NORTHEASTERN UNIVERSITY
Department of Electrical & Computer Engineering

EECE 4574

LAB REPORT

Experiment title: MICROSTRIP LINE RESONATOR

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Lab

Introduction

In this lab, we worked on assembling, tuning, and testing of the MFJ-9340 kit. This project is an accumulation of all the knowledge over the course of EECE 4574 and applies working knowledge of many fundamentals and specifics to RF circuitry. The end goal of the project is to understand a practical application of RF circuitry and work through testing and troubleshooting problems with a strong background in understanding the circuit in order to apply it to a more general application. This goal is to understand the block diagram below and be able to troubleshoot based on knowing how the circuit is expected to work and the observed behavior.

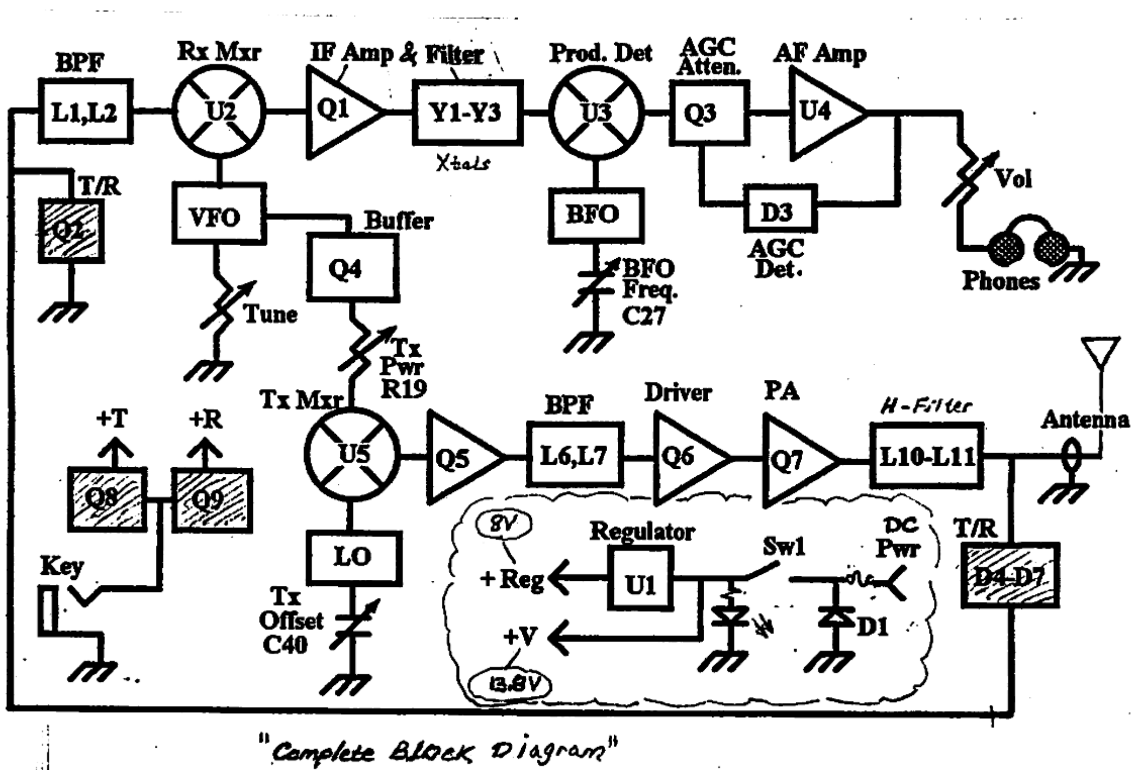


Figure-1: MFJ-9340 Block Diagram

To work through what we did this semester, we want to understand everything from receiving an antenna signal at 7MHz in Rx mode, passing it through a BPF to pass only the receiving frequency, going through the Rx Mixer with the VFO frequency at 5MHz, applifying with low noise amplification and filtering the mixer output to get rid of the image and negative of 2MHz and get the 12MHz IF frequency. Then passing the signal through another mixed with the BFO of 12MHz with C27 tuning to get a clean 600 Hz whistle, and finally passing it through the automatic gain control, and finally the audio frequency amplifier while getting rid of undesired frequencies and using feedback to the automatic gain control to control output volume to the speakers.

Then we also need working knowledge of the transmitting side. The Tx starts with pressing the keyer to trigger Q8 and Q9 to switch as electronically controlled switches. Then Rx input is cut off by the diodes D4-D7 and shorted by Q2 to gnd so that the 2 W output signal does not go into the receiver with voltages multiple magnitudes larger than usual. Then the switch also allows the driver and thus the power amplifier to start working to allow for no lost power when in Rx mode. In this mode, we have the VLO at 5MHz mixed with the local oscillator (LO) at 12MHz adjustable with C40 for fine tuning to get a very clean 7MHz signal. Then we applify this signal and put it through a BPF to get rid of the positive signal of 17MHz and put the 7MHz through the now activated driver and power amplifier. Since the PA produces harmonics for high efficiency working (due to Class-C filter) we then need to get rid of the harmonics with the harmonic filter L10-L11. Finally we have a clean output signal at 7MHz and 2 W or power that follows FCC regulations with harmonic strength 1000 times weaker than the RF signal.

With all of this we can successfully build, tune, test and troubleshoot the RF circuitry starting with the MFJ. This project requires us to go through first through hole soldering, alignment and tuning of Rx and Tx components, and then testing with another group and antennas to verify transmission and receiving capabilities.

This report will be covering the process, issues encountered and the results. The alignment and tuning section will go over the receiver section - BFO alignment to get 12 MHz + 600Hz, the VFO alignment to get a clean 5MHz, receiver BPF tuning for receiving 7MHz, and the final touches - and the transmission section - the carrier offset adjustments to get 7MHz output signal, the transmitter bandpass filter tuning to get maximum power output by ensuring that the filters peaks line up over the same resonant frequency so they are not on each other's skirts, and finally the power output adjustments to get max power while maintaining a clean signal without harmonics - and some issues encountered will be covered in the troubleshooting section. Then the testing section will cover the procedure for the testing and then the results found. Finally, this report will end with a conclusion summarizing the project and lessons.

Alignment & Tuning

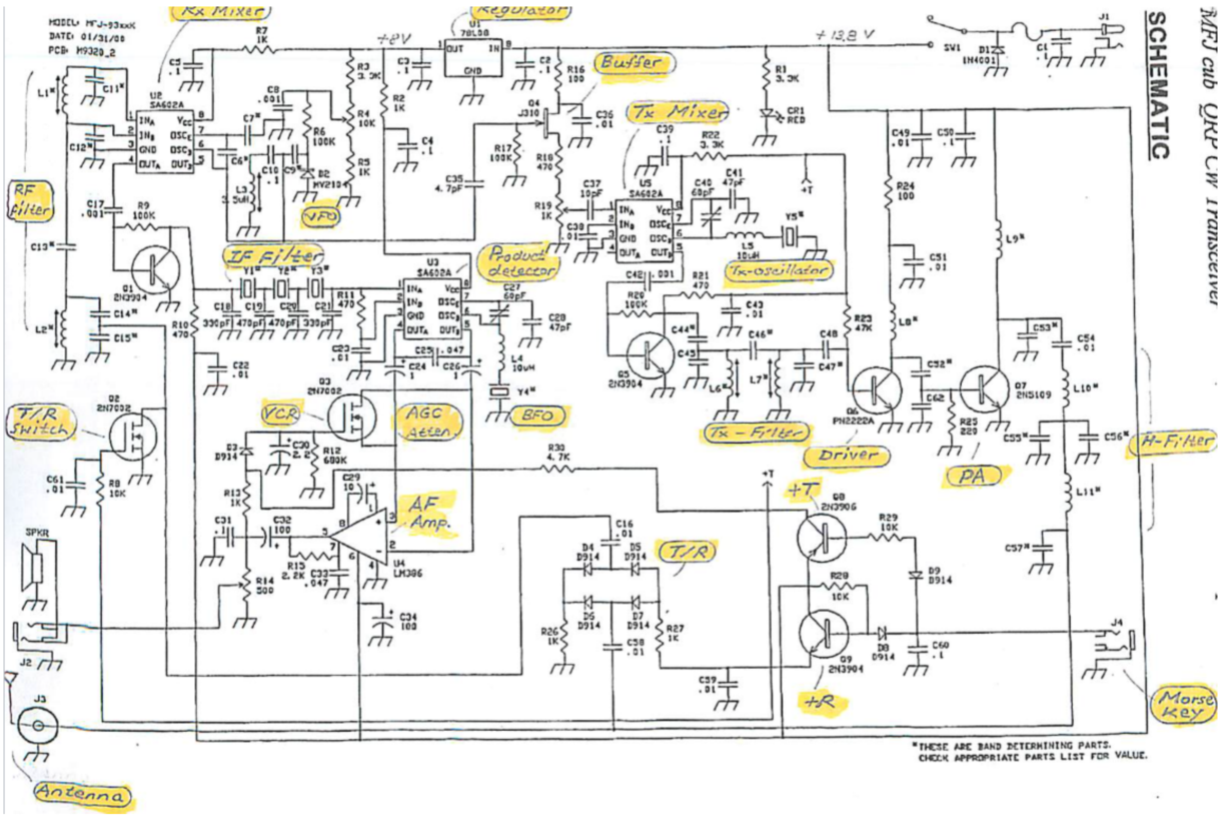


Figure-2: MFJ-9340 schematic

Before operations we went over the components on the PCB according to the schematic to make sure all parts were correctly placed. Inspected the bottom to check all soldering were smooth and shiny. The following tools and materials were used during the alignment and testing.

50 ohm dummy load:

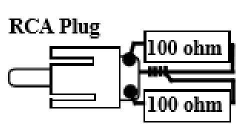


Figure-3: dummy load

Telegraph Key:

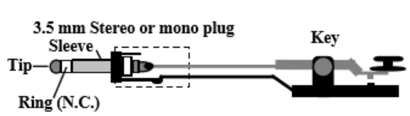


Figure-4: Telegraph key

We set up the cub on a non-metallic surface and powered up with a 13 volts DC input. By installing a dummy load at the cub's antenna jack, after pressing the sub's power switch on. We heard a clear "pop" sound in the test speaker and detected faint background noise.

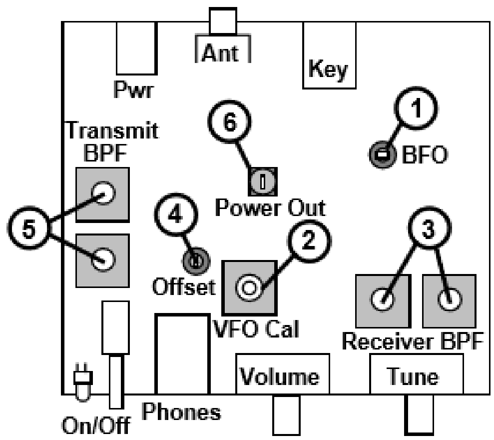


Figure-5: cub's six alignment points

Rx alignment:

In receive mode, Q8 is off which turns off the transmit power supply +T. 12v power goes in Q9 and turns it on, sends current through T/R switch(combination of 4 diodes), diodes are in low impedance and while during receive, Q2 is off then the signal goes in the RF filter(L/C band-pass filter). The mixer is part of SA502A which has the oscillator built in. The capacitance of D2 is proportional to its reverse bias, the other pot is connected to a resistor chain which allows us to adjust the frequency of the LO. 78L58, a voltage regulator which stabilizes the power supply into the Rx mixer circuit. The converted output IF goes through Q1(IF amplifier) and passes to IF filter. In the product filter, we have a 12MHz crystal and a trimmer which allows us to tune the 12MHz crystal frequency vs. IF filter so that we can get 600Hz beat notes from the output.

BFO alignment:
We aligned the BFO by using the broadband noise. Firstly, we powered on the board and adjusted the volume to maximum level monitoring the output with a speaker connected to the phone jack. Touched a test lead to R9 which serves as a noise antenna. Used a non-conductive alignment tool turned C27 through its range. The background noise changed audibly and made a swooshing sound until the noise was at its lowest pitch.

VFO alignment:
We used a receiver to align VFO. By adjusting L3, we listened for the cub;s VFO signal.First we connected a short pick-up lead to the SW receiver's antenna terminal and set the cub's tune

control fully counter- clockwise. Tuned the general-coverage receiver to the desired low-end VFO frequency which according to the given chart for MFJ-9340 should be in 4.940-5.000 MHz. Then we carefully adjusted L3 until we could hear the VFO signal. Then we rotated the tune control fully clockwise and tuned the general coverage receiver up in frequency to locate the VFO signal.

Receiver bandpass filter:
We adjusted L1/L2 using noise. First we terminated the antenna jack with a 50 ohm load and turned the volume to maximum. Touched a metal probe to the center pin of the antenna jack and used a tuning wand to tune L1/L2 until the noise was at the highest level.

Final Receiver alignment:
We applied a weak signal and monitored the cub's audio level using a phone app. Adjusted the rune dial from lower to a higher operating frequency across the signal. So the applied signal is weak on the low-frequency side and strong on the high side. The CW tone will go up in pitch on the strong side as operating frequency is increased. We observed that the test signal peaked at 600Hz which indicates that the C27 is well tuned.

PARTS	RESULT
L10 L11	0.8uH/1.09ohms 0.8uH/1.08ohms
C27(BFO)	After tune, clear “pop” heard from the test speaker
L3(VFO)	Test probe at R19, 5Mhz sine wave shown on oscilloscope
BPF	50 ohms dummy load connected and metal attached to antenna pin, noise at maximum level
Monitored output signal	Frequency: 620 Hz Amplitude: 850mV With 50mV input signal

Tx alignment:

In transmit mode, when the key is shut off which turns off Q9. So in the T/R circuit all four diodes are high impedance. The receiving signal will not go into the receiver. And Q2 is on which shorts the input to the ground. The same time Q8 is on and +T is on which turns on the Tx mixer. The output from the LO goes in a buffer and through the Tx mixer. The Tx oscillator is a 12Mhz crystal and the trimmer allows us to trim the Tx offset to match with the Rx offset. The output signal from the Tx mixer goes through a Tx buffer and filtered by the Tx filter. The final output signal is sent from H-filter to the antenna.

Carrier offset adjustment:

In order to adjust C40 offset somewhere near the 600Hz standard, we connected a keyer to the key jack and set volume about half open and pressed the key while tuning C40 for a 600Hz tone. We had a very hard time hearing the tone for this part.

Transmitter bandpass filter tune-up:
L6 and L7 should be adjusted for maximum RF power output. By depressing the key and observing power output indication. We adjusted L6 and L7 for maximum output.

Power output adjust:
We turned the output trimpot fully counter-clockwise and advanced R19 until output no longer rises sharply. Reduced R19 until output just begins to drop and stop at this point. After those steps we calculated RF output was 1.7743 watts into a 50 ohm load.

PARTS	RESULT
Load resistor	49.1 ohms
Voltage RMS	26.4V 26.4/2=13.2V
L6/L7	Max RF output power: 1.7743 watts
R19	No unwanted mixer spurs to the output signal

Testing

Procedure

The final step of verifying that the radio works as well as the application of all the work done thus far is the field test. The test involves the verification of receiving and transmitting a morse code signal over a hand strung antenna wire to another group in the opposite configuration (one in receiving mode while the other in transmission mode and vice versa). Our group did our test on Tuesday November 24th, working alongside the other group of:

Priscilla Lin and Daniel Vargas

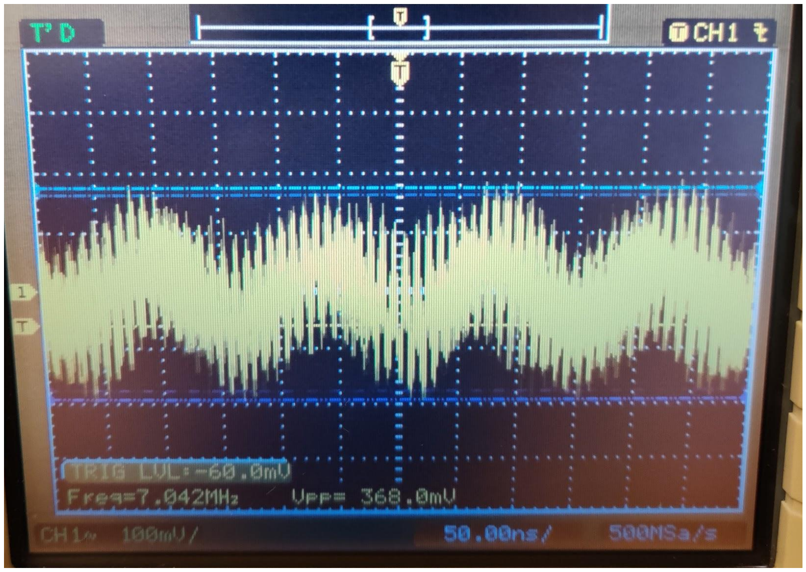
The basic steps of the test involved stringing the antenna wire across the room, attaching the antenna to the antenna input of the radio and then testing the circuit in transmit and receive modes. Our group started with receiving the signal transmitted by Priscilla and Daniel. Since the radio was already tuned to filter the received signal to a pleasant 600Hz whistle, the last step was to tune to the transmitting frequency. This is necessary since although the other team tuned their radio to 7MHz, a small shift of a few kHz could cause the signal to be missed entirely, but at the same time, since the signals are both close on the larger scale, we can use R4, the tuning POT to tune into the transmitting frequency. After tuning into the frequency we could hear a clear whistle coming from their transmission, but we adjusted for a stronger signal by adjusting the BFO filter since it was slightly off and this achieved a very audible signal.

The next step of the test was the transmission. In order to transmit properly, one needs to make sure they are transmitting on the correct frequency, at the proper/ max power output, and transmitting only the 7MHz signal with harmonics 1000 times weaker. We did not directly monitor the last result but watching the waveform of the output RF signal, it can be seen that the 7MHz signal is by far the dominant frequency. Our group verified the output waveform at 7MHz and over 1.5 W of power to show a very strong signal at the correct frequency. The other group had some issues tuning to our frequency so we also tried to tune to theirs and eventually the signal they found our signal but it was very weak due to detuned receiving on their side. To aid the process, our group continued to transmit the Morse signal by pressing the clicker on and off to differentiate from noise. After re-tuning, the other team verified our transmitting of our radio.

Results

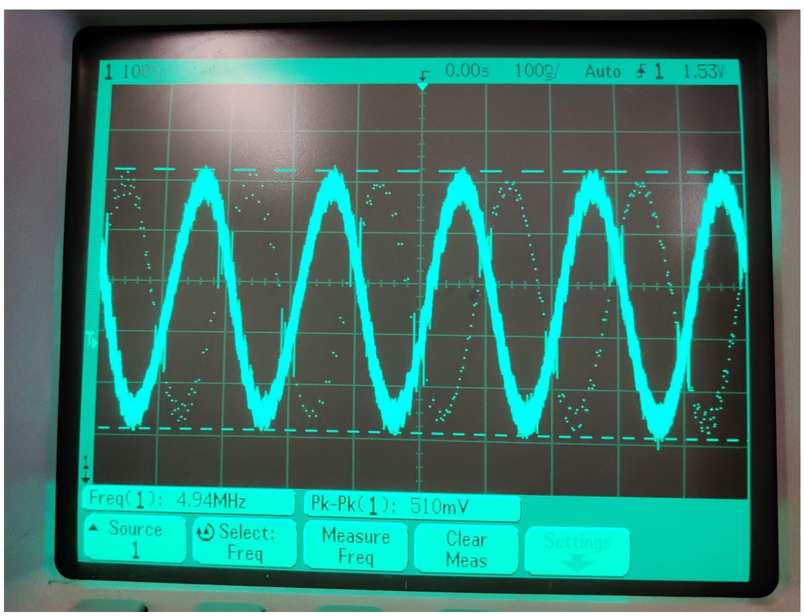
The results of the test are as follows

RX



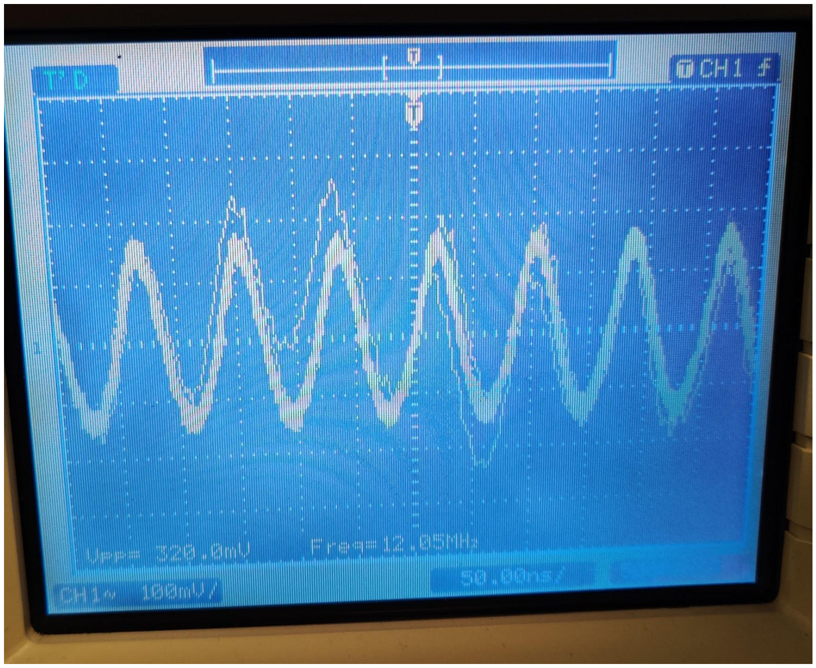
RF Input Signal after Coupling

The RF input shows a noisy signal at the antenna connection since the RF signal is often very weak and mixed with all frequencies of noise and interference, but proper filtering and amplification makes it so the desired signal at 7MHz is heard.



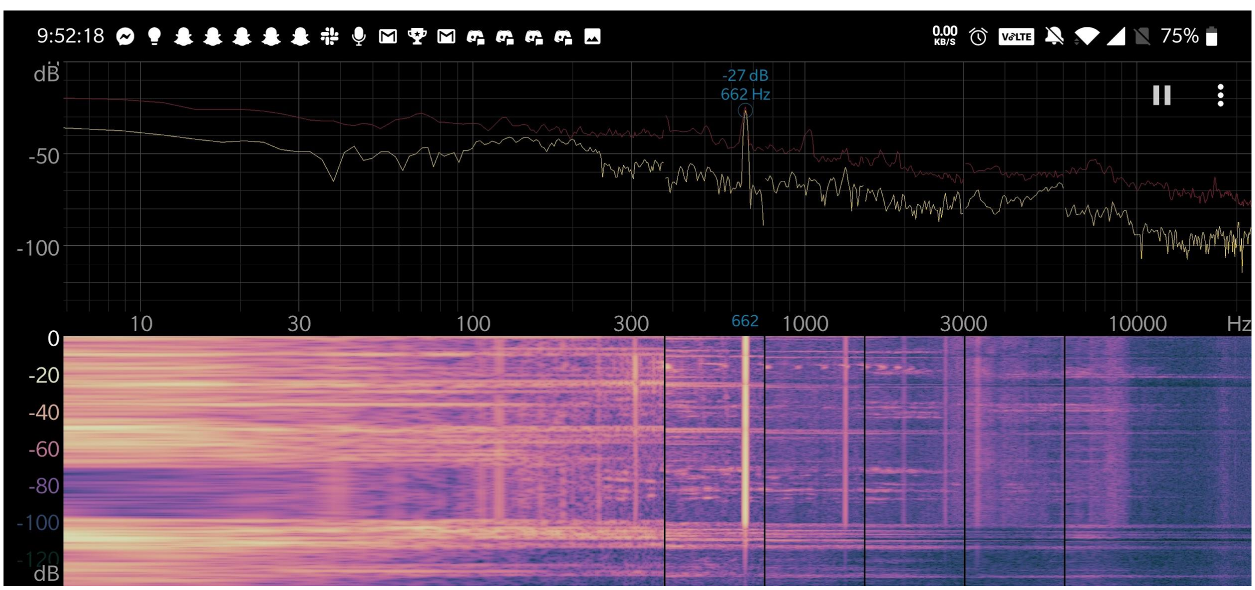
VFO Signal Measured at 4.94 MHz and 510mV P-P

The VFO signal shows the desired waveform at about 5MHz and a strong 510mV P-P, much larger than that of the noise on the signal. This ensures that the variable frequency oscillator is at a proper frequency (5MHz) to create an IF frequency at 12MHz.

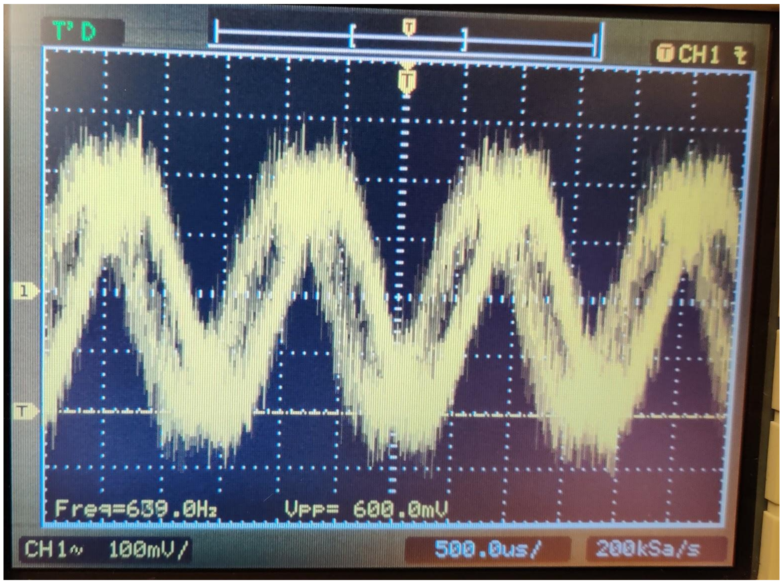


BFO Signal Measuring 320mV P-P at 12.05 MHz

The BFO signal shows the desired waveform at very close to 12MHz, and 320 mV peak to peak. The signal has some noise but can easily be distinguished from the noise. This BFO of 12MHz, and a small offset by 600Hz allows the received signal to be heard as a pleasant 600Hz whistle.



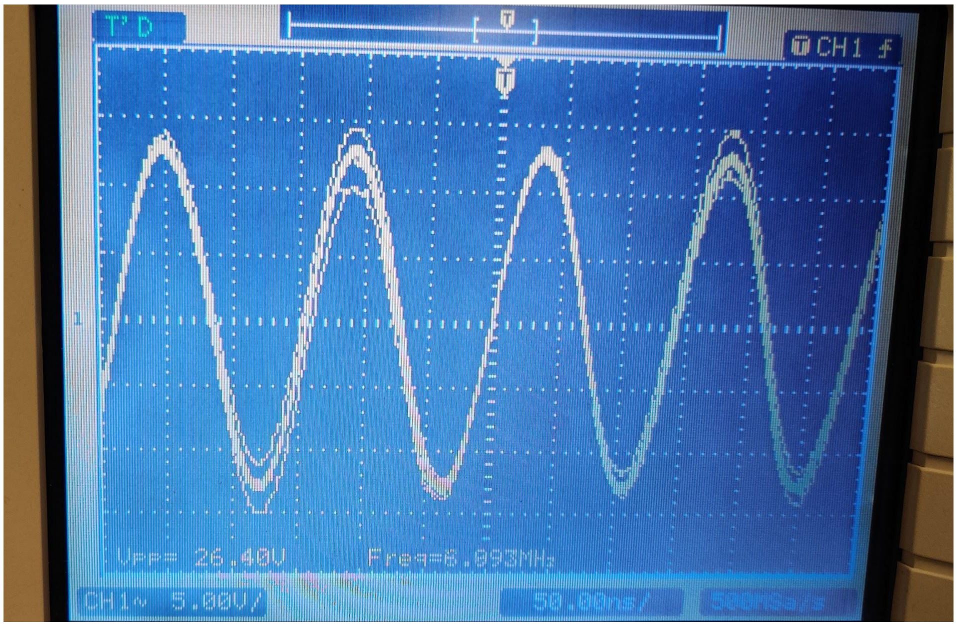
RX Signal Audio Received at 662 Hz and Shown on Spectrum



RX Signal on Oscilloscope Probing R14 Volume Control at Output Audio

The two Rx signal outputs show the received signal at the audio output. The first one on the audio spectrum analyzer shows the near 600 Hz audible tone at the output of the speaker. The second image of the oscilloscope probing the volume control resistor just before the output audio connector. This signal shows the 600Hz signal (due to the oscilloscope having difficulties triggering, 2 waves are seen) and a strong output voltage.

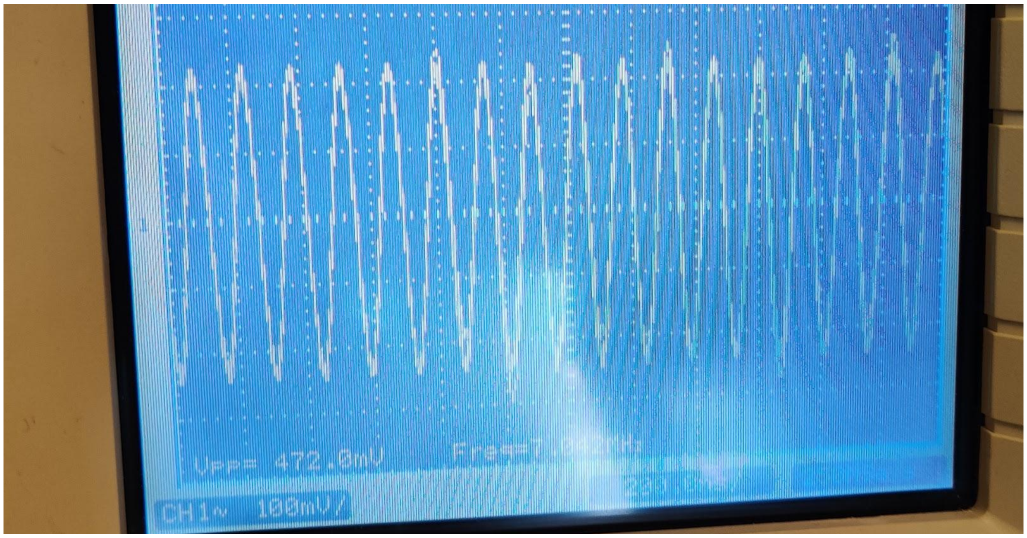
TX



7MHz TX Output Signal Across 50-Ohm Load

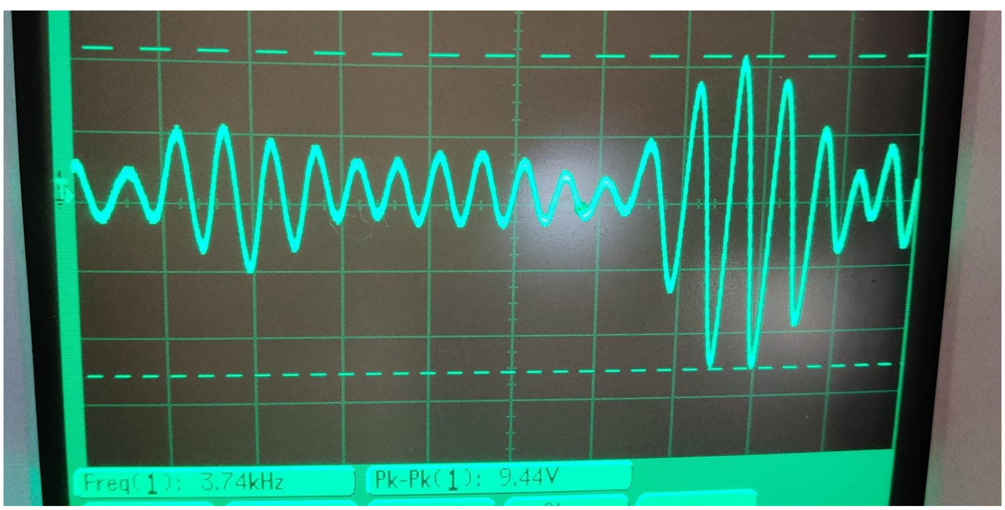
As seen above, the 7MHz TX output shows a 26.40V peak to peak value over a measured 49.1 Ohm load at 6.993MHz. This indicates excellent performance of the transmitter as the signal is transmitting close to the full 2W of power to the load at the correct frequency:
Load - 49.1 Ohm
V = 26.4 V
Voltage RMS - 26.4/2 = **13.2 V**
Power - ½ Vrms^2 / R = 1.7743 W

The total power output is 1.77 W which indicates a very well tuned transmitter band pass filter lining up with the peak of the additional filters to produce maximum output power. This strong signal is also indicated in the following image:



Picture Captured of Open Circuit Oscilloscopes in Lab Space during Transmitting 7MHz Signal

When conducting testing, due to the properties of open wires and wires acting as antennas, the oscilloscopes in the lab space during the transmission test were observed to pick up the transmitted 7MHz signal very clearly. When the key was pressed they would show a clear 7MHz signal at almost 500 mV peak to peak.



Picture of Received Signal of Partner's - Note: Signal Contains Harmonics

Finally, after conducting our transmission test, our partners received our signal but at the audio output got harmonics of the 600Hz signal due to issues with their receiver functionality.

Troubleshooting

Frequency drift:

Things went a bit tough at the alignment steps due to inexperience. The completed rig worked as we expected but the VFO drift was the only problem that we couldn't get rid of. After some research online, one of the solutions is to replace the VFO capacitors C6 and C9 with NP0 type disk ceramics, and that may tame down the drift. This issue might be caused by the component not fully "warmed up", a bunch of people experienced the same problem and their solution is to let the cub run for about 30mins and the drift is reduced dramatically, because this issue does not affect our test that much so we didn't approach this part.

Measuring beat frequency(R14):

When measuring the beat frequency while probing R14, we could not get a clear output. There was always a bunch of interrupting noise or the oscilloscope could not detect the edge of the waveform. We were able to see the waveform by eyes and calculated the frequency by time division and measure the peak to peak. In order to solve this problem we may have to run over the alignment steps and re-tune the cub.

Not setting current limit while testing Tx:

Right after we finished the Rx testing part, we connected a keyer and after press, the circuit did not react as we expected. We initially thought the circuit was shorted and could be a problem while soldering but then we figured out that Tx needs more power than Rx mode and the power supply didn't provide enough power to turn on Tx.

Missing tone for Tx receiving:

We assume this was caused by untuned C40. We might need to take a look at others' work to check the correct behavior and re-tune the capacitor more precisely.

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Conclusions

The MFJ construction project was a fantastic experience as it was enjoyable building the MFJ 9340 kit and operating it. It's a good compromise rig according to its cost. The cub is sensitive and portable as its size is small and only requires 13 volts to power it up, so users may use a battery pack and not worry about the cub draining too fast. With this the cub is able to achieve a 7MHz morse code signal and filter it to a pleasant 600Hz tone at the audio output, and transmit a near 2W signal on top of the 7MHz carrier frequency.

Overall the project was very successful, we were able to tune the receiving circuitry for clean reception of a signal and transmit morse code at 7MHz at 1.77 W. However, during the process it was discovered that the radio tuning is highly selective. Not only can the signal easily be missed when tuning the radio but noise can easily affect the system when the radio is not correctly tuned. This sensitivity played a large part in the lab as we needed to be precise with tuning frequencies. When communicating with the other group even though both groups tuned to 7MHz, we still needed to use fine tuning of R4 to communicate. For transmitting to achieve high power output the harmonic filter and BPF need to be on the same frequency to achieve maximum gain. However, in order to avoid harmonic distortion, the gain can not be turned too high.

For the receiving side of things, sensitivity plays a large part in getting a clean signal. There is the BPF, VFO, and BFO that need to be correctly tuned and the IF filter as well that needs to align with the other filters. Since the receiver picks up all frequencies and the received signal can be in the uV, the circuit needs to be highly selective and not applify any noise. If the circuit is slightly off frequency, the received signal will not be amplified and as a result this project required us to tune the receiver with precision. There were multiple times where we could not see the output signal due to noise and as a result we needed to tune the receiver multiple times.

Throughout this project we learned many lessons about RF circuitry that we can apply to radio applications. We learned the importance of sensitivity of a radio, and how easily noise interference and incorrect tuning can ruin communication.