# 4. TESTING

*Testing is an extremely important component of most projects, whether it involves a circuit, a process, power system, or software.*

*The testing plan should connect the requirements and the design to the adopting test strategy and instruments. In this overarching introduction, give an overview of the testing strategy. Emphasize any unique challenges to testing for your system/design.*

## 4.1 UNIT TESTING

*What units are being tested? How? Tools?*

Every subsystem in our design requires standalone unit testing. This includes the RF PCB, ADC PCB, microprocessor (both low and high level programming), and antennas.

### 1) Antenna Array Unit Testing

The primary unit of measure (and testing) in our complete system is **Frequency Response**.

Figure 1 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.

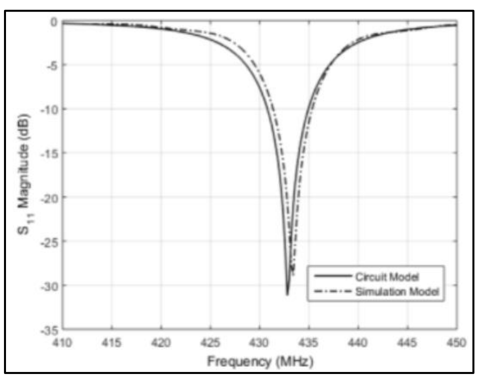


**Figure 1[1] – Antenna Array Simulated Frequency Response Example**

Frequency response is a product of antenna tuning. To determine whether an antenna is tuned correctly, we will use a directional coupler and spectrum analyzer.

[1] *Source:* https://www.wifi-antennas.com/profile/35-sandeepv/?do=content&type=forums_topic_post&change_section=1

### 2) RF PCB Unit Testing

Like the antenna array unit testing, we will utilize frequency response measurement and testing to show the RF PCB is emitting proper signal frequencies. This will be like the antenna frequency response unit testing except instead of attenuation, we will see a positive frequency response since we expect (and require) power actually being delivered to the antennas.

### 3) ADC PCB Unit Testing

Regarding unit testing for the ADC PCB, we will transmit the ADC PCB a known voltage. We will then read it through to the microprocessor (MCU) while concurrently converting the known voltage manually. If the two values—read through and manual—are a match, we will be able to confirm that the ADC PCB passed its respective unit testing phase.

### 4) Microprocessor Unit Testing

The microprocessor is integrated with the entirety of rest of the system (i.e., all sub-systems). Therefore, while viewing the microprocessor as a standalone "unit" system, we will be able to unit test the microprocessor by merely checking that all the microprocessor's drivers are functioning individually with one system at a time. Restated, we will perform MCU testing by ensuring that the MCU should be communicating only with the RF PCB or only with the ADC PCB when such commands are exclusively specified by the operator.

## 4.2 INTERFACE TESTING

*What are the interfaces in your design? Discuss how the composition of two or more units (interfaces) are being tested. Tools?*

There are multiple interfaces in our complete system—these interfaces connect the various sub-systems to one another. A list of our interfaces is below.

**Complete system interfaces:**

- ***Antenna array to RF PCB*** (and RF PCB to antenna array)
- ***Antenna array to ADC PCB*** (and ADC PCB to antenna array)
- ***RF PCB to microprocessor*** (and microprocessor to RF PCB)
- ***ADC PCB to microprocessor*** (and microprocessor to ADC PCB)
- ***Microprocessor to user interface display*** (and UI display to microprocessor)

We will use several different tools to test these various interfacing sub-systems. For example, **to test the microprocess-to-UI-display interface**, we will examine the user interface display output and manually compare it to the data that our low-level software is receiving from the ADC and RF PCBs, respectively. We will then be able to determine the accuracy of our user interface display.

As another example, we will use a system of observation and measurement to test the **RF-PCB-to-antenna-array interface**. This is perhaps the most important sub-system interface in our overall system. The RF PCB should enable an operator to switch between individual antennas in the array by sending commands from RF PCB that controls the antenna array accordingly. It will be obvious whether the RF PCB is correctly controlling antenna switching, because it will either turn off 7 of 8 antennas while leaving the intended antenna on to propagate RF signals, or it will fail to turn off 7 of 8 antennas while leaving the intended antenna on to propagate RF signals.

## 4.3 INTEGRATION TESTING

*What are the critical integration paths in your design? Justification for criticality may come from your requirements. How will they be tested? Tools?*

Our overall system is heavily reliant on complete sub-system integration functionality. **Figure 2 below depicts the interdependent sub-systems of our overall system.** The schematic below demonstrates the total reliance on—and criticality of—functional sub-system integration.

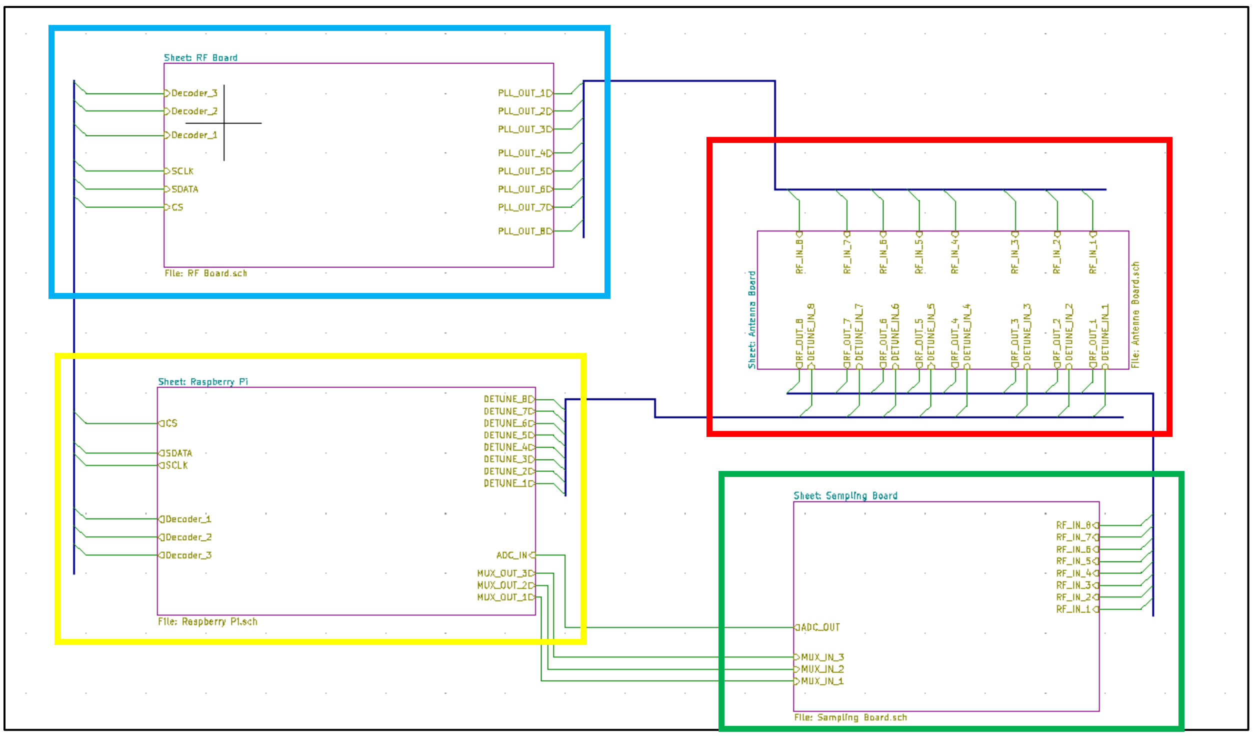


**Figure 2 - Full System Circuit**

**The upper right quadrant of Figure 2 (red box)** represents our **RF antenna array**. It includes eight I/O ports for each of the eight antennas. Complete RF antenna array integration requires that we tune, test, re-tune, and detune each antenna individually and in conjunction with the others. It also requires that we measure the analog signals being sent to the ADC from the antenna array. Finally, it requires that we check with switch and signal propagation functionality that comprise the relationship between the RF PCB and the antenna array.

**The lower right quadrant of Figure 2 (green box)** represents our **ADC PCB**. The ADC PCB will take signals from the RF antenna array and pass them to the microprocessor for processing and display. Complete ADC PCB integration requires that we test the accuracy of analog signals sent from the antenna array to the ADC PCB which are then passed to the microprocessor in the form of digital signals and data.

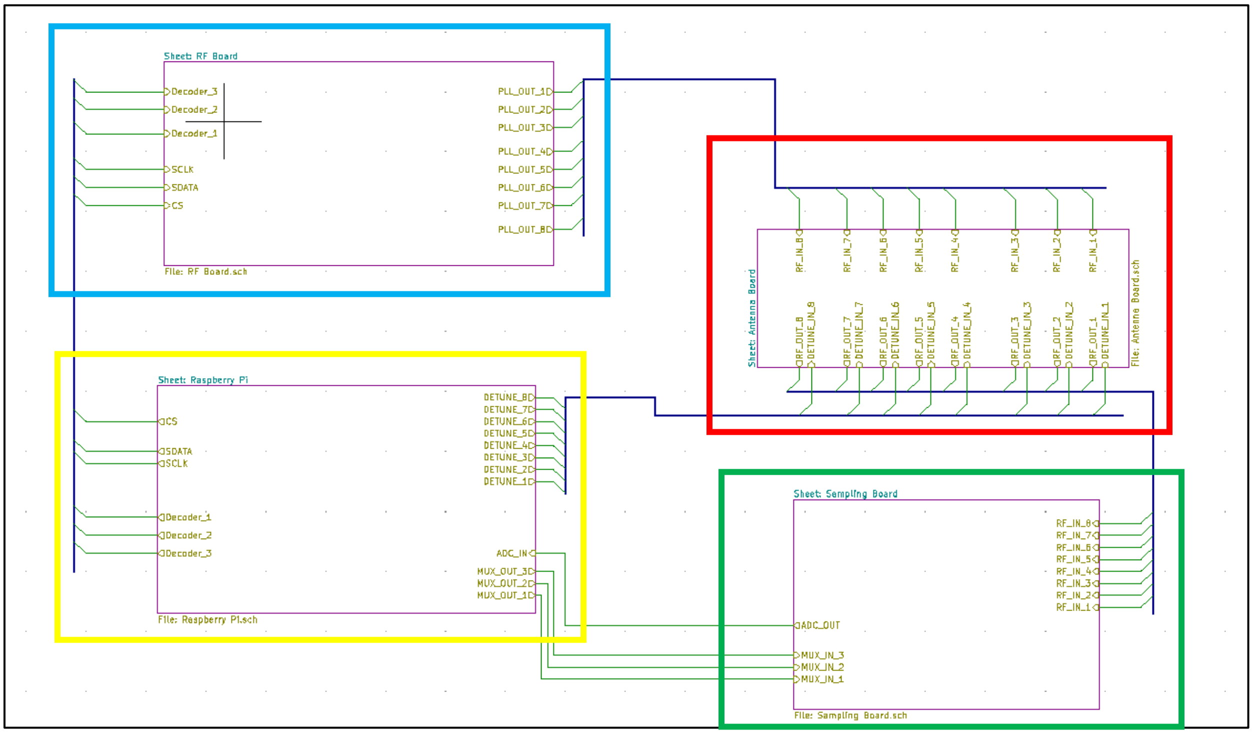


**Figure 2 - Full System Circuit** *(Duplicated for Reference)*

**The lower left quadrant of Figure 2 (yellow box)** represents our **microprocessor**. It will send user-input commands to the RF PCB and receive data from the ADC PCB. The microprocessor will house a considerable amount of software, so it will require standard software testing processes. However, it will also have to interface with the RF and ADC PCBs, and this will require manual testing of the signals and commands being sent to and from those sub-systems, respectively.

**The upper left quadrant of Figure 2 (blue box)** represents the **RF PCB**. It will receive and transmit power, receive signals from the antenna array, send commands to the antenna array, and receive user-input commands from the microprocessor. There are numerous tests we must run on the RF PCB, because it performs many different functions. One of the most important tests for the RF PCB is measuring the intended signal output against the actual signal output. This test will determine whether the "heart" of our project (the RF PCB) is accurately calibrated and properly controlling the "backbone" of our project (the antenna array).

## 4.4 SYSTEM TESTING

*Describe system level testing strategy. What set of unit tests, interface tests, and integration tests suffice for system level testing? This should be closely tied to the requirements. Tools?*

Our overall system requires functionality of several sub-systems that relate directly to our design requirements. The design requirements—are their respective system testing requirements—are summarized below:

1) **Antenna CST Modeling, Design, and Tuning**
    a. Testing for interoperability with RF PCB
    b. Testing for interoperability with ADC PCB
    c. Vector Network Analyzer used to test whether physical parts and assembly satisfy simulation parameters
    d. Test coupling between probes to ensure -30dB represented by S21

2) **RF PCB Design (PLL & Switches)**
    a. Testing for interoperability with antenna array
    b. Testing for interoperability with microprocessor
    c. Testing to ensure phase locked loop (PLL) produces 400MHz signal
    d. Testing to ensure power transfer across switches is at least 10dB
    e. "Smoke testing"[2] to ensure RF switches correctly turn on/off
    f. Smoke testing to ensure RF switches send signals to correct destination

3) **ADC PCB Design**
    a. Testing for interoperability with antenna array (accurate reception and conversion of analog signals)
    b. Testing for interoperability with microprocessor (accurate transmission of digital signals for processing)
    c. Testing to ensure ADC PCB sampling rate is 100kHz
    d. Testing to ensure ADC PCB resolution is 16 bits (or clear enough to be interpreted by microprocessor)

4) **Low Level Programming (Data Gathering)**
    a. Testing for interoperability with user ADC PCB (receiving digital signals)
    b. Testing for interoperability with RF PCB (sending operator commands)

5) **Data Processing and Display**
    a. Testing for sufficient user satisfaction and intuitiveness (~80%)

[2] "A quick test performed to ensure that the software works at the most basic level and doesn't crash when it's started. Its name originates from the hardware testing where you just plug the device and see if smoke comes out." *Source*: Testing PowerPoint, EE 491 Lecture, Fall 2021.

## 4.5 REGRESSION TESTING

*How are you ensuring any new additions do not break the old functionality? What implemented critical features do you need to ensure do not break? Is it driven by requirements? Tools?*

**Regression Testing in Antenna Array**

The clearest example of the need for regression testing in our overall system is in the addition of each individual antenna comprising our antenna array. There will be eight individual antennas in our 1x8 array of antennas, as shown in **Figure 3 below**. Each antenna must be able to function on its own, but it must also be tuned and re-tuned to account for the addition of adjacent antennas. This incremental tuning, re-tuning, and calibration process necessitates constant regression testing.

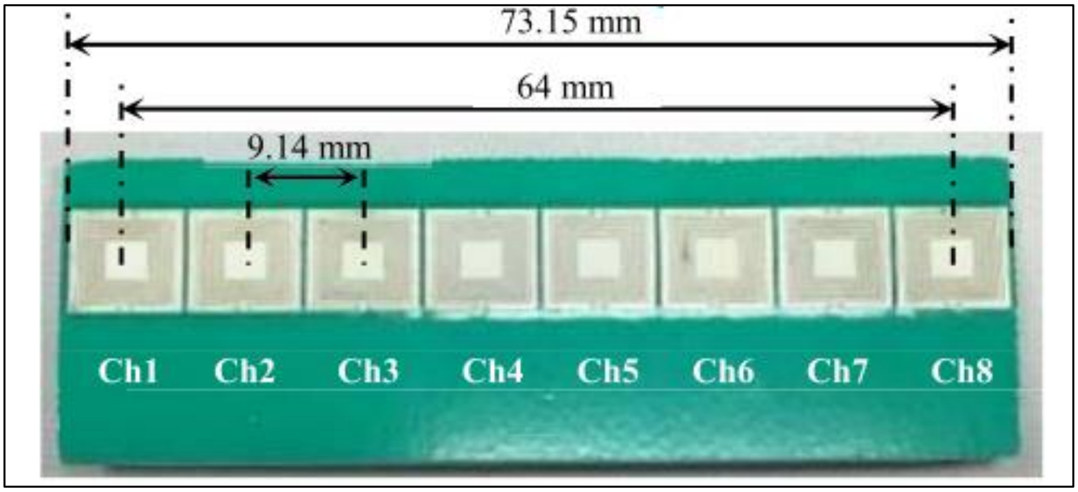


**Figure 3 – One-Dimensional Antenna Array Example[3]**

**Regression Testing in Sub-System Integration**

Regression testing will also be essential during the sub-system integration stage. As state several times previously, our project comprises many complicated sub-systems working interdependently. If any of these sub-systems fail, our entire system will fail to meet our design requirements. As such, each sub-system will be introduced slowly and tested incrementally to stave off regression during any and all integration phases.

[3] *Source*: https://ieeexplore.ieee.org/abstract/document/8815736

## 4.6 ACCEPTANCE TESTING

*How will you demonstrate that the design requirements, both functional and non-functional, are being met? How would you involve your client in the acceptance testing?*

Ultimately, our project will be designed to "image" objects that are hidden behind opaque structures. Testing system functionality is relatively straightforward:

1. **Manual object measurement** – We will measure a test object by hand as a base reference.

2. **Obscurement of object** – We will then hide the object behind a uniformly consistent surface (like drywall).

3. **Antenna array signal propagation and reception** – Our sub-systems—working in conjunction—will enable the RF antenna array to send signals and receive distorted signals in response that correlate with the object hidden under the opaque surface.

4. **User interface display output generation** – Our user interface display—controlled by our microprocessor—will generate a 2D image that is representative of the object behind the opaque surface.

5. **Comparison: UI-output-to-manual-measurement** – This is the final and most important step. We will compare our initial manual measurement results to measurement results gleaned from the system-generated user interface 2D image.

We will discuss an acceptable level of measurement error tolerance with our client. Preliminarily, we would like to produce imaging measurements with no more than approximately 20% measurement error. Of course, one of our primary design goals is to drive this measurement error percentage as low as possible. We will also test our system on several different sizes and shapes of objects, and on several different surfaces comprised of varying materials and thicknesses.

## 4.7 RESULTS

*What are the results of your testing? How do they ensure compliance with the requirements? Include figures and tables to explain your testing process better. A summary narrative concluding that your design is as intended is useful.*

### Antenna Array – Frequency Response Results

Figure 1 was first displayed in section 4.1 above, and it is displayed again below due to its critically important nature. The results of our design testing will confirm that we have achieved the optimality for our 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. Our results will allow us to recreate this graph with our own data and demonstrate that we are achieving our target result of less than -20dB for our application.

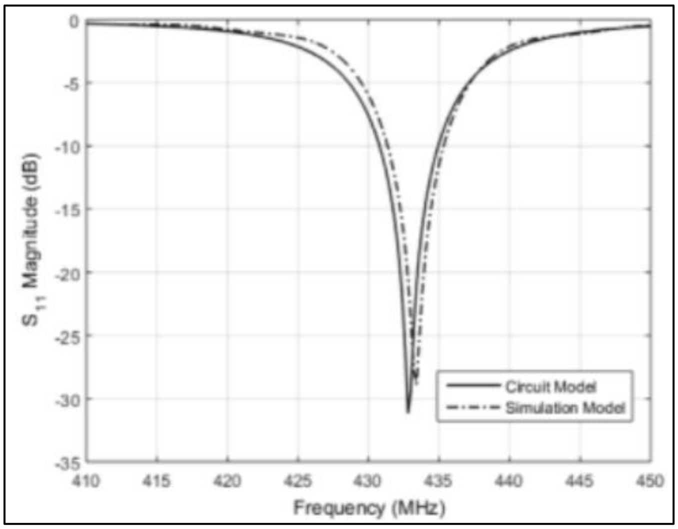


**Figure 1[4] – Antenna Array Simulated Frequency Response** *(Duplicated for Reference)*

### System and Acceptance Testing Results

As stated in section 4.6 above, the results of our system and acceptance testing will demonstrate that we are imaging objects hidden by opaque structures with repeatable accuracy. We will confirm this by comparing our user interface output measurements to manual physical measurements of the hidden objects during the testing phase. The result of this trial-and-error testing will lead to consistent measurement results that indicate our system is ready for production.

[4] *Source:* https://www.wifi-antennas.com/profile/35-sandeepv/?do=content&type=forums_topic_post&change_section=1