QL and QT propagation (e.g. Davies, *Ionospheric Radio*)

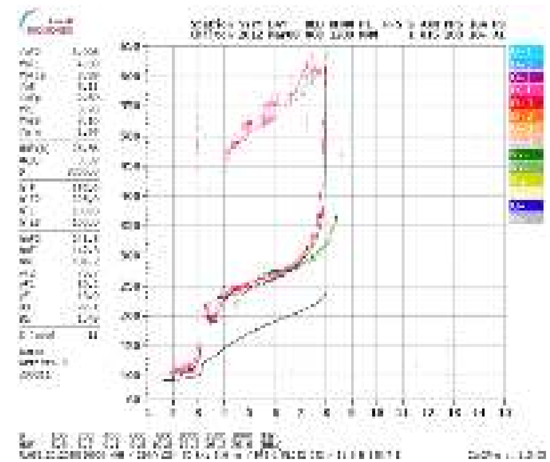
# Chilton Ionosonde Measurements (1)

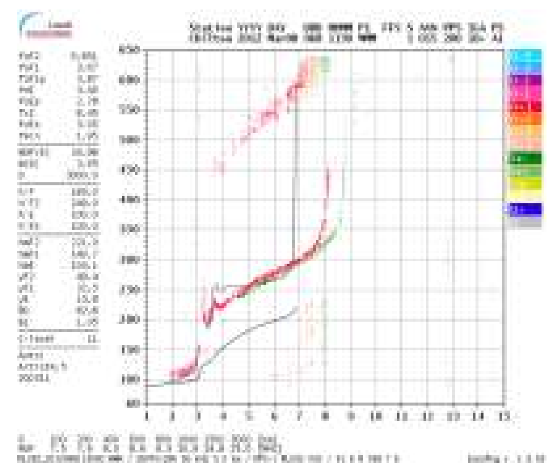
- Chilton ionosonde
  - 51.6°N, 1.3°W
- Data analysed for period 1996-2010
  - Manually scaled data (1996-1999)
  - Autoscaled data (2000-2010)

# Chilton Ionosonde Measurements (2)

- Autoscaling with ARTIST
  - Automatic Real-Time Ionogram Scaler with True height
- Assumption that ARTIST errors occur infrequently
  - Assumption that errors more likely to affect upper and lower deciles
  - Expert system for validating ionograms “fails” one-third

McNamara, L. F. (2006), Quality figures and error bars for Autoscaled Digisonde vertical incidence ionograms, *Radio Sci*., 41, RS4011, doi:10.1029/2005RS003440





# Chilton Ionosonde Measurements (3)

- Critical frequency measurements
  - *foF2*
  - *fxF2* (not a standard ionogram output parameter)
- Spread *F* Index, *fxI*
  - Maximum *F* region frequency recorded
  - Measure of spread *F* associated with overhead ionosphere
- When spread *F* is uncommon
  - Median *fxI* equal to median *fxF2*
- For this analysis, *fxI* used in lieu of *fxF2*

# Chilton Ionosonde Measurements (4)

- Sounding rates varied from 1996 to 2010
  - Hourly in 1996
  - Every 10 minutes in 2010
- Ionosonde measurements grouped according to timestamp
  - Time rounded to nearest hour
  - Comparison with ASAPS and VOACAP hourly predictions
- Calculated for each hour
  - Median *foF2* and median *fxI*
  - Upper and lower decile values (10% and 90%) for *foF2* and *fxI*

# Comparison Methodology

- Measurements compared with predictions
  - Median (MUF)
  - Upper decile (UD/HPF)
  - Lower decile (OWF/FOT)
- Matrix of differences for each hour of each month
  - Mean and standard deviation
- Assess
  - Diurnal variation
  - Month-to-month variation
  - Overall performance (1996-2010)

Plextek

# Comment on Results

- Conclusions from this work specific to Chilton
  - More generally the UK
- ASAPS and VOACAP predictions depend on non-identical global *foF2* maps
- Absolute/relative prediction errors depend on geomagnetic location

# Overall MUF Differences (1996-2010)

| Measurement (50%) | Prediction | Mean (MHz) | Standard Deviation (MHz) |
|---|---|---|---|
| *fxI* | ASAPS MUF | 0.09 | 0.25 |
| *foF2* | | -0.65 | 0.25 |
| *fxI* | VOACAP (SSN) MUF | 0.48 | 0.31 |
| *foF2* | | -0.25 | 0.30 |
| *fxI* | VOACAP (T) MUF | 0.34 | 0.29 |
| *foF2* | | -0.40 | 0.28 |

- ASAPS MUF prediction tended to *fxI* (*fxF2*)
  - Consistent with MUF equation
- VOACAP conservative for Chilton
  - Lower error using T-index

# Overall OWF/FOT Differences (1996-2010)

| Measurement (90%) | Prediction | Mean (MHz) | Standard Deviation (MHz) |
|---|---|---|---|
| *fxI* | ASAPS OWF | 0.37 | 0.32 |
| *foF2* | | -0.36 | 0.32 |
| *fxI* | VOACAP (SSN) FOT | 0.74 | 0.37 |
| *foF2* | | 0.01 | 0.37 |
| *fxI* | VOACAP (T) FOT | 0.63 | 0.34 |
| *foF2* | | -0.10 | 0.35 |

- ASAPS conservative for Chilton
- VOACAP more conservative for Chilton
  - FOT prediction tended to *foF2*
  - Small error reduction using T-index

# Overall UD/HPF Differences (1996-2010)

| Measurement (10%) | Prediction | Mean (MHz) | Standard Deviation (MHz) |
|---|---|---|---|
| *fxI* | ASAPS UD | -0.08 | 0.36 |
| *foF2* | | -0.8 | 0.36 |
| *fxI* | VOACAP (SSN) HPF | 0.36 | 0.40 |
| *foF2* | | -0.37 | 0.40 |
| *fxI* | VOACAP (T) HPF | 0.18 | 0.40 |
| *foF2* | | -0.54 | 0.39 |

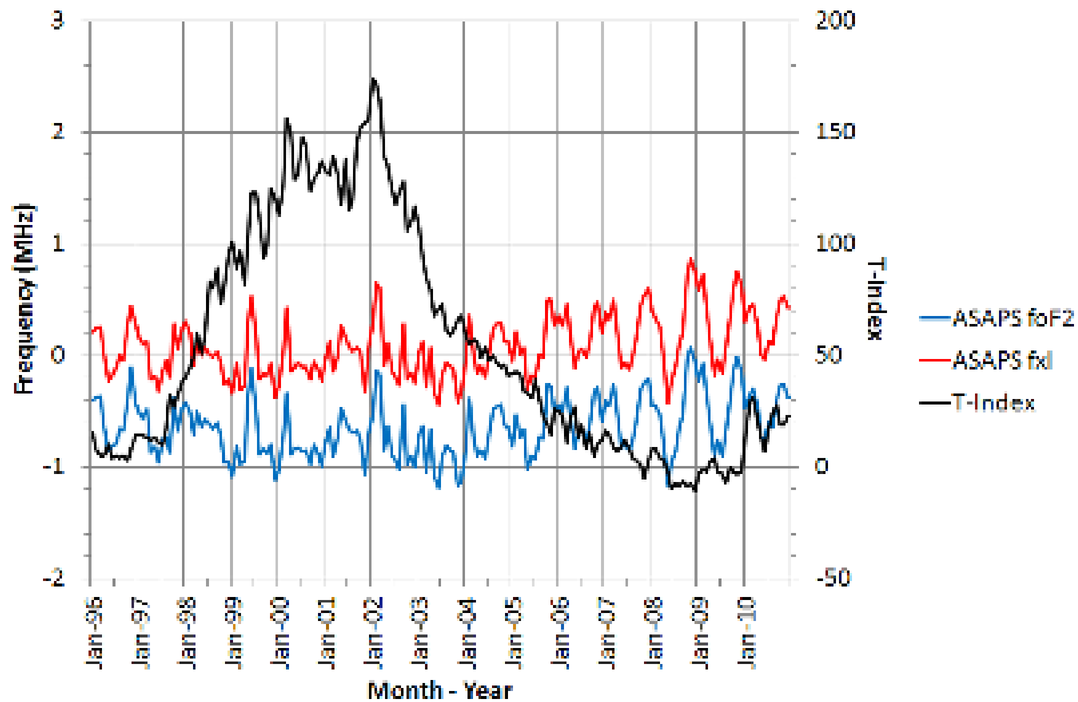
- ASAPS UD prediction tended to *fxI* (*fxF2*)
  - Consistent with MUF equation
- VOACAP conservative for Chilton
  - Lower error using T-index (more consistent with MUF equation)

# Results – ALE Frequency Planning

- ALE frequency planning (George Lane)
  - Follow diurnal maximum observed frequency (MOF) variation
  - Minimum frequency below lowest FOT/OWF
  - Maximum frequency close to maximum HPF/UD
- ASAPS might be better than VOACAP for generating UK ALE frequency scan lists
  - Based on overall results
  - VOACAP overall results show lower error using monthly T-index
- CAUTION – Still require full link budget analysis

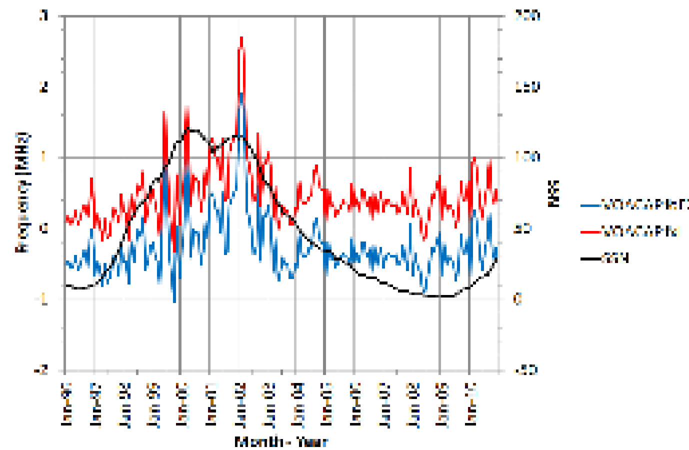
# Results – Monthly Variation (1)

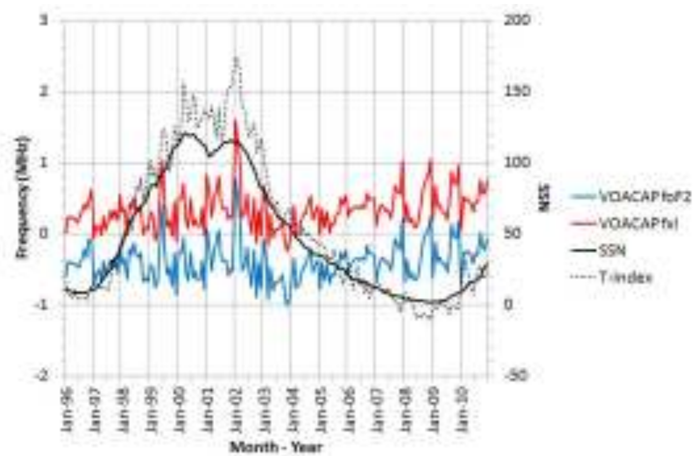
- Difference between median *foF2*/*fxI* and ASAPS MUF
  - Monthly average
  - Also T-index
- Cyclical pattern evident during solar minimum
- ASAPS MUF tended to *fxI*



# Results – Monthly Variation (2)

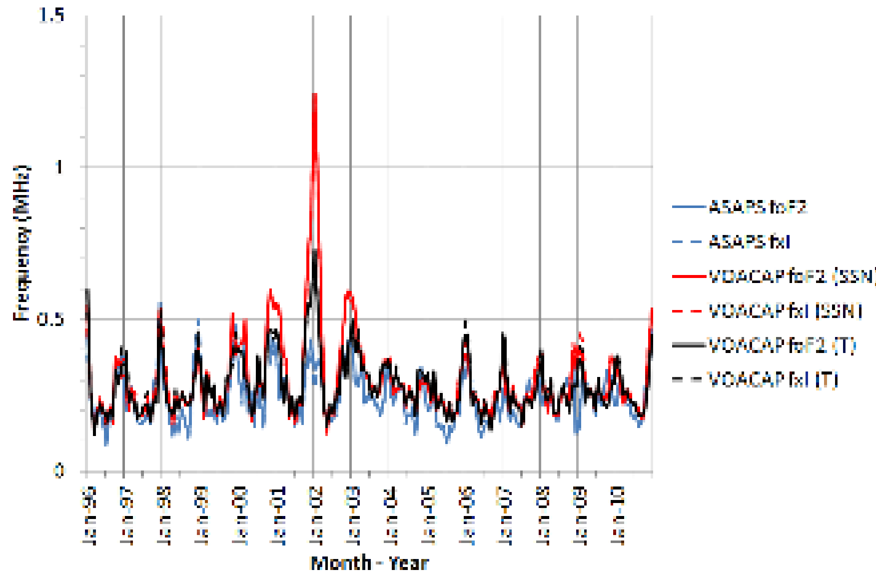
- Difference between median *foF2*/*fxI* and VOACAP MUF
  - Monthly average, SSN and T-index
- Cyclical pattern not evident
- VOACAP using SSN
  - Conservative MUF prediction
  - Larger errors during solar maximum
- VOACAP using T-index
  - Lower errors overall
  - Slightly larger during solar minimum



# Results – Monthly Variation (3)

- Difference between median *foF2*/*fxI* and ASAPS and VOACAP MUF
  - Average monthly standard deviation
- Both show cyclical pattern
  - Larger in winter




- Standard deviation generally comparable
  - VOACAP standard deviation larger during winter around solar maximum with SSN
  - VOACAP standard deviation lower using T-index

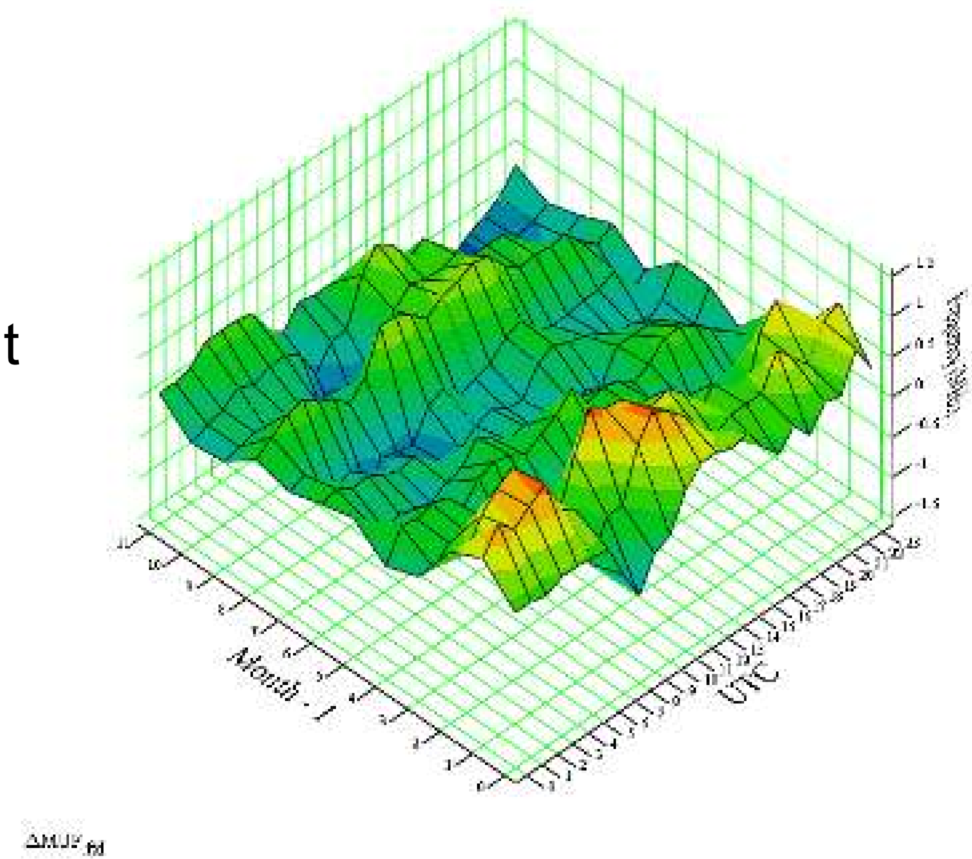
Plextek

# Results – Monthly Variation (4)

- Cyclical pattern
  - Difficulty predicting *F2* region ‘*winter anomaly*’
- VOACAP solar maximum discrepancies
  - ASAPS uses monthly T-index
  - VOACAP uses SSN (12-month running mean)
  - *‘Ersatz’* indices (e.g. T-index) outperform direct indices (e.g. SSN)
  - Sunspot number is only circumstantial index
    i.e. no physical basis for direct relationship between sunspot number and ionospheric response

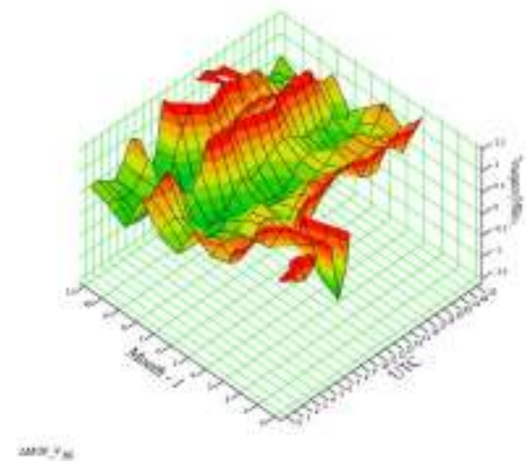
# Results – Variation over Year 2002 (1)

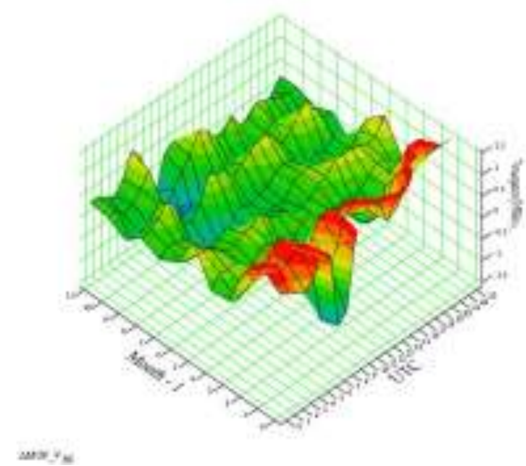
- Difference between median *fxI* and ASAPS MUF (2002)
- Large positive differences day and night during winter and early spring
- Some months in 2002 show negative differences during day and night



# Results – Variation over Year 2002 (2)

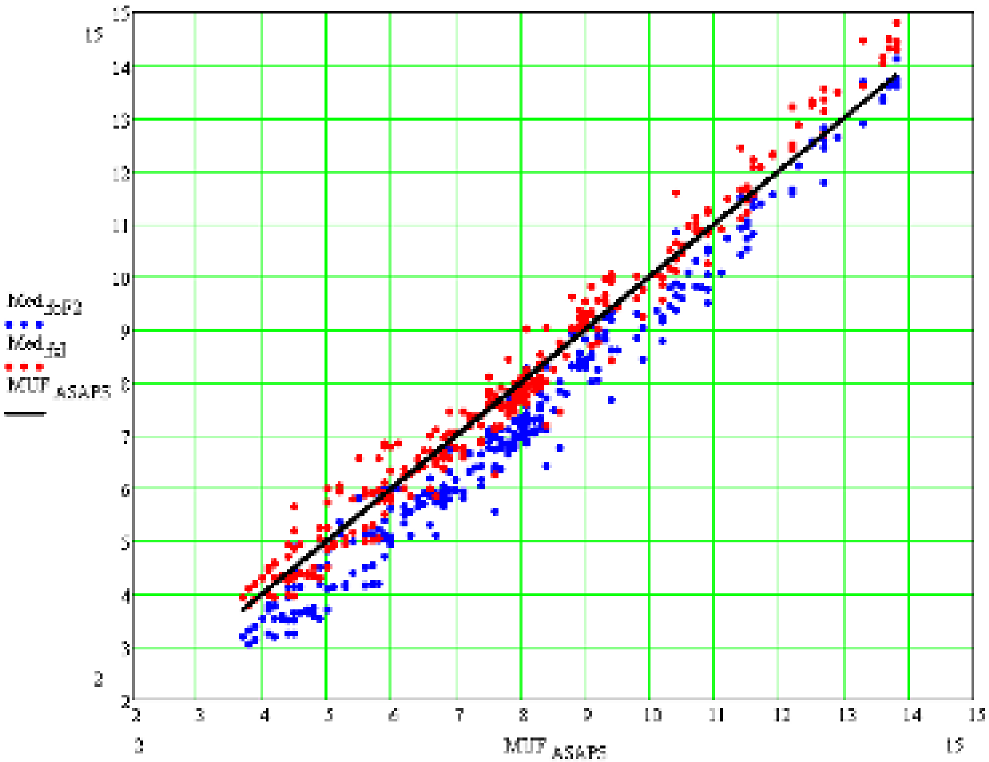
- Difference between median *fxI* and VOACAP MUF (2002)
  - Note truncated vertical scale
- SSN
  - Large positive differences at day and night for many months
  - Maximum difference ~4.5 MHz
- T-index
  - Significant improvement over whole year
  - Large positive difference remains during winter and early spring





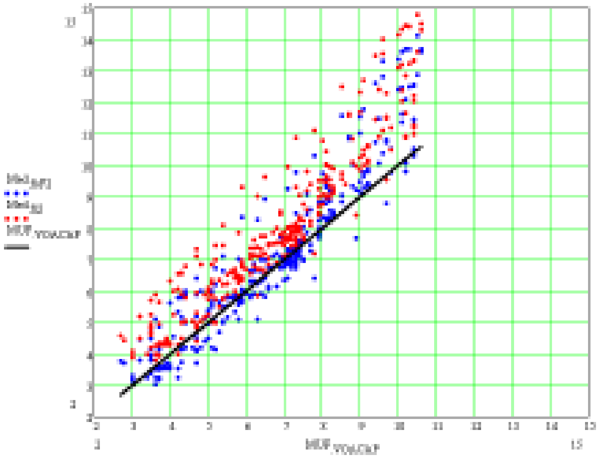
# Results – Variation over Year 2002 (3)

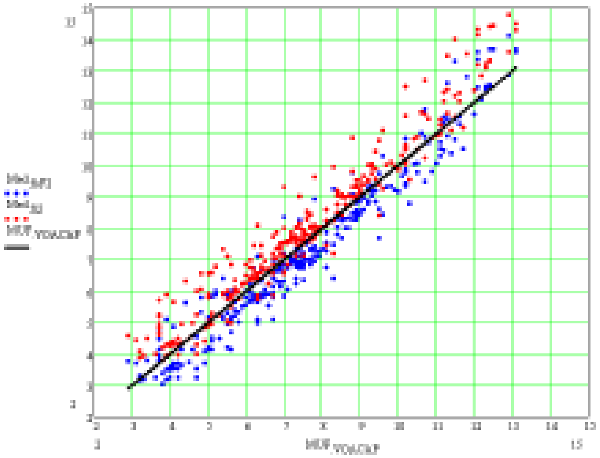
- Measured *foF2* and *fxI* versus ASAPS MUF (2002)
- ASAPS MUF prediction generally consistent with MUF equation except above ~12 MHz



# Results – Variation over Year 2002 (4)

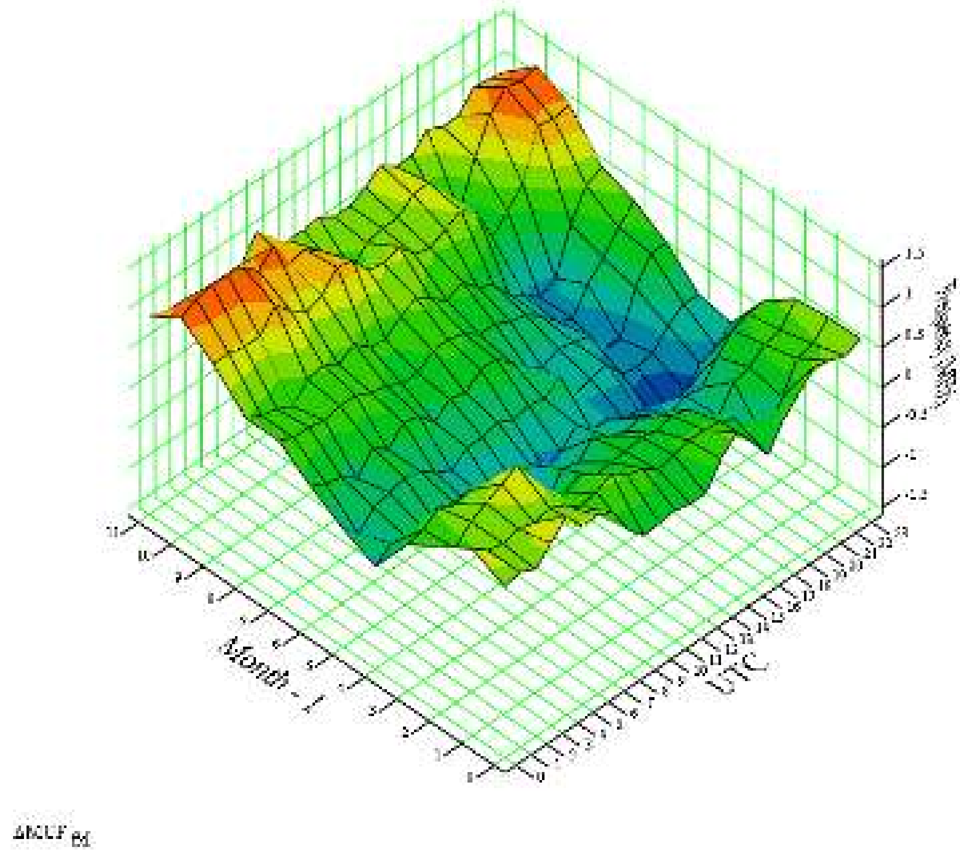
- Measured *foF2* and *fxI* versus VOACAP MUF (2002)
- SSN
  - VOACAP MUF prediction tended to *foF2*
  - Large differences above ~8 MHz
- T-index
  - Significant reduction of differences
  - Predictions still tended to *foF2*
  - Some large differences above ~11 MHz





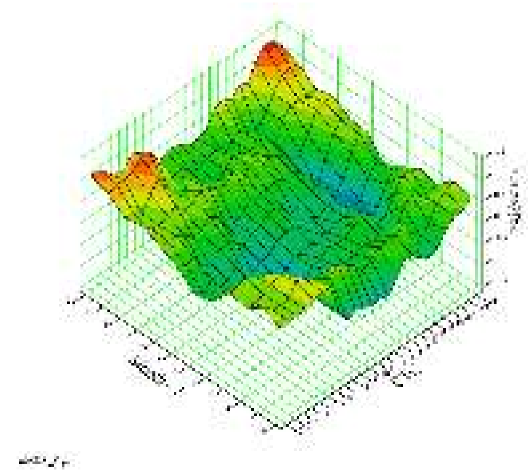
# Results – Variation over Year 2008 (1)

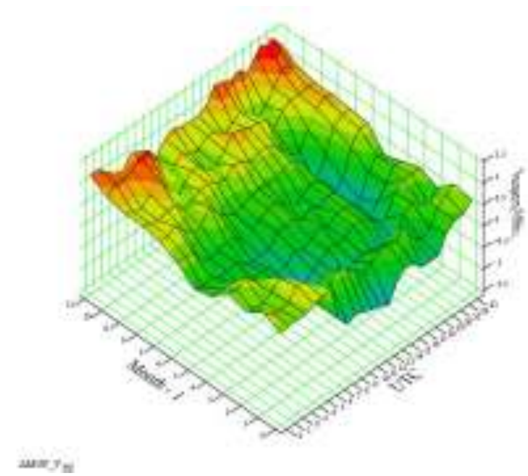
- Difference between median *fxI* and ASAPS MUF (2008)
- Large positive differences at night during autumn and winter
- Summer months in 2008 show negative differences during day



# Results – Variation over Year 2008 (2)

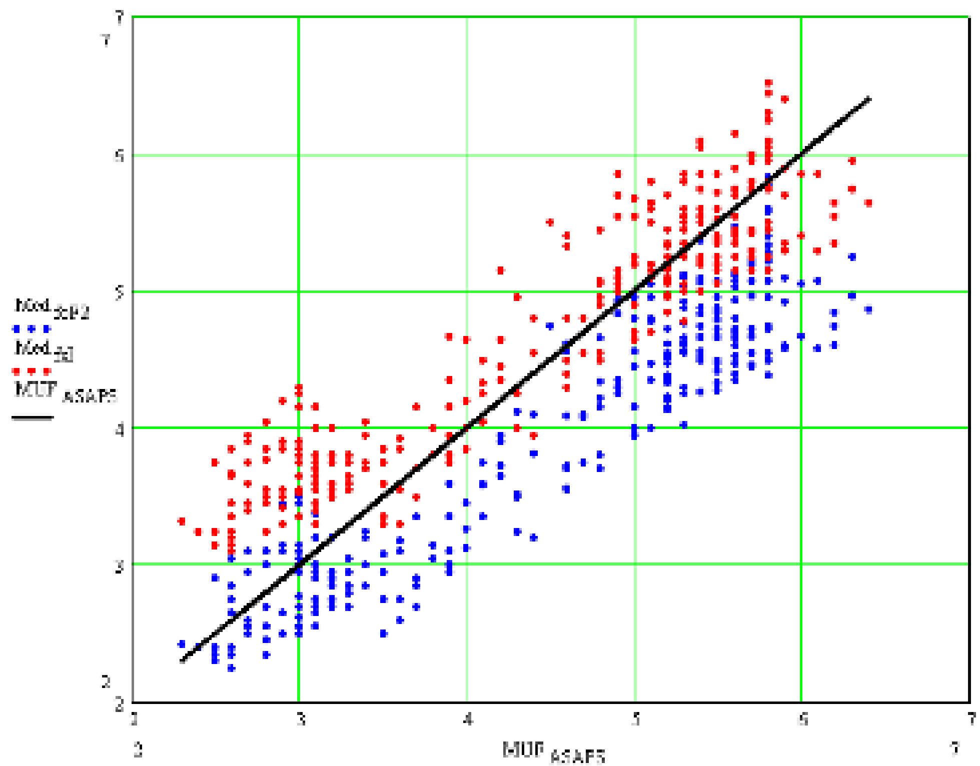
- Difference between median *fxI* and VOACAP MUF (2008)
- SSN
  - Large positive differences at night during autumn and winter
- T-index
  - Large positive differences at night during autumn and winter
  - Degradation in daytime during autumn and winter





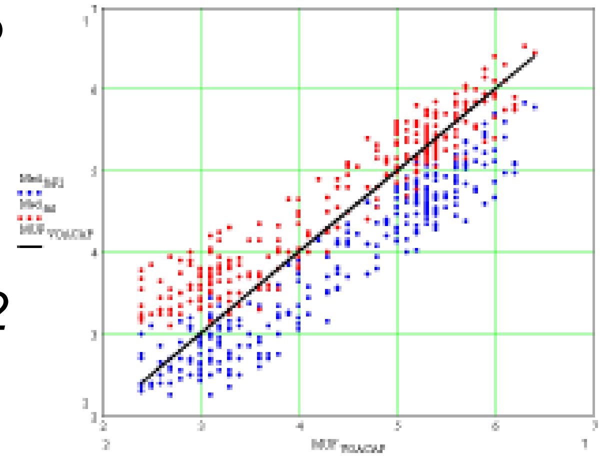
# Results – Variation over Year 2008 (3)

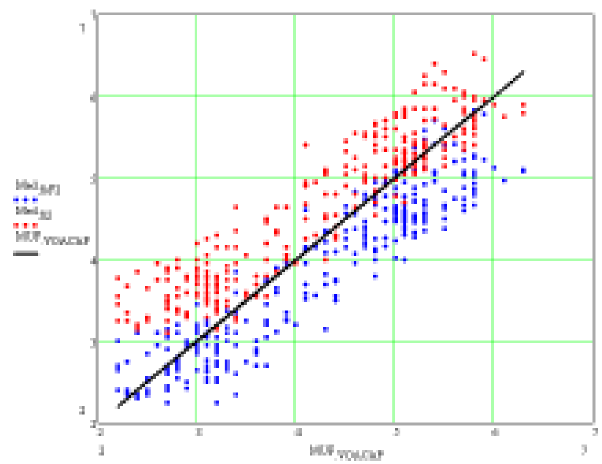
- Measured *foF2* and *fxI* versus ASAPS MUF (2008)
- ASAPS MUF prediction tended to *foF2* below ~4 MHz



# Results – Variation over Year 2008 (4)

- Measured *foF2* and *fxI* versus VOACAP MUF (2008)
- Both SSN and T-index
  - VOACAP MUF prediction tended to *foF2* below ~4 MHz
- T-index
  - Less consistent with MUF equation





Plextek

# Results – Variation over Year 2008 (5)

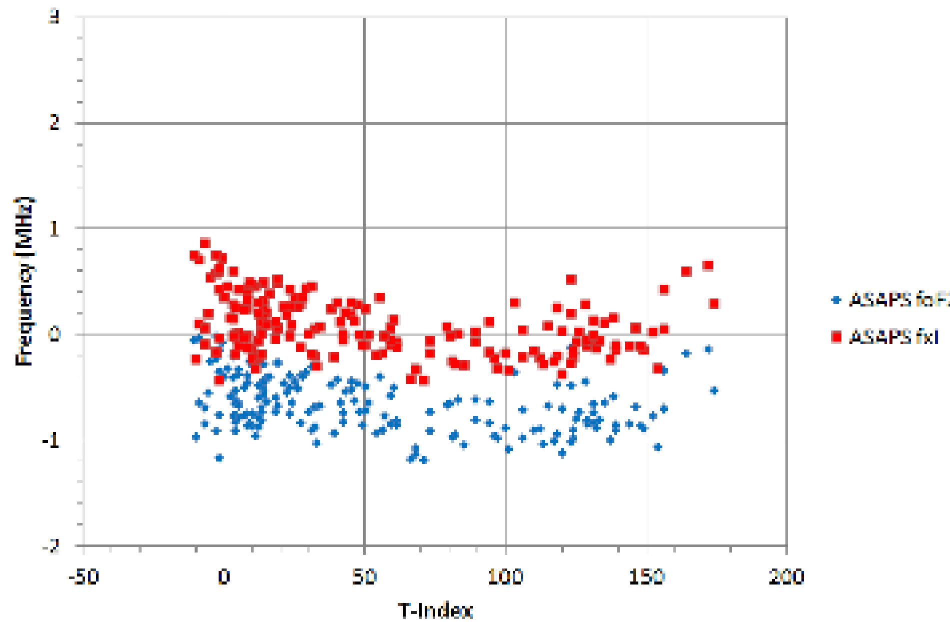
- Development of IONCAP
  - George Lane
    “There was very little data below 4 MHz but there was some for short paths that did go down to 2 MHz.”
- IONCAP developers modelled a fit to these cases
  - Understood to have given good results for NVIS situations
- Presumably, this also applies for REC533 and ASAPS

# Results – Variation over Year 2008 (6)

- Errors in *foF2* maps
- Errors due to ionogram autoscaling
  - Chilton autoscaled *foF2* measurements show positive errors at LF
    - Bamford, R. A., R. Stamper, and L. R. Cander (2008), A comparison between the hourly autoscaled and manually scaled characteristics from the Chilton ionosonde from 1996 to 2004, *Radio Sci.*, 43, RS1001, doi:10.1029/2005RS003401
- Spread *F*
  - High-latitude spread *F* begins at ~40° geomagnetic latitude
  - High-latitude spread *F* occurs mostly at night

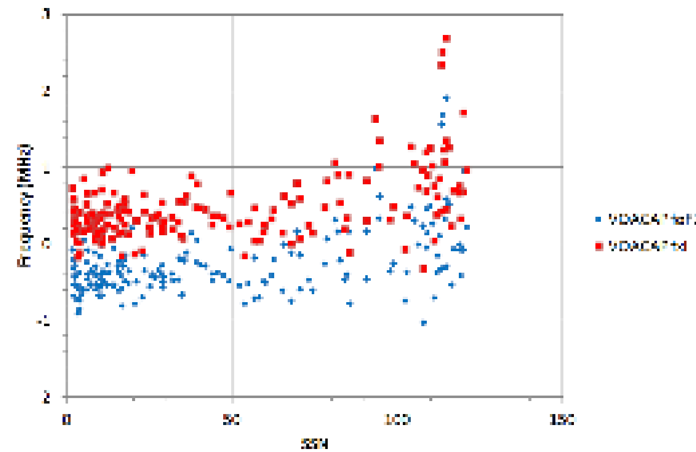
# Results – Solar Indices (1)

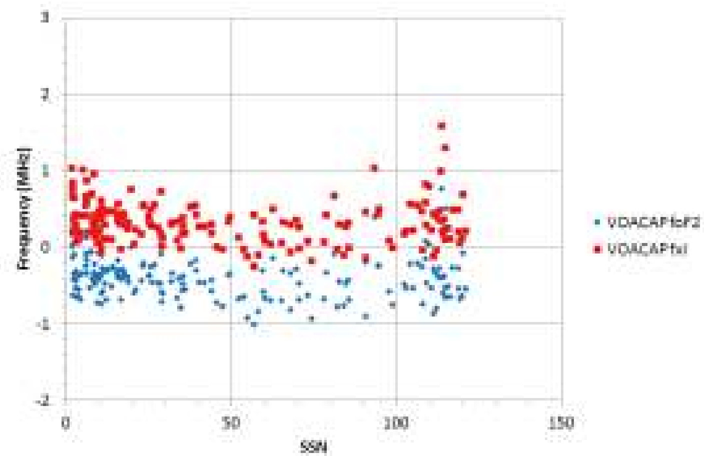
- Difference between median *foF2*/*fxI* and ASAPS MUF against T-index
- ASAPS MUF generally within ~10% of fxI
  - Except at low or negative T-index values
    - Autoscaling errors at LF?
    - Spread *F*?



# Results – Solar Indices (2)

- Difference between median *foF2/fxI* and VOACAP MUF against SSN (using SSN and T-index)
- SSN
  - Large differences for high SSN (i.e. > ~100)
- T-index
  - Reduction in differences for medium/large SSN (i.e. > ~50)
  - Slight increase at low SSN?

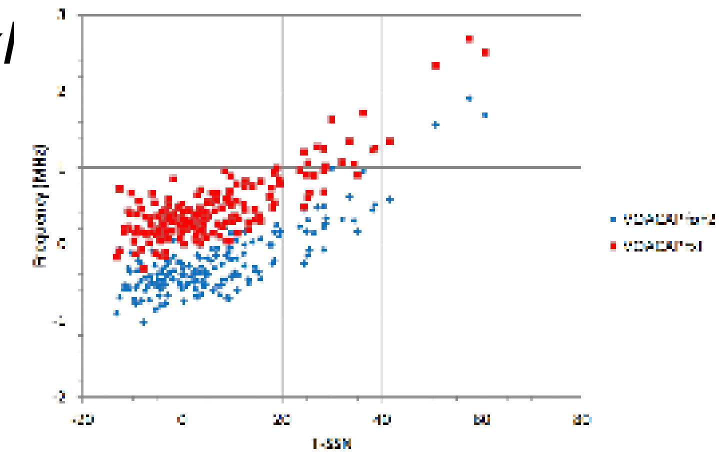


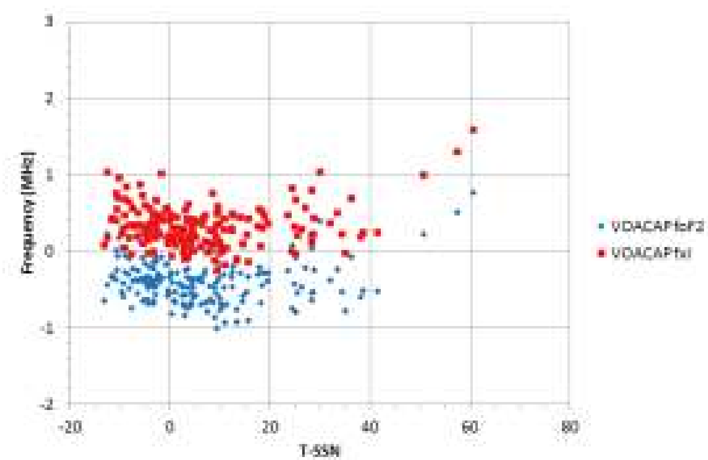



Plextek

# Results – Solar Indices (3)

- Difference between median *foF2/fxI* and VOACAP MUF against T-SSN
- SSN
  - VOACAP diverges from trends when T-SSN > ~15
  - Identifies periods when Chilton/UK NVIS basic MUF predictions might be inaccurate (or pessimistic)
- T-index
  - Lower differences for T-SSN > 0
  - Slight increase for T-SSN < 0?



# Results – Solar Indices (4)

- VOACAP predictions might be inaccurate (or pessimistic) for Chilton/UK NVIS basic MUF predictions when T-SSN > ~15
  - Assumes real-time access to T-index
    - Averaging of effective sunspot number?
    - 5-day average “strikes a good balance” (John M. Goodman )
    - IPS provide 7-day average
- During solar maximum
  - Consider effective sunspot number instead of SSN in VOACAP
- During solar minimum
  - Use SSN in VOACAP

# Summary (1)

- Conclusions specific to Chilton (more generally the UK)
- For the period 1996-2010
  - ASAPS basic MUF predictions generally agreed with Chilton *fxI* measurements
  - ASAPS MUF prediction consistent with zero-distance MUF equation
  - VOACAP predictions conservative (particularly around solar maximum)
  - Similar observations for upper decile (10%) predictions
  - ASAPS and VOACAP lower decile (90%) predictions conservative (VOACAP more so)

# Summary (2)

- Below ~4 MHz during winter nights around solar minimum
  - ASAPS and VOACAP MUF predictions tended towards *foF2*
  - Contrary to underlying theory
  - Autoscaling errors due to nighttime spread *F*?
- ASAPS errors increased at low or negative T-index values
  - Autoscaling errors due to nighttime spread *F*?
- VOACAP errors
  - Greatest at solar maximum using SSN
  - Errors might be large when T-SSN exceeds ~15
  - Errors reduced when using T-index

Plextek

# Acknowledgements


- UK Solar System Data Centre, RAL Space
  - Allowing the use of Chilton ionosonde data
- George Lane
  - Archiving a paper copy of the Nacaskul reference (now available at the DTIC)

# Wideband HF Spectral Sensing Results

Mark Jorgenson, Randy Nelson, Joe Lahart

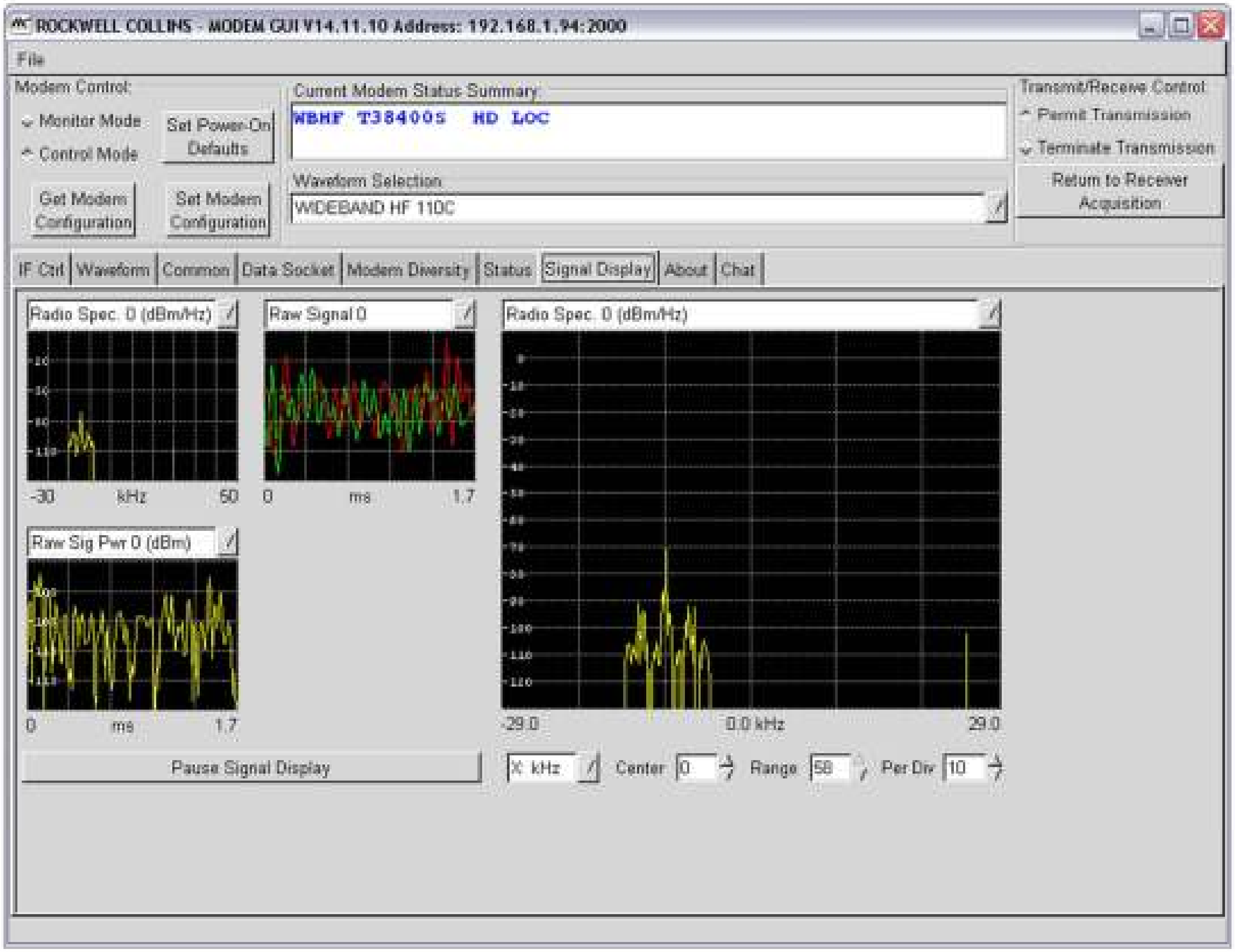
**HFIA / BLOS Comms – Sept, 2012**

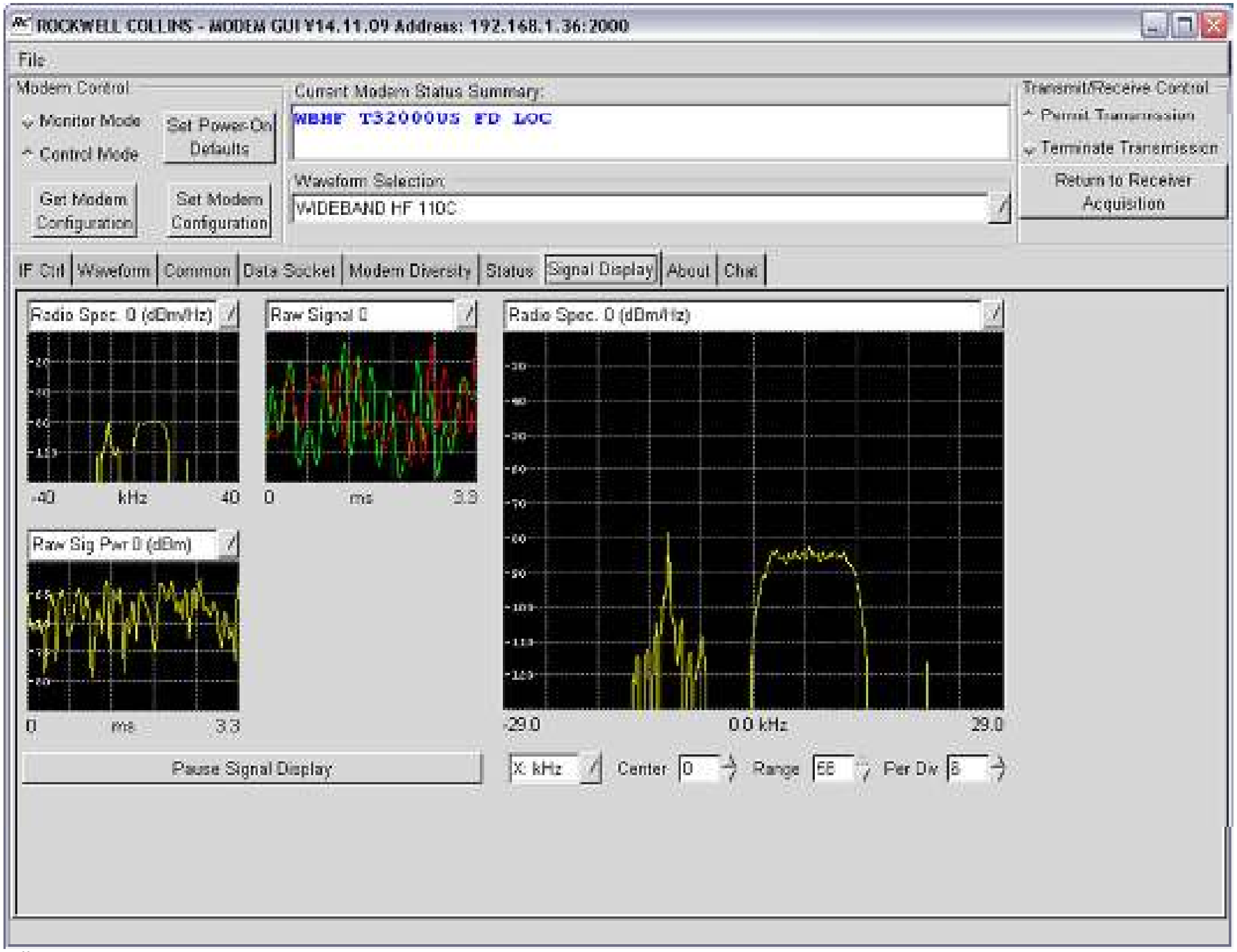
## Motivation

- Mil-Std 188-110C Appendix D provides the basis for a number of high capacity services over HF links – if the bandwidth is available
  - Eight data waveforms for eight HF bandwidths, 3 kHz through 24 kHz in 3 kHz increments
  - All eight waveforms fully autobaud, within a particular bandwidth selection
  - Bandwidth selection is an external function
- Harris and CRC have both shown spectrum sensing results indicating that channels up to 24 kHz may be commonly available, based on channel occupancy
- Spectral sensing capability is necessary for the development of a Wideband HF compatible ALE system
  - Playing nicely with others
  - Or not …

# ALE Considerations

- Current ALEs choose
  - Frequency
  - Data rate
  - Link maintenance - adapt data rate or look for a new channel
- WB ALE will have to choose
  - Frequency
  - Bandwidth (and offset)
  - Data rate
  - Adaptation involves data rate, bandwidth, offset or new channel
- May be more desirable for WB ALE to play nicely
  - Attempt to avoid channels with signals on them, even if they would provide good links
  - May not always be possible …


ROCKWELL COLLINS - MODEM GUI V14.11.10 Address: 192.168.1.94:2000
File
Modem Control:
Monitor Mode
Control Mode
Set Power-On Defaults
Get Modem Configuration
Set Modem Configuration
Current Modem Status Summary:
WBHF T38400S HD LOC
Waveform Selection:
WIDEBAND HF 110C
Transmit/Receive Control:
Permit Transmission
Terminate Transmission
Return to Receiver Acquisition
IF Ctrl
Waveform
Common
Data Socket
Modem Diversity
Status
Signal Display
About
Chat
Radio Spec. 0 (dBm/Hz)
-30
kHz
50
Raw Signal 0
0
ms
1.7
Raw Sig Pwr 0 (dBm)
0
ms
1.7
Radio Spec. 0 (dBm/Hz)
-29.0
0.0 kHz
29.0
Pause Signal Display
X: kHz
Center
0
Range
58
Per Div
10


ROCKWELL COLLINS - MODEM GUI V14.11.09 Address: 192.168.1.36:2000
File
Modem Control
Monitor Mode
Control Mode
Set Power-On Defaults
Get Modem Configuration
Set Modem Configuration
Current Modem Status Summary:
WBHF T3200US FD LOC
Waveform Selection:
WIDEBAND HF 110C
Transmit/Receive Control
Permit Transmission
Terminate Transmission
Return to Receiver Acquisition
IF Ctrl
Waveform
Common
Data Socket
Modem Diversity
Status
Signal Display
About
Chat
Radio Spec. 0 (dBm/Hz)
-40
kHz
40
Raw Signal 0
0
ms
3.3
Raw Sig Pwr 0 (dBm)
0
ms
3.3
Radio Spec. 0 (dBm/Hz)
-29.0
0.0 kHz
29.0
Pause Signal Display
X: kHz
Center
0
Range
56
Per Div
8

# Measurement campaign

- Spectral measurements included in the data
  - July 27
  - July 30 to Aug 1
  - Aug 6 to Aug 13
  - Aug 14 to Aug 20
  - Aug 21 to Aug 24

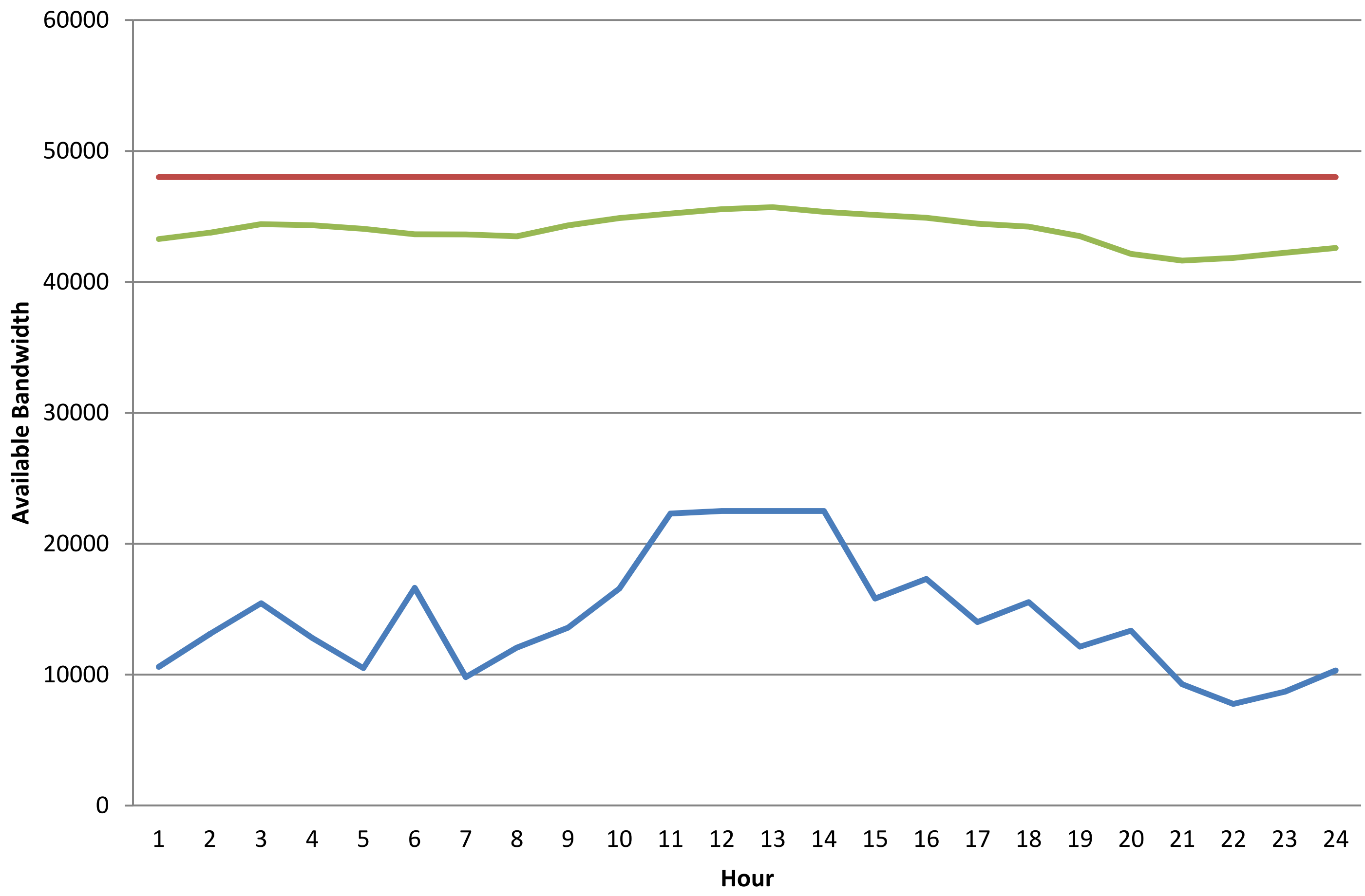
- Scan list of 246 frequencies across the HF band
  - 48 kHz receiver bandwidth

- Approximately 1.5 s per channel

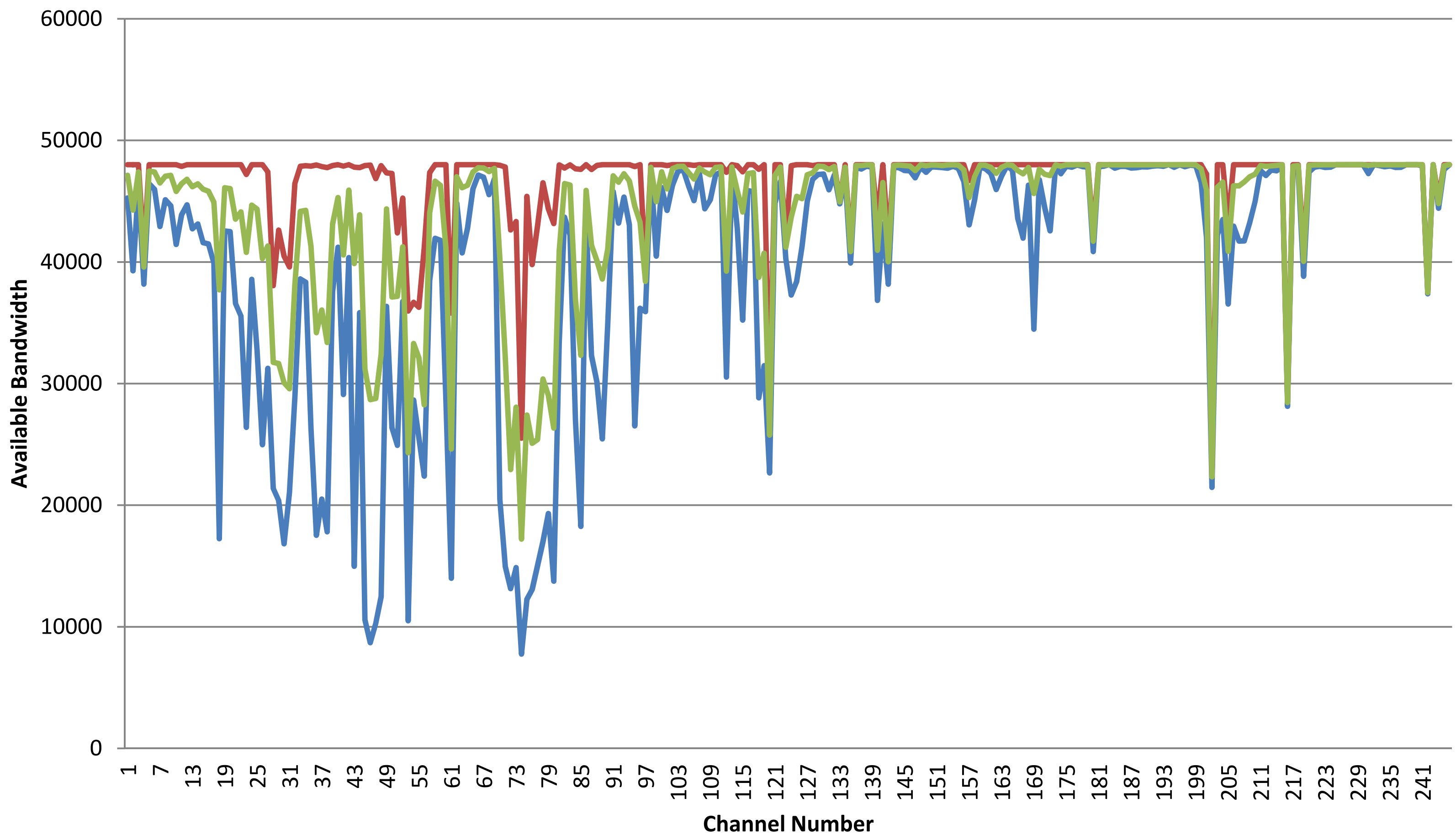
# Receiver Location – Cedar Rapids, Iowa

# Cedar Rapids, IA Lab 13 HF Station

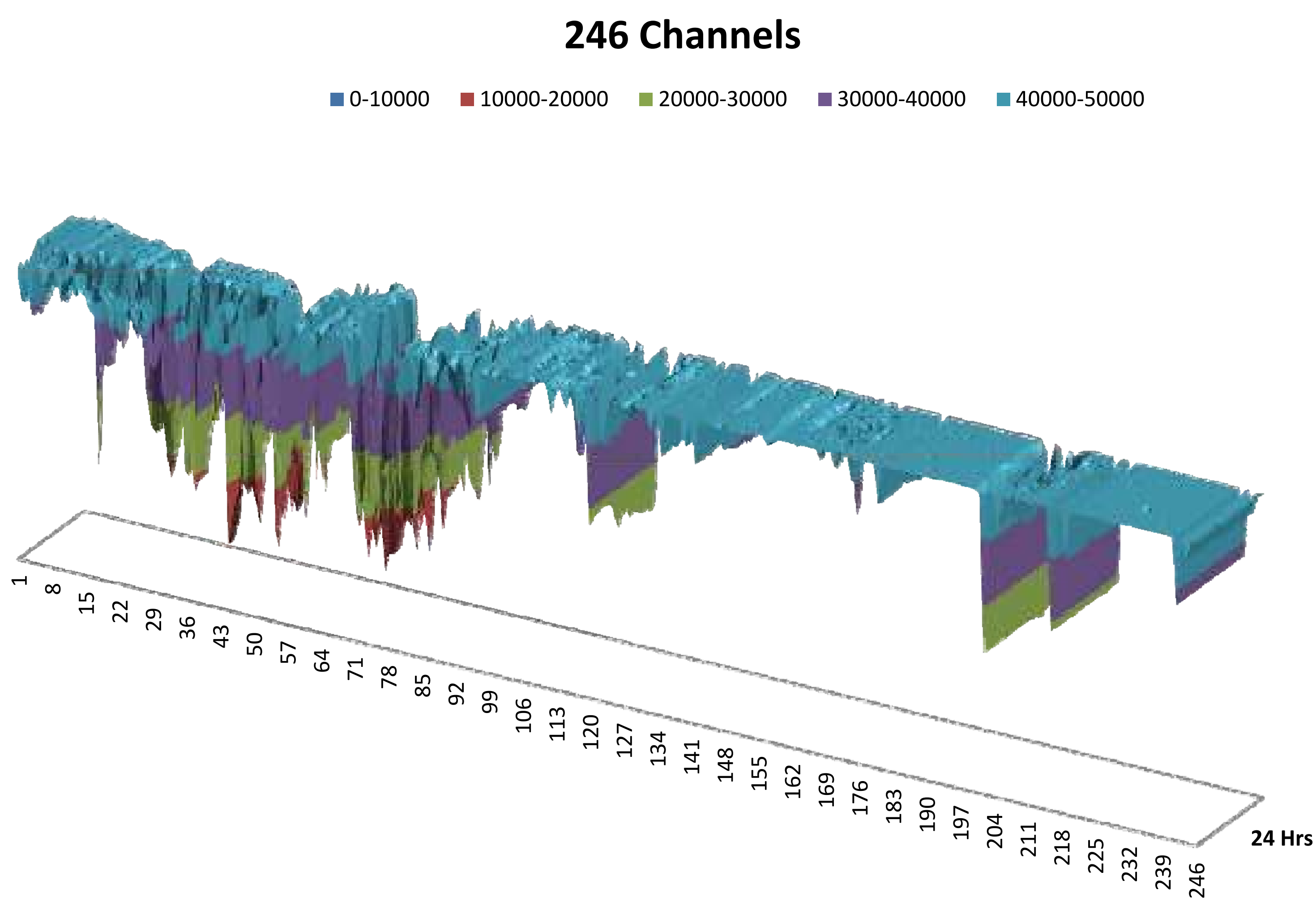
# Min, Max and Average Available BW by Time



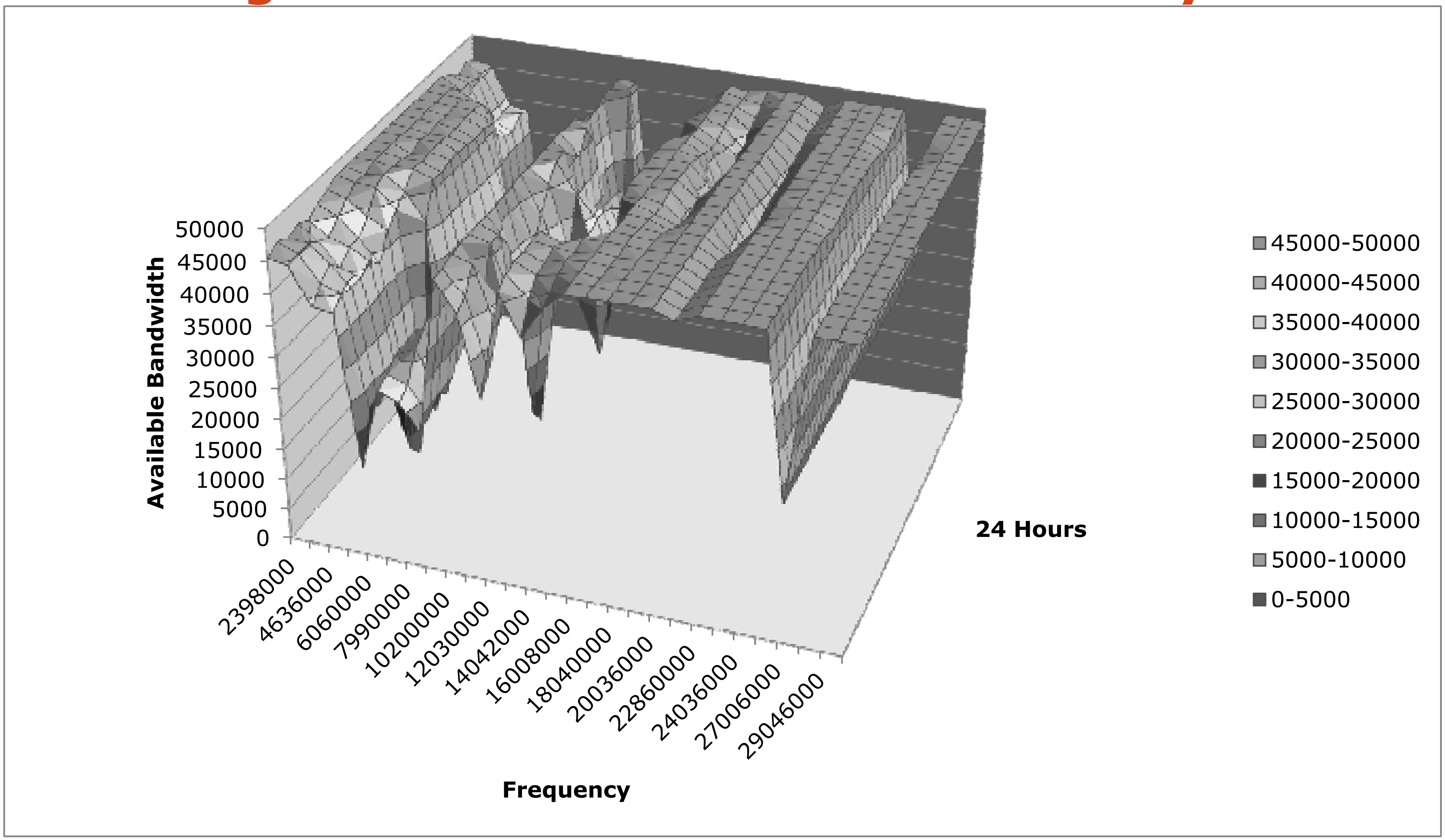
# Min, Max and Average Available BW by Channel



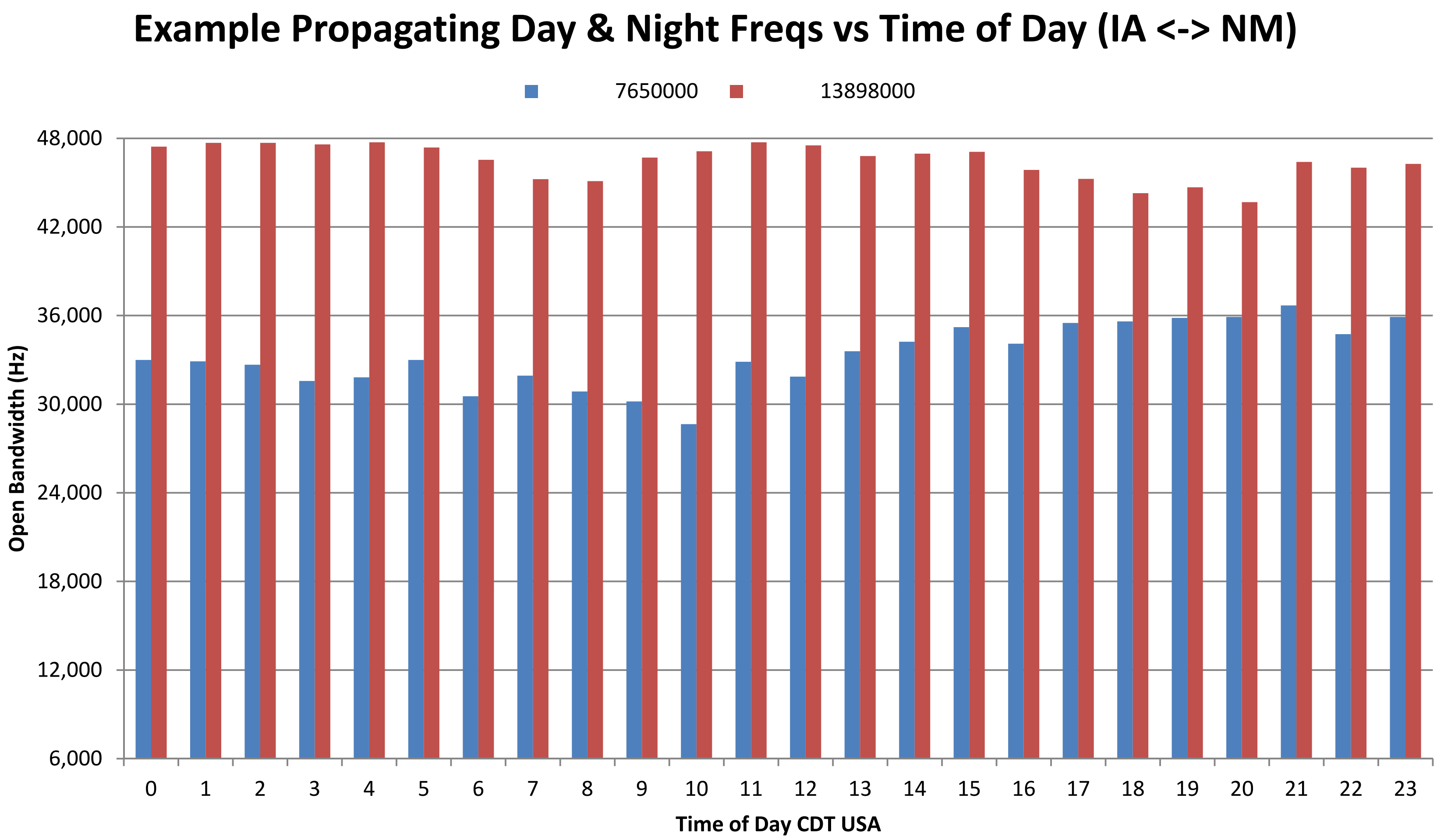
# Average Available Bandwidth Over 24 Hours



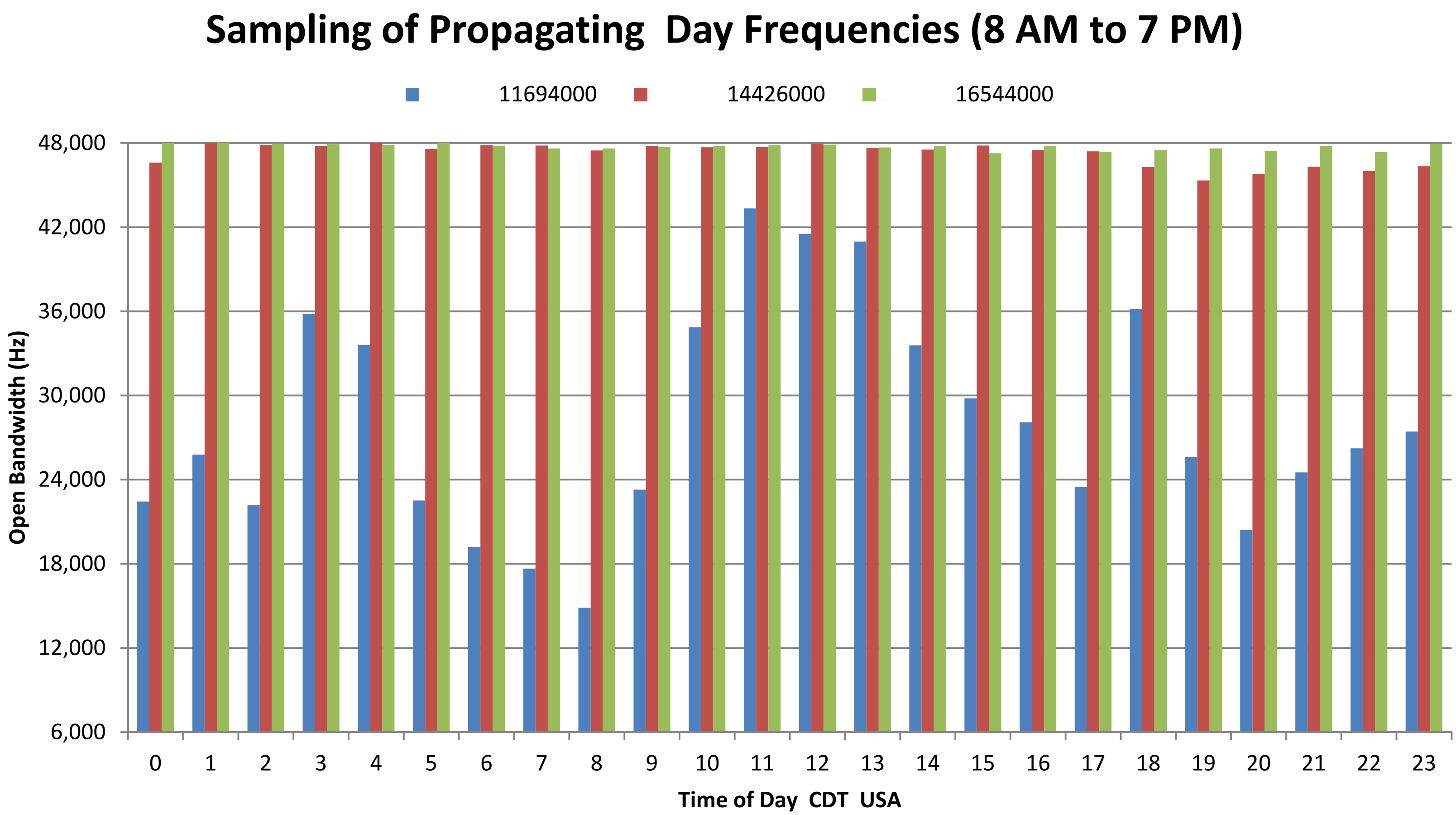
# Average Available BW for 30 Channels by Hour



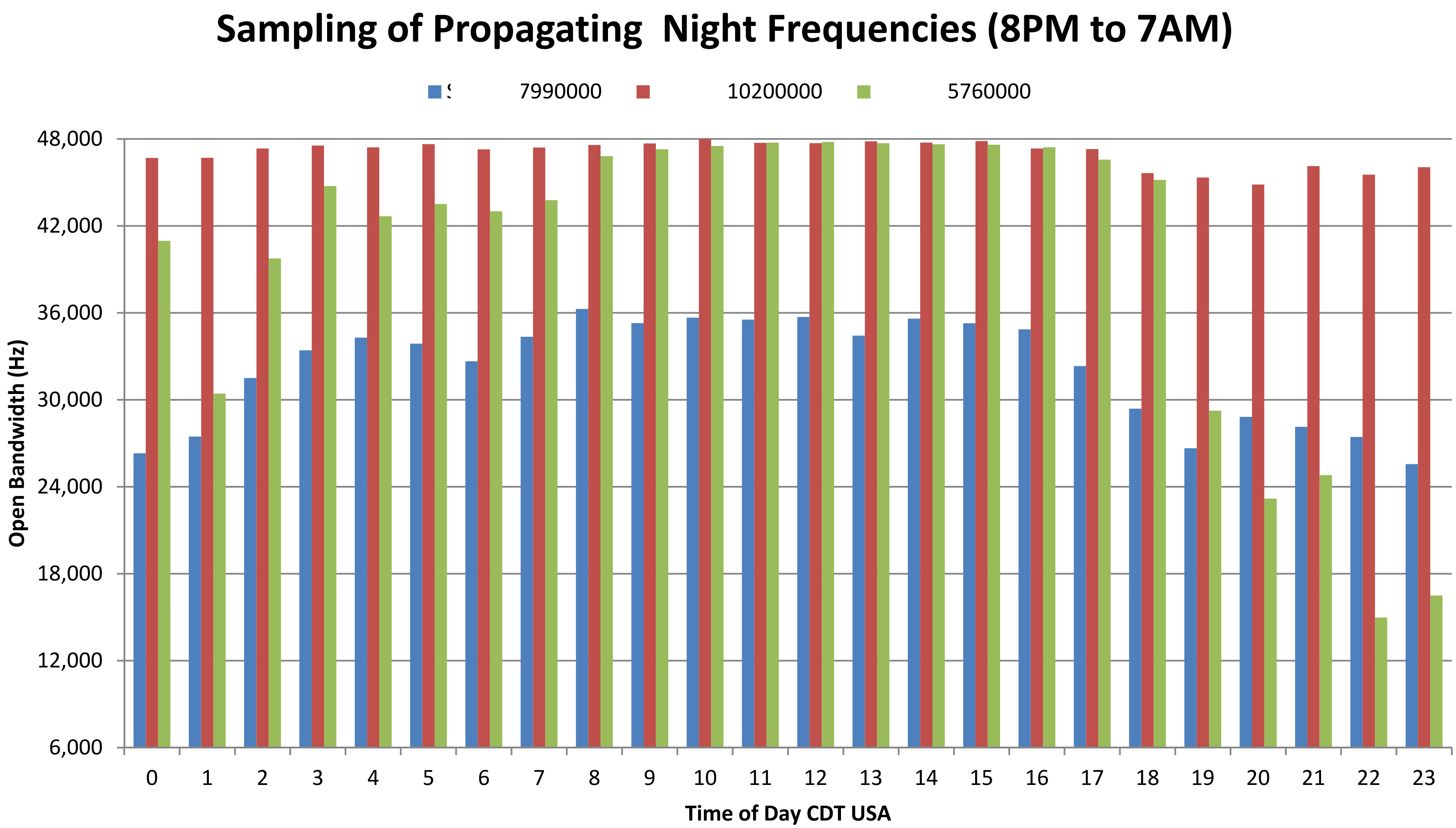
# Available Bandwidth: Las Cruces – Cedar Rapids



# Available Bandwidth: Las Cruces – Cedar Rapids



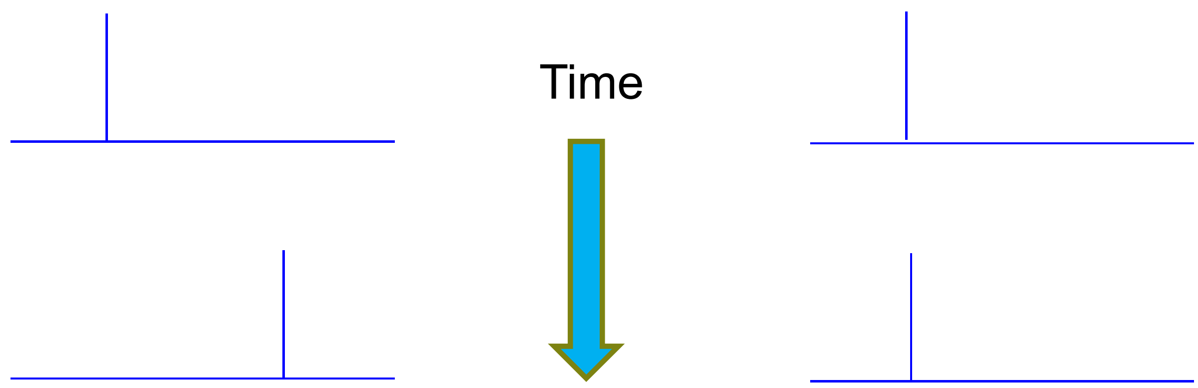
# Available Bandwidth: Las Cruces – Cedar Rapids



# Other Considerations

- Only looking at whether there is a detectable signal, not whether the channel could be used to pass data
- This data comes from an ALE perspective
  - Distinct scan list, not general frequency monitoring
- Determining occupancy may be require more sophisticated analysis than we've used thus far
  - Channels that show an exchange on an intermittent basis should probably be counted as fully occupied
  - Today we would only say they were occupied when we see a signal
  - Need to go beyond looking at independent snapshots to looking at a time history

- Just capturing available bandwidth by time is not enough




- All independent snapshots of the 24 kHz channels above show about 15 kHz of available bandwidth
- If the snapshots are close in time,
  - The channel on the left likely only has about 6 kHz of usable bandwidth
  - The channel on the right really does have 15 kHz available

# What’s Next

- Spectrum Analysis
  - More careful analysis of the data
  - Combining with propagation prediction to get estimates of predicted throughput, and then validating with over the air tests
  - European receiver site (Toulouse)
- Wideband HF
  - Continue to experimenting and refining ALE techniques for wideband HF
  - More testing with MARLIN (Subnet Relay) over Wideband HF
    - May be good reasons to look at dynamic TDMA rather than token passing with higher available data rates
    - Testing an IP network based on Subnet Relay/WBHF supporting video, file transfer, white boarding, etc. between Cedar Rapids and Las Cruces

# Questions, Comments, Suggestions?

?

# Investigating the Effects of Interleaver Size and FEC Code Constraint Over-the-Air for the US MIL-STD-188-110C Appendix D WBHF Waveforms

J. W. Nieto, W. N. Furman

# Presentation Overview

- Motivation
- Experiment
- Results
- Summary

# Motivation

- Most HF waveform standards provide several interleaver options
  - US MIL-STD-188-110C
    - Main Body
      - Zero, Short, Long
    - Appendix C
      - Ultra-Short, Very-short, Short, Medium, Long, Very-Long
    - Appendix D
      - Ultra-Short, Short, Medium, Long
    - Interleaver sizes go up to 10.24 seconds
- US MIL-STD-188-110C Appendix D provides the option to select a constraint length 7 or 9 convolutional code

# Motivation

- Benefits of interleaver size depend on many things
  - Transmit power
  - Type of multipath fading channel encountered on HF link
    - Number of paths
    - Fade rate of each path
  - Average signal-to-noise ratio (SNR) of link
  - Bandwidth of waveform
  - Modulation of waveform

– On-air testing allows evaluation of only one interleaver size and code constraint length option at a time

– Comparing performance of different options at different times is not valid since HF channel is not stationary

# Motivation

- In order to best compare the performance of different interleaver sizes and code constraint lengths over-the-air, comparison should be done at the same time
  – Is this possible ?

# Experiment

- For US MIL-STD-188-110C Appendix D, what if we
  - Transmit all zero data
    - Allows evaluation of all interleaver sizes
    - Allows evaluation of 7 and 9 code constraint lengths
  - Save received samples
  - Post-process samples for all possible interleaver sizes and code constraint lengths
- Possible issues
  - Is transmitting all zero data valid ?
    - Performance of all zero data and random data on AWGN and Mid-Latitude Disturbed channels very close
    - Peak-to-Average Power Ratio of waveforms very close

# Experiment

HARRIS

- Based on bit-error-rate (BER) and packet-error rate (PER, packet size 1000 bits) curves, effects of interleaver size and code constraint length only matter when SNR is close to the waterfall region
  - For example
    - If SNR of on-air link is too low for selected modulation, performance of all interleaver sizes and code constraint lengths will be poor
    - If SNR of on-air link is too high for selected modulation, performance of all interleaver sizes and code constraint lengths will be good

# Experiment

- Test Procedure
  - 3G used to select frequency and initial modulation
    - For example
      - 3G LQA score suggests using 16-QAM
      - Transmit 16-QAM for 1 minute
      - Transmit 8-PSK for 1 minute
      - Transmit 32-QAM for 1 minute
      - Transmit 16-QAM for 1 minute
      - Save all samples
      - Post process samples for all interleaver lengths and code constraint lengths
  - Repeat experiment multiple times using 3G to select frequency and starting modulation

# Experiment

HARRIS

## Link Tested - Short range NVIS path (167 km)

| Rochester, New York | Stockbridge, New York |
| --- | --- |
| wbhf prototype radio | wbhf prototype radio |
| 150 Watt power amplifier | 150 Watt power amplifier plus coupler |
| Broadband Dipole | Harris RF-1912 antenna |

# Results - Test 1

- Test 1
  - 24 KHz, WFID 6 (4-PSK)

BER

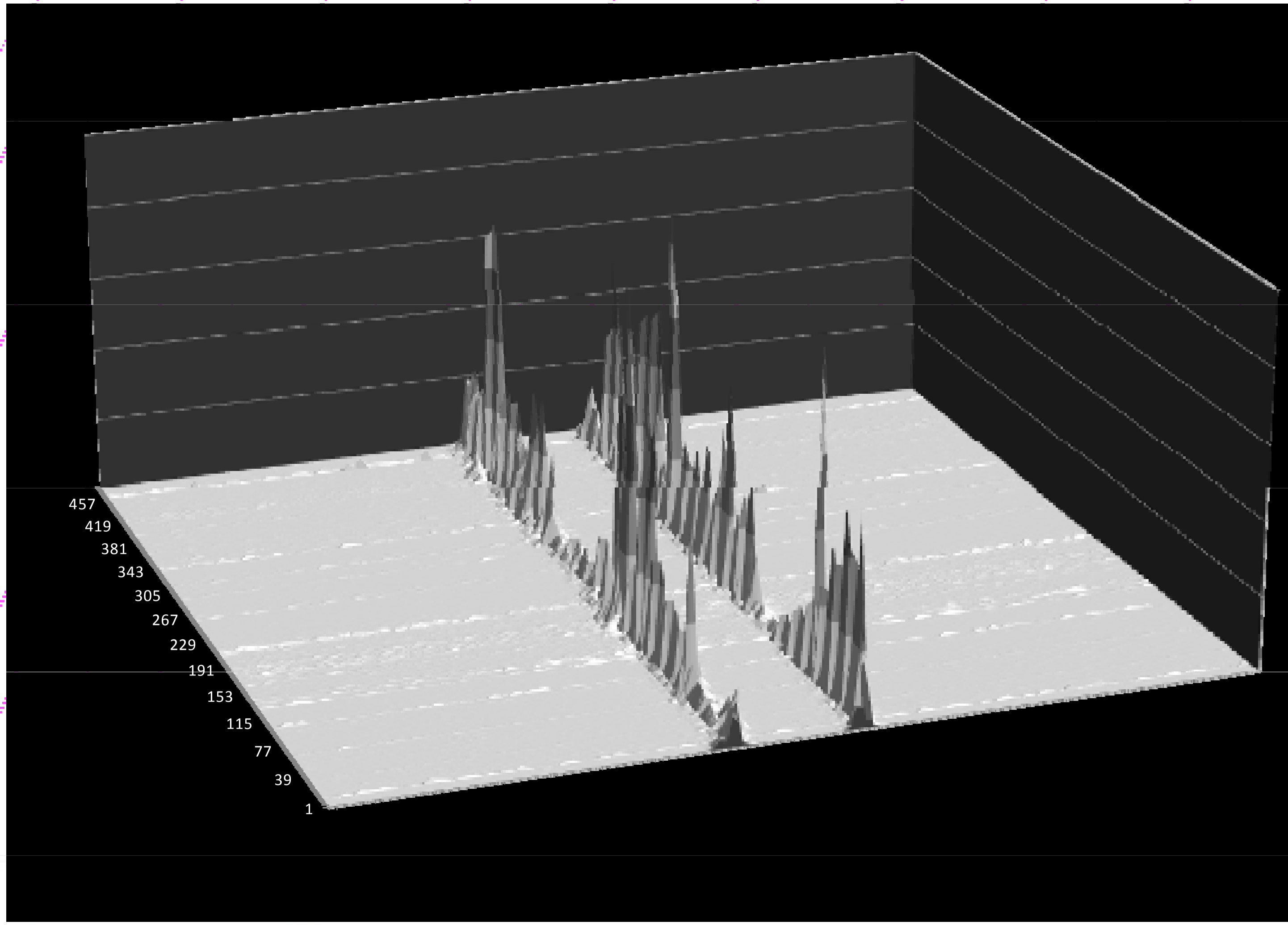
| US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|
| K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 9.4e-3 | 1.1e-2 | 4.2e-3 | 4.0e-3 | 2.6e-5 | 2.0e-5 | 0.0 | 0.0 |

PER

| US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|
| K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 5.7e-2 | 4.9.e-2 | 3.9e-2 | 3.4e-2 | 2.0e-3 | 6.4e-4 | 0.0 | 0.0 |

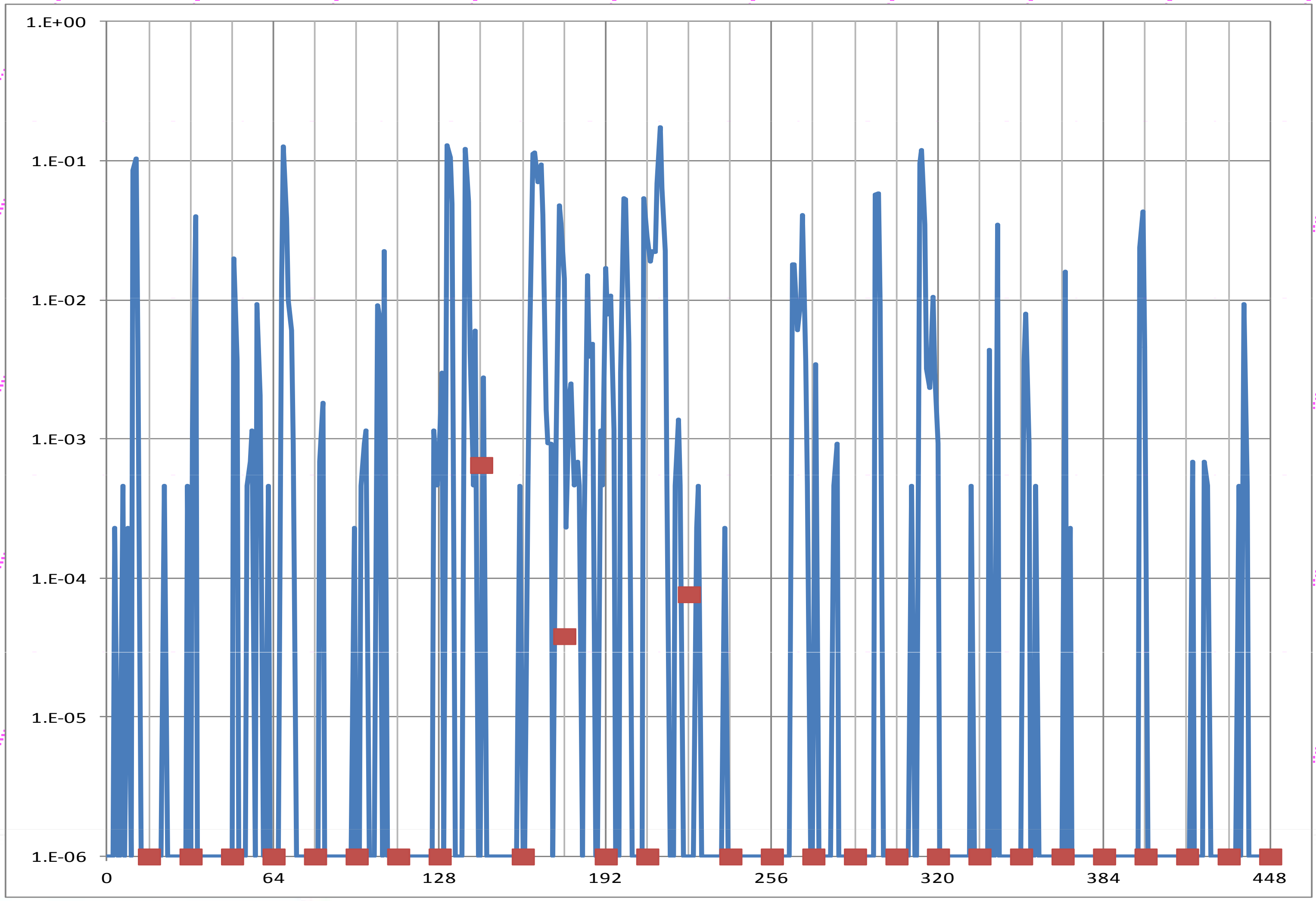
# Results - Test 1

## Multipath Profile Test 1



# Results - Test 1

Uncoded Error Rate (blue), Error Rate Medium Interleaver (red)



# Results - Test 1

BER

| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 6 | 9.4e-3 | 1.1e-2 | 4.2e-3 | 4.0e-3 | 2.6e-5 | 2.0e-5 | 0.0 | 0.0 |
| 5 | 4.0e-3 | 4.5e-3 | 3.9e-3 | 4.3e-3 | 0.0 | 4.8e-5 | 0.0 | 0.0 |
| 7 | 4.5e-3 | 4.8e-3 | 2.1e-4 | 1.3e-4 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | 4.1e-3 | 4.7e-3 | 3.6e-4 | 3.1e-4 | 1.2e-4 | 3.7e-5 | 0.0 | 0.0 |

PER

| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 6 | 5.7e-2 | 4.9e-2 | 3.9e-2 | 3.4e-2 | 2.0e-3 | 6.4e-4 | 0.0 | 0.0 |
| 5 | 2.0e-2 | 1.8e-2 | 1.2e-2 | 1.1e-2 | 0.0 | 1.3e-3 | 0.0 | 0.0 |
| 7 | 3.6e-2 | 3.1e-2 | 8.1e-3 | 4.3e-3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | 2.7e-2 | 2.4e-2 | 8.4e-3 | 8.4e-3 | 3.2e-3 | 1.3e-3 | 0.0 | 0.0 |

# Results - Test 2

Test 2, 24 KHz

BER

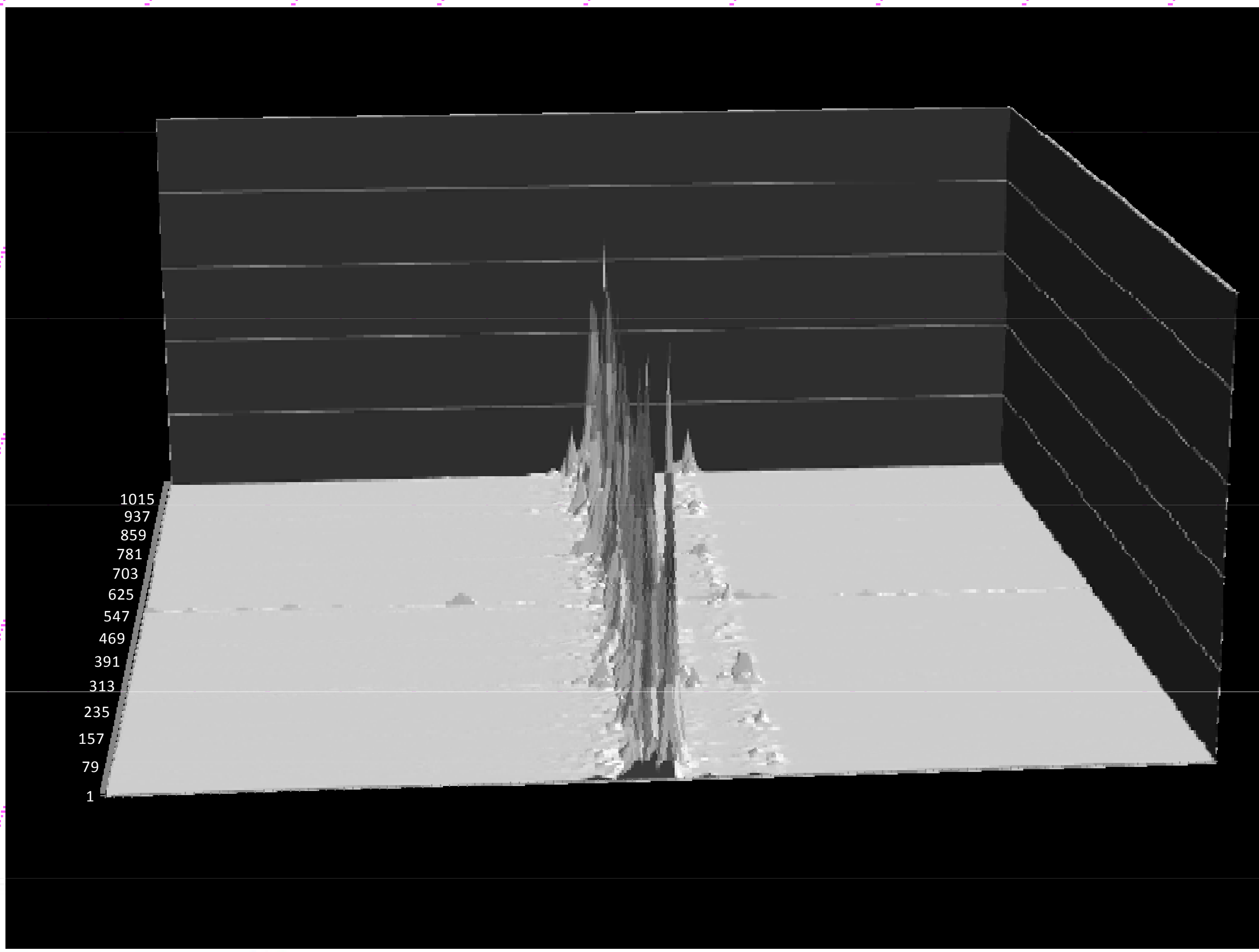
| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

PER

| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

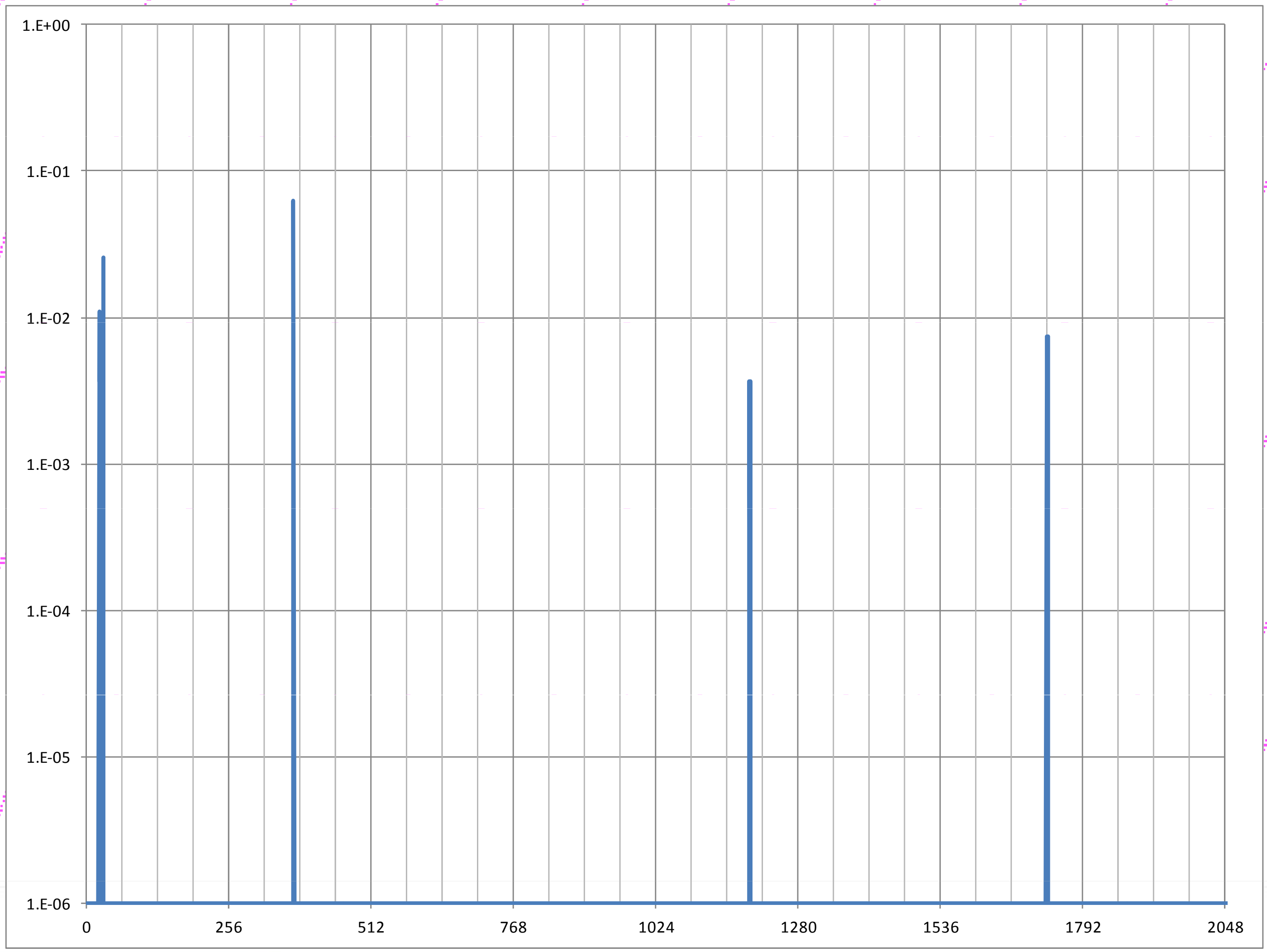
# Results - Test 2

## Multipath Profile Test 2



# Results - Test 2

Uncoded Error Rate



# Results - Test 3

Test 3, 24 KHz

BER

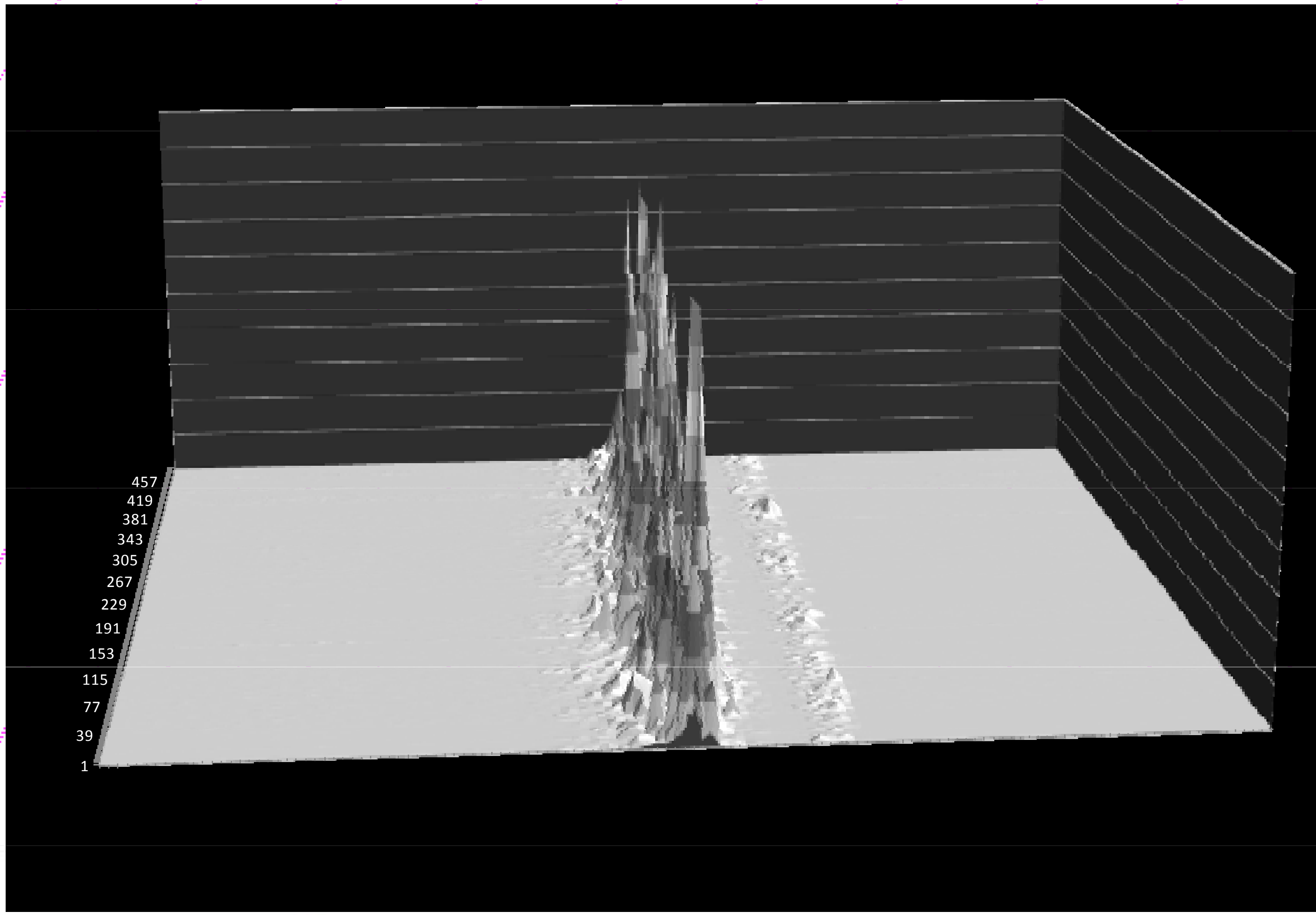
| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 10 | 2.9e-2 | 3.1e-2 | 2.7e-2 | 3.2e-2 | 1.6e-2 | 2.2e-2 | 1.4e-4 | 5.7e-5 |
| 9 | 3.5e-2 | 3.8e-2 | 2.9e-2 | 3.3e-2 | 2.0e-2 | 2.3e-2 | 0.0 | 0.0 |
| 11 | 2.6e-1 | 2.8e-1 | 2.9e-1 | 3.1e-1 | 3.4e-1 | 4.0e-1 | 4.0e-1 | 4.4e-1 |
| 10 | 7.6e-2 | 8.4e-2 | 8.1e-2 | 9.1e-2 | 4.4e-2 | 6.1e-2 | 2.6e-5 | 1.9e-6 |

PER

| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 10 | 1.6e-1 | 1.5e-1 | 1.4e-1 | 1.3e-1 | 7.9e-2 | 8.2e-2 | 1.1e-2 | 5.7e-3 |
| 9 | 1.5e-1 | 1.4e-1 | 1.2e-1 | 1.2e-2 | 6.8e-2 | 6.7e-2 | 0.0 | 0.0 |
| 11 | 7.2e-1 | 6.9e-1 | 7.3e-1 | 7.3e-1 | 8.3e-1 | 8.5e-1 | 8.9e-1 | 8.9e-1 |
| 10 | 3.5e-1 | 3.2e-1 | 2.9e-1 | 2.9e-1 | 2.5e-1 | 2.4e-1 | 2.8e-3 | 2.3e-4 |

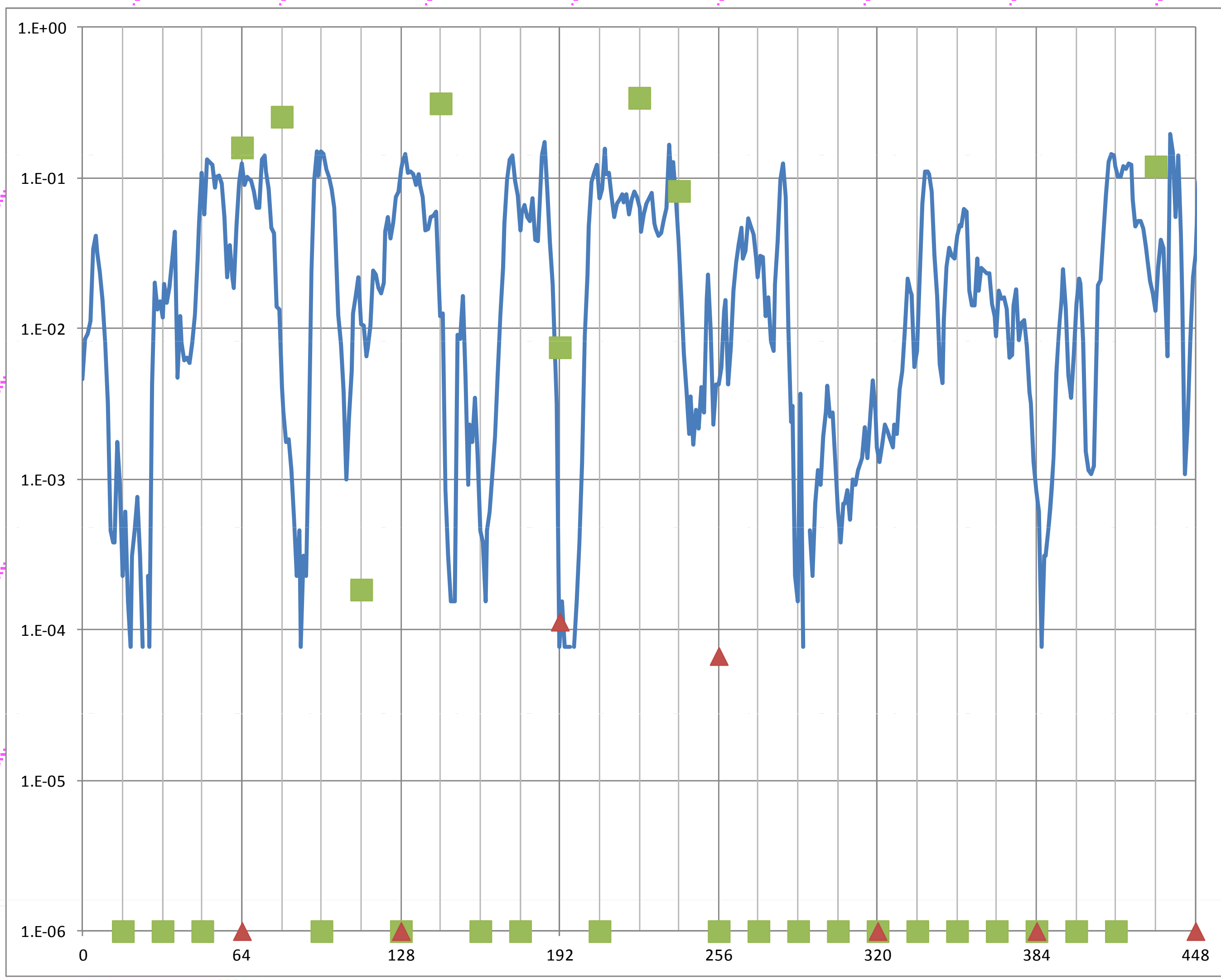
# Results - Test 3

## Multipath Profile Test 3



# Results - Test 3

Uncoded Error Rate (blue), Medium (green), Long (red)



# Results - Test 4

Test 4, 24 KHz

BER

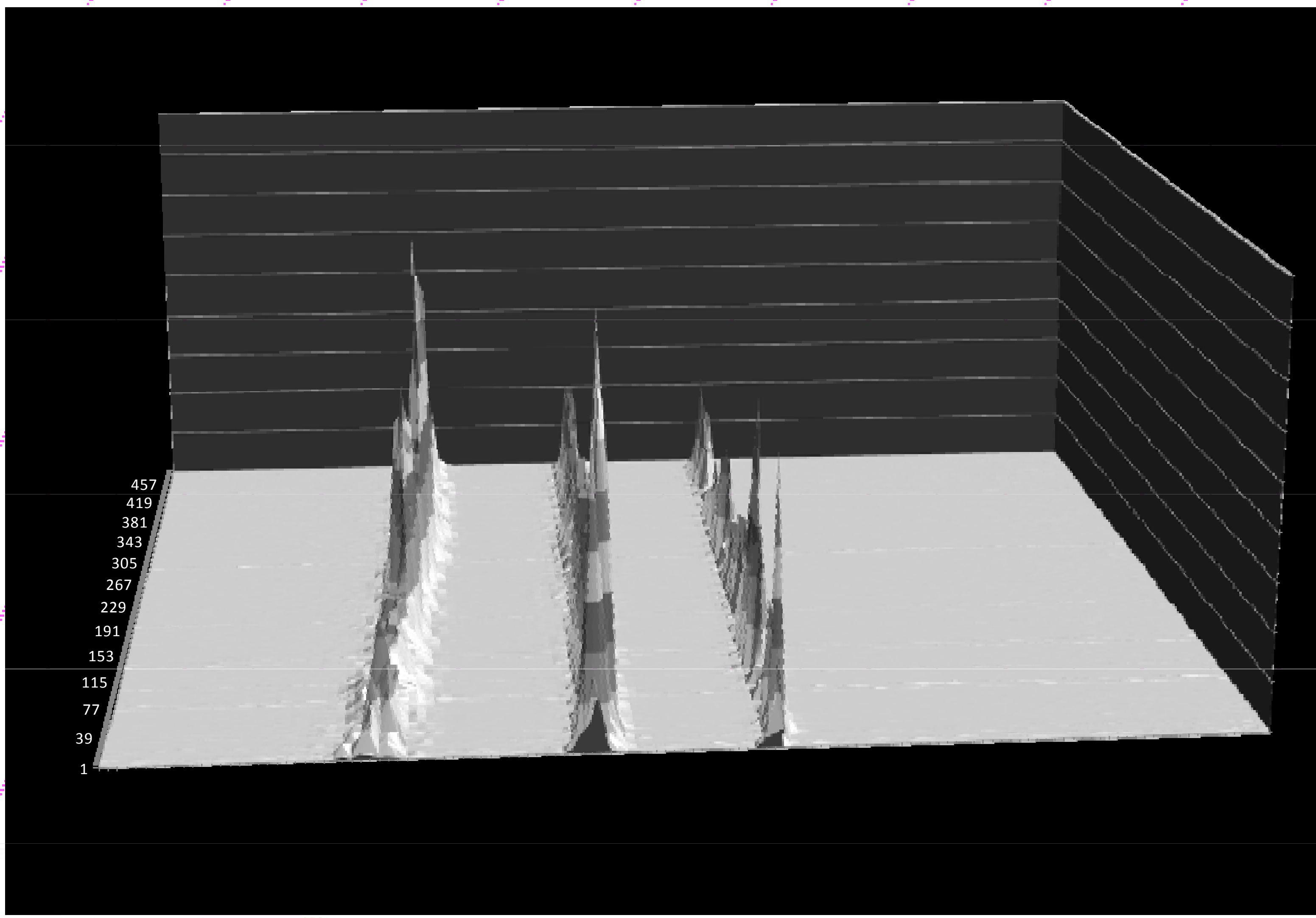
| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 8 | 2.5e-3 | 2.6e-3 | 1.8e-4 | 3.4e-4 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | 1.8e-2 | 2.0e-2 | 9.9e-3 | 1.2e-2 | 1.5e-4 | 1.3e-4 | 3.9e-5 | 0.0 |
| 9 | 9.1e-2 | 9.7e-2 | 9.1e-2 | 9.7e-2 | 8.3e-2 | 9.1e-2 | 1.1e-1 | 1.3e-1 |
| 8 | 2.0e-3 | 2.2e-3 | 1.9e-4 | 3.0e-4 | 2.3e-6 | 6.4e-6 | 0.0 | 0.0 |

PER

| WFID | US | | VS | | M | | L | |
|---|---|---|---|---|---|---|---|---|
| | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 | K=7 | K=9 |
| 8 | 2.0e-2 | 1.6e-2 | 3.9e-3 | 4.2e-3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | 9.2e-2 | 7.8e-2 | 6.4e-2 | 6.2e-2 | 1.8e-2 | 4.3e-4 | 4.6e-4 | 0.0 |
| 9 | 3.1e-1 | 2.9e-1 | 2.7e-1 | 2.6e-1 | 3.1e-1 | 2.9e-1 | 3.2e-1 | 3.1e-1 |
| 8 | 2.7e-2 | 2.2e-2 | 1.2e-2 | 1.4e-2 | 6.4e-4 | 6.4e-4 | 0.0 | 0.0 |

# Results - Test 4

Multipath Profile Test 4



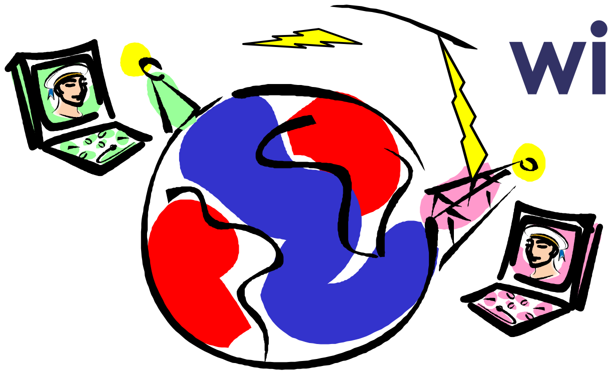
# Results

- General trends
  - In 8 out of 9 tests, long interleaver provided best performance
  - K=9 code provided slightly better performance than K=7 most of the time
- Note that for Automatic Repeat Request (ARQ) systems, added end-to-end latency of interleaver needs to be considered when selecting interleaver size

# Summary

- Harris has developed an approach to evaluate and compare the effects of interleaver size (IS) and code constraint length (CCL) over the air
- Additional information about HF channels can also be extracted from the received sample files
- Additional testing on NVIS, Long-Haul and other types of HF links is needed to properly understand the effects of IS and CCL
- ARQ systems must balance PER performance and end-to-end latency of interleavers to maximize throughput

# Spectrum issues for HF wideband communications



HFIA meeting, York (UK), Sept. 6th, 2012

C. Lamy-Bergot, J-B. Chantelouve, C. Leménager

Thales Communications & Security

THALES

# Presentation outline

## Context and motivation

- HF high data rate communications
- Spectrum availability and spectrum management issues

## Spectrum measurements

- Equipment used and measures done
- Measures analysis principle
- Occupations observed in Coulommiers, France

## Application to HF wideband communications

- Taking into account circuit reliability (propagation predictions)
- Comparing achievable throughputs

## Conclusions

# Context and motivation

## Need for tactical BLOS services at an affordable price → IP over HF (64 to 128 kb/s requirements)

→ use more bandwidth (higher spectrum efficiency won't be sufficient)

## … while remaining in a tactical context …

- Avoid using multiple radios (unsuitable except in larger ships/infra sites)
- Use reasonable power figures and tactical antennas

## … keeping capability to interoperate with legacy equipments …

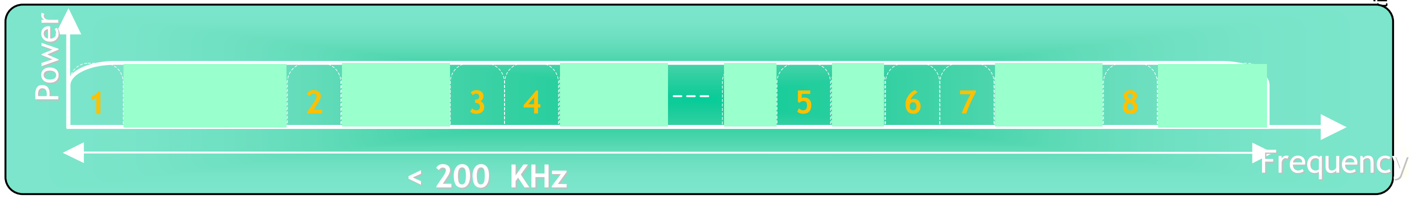
## … respecting spectrum usage & regulations …

- Availability of HF spectrum for larger than 3/6kHz sub-bands ?

## … and meeting SNR requirements for high data rate

## Possible channelizations for wideband approaches

- MIL STD 188 110 C: single carrier up to 24 kHz
- THALES HF XL approach (multi-narrow band approach) : n*3kHz in a 200kHz band



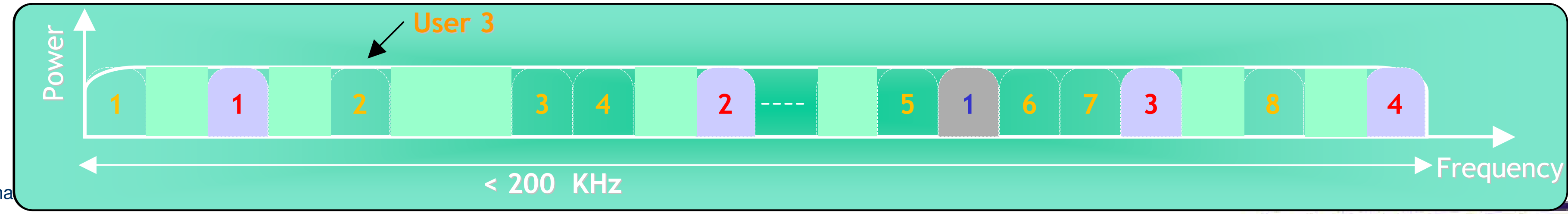
# Context and motivation

## Spectrum availability & management issues:

- Obtaining wideband emission authorizations?
- Dynamic management of wideband spectrum allocations ?
- Real-life availability of the bands (interferers, multiple use, …)

## Obviously …

- From HF users experience, 24kHz free allocations should be very difficult to obtain (impossible?)
- n*3kHz can be found much more easily than 1*24kHz
  - Typically, in 200kHz, one finds $\binom{66}{8} \approx 6.10^{9}$ possibilities for 8 non contiguous 3kHz allocations, to be compared to 59 possibilities for contiguous allocations !!
- Allowing use of non contiguous allocations will permit sharing with other users, adaptation to pre-existing allocations/unvoluntary jammers



## Is it better to use contiguous vs. non contiguous n*3kHz sub-bands?

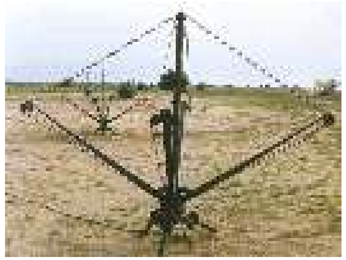
- **Let's imagine that**
  - the whole HF band is available
  - no other distant user will be disturbed by our emissions if we cannot detect them

- **and evaluate availability of contiguous and non contiguous spectrum allocations**
  - Placing us in real life conditions
  - Counting the number of "free" (i.e. not used) channels, whether 3kHz, 12kHz or 24kHz

Let us address in the following the issue of spectrum availability (for contiguous or non-contiguous n*3kHz) **independently of emission rights**

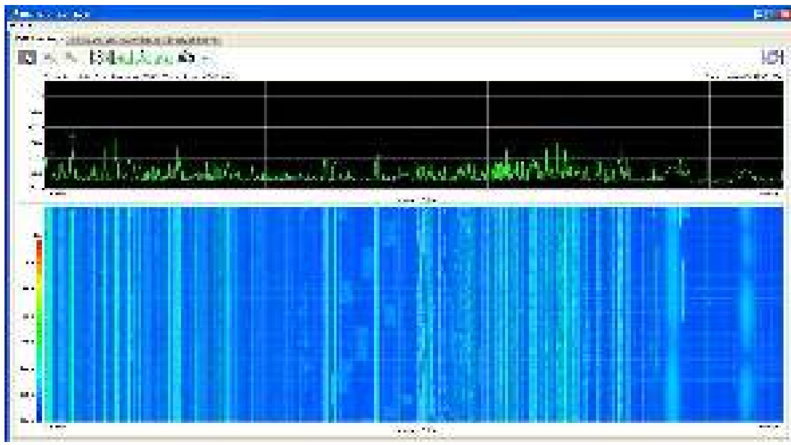
## Spectrum acquisitions for off-line analysis

- Location : Coulommiers, France
- Acquisitions in : Oct. 2011, Jan., March, April and May 2012
- Using THALES TRC6500 electronic warfare product for signal acquisition in HF band



## Acquisitions resolution for each spectrogram

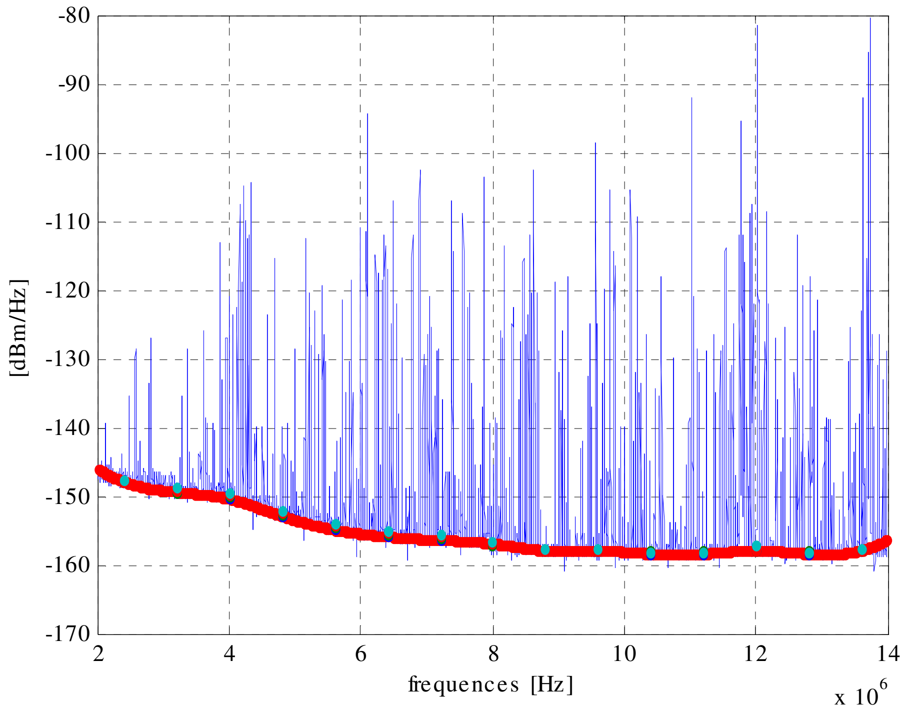
- 12 MHz band
- 24 hours continuous acquisition



# Measures done

## Exploiting the measures done

- **Step 1: estimation of noise level by statistical derivation of the noise level for each spectrogram**
  - Window considered: 1MHz x 15s
  - Hypothesis : normal distribution model





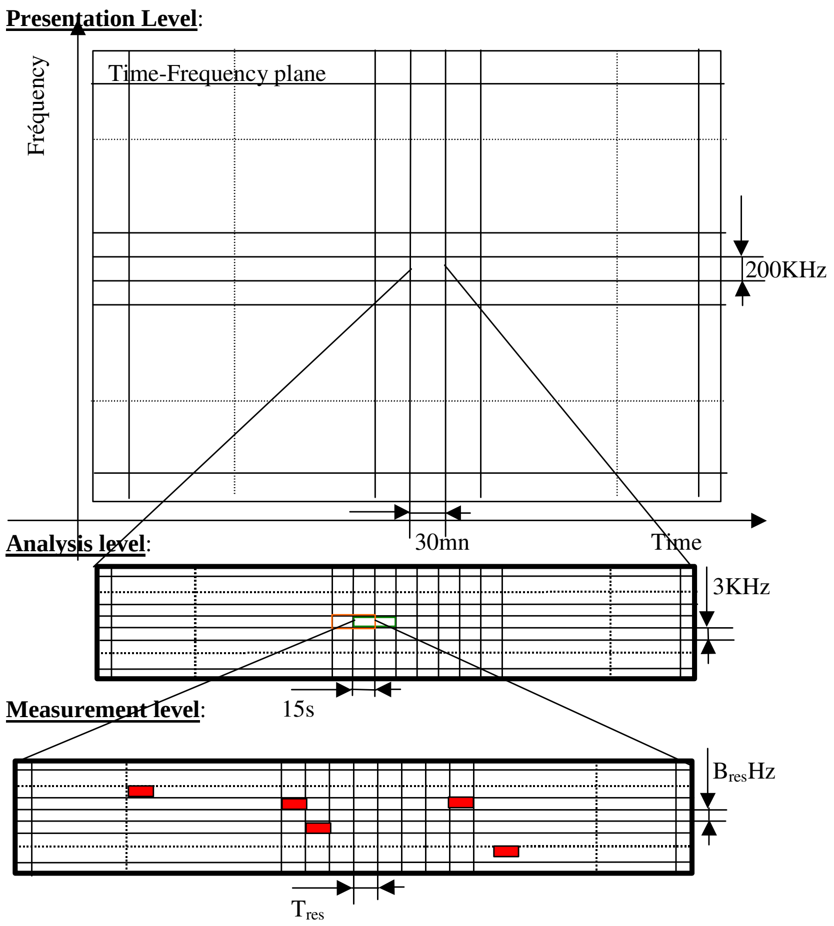





THALES

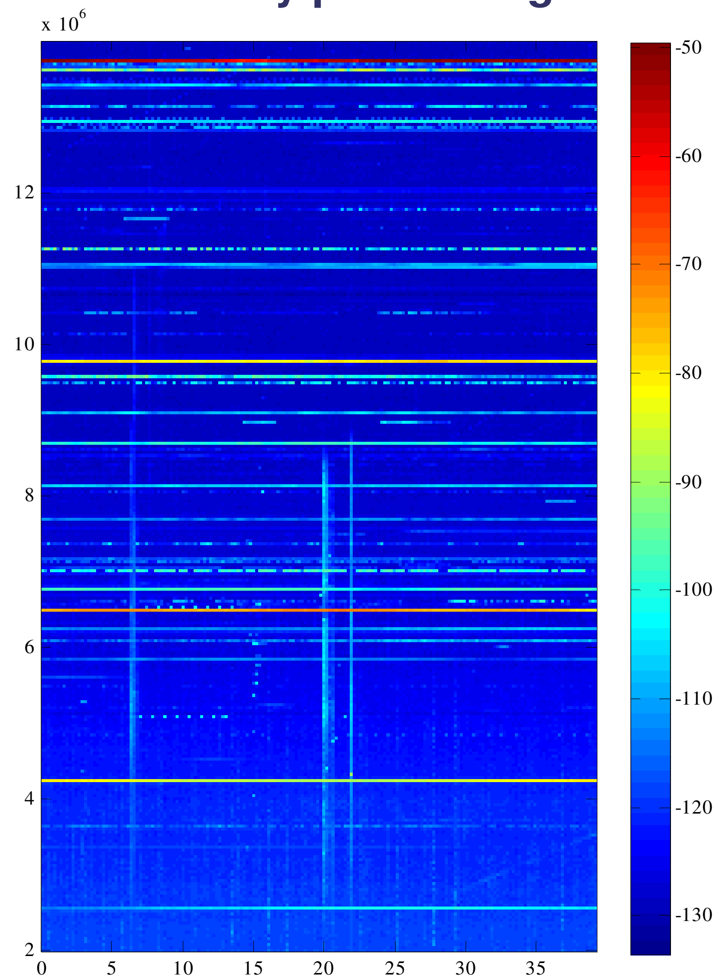
## Exploiting the measures done

- **Step 2 : estimating availability of time/frequency elementary cells**
  - Threshold : INR < 3dB (no interferer accepted above twice the estimated noise level)
    - This includes power test over each cell to remove strong pulse interferers
  - Counting number of cells with respect to 3/4 ratio corresponding to error correction capability

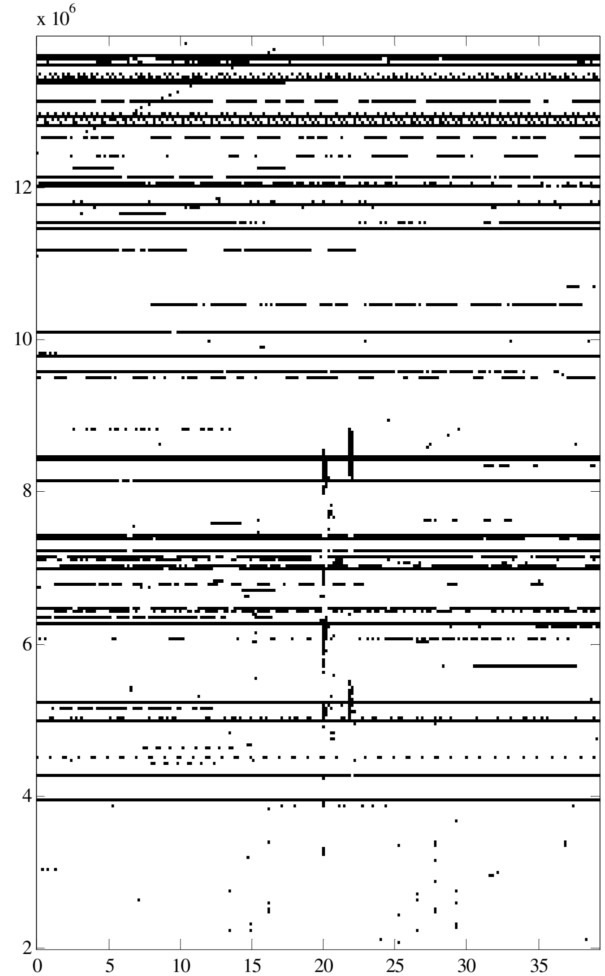


## Illustrations: elementary availability

- Obtained by processing with respect to noise level : INR<3dB




Acquired spectrogram (subset)




Elementary availability (white: available)

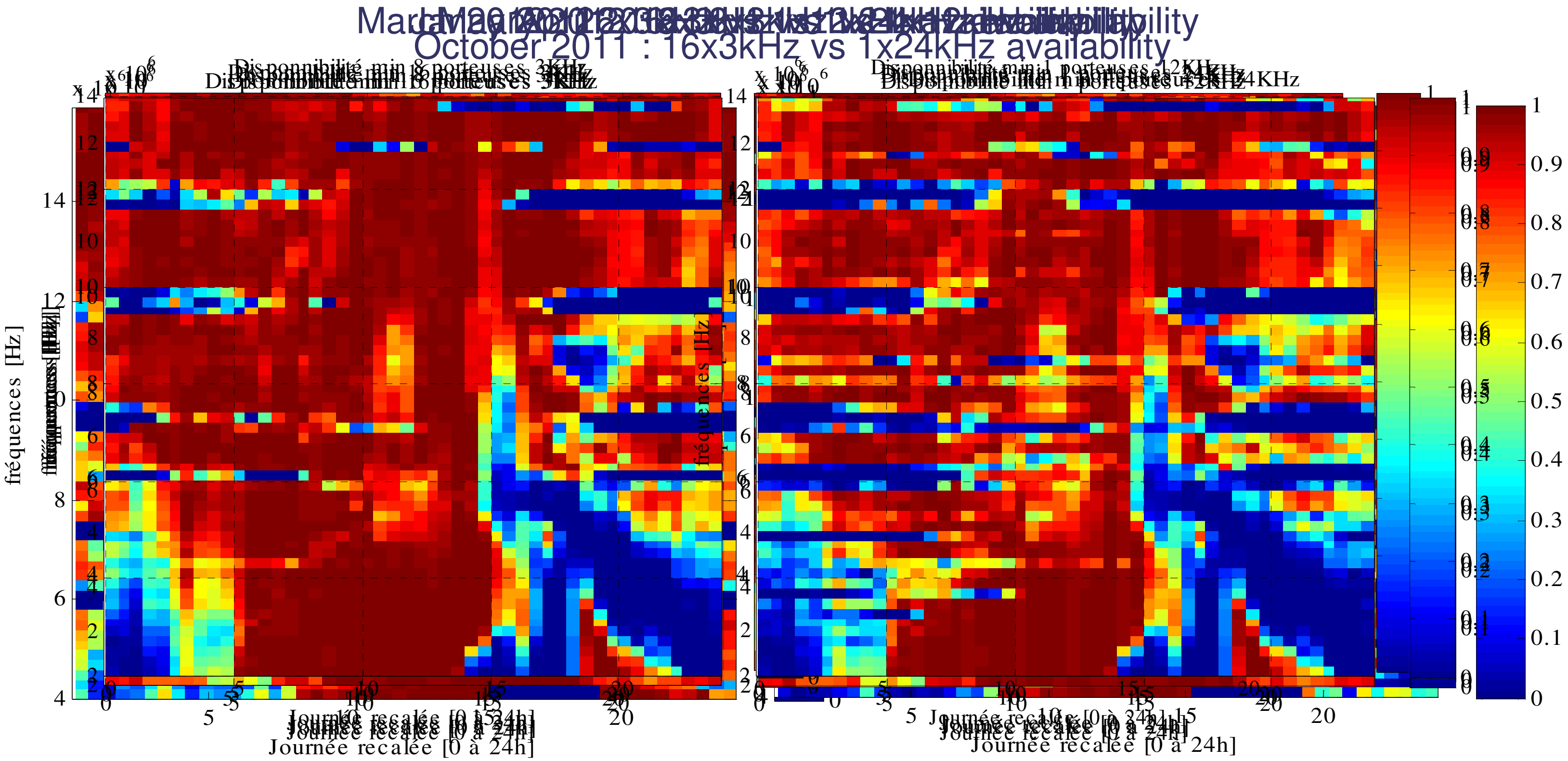


THALES

# Disponibility values

## Occupations observed in Coulommiers, France

- **Comparing contiguous (1x12kHz or 1x24kHz) and non-contiguous (8x3kHz or 16x3kHz availability)**





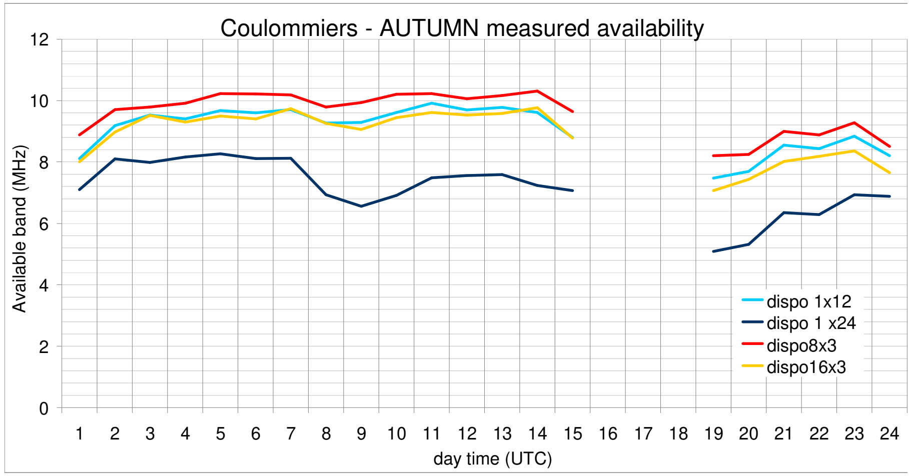


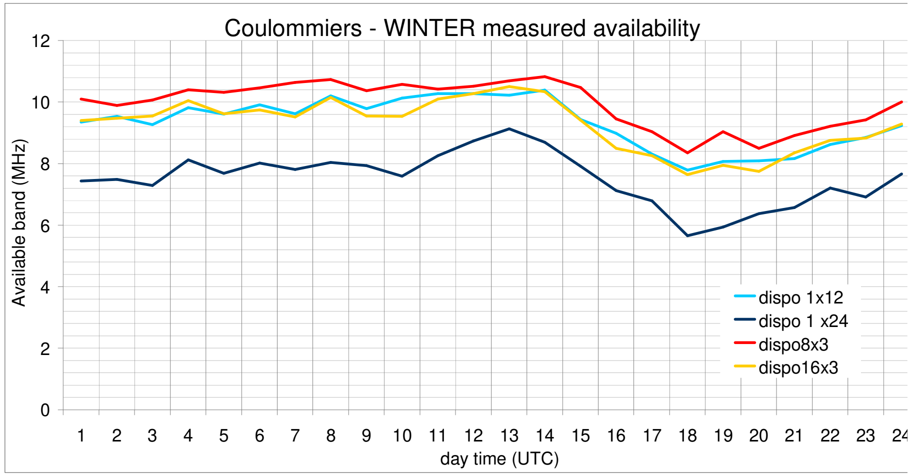


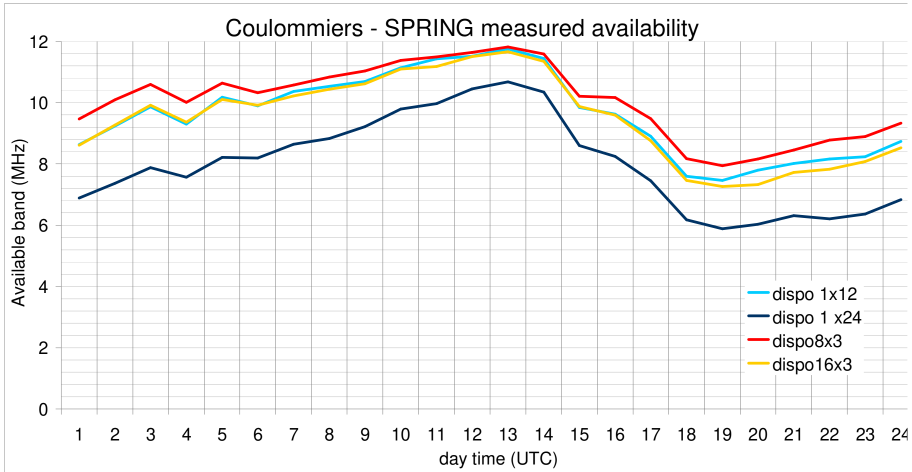

THALES

# Measures done

## Averaging in terms of measured availability:




**Availability of non contiguous 16x3kHz close to availability of contiguous 1x12kHz !!**

**Free contiguous 24kHz bands are rare … and often found in spectrum parts that won't be usable in practice (impossible to establish circuit)**

# Presentation outline

## Context and motivation

- HF high data rate communications
- Spectrum availability and spectrum management issues

## Spectrum measurements

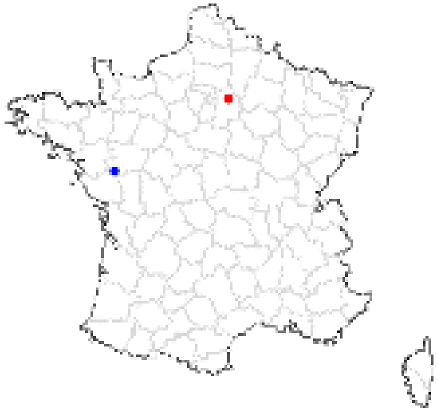
- Equipment used and measures done
- Measures analysis principle
- Occupations observed in Coulommiers, France

## Application to HF wideband communications

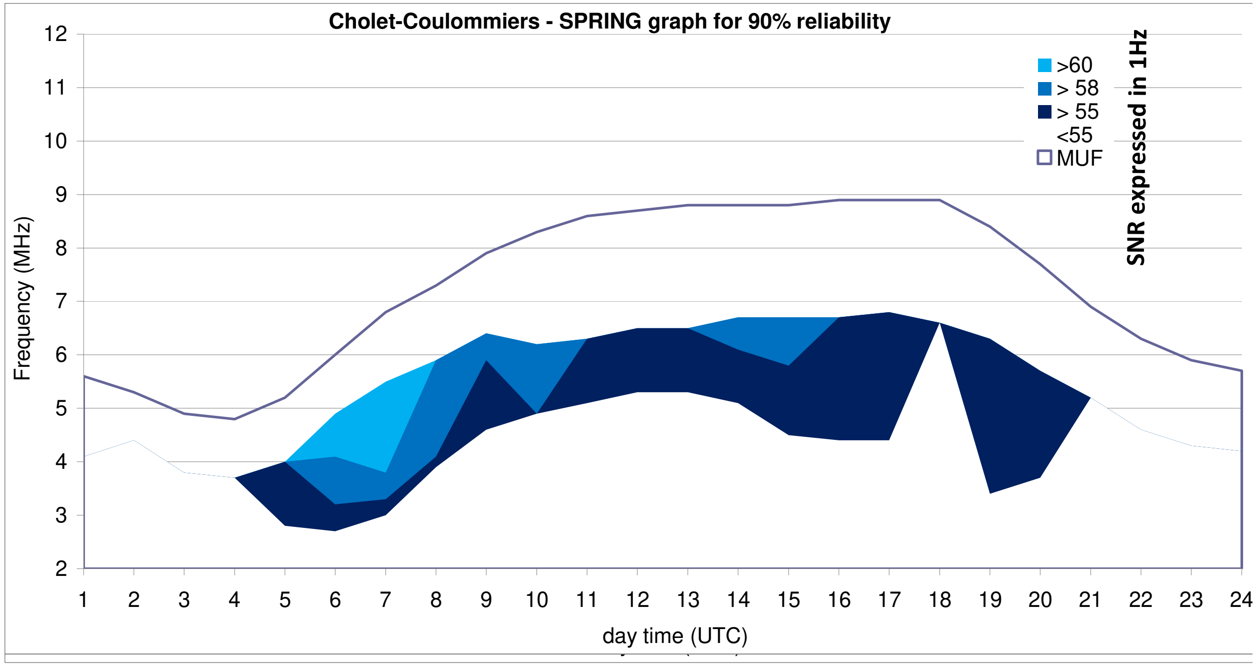
- Taking into account circuit reliability (propagation predictions)
- Comparing achievable throughputs

## Conclusions

# Circuit considered: Cholet → Coulommiers

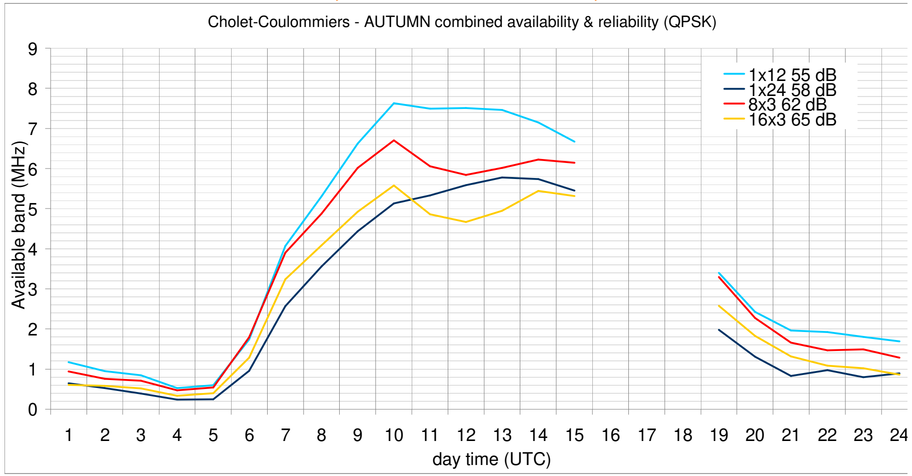


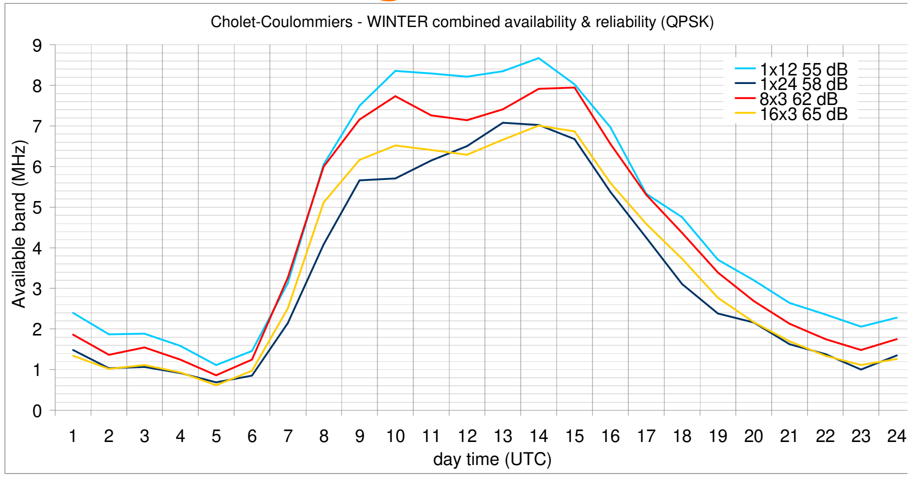
- ICEPAC
  - THALES NVIS wideband antenna “Butterfly”
  - TX power: 400W PEP
  - RX noise: rural calm
  - Required SNR : based on MIL STD 188 110C requirements

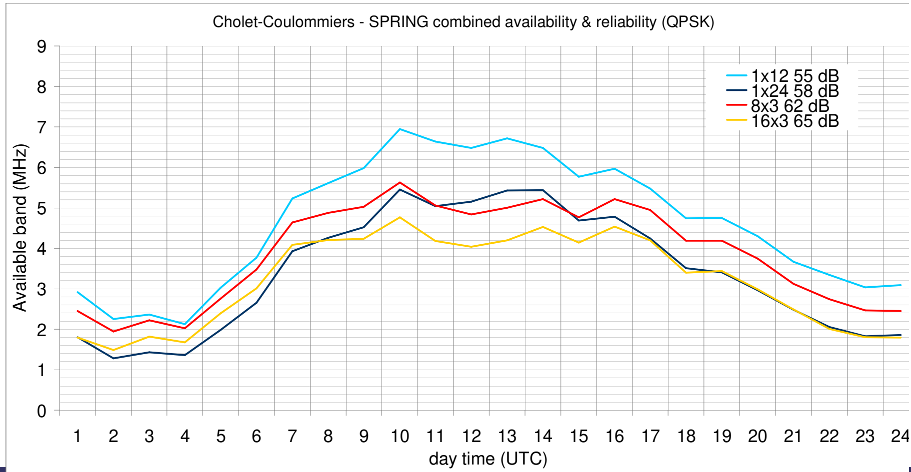


# Measures analysis

## Combined availability and reliability for QPSK modulation for 1x12kHz, 1x24kHz, 8x3kHz and 16x3kHz configurations



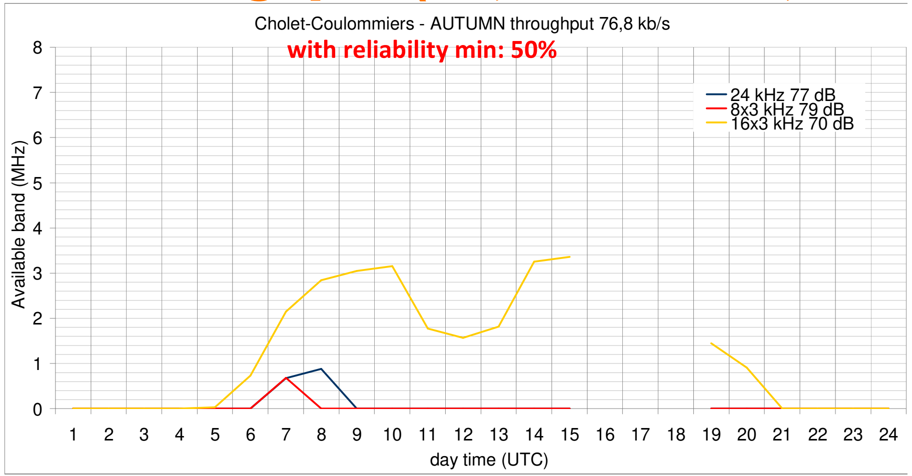



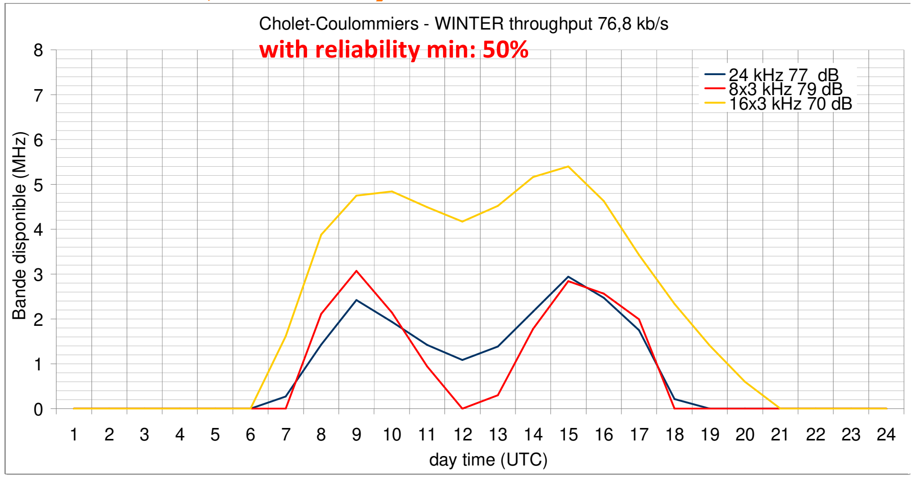



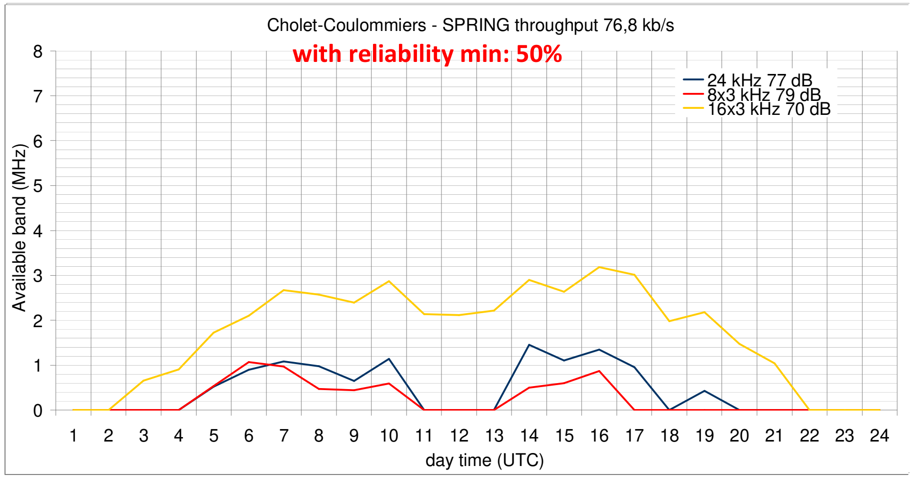

**Better availability for 12kHz due to lower SNR req. (half throughput)**
**Back-off cost for multi-carrier easily compensated for 8x3 vs. 24**
**16*3kHz often better than 24kHz (and double throughput)**

# Measures analysis

## Combined availability and reliability for same achieved throughput (25,6 kb/s – 51,2 kb/s and 76,8 kb/s)




**Reaching higher throughputs with XL approach !!**

# Conclusions



**Finding a block of 12 to 24kHz (contiguous) free and authorized spectrum in LUF/MUF is much more difficult than n*3kHz**

- Issue of pre-existing allocations (world-wide)
- Issue of dynamic spectrum management

**Furthermore, and independently of this issue, it appears that:**

- XL multiple narrow band approach allows to reach higher throughputs
- XL multiple narrow band approach offers a better spectrum availability
- XL multiple narrow band approach is much more flexible in terms of operational use

**Key observations:**

- 8*3kHz availability better than contiguous 12kHz and obviously than 24kHz
- 16*3kHz availability ~ contiguous 12kHz availability!

**Key observations: high data rate communications (64kb/s) obtained with good reliability in XL approach (taking into account back-off cost)**

A revision of STANAG 4539 to introduce wideband modems according to MIL STD 188 110C solutions should also standardize multi narrow band (n>2) approach.





# Thanks for your attention

catherine.lamy-bergot AT thalesgroup.com

and grateful thanks to our colleagues
Gilles Rogerieux and Hervé Petit for their help.