Cell Phone Transmission Detector and Display

ECE 445 Fa17: Project Proposal

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1 Introduction

1.1 Objective

Radio astronomy and weather research often relies on the detection of weak signals that must be distinguished from surrounding radio-frequency (RF) background noise.[1] Though there are attempts to limit the bands used for such remote sensing research to those outside crowded domains, signals such as giant pulses from Crab-like pulsars and HI emissions from galaxies are found in bands dominated by communications and other interference.[2] In addition, the bands that can be used for observations are often limited by attenuation effects of the Earth's atmosphere (allowing only frequency bands in the so-called radio window) and man-made radio frequency interference (RFI).[3] Internal RFI sources mainly include cellular devices and microwave ovens. The RF signal generated or received via active cellular transmission during a phone call or SMS sending/reception completely overpowers the signals of interest received by the observatories. In fact, an equivalent transmission originating from the Moon would still serve as a disrupting interference to inhibit astronomical research from Earth.[4]

Our goal in this project is two-fold. First, it is to mitigate the internal RFI contributions of active cellular transmission through a detection-prevention plan of action. We will develop a cell phone transmission detector that would notify a user if there is significant power in a certain RF band of interest (corresponding to call, SMS, or data) nearby. This device will be developed such that it will be stationary and housed in a gate that every visitor to an RF observatory will walk through. The second goal of our project is to educate the public on RFI. We will do this by developing a visual display that describes the ambient RF signals detected in the room. This public outreach factor will portray to viewers the various RF frequency bands and their corresponding signal strength in near-real-time.

1.2 Background

Cell phone transmissions are broken up into three distinct flavors: Code Division for Multiple Access (CDMA)[5,] Global System for Mobile Communications (GSM)[6,] and Long-Term Evolution (LTE)[7.] These different protocols for voice, SMS, and data transmission are all prevalent in today's world dominated by cell phones; each also occupies a different space in the RF spectrum. Additionally, different countries across the globe use different bands in the RF spectrum for CDMA, GSM, and LTE signals. In Puerto Rico, the Arecibo Observatory encounters this exact form of interference as a result of tourism to the site. In an effort to alleviate the problems caused by such interference, RFI mitigation techniques are being developed for the RF front-end, precorrelation, and postcorrelation (multiple points within the signal path).[2] However, these solutions are not enough to completely remove the noise from a nearby cell phone, nor are these techniques able to discern useful data from mere cell phone transmissions. Our detector will be self-contained, and each functional block of the detector system will be cheaper than currently available products.

1.3 High-Level Requirements

- The device must be able to detect different frequency bands; namely, the detection of CDMA, GSM, or LTE protocol bands of the United States (rather than Puerto Rico, for testing purposes), for a given carrier (AT&T) must be achievable.
- A display should display the active frequencies detected by the device.
- The device must notify the user or operator when a signal of a notable frequency is detected via both the display and a specific notification element (LED).

2 Design

The high-level design of this device is composed of an antenna and four modules: power supply, signal processing, power detection and notification, and display generation. The antenna receives RF signals and feeds it into the signal processing module and the power detection and notification module. The signal processing unit will perform band selection and subsequent signal processing to produce a digital signal that is fed into the display generation module. The power detection and notification module serves to detect power and notify users through discrete visual alert. The power supply will regulate wall outlet power and feeds specified power levels into all power-driven elements in each of the three other modules.

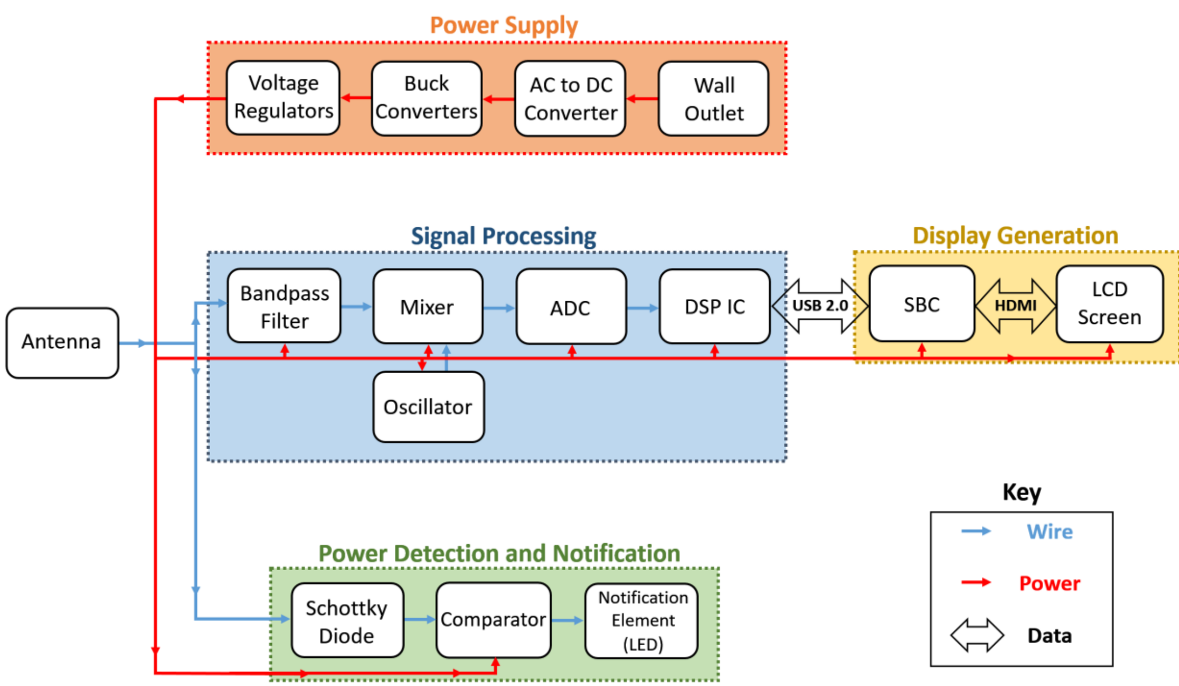

Figure 1: *Cell phone transmission detector block diagram*

2.1 Antenna

An appropriate antenna must be chosen to suit the needs of the design. These include the ability to cover all of the intended frequencies, the ability to connect to the rest of the device (SMA cables), and form factor.

Requirement 1: *Must cover frequency bands of 700 (4G LTE), 850 (call, 4G LTE), 1900 (call), 2300 (4G LTE) MHz and must operate at distances of at most 1m.*

2.2 Power Supply

In general, the device needs to be powered at different voltages and will draw a non-trivial amount of current. A few well-selected components placed in series can provide that versatility.

2.2.1 Wall Outlet

Since it is to be used in a stationary gate and display, the detector device will be powered by a simple wall outlet. Wall outlet converters can be added to the device as necessary to adapt to country-specific regulations.

Requirement 1: *Device must be directly capable of using US wall outlet voltage and current standards.*

2.2.2 AC to DC Converter

All of the ICs used in the other three modules require DC voltages. A rectifier circuit will be used in order to transform the wall outlet's AC to a usable DC.

Requirement 1: *Should regulate US wall outlet voltage (120 VAC) to 24 VDC +/- 5%.*

2.2.3 Buck Converters

High voltage needs to be stepped down (DC-DC) to reasonable levels to be inputted into the voltage regulators and then the individual components.

Requirement 1: *Buck converter 1 will step down to 1.2V (DSP IC) to within +/- 15%.*

Requirement 2: *Buck converter 2 will step down to 1.8V (ADC) to within +/- 20%.*

Requirement 3: *Buck converter 3 will step down to 3.3V (Mixer, LCD) to within +/- 15%.*

Requirement 4: *Buck converter 4 will step down to 5.0V (Comparator, SBC, LCD) to within +/- 15%.*

Requirement 5: *Buck converter 5 will step down to 10V (Oscillator) to within +/- 20%.*

2.2.4 Voltage Regulators

Voltage regulators will be used to accurately power each component in the device. This helps protect our circuit as well as the users of the device.

Requirement 1: *Regulator 1 will supply 1.2V to within +/- 5% under 500mA load.*

Requirement 2: *Regulator 2 will supply 1.8V to within +/- 5% under 500mA load.*

Requirement 3: *Regulator 3 will supply 3.3V to within +/- 5% under 1A load.*

Requirement 4: *Regulator 4 will supply 5.0V to within +/- 5% under 1.5A load.*

Requirement 5: *Regulator 5 will supply 10V to within +/- 10% under 1A load.*

2.3 Signal Processing

We will need to apply signal processing techniques on the RF signal to obtain the frequency spectrum of ambient signals. We apply a bandpass filter to isolate the band that we want. A mixer is then used in tandem with an oscillator to convert the signal to an intermediate frequency. We then pass this into an ADC to digitize the signal for interfacing with the DSP chip.

2.3.1 Bandpass Filter

As somewhat of a pre-selector, a bandpass filter will be applied to the incoming RF signal to perform some initial noise filtering as well as reject IF 'image' frequencies that could be introduced later by the mixer.

Requirement 1: *Filter impulse response must be centered within 1% of intended center frequency and must achieve –20dB fractional bandwidth of 1kHz +/- 5%*

2.3.2 Oscillator

As with most receivers, a mixer is needed to down-convert (or up-convert) signals to different frequencies. The incoming RF signal is one input, but the other will come from the oscillator. It must be adjustable so that different bands of frequencies can be focused on.

Requirement 1: *Must be adjustable to cover all frequency ranges; must be tunable to within 5% of the intended mixing frequency.*

2.3.3 Mixer

A mixer must be used to down-convert the RF signal to an intermediate frequency (IF) for input into the DSP IC.

Requirement 1: *Should have loss of no more than 5dB, 'half-IF' and other spurious signals should be >10dB less than intended output frequency.*

Requirement 2: *Must down-convert to a specific IF band within operating bounds of the DSP IC.*

2.3.4 ADC

The incoming, analog signal must be converted to a digital signal in order to be further processed by the DSP IC.

Requirement 1: *Should be a 12-bit converter.*

2.3.5 DSP IC

In order to additionally process the incoming signal, a DSP IC will be used. More filtering and other operations can be accomplished more easily and accurately using the DSP chip.

Requirement 1: *Should be capable of interface with selected ADC.*

Requirement 2: *Must be capable of performing processing functions within 5% of ideal function.*

2.4 Power Detection and Notification

2.4.1 Schottky Diode

Schottky diodes are very useful for the detector implementation due to two characteristics: its low forward voltage and its fast switching speed. These qualities are both desirable in an RF setting; incoming signals will be weak and of high frequencies.

Requirement 1: *Diode must have forward breakdown voltage of 300 mV.*

2.4.2 Comparator
This circuit will be used for the actual thresholding logic for determining if there's an unexpected spike in the aforementioned frequency ranges.

2.4.3 Notification Element
This will be our user interface. If significant RFI is detected we're going to need to notify the user. This will be through a LED, which serves as a visual alarm system of sorts.

Requirement 1: *LED must require no more than 3.3V.*

2.5 Display Generation
We will have a Raspberry Pi Zero and install Python (and the "matplotlib" library). The DSP will send it's the processed data over a serial port to the computer. We will run a Python program on the computer that then handles the stream of data and plots the incoming data as a frequency spectrum. This will allow us to see which bands are being occupied, and if we can see a spike within the bands in question.

2.5.1 Single-board Computer (SBC)
The SBC (a Raspberry Pi Zero) will serve to take in the DSP IC output and manipulate it to a usable input for the LCD screen. This will involve installing Python onto the SBC and using a pre-written plotting library to plot data in near-real-time.

Requirement 1: *Will be able to use Python to plot data and interface with an LCD screen.*

Requirement2: *5V, 1.2A PSU to power the Raspberry Pi Zero via micro-USB*

2.5.2 LCD Screen
This screen will allow easy visualization of the frequency-domain ambient signals in the environment of the device, limited to some frequency bands.

Requirement 1: *Screen must be able to be powered by 5V and include a video connector port to interface with mini-HDMI port on Raspberry Pi Zero.*

2.6 Risk Analysis
The most significant risk factor in this project is the antenna, simply because detecting relevant RF signals hinges on the ability of the antenna to pick up and transmit such signals to the detector circuit and display circuit. Cell phones have a wide range of RF communications, spanning across the use cases of voice calls, SMS, 4G LTE data, and even Bluetooth in some cases. Moreover, phones are not constantly transmitting RF signals unless the phone is being used. Therefore, it is difficult to develop a foolproof 100% accurate detection system for a phone that is not in airplane mode. In addition, the signal strength would vary per the direction of the antenna, so this will have to be considered.

To mitigate the risk with picking up RF signals, we aim to narrow our focus to realms of phone use that exhibit frequent use, such as 4G LTE data use. It may be possible to use multiple antennas to detect additional bands; however, this is not our primary focus.

3 Ethics and Safety
One of the main issues we must keep in mind is that we must abide by FCC regulations. This will most likely not be an issue if we are only receiving RF signals, however we must still take precaution to not

arbitrarily transmit waves. This could result in problems such as jamming signals, which is not only illegal, but would defeat the purpose of the detecting RFI in the first place.

Another key ethical point we deal with stems from the nature of this project, namely that we are "to improve the understanding of technology; its appropriate application, and potential consequences;" (IEEE Code of Ethics #5).[8] One of the goals of this project is to visually educate the visitors of the Arecibo Observatory about the effects of RFI, which affects the measurements carried out by researchers.

Another issue we must deal with is the fact that we only have one RF expert on our team. To abide by the IEEE Code of Ethics #6,[8] we designate our RF expert as the primary designer of the receiver circuit.

4 References

[1] Marr, Jonathan M.; Snell, Ronald L.; Kurtz, Stanley E. (2015). Fundamentals of Radio Astronomy: Observational Methods. CRC Press. pp. 21–24.

[2] *Bhat, N. D. R., J. M. Cordes, S. Chatterjee, and T. J. W. Lazio (2005). Radio frequency interference identification and mitigation using simultaneous dual-station observations, Radio Sci., 40, RS5S14, doi:10.1029/2004RS003172.*

[3] *Porko, J. P. G. (*2011). *Radio frequency interference in radio astronomy, Master's Thesis, Aalto School of Electrical Engineering.*

[4] *"Radio Frequency Interference", 2017. The National Radio Astronomy Observatory. https://public.nrao.edu/telescopes/radio-frequency-interference/ [Retrieved: September 17, 2017].*

[5] *Guowang Miao; Jens Zander; Ki Won Sung; Ben Slimane (2016). Fundamentals of Mobile Data Networks. Cambridge University Press.*

[6] *"GSM Bands information by country". WorldTimeZone.com. 2016-01-16 [Retrieved: September 17, 2017].*

[7] ETSI TS 136.101 V13.3.0 (2016-05) - LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 13.3.0 Release 13).

[8] *"IEEE Code of Ethics", http://www.ieee.org/about/corporate/governance/p7-8.html*.