1.1 PROBLEM STATEMENT

What problem is your project trying to solve? Use non-technical jargon as much as possible.

This project involves the design and construction of an imaging array consisting of resonant antennas with radio frequency (RF) circuitry for generation and detection of signals that can provide a visual depiction of hidden structures, objects, or biomedical anomalies. The problem this project will solve is the need to identify objects that cannot be viewed at the surface level of various types of materials.

There are numerous industries and applications that face this generalized need. The two primary areas of need our project will address are as follows:

(1) **Imaging through walls or other structures** – This problem focus relates to, in essence, stud finding or identification of embedded cables and other objects in building structures. Large sums of money are spent retroactively repairing damaged utilities or improperly placed wall mounts because of the difficulty in identifying the objects behind drywall, plaster, or other common building materials. A proper solution will provide transparency for objects hidden behind solid or opaque structures.

(2) **Biomedical imaging** – The medical industry faces a constant need for means to identify tumors, blood clots, cancerous growths, tissue damage, and other medical anomalies that lie under the epidermis (outer skin layer). A solution to address this need will provide imaging of these concerning anomalies via a non-invasive, safe, effective method of rendering images of the anomalies or identifying inconsistencies in unseen tissue.

1.2 REQUIREMENTS & CONSTRAINTS

List all requirements for your project. This includes functional requirements (specification), resource requirements, qualitative aesthetics requirements, economic/market requirements, environmental requirements, UI requirements, and any others relevant to your project. When a requirement is also a quantitative constraint, either separate it into a list of constraints, or annotate at the end of requirement as "(constraint)". Other requirements can be a single list or can be broken out into multiple lists based on the category.

1.2.1 REQUIREMENTS

Our RF imaging array project contains several concurrent and cross-compatible required deliverables. These requirements are enumerated and elaborated upon on the following pages:

1. Computer Simulation Technology Modeling and Antenna Design

The backbone of our project is the antenna array design. 8 RF antennas will be placed adjacent to one another in a one-dimensional array of antennas. These antennas emit radio frequencies in all directions and must be studied carefully for application appropriateness prior to being procured (i.e., purchased by our team). Then, they must be assembled and calibrated in a stationary array, as shown in Figure 1 below. Assuring functionality requires use of Computer Simulation Technology (or CST for short), as shown in Figure 2 below. The specific application we will use is CST Studio Suite. CST Studio Suite will enable us to determine whether our antenna array is tuned correctly, matched correctly, built correctly, and then how we can expect it to behave in real (i.e., physical) applications.

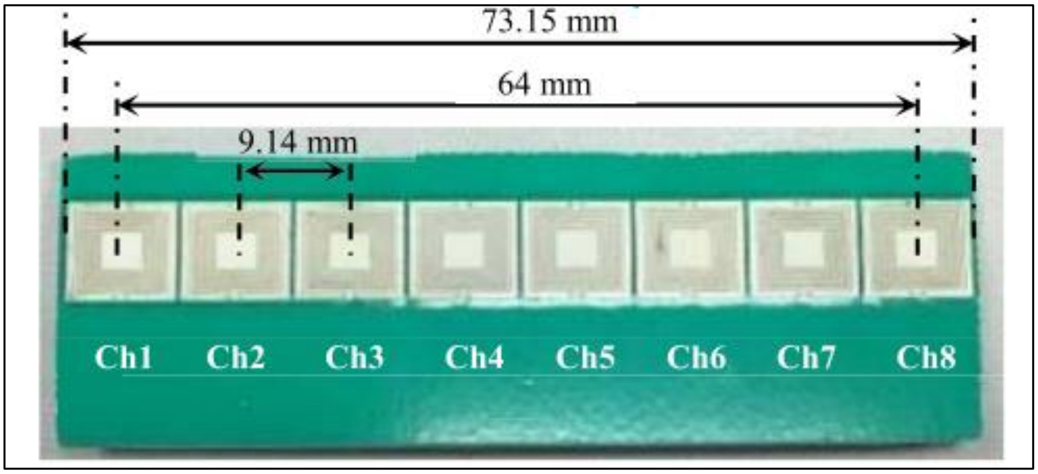

Figure 1 – One-Dimensional Antenna Array Example
Source: https://ieeexplore.ieee.org/abstract/document/8815736

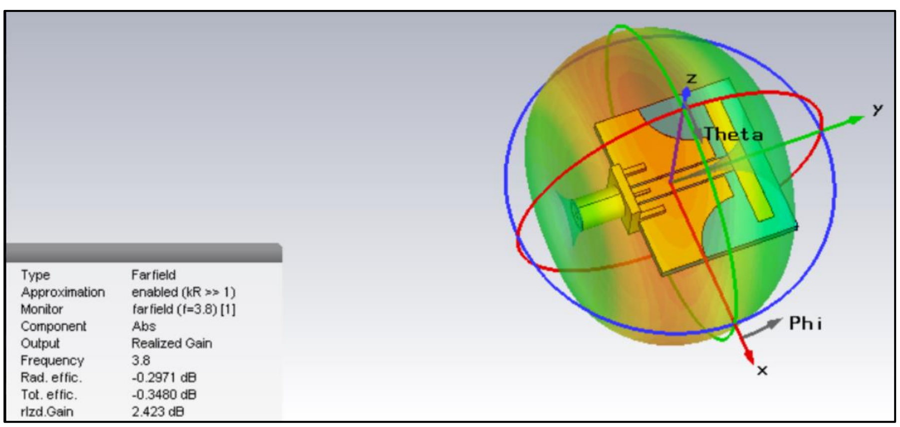

Figure 2 – CST Antenna Emission Rendering Example
Source: https://www.wifi-antennas.com/profile/35-sandeepv/?do=content&type=forums_topic_post&change_section=1

2. Antenna Tuning

Tuning our antenna array is an essential requirement of our project design. Each individual antenna of the eight-antenna array must be tuned to function properly on its own, and then all antennas must be re-tuned to function while stationed immediately adjacent to one another. Antennas emitting and receiving radio frequencies will inevitably interfere with each other. However, CST Studio Suite will again allow us to simulate these outcomes and design an array that is calibrated to minimize cross-interference between individual antennas. Ultimately, the antennas should be calibrated to optimize emission projection and reception.

Figure 3 below is a critically important representation of the optimality for RF antenna emissions: S11 (on the y-axis) represents the amount of power reflected back from the object that the antenna's outgoing RF emissions are directed towards. For an ideal antenna, all the power would be transmitted, so the magnitude of S11 should be negative infinity. However, since that is not possible, anything less than -20dB will be sufficient for our application.

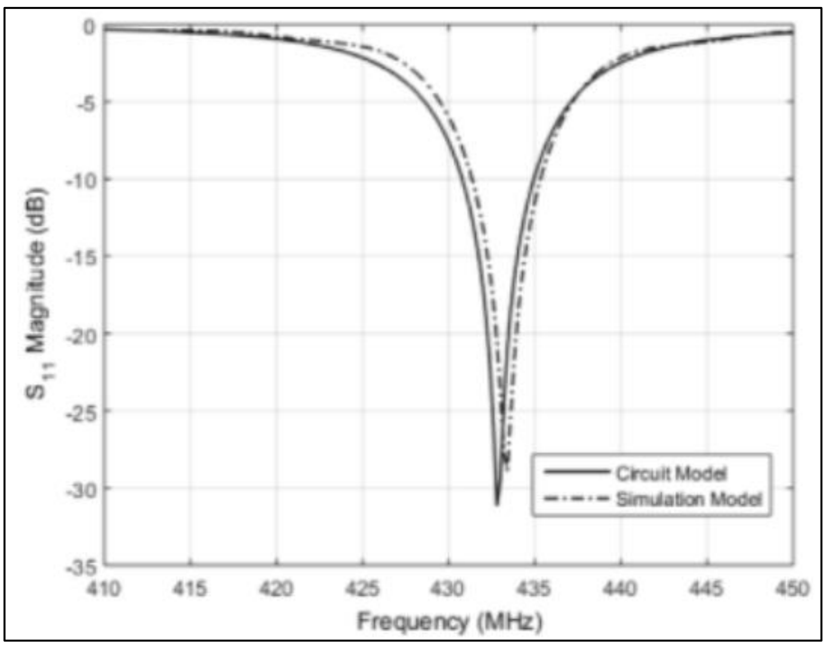

Figure 3 – Antenna Array Simulated Frequency Response Example
Source: https://www.wifi-antennas.com/profile/35-sandeepv/?do=content&type=forums_topic_post&change_section=1

3. RF PCB Design (PLL & Switches)

We will have to design two printed circuit boards (PCBs) for our project: the first is a PCB for the RF antenna array. This PCB will include a phase-locked loop and switches to operate the various antennas in the eight-antenna array. A phase-locked loop (PLL) is a control system used to generate an output signal with related output and input phases. This also correlates with enabling us to output a consistent output signal with constant frequency. This is crucial in an RF system as the system relies on a precise design frequency; changing this frequency would result in larger losses or a decrease in the expected power gain in the signal we are trying to send to the antenna to propagate out. Once the signal has been produced, we will use RF switches to selectively choose which antenna in our array we want to send the signal to which prevents interference and coupling between the many antennas.

Figure 4 below includes a red box around an exemplary image of what will eventually be our RF PCB design that includes both a PLL and switches. This RF PCB will interact with and control the RF antenna array while transmitting data to and from our software, analog-to-digital converter, and user-interface data display, all of which are explained on the subsequent pages.

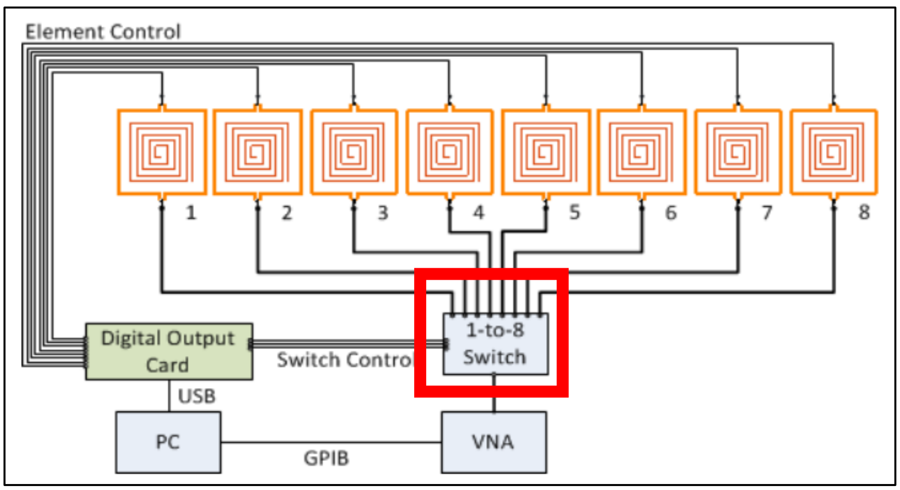

Figure 4 – Example of RF PCB Containing PLL and Switching Functionality
Source: https://ieeexplore.ieee.org/abstract/document/8815736

4. ADC PCB Design

Our project design further requires a PCB layout of a subsystem utilizing an analog-to-digital (ADC) integrated circuit (IC) for interpretation of the data coming from the antenna array. An ADC is a system that takes real-time analog data and models it as digital data that is usable by the microcontroller governing our overall system. This will involve utilization of layout principles set forth in the documentation for the IC, as well as documenting what the output of this IC will look like to simplify the work of our microcontroller team.

5. Low Level Programming (Data Gathering)

A microprocessor must be programmed to control our hardware devices. We are likely to use a raspberry pi, but an FPGA or other microprocessor could also be used. This microprocessor will control several functions: (1) device commands and controls, (2) data gathering, (3) data display, and (4) user-interface communication and interaction.

The “low level” programming entails controlling devices and gathering data therefrom to provide information to the user. Specifically, data about the RF antenna emissions will be collected by the microprocessor. This data will be sent to the user interface thereby providing the user with information about emissions inconsistencies. Such inconsistencies include hidden structures in walls or biomedical anomalies that lie under the epidermis (outer layer of skin) and cannot be viewed by the human eye. An image of the raspberry pi we are considering for our microprocessor is displayed in Figure 5 below:

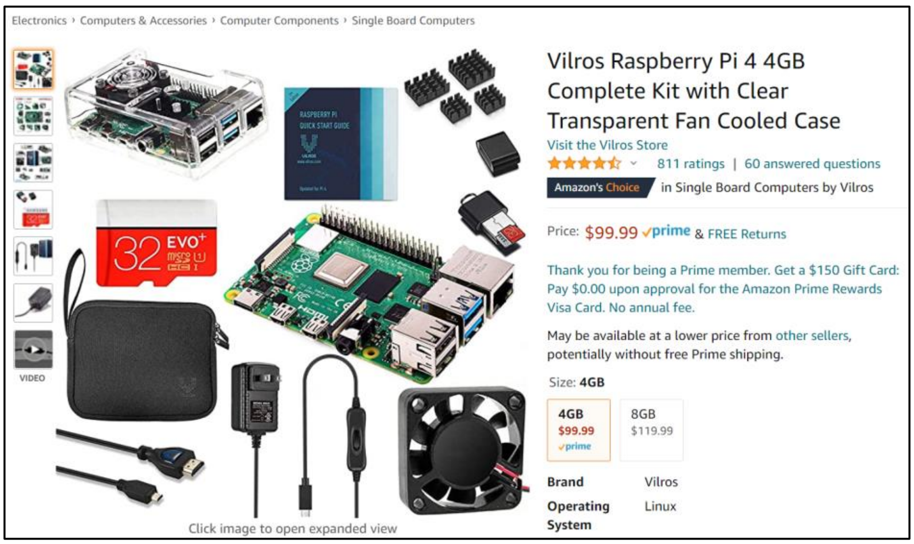

Figure 5 – Raspberry Pi Candidate for Microprocessor
Source: https://www.amazon.com/Vilros-Raspberry-Complete-Transparent-Cooled/dp/B07VFCB192?ref_=ast_sto_dp&th=1&psc=1

6. Data Processing and Display

The final requirement for our project involves microcontroller configuration (as in Figure 5 above) for data processing, coupled with a user interface for data display. Our hardware device will only be usable if we implement software that provides an easily understood visual or quantitative depiction of the information generated and collected by the antenna array working in conjunction with the other various components listed above. We plan to use Tornado (a Python web framework) to display the data on electronic devices like laptops or smartphones while a Python script will power the backend functionality.

1.2.2 CONSTRAINTS

There are several constraints related to both the technical aspects of our project and our collective group resources.

1. **Budget** – We must purchase our project parts ourselves, and we are all still full-time students, so cost-consciousness is a significant factor. We may seek out funding assistance from corporate sponsors. Currently, we seek to keep our total spend below $300. This is a quantitative constraint.

2. **Number of Antennas in Array** – There will be eight antennas in our antenna array. This cap is necessary to reduce workload to reasonable levels, but more antennas could potentially increase performance. This is a quantitative constraint.

3. **Novel Concepts** – We are constructing a project at the cutting edge of RF antenna technology. This will challenge us conceptually and require that we educate ourselves on material we were previously unfamiliar with. The intrinsic constraint here is the limit of our collective technical knowledge and capabilities. This is a qualitative constraint.

4. **Appealing and Effective User Interface** – We must provide a display that a "casual user" of stud-finding or biomedical imaging technology can interpret. The casual user's knowledge of and experience with an imaging array for stud finding is a qualitative constraint.

1.3 ENGINEERING STANDARDS

What Engineering standards are likely to apply to your project? Some standards might be built into your requirements (Use 802.11 ac wifi standard) and many others might fall out of design. For each standard listed, also provide a brief justification.

STANDARD: P1128 - Recommended Practice for Radio-Frequency (RF) Absorber Evaluation in the Range of 30 MHz to 40 GHz

ABSTRACT:

> The purpose of this recommended practice is to recommend realistic and repeatable criteria, as well as recommended test methods, to characterize the absorber characteristics applied to a metallic surface. This recommended practice covers the parameters and test procedures for the evaluation of radio-frequency (RF) absorbers over the frequency range of 30 MHz to 40 GHz. Examples include those used for radiated emissions and immunity testing of electronic products or general antenna measurements. The evaluation measurements can be performed in frequency and/or time domain.

Source: https://standards.ieee.org/project/1128.html

APPLICATION TO OUR PROJECT:

This standard is related to our project in many respects. Specifically, we are going to use measurement techniques for the evaluation of RF antennas. We are also concerned with frequencies used for radiated emissions and general antenna measurements. However, we are not yet certain whether our RF antenna frequency range falls within the 30MHz to 40GHz range. Moreover, we do not expect to test our device on “metallic surfaces,” which this standard is directed towards. Instead, we plan to focus on plywood, drywall, and (if time) human tissue. Therefore, as the parameters of our project become clearer, we will keep this standard in mind and reevaluate its future applicability to our project design requirements.

1.4 INTENDED USERS AND USES

Who benefits from the results of your project? Who cares that it exists? How will they use it? Enumerating as many "use cases" as possible also helps you make sure that your requirements are complete (each use case may give rise to its own set of requirements).

There are numerous industries and applications that constitute our use cases. The two primary use cases our project will address are listed below:

(1) **Imaging through walls or other structures** – This use case focus relates to, in essence, stud finding or identification of embedded cables and other objects in building structures. Large sums of money are spent retroactively repairing damaged utilities or improperly placed wall mounts because of the difficulty and identifying the objects behind drywall, plaster, or other common building materials. The standard "user" is a homeowner, construction worker, foreman, maintenance employee, cable installer, electrician, and the like. A proper solution will provide transparency for objects hidden behind solid or opaque structures.

(2) **Biomedical imaging** – The medical industry presents a unique use case for our project. Healthcare providers (such as doctors) maintain a constant need for means to identify tumors, blood clots, cancerous growths, tissue damage, and other medical anomalies that lie under the epidermis (outer skin layer). The standard "user" is a radiologist, nurse, doctor, or other diagnostic healthcare worker. A solution to address this need will provide imaging of concerning deep-tissue anomalies. The imaging will be presented through a non-invasive, safe, effective method of rendering images of the anomalies or identifying inconsistencies in unseen tissue.