Implementing an 18 MHz Radio Transmitter

Bruno E. Gracia Villalobos

Honors EE 4113

Professor Hansen

University of Texas at San Antonio

May 12, 2019

Abstract

To fulfill the requirement of an “Honors contract” for a Highest Honors distinction, this paper was written to explore the implementation of an 18 MHz radio transmitter using “dead-bug” construction techniques—a rapid prototyping approach for high speed circuits on a copper ground plane to reduce parasitics; this circuit has short lead-to-lead signal paths, components’ proximity to the ground plane, and RC filtered DC power rails. Apart from the dead-bug style, the transmitter consists of 3 sub-circuits, all powered by a 9V battery: a crystal-based Colpitts oscillator, a Class A RF amplifier, and a Class C RF amplifier with an AM modulator. The purpose of this transmitter is to inject a signal in the circuit to AM modulate the 18 MHz carrier generated by the transmitter. The transmitter then outputs the signal to an antenna through a BNC cable that broadcasts the AM modulated signal to a *Grundig YB-400* hand-held short-wave radio. The circuit transmitted “A Horse With No Name” by America modulated with the carrier 60 yards away in a closed environment. A modification to enable the circuit to broadcast the signal at a higher power successfully modulated a 440 Hz square wave with the carrier as far as 80.3 yards in the underground service tunnel at the University of Texas at San Antonio (UTSA).

1.0 Prototyping

1.1 The Colpitts Oscillator

The first sub-circuit of the amplifier consists of the Colpitts Oscillator. The main function of this circuit is to generate a sinusoidal like waveform to oscillate at 18 MHz with a peak-to-peak voltage of around 1V. It is built with an 18.0ECSR crystal oscillating at 18 MHz, a KSC1674 NPN BJT, ceramic capacitors, and resistors. The output of the circuit can be attenuated or gained using a 1k ohm potentiometer. Figure 1 displays the Colpitts Oscillator in schematic form.

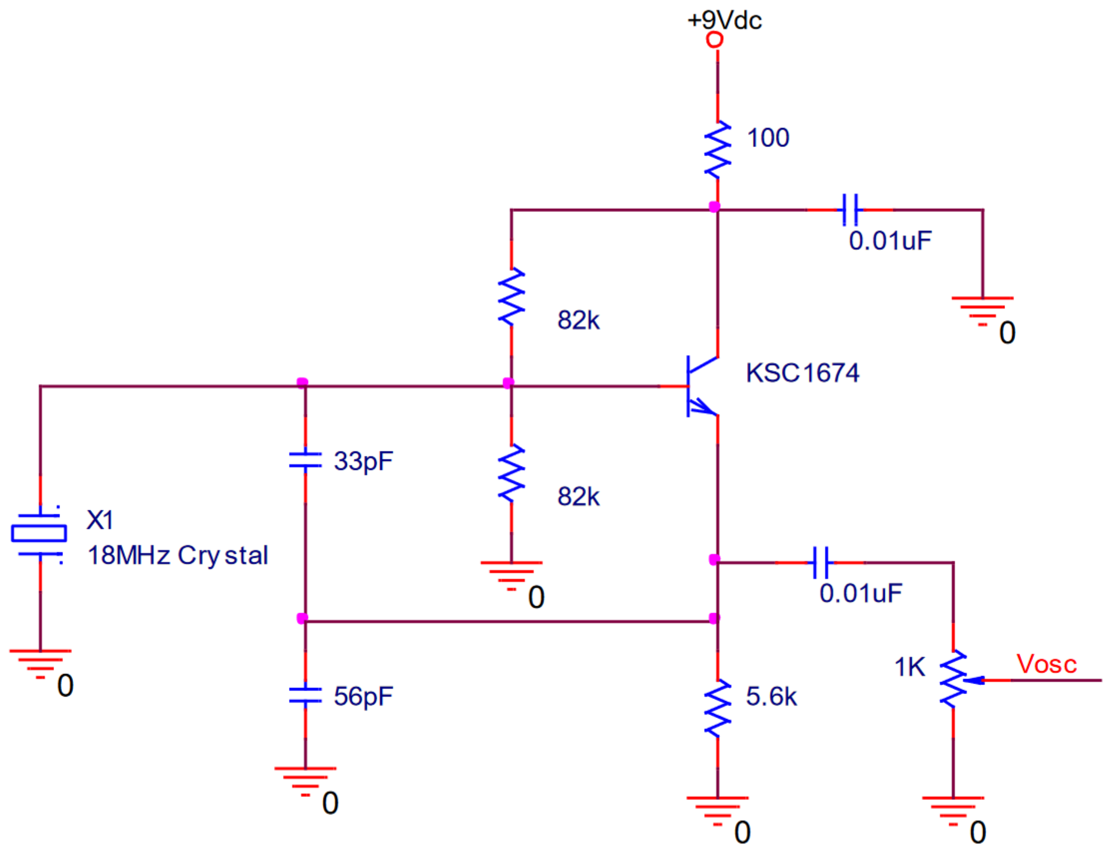

Figure 1: Colpitts Oscillator

The 9V DC rail shown in Figure 1 has an RC lowpass filter to remove high frequency noise from entering as well as high frequencies from leaving the circuit with a cutoff frequency of

$$1/(2\pi*100*0.01u) = \sim 159 \text{ kHz.}$$

With an 18MHz output, this effectively filters any interfering frequencies above 159 kHz.

The prototyping of the Colpitts oscillator follows next. The circuit was built logically from left to right as the schematic shows the signal path from the oscillator to the 1k potentiometer at the BJT's emitter. Figure 2 displays this subsection of the circuit on the copper ground plane dead-bug style.

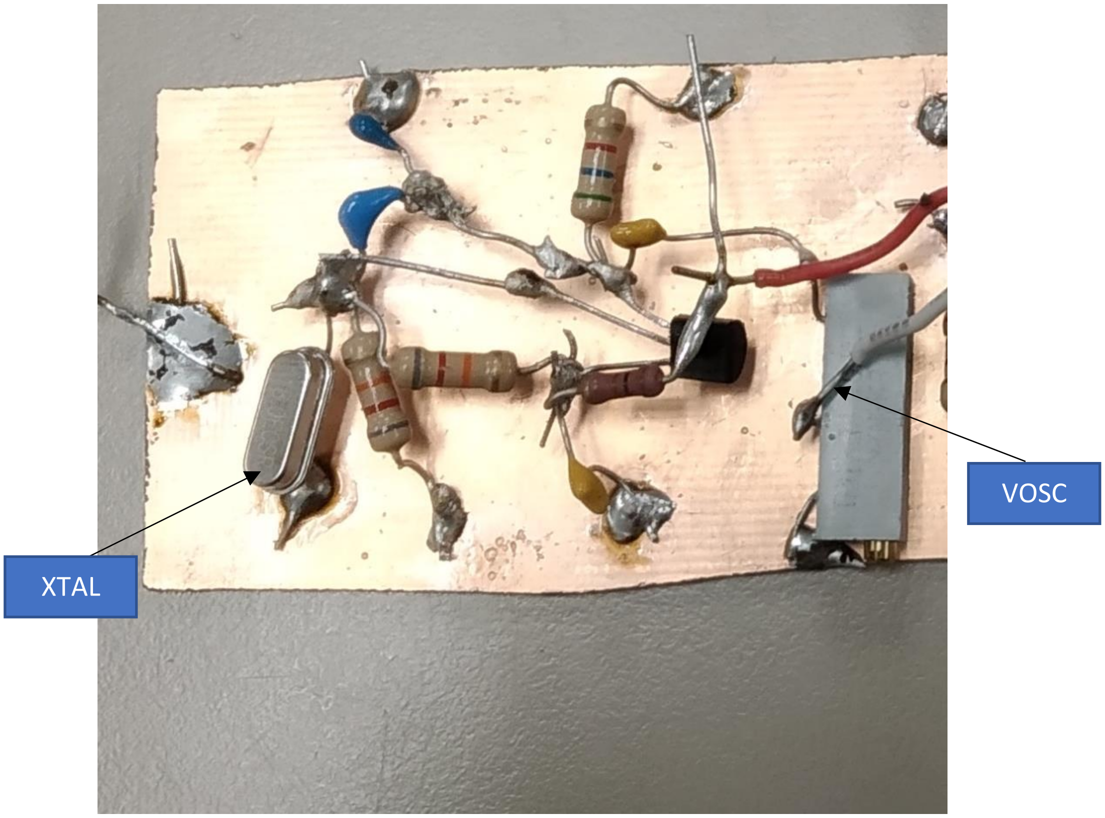

Figure 2: Dead-bug construction of the Colpitts Oscillator on a copper ground plane

1.2 Class A RF Amplifier

Once the Colpitts Oscillator successfully output a sinusoidal like waveform at around 1V, the Class A RF Amplifier was constructed next. This circuit essentially acts as a bandpass, high-Q amplifier that keeps the output from the Colpitts Oscillator within the ballpark of 18 MHz. As a result, the sinusoidal waveform at the Vtest node shown in Figure 3 will look more like a sine wave since the noisy, extra harmonics generated by the Colpitts oscillator will be removed. Above all, this circuit is the continuation from Figure 2; The output of the Colpitts Oscillator is the input signal for the Class A RF Amplifier.

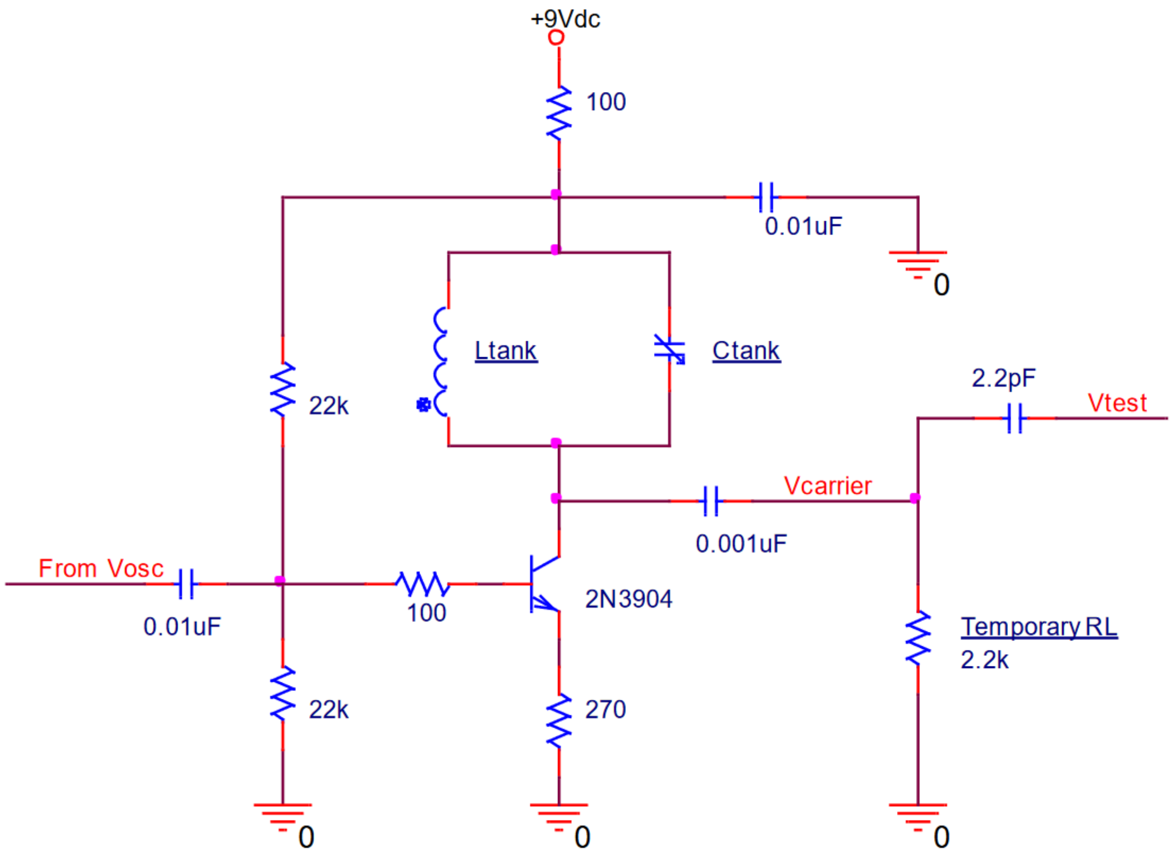

Figure 3: Class A RF Amplifier

For the Ltank and Ctank values, a variable capacitor and an inductor value was chosen to keep a Q of approximately 9. These values were calculated to be 36.2 pF and 2.16 uH respectively and rounded to the nearest E12 value. With a Q of 9, the bandwidth of this circuit is B = fo/Q = 18MHz / 9 = 2 MHz. The variable capacitor was chosen to selectively alter the value of the resonant frequency of the tank circuit so that the output of the amplifier at the 2.2k ohm load will stay on average at 18MHz. At the same time, the amplifier also has an RC filter to remove high frequency noise on the 9V rail just like the Colpitts Oscillator.

In Figure 4, the Class A RF Amp is seen right next to the Colpitts Oscillator prototyped dead-bug style. After testing the output of the Class A RF Amp alone, its input was connected to the output of the Colpitts Oscillator. *Vtest* is shown at the top of the 2.2k ohm load and *Vosc* is the incoming signal from the Colpitts Oscillator potentiometer output at the 0.01uF ceramic capacitor.

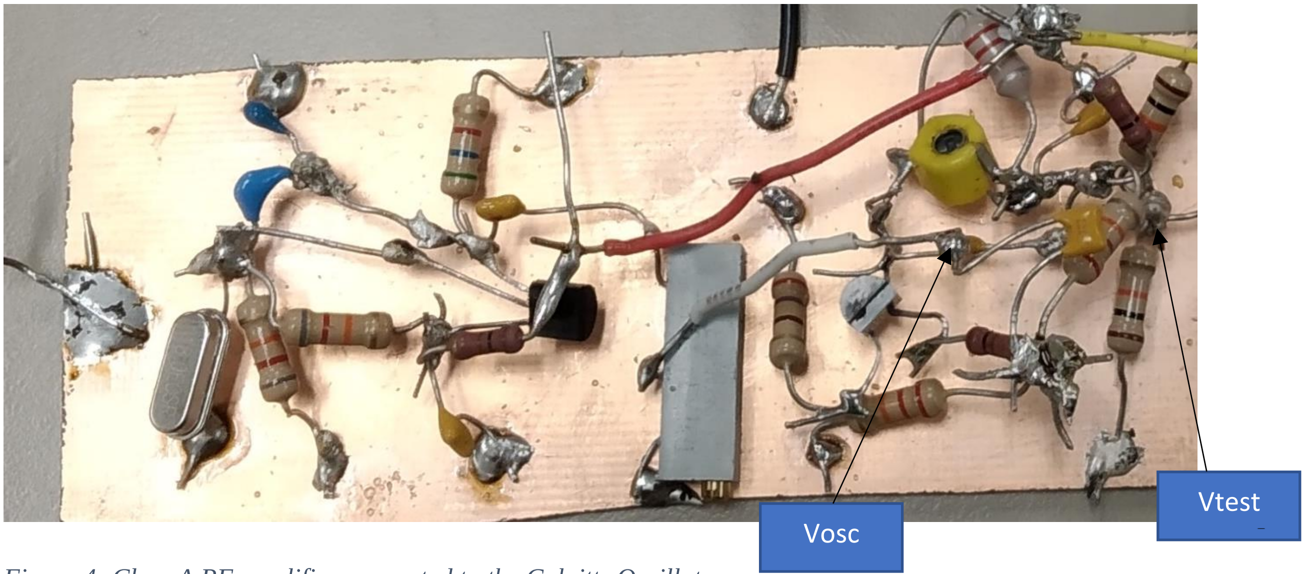

Figure 4: Class A RF amplifier connected to the Colpitts Oscillator

To reiterate on the dead-bug construction method, the proximity of components maintains signal integrity by lowering parasitics for the high frequency 18MHz sinusoidal waveform. In addition, the low altitude of the components with respect to the ground plane also allows return currents to be close to the signal lines, which further adds to the signal integrity of the circuit. It is important to mention the 0.001uF capacitor connected from the BJT collector to the 2.2k load is there to prevent the modulator from the Class C Amplifier to “seep” back into this circuit due to the large reactance seen by the audio frequency of the modulator.

1.3 Class C RF Amplifier with AM Modulator

At this stage, the output from both the Colpitts Oscillator and the Class A RF amp generates a stable and filtered sinusoidal carrier signal for the transmitter running at 18 MHz. However, there has not been a place to inject the modulator signal to modulate with the carrier so far. The purpose of the Class C RF Amplifier is to combine both the carrier and the modulator for transmitting the signal with enough power to the antenna to broadcast to a short-wave radio. For this, the amplifier must be efficient and have a bandpass response for keeping the transmission within band. The Class C RF Amplifier is the perfect choice for the above point, and as such, transmits both carrier and modulated signal with a bandpass response and with a power efficiency of at least 80%. Figure 5 demonstrates the schematic for the amplifier.

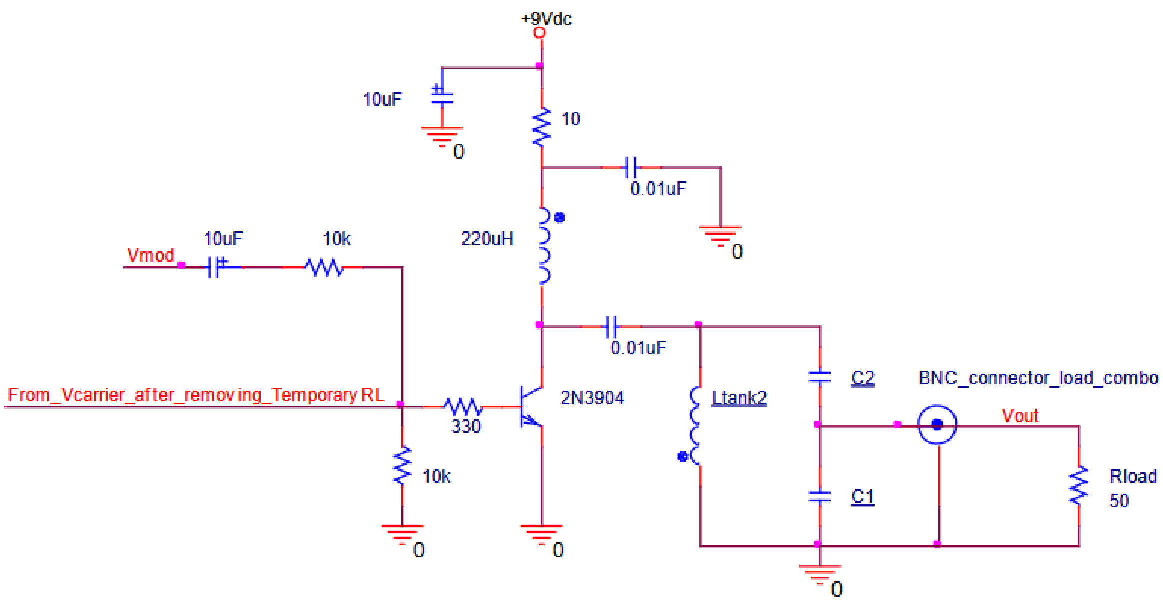

Figure 5: Class C RF Amplifier with AM Modulation Input Vmod

When first prototyping this circuit, values for *Ltank2*, *C1*, and *C2* were calculated for a Q of 5. Rounding off for E12 values, *Ltank2* was chosen as 1.8uH, *C1* as 180pF, and *C2* as 56pF. The values of *C1* and *C2* effectively create a capacitive divider for the *Ltank2* to see an output impedance of 1000 ohms; this is important because it helps the power efficiency of the amplifier. With the Q of 5, the circuit boasted a bandwidth of B = fo / Q = 18 MHz / 5 = 3.6 MHz. Compared to the Class A RF Amplifier, the bandwidth of this amplifier is 1.8 times as wider.

As the final configuration for the 18 MHz radio transmitter, Figure 6 showcases the construction of the Class C RF Amplifier with the AM Modulation input connected to the output of the Class A RF Amplifier. The two extra red and black wires were originally connected to the circuit for use with a DC power supply, but the circuit was modified to be portable for testing outdoors. The BNC connector transmits the signal to a custom dipole antenna made by Professor Hansen.

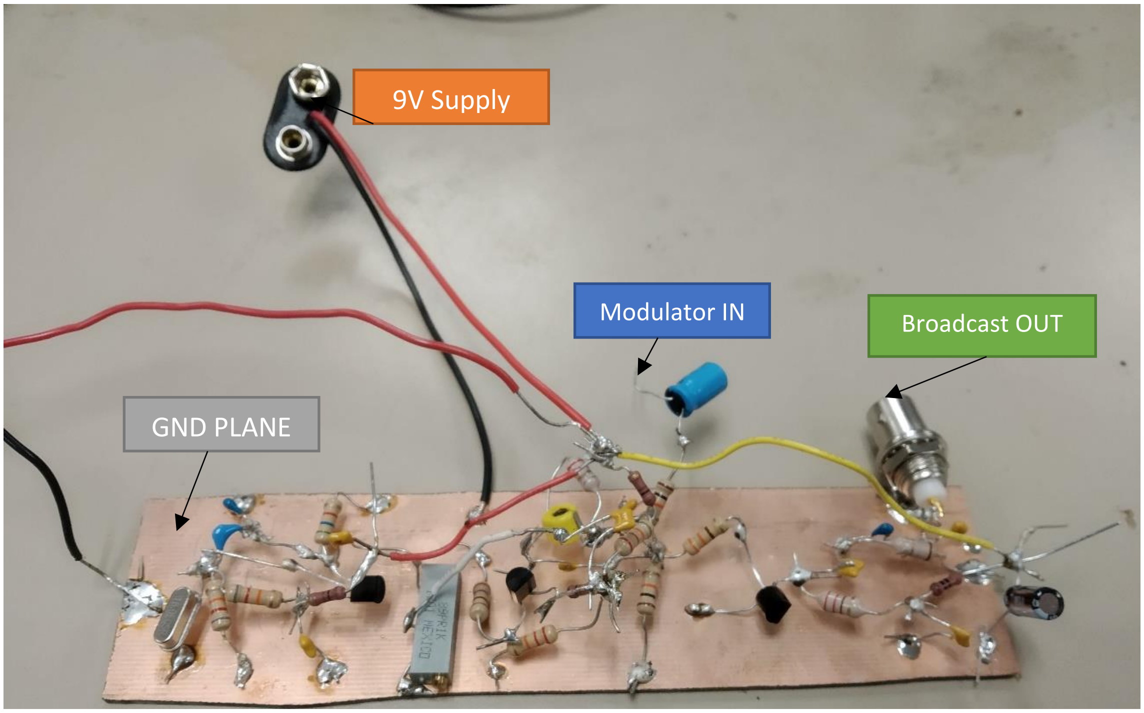

Figure 6: The complete 18 MHz Radio transmitter with the Colpitts Oscillator, Class A Amplifier, and Class C Amplifier connected in succession

1.4 Testing the Transmitter

With the transmitter built, the next step was to test the unmodulated output for measuring the power output. Since the oscilloscope has a 50-ohm output, a 50-ohm BNC terminator stub was embedded first to the broadcast OUT to impedance match with the scope as shown in Figure 7. For the author's learning purposes, a technique involving two 100-ohm resistors soldered in parallel affixed to the BNC connector was also tested shown in Figure 8. Yet, the latter method was preferred due to poor mechanical integrity of the parallel combination's lead.

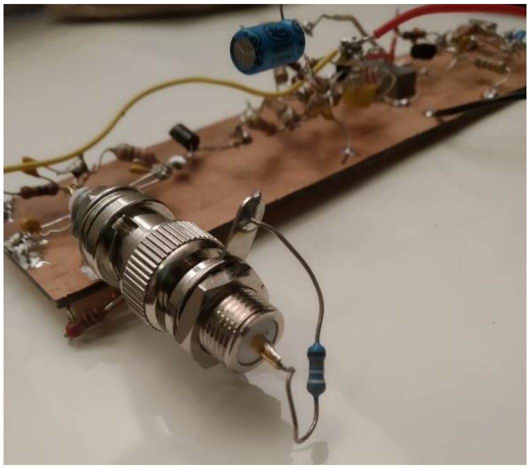

Figure 7: 50 ohm terminating BNC Output

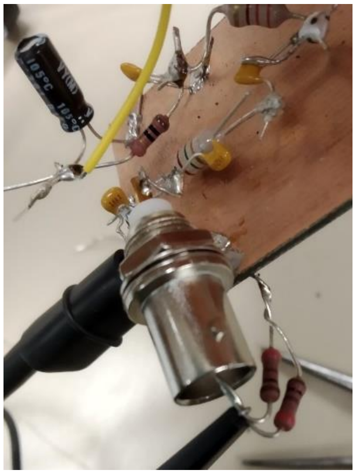

Figure 8: Two 100 ohm in parallel BNC

For testing the signal, the x10 scope probe was frequency compensated using the oscilloscope. Next, the probe was set to the terminator 50-ohm resistor on the BNC connector, and the ground clip affixed to the ground plane of the copper board. With 9V power in the circuit, the unmodulated output as shown in the oscilloscope is demonstrated in Figure 9.

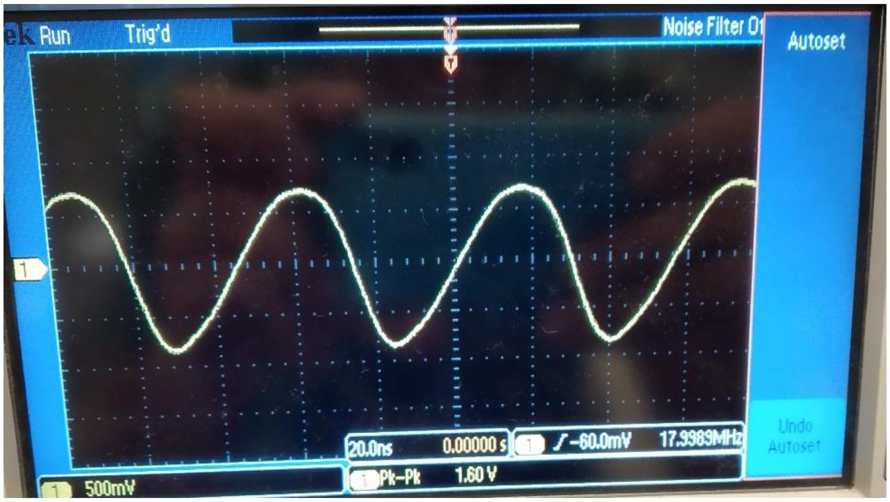

Figure 9: Unmodulated output shows 1.60Vpp

With this output, the average transmitted power is

$$P_{avg} = V_p^2 / 2 \cdot R_{load} = (1.60/2)^2 / 2 \cdot 50 = 6.40\ \text{mW}.$$

Now, with the circuit working up to specification, the next step was to test the farthest distance a short-wave radio could detect the signal. In Section 2.0, the outdoors test is conducted.

2.0 Broadcasting “America - A Horse With No Name” 60 Yards Away

To test the 18 MHz transmitter, the circuit and the custom dipole antenna were tested outside at the service tunnel of the University of Texas at San Antonio as shown in Figure 10. For the receiver device, a *Grundig YB-400* short-wave radio was used by Professor Hansen to measure both the signal strength and audible modulator as distance from the antenna increased; the *Grundig* is displayed in Figure 11. The modulator was “America – A Horse with No Name.”

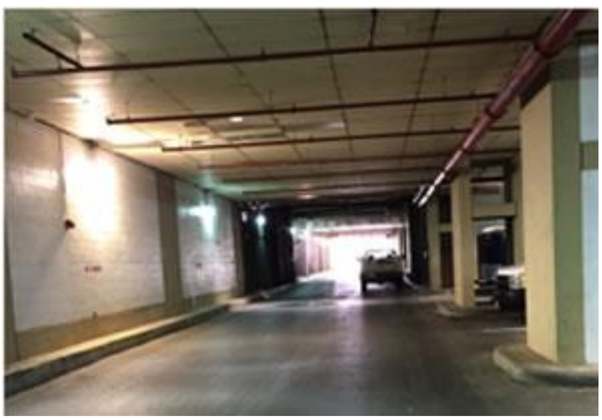

Figure 10: The test environment: a service tunnel at UTSA (source)

Figure 11: The receiver: A Grundig YB-400

To begin the test, the antenna was placed on the floor. The 18 MHz transmitter was then connected to the antenna through the BNC port, and a *Xiaomi Mi A2 lite* smartphone was used to output the modulator through the embedded 3.5mm jack; The signal was fed into the 10uF capacitor input of the Class A RF amplifier using a custom 3.5mm to probe connector. Once the test equipment was ready, the 9V battery powered up the circuit and Professor Hansen started to walk away from the antenna in a straight line with the *Grundig* listening to the 18 MHz band.

An audio clip was recorded as Professor Hansen analyzed the signal strength on the *Grundig* with increasing walking distance from the antenna. From this test run, the signal reached 60 yards from the antenna in the service tunnel environment until reaching a signal strength of 0. Figure 12 compares the signal strength to the direct distance from the antenna.

Distance from Antenna in yd	**Landmark**	**Signal Strength**
3.3		5
~5	White pipes out of Engineering Building	4
~10	1.00.27 Doorway	3
~25	Danger no parking sign	3
~35	Loading bay	Fading to 2
~55	Sideview mirrors on the wall	Static at 1
~60	T-4P Door	0

Figure 12: Distance vs. Signal strength measured by the Grundig

Given the source tunnel serves as a reflection heavy test environment, the results do not showcase the true broadcast potential of the transmitter. Nevertheless, for an average power of 6.40 mW for the unmodulated carrier signal, the broadcasting strength of the 18 MHz transmitter is truly remarkable for broadcasting at receivable signal at 60 yards away. In section 3.0, the Class A amplifier circuit is modified to increase the broadcast signal strength of the transmitter.

3.0 Modifying the Q for Higher Power

In this section, the Class A amplifier is modified with a lower Q, and with a lower matched impedance to increase the average power output, and in turn, a signal strength capable of reaching a farther distance from the antenna. To accomplish this measure, a Q of 3 and a matched impedance of 500 to the *Ltank2* were selected. The calculated values are shown in schematic form in Figure 13.

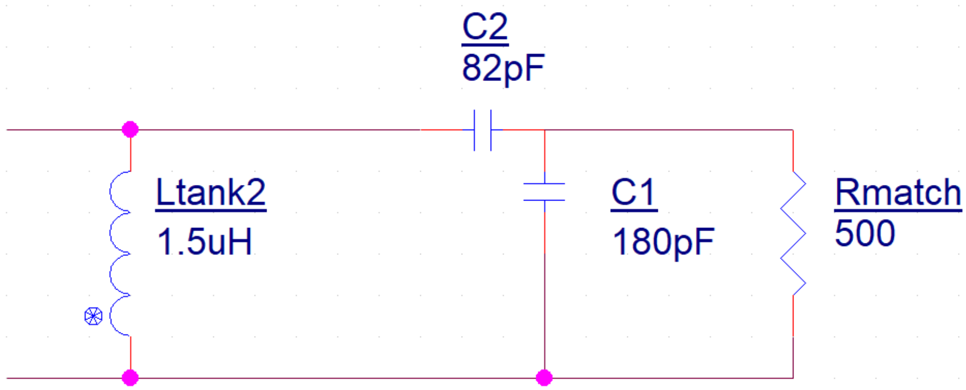

Figure 13: Replacement values for a higher power output in the Class A RF amplifier

With the new configured values, the previous *Ltank* and *C1*,*C2* values were unsoldered from the circuit and replaced with the ones in Figure 13. Using the same test technique as defined in 1.4, the modified circuit was powered to calculate the average power consumption at the BNC output. The following oscilloscope screenshot demonstrates the new unmodulated output of the transmitter (the carrier signal) in Figure 14.

Figure 14: Carrier signal (unmodulated) from modified circuit

.With a 0.3V increase in amplitude, the average power consumption of the modified circuit at the BNC output is:

Pavg = (Vpp/2)^2 / 2*50 = (2.20/2)^2 / 2*50 = 12.1 mW

Compared to the average power of the original transmitter configuration, the modified Class A amplifier can output

% increase = 100* 12.1 mW / 6.4 mW = 189% increase in power!

Before proceeding to test the transmitter outside again, the carrier and modulator signal were tested in an oscilloscope as shown in Figure 15. For testing the modified circuit, a 440 Hz square wave tone was chosen as the modulator due to its easily perceivable tone. The next section elaborates on the test procedure for this modified circuit.

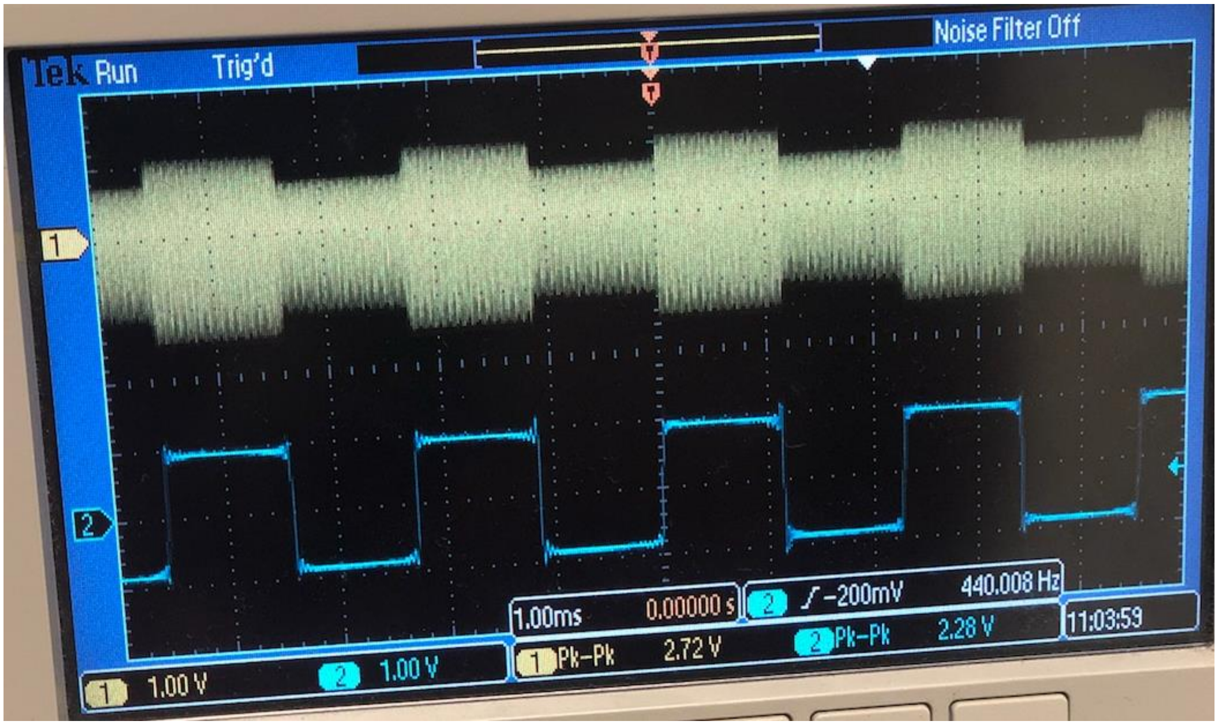

Figure 15: Channel 2 (blue): Carrier output from smartphone. Channel 1 (yellow) AM modulated carrier

4.0 Broadcasting A 440 Square Wave Tone 80 Yards Away

The new circuit was broadcasted in the same service tunnel as specified in section 2.0. In addition, the same testing procedure was followed. However as mentioned in section 3.0, a 440 Hz square wave was used as the modulator rather than a song. Figure 16 displays the transcript of the walkthrough of the test performed by Professor Hansen in a distance vs. signal strength table.

Distance from Antenna in yd	**Landmark**	**Signal Strength**
3.3		5
~5	White pipe	4
~10-15	1.00.264 Door	4
~25	Danger no parking sign	3 and ½
35	Loading dock	3, flicker to 4
~40-50	Street	3 or 2 then jump to 3
55	T-4s	Flicker at 2
60	T-4p	Flicker at 1
70	No parking sign	0 but tone still audible
80.3	10 ft past 1.00.14	Lost tone

Figure 16: Distance vs signal strength read from the Grundig

The new design effectively increased the transmitter broadcast distance 20.3 yards. Compared to the old design, the only quantities that changed were the Q components Ltank2 and C1, and C2. Apart from these changes, no other components were modified and the same test equipment was used. As a result, the modified circuit seems to have accomplished a great feat.

5.0 Conclusion

For future modification to the transmitter, I would like to test a lower Q of about 2 with a larger power supply. Given transmission distance increased by 20 yards without considerable hardware changes, and at the cost of a few cents of components, I cannot imagine how far the circuit can broadcast with the proposed changes.

Given an enclosed test environment with virtually endless reflections, the transmitter did not get to “shine” as much as it would have in the football field at UTSA. To completely fulfill my goals for this project, testing a higher power configuration outdoors would be necessary; the proof is there that the transmitter still has room for improvement.

For putting the modified circuit into application, the transmitter could be used as a “radio station” for a club or an organization that would like to broadcast information/songs to students in the ~80-yard radius. The downside is the requirement for a short-wave radio like the *Grundig* which has been discontinued by the manufacturer; however, there are other options available in the market and it would be nice to hear what students come up with the small radio station.

Modifying the original configuration of the 18 MHz transmitter was a fun exercise to learn about RF engineering in general. Doing the paper and the extra analysis strengthened both my circuit debugging skills, and engineering design skills. Furthermore, I learned about the importance of test environments, and how they can severely impact the performance of the device under test (DUT). From a Computer Engineering standpoint, I would not have learned these topics without exploring the Honors contract program that led me to pursue this project.

In the end, I appreciate the time that was taken on behalf of my EE 4113 Professor, Dr. Lars Hansen to help me learn what my Computer Engineering courses did not get to offer. Thank you

References

- EE 4113 lectures
- Professor Hansen