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Modeling and Experimental Support for Detection of Linear Conductors
Task Authorization 5: Spectrum Analyzer Verification

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Project Team

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Table of Contents

List of Tables

List of Figures

1 Introduction

There is an ongoing research program at Defence Research and Development Canada (DRDC) Suffield Research Centre (SRC) to explore electromagnetic (EM) scattering from linear conductors to better understand the physical phenomena governing this effect. The purpose of this contract is to provide technical expertise to supplement the efforts at DRDC by furthering the research on EM scattering through experimental and theoretical means.

The need to detect linear conductors is pertinent to military and commercial interests. A number of commercial applications would benefit from a reliable method to detect buried infrastructure such as wires, pipes, rods and other infrastructure critical to the delivery of crucial services to consumers. Detection of these conductors would help to significantly reduce the number of occurrences resulting in interruptions to power, water and communications services that result from excavation operations. This would directly result in time and money savings for businesses and consumers alike and help alleviate associated safety and environmental concerns.

The goal of this contract is to further the work done in previous contracts through continued model development and focused experiments that provide new insights into scattered field detection. Ultimately, the primary objective of this work is to move the research forward to the final goal of developing a reliable detection system.

This report is a continuation of an ongoing assessment of using higher frequencies, in particular the frequency modulation (FM) band, in order to detect linear conductors. A prior contract (C-CORE 2017) examined the feasibility of using a software defined radio (SDR) as a receiver for FM stations. By using the real signal strength indicator (RSSI) and automatic gain control (AGC) characteristics, it was possible to plot the received field strength for that station while moving the receiver across and along the linear conductor. While that study demonstrated some encouraging results, it was decided to re-execute the experiment while using a portable spectrum analyzer (SA) in order to record more spectral information about the received signal, with the conjecture that its superior resolution bandwidth would allow better discrimination of the signal from the noise.

This work has been carried out under Task Authorization (TA) 5 entitled “Multispectral measurement of scattered radiation from linear conductors.” This TA is authorized under contract No. W7702-175832/001/EDM with DRDC Suffield.

1.1 Scope

This report provides an overview of the work carried out to develop and test a different sensor capable of measuring EM fields around shorter wires (< 20m) in order to determine the feasibility of detection, thereby building on similar work already completed. The sensor style is described and the experimental plan and results are presented, along with a discussion as to the overall feasibility of the detection scheme.

1.2 Definitions

Acronym	Definition
AGC	Automatic Gain Control
AM	Amplitude Modulation
API	Application Programming Interface
COTS	Commercial Off-The-Shelf
dBm	Decibel-milliwatt
DRDC	Defence Research and Development Canada
EM	Electromagnetic
FM	Frequency Modulation
HF	High Frequency
PC	Personal Computer
RF	Radio Frequency
RSSI	Real Signal Strength Indicator
SDK	Software Development Kit
SDR	Software Defined Radio
SRC	Suffield Research Centre
TA	Task Authorization
UHF	Ultra-High Frequency

2 Background

Under prior contracts (C-CORE 2013, 2014), it had been demonstrated that detecting long linear conductors, with lengths on the order of 75m, was feasible by making use of local AM transmitters of opportunity such as commercial radio stations. The primary field generated by an AM transmitter would induce currents in the wire. The currents then generated secondary fields which could then be detected with a magnetic field sensor. This scheme works in part because the wire length is an appreciable fraction of the wavelength at AM frequencies and acts as an antenna.

There has been an increasing interest in the feasibility of detecting shorter wires of lengths less than 20m. Transmitters radiating higher frequencies, and hence shorter wavelengths which are amenable to reception by these shorter wires, must be considered. An initial proof-of-concept was considered in a prior contract, where transmitters of opportunity in the FM band (such as local commercial radio stations) were considered and re-radiated fields measured using an SDR.

The experiment proposed herein is based on measuring re-radiated fields in the proximity of a linear conductor for different frequencies in the FM band using a portable spectrum analyzer. A spectrum analyzer has the advantages of readily providing a greater array of spectrum data that could be processed to discern features as a result of crossing a conductor. In addition, with greater resolution bandwidth, the noise floor can be reduced further than in the case of an SDR, which could increase the likelihood of detection.

3 Experiment Apparatus

The selected sensor comprises the spectrum analyzer, the sensor head, and a personal computer (PC) to accept the data stream and record it to a file for later processing. These components are described in greater detail in the following subsections.

3.1 Spectrum Analyzer

The Signal Hound USB-SA44B, shown in Figure 1, is a commercial off-the-shelf (COTS) portable spectrum analyzer and was selected for its wide frequency range, narrow resolution bandwidth, and correspondingly lower displayed average noise level (DANL)

Figure 1. USB-SA44B portable spectrum analyzer.

The relevant features of the USB-SA44B are:

- Frequency range of 1 Hz to 4.4 GHz;
- Resolution bandwidth of 0.1 Hz to 250 kHz;
- DANL of less than -139 dBm for frequencies of 10 kHz to 2.6 GHz;
- Extended operating temperature range of -40°C to 85°C;
- Easy-to-use Spike software for general applications; and
- Readily available software development kit (SDK) for specific applications.

The spectrum analyzer is also powered by USB connected to a laptop, allowing for easy deployment in mobile applications such as the proposed experiment.

3.2 Sensor Head

A monopole whip-style antenna, shown in Figure 2 was used as the pickup device for the spectrum analyzer. It has a length of 38 cm and covers the FM band of interest. Note that this is not exactly the same sensor head as was used for the prior SDR testing (C-CORE 2017) since that sensor head had been delivered under that contract. However, this antenna is sufficient for testing the proof-of-concept outlined here.

Figure 2. Monopole antenna.

3.3 Personal Computer and Software

A portable laptop computer is used to log the data generated by the spectrum analyzer. There is a SDK available that provides an Application Programming Interface (API) containing a number of functions that allow the PC to configure the SDR and record spectrum data. The relevant functions are summarized in Table 1.

For the purposes of the functional tests, a graphical user interface (GUI) software application was developed to record a frequency sweep over a given centre and span, all at sample rate of 10 Hz. Functions are provided to specify resolution bandwidth, reference level, video detection parameters, as well as retrieving sweep information. While the software included with the spectrum analyzer was also capable of recording data, the custom software allowed for a more flexible output file format. This format can then easily be imported into data analysis software for processing of results.

In all tests, the recorded values were analyzed for artifacts or anomalies to determine if any indication of a linear conductor or other object was observed.

Table 1. USB-SA44B API function list.

Function	Description
saOpenDevice	Establish connection with the USB-SA44B and obtain device handle.
saCloseDevice	Release the device handle.
saConfigCenterSpan	Specifies the centre frequency and the span
saConfigAcquistion	Specifies the video detector (max/min or averaging) and scale.
saConfigLevel	Sets the reference level.
saConfigSweepCoupling	Sets the resolution bandwidth and image rejection.
saInitiate	Changes the operational mode of the device.
saQuerySweepInfo	Returns the anticipated sweep length and frequency bin size.
saGetSweep_32f	Returns the values corresponding to the frequency sweep.
saGetSerialNumber	Returns the serial number; used for checking communications.

4 Operational Testing and Results

Testing of the apparatus outlined in Section 3 loosely followed the same test plan in the previous contract which assessed the SDR (C-CORE 2017). It was decided to once again measure received fields while crossing long conductors and while travelling along the conductor axis, as indicated in Figure 3. As in the prior report the intention is to examine whether a standing wave pattern is seen as anticipated. For the across wire path, the measurements are started and stopped approximately 5m away from the wire. For the along wire path, the measurements are started and stopped approximately 2m away from the wire. Hence the wire can be assumed to be located close to the middle of the time series.

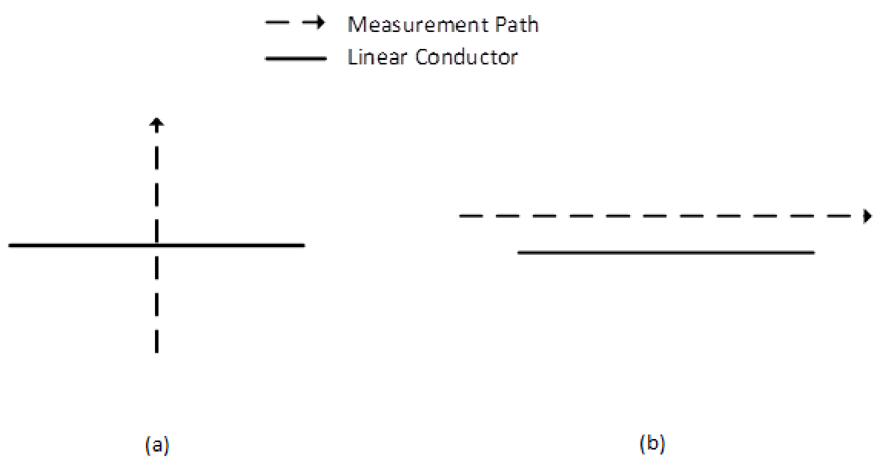

Figure 3. Measurement paths.

Tests were restricted to transmitters of opportunity in the FM band. A narrower frequency sweep, such as depicted in Figure 4, which encompasses only the sidebands of the strongest received station (99.1 MHz), was recorded. A wider frequency sweep, such as depicted in Figure 5, which encompasses the entire FM band of radio stations, was also recorded in order to see if the additional stations showed similar trends. Note that for the wider band sweep, stations can be identified at 93.5 MHz, 94.7 MHz, 97.5 MHz, 99.1 MHz, 101.1 MHz, 101.9 MHz, 105.9 MHz, and 106.9 MHz. These all represent commercial and public FM radio stations broadcasting in the St. John’s, NL region.

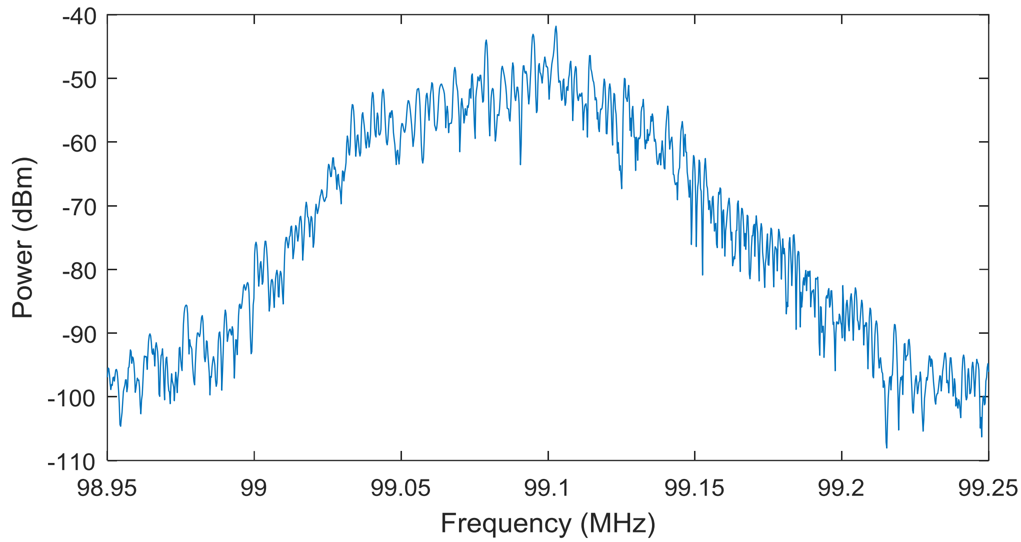

Figure 4. Sample narrow band sweep.

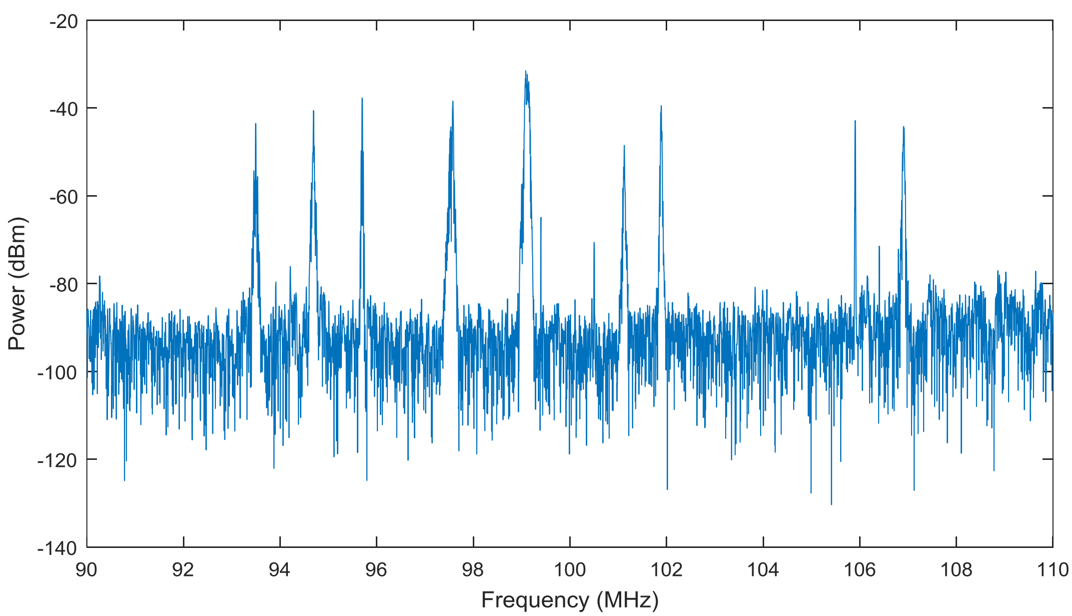

Figure 5. Sample wide band sweep.

Table 2 summarizes the experiment variations outlined above. The results are grouped according to conductor length. Each figure is presented as four subplots, encompassing the permutations of frequency range and orientation. Note that each subplot has been produced while using a five-point moving average, so as to more easily identify features where they exist.

Table 2. Experiment variations.

Variable	Permutations
Frequency	Wide range (90 MHz to 100 MHz, 10 kHz RBW)
	Narrow range (98.95 MHz to 99.25 MHz, 1 kHz RBW)
Conductor length	50 m
	12 m
	6 m
	3 m
Orientation	Across
	Along axis

4.1 Results for 50m

Figure 6 summarizes the results for the 50m conductor. It is noticed that for the across wire path, narrow band, that there is a series of higher measurements between two nulls at the 5 and 15 second mark. There is a noticeable peak at the 10 second mark, flanked by two other peaks at the 5 and 14 second marks. For the along axis measurements, it is difficult to discern the standing wave pattern in both wide and narrow band measurements; however, there is an initial null followed by a peak in the narrow band, followed by a gradual decline. Note that the peaks at the start and end of each of the time series correspond to the start and end antenna orientation, which is more vertical and hence more receptive of the primary field.

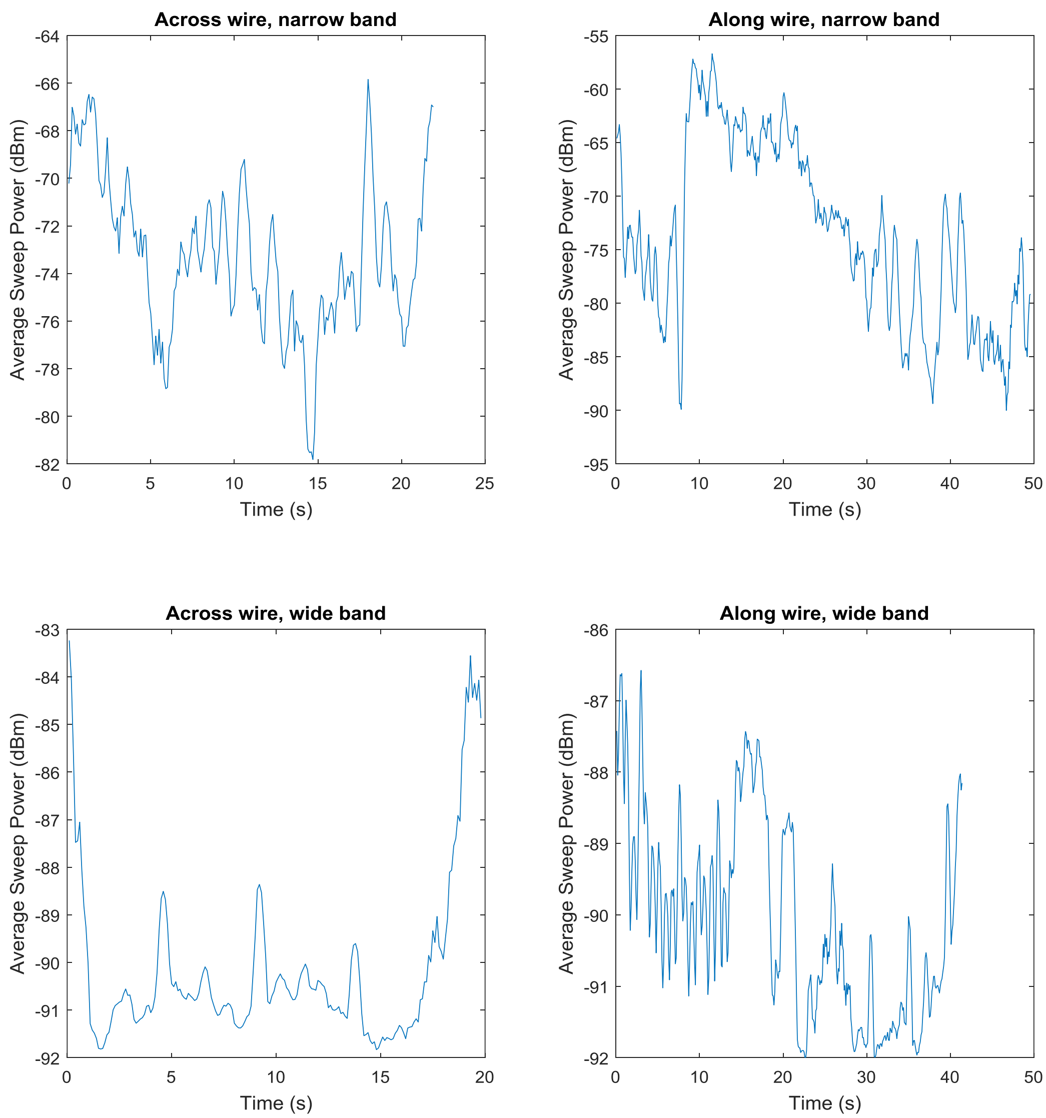

Figure 6. 50m conductor results.

4.2 Results for 12m

Figure 7 summarizes the results for the 12m conductor. A strong null can noted at the 10 second mark for the across wire, narrow band measurements. Also, the peak at the 9 second mark, flanked by two others at the 4 and 13 second marks, are also very distinguishable in the wide band measurements, as they were in Figure 6. These peaks are approximately a wavelength apart. Therefore, they are attributable to reflections of the primary field off the conductor and constructively adding with the received field on the sensor head. This is a feature that could possibly be exploited. The along wire peaks and nulls are only somewhat noticeable, and appear to be more favorable in the narrow band case as in Figure 6.

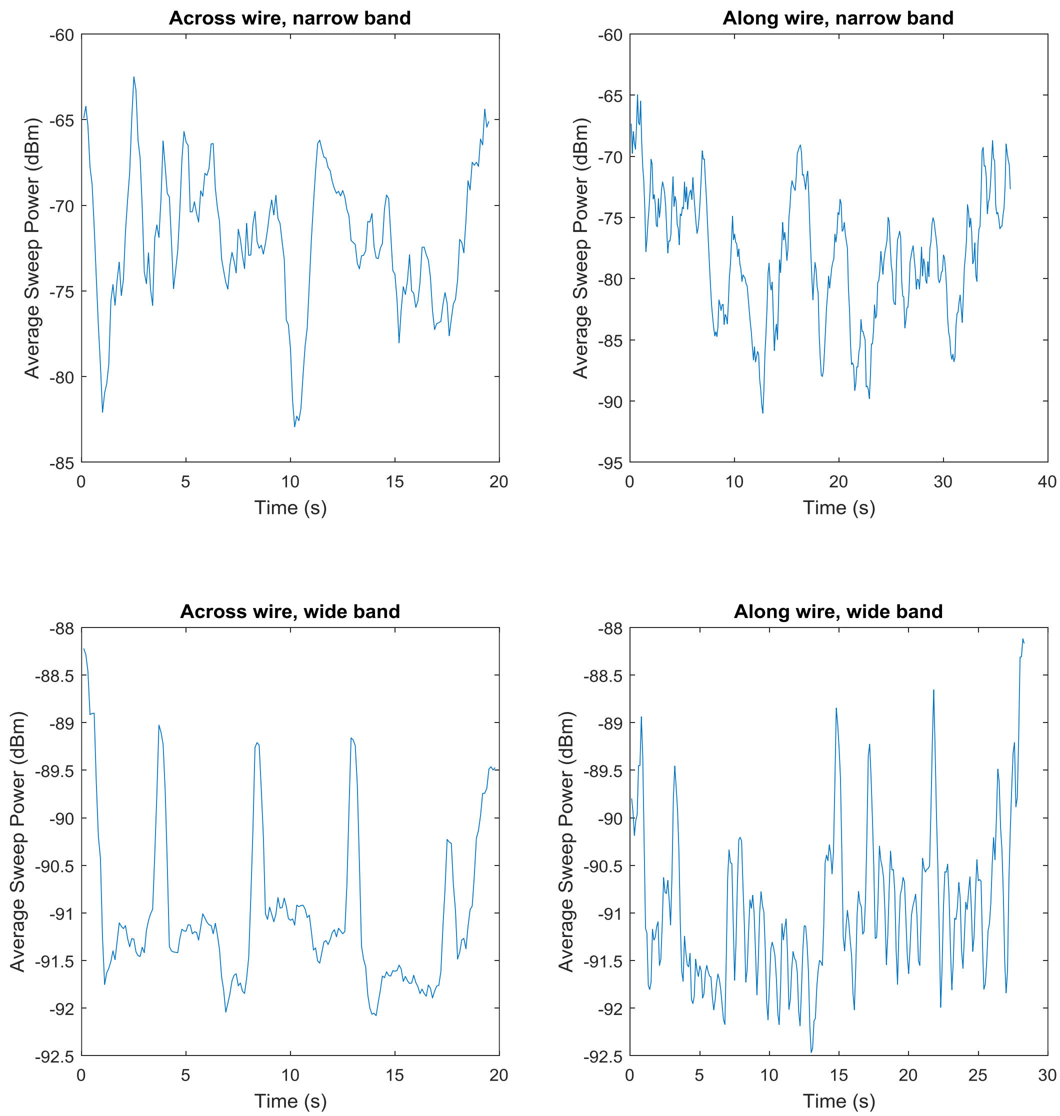

Figure 7. 12m conductor results.

4.3 Results for 6m

Figure 8 summarizes the results for the 6m conductor. There is no readily distinguishable feature in the narrow band measurement while crossing the wire, which makes sense since the shorter wire is capturing and reradiating less FM RF energy. However, in the wide band measurements, three peaks centred at the wire crossing are very noticeable once again. The standing wave pattern is once again rather non-distinct in the along-wire paths; however, the narrow-band measurements look slightly better.

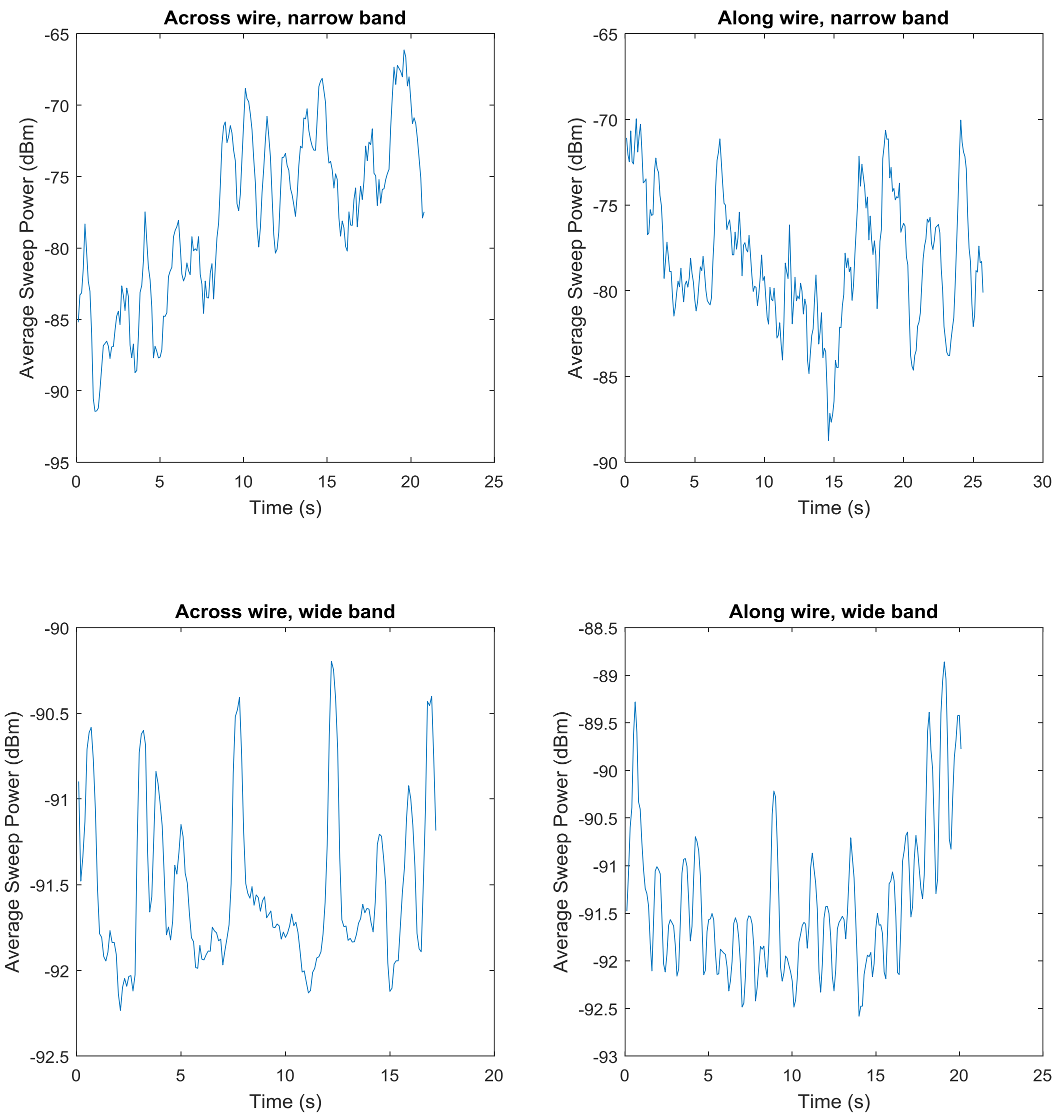

Figure 8. 6m conductor results.

4.4 Results for 3m

Figure 9 summarizes the results for the 3m conductor. Once again, with a shorter wire length, there is no strong feature in the narrow band across wire measurement. The same three-peak feature that has been noticed for the other wire lengths is once again visible, however less distinct in this case. The along wire standing wave pattern is once again indistinct.

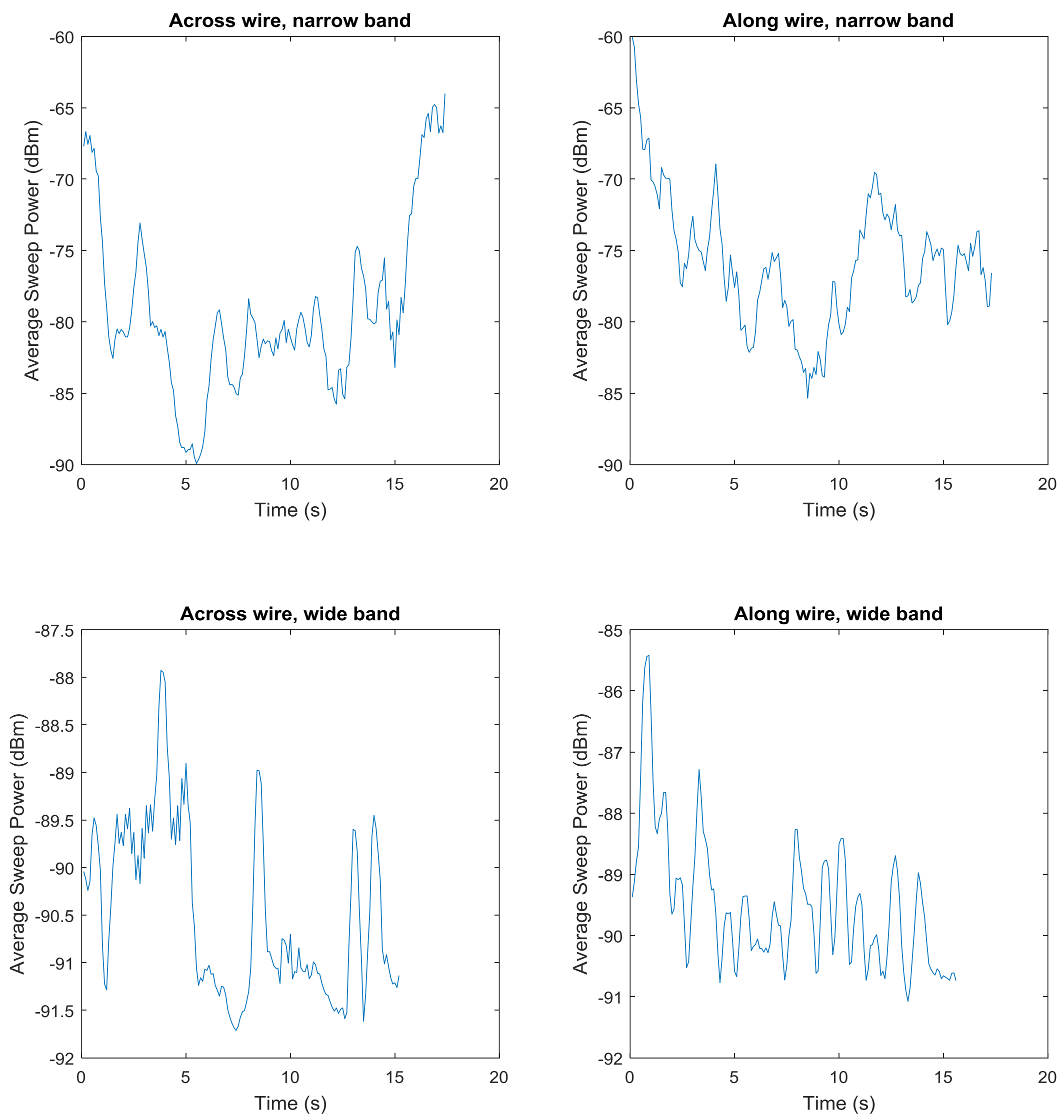

Figure 9. 3m conductor results.

5 Conclusions and Recommendations

The objective of this work was to continue efforts in implementing and evaluating a multispectral measurement device for the detection of linear conductors. A prototype measurement device was assembled to examine reradiated fields arising due to currents induced by nearby transmitters of opportunity operating in the FM frequency band. Functional testing was performed and suggested the feasibility of the detection concept, agreeing with previous studies performed in the FM band (C-CORE 2017) and at AM band frequencies (C-CORE 2013).

The results of the across wire measurements, presented in Section 4, suggest that for wide band measurements (that is, averaging over the entire FM band), a similar strong feature is noticed for all wire lengths. Further, this feature appears to be the same in each case: a three-peak pattern centered at the wire crossing. It is noted that each of the peaks appear to be separated by approximately a wavelength, 3m for the center of the FM band. As suggested in Section 4.2, this is due to reflections from the conductor constructively adding with the primary field at the sensor head. Another way of conceiving the phenomenon is as a mutual coupling effect between the sensor head antenna and the linear conductor to be detected: the proximity of two linear antennas changes their respective impedances (Balanis 1997), and could result in this periodic resonance effect. It is noticed only in the wide band measurements, which makes sense for two reasons: first, the average transmitted power over the entire band is more likely to be constant than over a narrow band; and second, the range of wavelengths radiated over the entire band is more likely to result in constructive addition at the sensor head. This feature could be exploited; a further trial of this experiment could test to see if more of these peaks occur at multiples of one wavelength away from the wire.

Features appear to be less noticeable to non-existent in the narrow band measurements, notwithstanding the strong null in the 6m wire crossing.

The along-axis measurements do not reveal readily identifiable standing wave patterns, however they do appear somewhat more distinct in the narrow band case. This makes sense since the standing wave for a focused frequency band should be more noticeable, rather than for a larger span of frequencies as in the wide band case. It is worth noting that for 12m, 6m, and 3m wires, the wide band along axis measurements exhibit a “ringing”: that is, more smaller peaks and nulls than in the narrow band case. Again, this could be explained by the fact that there are many stations of different frequencies establishing a standing wave pattern. Measuring the wide spectrum and averaging could result in this resulting “finer” standing wave pattern.

For all wire lengths, these measurements suggest the core concept of linear conductor detection using transmitters of opportunity is possible at FM band frequencies, even for shorter wires of 3m length. This is in addition to the feasibility that was suggested in the prior contract involving the SDR (C-CORE 2017). Given these, a logical next step would be developing a model for reradiated fields arising from currents induced in linear conductors by nearby FM transmitters of opportunity. Such a model could follow a similar method as that developed for AM transmitters (C-CORE 2013). The spectrum analyzer could then be used with a specialized electric near-field probe (antennas such as were used are more intended for far-field measurements) to measure the re-radiated fields more accurately. This could then provide a reasonable groundtruthing of the model.

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This report is a continuation of an ongoing assessment of using higher frequencies, in particular the frequency modulation (FM) band, in order to detect linear conductors. Reradiated fields arising from transmitters of opportunity, such as commercial FM stations, were measured using a portable spectrum analyzer (SA). In this way, more spectral information about the received signal, with the conjecture that its superior resolution bandwidth, would allow better discrimination of the signal from the noise. The sensor style is described and the experimental plan and results are presented, along with a discussion as to the overall feasibility of this detection scheme.