Interference Environment and Wideband Channel Availability

William Furman, John Nieto, Eric Koski

Harris Corporation

RF Communications Division

THIS INFORMATION WAS APPROVED FOR PUBLISHING PER THE ITAR AS "FUNDAMENTAL RESEARCH"

Presentation Overview

- Introduction
- Previous HF Availability Studies
- Measurement System Overview
- Data Collection and Analysis
- Results
- Summary / Way Forward

Introduction

- HF continues to be an important data communications technology
- Increasing need by the user community for higher data rates
- Recent US MIL-STD-188-110C defines a family of wideband HF data waveforms which spans contiguous bandwidths from 3 to 24 kHz
- Other channel–bonding approaches combine multiple 3 kHz channels to achieve higher data rates
- An important consideration when fielding a wideband HF data system is the channel availability
- This presentation examines channel availability specifically for the US MIL-STD-188-110C contiguous bandwidth,3-24 kHz approach.

Previous HF Availability Studies

- There is a wealth of availability studies documented in the literature from G. F. Gott (et. Al.) (mid 1980s onward)
  - Based on long term measurement campaigns in the UK and Europe
  - Parametric model developed for use in Frequency management and planning
- Recent experimentation has been performed by Warner, Bantseev and Serinken (2011)
  - Measurements in Ottawa Canada
  - Specific investigation into 3,12 and 24 kHz contiguous channels
  - Concluded that spectrum availability could support wideband HF
- A recent study by Berg, Johansson and Nagy (2012)
  - Metric based on occupancy less than 5 or 50% in 9 out of 10 days
  - Noted that a frequency adaptive system has potential for better wideband capacity

- Harris has developed an adaptive system that selects the best channel, determines available bandwidth and offset for wideband communications.
- To gauge the suitability of wideband HF over specific links, a way to survey and measure channel availability was needed
- Channel availability measurements need quick revisit times so that links that are suitable for tactical messages and ARQ systems can be properly detected
  - Short messages
    - On-air times of less than a minute
  - Adaptive data link protocols
    - STANAG 5066

Measurement System Overview

- Perseus SDR
  - Full HF Coverage
  - 14 bit 80 MS/s
  - FPGA can shift LO and decimate to 48 kS/s through 2 MS/s
  - USB interface to DSP
  - Software Developers Kit
  - Same SDR as used by Berg
- Clifton Labs Z1501D
  - Active Antenna
  - Short whip
  - 20 kHz to 30 MHz
  - FET to couple to 50 ohm

Data Collection

- For each sweep the Perseus LO is stepped by 1 MHz, every second, from 2.5 MHz to 29.5 MHz.
- I and Q samples are collected at a sample rate of 2Ms/s
- Full sweep of HF band in under 30 seconds
- 4096 pt FFT with a Kaiser window is used
- Magnitude –Squared of 488 FFT's are averaged for each 1second, 1 MHz observation
- Initial frequency bin resolution of 488.28125 Hz, post processed into 3 kHz bins
- Sweep repeated every 60 seconds
- This functionality was implemented by using the Perseus SDK and generating a custom program to control the SDR and record data

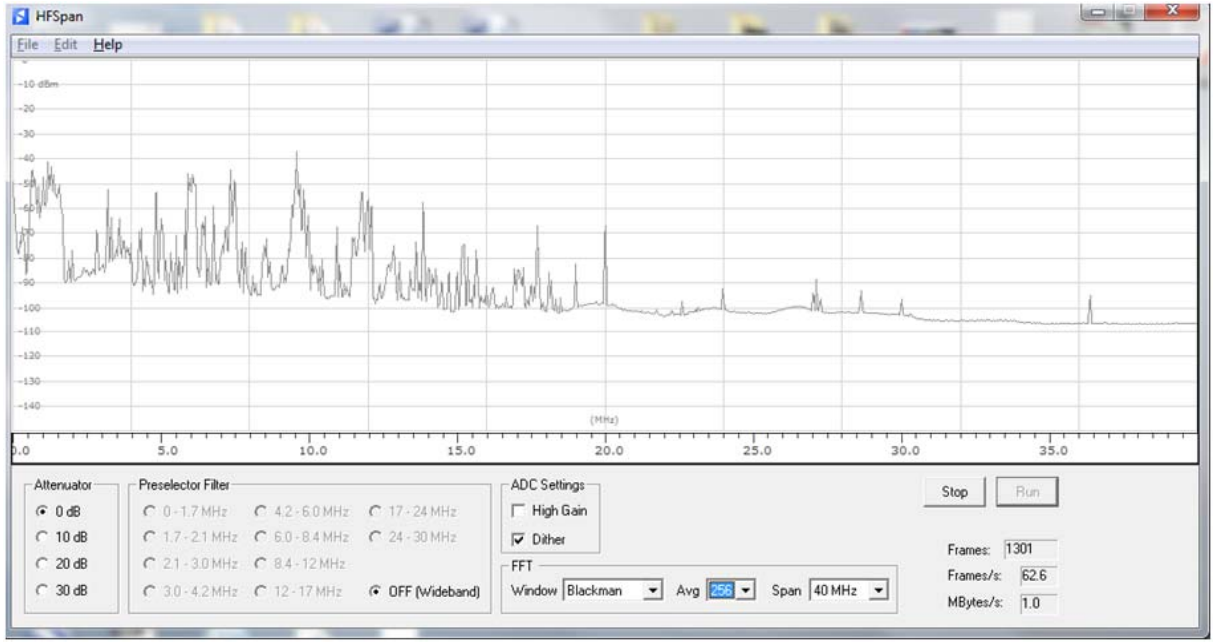
Data Analysis – Part 1

- Each sweep observation file processed in 1 Mhz segments
- Measured RX power sorted and noise floor calculated by averaging the 10 lowest values
- For each 3 kHz bin, if the RX power was 10dB above the noise floor it was considered occupied
- Each sweep observation file converted to 9334 values, (1,0) indicating if that 3 kHz segment was occupied

- Channel Minute Availability (CMA)
  - If a specific 3 kHz bin was available for 3 observations in a row it was considered available for the current minute
  - This biases the availability to channels that are relatively unused for a few minutes and not experiencing sporadic use or interference (Good for tactical messaging)
  - CMA is a good best case metric which assumes all channels equally available and a low overhead adaptive wideband HF ALE system
  - Each 3 KHz bin could have up to 60 available minutes in an hour.
  - For each 1 MHz segment there can be a total of 60*1000000/3000 = 19980 (3 kHz)
  - Results displayed as a normalized CMA (0.0 – 1.0)
  - Processing repeated for bandwidths of 12 and 24 kHz

Results

- Monitoring was done at locations in Rochester, NY and Wokingham UK area in May and June 2013
- Approximately one week of 24 hour data was collected at each site
- Perseus HFSpan utility used to spot check for any local interference



- In following charts –
  - Values above 0.75 are coloured green
  - Values between 0.5 and 0.75 are coloured yellow
  - Values between 0.25 and 0.5 are coloured orange
  - Values below 0.25 are coloured red

US Results 3 kHz

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
0	0.74	0.57	0.75	0.90	0.82	0.77	0.79	0.75	0.93	0.82	0.88	0.86	0.85	0.86	0.95	0.91	0.96	0.99	0.98	0.98	0.99	0.99	1.00	0.99	0.97	0.94	1.00	0.99
1	0.76	0.64	0.72	0.85	0.76	0.71	0.83	0.72	0.89	0.78	0.87	0.92	0.86	0.87	0.94	0.90	0.96	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.96	0.90	0.99	0.99
2	0.82	0.67	0.72	0.83	0.75	0.71	0.83	0.70	0.90	0.78	0.85	0.89	0.85	0.91	0.95	0.91	0.95	0.98	0.99	0.99	1.00	0.99	1.00	0.99	0.98	0.94	0.99	0.99
3	0.85	0.71	0.74	0.84	0.75	0.75	0.83	0.76	0.93	0.79	0.84	0.87	0.85	0.88	0.96	0.91	0.97	0.99	0.99	0.99	1.00	0.99	1.00	1.00	1.00	0.98	0.99	0.99
4	0.79	0.71	0.73	0.83	0.75	0.78	0.82	0.80	0.93	0.78	0.86	0.87	0.85	0.84	0.96	0.91	0.98	0.99	0.99	0.99	1.00	0.99	1.00	1.00	1.00	0.98	0.98	0.99
5	0.79	0.71	0.76	0.86	0.78	0.86	0.83	0.86	0.94	0.78	0.87	0.85	0.84	0.83	0.96	0.92	0.97	0.99	0.99	1.00	1.00	0.99	1.00	1.00	1.00	0.98	0.99	0.98
6	0.79	0.71	0.76	0.86	0.81	0.87	0.83	0.89	0.95	0.81	0.88	0.85	0.88	0.84	0.97	0.94	0.99	1.00	1.00	1.00	1.00	0.98	1.00	1.00	0.99	0.98	0.99	0.98
7	0.72	0.67	0.72	0.87	0.84	0.92	0.84	0.92	0.96	0.85	0.90	0.87	0.93	0.89	0.98	0.94	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.99
8	0.71	0.68	0.72	0.86	0.87	0.93	0.85	0.92	0.97	0.91	0.93	0.90	0.97	0.95	0.98	0.96	0.99	0.99	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.98	0.98	0.98
9	0.69	0.70	0.73	0.88	0.85	0.93	0.87	0.91	0.97	0.92	0.94	0.94	0.98	0.96	0.99	0.97	1.00	0.99	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.98	0.99	0.98
10	0.59	0.61	0.73	0.88	0.87	0.93	0.87	0.87	0.97	0.88	0.94	0.92	0.98	0.93	0.98	0.96	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.98
11	0.59	0.59	0.72	0.91	0.91	0.90	0.87	0.85	0.97	0.83	0.91	0.89	0.97	0.86	0.98	0.90	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	0.99
12	0.64	0.53	0.75	0.94	0.93	0.88	0.91	0.87	0.97	0.82	0.93	0.90	0.95	0.84	0.97	0.86	0.98	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00
13	0.64	0.49	0.77	0.97	0.95	0.88	0.88	0.90	0.96	0.88	0.93	0.90	0.93	0.79	0.97	0.86	0.98	1.00	0.99	0.97	1.00	1.00	1.00	1.00	0.99	0.98	1.00	1.00
14	0.67	0.49	0.76	0.98	0.95	0.91	0.85	0.93	0.97	0.89	0.93	0.90	0.92	0.78	0.97	0.86	0.98	0.99	0.99	0.97	0.99	1.00	1.00	1.00	1.00	0.97	0.99	0.99
15	0.68	0.51	0.75	0.98	0.94	0.95	0.87	0.94	0.98	0.91	0.93	0.91	0.92	0.81	0.98	0.88	0.98	1.00	1.00	0.97	0.99	0.99	1.00	1.00	0.99	0.97	0.99	0.99
16	0.73	0.50	0.75	0.97	0.95	0.97	0.88	0.95	0.97	0.94	0.93	0.91	0.93	0.80	0.97	0.92	0.98	0.99	0.99	0.97	0.99	0.99	1.00	1.00	1.00	0.96	0.98	0.98
17	0.73	0.50	0.76	0.98	0.96	0.97	0.86	0.95	0.98	0.93	0.94	0.90	0.94	0.78	0.97	0.89	0.97	0.99	0.99	0.96	0.99	0.99	0.99	1.00	0.99	0.96	0.99	0.98
18	0.74	0.50	0.76	0.97	0.95	0.97	0.85	0.94	0.98	0.94	0.93	0.88	0.96	0.80	0.97	0.90	0.97	0.99	1.00	0.97	1.00	0.99	0.99	1.00	0.99	0.96	1.00	0.99
19	0.74	0.54	0.76	0.98	0.95	0.97	0.85	0.94	0.98	0.92	0.91	0.90	0.95	0.82	0.97	0.92	0.98	0.99	1.00	0.97	0.99	0.99	0.99	0.99	0.97	0.94	1.00	0.98
20	0.76	0.56	0.78	0.97	0.94	0.95	0.85	0.92	0.98	0.87	0.89	0.91	0.93	0.83	0.98	0.91	0.98	0.99	0.99	0.98	0.99	0.98	0.99	0.99	0.98	0.96	0.99	0.99
21	0.77	0.57	0.79	0.98	0.94	0.94	0.85	0.88	0.98	0.85	0.87	0.91	0.92	0.86	0.97	0.91	0.96	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.95	0.99	0.98
22	0.74	0.59	0.79	0.97	0.92	0.89	0.82	0.83	0.96	0.86	0.87	0.90	0.90	0.89	0.96	0.90	0.96	0.99	0.99	0.97	0.98	0.98	0.99	0.99	0.96	0.95	0.98	0.99
23	0.76	0.61	0.78	0.95	0.89	0.84	0.80	0.76	0.95	0.86	0.89	0.87	0.87	0.87	0.96	0.91	0.96	0.99	0.99	0.98	0.99	0.98	0.99	0.99	0.97	0.95	0.99	0.99

US Results 12 kHz

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
0	0.71	0.50	0.70	0.85	0.72	0.66	0.69	0.62	0.88	0.74	0.80	0.76	0.76	0.76	0.91	0.85	0.93	0.98	0.98	0.96	0.98	0.98	0.99	0.99	0.94	0.90	0.99	0.99
1	0.71	0.55	0.63	0.78	0.64	0.58	0.72	0.60	0.83	0.67	0.78	0.84	0.76	0.78	0.91	0.83	0.93	0.98	0.99	0.97	0.98	0.99	0.99	0.99	0.94	0.84	0.99	0.98
2	0.78	0.56	0.62	0.77	0.63	0.59	0.73	0.58	0.84	0.67	0.74	0.83	0.76	0.83	0.91	0.84	0.93	0.98	0.98	0.99	0.99	0.98	0.99	0.99	0.97	0.90	0.99	0.99
3	0.81	0.61	0.65	0.77	0.64	0.62	0.73	0.64	0.87	0.69	0.73	0.79	0.77	0.80	0.93	0.85	0.95	0.98	0.99	0.99	0.99	0.99	1.00	1.00	1.00	0.96	0.99	1.00
4	0.75	0.62	0.63	0.76	0.65	0.67	0.71	0.68	0.87	0.67	0.74	0.79	0.77	0.74	0.93	0.85	0.96	0.99	0.99	0.99	1.00	0.99	1.00	1.00	1.00	0.96	0.97	0.99
5	0.75	0.63	0.66	0.79	0.69	0.75	0.72	0.75	0.89	0.69	0.76	0.76	0.76	0.72	0.94	0.87	0.95	0.99	0.99	0.99	1.00	0.98	0.99	1.00	0.99	0.97	0.99	0.98
6	0.75	0.63	0.68	0.81	0.73	0.78	0.74	0.80	0.90	0.70	0.78	0.75	0.80	0.74	0.95	0.89	0.98	0.99	0.99	1.00	1.00	0.97	1.00	1.00	0.99	0.97	0.99	0.98
7	0.68	0.59	0.65	0.82	0.76	0.87	0.74	0.85	0.92	0.76	0.81	0.80	0.88	0.81	0.96	0.89	0.99	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	0.99	0.99
8	0.67	0.61	0.65	0.81	0.80	0.89	0.77	0.86	0.95	0.85	0.87	0.84	0.95	0.91	0.97	0.93	0.98	0.99	1.00	1.00	1.00	0.98	0.99	1.00	0.99	0.97	0.97	0.98
9	0.65	0.61	0.65	0.84	0.78	0.90	0.80	0.85	0.95	0.87	0.90	0.89	0.96	0.91	0.98	0.95	0.99	0.99	1.00	1.00	1.00	0.99	1.00	1.00	0.99	0.97	0.99	0.98
10	0.55	0.53	0.66	0.84	0.79	0.88	0.79	0.78	0.95	0.79	0.89	0.86	0.97	0.88	0.96	0.92	0.99	1.00	0.99	1.00	1.00	0.99	0.99	1.00	0.99	0.98	0.99	0.98
11	0.56	0.50	0.68	0.87	0.85	0.84	0.79	0.74	0.96	0.72	0.84	0.81	0.95	0.76	0.96	0.83	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00	1.00	0.98	0.99	0.99
12	0.60	0.47	0.72	0.91	0.89	0.81	0.85	0.79	0.95	0.73	0.88	0.82	0.92	0.74	0.94	0.77	0.97	0.99	1.00	0.97	1.00	0.99	1.00	1.00	0.99	0.98	0.99	1.00
13	0.60	0.44	0.74	0.96	0.92	0.81	0.82	0.85	0.94	0.79	0.88	0.83	0.88	0.68	0.95	0.77	0.96	0.99	0.99	0.95	0.99	0.99	1.00	1.00	0.99	0.97	0.99	1.00
14	0.64	0.44	0.73	0.98	0.92	0.85	0.81	0.88	0.96	0.83	0.88	0.84	0.87	0.66	0.94	0.77	0.96	0.99	0.99	0.95	0.99	0.99	1.00	1.00	0.99	0.95	0.98	0.99
15	0.65	0.46	0.73	0.98	0.92	0.92	0.84	0.90	0.97	0.86	0.88	0.85	0.86	0.70	0.95	0.81	0.96	0.99	1.00	0.95	0.99	0.99	1.00	1.00	0.99	0.94	0.99	0.99
16	0.70	0.45	0.72	0.97	0.92	0.95	0.84	0.91	0.96	0.90	0.89	0.83	0.88	0.68	0.94	0.87	0.95	0.98	0.99	0.95	0.98	0.97	1.00	0.99	0.99	0.93	0.97	0.98
17	0.70	0.45	0.74	0.98	0.93	0.95	0.82	0.92	0.97	0.89	0.90	0.82	0.90	0.65	0.94	0.81	0.95	0.99	0.98	0.93	0.98	0.99	0.99	1.00	0.98	0.92	0.98	0.98
18	0.70	0.45	0.73	0.97	0.92	0.95	0.82	0.90	0.97	0.89	0.88	0.80	0.92	0.69	0.95	0.83	0.95	0.99	1.00	0.95	1.00	0.98	0.98	1.00	0.98	0.93	0.99	0.98
19	0.70	0.49	0.73	0.97	0.93	0.95	0.81	0.90	0.97	0.85	0.84	0.84	0.90	0.74	0.95	0.86	0.96	0.98	0.99	0.95	0.99	0.98	0.98	0.99	0.95	0.90	0.99	0.98
20	0.72	0.51	0.75	0.96	0.92	0.92	0.81	0.86	0.98	0.77	0.81	0.85	0.87	0.75	0.96	0.85	0.95	0.99	0.98	0.97	0.99	0.97	0.98	0.99	0.97	0.93	0.99	0.98
21	0.73	0.53	0.76	0.97	0.91	0.89	0.80	0.80	0.97	0.76	0.78	0.85	0.86	0.80	0.94	0.86	0.94	0.98	0.98	0.97	0.99	0.98	0.98	0.99	0.94	0.91	0.98	0.98
22	0.70	0.54	0.77	0.97	0.88	0.81	0.76	0.73	0.94	0.77	0.79	0.83	0.83	0.83	0.93	0.85	0.93	0.99	0.98	0.95	0.97	0.97	0.98	0.98	0.94	0.91	0.97	0.98
23	0.72	0.56	0.74	0.93	0.82	0.74	0.71	0.64	0.92	0.78	0.82	0.79	0.78	0.79	0.92	0.87	0.93	0.99	0.99	0.96	0.98	0.97	0.99	0.98	0.95	0.91	0.98	0.99

US Results 24 kHz

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
0	0.67	0.44	0.63	0.80	0.62	0.57	0.59	0.49	0.83	0.61	0.70	0.69	0.68	0.67	0.87	0.80	0.91	0.98	0.97	0.95	0.98	0.99	0.99	0.99	0.92	0.85	0.99	0.99
1	0.66	0.45	0.53	0.70	0.51	0.48	0.63	0.50	0.77	0.54	0.68	0.79	0.67	0.70	0.87	0.75	0.90	0.98	0.99	0.96	0.97	0.99	0.98	0.99	0.91	0.79	0.98	0.98
2	0.71	0.46	0.53	0.69	0.51	0.49	0.63	0.47	0.77	0.54	0.60	0.76	0.69	0.75	0.86	0.76	0.90	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.95	0.86	0.99	0.99
3	0.76	0.51	0.55	0.70	0.52	0.52	0.64	0.52	0.81	0.58	0.61	0.69	0.70	0.72	0.90	0.78	0.93	0.98	0.99	0.99	0.99	0.99	1.00	1.00	1.00	0.94	0.99	1.00
4	0.70	0.52	0.53	0.68	0.55	0.56	0.62	0.57	0.81	0.55	0.64	0.69	0.70	0.64	0.90	0.79	0.95	0.98	0.99	0.99	1.00	0.99	1.00	1.00	1.00	0.95	0.97	0.99
5	0.70	0.54	0.55	0.71	0.58	0.65	0.61	0.66	0.83	0.57	0.65	0.66	0.68	0.62	0.91	0.83	0.94	0.99	0.98	0.99	1.00	0.98	0.99	1.00	0.99	0.96	0.99	0.98
6	0.70	0.55	0.59	0.74	0.65	0.70	0.64	0.70	0.86	0.55	0.66	0.66	0.73	0.63	0.92	0.83	0.97	0.99	0.99	1.00	1.00	0.97	0.99	1.00	0.99	0.97	0.99	0.98
7	0.63	0.51	0.56	0.75	0.70	0.81	0.66	0.77	0.89	0.66	0.72	0.72	0.84	0.71	0.95	0.83	0.99	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	0.99	0.99
8	0.62	0.53	0.56	0.74	0.73	0.83	0.69	0.80	0.92	0.78	0.81	0.79	0.93	0.87	0.96	0.90	0.98	0.99	0.99	1.00	1.00	0.98	0.99	1.00	0.99	0.97	0.97	0.98
9	0.60	0.53	0.55	0.77	0.71	0.84	0.74	0.79	0.93	0.80	0.85	0.85	0.95	0.87	0.97	0.92	0.99	0.99	1.00	1.00	1.00	0.99	0.99	1.00	0.99	0.97	0.99	0.98
10	0.51	0.46	0.58	0.78	0.73	0.82	0.72	0.68	0.93	0.68	0.85	0.80	0.96	0.81	0.94	0.88	0.99	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.99	0.97	0.99	0.98
11	0.52	0.43	0.64	0.82	0.79	0.76	0.72	0.64	0.94	0.59	0.81	0.72	0.93	0.65	0.93	0.75	0.98	1.00	1.00	0.99	1.00	0.99	0.99	1.00	1.00	0.97	0.99	0.99
12	0.56	0.41	0.69	0.89	0.86	0.72	0.80	0.69	0.94	0.60	0.85	0.72	0.88	0.60	0.91	0.67	0.96	0.99	1.00	0.96	1.00	1.00	1.00	1.00	0.99	0.98	1.00	1.00
13	0.57	0.39	0.72	0.95	0.90	0.75	0.77	0.79	0.92	0.67	0.84	0.75	0.83	0.56	0.92	0.66	0.96	0.99	0.98	0.94	0.99	1.00	1.00	1.00	0.98	0.96	1.00	1.00
14	0.60	0.40	0.71	0.98	0.90	0.79	0.77	0.85	0.95	0.75	0.84	0.78	0.81	0.54	0.91	0.66	0.95	0.98	0.99	0.92	0.99	0.99	0.99	1.00	0.99	0.93	0.99	0.99
15	0.62	0.41	0.70	0.98	0.89	0.87	0.80	0.87	0.96	0.81	0.84	0.78	0.81	0.58	0.93	0.71	0.95	0.99	1.00	0.93	0.99	0.99	1.00	1.00	0.98	0.92	0.99	0.99
16	0.65	0.40	0.69	0.96	0.90	0.92	0.80	0.89	0.95	0.86	0.85	0.77	0.83	0.55	0.91	0.80	0.94	0.98	0.99	0.92	0.98	0.97	0.99	0.99	0.99	0.90	0.97	0.98
17	0.66	0.41	0.72	0.98	0.92	0.92	0.79	0.90	0.96	0.85	0.86	0.76	0.85	0.52	0.91	0.73	0.94	0.99	0.98	0.89	0.97	0.99	0.98	1.00	0.98	0.89	0.98	0.98
18	0.66	0.41	0.70	0.97	0.90	0.93	0.78	0.87	0.97	0.84	0.83	0.74	0.88	0.58	0.92	0.76	0.94	0.98	0.99	0.93	1.00	0.99	0.98	1.00	0.97	0.90	0.99	0.98
19	0.66	0.45	0.70	0.97	0.92	0.92	0.77	0.85	0.97	0.78	0.79	0.75	0.85	0.65	0.93	0.79	0.94	0.98	0.99	0.93	0.99	0.98	0.98	0.98	0.94	0.87	0.99	0.98
20	0.68	0.47	0.72	0.96	0.89	0.88	0.77	0.79	0.97	0.68	0.74	0.78	0.82	0.67	0.94	0.79	0.94	0.99	0.98	0.96	0.99	0.97	0.98	0.99	0.95	0.90	0.99	0.98
21	0.69	0.49	0.73	0.97	0.88	0.84	0.76	0.68	0.96	0.67	0.72	0.78	0.80	0.73	0.90	0.81	0.91	0.98	0.98	0.96	0.98	0.98	0.98	0.98	0.92	0.87	0.98	0.98
22	0.65	0.49	0.75	0.97	0.83	0.75	0.71	0.59	0.92	0.65	0.71	0.76	0.76	0.75	0.89	0.81	0.90	0.99	0.98	0.92	0.96	0.97	0.98	0.98	0.91	0.86	0.97	0.98
23	0.69	0.51	0.70	0.92	0.75	0.65	0.64	0.52	0.88	0.69	0.73	0.71	0.70	0.70	0.88	0.82	0.91	0.99	0.99	0.93	0.98	0.97	0.98	0.98	0.93	0.86	0.98	0.99

US Results

- Availability does decrease as bandwidth increases
- Increased occupancy noted during evening hours
- As expected high availability noted for higher (non-propagating) frequencies
- 3 KHz bandwidth very high availability
- 12 kHz slightly less availability
- 24 kHz availability still greater than 50% during evening hours and greater than 75% during daytime hours

UK Results 3 kHz

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
0	0.81	0.91	0.57	0.66	0.49	0.72	0.71	0.66	0.96	0.88	0.87	0.77	0.91	0.88	0.95	0.91	0.92	0.98	0.98	0.99	1.00	1.00	0.91	1.00	0.99	0.95	0.99	0.98
1	0.81	0.91	0.52	0.61	0.45	0.75	0.71	0.65	0.96	0.88	0.84	0.77	0.95	0.91	0.96	0.90	0.92	0.98	0.98	0.99	1.00	1.00	0.92	0.99	0.99	0.97	0.99	0.98
2	0.81	0.92	0.52	0.60	0.51	0.78	0.70	0.64	0.97	0.87	0.80	0.79	0.97	0.94	0.96	0.92	0.93	0.98	0.98	0.99	1.00	1.00	0.94	1.00	0.99	0.99	0.98	0.98
3	0.82	0.92	0.52	0.58	0.54	0.81	0.69	0.75	0.97	0.89	0.84	0.80	0.97	0.94	0.96	0.93	0.94	0.98	0.98	0.99	1.00	1.00	0.94	1.00	0.99	0.99	0.99	0.97
4	0.85	0.93	0.58	0.61	0.58	0.81	0.73	0.79	0.98	0.89	0.83	0.82	0.97	0.90	0.95	0.92	0.93	0.98	0.98	0.99	1.00	1.00	0.91	1.00	0.99	0.99	0.99	0.98
5	0.90	0.93	0.61	0.64	0.59	0.86	0.71	0.87	0.98	0.86	0.84	0.84	0.95	0.84	0.94	0.90	0.93	0.97	0.98	0.99	1.00	1.00	0.88	0.99	0.99	0.99	0.99	0.98
6	0.93	0.95	0.55	0.68	0.56	0.87	0.70	0.87	0.98	0.84	0.87	0.82	0.93	0.81	0.95	0.81	0.93	0.97	0.98	0.99	1.00	0.99	0.92	1.00	0.99	0.99	0.98	0.98
7	0.96	0.99	0.65	0.69	0.72	0.86	0.72	0.90	0.98	0.90	0.90	0.88	0.94	0.84	0.93	0.71	0.92	0.97	0.97	0.98	1.00	0.99	0.90	1.00	0.99	0.99	0.99	0.98
8	0.97	0.99	0.63	0.73	0.71	0.87	0.72	0.94	0.98	0.92	0.90	0.86	0.97	0.90	0.94	0.77	0.92	0.97	0.97	0.99	0.99	1.00	0.89	1.00	0.99	0.98	0.99	0.98
9	0.98	1.00	0.66	0.74	0.75	0.91	0.75	0.95	0.99	0.95	0.90	0.91	0.98	0.89	0.94	0.82	0.93	0.98	0.98	0.98	1.00	1.00	0.91	1.00	0.99	0.99	0.99	0.98
10	0.98	1.00	0.66	0.71	0.76	0.94	0.71	0.97	0.98	0.97	0.91	0.94	0.98	0.90	0.94	0.82	0.93	0.97	0.98	0.96	1.00	0.99	0.89	1.00	0.99	0.98	0.99	0.98
11	0.98	1.00	0.66	0.73	0.76	0.95	0.77	0.98	0.98	0.98	0.93	0.93	0.98	0.88	0.94	0.80	0.94	0.95	0.97	0.95	1.00	1.00	0.93	1.00	0.99	0.99	0.98	0.98
12	0.98	1.00	0.65	0.72	0.78	0.95	0.82	0.98	0.99	0.98	0.95	0.89	0.97	0.87	0.94	0.80	0.93	0.96	0.98	0.94	1.00	1.00	0.93	1.00	0.99	0.99	0.98	0.98
13	0.98	1.00	0.68	0.73	0.76	0.96	0.83	0.96	0.98	0.97	0.93	0.86	0.97	0.83	0.93	0.76	0.92	0.97	0.98	0.94	1.00	1.00	0.94	1.00	0.99	0.99	0.99	0.98
14	0.97	0.99	0.70	0.73	0.75	0.97	0.83	0.95	0.98	0.96	0.92	0.89	0.98	0.79	0.93	0.77	0.92	0.98	0.98	0.96	1.00	1.00	0.93	1.00	0.98	0.99	0.99	0.98
15	0.99	1.00	0.66	0.73	0.74	0.97	0.82	0.92	0.98	0.92	0.90	0.86	0.97	0.77	0.94	0.78	0.93	0.98	0.98	0.96	1.00	1.00	0.94	1.00	0.99	0.99	0.98	0.98
16	0.93	0.98	0.68	0.75	0.75	0.93	0.85	0.85	0.98	0.85	0.87	0.81	0.97	0.69	0.94	0.85	0.93	0.98	0.98	0.97	1.00	1.00	0.95	1.00	0.99	0.99	0.98	0.98
17	0.84	0.95	0.72	0.78	0.74	0.85	0.86	0.75	0.98	0.76	0.83	0.83	0.97	0.68	0.94	0.84	0.92	0.98	0.98	0.96	1.00	1.00	0.94	1.00	0.98	0.98	0.99	0.98
18	0.89	0.97	0.68	0.71	0.71	0.76	0.79	0.61	0.96	0.67	0.83	0.80	0.94	0.70	0.94	0.84	0.90	0.97	0.98	0.96	1.00	1.00	0.94	1.00	0.98	0.97	0.98	0.98
19	0.84	0.95	0.69	0.70	0.60	0.64	0.72	0.52	0.95	0.66	0.76	0.78	0.90	0.75	0.93	0.84	0.90	0.97	0.97	0.95	1.00	1.00	0.93	1.00	0.98	0.96	0.98	0.98
20	0.88	0.95	0.70	0.70	0.55	0.50	0.70	0.49	0.94	0.65	0.78	0.79	0.86	0.75	0.93	0.86	0.90	0.97	0.98	0.97	1.00	1.00	0.94	1.00	0.99	0.97	0.98	0.98
21	0.86	0.91	0.74	0.71	0.54	0.45	0.69	0.53	0.93	0.69	0.83	0.81	0.84	0.79	0.93	0.89	0.90	0.97	0.98	0.98	1.00	1.00	0.87	1.00	0.99	0.97	0.98	0.98
22	0.79	0.90	0.67	0.75	0.55	0.56	0.72	0.65	0.95	0.75	0.87	0.87	0.87	0.85	0.94	0.90	0.92	0.97	0.98	0.99	1.00	0.99	0.89	1.00	0.98	0.98	0.99	0.98
23	0.79	0.91	0.65	0.77	0.54	0.63	0.71	0.63	0.94	0.80	0.89	0.85	0.88	0.88	0.95	0.91	0.92	0.97	0.98	0.99	1.00	0.99	0.91	1.00	0.99	0.98	0.98	0.98

UK Results 12 kHz

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
0	0.71	0.85	0.46	0.57	0.35	0.56	0.58	0.52	0.92	0.78	0.79	0.69	0.87	0.79	0.89	0.82	0.81	0.96	0.95	0.99	1.00	0.99	0.83	0.99	0.98	0.93	0.97	0.96
1	0.71	0.85	0.42	0.51	0.32	0.61	0.58	0.51	0.92	0.79	0.76	0.71	0.91	0.85	0.89	0.80	0.81	0.96	0.95	0.99	1.00	0.99	0.85	0.99	0.98	0.95	0.96	0.95
2	0.71	0.86	0.43	0.51	0.39	0.63	0.59	0.46	0.93	0.77	0.73	0.76	0.95	0.88	0.90	0.83	0.82	0.96	0.95	0.99	1.00	0.99	0.87	1.00	0.98	0.99	0.96	0.95
3	0.72	0.86	0.44	0.48	0.42	0.68	0.59	0.60	0.95	0.80	0.77	0.75	0.95	0.89	0.88	0.84	0.83	0.96	0.95	0.99	1.00	0.98	0.85	1.00	0.98	0.99	0.96	0.94
4	0.76	0.89	0.50	0.52	0.47	0.70	0.63	0.66	0.96	0.81	0.75	0.77	0.94	0.81	0.87	0.82	0.83	0.95	0.95	0.99	1.00	0.98	0.81	0.99	0.98	0.99	0.96	0.95
5	0.83	0.90	0.55	0.57	0.47	0.77	0.61	0.79	0.95	0.76	0.76	0.78	0.92	0.73	0.85	0.80	0.82	0.95	0.95	0.98	0.99	0.98	0.76	0.99	0.98	0.99	0.96	0.95
6	0.88	0.93	0.51	0.63	0.47	0.77	0.60	0.80	0.95	0.72	0.81	0.75	0.89	0.68	0.87	0.66	0.82	0.94	0.95	0.97	0.99	0.98	0.82	0.99	0.97	0.98	0.96	0.95
7	0.93	0.98	0.61	0.66	0.64	0.78	0.63	0.84	0.95	0.81	0.83	0.82	0.90	0.73	0.83	0.52	0.81	0.95	0.94	0.96	0.99	0.98	0.79	0.99	0.97	0.98	0.97	0.95
8	0.95	0.98	0.59	0.71	0.65	0.79	0.63	0.90	0.96	0.86	0.83	0.80	0.94	0.82	0.86	0.62	0.82	0.95	0.94	0.97	0.99	0.99	0.79	0.99	0.98	0.97	0.97	0.95
9	0.97	0.99	0.63	0.72	0.69	0.86	0.67	0.93	0.97	0.91	0.84	0.86	0.96	0.80	0.86	0.68	0.83	0.96	0.95	0.95	1.00	0.98	0.83	0.99	0.98	0.98	0.97	0.95
10	0.96	1.00	0.63	0.69	0.70	0.89	0.64	0.96	0.96	0.95	0.86	0.91	0.96	0.82	0.85	0.68	0.82	0.94	0.95	0.92	1.00	0.98	0.78	0.99	0.98	0.97	0.97	0.95
11	0.97	1.00	0.63	0.71	0.72	0.91	0.71	0.97	0.96	0.97	0.88	0.88	0.96	0.79	0.86	0.65	0.83	0.91	0.94	0.90	1.00	0.99	0.85	0.99	0.98	0.97	0.96	0.95
12	0.96	1.00	0.63	0.70	0.74	0.91	0.76	0.96	0.97	0.96	0.90	0.84	0.95	0.76	0.86	0.66	0.82	0.92	0.95	0.90	1.00	0.99	0.84	0.99	0.98	0.98	0.95	0.96
13	0.98	1.00	0.66	0.71	0.71	0.93	0.77	0.92	0.96	0.94	0.88	0.78	0.95	0.68	0.85	0.61	0.82	0.94	0.95	0.90	1.00	0.99	0.88	0.99	0.97	0.98	0.97	0.96
14	0.95	0.99	0.67	0.70	0.69	0.95	0.76	0.92	0.96	0.93	0.87	0.82	0.96	0.61	0.85	0.62	0.82	0.96	0.96	0.93	1.00	0.99	0.86	0.99	0.97	0.98	0.96	0.96
15	0.98	1.00	0.63	0.72	0.68	0.93	0.74	0.86	0.96	0.86	0.83	0.79	0.94	0.61	0.86	0.62	0.82	0.96	0.96	0.93	1.00	0.99	0.88	0.99	0.97	0.98	0.96	0.96
16	0.88	0.96	0.65	0.71	0.68	0.86	0.77	0.75	0.96	0.74	0.78	0.73	0.94	0.50	0.85	0.73	0.83	0.95	0.95	0.94	1.00	0.99	0.89	0.99	0.97	0.98	0.96	0.96
17	0.75	0.88	0.67	0.70	0.63	0.73	0.77	0.56	0.95	0.60	0.71	0.74	0.93	0.52	0.86	0.70	0.81	0.95	0.95	0.93	1.00	0.99	0.87	0.99	0.95	0.97	0.97	0.96
18	0.82	0.93	0.62	0.64	0.59	0.60	0.67	0.42	0.93	0.51	0.71	0.70	0.88	0.54	0.85	0.70	0.79	0.93	0.96	0.93	0.99	0.99	0.87	0.99	0.96	0.95	0.96	0.95
19	0.76	0.90	0.63	0.62	0.46	0.46	0.59	0.34	0.91	0.47	0.64	0.68	0.83	0.61	0.85	0.72	0.79	0.94	0.94	0.91	0.99	0.99	0.86	1.00	0.96	0.93	0.95	0.96
20	0.81	0.91	0.62	0.61	0.40	0.32	0.56	0.32	0.88	0.48	0.67	0.71	0.77	0.58	0.84	0.74	0.79	0.95	0.95	0.93	0.99	0.99	0.87	0.99	0.97	0.95	0.95	0.95
21	0.78	0.85	0.63	0.63	0.38	0.28	0.54	0.36	0.87	0.52	0.71	0.74	0.74	0.65	0.84	0.79	0.79	0.94	0.95	0.96	0.99	0.98	0.76	0.99	0.97	0.94	0.95	0.96
22	0.69	0.84	0.57	0.66	0.40	0.39	0.58	0.49	0.90	0.59	0.78	0.80	0.80	0.75	0.87	0.79	0.82	0.94	0.96	0.98	1.00	0.98	0.81	0.99	0.97	0.97	0.97	0.97
23	0.69	0.84	0.53	0.67	0.39	0.47	0.58	0.50	0.89	0.68	0.81	0.78	0.82	0.79	0.87	0.82	0.82	0.94	0.96	0.99	1.00	0.98	0.83	0.99	0.98	0.97	0.96	0.96

UK Results 24 kHz

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
0	0.59	0.77	0.39	0.48	0.21	0.39	0.45	0.39	0.89	0.68	0.70	0.61	0.82	0.67	0.82	0.70	0.76	0.94	0.93	0.99	1.00	0.98	0.76	0.99	0.98	0.90	0.97	0.94
1	0.58	0.76	0.34	0.41	0.20	0.46	0.47	0.35	0.90	0.70	0.66	0.66	0.87	0.73	0.82	0.69	0.77	0.94	0.93	0.99	1.00	0.98	0.77	0.99	0.98	0.93	0.96	0.92
2	0.59	0.79	0.37	0.41	0.27	0.48	0.48	0.32	0.91	0.65	0.64	0.72	0.93	0.80	0.83	0.75	0.78	0.94	0.93	0.98	1.00	0.99	0.81	0.99	0.98	0.98	0.95	0.91
3	0.59	0.78	0.40	0.38	0.30	0.54	0.50	0.44	0.93	0.72	0.68	0.71	0.93	0.81	0.82	0.77	0.80	0.94	0.93	0.98	1.00	0.99	0.78	0.99	0.98	0.98	0.95	0.90
4	0.64	0.84	0.44	0.42	0.35	0.57	0.54	0.53	0.95	0.73	0.67	0.72	0.92	0.71	0.81	0.72	0.80	0.93	0.93	0.98	0.99	0.98	0.72	0.99	0.98	0.98	0.95	0.91
5	0.74	0.86	0.49	0.49	0.36	0.66	0.52	0.70	0.93	0.65	0.67	0.71	0.88	0.61	0.79	0.68	0.79	0.92	0.93	0.97	0.99	0.98	0.66	0.98	0.98	0.98	0.96	0.91
6	0.81	0.89	0.46	0.57	0.36	0.66	0.50	0.70	0.93	0.56	0.71	0.68	0.84	0.53	0.81	0.50	0.79	0.92	0.92	0.95	0.99	0.98	0.74	0.98	0.98	0.97	0.96	0.91
7	0.89	0.96	0.56	0.64	0.55	0.69	0.54	0.78	0.93	0.73	0.74	0.76	0.85	0.60	0.76	0.37	0.77	0.93	0.92	0.94	0.99	0.98	0.70	0.99	0.97	0.98	0.97	0.92
8	0.93	0.98	0.55	0.68	0.58	0.72	0.55	0.86	0.94	0.80	0.76	0.74	0.91	0.71	0.79	0.45	0.78	0.93	0.92	0.96	0.98	0.99	0.70	0.99	0.98	0.95	0.97	0.92
9	0.95	0.99	0.59	0.71	0.63	0.79	0.58	0.90	0.95	0.86	0.79	0.81	0.94	0.67	0.79	0.51	0.79	0.94	0.93	0.93	0.99	0.98	0.75	0.99	0.98	0.97	0.97	0.92
10	0.95	0.99	0.60	0.66	0.65	0.83	0.56	0.93	0.94	0.92	0.80	0.87	0.94	0.72	0.78	0.50	0.78	0.91	0.93	0.87	0.99	0.97	0.69	0.98	0.98	0.94	0.96	0.91
11	0.96	0.99	0.60	0.69	0.67	0.87	0.63	0.95	0.95	0.94	0.84	0.84	0.94	0.68	0.79	0.49	0.79	0.88	0.92	0.85	0.99	0.98	0.78	0.99	0.98	0.96	0.96	0.92
12	0.96	1.00	0.60	0.68	0.68	0.88	0.69	0.95	0.96	0.94	0.85	0.78	0.91	0.64	0.79	0.50	0.78	0.89	0.93	0.85	0.99	0.98	0.77	0.99	0.97	0.96	0.94	0.93
13	0.97	1.00	0.63	0.69	0.66	0.90	0.71	0.88	0.95	0.91	0.83	0.70	0.92	0.53	0.77	0.42	0.78	0.92	0.93	0.85	1.00	0.99	0.81	0.99	0.98	0.97	0.96	0.93
14	0.94	0.98	0.65	0.68	0.64	0.93	0.69	0.87	0.94	0.89	0.80	0.75	0.95	0.49	0.76	0.45	0.77	0.94	0.94	0.89	1.00	1.00	0.79	0.99	0.97	0.97	0.96	0.93
15	0.97	1.00	0.61	0.70	0.62	0.90	0.65	0.77	0.94	0.76	0.75	0.71	0.91	0.48	0.78	0.44	0.78	0.94	0.93	0.90	1.00	0.99	0.80	0.99	0.97	0.97	0.95	0.94
16	0.84	0.94	0.60	0.68	0.60	0.81	0.68	0.61	0.95	0.59	0.69	0.62	0.92	0.34	0.78	0.56	0.79	0.93	0.93	0.92	1.00	0.99	0.83	0.99	0.97	0.96	0.95	0.93
17	0.66	0.82	0.62	0.65	0.54	0.60	0.68	0.41	0.92	0.44	0.64	0.62	0.89	0.40	0.78	0.53	0.76	0.92	0.93	0.90	1.00	1.00	0.80	0.99	0.96	0.95	0.95	0.93
18	0.76	0.90	0.56	0.57	0.46	0.44	0.56	0.26	0.89	0.35	0.62	0.56	0.83	0.40	0.78	0.52	0.73	0.90	0.93	0.89	0.99	0.99	0.80	0.99	0.95	0.92	0.95	0.92
19	0.67	0.85	0.57	0.54	0.32	0.28	0.45	0.17	0.86	0.31	0.52	0.57	0.75	0.50	0.76	0.55	0.72	0.91	0.92	0.86	0.99	0.99	0.78	0.99	0.95	0.89	0.93	0.93
20	0.73	0.87	0.55	0.52	0.23	0.16	0.43	0.20	0.83	0.32	0.56	0.60	0.67	0.42	0.76	0.57	0.72	0.93	0.93	0.90	0.99	0.99	0.80	0.99	0.97	0.91	0.94	0.92
21	0.67	0.79	0.54	0.53	0.21	0.13	0.40	0.22	0.81	0.37	0.62	0.67	0.65	0.46	0.75	0.68	0.73	0.92	0.93	0.94	0.99	0.99	0.65	0.99	0.97	0.91	0.94	0.93
22	0.60	0.78	0.46	0.57	0.24	0.21	0.43	0.36	0.85	0.41	0.69	0.73	0.74	0.58	0.79	0.69	0.77	0.92	0.94	0.98	0.99	0.98	0.73	0.99	0.97	0.96	0.96	0.95
23	0.59	0.76	0.43	0.58	0.25	0.29	0.45	0.36	0.84	0.55	0.71	0.72	0.76	0.66	0.80	0.72	0.77	0.92	0.94	0.99	1.00	0.98	0.75	0.99	0.98	0.95	0.95	0.93

UK Results Summary

- Overall 3 kHz results show less availability than US but still many cases greater than 75% during the day and 50% during the evening
- 12 kHz results show a slight drop in availability with some evening segments below 50%
- 24 KHz results illustrate further reduction in availability, however still considerable segments greater than 50%. The evening hours are far worse with some segments dropping below 50% availability
- UK results show some segments that indicate high availability all day, such as 3 and 10 MHz, that may be due to wider bandwidth local interference

Propagation Based Comparison

- The analyzed data was further examined based on two different frequency band use case assumptions
  - NVIS 4-8 MHz
  - 2000 km 8-15 MHz
- The average CMA was calculated for each frequency segment for each location and channel bandwidth
- Overall availability is lower in the UK, though still quite useable
- In the US availability is similar for both types of links
- In the UK, availability is lower for the NVIS link, possibly indicating a much higher occurrence of users eroding channel availability

	U.S. 3 kHz	U.S. 12 kHz	U.S. 24 kHz	U.K. 3 kHz	U.K. 12 kHz	U.K. 24 kHz
NVIS 4-8 MHz	0.85	.80	0.74	0.71	0.62	0.54
2000 km 8-15 MHz	0.89	0.82	0.75	0.85	0.78	0.69

Summary

- Harris has fielded a low cost, easily transported, channel availability measurement system
- System has been used to do some preliminary measurements of wideband HF channel availability in 3, 12, and 24 kHz bandwidths
- A data collection and analysis procedure has been proposed
- A new metric, the Channel-Minute availability (CMA) has been proposed and used to more accurately capture channels that could be used by an adaptive wideband ALE based system for the conveyance of tactical HF messages
- Harris has tested an adaptive wideband HF system in a number of locations worldwide, all with good results
- Results show higher occupancy in the UK compared to US but still quite useable for the wider bandwidth channels

Way Forward

- Inexpensive system could be fielded by a number or countries/ organizations
- Collected data could be shared among all participants
- Harris could make available the data collection and data analysis software used for this paper
- Perhaps under the HFIA a working group could be established to define and agree upon the definition of availability metrics and the interpretation of results