

# Wideband HF Channel Availability – Measurement Techniques and Results

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## ABSTRACT

*In September of 2011 the U.S. MIL-STD-188-110 HF Data Modem standard [1] was updated to include the definition of wideband HF data modes. These modes occupy bandwidths from 3 up to 24 kHz and provide user data rates from 75 to 120000 bps. Since most of the wider modes occupy more bandwidth than the traditional 3kHz HF SSB allocations there is a great interest in determining the usability of these wider bandwidth waveforms in the already crowded HF spectrum (referred to as channel availability). The HF Industry Association (HFIA) has authorized a working group to examine this issue, develop unified measurement and analysis techniques, and collect measurements worldwide. This paper will provide a discussion of the working group's measurement and analysis techniques and provide some preliminary results.*

## 1. INTRODUCTION

The past twenty years has been a fertile development period for the design and implementation of technologies that provide reliable communications over 3 and 6 kHz HF radio links. The HF frequency band, covering from 2 to 30 MHz, is a very important communications medium as it provides Beyond Line Of Sight (BLOS) communications without the use of satellites or radio-relay. This work has been documented in several NATO standards [2-6] and US military standards [1]. In 2011 U.S. MIL-STD 188-110C (110C) was updated and published. Appendix D of the 110C standard (110C-D) defines a new family of wideband waveforms which can occupy contiguous bandwidths from 3 to 24 kHz, in increments of 3 kHz and can provide data rates from 75 bits per second (bps) up to 120 kbps. Since the HF band has been traditionally used with 3 kHz channel allocations, there existed some concern that wider contiguous bandwidths, as required by 110C-D, would not be readily available, especially in Europe, which has a reputation for HF channel congestion.

The HF Industry Association decided to form a working group to specifically look at the measurement of channel availability. The goals of this working group are:

- Under the auspices of the HF Industry Association (HFIA), collaboratively field a substantial number of HF wideband channel availability measurement stations in diverse locations worldwide
- Use common hardware, (SDR and antenna), collection software, and analysis software so that results can be easily and accurately compared between all sites
- Share the collected data and analysis results among all members of the HFIA

To date three working group meetings have been held; February 2014, September 2014 and February 2015. The next working group, to be held in conjunction with the next HF Industry Association meeting, is tentatively scheduled for September 2015 in Brussels, Belgium. The HFIA website, [www.hfindustry.com](http://www.hfindustry.com), is a good source of information and contains all the presentations and meeting summaries of both the HFIA

proper and the wideband HF Channel Availability Working group. A number of HFIA member establishments have since fielded measurement systems and have provided input on the channel availability measurement and evaluation software.

This paper begins with a brief overview of the common measurement system being used by the HFIA working group. This is followed by a discussion of the analysis methodology used and presentation formats selected to display the measured data. Next, the paper presents some of the preliminary results, collected by members of the HFIA working group and discusses some of the issues that have been addressed to date. The paper concludes with a discussion of future measurement plans.

## **2. WIDEBAND CHANNEL AVAILABILITY MEASUREMENT SYSTEM**

In 2012 Harris introduced a new tactical manpack radio, the RF-7800H, that implements the new wideband HF data waveforms as defined in 110C-D. Harris additionally developed a feature that adaptively selects the best channel, and determines the available bandwidth and offset required for optimal wideband HF communications [7]. Harris has had significant success in deploying this adaptive system, achieving increased data rates for the same amount of transmit power as a narrowband system. In order to gauge the suitability of wideband HF to a proposed operational location or environment, Harris needed to have a quick and easy way to determine if the HF spectrum availability would support the use of wideband HF and as a result developed an easy to use HF spectrum availability measurement system. This system was initially described in a paper at the Nordic HF13 conference [8] and has become the basis of the measurement system being used by the HFIA working group.

### **2.1 SYSTEM REQUIREMENTS**

It was determined that a channel availability measurement system should meet the following requirements:

- Small, lightweight, easily transportable
- Relatively low-cost
- Omni-directional antenna to support both long-haul and NVIS measurements
- Ability to collect data for 24 hour periods, measuring occupancy from 2 to 30 MHz
- Flexible RX architecture to support different measurement scenarios in terms of measurement bandwidth, observation time, and revisit period.

### **2.2 PERSEUS SDR**

Measuring 2 to 30 MHz with flexible observation and revisit rates requires a wider bandwidth receiver than the typical 3, 24 or even 200 kHz bandwidth receiver. The Perseus SDR produced by Microtelecom meets this goal. The Perseus signal path consists of some selectable attenuation, a bank of pre-selector filters and a low noise calibrated amplifier. The output of the amplifier feeds a 14 bit 80 MS/s analog to digital converter, the output of this converter is fed into the Perseus's FPGA. Within the FPGA the signal can be mixed with a digitally synthesized Local Oscillator (LO) creating a complex In phase (I) and Quadrature (Q) signal that can be filtered and decimated to sample rates of approximately 125 kS/s to 2 MS/s. Processed samples are fed to a host PC via a USB connection. The Perseus SDR receiver is the same device used by Berg et al in [9] for their availability experiments.

To date a fair number of Perseus receivers have been purchased and deployed by members of the working group. No major issues or equipment failures have been observed.

### **2.3 CLIFTON LABS ANTENNA**

The Clifton Labs Z1501D is an easily transportable and deployable whip antenna. It is an electric field responding "active" antenna, employing a high impedance field effect transistor input stage to efficiently couple an electromagnetic field from a physically short antenna to a low impedance (50 ohms) load. The Z1501D allows efficient reception of frequencies from 20 kHz to 30 MHz (usable beyond 100 MHz with

reduced performance) with a single relatively short vertical rod antenna. The combination of the Perseus receiver and the Clifton Labs Z1501D antenna was used to collect all of the data presented in this paper.

To date there have been some deployment and fielding issues with this antenna. The telescoping antenna that comes with the antenna is not robust enough for a winter deployment in western NY. This can be replaced with a military grade whip antenna. There have also been some issues with the fielding of this antenna; a ground deployment, as opposed to a building based deployment, with a good ground such as a copper pipe, seems to work best. Data collected to date has been collected both with this antenna as well as other HF antennas available to the various working group members.

## **2.4 DATA COLLECTION SOFTWARE**

Although the Perseus receiver ships with a very useful SDR interface program as well as another utility, HFSPAN that visually displays the entire HF radio spectrum, a bespoke control program was desired for exact control of the data collection process. Microtelecom does provide a Software Developers Kit (SDK) which was utilized as a starting point to generate the new Perseus control and data collection program. The initial and primary requirement was to sweep the full HF spectrum from 2 to 30 MHz in a relatively short amount of time. For each sweep of the HF band it was decided to step the Perseus LO frequency from 2.5 to 29.5 MHz, in increments of 1.0 MHz and at each step collect one second of I and Q samples at a sample rate of 2 MS/s. This provides a full sweep of the HF band in less than 30 seconds. The complex I and Q samples are windowed by a Kaiser window and fed into a 4096 point FFT, yielding a frequency bin resolution of 488.28125 Hz. The magnitude squared of each FFT output bin is calculated and then averaged over the 488 FFT observations which make up the one second, taking only the center half of the FFT spanning the LO frequency plus/minus 500 kHz.

In the system, as initially fielded, a sweep of the HF band is performed every 60 seconds for a period of twenty four hours. For this case the observation time is one second and the revisit rate is one minute. A data file, containing the full 2 to 30 MHz average power measurements in dB is generated for each sweep. For each twenty four hour run a set of 1441 data files is generated. To date, data has been collected at a number of sites in the U.S., U.K., Norway, and France.

There has been some discussion within the working group that the sampling approach described above may miss some channel utilization. Current plans include altering the sampling so that a given frequency is monitored for a longer period of time and therefore the measurements may be more responsive to intermittent transmissions. This will of course be at the expense of being able to monitor the entire frequency band as quickly as in the initial sampling scheme.

## **3. ANALYSIS METHODOLOGY**

### **3.1 INITIAL PROCESSING**

As can be appreciated each twenty four hour experiment generates a great quantity of data. It was decided to evaluate occupancy for each one MHz block for each one hour of measurement. First, each measurement sweep is individually processed. The measured signal levels, at a bin resolution of 488.28125 Hz are converted into a 3 kHz resolution by summing the linear power in each 3 kHz segment. When the 3 kHz boundary falls within a bin the power is simply linearly split between the current and next 3 kHz bin. The main goal of the processing software is to establish a noise floor so that any 3 kHz channels which have a received signal level more than a specified threshold above this noise floor can be considered as unavailable.

Initially, to establish a noise floor for each one MHz segment the 3 kHz based power values were sorted and the average of the ten lowest values was calculated. Each 3 kHz segment was then compared to a threshold of 10 dB above the noise floor. If the segment value was greater than the threshold it was considered occupied, otherwise it was considered available. Through experimentation it was found that a given 1 MHz section of measurements could actually have a variable or slanted noise floor. In this case the above noise floor technique would result in a lower estimate which in turn would actually increase our estimate of channel un-

availability. A newer noise floor determination technique has been developed which uses a sliding window median filter to establish and track the noise floor as it spans each 1 MHz section.

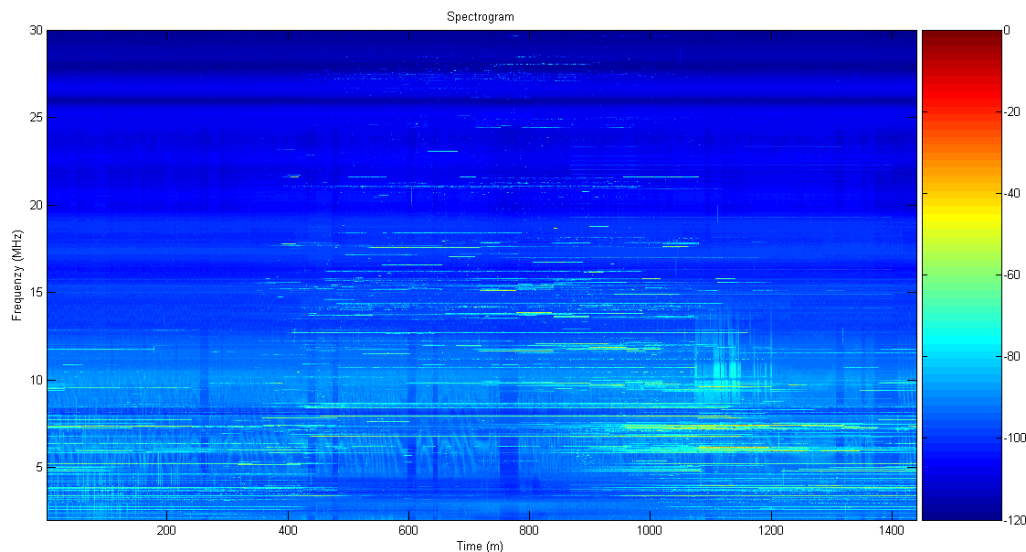
At the end of this processing each sweep observation file, representing one minute's observation, is represented by a vector of 9334 values of 1 or 0 (available or occupied). Once all the sweep data is converted in this fashion it is further processed to yield availability metrics for bandwidths of 3 to 48 kHz.

### 3.2 CHANNEL-MINUTE AVAILABILITY

The Chanel-Minute Availability (CMA) metric, initially defined in the Nordic HF13 paper [8], was defined to give an indication of how much bandwidth is available without regard to channel assignments and allocations. If a single 3 kHz channel is shown to be available for three measurements in a row, signifying that the channel was available for at least two minutes, then that channel is considered available for that minute. This rule was applied to include channels that were statically available for several minutes and to discount channels that were sporadically changing in occupancy, such as an active communication channel with bi-directional digital traffic or voice. Applying the CMA metric, each 3 kHz channel, in the 2 to 30 MHz range could have a maximum availability of 60 in each hour. The two minute constraint was chosen to indicate the availability for tactical messaging, although the communications could be shorter or longer than this duration. CMA is a very good metric to describe how much capacity is available. CMA can be viewed as the best case maximum channel availability, however it needs to be stated that in order to harvest this availability an adaptive wideband HF system that could find unused spectrum, coordinate its use, transfer data, and return the channel to availability with the minimum of overhead would be required. This approach is consistent with the recommendations of and Berg et al. [9] and Warner et al. [10].

## 4. RESULTS TO DATE

The collected data can be processed, analyzed, and visually displayed in a number of different ways. Figure 1 below shows the results of a Matlab program that displays the raw collected data from Hønefoss in southern Norway [11]. Matlab creates a spectrum by taking each 1 minute set of results, stacking them side by side and color coding based on the intensity of the measured signal. The expected frequency rise during mid-day is easy to see as are some bands of light interference. At approximately 1100 minutes and centered at 10 MHz there is a portion of higher channel usage.



**Figure 1 - Spectrogram of measured interference, southern Norway, February 2015**

An alternate way to examine the measured data is via the CMA defined above. Again, this should give a good feel for the best case channel availability. Figure 2 displays the same data analyzed for the CMA metric

for a bandwidth of 24 kHz. The analysis software will generate a diagram like this for each bandwidth of interest. It should be noted that in this display the frequency and time axis are swapped.

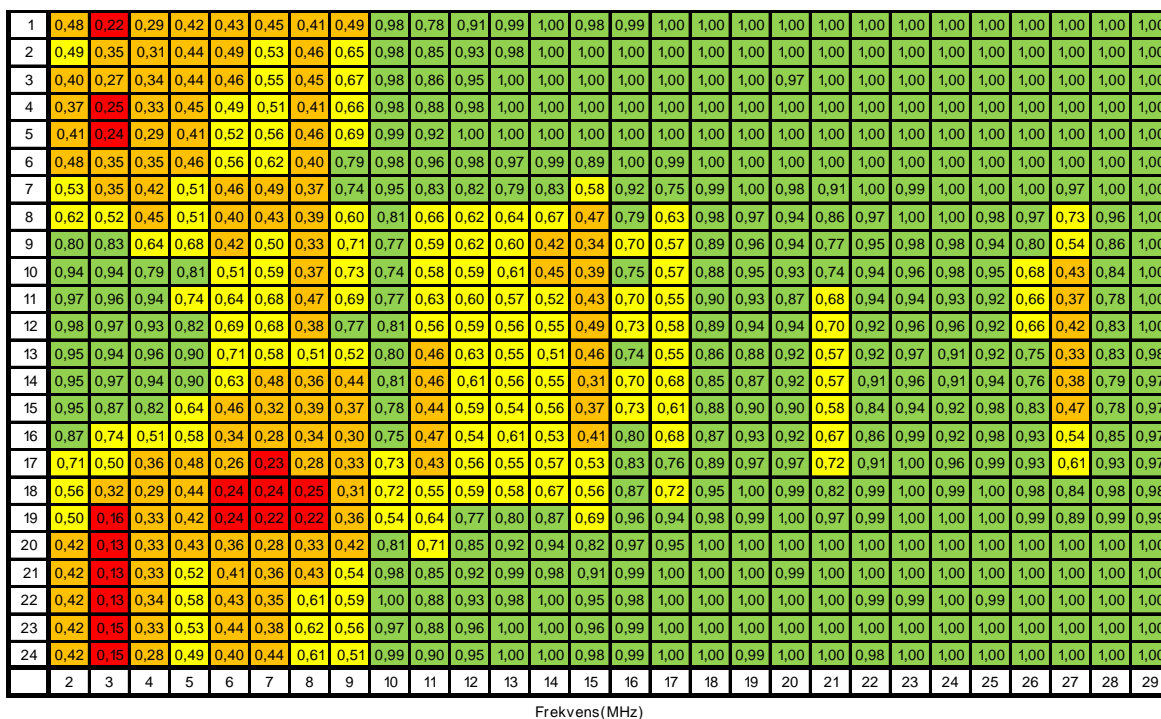


Figure 2 - CMA - southern Norway, February 2015

Figures 3a and 3b below display the results of data collected by Thales in Belgium [12]. Figure 3a displays the CMA obtained for 3 kHz channel availability. Figure 3b displays the CMA obtained for 24 kHz channel availability. As expected as wider bandwidth channels are required, the overall channel availability diminishes due to interferers which leave less contiguous unused bandwidth. It is important to note that the CMA metric is a percentage of the total number of possibly available channels of the selected bandwidth. For the case of no interference, channel availability for both 3 and 24 kHz would show 100% but obviously there would be 8X more 3 kHz channels than 24 kHz channels.

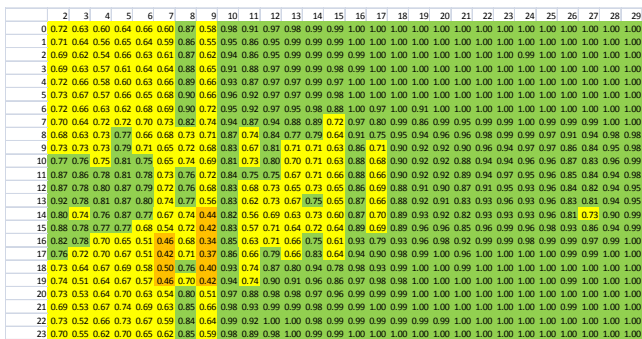


Figure 3a - CMA 3 kHz - Belgium, November 2014

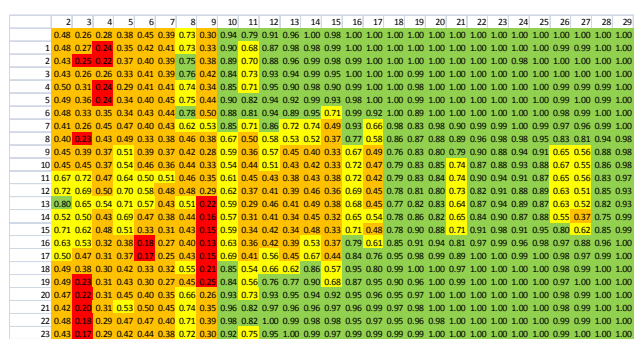


Figure 3b - CMA 24 kHz - Belgium, November 2014

One last example of data collected by the working group is provided by Babcock [13], in Figure 4. This data was collected at their Forest Moor site in Yorkshire, UK using a rather significant conical wideband RX antenna. This data again shows the expected time of day variations of channel utilization including the lack of lower frequency propagation during the day, and the corresponding increased use of these frequencies during

the evening hours as well as wide availability of the higher frequencies. These higher frequencies however could very well be available because they are not “connected” or propagating to the monitoring location. The MUF of the links from transmission sources to Forest Moor, during this period, was below these frequencies. This potentially highlights the need of spatially diverse measurement locations in order to capture channel occupancy otherwise missed due to the realities of HF propagation.

One interesting segment shows some channel utilization, during the day in the 26-28 MHz band. This could possibly be some Citizens band or Land Mobile radio utilization.

	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	0.61	0.36	0.34	0.49	0.34	0.37	0.58	0.27	0.76	0.64	0.83	0.91	0.96	0.92	0.95	0.99	0.99	1.00	0.98	0.99	0.98	0.99	0.99	1.00	0.98	0.98	0.99	1.00
1	0.59	0.40	0.29	0.48	0.34	0.41	0.56	0.28	0.75	0.58	0.85	0.88	0.96	0.93	0.96	0.98	0.99	1.00	0.98	0.99	0.99	0.99	0.98	1.00	0.98	0.99	0.99	1.00
2	0.57	0.41	0.32	0.51	0.37	0.43	0.56	0.35	0.80	0.52	0.82	0.89	0.96	0.88	0.96	0.97	0.99	1.00	0.98	0.99	0.98	0.99	0.98	1.00	0.98	0.99	0.99	1.00
3	0.58	0.44	0.37	0.48	0.41	0.42	0.56	0.46	0.85	0.64	0.86	0.91	0.96	0.90	0.96	0.99	0.99	1.00	0.98	0.99	0.98	0.99	1.00	0.98	0.99	0.99	1.00	
4	0.56	0.42	0.34	0.49	0.39	0.44	0.57	0.43	0.80	0.62	0.94	0.94	0.96	0.94	0.96	0.99	0.99	1.00	0.98	0.98	0.98	0.99	0.98	1.00	0.98	0.99	0.99	1.00
5	0.58	0.48	0.39	0.44	0.38	0.43	0.51	0.39	0.72	0.68	0.88	0.87	0.95	0.87	0.96	0.98	0.99	0.99	0.98	0.99	0.99	0.98	1.00	0.98	0.99	0.99	1.00	
6	0.61	0.53	0.41	0.48	0.38	0.42	0.56	0.54	0.74	0.67	0.83	0.79	0.89	0.69	0.95	0.89	0.99	0.99	0.97	0.99	0.99	0.98	1.00	0.98	0.99	0.99	1.00	
7	0.58	0.54	0.43	0.55	0.39	0.44	0.60	0.59	0.77	0.64	0.81	0.66	0.73	0.56	0.86	0.68	0.97	0.97	0.95	0.91	0.98	0.99	0.99	1.00	0.97	0.96	0.99	1.00
8	0.60	0.57	0.45	0.62	0.35	0.50	0.59	0.53	0.69	0.49	0.61	0.60	0.54	0.54	0.80	0.63	0.92	0.97	0.94	0.88	0.95	0.98	0.96	0.98	0.92	0.80	0.95	1.00
9	0.61	0.69	0.53	0.64	0.32	0.55	0.60	0.48	0.69	0.47	0.60	0.57	0.48	0.53	0.77	0.65	0.86	0.92	0.87	0.84	0.92	0.97	0.95	0.91	0.68	0.55	0.87	0.99
10	0.65	0.82	0.58	0.70	0.34	0.58	0.62	0.50	0.66	0.48	0.60	0.56	0.54	0.51	0.76	0.57	0.84	0.92	0.92	0.80	0.91	0.96	0.91	0.91	0.66	0.39	0.82	0.98
11	0.79	0.87	0.59	0.81	0.44	0.63	0.63	0.49	0.64	0.50	0.55	0.55	0.58	0.52	0.75	0.54	0.86	0.92	0.92	0.79	0.89	0.96	0.85	0.88	0.55	0.27	0.75	0.97
12	0.78	0.90	0.65	0.82	0.48	0.66	0.65	0.47	0.65	0.47	0.58	0.53	0.57	0.52	0.69	0.57	0.85	0.94	0.91	0.77	0.92	0.97	0.88	0.91	0.60	0.31	0.77	0.98
13	0.76	0.94	0.87	0.85	0.51	0.62	0.71	0.38	0.72	0.49	0.61	0.53	0.56	0.47	0.67	0.56	0.78	0.91	0.87	0.66	0.89	0.96	0.90	0.91	0.57	0.25	0.73	0.94
14	0.79	0.90	0.80	0.78	0.39	0.51	0.66	0.29	0.68	0.37	0.53	0.48	0.51	0.39	0.69	0.60	0.80	0.91	0.86	0.65	0.85	0.95	0.89	0.91	0.52	0.22	0.66	0.94
15	0.90	0.95	0.91	0.86	0.60	0.58	0.77	0.42	0.73	0.45	0.61	0.60	0.60	0.54	0.75	0.60	0.79	0.91	0.90	0.79	0.89	0.97	0.91	0.92	0.65	0.29	0.73	0.96
16	0.86	0.87	0.70	0.70	0.27	0.35	0.60	0.21	0.64	0.29	0.56	0.50	0.52	0.45	0.72	0.65	0.81	0.91	0.87	0.73	0.90	0.97	0.92	0.92	0.61	0.29	0.75	0.97
17	0.67	0.54	0.41	0.51	0.15	0.27	0.56	0.25	0.66	0.36	0.51	0.50	0.43	0.40	0.75	0.69	0.84	0.92	0.89	0.81	0.93	0.97	0.93	0.94	0.72	0.50	0.86	0.97
18	0.58	0.35	0.45	0.49	0.15	0.30	0.57	0.26	0.71	0.39	0.53	0.54	0.49	0.52	0.85	0.71	0.88	0.97	0.93	0.86	0.97	0.98	0.96	1.00	0.94	0.83	0.97	0.99
19	0.59	0.37	0.47	0.49	0.16	0.27	0.52	0.21	0.69	0.34	0.59	0.58	0.58	0.63	0.85	0.84	0.93	0.99	0.94	0.93	0.97	0.98	0.97	1.00	0.95	0.85	0.98	0.99
20	0.59	0.39	0.46	0.51	0.21	0.31	0.58	0.24	0.71	0.41	0.67	0.66	0.65	0.66	0.89	0.86	0.94	0.98	0.94	0.96	0.98	0.98	0.98	1.00	0.96	0.92	0.99	0.99
21	0.57	0.36	0.38	0.50	0.23	0.32	0.51	0.27	0.74	0.50	0.71	0.75	0.70	0.75	0.90	0.91	0.96	0.99	0.96	0.98	0.99	0.98	1.00	0.98	0.97	0.99	1.00	
22	0.53	0.32	0.37	0.53	0.29	0.37	0.61	0.29	0.73	0.54	0.72	0.83	0.84	0.87	0.94	0.97	0.99	0.99	0.98	0.99	0.99	0.98	1.00	0.98	0.97	0.99	1.00	
23	0.61	0.37	0.38	0.51	0.31	0.39	0.62	0.29	0.74	0.48	0.84	0.89	0.94	0.89	0.96	0.98	0.99	1.00	0.98	0.99	0.98	0.99	1.00	0.98	0.98	0.98	0.99	1.00

Figure 4 – CMA 12 kHz – Forest Moor, UK, November 2014

## 5. CONCLUSIONS AND FUTURE WORK

This paper has reported on the preliminary results of the HFIA measurement campaign to evaluate HF channel availability throughout the world. This effort has defined a common set of hardware, collection software, and analysis software. This approach of utilizing common hardware and software and an agreed upon set of metrics to define when a channel is occupied versus unoccupied will support multiple participants measuring data and allow fair comparison of results.

In the coming year the working group hopes to collect more data from many sites around the world. Rockwell Collins plans a series of measurements in Iowa, Washington (Seattle area), Las Cruces, Tampa, Brazil, Australia (two sites), Singapore, and India. Harris plans to continue measurements in western New York as well as the UK. Norway is planning a series of measurements in both southern and northern Norway.

Additionally, the group hopes to resolve many technical issues including:

- Effects of different observation times and revisit rates in the measurement system
- Antenna deployment issues
- Comparison of different antenna systems for measurement
- Correlation of results with assigned HF bands
- Use of results for performance prediction on specific links



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