Testing of 10 GHz Instantaneous Bandwidth RF Spectrum Monitoring at Idaho National Labs

Scott H. Bekker, Aaron S. Traxinger, Colton R. Stiffler, Alex J. Woidtke, Michael D. Chase, Wm. Randall Babbitt, Kristian D. Merkel
S2 Corporation
Bozeman, MT 59715
merkel@s2corporation.com

Zeb W. Barber
Spectrum Lab, Montana State University
Bozeman, MT 59717-3510
barber@spectrum.montana.edu

***Abstract*—S2 Corporation tested its wideband RF spectrum monitor at Idaho National Labs (INL) in December 2013. Rich RF spectrum data was collected over 0.5-10 GHz with 250,000,000 unique frequencies per second, with a resolution bandwidth below 0.1 MHz and full spectrum frame rate of at least 2,000 frames per second. Wireless signals at INL were controlled during captures, and concurrently an FCC Special Transmit Authority (STA) allowed transmission in frequency hopping signals across the 10 GHz bandwidth for calibration and added signal environment.**

Keywords—wideband spectrum analysis, spectrum sensing, radio frequency

I. Introduction

A spectrum monitoring test at Idaho National Laboratories (INL) was conducted from December 16 - 20, 2013, with an objective to demonstrate the S2 Corporation leap-ahead capability in full RF spectrum monitoring. The S2 system provided a common operating picture (COP) of total RF spectral awareness during field tests over 0.5-10.5 GHz. Mobile hardware was transported from Bozeman MT, to INL and located at the cellular tower cite near EBR-1 for collection.

II. Testing Details

A. S2 Mobile Processing System

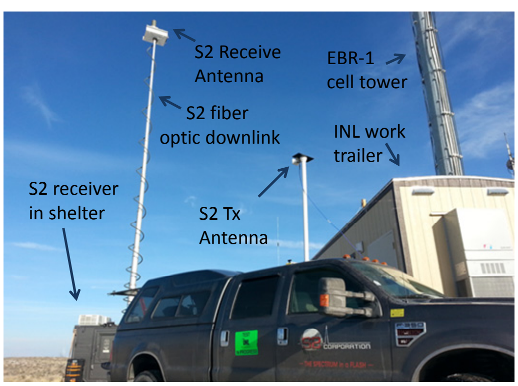

Fig. 1. S2 equipment at INL near EBR-1 cell tower for spectrum monitoring technology testing, with INL provided work trailer.

Fig. 1 shows the setup with a directional receive antenna on a 42 foot high mast, with a fiber optical feed down the S2 receiver located in a fixed S250 shelter. Fig. 2 shows the S2 hardware inside the shelter. An INL provided work trailer was used for personnel to operate system controls, displays and data processing. The company pickup truck was equipped with a directional horn antenna mounted to the roof for transmission, where a small generator located in the bed of the truck provided power to two signal generators and RF amplifiers that fed the Tx antenna. The signal generators were programmed with the allowed frequencies from the FCC Special Transmit Authority (STA) across 0.5-10.5 GHz.

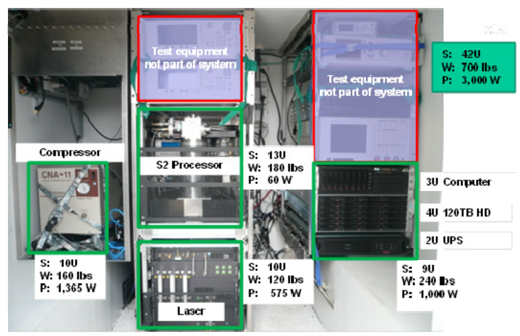

Fig. 2. S2 EBAC hardware used for field testing demonstrations.

B. Location

Fig. 3 shows a map of INL and the location of the receiver. The gray area in Figure 3 shows simulated site analysis for RF line of sight propagation window at INL. The STA approved transmitter antenna was mobile, during collects was located on various INL roads north of the receiver site, with two collects noted, one about 2 miles away on West Portland Ave northwest of CFA, and two about 8 miles away on the T-3 road, north of INTEC. RF activity was picked up from the INL wireless test bed activity as coordinated by INL personnel.

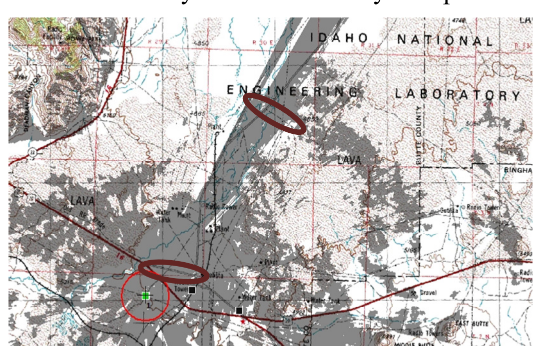

Fig. 3. Map overview of INL showing the location of the S2 EBAC hardware location near the EBR-1 cell tower (circle), and locations of mobile transmitter (ovals).

C. Overview

The S2 spectrum monitoring system has full spectrum capture which far exceeds the instantaneous bandwidth (or stare) of typical RF spectrum analyzers, based on sweeping local oscillators or stepped windows for doing FFTs. Additionally, S2 has a high performance in the most stringent term of spur-free-dynamic-range (SFDR), with >57 dB shown during the tests and >63 dB as demonstrated in our lab, that far exceed the capabilities of wideband digitizers. For example, a 10 GHz wideband digitizer has only 41 dB SFDR and generates an enormous 25 Gs/s continuous data, and to do continuous spectrum displays (like the S2 system is doing) would require a massive core of FFT processors running on >10 kW [1].

Table I shows the S2 Corporation spectral monitoring capabilities as demonstrated at INL, and as demonstrated in our lab [2] and possible in the near term. Also note that while spectrum sensing was demonstrated here, we also have the inclusion of additional functions of phase sensitive wideband direction finding, vector signal analysis and demodulation, and wideband and covert RF communications.

TABLE I. SPECTRUM MONITORING HARDWARE SPECIFICATIONS

System Parameter	Configuration		
	Mobile Hardware as demonstrated at INL	***Upgrades as demonstrated in S2 Corp Labs***	***Possible with continued R&D***
Full frequency Coverage	0.5-10.5 GHz	0.1-40 GHz	0.1-110 GHz
Bandwidth	10 GHz	20 GHz	110 GHz
Band 1	0.5-10.5 GHz	0.1-20 GHz	0.1-25 GHz
Band 2	10-20 GHz	20-40 GHz	25-50 GHz
Band 3	n/a	n/a	50-75 GHz
Band 4	n/a	n/a	75-110 GHz
Frame Rate	2-5 kfps	2-50 kfps	Up to 1 Mfps
Resolution Bandwidth	20 kHz-1 MHz	Down to 10 kHz	Down to 5 kHz
SFDR	57 dB	63 dB	>70 dB
RF Power Sensitivity	-110 dBm	-132 dBm	Up to 10 dB better

III. TESTING DETAILS

The S2 spectrum recording device was operated over three days, and when in capture mode was measuring an aggregate of up to 500,000,000 frequencies per second, all of which were digitally streamed to disk. The spectrograms that were displayed in real-time with full spectrum 0.5-10.5 GHz were shown and recorded. The S2 receiver provided continuous 100% time capture, with wideband coverage, and rapid update rates of at least 2,000 frames per second (each frame being the full instantaneous bandwidth) recorded to disk in real time. Real time displays at video rates are calculated in GPUs and show the spectrum in a "maximum hold" of the frame updates of typically 5 Hz (0.2 secs, user defined) on external monitors, which for a 2,000 Hz actual frame rate is the maximum value being displayed of 400 frames. This system has a readout variation ability with rapid configurability as shown in the chart in Fig. 4. The full spectrum for a 2,000 Hz frame rate (the typically slowest update rate) has 125,000 frequency pixels per frame, each pixel being 80 kHz wide for 10 GHz capture, and each pixel 16 kHz wide for a 2 GHz capture. All 125,000 pixels in frequencies per frame are recorded and available for zooming, but since modern displays only have about 2,000 pixels across their width, we show the full spectrum display with a ~80x reduction in frequency display with each displayed pixel being the maximum of ~80 pixels.

	BANDWIDTH	1	2	5	10	GHz	Freq. Pixels per Frame	Time Pixels per second	FR Loss, dB
Read time, µs	Frame Rate, kHz	FREQUENCY PIXEL WIDTH							
500	**2**	0.010	0.016	0.040	0.080	MHz	125,000	2,000	-3.84
200	**5**	0.020	0.040	0.100	0.200		50,000	5,000	-1.53
100	**10**	0.040	0.080	0.200	0.400		25,000	10,000	-0.77
50	**20**	0.080	0.160	0.400	0.800		12,500	20,000	-0.38
20	**50**	0.20	0.40	1.0	2.0		5,000	50,000	-0.15
10	**100**	0.40	0.80	2.0	4.0		2,500	100,000	-0.08
5	**200**	0.80	1.60	4.0	8.0		1,250	200,000	-0.04

Fig. 4. Variation in readout parameters for the tests. Blue cells indicate rates shown in this paper; green cells were used at INL.

For the spectrum analysis demonstrations, the S2 RF sensor device was operated in a single-band configuration, covering 0.5-10.5 GHz. This band was linked to a directional wideband antenna from Ventis Corp. which was mounted on the shelter mast and extended to 42 feet. There is a conversion from RF to optical via an electro-optical phase modulator (EOPM) at the antenna after a preamplifier, and the modulator was connected to the S2 RF receiver hardware via a rugged stainless steel jacketed fiber optical cable contained within a Nycoil housing that attached from the antenna to the S2 hardware located in an S250 shelter on a trailer. RF activity as observed on-site was primarily below 3 GHz. Given this assessment, we focused mostly on 0.5-10.5 GHz spectrum captures and in characterizing the RF environment of the area, and detection of continuous and short up time transmitters. In total, we collected over 7.5 Terabytes of data during the test, representing about 4.1 hours of recorded spectra. Of that data, 111 seconds is visualized in this paper, or <1% of the total.

IV. QUANTITATIVE/QUALITATIVE RESULTS

The experiment had several successful outcomes. The S2 systems showed its capabilities can instantaneously detect full span RF spectrum between 0.5-10.5 GHz in real time, with high sensitivity, specifically several continuous and transient RF pulses observed, and some cellular signals being controlled by the INL staff and by the agile signals by S2 Corp staff.

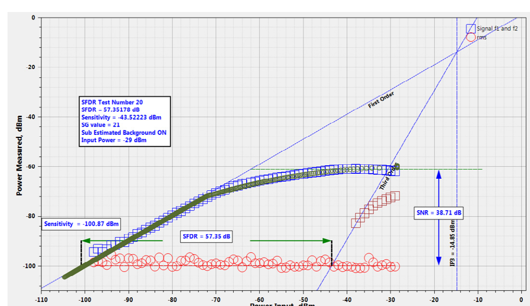

Fig. 5. SFDR and sensitivity measurement taken with apreamplifier, showing 57 dB SFDR during testing with a sensitivity of -101 dBm on 10 ms long pulses.

An on site SFDR test was conducted by driving the input of the S2 EBAC with two RF CW signals separated in frequency and being swept in power to determine two-tone dynamic range. Testing was done both with and without a preamplifier. With a preamplifier, there is gain and also a block upconverter that converts the RF signals from 0.5-10.5 GHz to 12-22 GHz which avoids second harmonics generated by the electro-optical phase modulator (EOPM). Without a preamplifier, RF CW signals are fed directly to the EOPM, typically on carriers between 12-20 GHz for accurate comparison. With the preamp, the sensitivity was -101 dBm and the SFDR was 57 dB. Results from this test are shown in Fig. 5, where blue indicates the peak signal strength, red is the measured RMS noise floor of S2 EBAC system, and brown is the peak amplitude of third order intermodulation distortions.

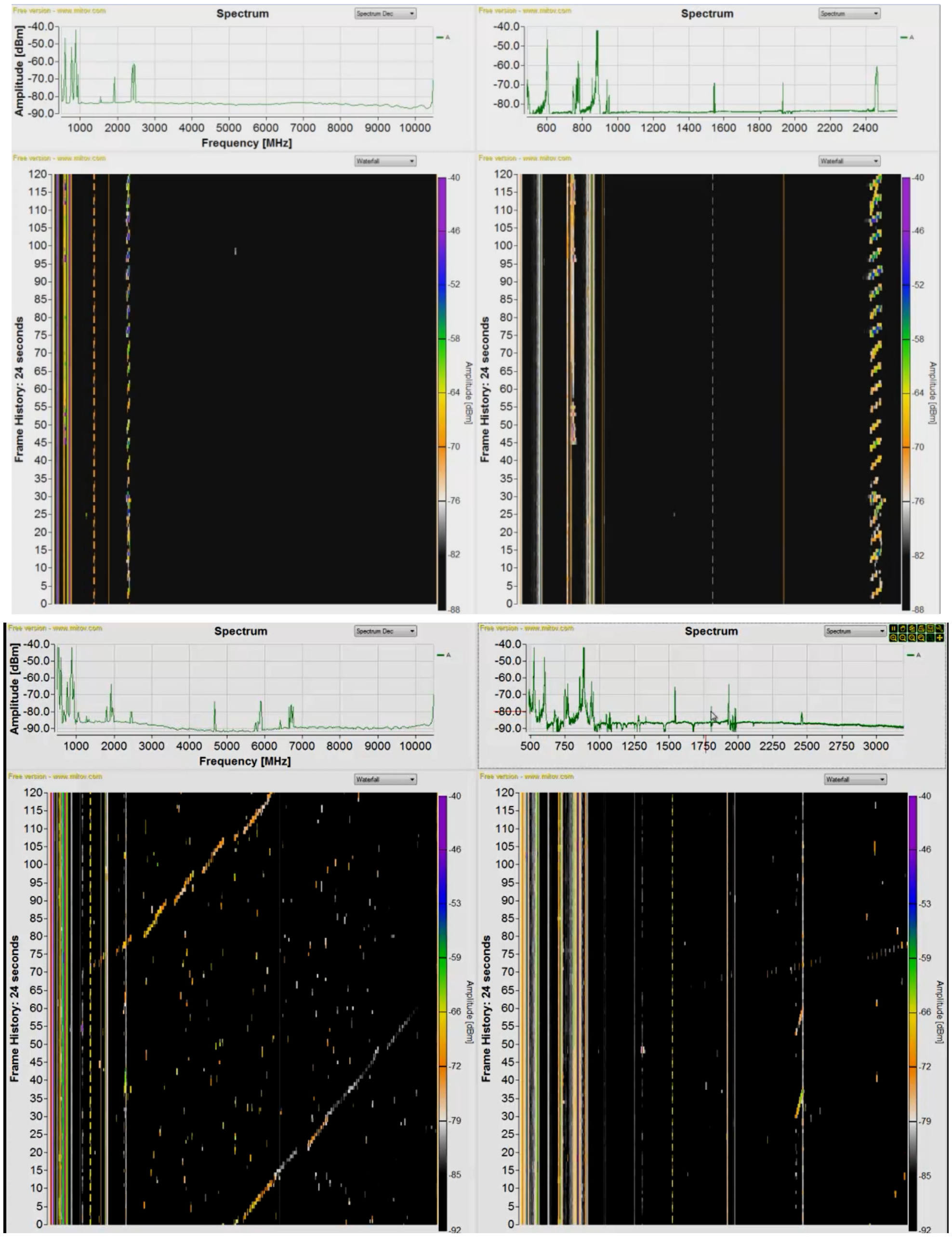

Fig. 6 Top, captures of ambient RF spectrum without S2 transmitting. Bottom, same display when S2 was transmitting two signal generators (one stepping and one randomly hopping). Left: Full 0.5-10.5 GHz capture, Right: Digital zooms in frequency.

Fig. 6 shows the spectrum capture display for 10 GHz without and with transmitting by S2 Corp under the STA. For the case of transmitting signals, the S2 truck was located along the north road about 2 miles from the EBR-1 cellular tower receiver location, while similar but weaker results were captured (not shown here) when the truck was along the INL T-3 road about 8 miles away. The right display in each case shows zooming into more detail in the frequency domain, with the waterfall being the same history of 24 seconds (user defined) for both cases.

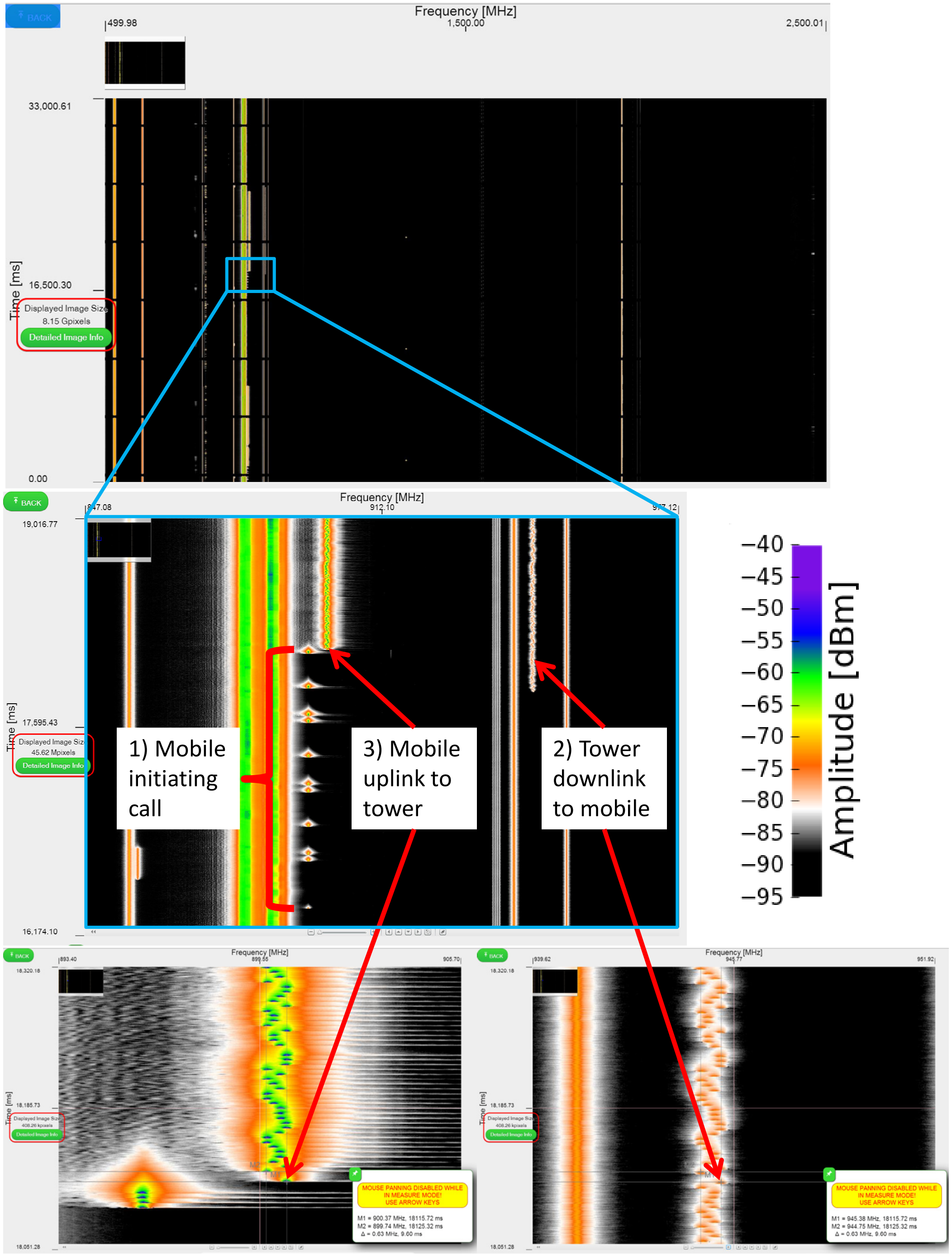

Fig. 7. Full 0.5-2.5 GHz spectrum capture with callout zoom traces on a GSM cell call in the 900 MHz band.

Fig. 7 shows more details of a unique 33 second capture which was set to 2.0 GHz of bandwidth, from 0.5-2.5 GHz. For this capture, the frequency pixel width was 16 kHz, and time pixels were 500 us (2 kHz frame rate). Progressively deeper zoom levels are shown in the figure, looking at a signal of interest across the whole display. The numbered callouts show the controlled connection of an INL mobile cellular device to the cell tower CFA-609 B. First, the mobile handset initiates a call on FCC channel 30 at 896 MHz through a series of pulses. Callout 2 shows the initial cell tower response on FCC channels 49, 50, 51, and 52 at respective downlink frequencies of 944.8, 945, 945.2, and 945.4 MHz as shown in Fig. 8. In callout 3, the mobile device responds back to the tower on the FCC downlink for hopping on channels 49, 50, 51, and 52 at 899.8, 900, 900.2, and 900.4 MHz. Not shown here, the full display [3] also shows the call terminating with the handset ceasing transmission first, followed by the tower ceasing transmission.

CHN #	FCC Channel	Uplink(Mhz)	Downlink(Mhz)	Site / Hoping List
30	30	896	941	CFA-609 B
49	49	899.8	944.8	CFA-609 B
50	50	900	945	CFA-609 B
51	51	900.2	945.2	CFA-609 B
52	52	900.4	945.4	CFA-609 B

Fig. 8. FCC channels observed for a 900 MHz GSM call

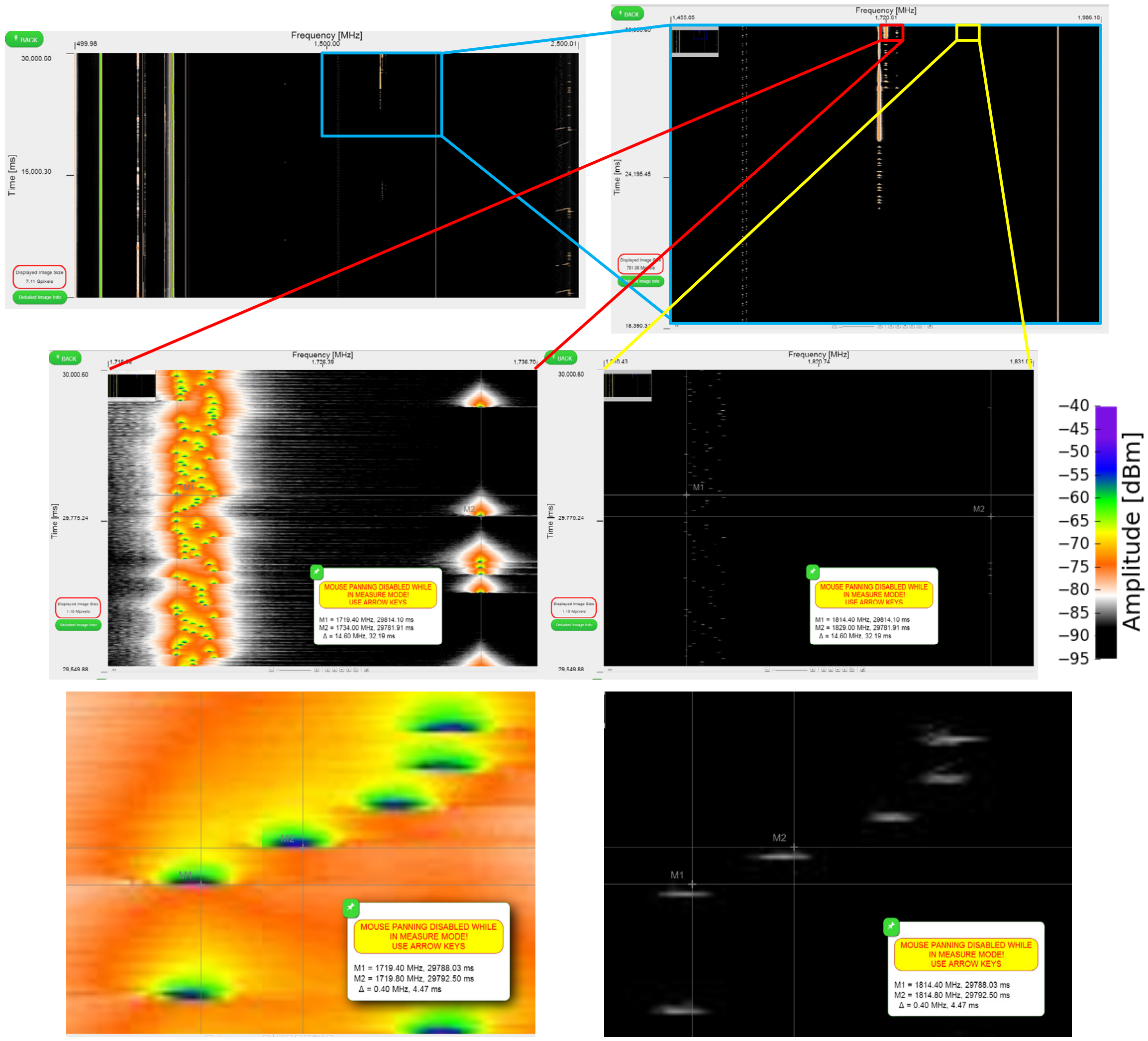

Fig. 9. Full 0.5-2.5 GHz spectrum capture with detail of a cellular call in the 1800 MHz GSM band.

Another spectrum capture in Fig. 9 depicts a GSM call in the 1800 MHz cellular band. In this display, the same settings as Fig. 8 apply, while the call is at different frequencies. The mobile device spectrum is shown in zooms with the uplink (1719.4-1734 MHz) on the lower left of Fig. 9 and downlink (1814.4-1829 MHz) on the lower right, as shown in Fig. 10. One can see the individual hopping frequencies, and the direct correlation between mobile device and tower channel doing frequencies hops with the tower transmissions occurring slightly prior in time to the mobile device transmissions.

FCC Channel	Uplink(Mhz)	Downlink(Mhz)	Site / Hopping List
558	1719.4	1814.4	CFA-609 B H
559	1719.6	1814.6	CFA-609 B H
560	1719.8	1814.8	CFA-609 B H
562	1720.2	1815.2	CFA-609 B H
563	1720.4	1815.4	CFA-609 B H
564	1720.6	1815.6	CFA-609 B H
565	1720.8	1815.8	CFA-609 B H
566	1721	1816	CFA-609 B H
567	1721.2	1816.2	CFA-609 B H
631	1734	1829	CFA-609 B H

Fig. 10. FCC channels observed in the cell call with spectrogram shown in Fig. 9.

These pixel level data files and many others are available for viewing on our web page using common web browsers [3].

Acknowledgments

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References

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[2] K. D. Merkel, S. H. Bekker, A. S. Traxinger, C. R. Stiffler, A. J. Woidtke, M. D. Chase, Wm. R. Babbitt, Z. W. Barber, C. H. Harrington "20 GHz Instantaneous Bandwidth RF Spectrum Analyzer Measurements with High Sensitivity and Spur Free Dynamic Range" Proceedings of the GOMAC2014 Conference, Charleston, SC, April 2014

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