Tufts University

School of Engineering
Department of Electrical and Computer Engineering

EE22 – Electronics II
Fall 2012 – Prof. Sonkusale

Final Project: AM Transmitter with Colpitts Oscillator
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Purpose

This final project was divided into two parts. The purpose of the first part was to design and build a modified version of the Colpitts Oscillator. The purpose of the second part was to design and build the amplitude modulation transmitter circuit using the Colpitts Oscillator created in the first part. Both parts were simulated using LTSpice.

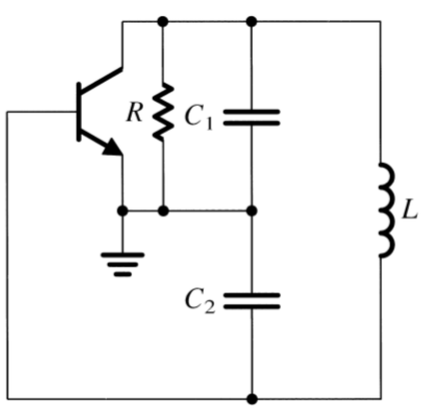
Introduction

An amplitude modulation (AM) transmitter is used to transmit signals wirelessly. Amplitude modulation involves modifying a signal of interest (e.g. microphone input) with a carrier signal at a specific frequency *f*. The two signals are multiplied together, and this new modified signal is then transmitted over the air. A demodulator receives the signal via antennae, multiplies the received signal with the carrier signal with frequency *f*, and then filters out the original signal. This process is known as amplitude modulation because the amplitude of the carrier signal is "modulated" according to the input signal. No information from the input signal is lost.

An oscillator circuit is a linear feedback system with an amplification component, A(s), and a feedback component, β(s), resulting in a gain of (A(s))/(1-A(s)β(s)). The output signal, x_o, is modified by the feedback and becomes x_f. x_f is then added onto the input signal, x_s, which is amplified and becomes x_o. In order to obtain oscillation, the denominator 1-A(s)β(s) must equal 0 for some value of ω, resulting in an unstable gain. This happens when the loop gain L(s)=A(s)β(s)=A(jω)β(jω)=1 (the Barkhausen criterion). The frequency ω at which this happens is ω_o. This oscillation can be used as the carrier signal for the AM transmitter, and its frequency can be set by the designer.

A Colpitts Oscillator (Figure 1) uses capacitors, inductors, and feedback in order to create sustained oscillations. The frequency at which oscillations take place is calculated using the relation $\omega_0 = 1/(L^*(C_1C_2)/(C_1+C_2))$.

Figure 1. Standard Colpitts Oscillator



Materials

Colpitts Oscillator

- Wires
- Breadboard
- 2N3704 npn
- 10 kOhm potentiometer
- 39 kOhm, 18 kOhm, 470 Ohm resistors
- 1 mH inductor
- 1 nF, 95 pF, 475 pF, 10 uF capacitors
- Variable capacitor
- DC Power Supply
- Tektronix TDS 2012 oscilloscope
- Instek GMD-8245 multimeter
- LTSpice software
- PCB board

AM Transmitter

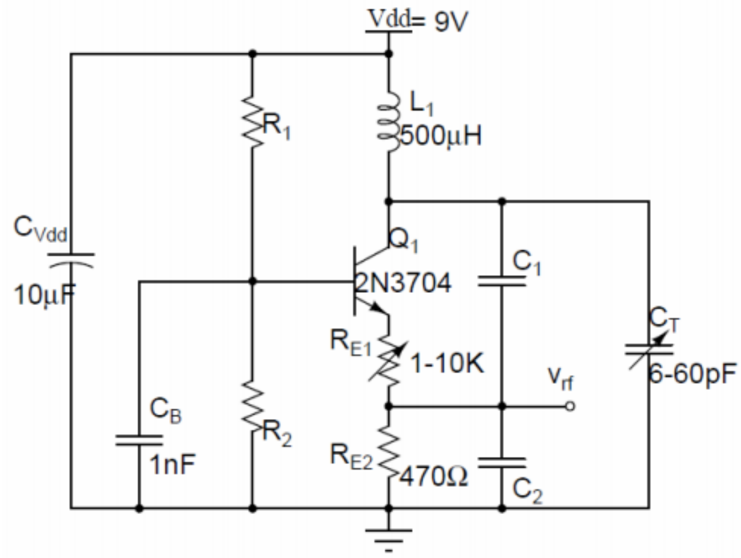
- Wires
- Breadboard
- 2N3704 npn
- 10 kOhm potentiometer
- 18 kOhm, 22 kOhm, 33 kOhm, 15 kOhm, 1 kOhm, 2.2 kOhm resistors
- 470 uH inductor
- 100 pF, 820 pF, 150 pF, 3.3 uF capacitor
- Variable capacitor
- DC Power Supply
- Tektronix TDS 2012 oscilloscope
- Instek GMD-8245 multimeter
- LTSpice software
- PCB board

Experimental Procedure

Colpitts Oscillator

A modified version of the Colpitts Oscillator (Figure 2) was designed in this experiment. The values of R_1, R_2, C_1, and C_2 in the circuit were determined using known relationships and requirements. The resistors R_1 and R_2 were set to bias the BJT such that the collector current was 1mA. $R_1||R_2$ was also supposed to be 12 kOhm.

Figure 2. Modified Colpitts Oscillator



The values of the capacitors C_1 and C_2 were set such that $C_2 = 5*C_1$. A desired oscillation frequency of 800 kHz was also used to calculate the capacitances. The relationship between oscillation frequency and capacitances was given by the equation:

$$w_0 = 1/\sqrt{L * (C_1 * C_2)/(C_1 + C_2)}$$

After the values of R_1, R_2, C_1, C_2 were calculated, the circuit was modeled in LTSpice and the operating point was measured. Capacitance values were adjusted until the collector current was at 1 mA. The voltage drop across the potentiometer and 470 Ohm resistor in series was measured to ensure that oscillations had a frequency of 750-800 kHz. The fast fourier transform (FFT) of this voltage and the FFT of the current through the inductor were examined. The effect on oscillation frequency of changing the capacitance of a tuning capacitor from 9 pF to 90 pF was also observed.

With the simulation complete, the circuit was implemented. Measured values were compared to simulated values. If the results were consistent enough, the finished oscillator circuit was soldered onto a PCB board.

AM Transmitter

The AM Transmitter portion of the circuit is given in Figure 3. With the desired bias points known, the values of R_1, R_2, R_3, and R_4 were first calculated. The values of these resistors were related by the following relation: $R_1 || R_2 = R_3 || R_4$ 10 kOhm. R_E was calculated using the emitter current of Q_2, which was known to be 1 mA. C_2 was calculated using

$$f_0 = 1/(2 * \pi * R * C)$$

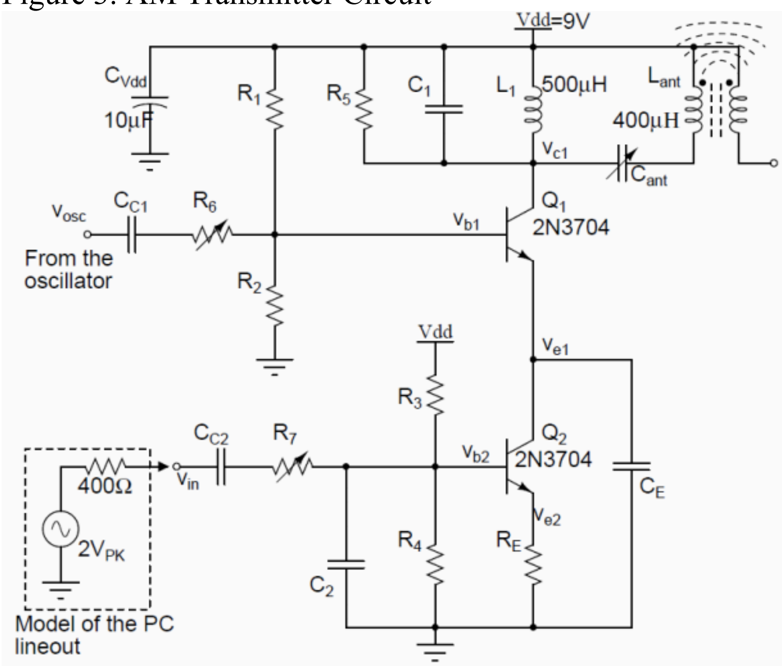
with f_0 = 20 kHz (the worst-case cut-off frequency).

C_E was chosen such that the impedance was approximately 5. C_{c1} and C_{c2} were chosen such that their resulting cutoff frequencies were at 100 kHz and 5 Hz, respectively. C_1 was chosen such that oscillation took place at 750 kHz. R_5 was calculated such that the bandwidth was 300 kHz.

After calculating the above values, the AM transmitter circuit was simulated using LTSpice. The presence of amplitude modulation was evaluated by measuring the inductor current and the collector current. The FFT of both currents were examined.

The AM transmitter circuit was constructed on a breadboard and connected to the previously built Colpitts Oscillator. The functionality of the circuit was tested using a conventional AM radio tuned to the frequency of the Colpitts Oscillator. The potentiometers and the variable capacitor were adjusted until a clear signal was obtained. The circuit was soldered onto a PCB board.

Figure 3. AM Transmitter Circuit



Results

Colpitts Oscillator

After calculating the values of R_1, R_2, C_1, C_2, the corresponding circuit schematic was created in LTSpice (Figure 4). The base voltage was determined to be 2.85V after a DC sweep. Using the relationships mentioned in the "Experimental Procedure" section above, the following values were calculated: R_1 = 39.86 kOhm, R_2 = 17.17 kOhm, C_1 = 95 pF, and C_2 = 475 pF. LTSpice was then used to determine the DC operating point, the quiescent voltages, the quiescent currents, and the frequency response of the Colpitts Oscillator circuit.

Figure 4. LTSpice simulation of Colpitts Oscillator circuit

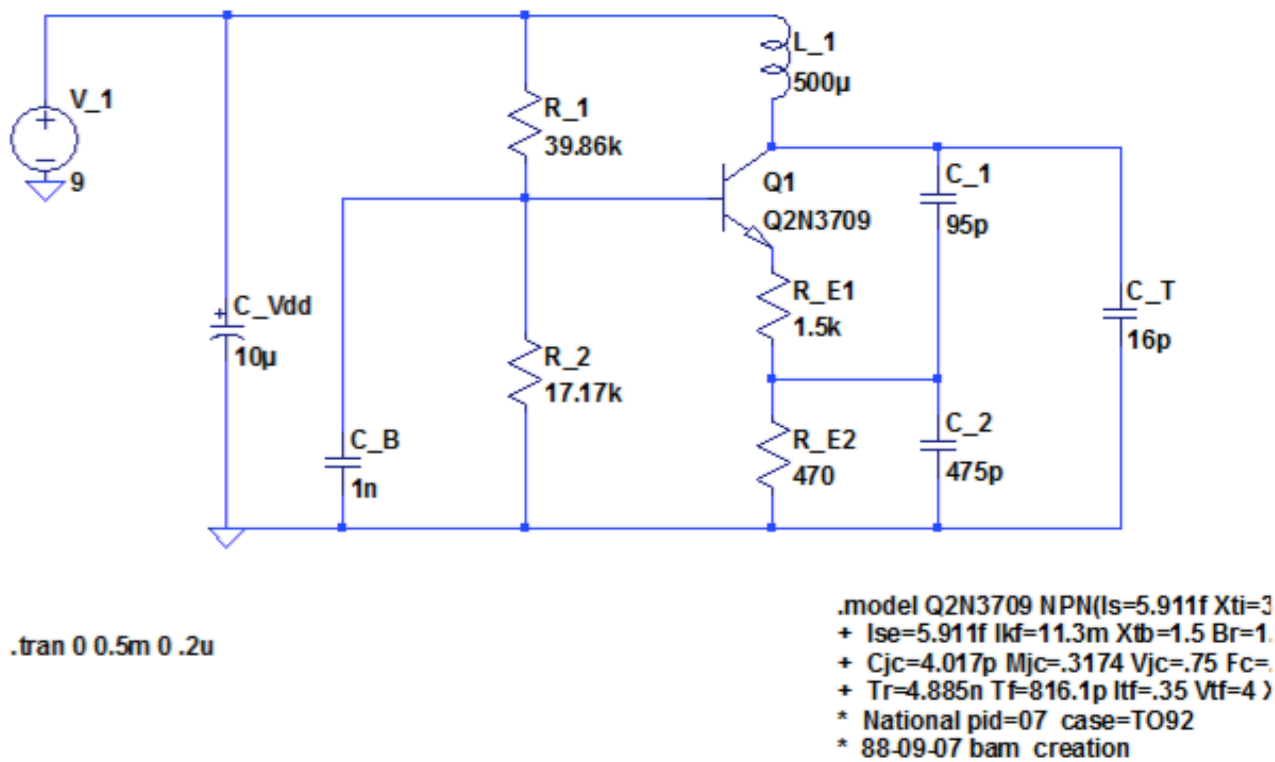


Table 1. Measured voltages and currents of LTSpice simulation of Colpitts Oscillator

V(n001):	9	voltage
V(n003):	2.57397	voltage (base)
V(n005):	0.454947	voltage
V(n002):	9	voltage (collector)
V(n004):	1.90691	voltage (emitter)
Ic(Q1):	0.000956669	device_current
Ib(Q1):	1.13041e-005	device_current
Ie(Q1):	-0.000968001	device_current
I(C_vdd):	9e-017	device_current
I(C_t):	1.44e-022	device_current
I(C_2):	2.161e-022	device_current
I(C_b):	2.57397e-021	device_current
I(C_1):	8.1178e-022	device_current
I(L_1):	0.000956669	device_current
I(R_e1):	0.000967973	device_current
I(R_e2):	0.000967973	device_current
I(R_2):	0.000149911	device_current
I(R_1):	0.000161215	device_current
I(V_1):	-0.00111788	device_current

The simulated circuit was observed to produce sustained oscillations.

Figure 5. LTSpice simulation of oscillation of voltage across R_E2

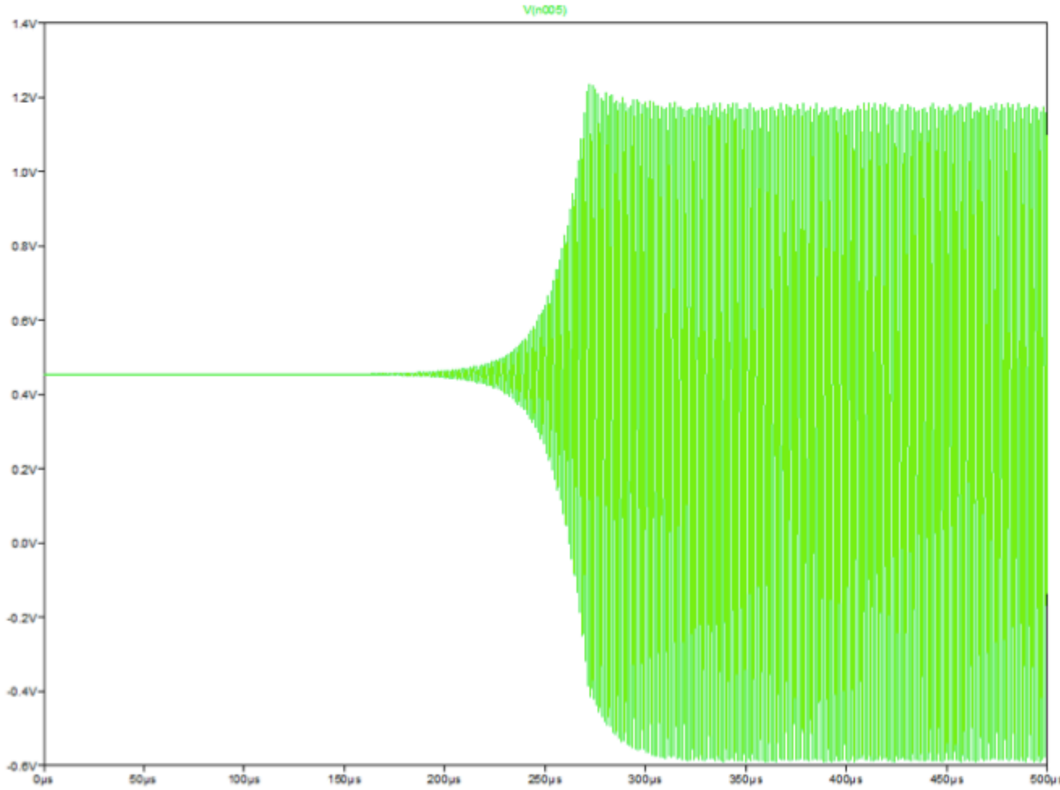
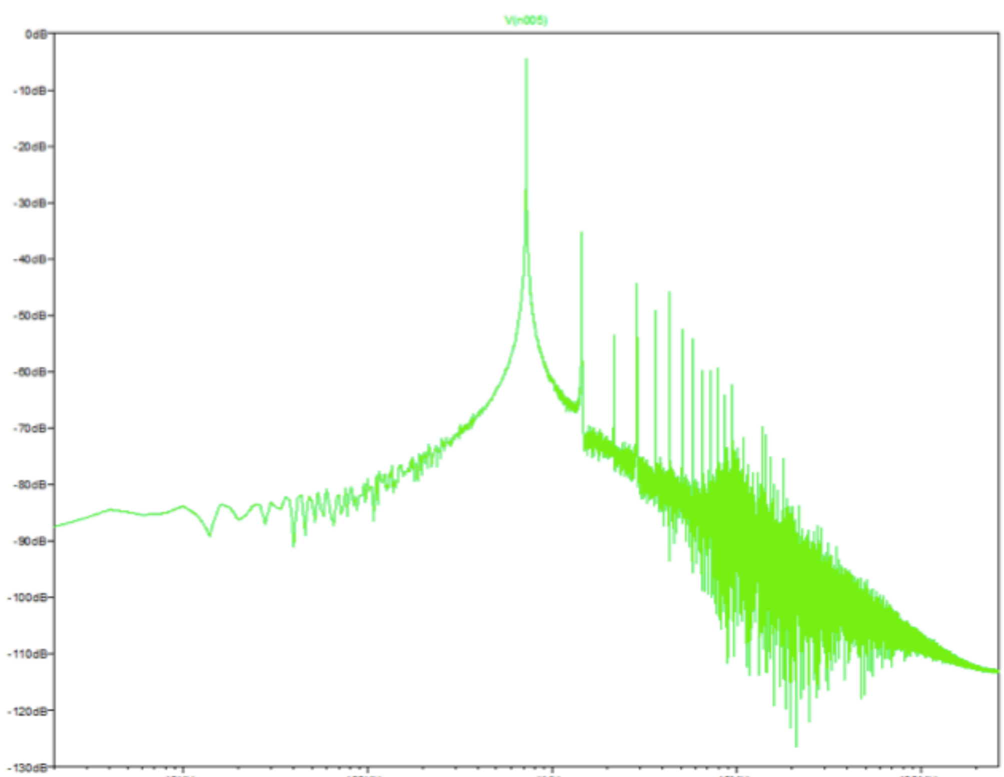


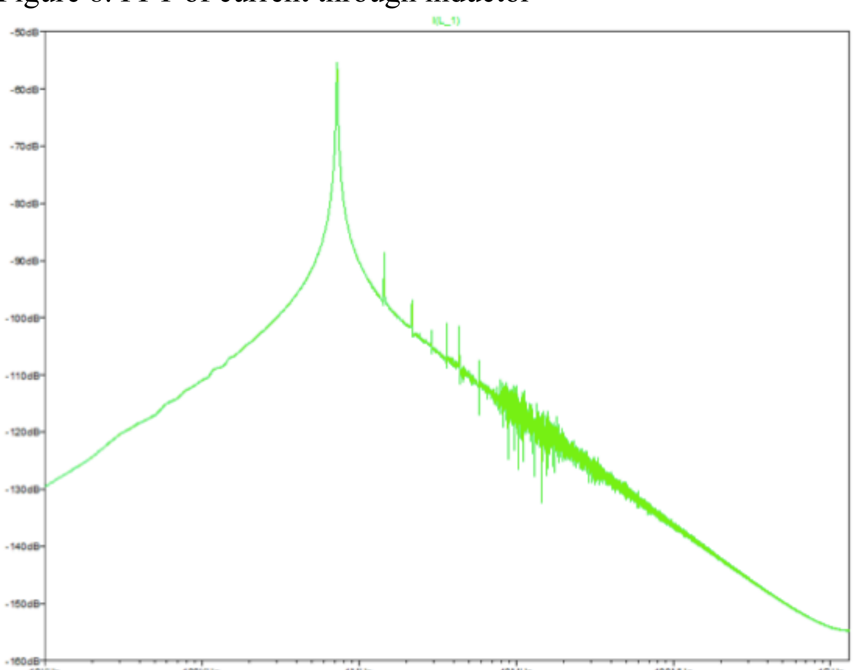
Figure 6. FFT of voltage across R_E2



The first four harmonics shown by the plot in Figure 6 were: -5.01 dB, -35.4981 dB, -53.8008 dB, and -44.5207 dB.

Figure 7. LTSpice simulation of oscillation of current through inductor

Figure 8. FFT of current through inductor



The first four harmonics as shown by the plot in Figure 8 were: -57.8198 dB, -90.2093 dB, -99.8589 dB, and -104.468 dB.

With C_T at 9 pF, the frequency of oscillations was 748.741 kHz. With C_T at 90 pF, the frequency of oscillations was 549.707 kHz.

AM Transmitter

After calculating the values of R_1, R_2, R_3, R_4, R_E, C_1, C_2, C_{c1}, C_{c2}, and R_5, the corresponding circuit schematic was created in LTSpice (Figure 9). Using the relationships mentioned in the "Experimental Procedure" section above, the following values were calculated: R_1 =18 kOhm, R_2 = 22.5 kOhm, R_3 = 32.1 kOhm, R_4 = 14.5 kOhm, R_E = 2.1 kOhm, C_2 = 795 pF, C_E = 63.66 nF, C_{c1} = 159.2 pF, C_{c2} = 3 uF, C_1 = 90 pF, and R_5 = 942.478 Ohm.

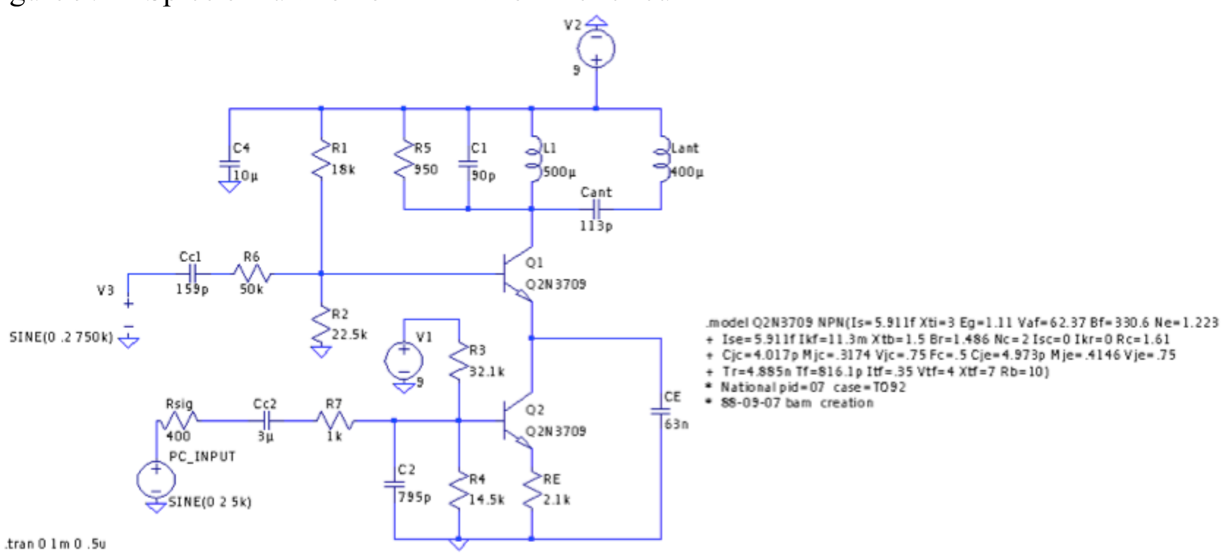
C_1 was calculated using the equation:

$$C_1 = \frac{1}{L * \omega^2}$$

R_5 was calculated using the equation:

$$BW = \frac{R_5}{L}$$

Figure 9. LTSpice simulation of AM transmitter circuit



The voltage across the antenna was measured and analyzed using FFT.

Figure 10. LTSpice simulation of modulated signal

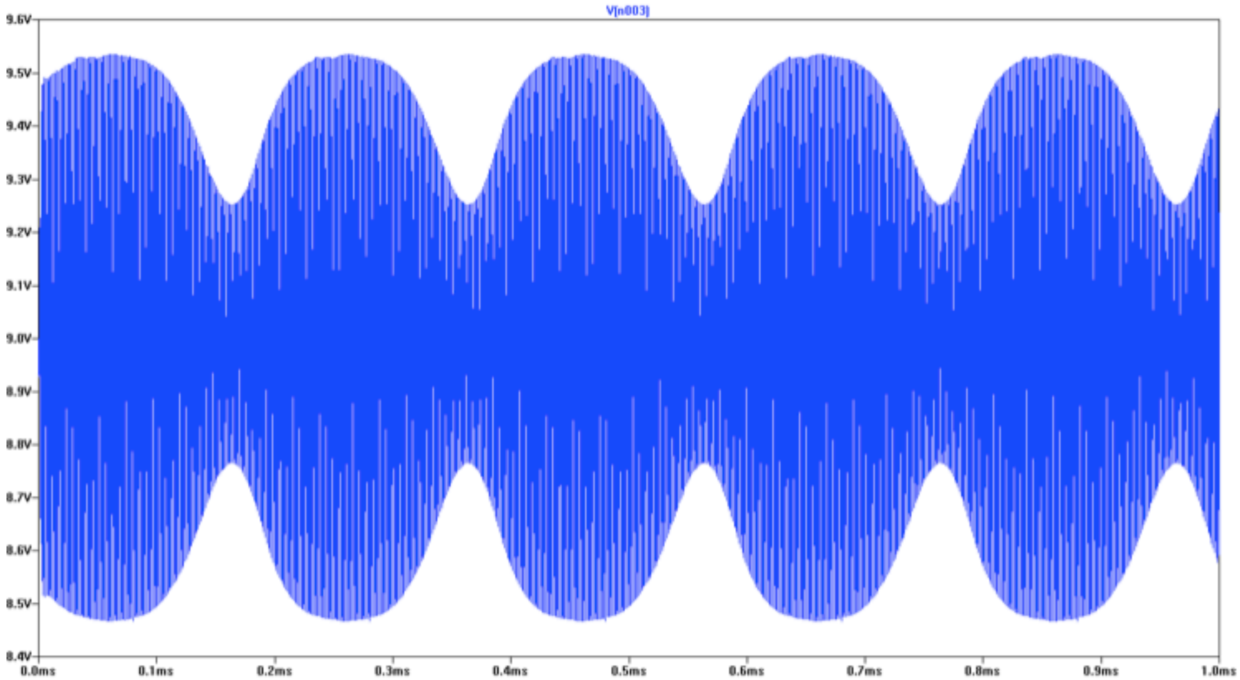


Figure 11. FFT of modulated signal

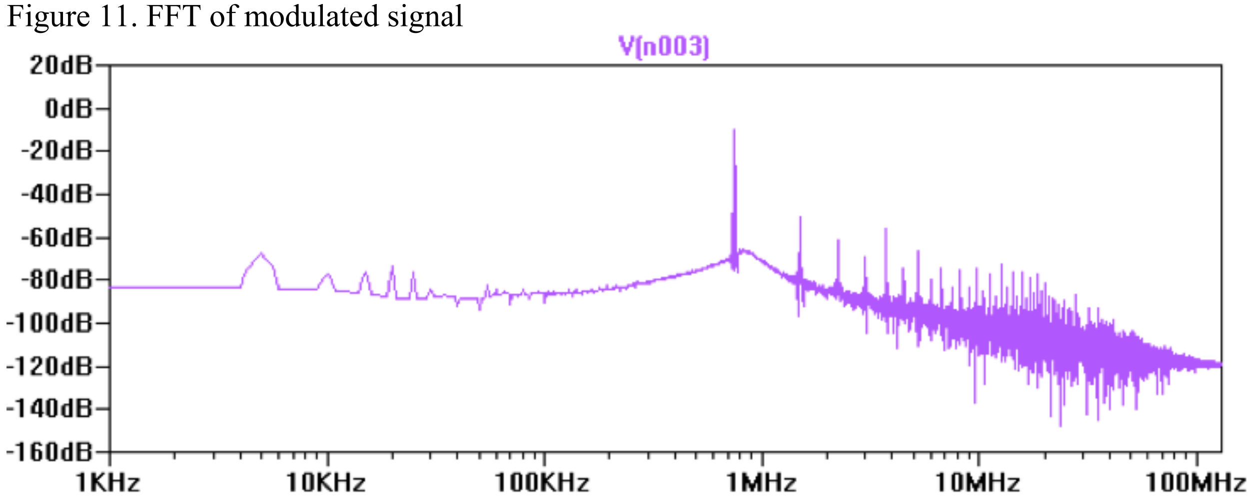


Figure 10 shows clear amplitude modulation of a higher frequency carrier signal, which was expected of an AM transmitter circuit. Figure 11 shows two sidebands at the left side of the plot related to the input signal. The presence of these side bands indicated that the measured voltage contained a large portion of the input signal

After successfully building and testing the circuit according to the guidelines described in the "Experimental Procedure" section above, the AM transmitter circuit with the Colpitts Oscillator were soldered onto two PCB boards, shown in Figures 12 and 13.

Figure 12. Soldered AM transmitter circuit with Colpitts Oscillator (front)

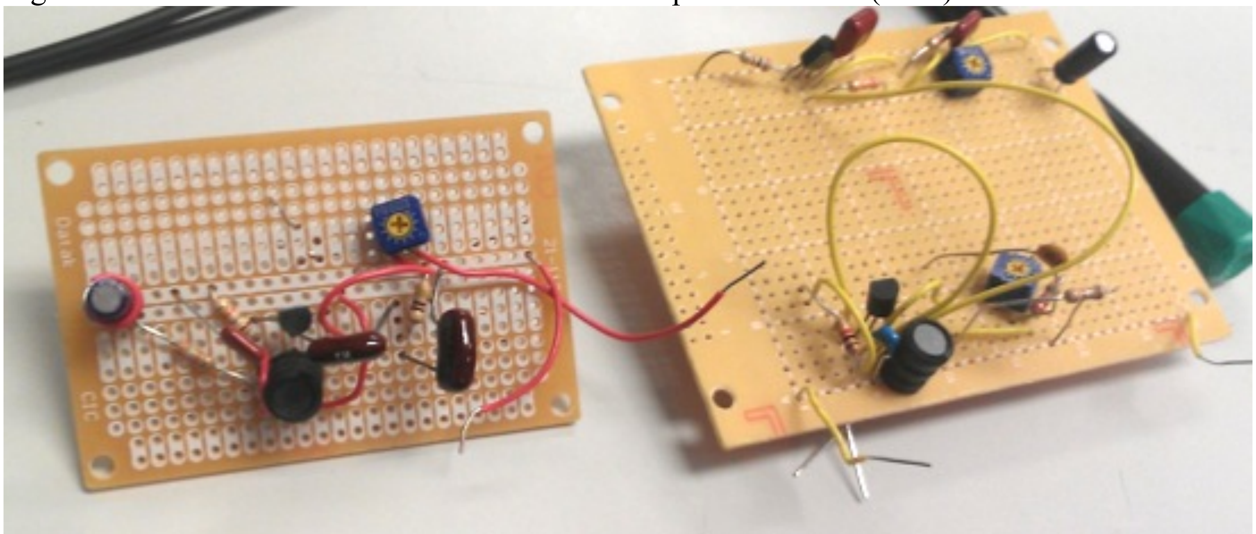
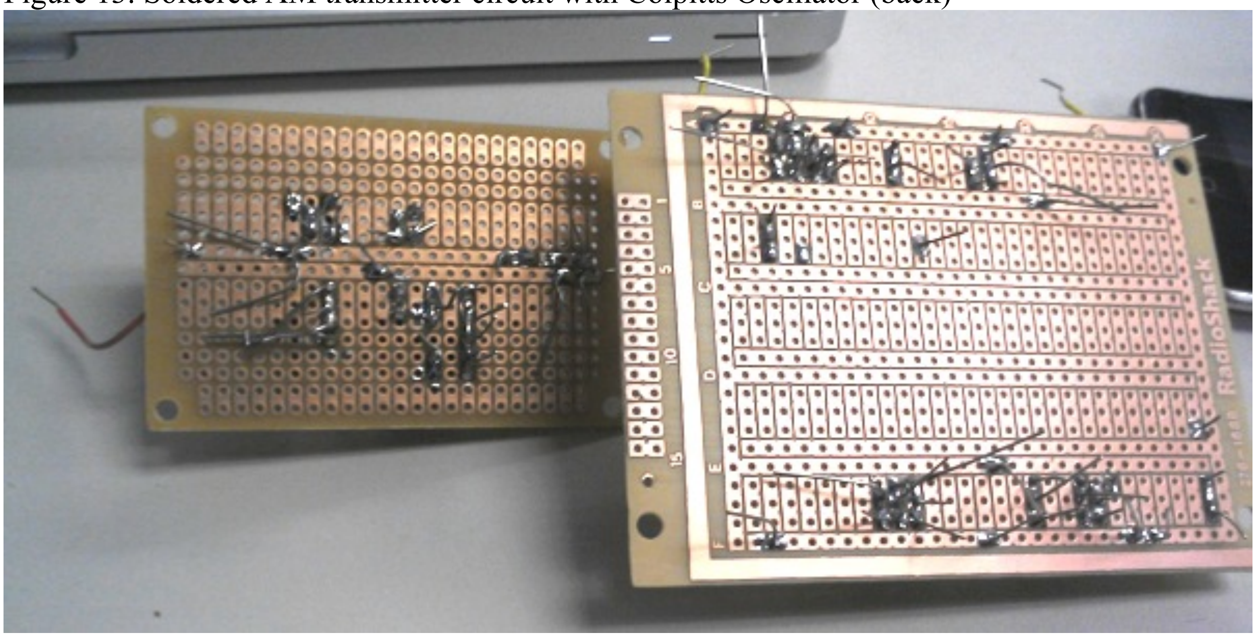


Figure 13. Soldered AM transmitter circuit with Colpitts Oscillator (back)



Discussion and conclusion

The overall architecture of the constructed amplitude modulator is given in Figure 14. The principle behind the AM transmitter is as follows: the bottom BJT (Q2) shown in Figure 9 acted as a current source that varied according to an inputted audio signal. With the voltage at the drain of Q2 changing over time, the amplification factor of the top BJT (Q1) also changed over time. Because Q1 was amplifying the inputted carrier signal, the changes in its g_m resulted in amplitude modulation of the carrier signal. How the amplitude was modulated can be directly related to the inputted audio signal, ideally leading to no information lost.

The project illustrated the imprecision of analog circuitry in lab. Different components have slightly different values, and environmental factors can introduce unexpected changes in results. No measurements made in lab matched calculated/simulated results perfectly. Though the AM transmitter circuit worked, the performance of the circuit did not exactly replicate that of the AM transmitter simulated using LTSpice. In order to account for imperfections, “tweakable” discrete components such as the potentiometer and the variable capacitor were used. LTSpice was useful in demonstrating how the circuit should have behaved at least on a qualitative level.

Ultimately, this project went smoothly and successfully demonstrated important electrical engineering principles through practical applications. The project allowed the designer to incorporate several different types of discrete components (npn BJTs, capacitors, potentiometers, resistors, inductors) to create a fully functional AM transmitter circuit. The project utilized the concepts of oscillation, signal filtering, system design, and modulation, proving that the whole is greater than the sum of its parts.

Figure 14. Architecture of amplitude modulator