Distanced Observation of Magnetic Field Anomalies During Periods of Power Failure and Applications in Remote Classification of Electrical Activity

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***Abstract*—During research focusing on radio frequency field transmission detection from broadcasters on known frequencies at known time and transmission in the magnetic field, anomalies were detected in frequencies outside of the frequency scope of the original research. Analysis of these anomalies indicated they were linked to an ongoing power issue in which a fuse had failed in a power transformer located approximately 1.3 miles from the magnetic field sensor system and antenna. The research crew, through the use of digital signal processing software, were able to diagnose the problem and assist electrical crews with fixing the issue while observing the anomaly at a distance that typically would be outside of the range of detection. The results supplemented previous research indicating magnetic field behavior is dissimilar to companion electronic field behavior during propagation by demonstration the collection of the magnetic field from an RF broadcaster located within a Faraday cage. The magnetic field was collected for analysis while the RF was undetectable. This incidental researched supported the potential for use of magnetic fields in remote sensing and remote classification of electronic activity. Further data analysis, including a meta-analysis of previously conducted studies which also produced anomalies validated that at a distance the magnetic field may be a viable candidate remote sensing of electrical activity, such as power outages, or radio frequency activity, when a standard electrical field antenna is less suitable.**

Keywords–computational; science; magnetic; fields; low frequency; human; activity; remote; sensing.

I. Introduction

The broader field of remote sensing is typically associated with the identification of vegetation and features of a given area using active sensors to annotate and compare the reflectance curve signature of varying bands of the electromagnetic spectrum. Although typically relegated to passive sensors, it may be possible to remotely sense and classify activity using passive sensors to detect activity from varying emission sources and algorithms for classification. The particular interest of this research was the observation of such emissions and anomalies in the magnetic field at atypical distances and the potential for use in remote sensing and classification applications. The intent of this research is the validate the potential for magnetic fields to serve as a potential dimension of remote sensing and classification of activities, particularly so when frequencies are lower than standard use and common electrical field antennas become cumbersome due to size requirements.

There are numerous examples of the influence of magnetic fields on biological tissue and activity. For example, studies have shown that grazing animals typically align north and south when undisturbed, but near power lines (and subsequently the associated magnetic fields), the alignment changed [1], and there is even a correlation with the increase in stroke in some populations during geomagnetic storming [2]. Previous research has identified the possibility of magnetic fields to penetrate a Faraday cage, as well as their ease of detectability when compared to the associated electrical field and the accompanying antenna size requirements of electrical field detection [3].

Some of the data collected in this research was unintended and is based on anomaly observations and identification in the magnetic field while conducting other research in the magnetic field. Initially the study was setup to collect signatures of basic electrical activity at a distance, in a controlled environment, when an anomaly occurred nearby, the focus was changed to gather data on the anomaly. Consequent to the observation and identification of the anomalies, research teams were able to assist local utilities in the identification and repair of power lines at a distance of approximately 13 miles.

In Section 2, we will describe the testing setup and methodology of the original research being conducted. The section focuses on physical setup, sensor calibration and the data collection. In Section 3, the paper focuses on the observation of anomalies, which changed the focus of the original research and the processing of the data, including visual analysis of the anomalies over time in comparison to observed activities. Section 4 primarily focuses on a forensic scrub of previously collected data in which anomalies were observed and a comparison of those anomalies to known events, and in Section 5 we present our conclusions.

II. The Testing

The original setup of the sensor includes RF shielded boxes to limit interference, fiber optic cable, and battery power for both the computer and all other equipment. The sensors are calibrated using Helmholtz coils to create a uniform magnetic field, and the data is handled by custom created digital signal processing software, which displays the entire collection band and all 6 axes of the sensors on a waterfall display at once. The software sample rate is adjusted by the band used, and the software enables record and life Fourier transform and spectral

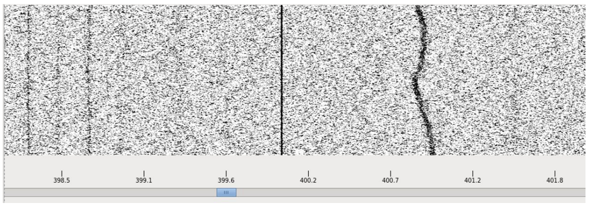

Figure 1. The live signal waterfall collection screen view from the digital signal processing computers.

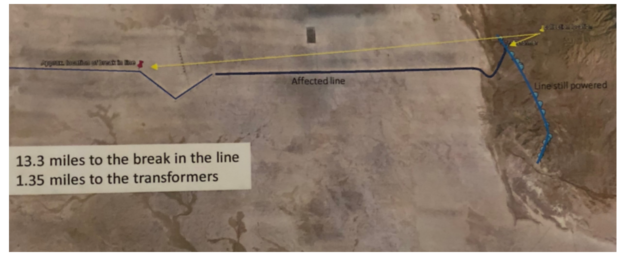

Figure 2. The layout and measurement of the original research site including distances from power lines and transformer boxes that were the source of the magnetic anomalies.

density processing as well as audiometric analysis (in the case where a signal is a suspected audio transmission). More details of the setup are provided below.

A. The Setup

Routine research was being conducted in an isolated desert environment to reduce the man-made electromagnetic interference. The intent of the research was waveform analysis of radio signals transmitted at the UHF band from radios transmitted at ground level from a distance of approximately 15 miles.

The sensors were battery powered magnetic loop antennas placed on the ground, on a ridge approximately 500 feet in altitude above the ground level, isolated in radio frequency shielded boxes, and fed fiber optic cabling to reduce the likelihood of interference. Two battery powered Linux powered computers dedicated to digital signal processing were located within a battery powered trailer and used for digital signal processing to monitor the entire spectrum of frequencies which the antenna was able to monitor.

B. Sensor Calibration

To ensure the proper calibration of the sensors and software in the magnetic field, a standard two coil Helmholtz coil was used, spaced apart approximately 3 feet. The coils were powered by uniform frequency electricity to create a uniform magnetic field between the two coils. The sensor was placed between the coils while inside the radio frequency shield box, and calibration adjustments were made to ensure the frequency of the detected uniform magnetic field matched the frequency of electricity powering the coils. Sensors were calibrated each day before the tests were conducted [3].

C. Data Collection and Handling

Data collected by the sensors is displayed as shown in Figure 1. The display shows a live feed from the antennas in the entire band, with darker colors indicating stronger signals. The x axis indicates frequency while the y axis is time, with the current time being at the top of the screen. The darker lines signify a strong signal detected in the frequency (x axis) [3]. The system allows for isolate of specific frequencies and conversion to wave form via Fast Fourier transform. Darker or more condensed dark points appear on the screen (typically in line form) in areas of stronger frequency presence. A strong radio signal would place a dark line from top to bottom of the screen in the frequency of the broadcast and for the duration of the broadcast. Figure 2 illustrates the the setup and placement of sensors in relation to power lines and transformers for the duration of the collection. Exact measurements were made using Google Maps functionality.

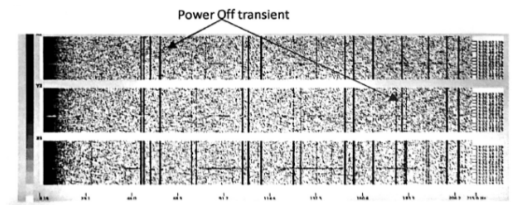

Figure 3. Waterfall display of frequency density.

III. Anomaly Observation and Post Fourier Transform Analysis

The anomaly in question was noticed during routine research as shown in Figure 3. The X axis represents frequency ranging from .1 Hz to 1000 Hz, and Y axis representing time, with the most recent being at the top of each waterfall. Each band represents a different axis of the Cube antenna. The center band (Y2) shows a total disruption of frequencies at the time of power loss with the top band (Y1) showing a likely spectral density loss at time of power loss at approximately 60 Hz. The reduction of spectral density was significant enough to warrant further examination, particularly given that spectral density from human activity is often detected in the 50 and 60 Hz range [4], and a power reduction or loss at one location would not necessarily ensure a total loss of frequency detection on the display. Prior to the power outage, the signal and decibel level are stable and appear as expected.

A. Visual Analysis of Power Outage

Shortly after the anomalies were noticed in the waterfall observation screen, a power truck was observed approaching a power line approximately 13 miles away. Times were noted and the data was recorded for analysis as the power company began working to isolate the problem. A post-Fourier transform analysis of the incident as shown in Figure 4, focusing on a single frequency, revealed a clear disruption in power and violent shifts in both amplitude of the signal and frequency.

B. Visual Analysis of First Fix Attempt

An initial attempt by the power company to re-energize the power lines, similar to a circuit breaker system, appeared to have some effect for a few seconds, as shown in Figure 5, but the power almost immediately failed. Power crews continued working to identify and isolate the problem. Figure 5 also demonstrates that while the decibel level dropped drastically, there was still signal to be detected, although it was relatively unstable.

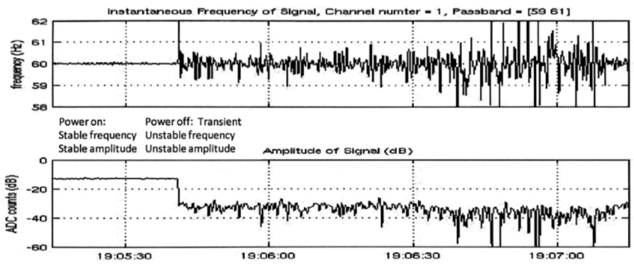

Figure 4. Wave form and decibel variation after loss of power due to blown fuse.

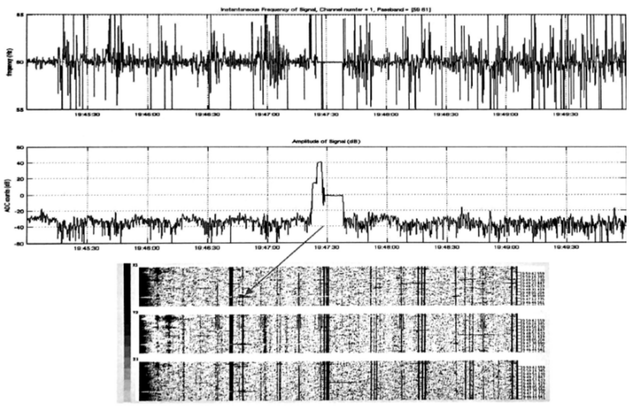

Figure 5. Changes in wave form, decibel level and frequency presence during the first attempt to restore power with a blown fuse.

C. *Visual Analysis of Fuse Replacement*

Research crews monitoring the sensor and anomalies made contact with the testing range and power crew, and based on wave form activity and axis location shown in Figures 3 and 4, as well as post-fix attempt activity shown in Figure 5, speculated that it was likely a fuse that needed replacing. Crews replaced the fuse located in the transformer box approximately 1.3 miles from the sensor as shown in Figure 2. The attempt to restore power following the fuse change was successful as shown in Figure 6. The return to normal decibel level and frequency matched the frequency and decibel level of the power line prior to the blown fuse.

IV. Prior Data Comparison

Following the incidental research, a data scrub for comparison was conducted that revealed similar results of much greater magnitude.

A. *Wallops Island Launch*

On the 20th of November, 2013 research in the magnetic field was being conducted on Wallops Island against a known launch of a Minotaur I rocket from Wallops Island, VA. Once sensor was located approximately 4 miles from the launch site, while the second was located 50 miles from the launch site. Collection from the site located 50 miles away was intermittent and not saved as it was unreliable at best, while data collection at the 4 mile location was remarkably clear and is displayed in Figure 7 with an offset of 16 seconds from actual launch, with times aligning with actual recorded times with a uniform offset of 16 seconds. The bulk of the detections appear between

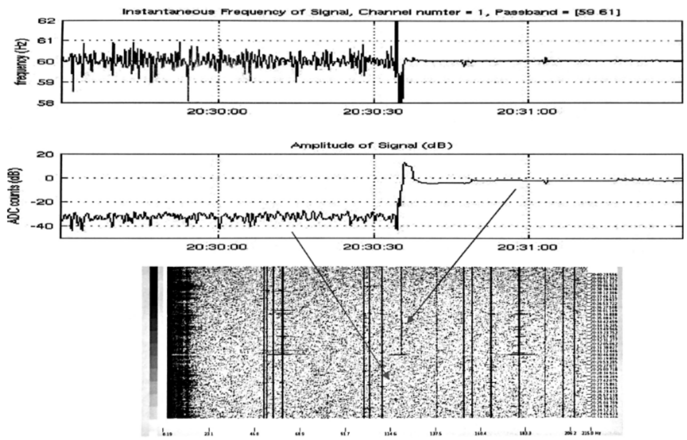

Figure 6. Frequency and decibel level normalize after restoration of power following a fuse change. The change is also depicted on the waterfall.

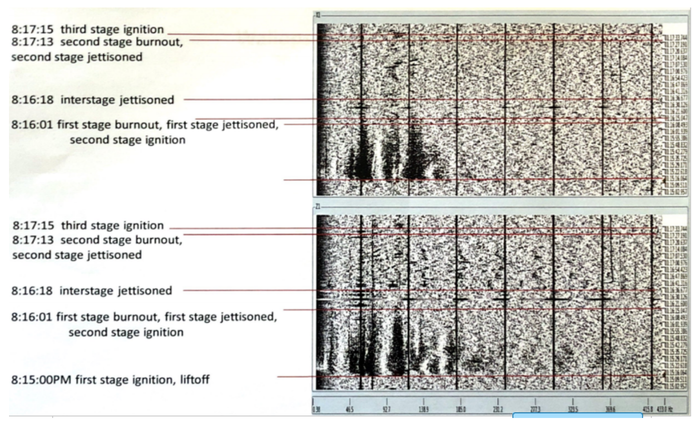

Figure 7. Waterfall image of the 2013 Wallops Island launch of a Minotaur I on the 20th of November.

46 and 140 Hz. Detections of the flight were made slightly beyond 3rd stage ignition which would place the rocket at approximately 120 Km above the surface of the earth and 170 Km in linear distance away from the launch site.

It was originally assumed that the detections were likely emissions from rocket but following the analysis of the data of the power outage, a further review was conducted. To ensure the frequencies detected were not radio or computer hardware and no hardware or electronics were found to match frequencies of detection as shown in Figure 8. Given the frequency of detection compared to the frequencies used in Figure 8, it is possible the signals detected were the result electromagnetic field induction by the rocket passing through the earths magnetic field.

V. Conclusion

Previous research documented the apparent ability of magnetic fields associated with a radio frequency broadcast to penetrate a Faraday cage [3], while the associated radio frequency remained undetectable. The previous conclusion warranted further research into the propagation of magnetic fields. The results of this inadvertent study serve to validate the original premise that magnetic fields appear to behave

SOURCE	1	2	3	4	5
Function	Command Destruct	Tracking Transponder	Tracking Transponder	Launch Vehicle	Instrumentation on Telemetry (Optional)
Receive/Xmit	Receive	Transmit	Receive	Transmit	Transmit
Band	UHF	C-Band	C-Band	S-Band	S-Band
Frequency (MHz)	416.5 or 425.0	5765	5690	2288.5	2269.5
Bandwidth	N/A	N/A			
Power Output	N/A	400 W (peak)	N/A	10 W	10 W
Sensitivity	-107 dB		-70 dB		
Modulation	Tone	Pulse Code	Pulse Code	PCM/FM	PCM/FM

Figure 8. Table 4-12 from the Minotaur I users guide, showing operating, radio and telemetry frequencies during the use of the Minotaur I [5]

differently than their electrical field partners and that further research is warranted.

Specifically in this case, waveform and spectral density coupled with visual isolation were adequate to remotely classify or ”remotely sense” electrical activity. To further research the viability of this phenomena and its applicability in the field of remote sensing, research should move to blind testing methods, as well as electromagnetically challenging environments. Further research should also include duplication of this event in varying electromagnetic environments to test against algorithms for detection when compared to similar but intentional disruptive events. Results may serve to determine if a difference in a blown fuse and induced events such as a light switch can be determined amongst the varying levels of environmental noise.

Finally, if validated, the potential for characterization of space launches by electromagnetic field detection via magnetic loop antennas offers yet another axis of data collection in the field of remote sensing of human activity and potentially in electronic activity classification. The potential has a wide variety of public safety applications, such as alternative and supplementary geo-location of aircraft travel, including potentially those who have lost power in emergency situations resulting in a loss of radio and transponder broadcast.

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