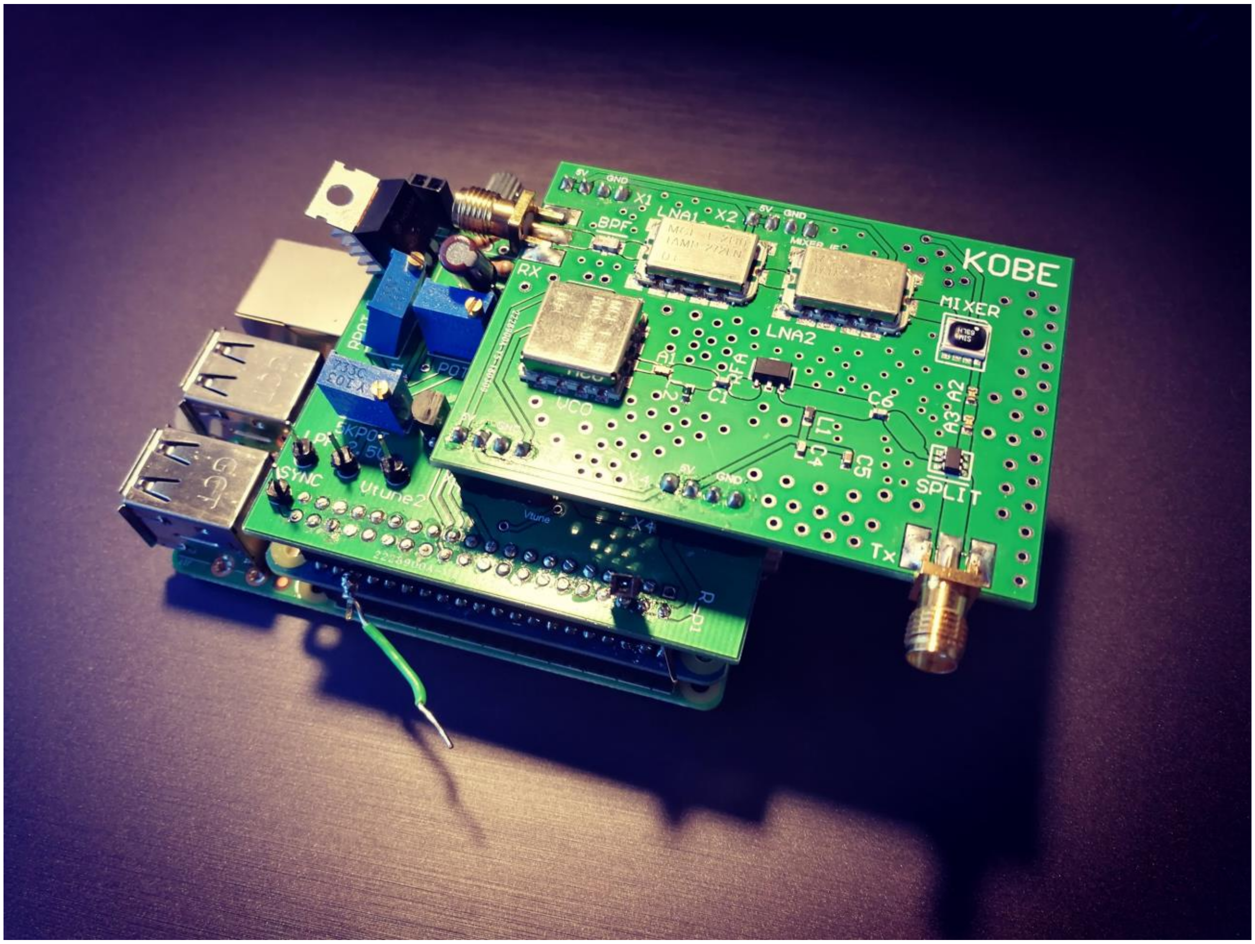

System Planning & Implementation

EEC 134 Application Note

Team Kobe

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1. Introduction

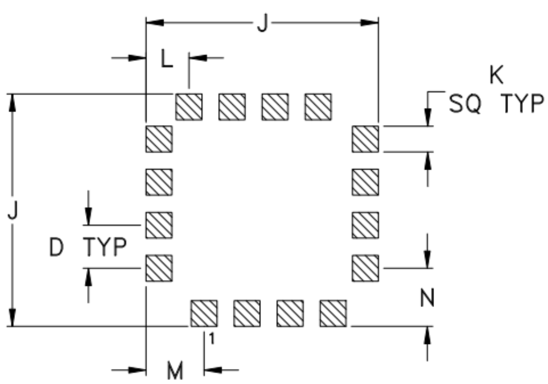
The objective of this application note is to provide the reader with an understanding of the planning, considerations, and implementation of the overall radar system. In particular, this outline will cover the entire PCB process from design to assembly, integration of a Raspberry Pi 3 to function as the onboard signal processor, and the successful use of two Yagi antennas as both the transmitter and receiver. Since I personally worked on these portions of the project, insights and suggestions for improvements will also be included. The specifics of the RF system design will not be discussed.

If your team wants to start work on the design of the radar system before Quarter 2, it is entirely doable to start early based on the reports from previous years. All the information to begin developing your own radar is available and the labs during Quarter 1 primarily serve to guide you through the process. Starting early will give you additional time to work on the problems that will come up during the development process. There was a delay on the first round of PCB orders this year which made it impossible for a second order to be made through the class. The result was a large period of time waiting for the PCBs to arrive and then a very hectic rush of assembly and testing at the end.

2. PCB Design and Assembly

A. Datasheets

It is very important that careful reading of the component datasheets and additional checks are made to prevent costly mistakes on the PCB layout. In addition to making sure the components will work for the correct frequency range, it's also necessary to confirm that you have the correct component footprint dimensions and recommended layout of necessary resistors, capacitors, and inductors. Every part of the design is important and an issue with a single component can prevent the whole system from functioning properly. These are significant issues that affected a few teams this year, where double checking datasheets before PCB order placement would have prevented them from occurring.



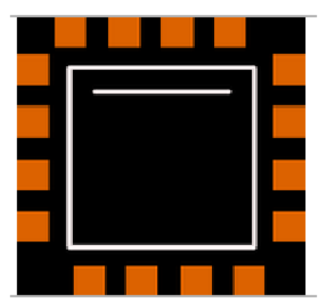


Fig 1: Datasheet to Footprint

B. Two Board Stack

We split our system into two boards that independently handle the RF and baseband signals. The RF board lies on top to prevent its signals from radiating up into the baseband if it were on the bottom. This decision was based on suggestions found in the previous year's reports as well as our own experience putting together the first quarter's boards.

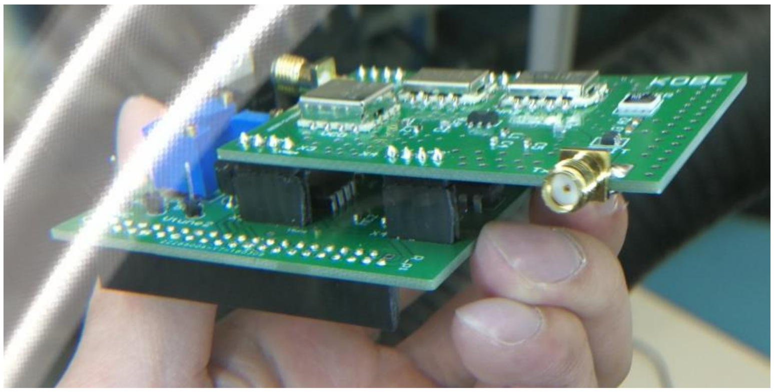


Fig 2: Baseband and RF board Stack

Stacking the boards reduces the length of the microstrip lines and gives greater freedom in the PCB layout as the lines can now pass right over each other instead of traveling down the length of a longer board. When compared to low frequency signals, the RF signals required greater design considerations that also came with increased layout restrictions. Separating the two subsystems allowed us to keep their opposing design focuses isolated from each other. This also made trouble shooting easier and in the possibility that a failure occurred in one board, only half of the total system needed to be remade.

Creating a modular stack comes with numerous advantages wherein the only real downside exists in careful arrangement of the PCB layout and thus more work for your PCB designer. Care must be taken to arrange larger components for better vertical clearance of the stack and to properly align the inter-board connections with the same distance of separation for each layout. In Figure 3, the RF board on the left will extend outward to the right to give more room with vertical clearance on the baseband board.

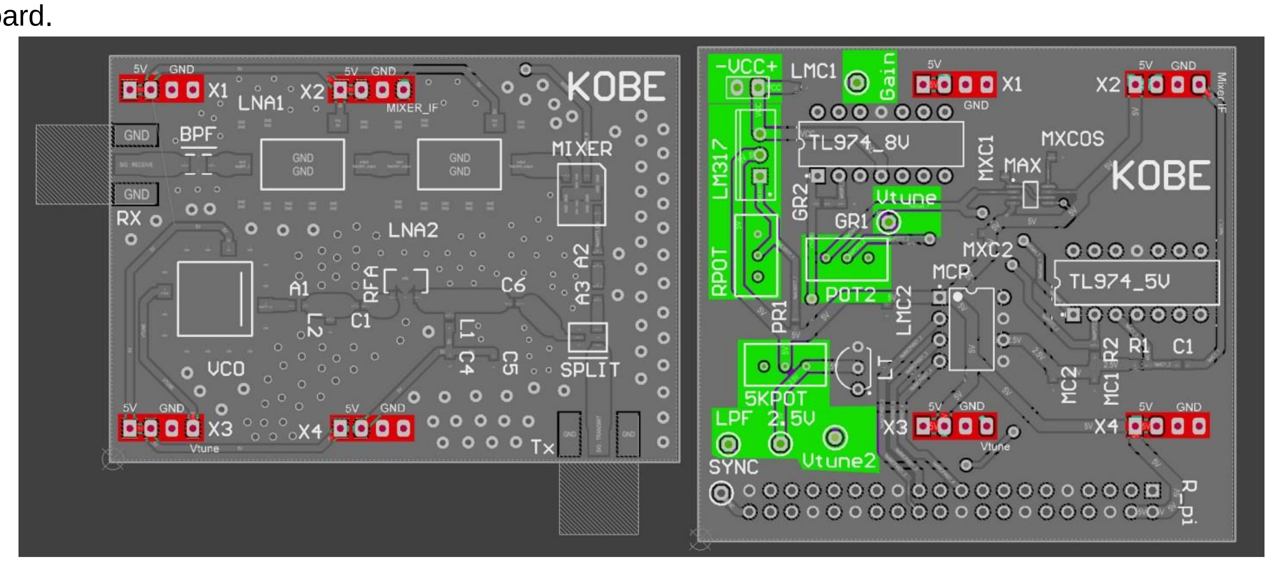


Fig 3: (Red) Placement of Inter-board Connections & (Green) Items with High Vertical Clearance

C. RF Board

The RF board exclusively contains components that are necessary to generating and receiving high frequency signals. This led us to make sure we had via fencing, wider microstrips for impedance matching, straight transmission lines, and no crossing of other microstrips over the RF lines. These requirements restrict how the PCB must be laid out and add another reason to separate the RF subsystem from the baseband.

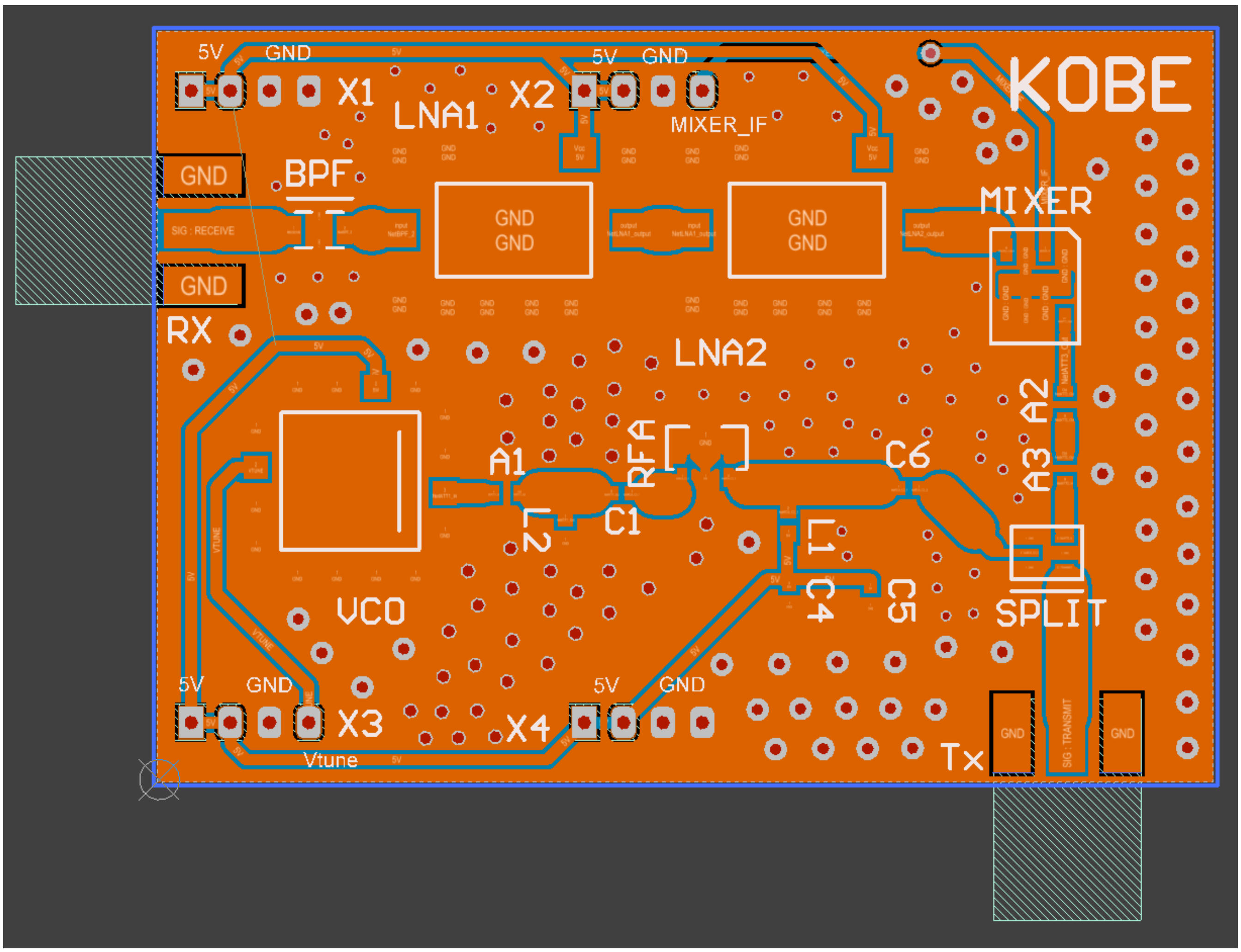


Fig 4: RF PCB Layout

D. Baseband Board

With the RF system on a separate board, the baseband could have components placed much closer together and allow its transmission lines to cross over each other. The baseband board is where everything starts and eventually makes its way back to. Power regulation is done through the LM317, the microcontroller generates a triangle wave out the MCP4921 DAC, and a DC offset is added to complete the Vtune signal which is sent up to the VCO. The received signal from the RF side makes its way back down the baseband, receives a gain from the TL974IN, and passes through an active LPF before making its way into the audio cable.

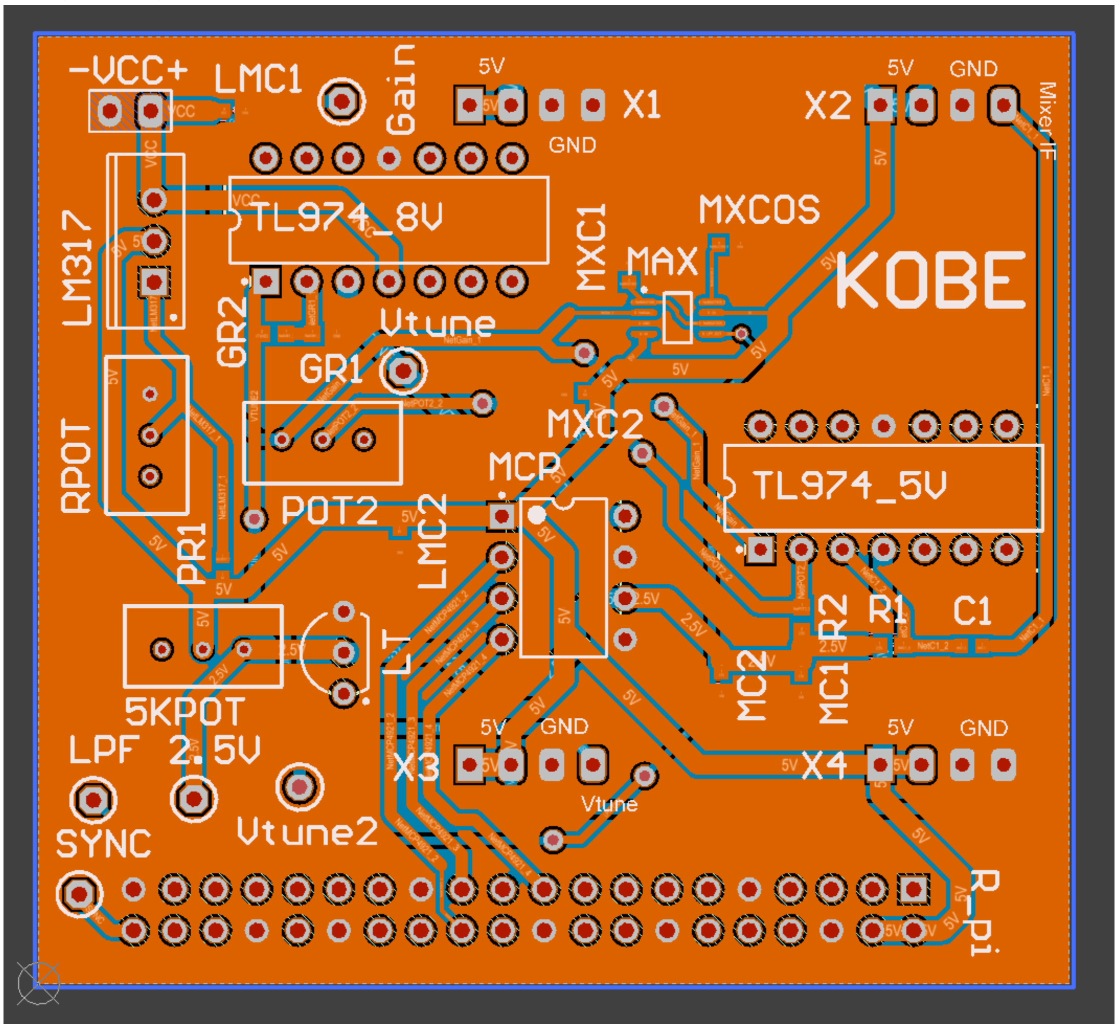


Fig 5: Baseband PCB Layout

E. Logistics

Components that were once available during the Quarter 1 labs might not be in-stock once assembly starts and the shortages will continue to get worse as teams run through the class inventory. Plan ahead and buy all of the parts you need for your system instead. When PCB order times are too long and your team needs a board sooner than later, consider ordering a board outside of the class order. My team had multiple boards ordered from China-based EasyEDA that had a consistent turn-around time of 6 days, where 10 boards with DHL shipping ran us $21. Keep in mind that the Chinese New Year will shut down Chinese PCB manufacturers during the majority of February.

F. PCB Assembly

Assembly is the first stage where unexpected issues start to come into play. As the second quarter of the RF project draws into its final weeks, availability of the assembly workshop will drop sharply as teams scramble to finish their boards. Keep in mind that there is only one machine available for SMD soldering that will also be used by students from the NATCAR project. Getting to the workshop early can ensure that your team gets access to the equipment first.

I highly suggest making PCB assembly easier by designing the PCB layout around these issues. Although there is little to no availability of through-hole RF components, ~~it is possible to replace all the passives and baseband components with through-hole versions to limit your team's reliance on the SMD soldering machine and the PCB oven.~~ The difference in weight is negligible and will drastically improve your team's ability to troubleshoot issues with your board. In addition to using as many through-hole components as possible, reduce the amount of solder points on your design by choosing integrated components that require minimal passives.

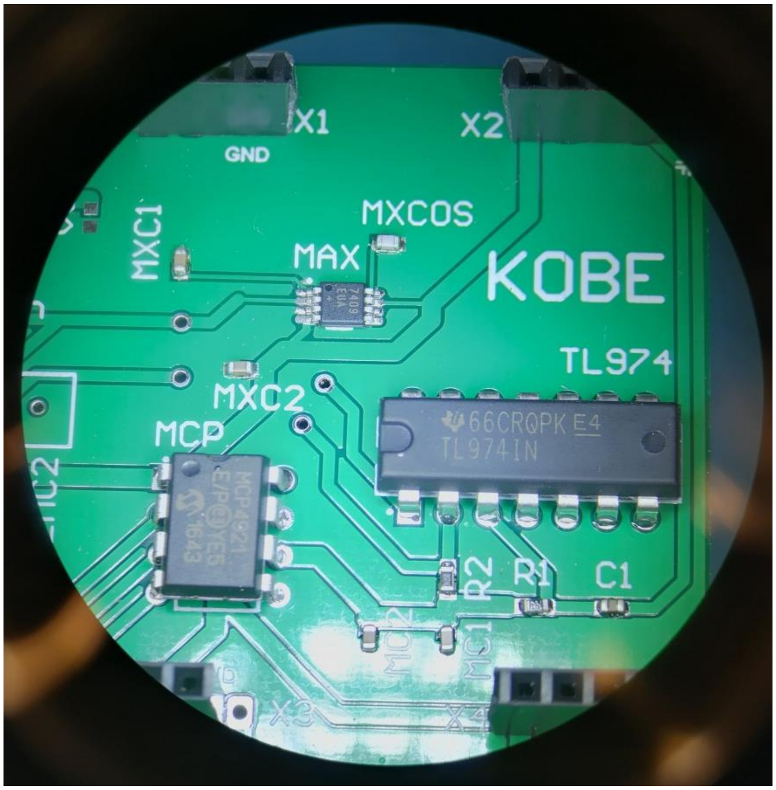


Fig 6: Close-up of Baseband PCB Featuring Through-hole and SMD Soldering

Add appropriate silk labels to all components to facilitate ease of assembly. Try to use components with the largest foot prints to make soldering easier and prevent solder bridges. In Figure 6, the Maxim LPF is the smallest IC our team used and was much more difficult to solder than the through-hole DAC and op-amp beside it.

3. Microcontroller Integration

A. Function Generation: Teensy 3.2

The Teensy 3.2 microcontroller from the first quarter does a very good job at controlling the MCP4921 DAC to generate the triangle wave going into the VCO Vtune. Its low power consumption also means that the LM317 power regulator can maintain a lower operating temperature without the need of a heat sink. Although the Teensy is capable of sending out the necessary SPI controls to the DAC, it does not have the necessary processing power for onboard processing. This year's teams attempted the onboard processing with the Teensy 3.6, PSoC 5, and Raspberry Pi 3.

B. Onboard Processing: Raspberry Pi

In attempting the challenge of adding an onboard processor to our system, I chose the Raspberry Pi 3 for its power and my familiarity with it. The Raspberry Pi offers an easy to use, Linux based platform to replace the Teensy's SPI control of the DAC and serve as the onboard digital processor of the received waveforms. With a monitor, keyboard, and mouse connected to it, the Raspberry Pi functions just like any other computer. We were able to run the Python range measurement code and run Audacity at the same time on the Pi.

Fig 7: In-Progress Transmitting and Receiving using Raspberry Pi

However, the Pi lacks a built in line in to record the waveform the same we did in the last lab of Quarter 1. We initially thought that using a USB soundcard would suffice, but I discovered a week before the competition that most if not all these USB devices could only record in mono. This issue was resolved with the purchase of the AudioInjector sound card for the Pi that added stereo capability. Including the Pi itself, our entire system had become a hefty stack of four boards.

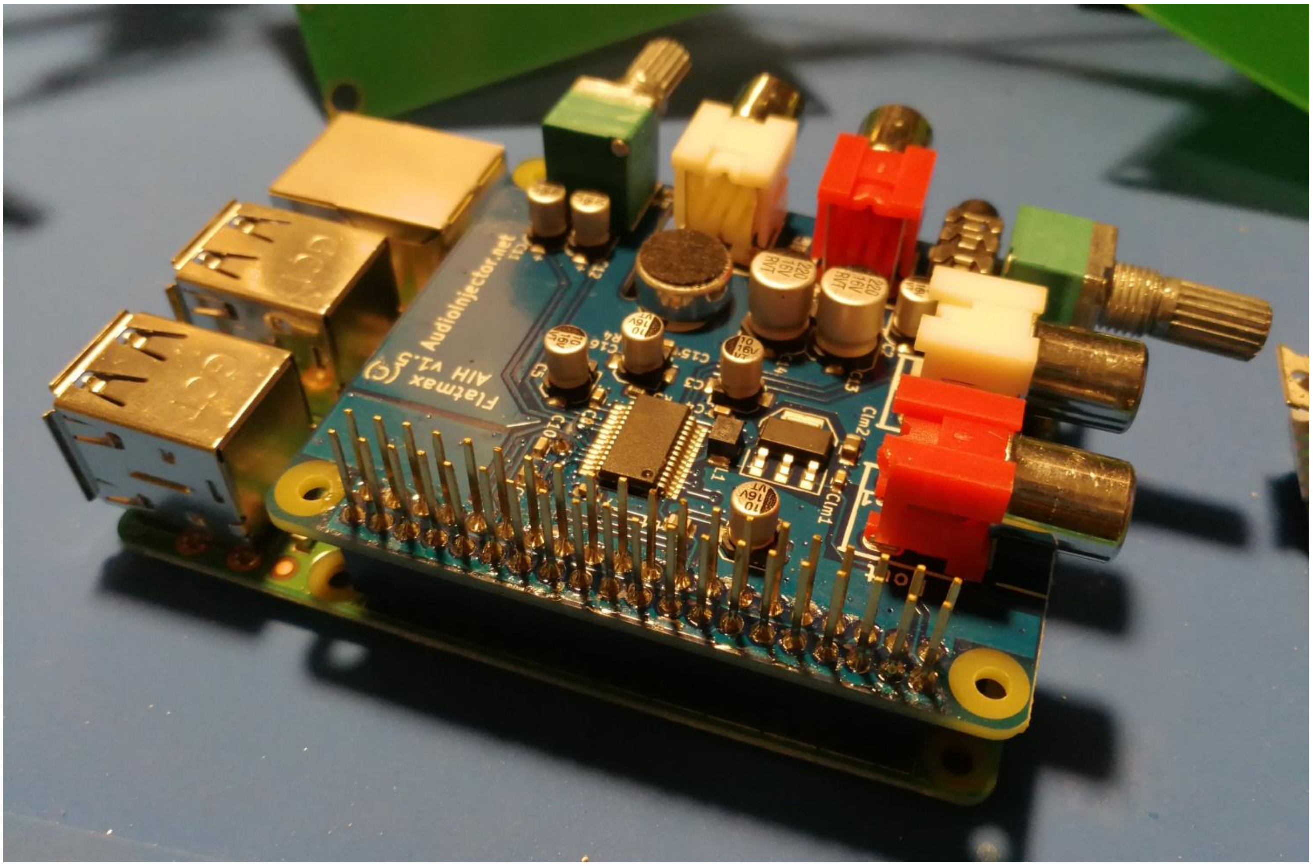


Fig 8: Raspberry Pi with AudioInjector Line In

C. <u>Mistakes and Considerations</u>

On the day of the competition, our system failed to pick up anything past 10 meters and the range plot had quite a lot of noise. Subsequent debugging and testing revealed that the culprit was our Vtune triangle wave signal which had an extremely low resolution. Unfortunately for us, we had only tested the entire system with the Pi the previous night at a maximum range of 10 meters. In addition, the Pi draws a significant amount of power and required a separate LM317 power regulator. Post competition testing showed issues with the Pi properly generating the sync and Vtune signals when we had a loose micro USB cable. I suggest that if future teams want to use a Raspberry Pi for onboard processing, sufficient testing must be done to ensure it can properly substitute in as the function generator and receives enough power.

4. Antenna Comparison

A. Initial Outdoor Testing

The first real round of testing was conducted right in front of Kemper at a maximum range of 100 feet. To find the optimal antenna configuration, we experimented with different combinations of coffee can and Yagi antennas on both the transmitter and receiver.

Fig 9: Initial Testing Area

Compared to our later results at Hutchinson field, the data gathered here has much more noise that is attributed to reflection off the surrounding buildings.

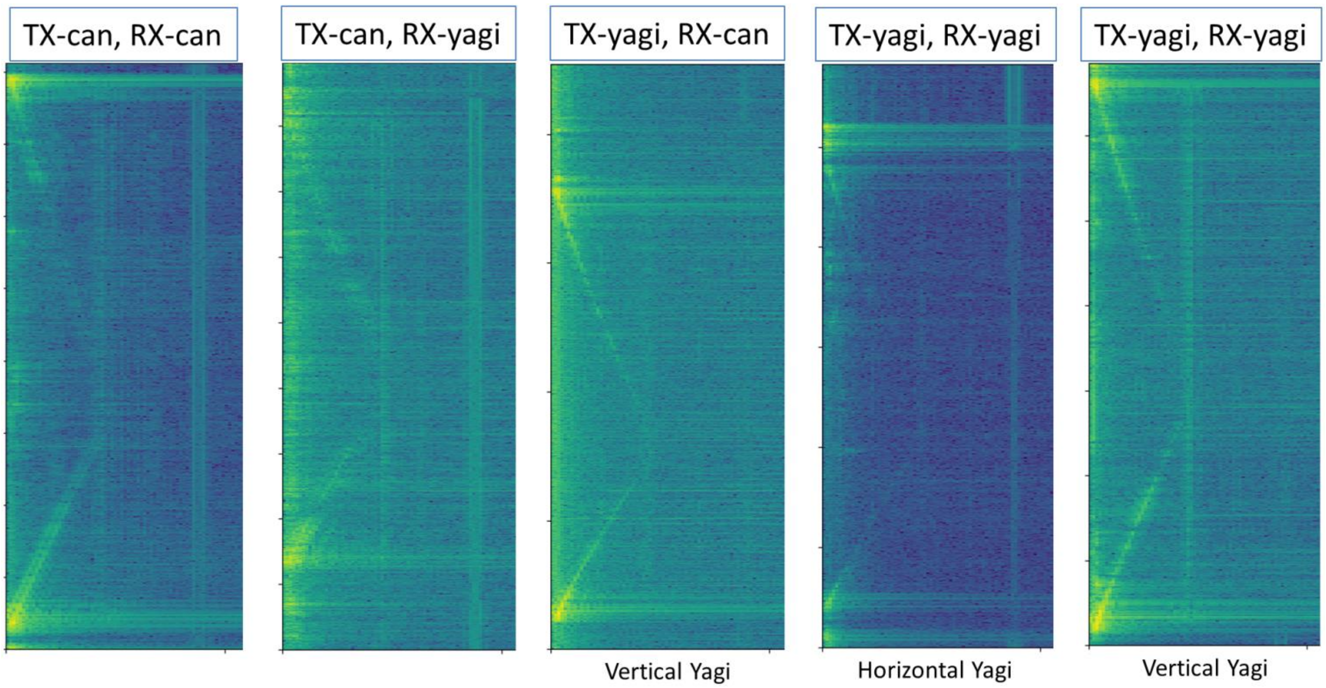


Fig 10: Side-by-side Comparison of Antenna Combinations

Teams from last year used either two Cantennas or a combination of the Cantenna as the receiver and a Yagi as the transmitter. However, our initial tests show great performance when two Yagis are used in the vertical position. The range lines on the plot are much more clear and stronger than the other combinations.

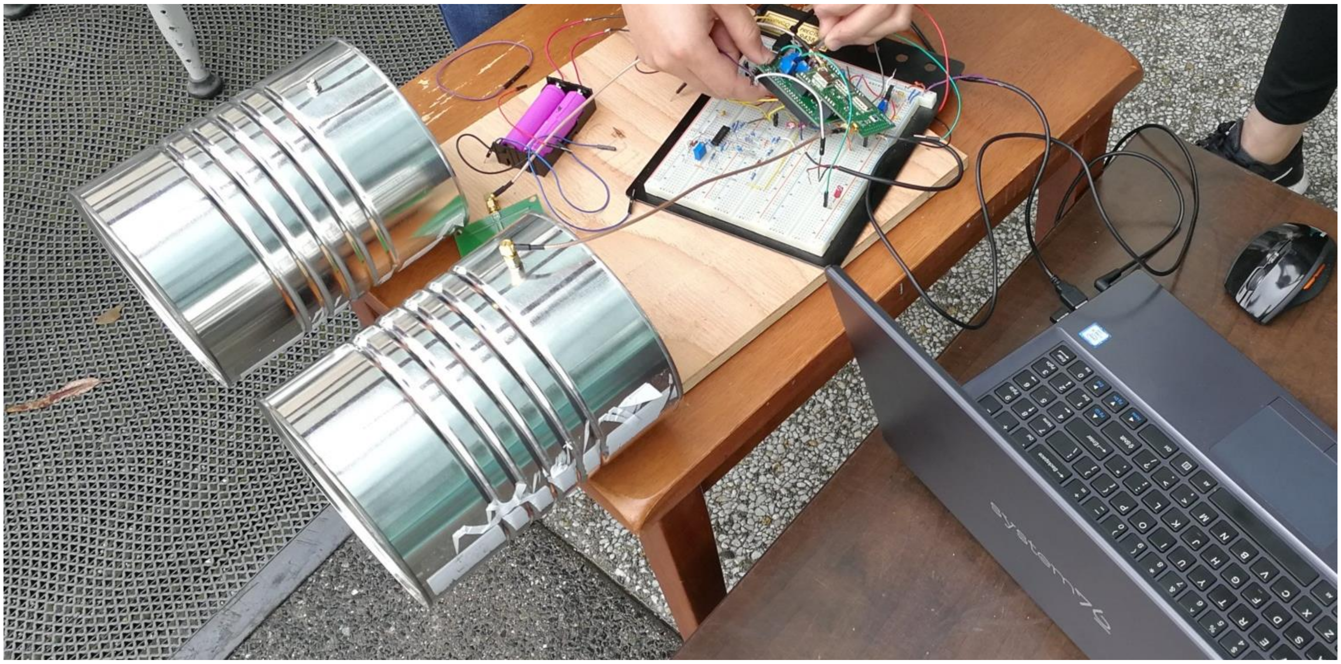


Fig 11: Test Setup of Cantennas

Fig 12: Test Setup of Yagi Antennas

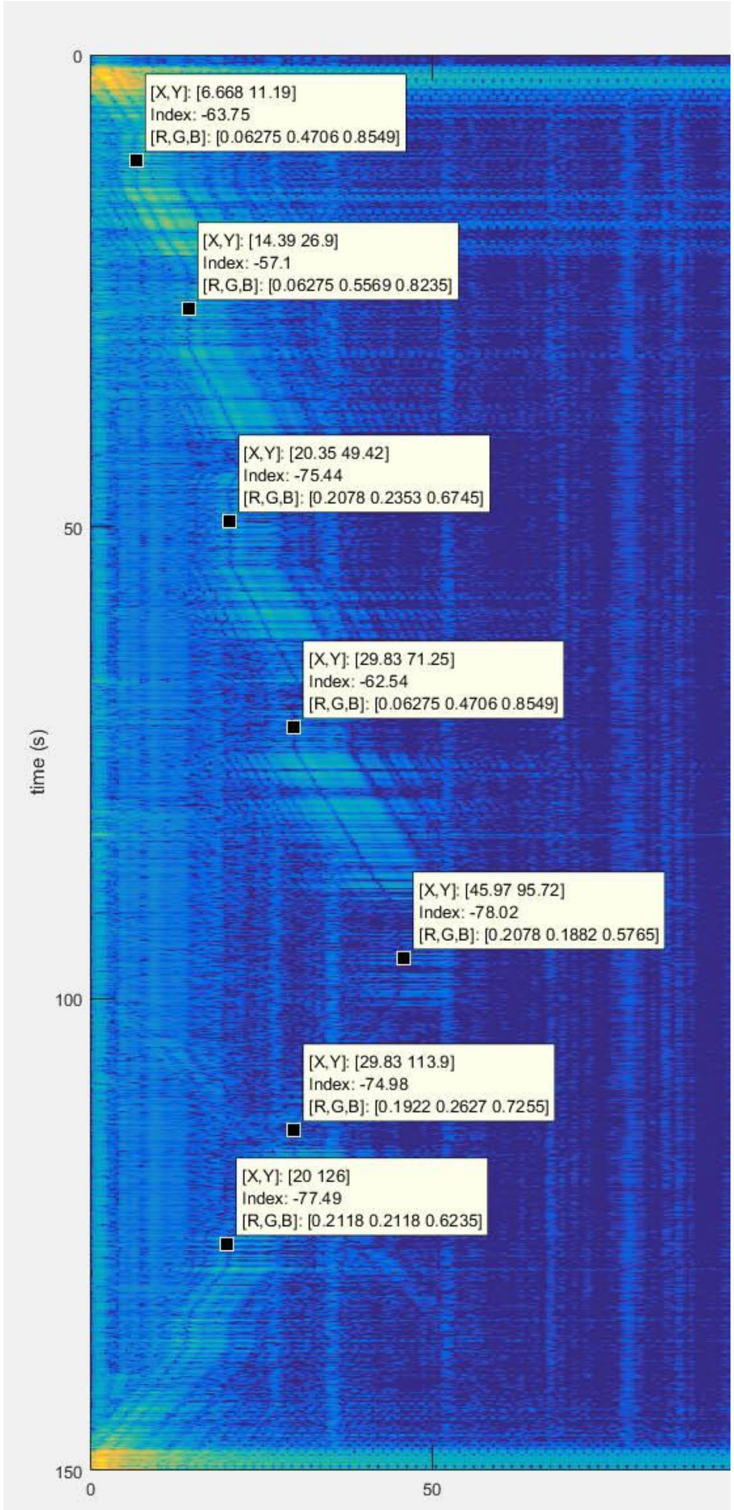


Fig 13: Final Test w/Cantenna @ 7.3, 15.2, 21.3, 30.5, and 45.7 Meters

After fixing our problems with the sync and Vtune signals, we went out to Hutchinson field again to test out our system and received very good range guesses.

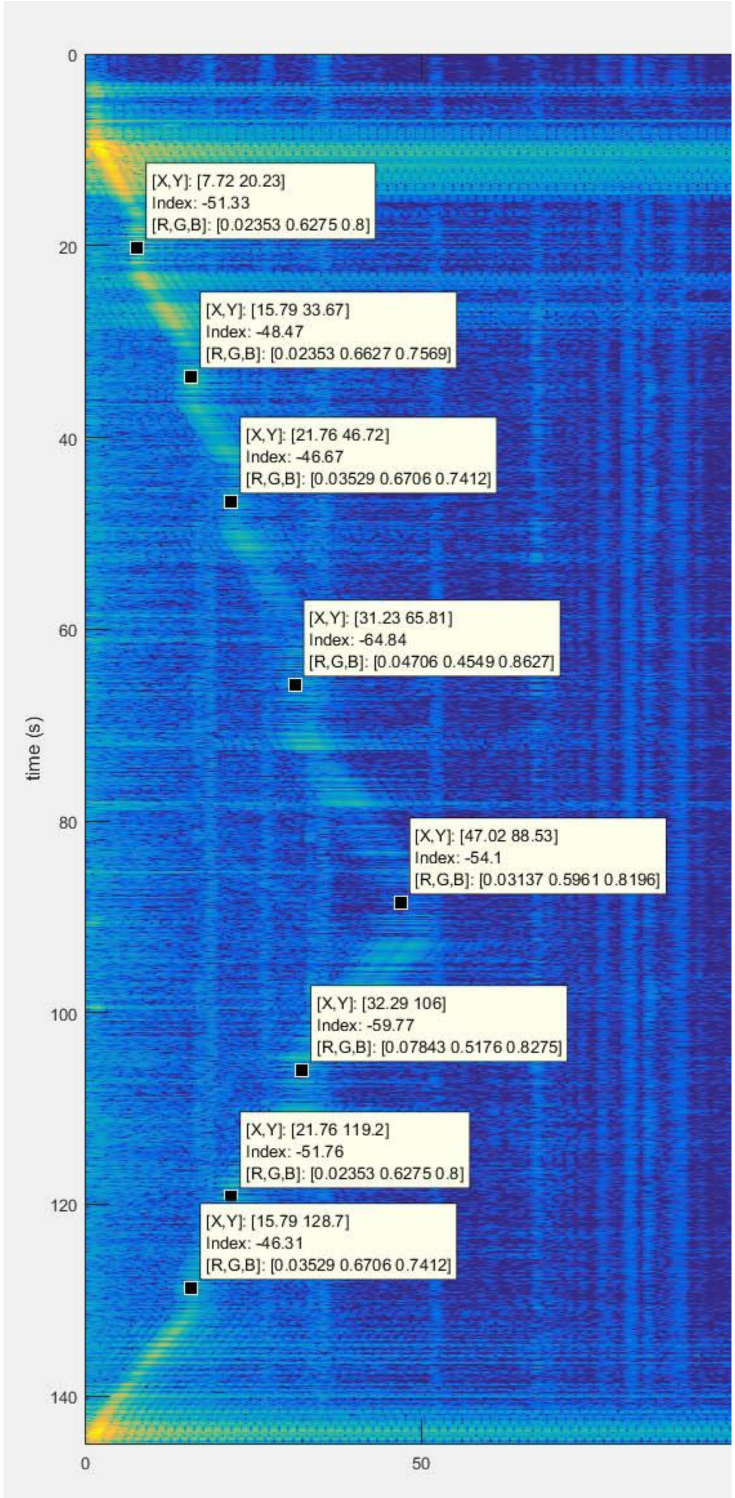


Fig 14: Final Test w/Yagi @ 7.3, 15.2, 21.3, 30.5, and 45.7 Meters

At range, the dual Yagi antennas prove to be the definitive winner against the cantennas. The range lines are noticeably clearer than our initial test. Both antennas yield results within 1 meter of the actual distances.

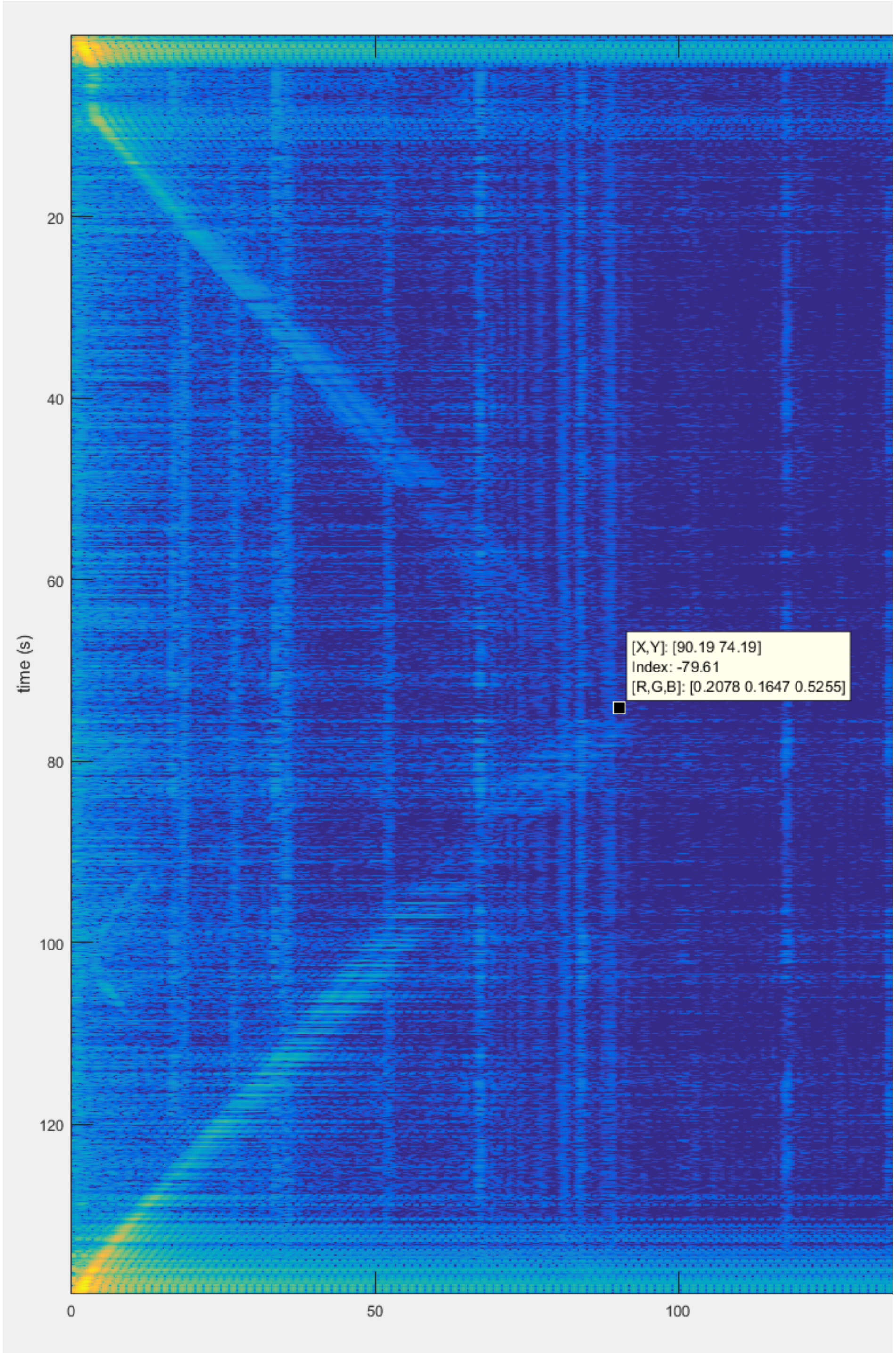


Fig 15: Maximum Tested Range of 90 Meters

Just to see what results we would get with our system, we did a single maximum range test and were able to achieve a reading at 90 meters. Based on this result, I think it's entirely possible to go beyond 100 meters with just the Yagi antennas. For increased directivity, I suggest building a Yagi Cantenna using Andrew McNeil's tutorial on YouTube.

Yagi Soldering

The Yagi antenna manufacturer recommends that the connection is made by cutting open the SMA cable and soldering the center and ground pins to the board without using the usual SMA connector. This method results in a very weak connection that can easily break through flexing of the cable. Instead, it's possible to remove the center pin of the SMA connector and thread the stripped cable through. I added heat resistant tape to keep the cable snug against the connector and sealed it all up with heat shrink wrap. This alternative offers the best way to connect the SMA cable.

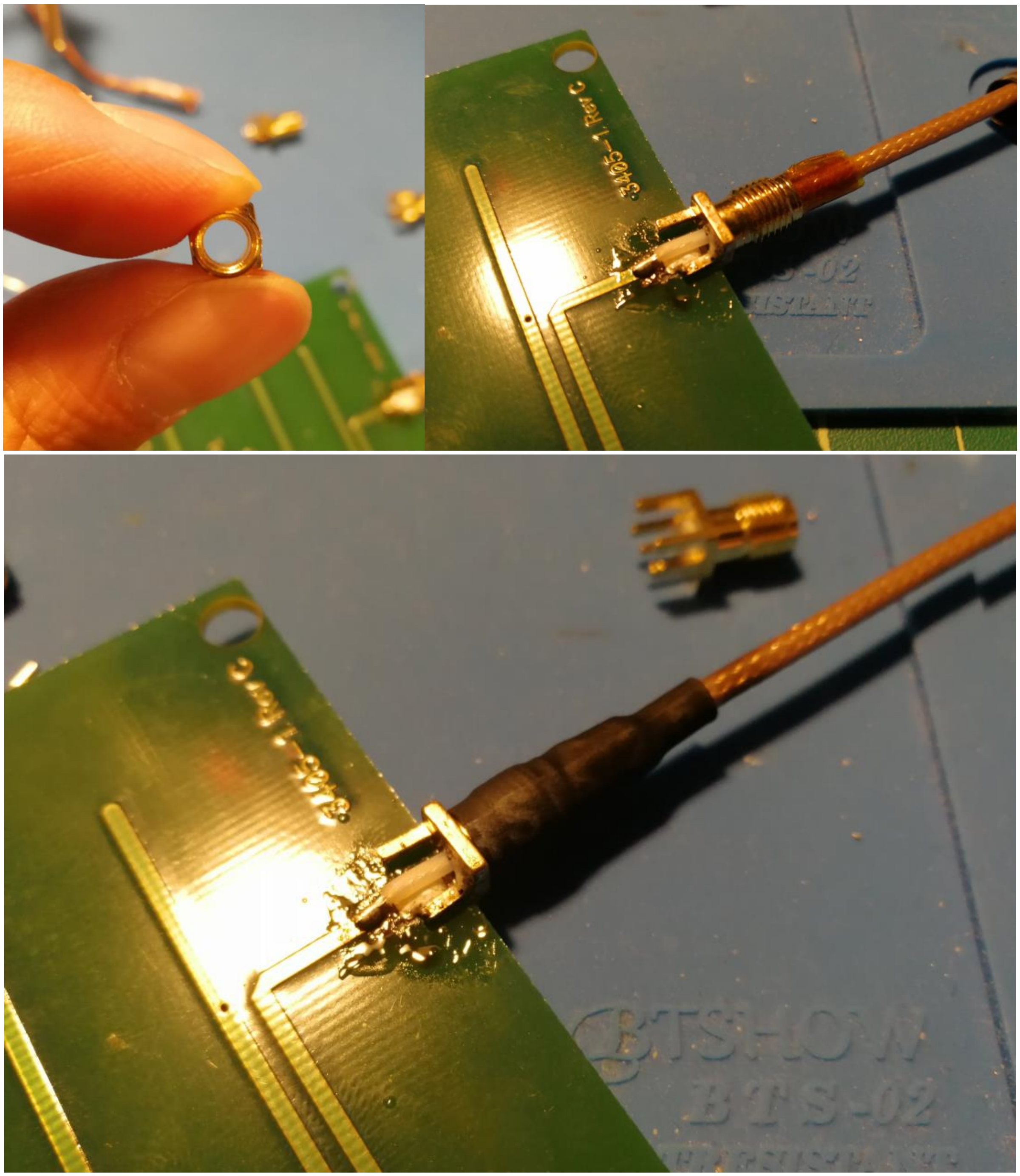


Fig 16: Alternative Connection of SMA Cable to Yagi Antenna