WIRELESS COMPUTER SPEAKERS

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ECE 345

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Abstract

The purpose of the project was to build a wireless computer speaker system. The project in essence involves the design and implementation of an FM transmitter and receiver circuit. The initial target frequency was 54 MHz and single down conversion receiver using MC3361 was to be accomplished. A technical difficulty in the receiver end forced us to halt the transmitter work and focus on the receiver system, in which we eventually changed the frequency to 18.175 MHz.

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1. INTRODUCTION

The purpose of our project is to build a wireless computer speaker system. The transmitter will produce an analog FM signal at 54 MHz. We will produce the FM signal in a similar way that commercial FM is produce. We will design a phase modulator and produce a narrow band FM signal that will be multiplied in frequency and filtered at 54 MHz. The signal will be transmitted and sent through the antenna. The purpose of the receiver is to take the 54 MHz signal and demodulate the transmitted message using a quadrature demodulator that we will use in the MC3361 chip. The demodulated signal is then amplified and sent to the speakers. The project specifications are as follows:

- Modulation Index = 5
- Maximum Frequency Deviation = 75 KHz
- Modulating Frequency Bandwidth = 15 KHz
- Transmission Bandwidth = 200 KHz
- Transmitted output power = 0dBm
- Working Range = 30 ft.

The initial Narrowband FM signal will have a Modulation Index of 0.28.

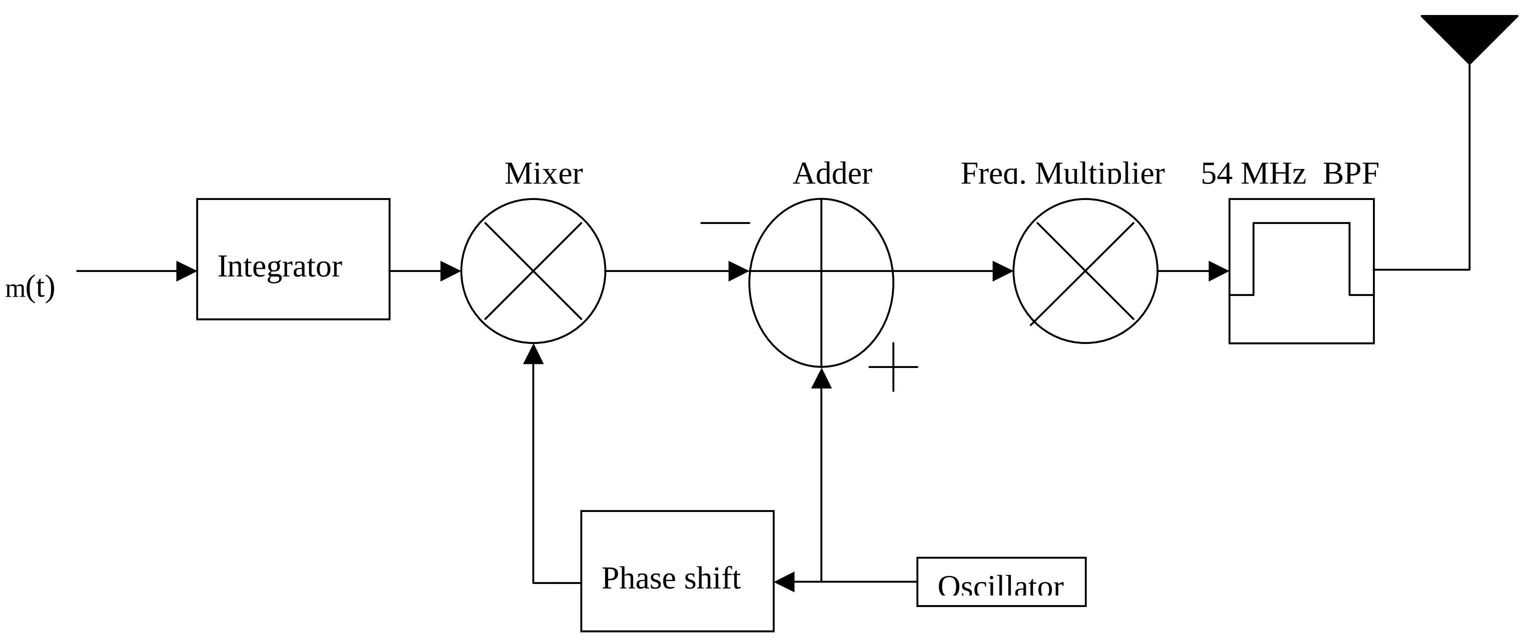

Figure 1. Transmitter block diagram

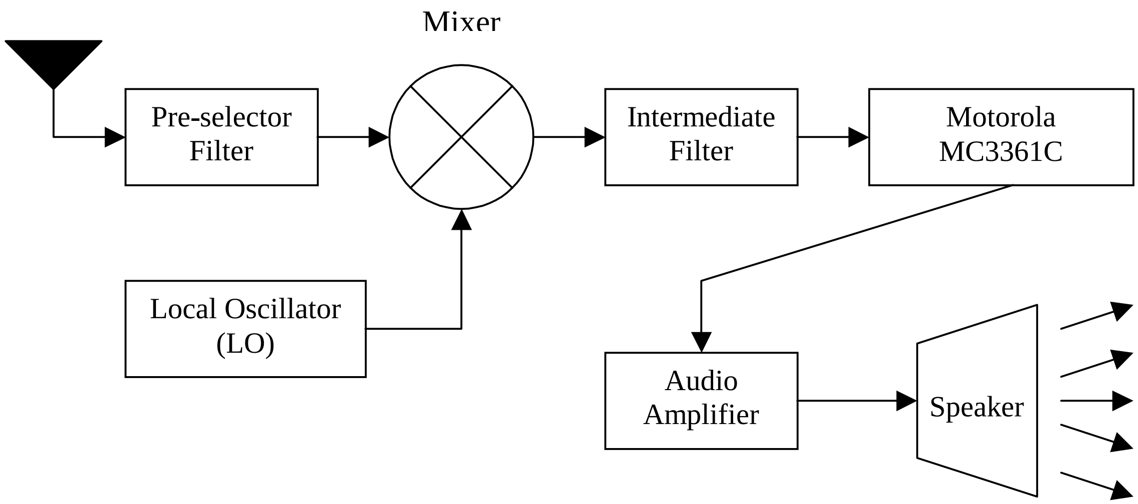

Figure 3 Receiver Block Diagram

2. TRANSMITTER DESIGN PROCEDURE

$$s(t) = A_c \text{Cos} [2\pi f_c t + 2\pi k_f \int_0^t m(t)\, d t] \quad (1)$$

$$s(t) = A_c \text{Cos}(2\pi f_c t) - \beta A_c \text{Sin}(2\pi f_c t) \text{Sin}(2\pi f_m t) \quad (2)$$

$$s(t) = A_c \text{Cos}[2\pi f_c t + \beta \text{Sin}(2\pi f_m t)] \quad (3)$$

Equation (1) is the definition of FM modulation. Equation (2) represents the function that our transmitter block diagram implements before the frequency multiplier. Equation (3) is the signal sent through the antenna as a Broad Band FM signal.

2.1 Integrator

The purpose of the integrator circuit is to integrate the incoming audio signal coming from the audio output on the speakers. The output of the integrator circuit is given by equation (4). In our case we need to make the term 1/RC = .28.

$$Vout = 1/RC \int_0^t Vin(t)\, dt \quad (4)$$

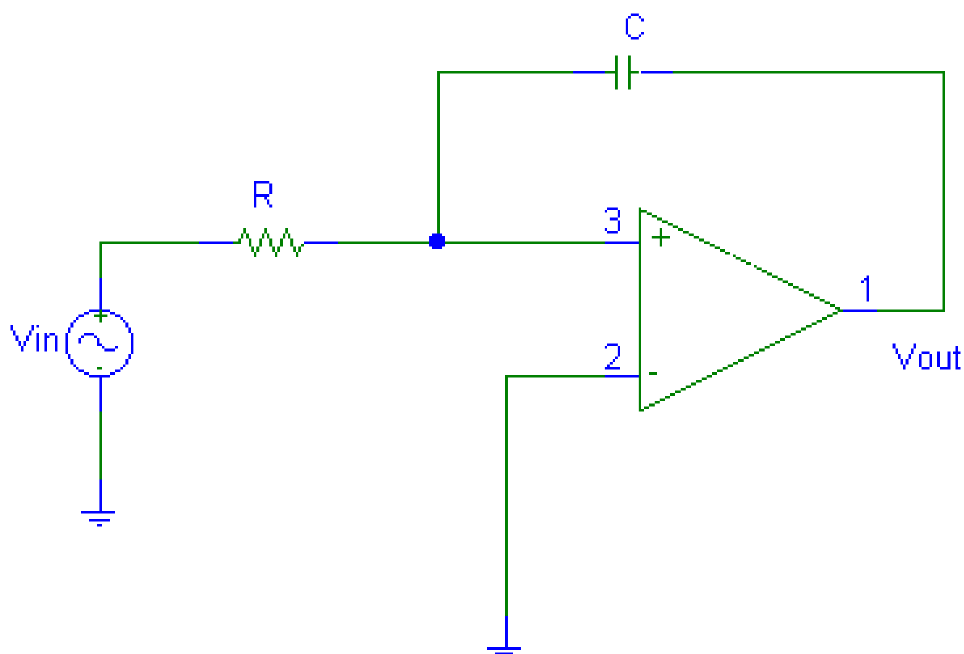

Figure 2.1: Integrator Circuit

2.2 Mixer

The purpose of the mixer circuit is to multiply the two signals in time. There are different configurations of mixers, in which the complexity increases with the number of components. A doubly balanced four diode mixer would be the ultimate mixer implementation. We chose this circuit as a basic mixer, because we want to keep the design as simple as possible in order to be able to overcome debugging problems quickly. The circuit in figure 2.2 accomplishes the multiplication needed and is described by equation (5).

$$Vout = V1(t) * V2(t) \tag{5}$$

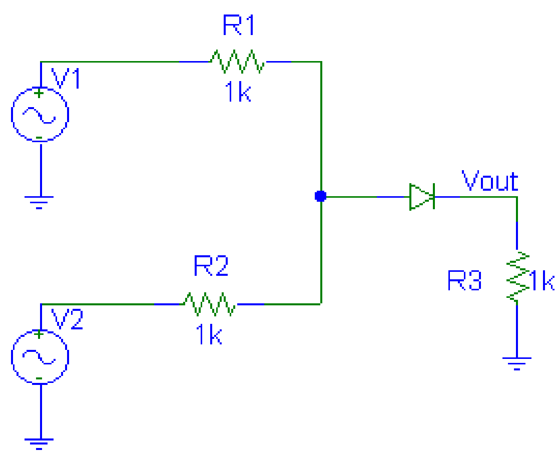

Figure 2.2: Mixer

2.3 Local Oscillator

The purpose of the local oscillator is to provide the starting frequency of our Narrow Band FM signal, which is 3MHz. We decided to use Colpitts crystal oscillator for our design and we are using our quarts crystal as a high Q inductor. The crystal oscillator topology is given in figure 2.3a and figure 2.3b is the actual oscillator circuit.

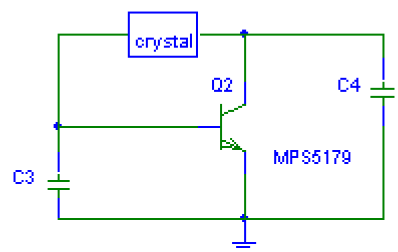

Figure 2.3a: Basic Colpitts Basic Crystal Oscillator

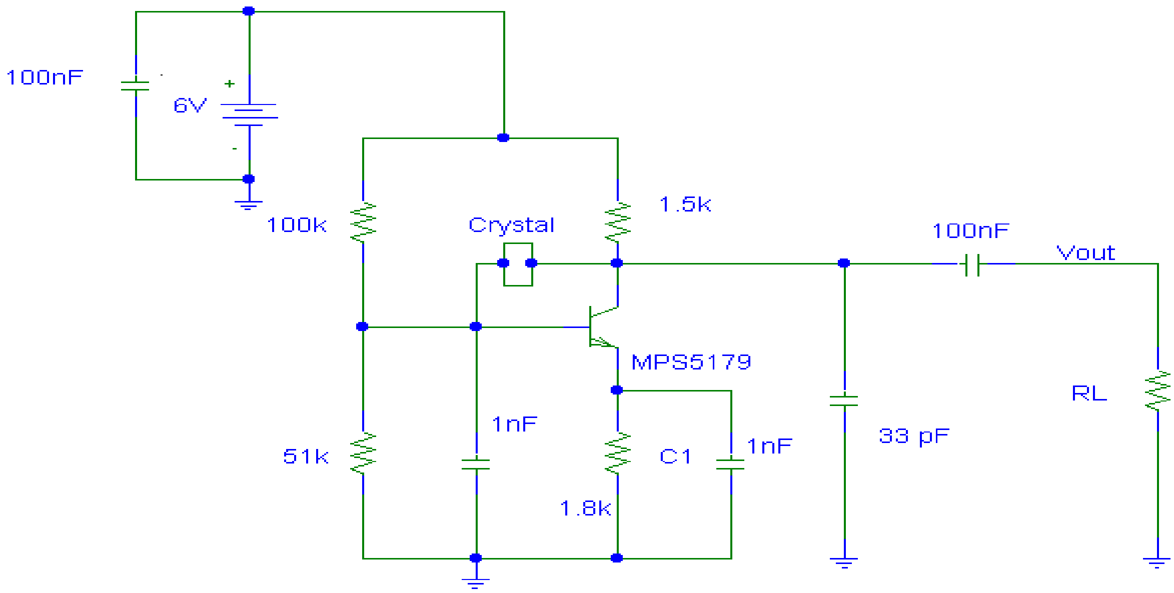

Figure 3.b: Actual Crystal Oscillator

2.4 –90 Phase Shifter

The purpose of the phase shifter circuit is to provide the capability of shifting the carrier by – 90 degrees. This will enable us to produce the Quadrature carrier at 3 MHz, which we need to multiply by the integrated audio signal. The passive pi network given in figure 2.4 accomplishes the task of shifting the input signal by –90 degrees.

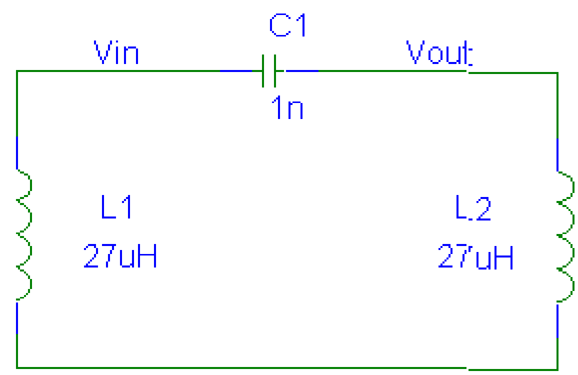

Figure 2.4: -90 Degree Phase Shifter.

2.5 180 Degree Phase Shifter

The purpose of this phase shifter is to provide us with the negative sign of the Quadrature carrier and the integrated audio signal that will go into the adder. This task is easily accomplished with a transformer. The other choice would be to design a pi network that will produce an phase shift of 180 degrees, but this would be much more work.

2.6 Adder

The purpose of the adder is to produce the output voltage of the two incoming signals. Figure 2.5 is a general circuit that will implement this task. The adder could also be implemented by using an op amp, but we chose to try the adder in figure 2.5 for its simplicity. The output voltage is given by equation (6).

$$Vout\,(t) = V1(t) + V2(t) \tag{6}$$

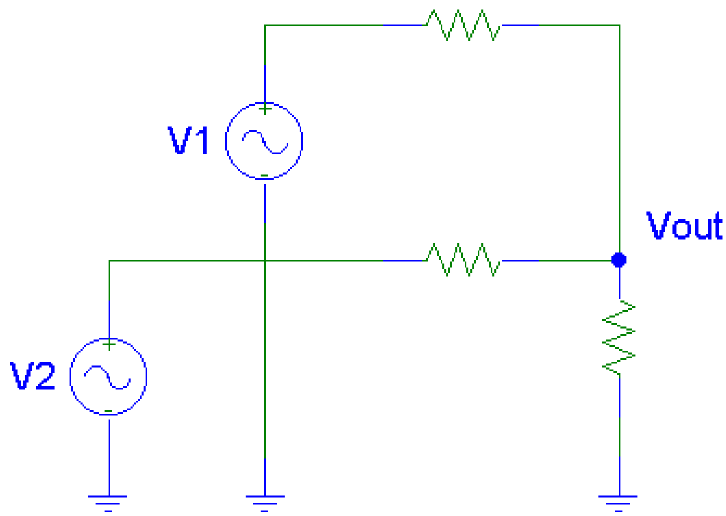

Figure 2.6: Voltage Adder

2.7 Frequency Multiplier

The purpose of the frequency multiplier is the same is to provide frequency products of the input. The incoming signal will have a carrier frequency of 3 MHz and it is described by equation (2). The circuit has the same as that of the Mixer circuit. The difference is that we need the 18th product since our carrier frequency of 3 MHz times 18 will give the 54 MHz carrier frequency of the broad band FM signal. We also want the modulation index of 5 and before the frequency multiplier the Modulation index is 0.28. After the frequency multiplier the Modulation Index is 5.04. At this point we have accomplished the broad band FM signal described in the introduction.

An important characteristic of this frequency mixer is that it needs to be implemented in stages. It is a cascade of 3 circuits with a band pass filter in between. We will accomplish this mixer in three stages and the first stage we will filter out the 3rd harmonic, which will have a carrier frequency of 9MHz. The 3rd harmonic is then feed to the second mixer stage and the 3rd harmonic is then filtered out. This procedure will give us the 27 MHz carrier frequency. We put the 27 MHz signal through another mixer and the last filter will filter out the second harmonic, thus producing the 54 MHz carrier frequency and the broad band FM signal that we specified.

2.8 Band-pass Filter

The purpose of this filter is to filter out the second harmonic after the third mixer stage. The images will be separated every 27MHz so this filter is very relaxed and can be performed by a series LC network.

This network has the resonant frequency given by equation (7) and the general from is given in figure 2.7. The cutoff frequency of the filter may not sharp enough so a higher order Butterworth filter may be needed.

$$F_s = 1/2\pi\sqrt{LC} \qquad (7)$$

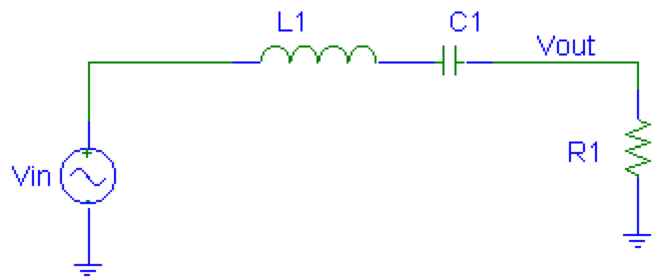

Figure 2.7: Simple Band-pass Filter

2.9 Amplification

The purpose of this section is to amplify the signal to 0dBm. The amplification section may involve the use of DC biased BJT cascaded in parallel to achieve the appropriate amplification.

3. RECEIVER DESIGN PROCEDURES

The function of our receiver is to detect our modulated signal and to ultimately recover the message being transmitted. Our receiver performs as a single down conversion receiver that will down convert the incoming modulated signal to a specified frequency determined by the frequency of the incoming signal and the local oscillator. Then the signal will be sent to a special circuit that will demodulate and amplify it before the signal is sent to the speakers to be heard by the user. The main components of our receiver are the pre-selector filter, mixer, local oscillator, intermediate filter, Motorola MC3361C Narrowband FM demodulator chip, National Semiconductor LM748 Amplifier chip, and speakers.

3.1 Pre-selector Filter

The pre-selector filter's job is to filter out undesired signals and limit the input to the specified transmission bandwidth of 200 KHz. The desired incoming signal is in the form of the following general equation:

$$s(t) = A_c \text{ Cos } (2\pi f_c t + B\sin (2\pi f_m t)) \tag{8}$$

where,

A_c is the carrier amplitude
f_c is the carrier frequency
f_m is the modulated frequency

3.2 Mixer

The mixer will multiply are incoming signal with our LO to obtain the down converted frequency of 875 KHz. To save on cost and circuit confusion we decide to use the mixer on the Motorola MC3361C chip. The other option was to construct a mixer for the receiver like the mixer in figure 2.2 but we went for the chip's mixer because it was very reliable.

3.3 Local Oscillator (LO)

The LO's primary function is to mix with the incoming signal to get the frequency difference between the carrier and the LO. The oscillator will have the topology of the crystal Colpitts-type circuit shown in figure 2.3a.

3.4 Intermediate Filter

The intermediate filter is used after the mixer to obtain the down converted signal. Its purpose is to pass the frequency of interest and reject noise and the unwanted image. The filter is implemented by a 2-pole Butterworth band-pass filter center at $f_c – f_{lo}$. The output of the filter has the following signal:

$$s(t) = A_c/2 \text{ Cos } (2\pi(f_c-f_{lo})t + B \text{ Sin } (2\pi f_m t)) \tag{9}$$

3.5 Motorola MC3361C

The MC3361C is low power narrowband FM demodulator chip that when given our signal will send it through a limiter circuit and quadrature discriminator. The limiter will smooth out the sinusoidal amplitude and the discriminator will provide output voltages proportional to the frequency deviations. A quadrature coil circuit, which consists of a tunable LC filter, allows us to center the discriminator's center frequency.

3.6 Audio Amplifier LM748

The LM748 amplifies our audio signal since our signal strength is very weak and not strong enough to drive the speaker. After amplification the audio signal is sent to a speaker where it can be heard.

4. RECEIVER DESIGN DETAILS

4.1 Pre-selector Filter

To accomplish this we used a 2-pole Butterworth band-pass filter centered at our incoming carrier frequency of 54 MHz and a bandwidth of 200 KHz. To construct the band-pass Butterworth filter we first had to consider a low-pass prototype and frequency translate it to the desired center frequency. Frequency translation from low-pass to band-pass requires all shunt capacitors in the low-pass prototype be replaced by parallel tuned circuits and all series inductors be replaced by series tuned circuits. The filter must first be normalized to a new intermediate low-pass filter by the following equations:

$$L' = (R'/R)(\omega/\omega')L \quad (10)$$

$$C' = (R/R')(\omega/\omega')C \quad (11)$$

where,

L', C', ω' and R' are the desired values
L and C = 1.4142 (values obtained in the Butterworth Low-Pass Filters tables)
$R = 1\ \Omega$
$\omega = 1$ radian/sec.

Finally, the intermediate components are replaced with resonator circuits tuned to 54 MHz with the following equations:

$$L^* = 1/(C'(2\pi f_c)^2), \text{ parallel-resonating inductor} \quad (12)$$

$$C^* = 1/(L'(2\pi f_c)^2), \text{ series-resonating capacitor} \quad (13)$$

Figure 4.1 shows the filters schematic.

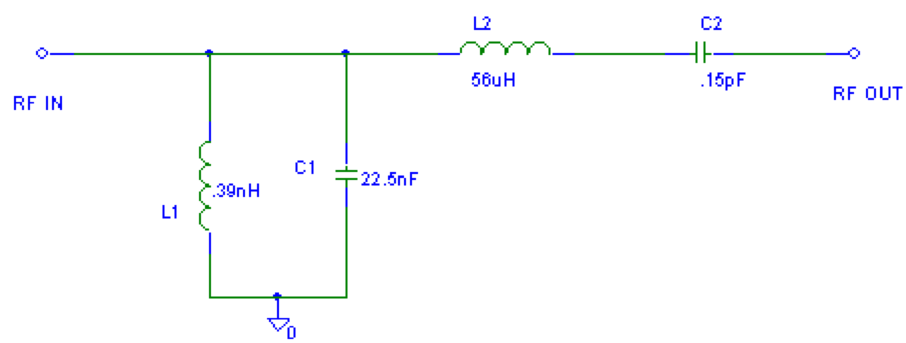

Figure 4.1: 2-pole Butterworth Band-pass Filter

4.2 Mixer

The purpose of our mixer is to multiply the incoming modulated signal with the receivers LO to obtain the sum and difference of the frequencies components. The Motorola MC3361C includes our mixer for the receiver on the chip. The output will have the form of the following equation:

$$s(t) = A_c/2\ [\mathrm{Cos}\ (2\pi(f_c\text{-}f_{lo})t + \theta) + \mathrm{Cos}\ (2\pi(f_c+f_{lo})t + \theta)] \quad (14)$$

where,

$$\theta = B\ \mathrm{Sin}\ (2\pi f_m t) \quad (15)$$

contains our message.

4.3 Local Oscillator (LO)

We want our crystal oscillator to operate at 53.125 MHz so when the carrier frequency of 54 MHz is mixed with the LO we'll obtain the down converted frequency of 875 KHz. To achieve oscillation we used the topology of a crystal controlled Colpitts and analyzed it as a feedback system with a loop gain equal to 1 and a phase angle of 0. Those requirements are called the "Barkhausen Criterion" for oscillation. Figure 4.2 shows the feedback system and equation (16) shows the voltage transfer function. Our completed oscillator circuit is shown on figure 4.3.

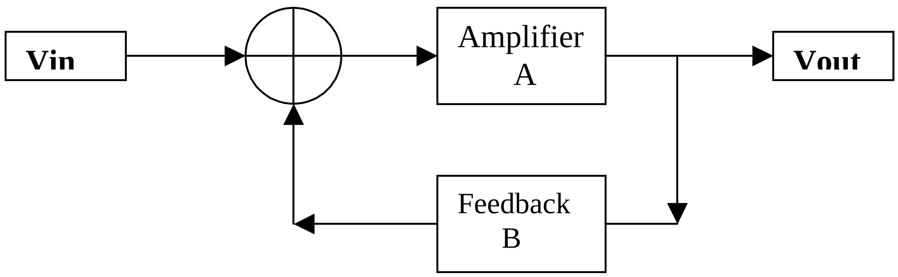

Figure 4.2: Feedback System

$$Vout/Vin = A/(1 - AB) \quad (16)$$

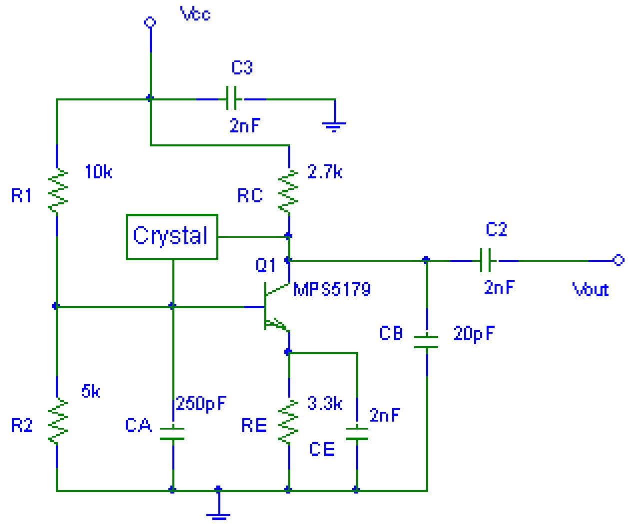

Figure 4.3: Completed Crystal Oscillator Circuit

4.4 Intermediate Filter

This filter was implemented using a 2-pole Butterworth band-pass filter with a bandwidth of 200 KHz. The design equations followed are those presented in 4.1 Pre-selector Filter. The purpose of this filter is to filter out the unwanted image caused by the mixing stage in our receiver and pass the down converted frequency of 875 KHz from equation (9). The following equation shows the difference in frequencies and what the center frequency of the IF should be:

$$F_c - F_{lo} = F_{cbp} \tag{17a}$$

therefore,

$$54 \text{ MHz} - 53.125 \text{ MHz} = 875 \text{ KHz} \tag{17b}$$

The schematic of the band-pass filter is the same as figure 4.1 with the exception of the following component values from equation (14) & (15):

$$L_1 = L^* = 1.47\text{uH}$$
$$C_2 = C^* = 590\text{pF}$$

4.5 Motorola MC3361C

The MC3361C chip functions as a narrowband FM demodulator. It takes the modulated signal after the IF and sends it through a limiter circuit and to the quadrature discriminator where it's sent to the audio amplifier to give the signal a boost before coming out the speaker. Here, we bought used a tunable Quadrature coil to center the frequency of the discriminator.

4.5.1 Limiter

During transmission variations of the carrier amplitude at the receiver input comes from noise or interference. The limiter circuit functions to remove all amplitude variations caused by that noise or interference for the incoming signal. Then the signal is sent to the quadrature discriminator.

4.5.2 Quadrature Discriminator

The signal from the output of the limiter is passed through the following discriminator:

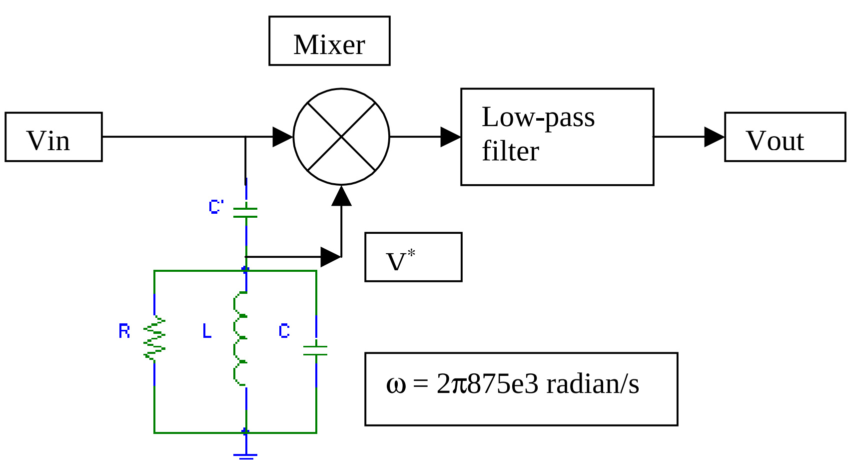

Figure 4.4: Quadrature Discriminator

When the input signal deviates from the parallel resonance of our quadrature coil this causes a phase difference between the input voltage and the voltage at the quadrature coil. The signal is the passed through a mixer and low-pass filter in the MC3361C chip. That combination functions as a phase detector, which provides an output voltage, that is proportional to the frequency deviations.

4.6 Audio Amplifier

After the quadrature discriminator we obtain the original audio signal but due to its low signal strength we must first amplify it in order to drive the speaker. The LM748 gives us the necessary amplification needed before sending the signal to the speakers. We used the following schematic to achieve our amplifier:

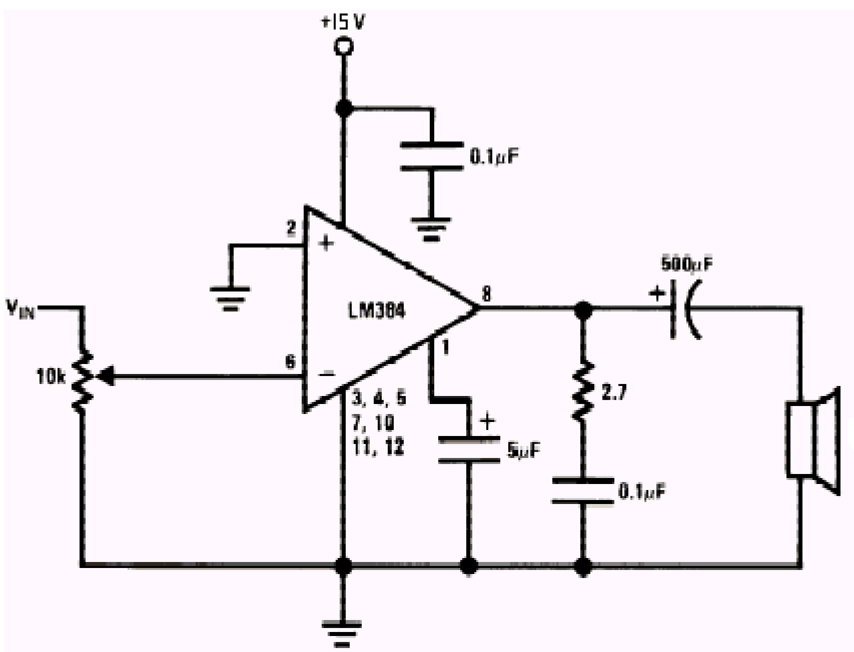

Figure 4.5: Audio Amplifier

5. DESIGN VERIFICATION

The purpose of our FM receiver is to be able to demodulate a signal. That is, the receiver must be able to receive an FM signal with a carrier frequency of 18.175 MHz and a maximum frequency deviation of 75 KHz. The receiver must be able to recover the modulated signal. Figure 3.1 shows the picture of our receiver oscillator at 17.7 MHz and the modulated signal at 18.175 MHz in the spectrum analyzer. We performed the test for the case when the modulated signal was 1KHz and for the case when the modulated signal was 400Hz. Figure 1 shows the signal sent through the speaker which was a 1KHz tone and figure 3.3 shows the case for a modulated 400Hz tone. Both test show that our receiver is able to demodulate a modulated carrier at 18.175 MHz.

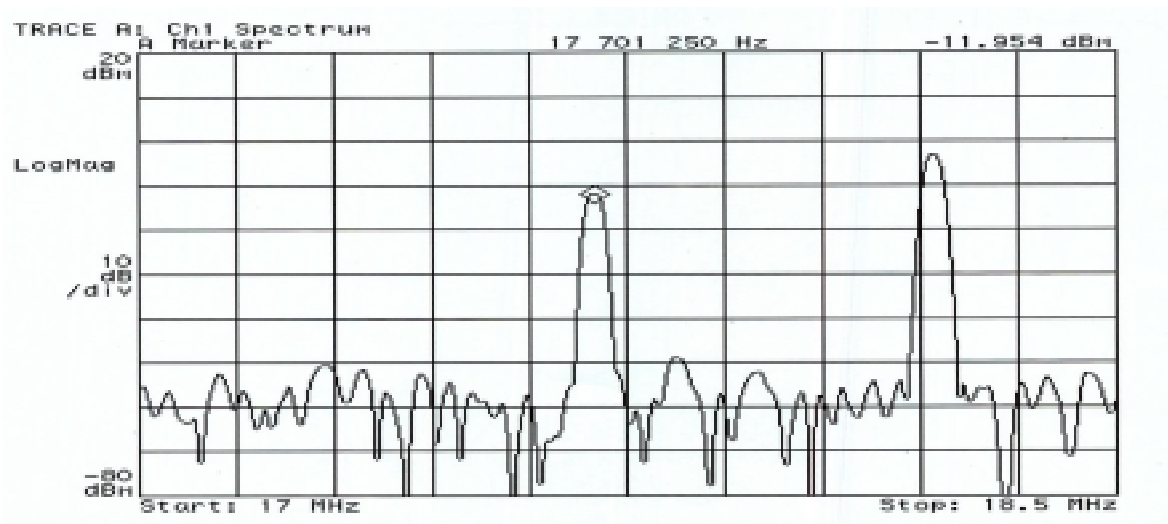

Figure 3.1: Local oscillator in receiver and 18.175MHz modulated signal

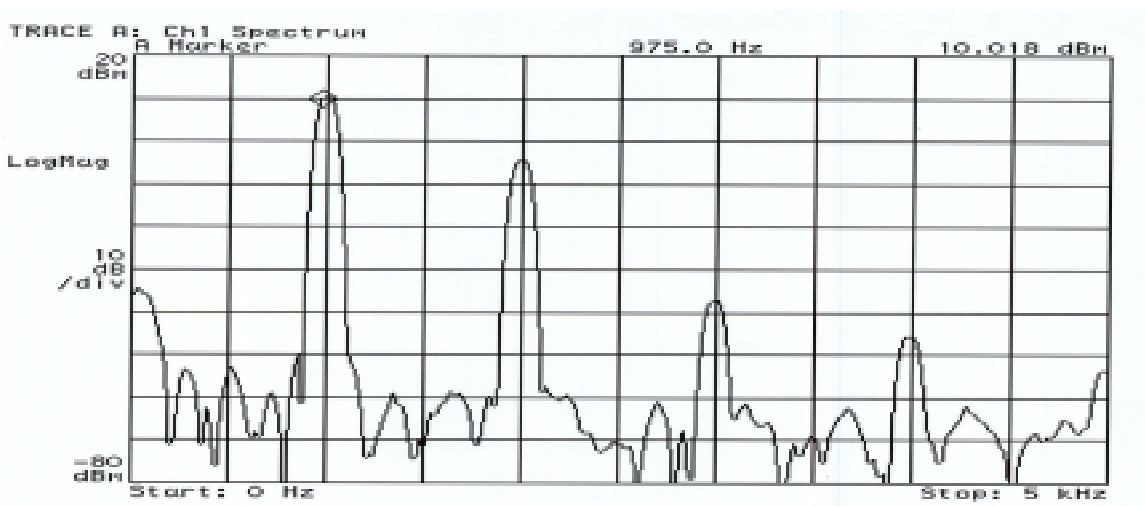

Figure 3.2: Demodulated 1KHz tone

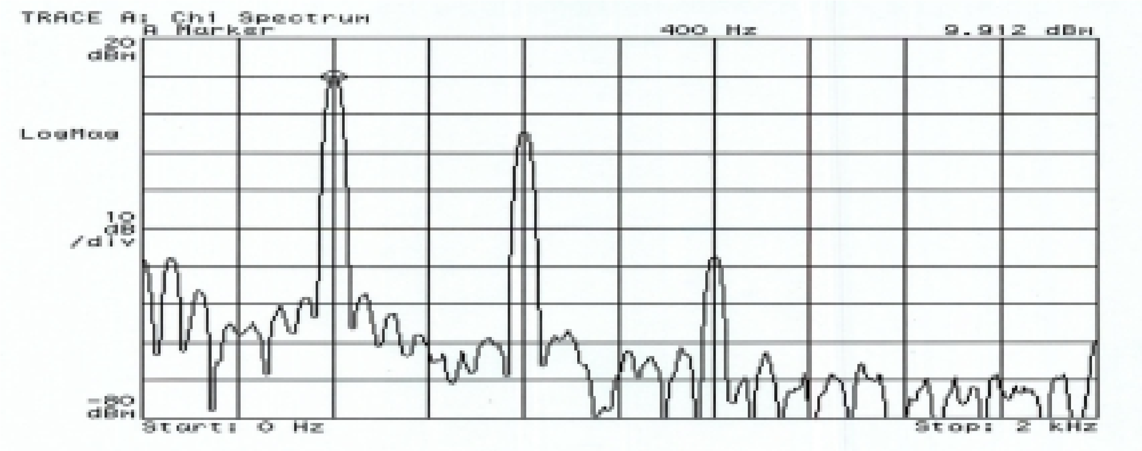

Figure 3.3: Demodulated 400 Hz tone

6. COST

The cost of our final project did not deviate too much from what we proposed. Our grand total was $19612.62 and the details are given in table 5.1.

Table 5.1: ITEMIZED COST OF PROJECT

	Hourly Wage	Overhead Modifier	Total Hours	Cost
Erick Gómez	$29	2.5	135	$9,787.50
Jeremiah Robbennolt	$29	2.5	135	$9,787.50
		total labor cost		$19,575
Parts	Cost			
Quartz Crystal .125MHz	$4.51			
Quartz Crystal 3MHz	$0.91			
MC3361	$1.58			
LM384 Audio Amp	$0.66			
Speakers	$9.99			
Miscellaneous (diodes,R,C,L,Op amp & transistors)	$20			
			Total Parts Cost	$37.65
			Grand Total	$19,612.65

7. CONCLUSION

The initial project targeted to implement an FM Transmitter and Receiver at 54 MHz. We halted the transmitter work, because of a technical challenge that we encountered on the receiver side. That is, the frequency of oscillation needed on the receiver was one third of the frequency needed to be able to demodulate a 54 MHz FM signal. As a result, we were able to produce an FM receiver that works at one third of the initial 54 MHz, which is 18.175 MHz. The .125 MHz term comes into place, because we perform the demodulation at 455 KHz.

The only improvement that our receiver system needs is a frequency mulitplier by 3 and a band-pass filter. This will allow us to achieve the desired 54 MHz channel. We also need to develop the transmitter circuit.