Final Report for Project Lab 3

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ECE 3333

Narrow Band FM Transmitter

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ABSTRACT

This is a report that provides descriptive information on the design and processes that were involved in the creation of a Narrow Band FM Transmitter. The transmitter is optimized in a way such that it can generate a tunable carrier frequency in the range 28 MHz to 29.7 MHz. The input of the system is sourced from an Electret Microphone which operates within the provided range of 200 Hz to 3000 Hz. In addition, the transmitter must generate +10dBm output signal, and all harmonics in the output signal must be suppressed within -60dBc.

This report consists detailed information on each of the components required to fulfill all the requirements for the project including descriptions, schematics, simulations and test readings. The paper also provides how all the components work together and the overall budget to show the cost incurred for the production of the project. A Gantt chart is also added how the team managed time and collaborated on a weekly basis to see the project through to its completion.

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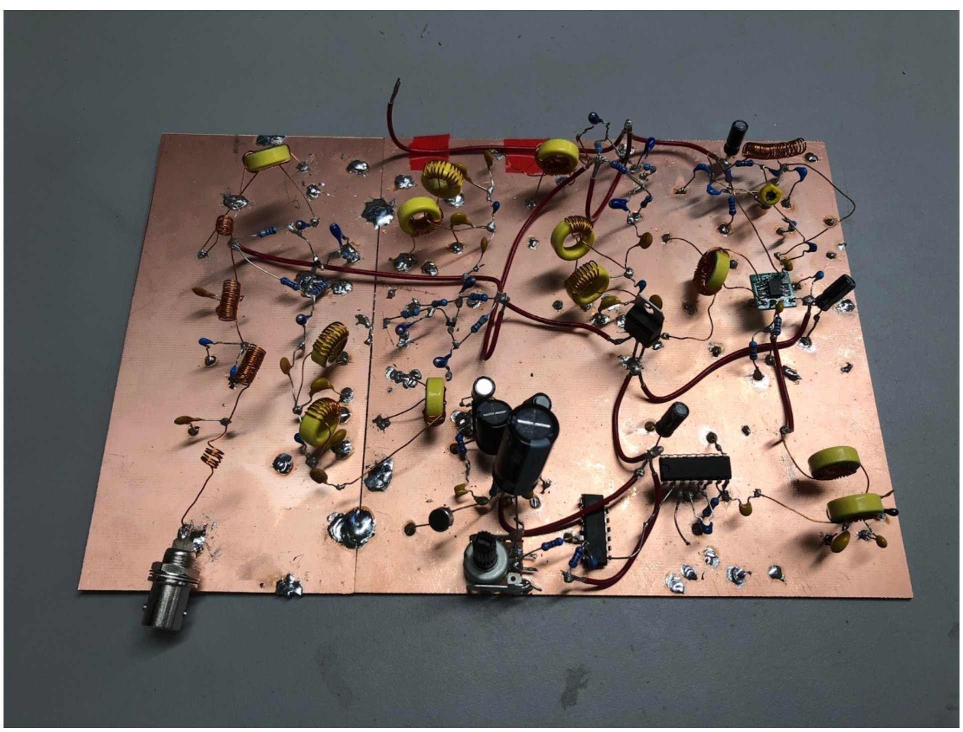
INTRODUCTION

The following paper provides detailed information of the planning, design processes, and implementation of the progress of the Narrow Band FM Transmitter Project. The paper provides information on each individual component being used in the engineering of the Narrow Band FM Transmitter that allows it to carry out the required tasks. The transmitter must be designed in a way such that it can generate an output with tunable carrier frequency in the range 28 MHz to 29.7 MHz. A Colpitts Oscillator is used as the Local Oscillator (LO) for the system for the tunable frequency generation. An Electret Microphone is used for the input signal of the system and operates within the provided range of 200 Hz to 3000 Hz. The output signal generated must be +10dBm and any harmonics on the output signal must be suppressed to -60dBc. Bandpass filter and Low Pass filter are used for suppressing harmonics on the output signal.



NBFM Transmitter

DESIGN

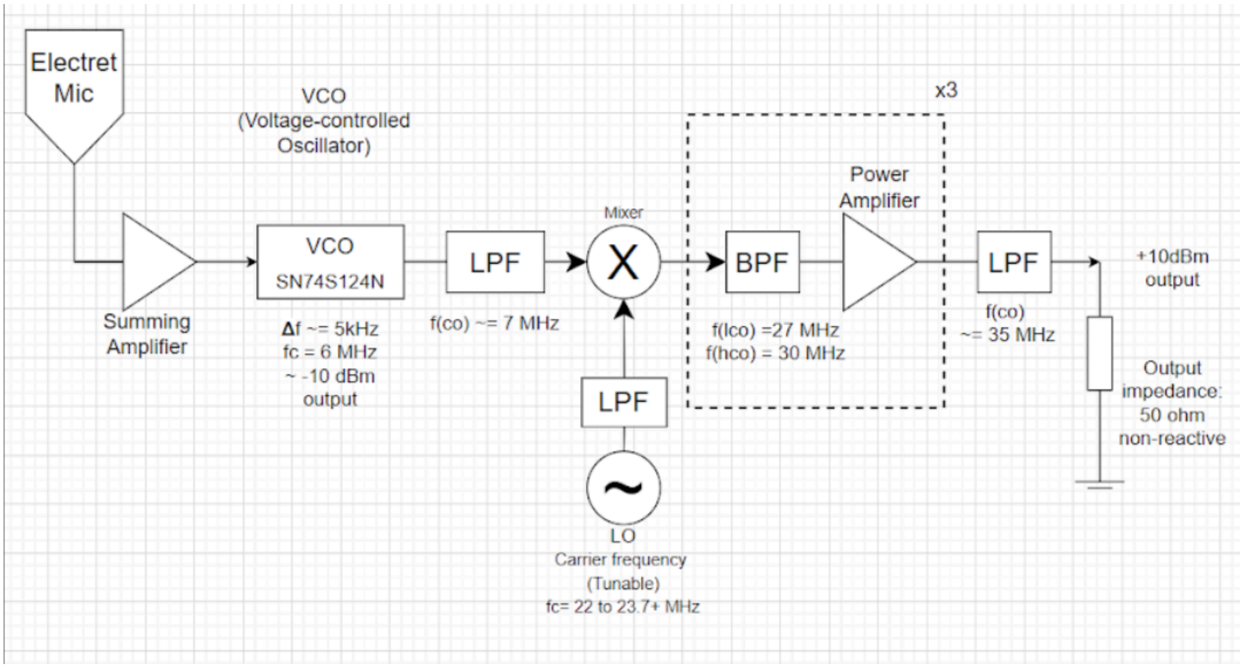


Figure 1: Block Diagram. A breakdown of what is being used and how we are using them to achieve the project requirements.

Figure 1 above is the block diagram for the Narrow Band FM Transmitter system. The input of the system is generated from an Electret Microphone passed through a Linear Amplifier. The sensitivity of the microphone has a rating of -38dBm and the Bandwidth it generates is 3 kHz. The signal is then passed through a Voltage-Controlled Oscillator (VCO) which has a frequency deviation of 5 kHz and a carrier frequency (fc) of 6 MHz with -25 dBm output. That signal is passed through a Low-Pass filter with a cutoff frequency at 6 MHz to suppress all harmonics outside of 6 MHz. A Colpitts Oscillator is used for generation the tunable carrier frequency within the required range of 28 MHz to 29 MHz. The Colpitts Oscillator generated the tunable frequency within the range 22 MHz to 23.7 MHz which adds with the signal of 6 MHz from the VCO at the SA602 mixer to generate a total of 28 MHz to 29.7 MHz. The signal from the mixer is then passed through a Linear Amplifier, which passes through a Band-Pass filter which suppresses the signal within 27 MHz to 30 MHz to cancel harmonics outside the range. A Power Amplifier is used to increase the power output to 10 dBm which is the project requirement.

ELECTRET MICROPHONE

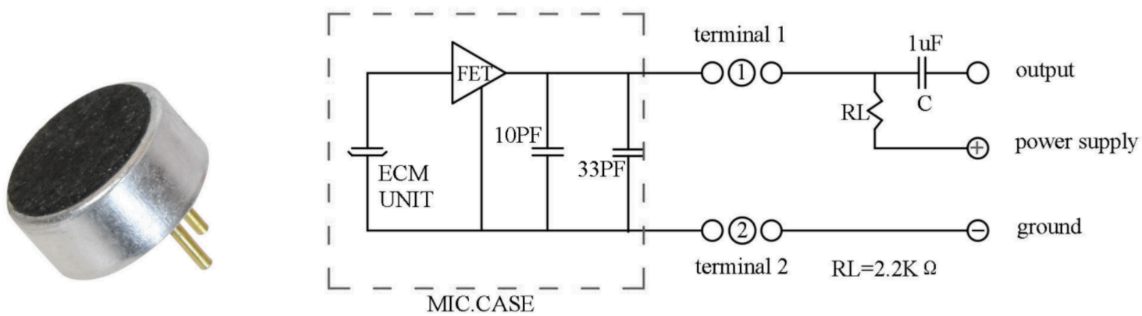


Figure 2: Electret Microphone [1]. General circuit schematic of the inside of an electret microphone casing.

The Electret Microphone being used is the CMEJ-0627-42-P [1]. Figure 2 above shows what the microphone looks like and the general circuit of the microphone to generate an output using a power supply. A 1uF capacitor needs to be used with a load resistance (RL) of 2.2KΩ to generate a signal on the output. The specifications of the microphone are as follows [1]:

Sensitivity (S): -45 to -39 dB

Supply voltage (VDD): 1 to 10 V

Current Consumption: with VDD 2V and RL 2.2kΩ is 0.5mA

Frequency range: 100 Hz to 10,000 Hz

Output Impedance (Zout): 1kΩ to 2.2kΩ

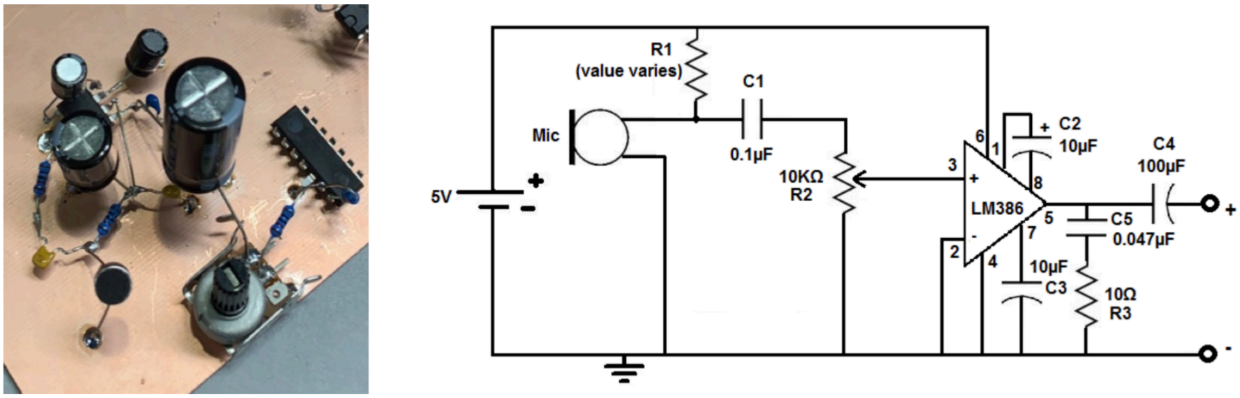


Figure 3: Audio Amplifier Circuit [3]. The photo on the left shows the physical build of the audio amplifier circuit using the CMEJ-0627-42-P microphone and the LM386 op-amp [2]. The figure on the right is the actual circuit schematic of the design that was built.

In order to amplify the signals from the electret microphone an audio amplifier circuit was designed using the LM386 op-amp. The circuit schematic for the design is shown on the right-hand side of Figure 3 above. A 470uF electrolytic capacitor was used instead of 100uF at C4. A 10uF capacitor was used on pin 7 to reduce noise. The 10uF capacitor from pins 1 and 8 makes the gain of the circuit 200. Instead of a 10kΩ potentiometer, a 10kΩ load resistor is used to connect the electret microphone. R1 is also set at 10kΩ.

ELECTRET MICROPHONE TESTING

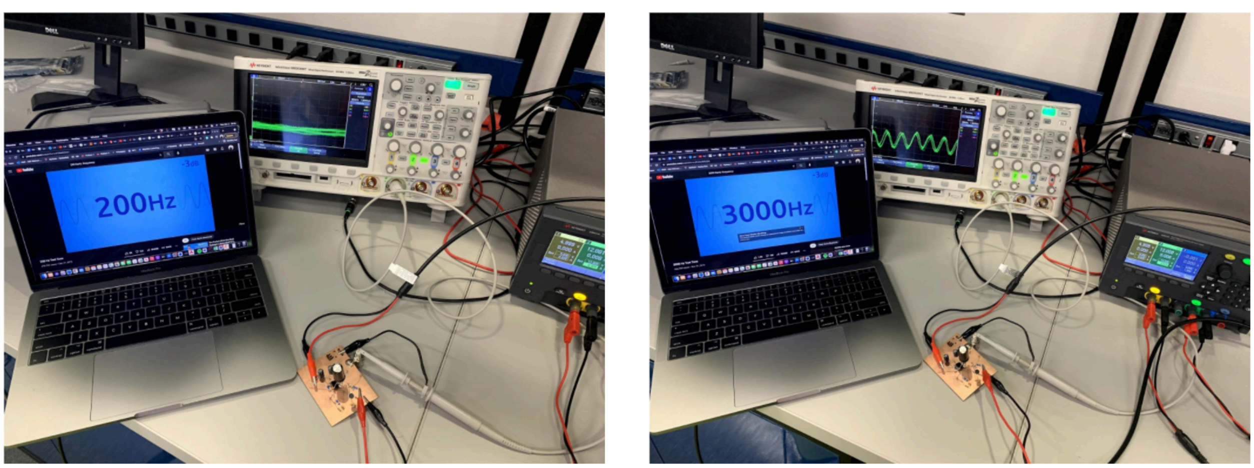


Figure 4: Testing of the Electret Microphone. Testing was conducted by using input audio signals at 200Hz and 3000Hz frequencies, and corresponding output readings were taken in an oscilloscope.

The electret microphone circuit with the audio amplifier was tested using 200 Hz and 3000 Hz frequency. The output for the corresponding audio input signals were tested in an oscilloscope. Due to 200Hz being a very low signal, not much can be observed on the oscilloscope for that signal. However, a perfect sine wave oscillation was obtained for the testing of the 3000Hz audio input.

The electret microphone provides the input for the VCO which requires an input voltage of approximately 250 mVpp. It is here where the potentiometer on the output of the amplifier is used to change the Vpp of the signal to meet the VCO requirements.

SUMMING AMPLIFIER

The VCO also requires a DC voltage on its input from the Electret Microphone. That voltage needs to be in the range of 1.5V to 2.5V. Initially, the electret microphone amplified circuit has a much lower DC offset (in the 100mV range). As a result, an LM348N summing amplifier [4] is used to provide the required DC offset for the VCO.

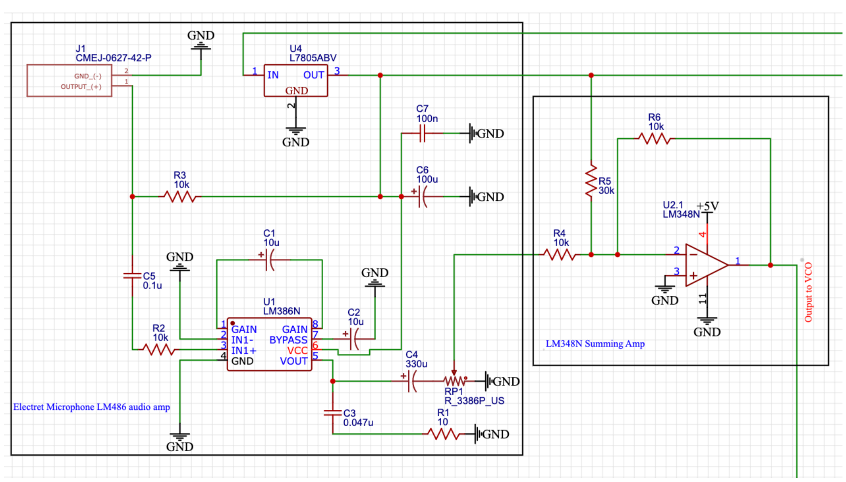


Figure 5: LM348N Summing amp with Electret Microphone Circuit. The Figure above shows the circuit schematic of the Summing Amp LM348N [4] on the block to the right. The block on the left is the electret microphone amplified circuit the output of which goes into the summing amp to generate the required DC Offset. The output from the Summing amp then goes into the input of the VCO.

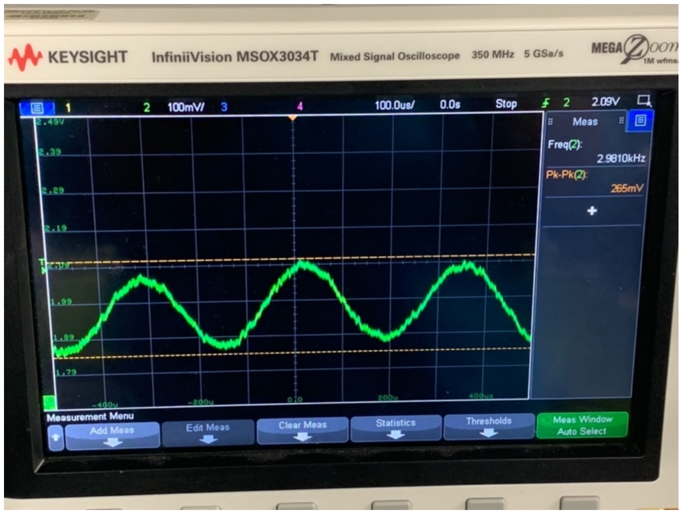


Figure 6: Testing the Microphone with the Summing amp. The Figure shows the results obtained when 3000Hz audio input signal is sent through the microphone. The results are obtained on an oscilloscope, and it can be seen that there is a DC offset of 2.09V which meets our requirement, along with 265mVpp which also meets the requirement for the VCO.

MODULATED AUDIO SIGNAL

Figure 7: Modulated mixed signal with audio frequencies. The mixed output from the NBFM transmitter was tested on a spectrum analyzer and the test was carried out for an audio input signal of 3000 Hz. The 100kΩ potentiometer on the output of the audio amplifier is used to change the Bandwidth of the modulated signal. The signal on the left has a higher bandwidth than the one on the right. The potentiometer allows us to keep the frequency deviation within 5kHz.

VOLTAGE-CONTROLLED OSCILLATOR (VCO)

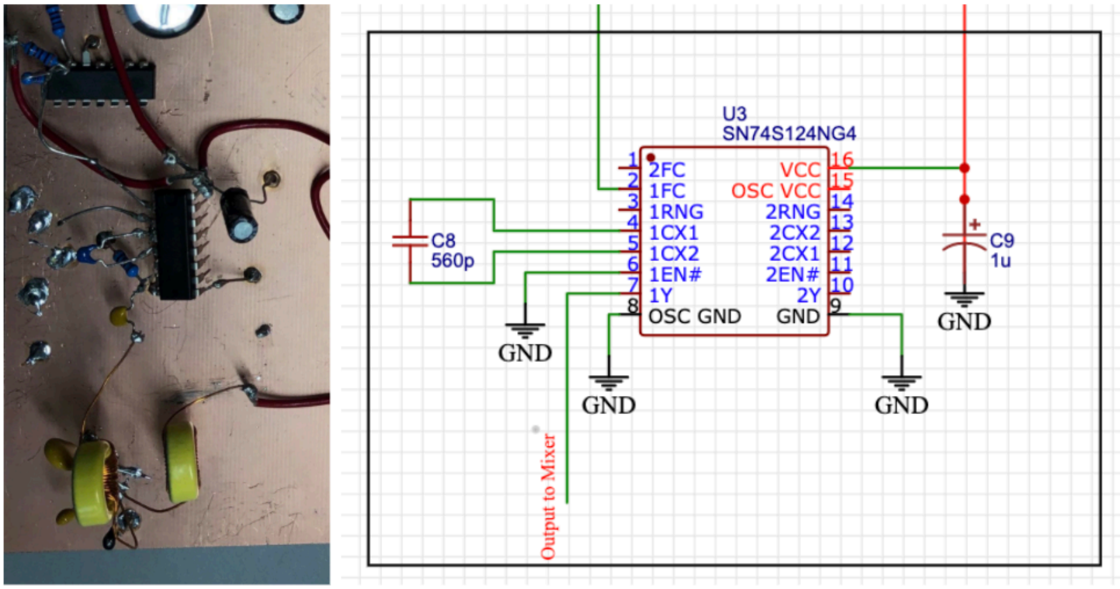


Figure 8: Voltage-Controlled Oscillator Circuit & Schematic. The Figure shows the actual build of the VCO with a LPF on its output and to the right is the schematic of the SN74S124NG4 [5] VCO with all the required connections on its pins.

The VCO being used is the SN74S124 [5] and the connections of the pins is showed in Figure 8 above. The VCO uses the signal from the Electret Microphone as an input signal voltage and delivers an output signal. The frequency output from the VCO is determined by the voltage level from the VCO. A 560pF capacitor connects to the CX1 pin on the VCO which results in the base frequency of 6 MHz. The Vcc to the VCO is 5V and there is a 2 VDC offset along with the modulating signal from the microphone into the Vin pin of the VCO. This causes the signal from the VCO to have a 5 kHz deviation. The output from the VCO is sent through pin 1Y which sends an FM Modulated output signal with a carrier frequency of 6 MHz to the Mixer. This signal adds with the frequency from the Local Oscillator (Colpitts Oscillator) which gives us the required carrier frequency of 28 to 29.7 MHz.

VOLTAGE-CONTROLLED OSCILLATOR TESTING

Figure 9: Output signal from VCO before and after filtering. A Low Pass Filter was connected on the output of the VCO. The output signal was tested on an oscilloscope once before filter was applied (left) and once after filter is applied (right). Before filtering a variation of a square wave signal was obtained. After filtering, the LPF produced a sine wave for the output of the VCO to go into the mixer.

TUNABLE COLPITTS OSCILLATOR

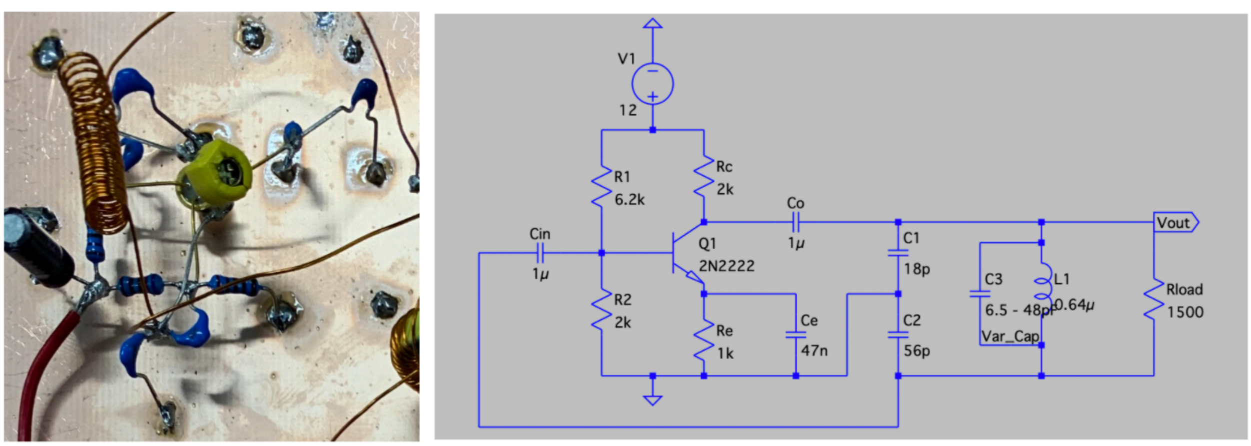


Figure 10: Tunable Colpitts Oscillator Circuit. The picture on the left shows the actual physical build of the Colpitts Oscillator, and to the right is its circuit schematic. A 2N2222 transistor was used along with 18pF and 56pF for C1 and C2 respectively, and an air core inductor was created for 0.64uH.

A variable capacitor with the range of 6.5pF to 48pF is used for tuning the carrier frequency of the oscillator. The above Colpitts oscillator is tunable within the range 21MHz to 37MHz. Which covers the required range for the project specifications. Required frequency from the LO is 22MHz to 23.7MHz. The oscillator was designed by considering a load resistance of 1500Ω which is also the input resistance for the mixer. As a result, no impedance matching is required on the output of the oscillator. The frequency from the Colpitts oscillator adds with the 6MHz frequency from the VCO on the mixer to give the modulated mixed signal.

TUNABLE COLPITTS OSCILLATOR TESTING

Figure 11: Colpitts Oscillator Oscillation. The Colpitts Oscillator was tested on an oscilloscope. A sine wave oscillation was obtained on the oscilloscope. A sine wave was generated with a frequency of 28 MHz and a Vrms of 238mV which is essential for its connection with the mixer.

TUNING OF THE MODULATED SIGNAL

Figure 12: Tuning of Modulated Mixed Signal. The NBFM Transmitter was connected to the Spectrum Analyzer, and the modulated signal was tuned using the variable capacitor on the Colpitts Oscillator. The modulated signal tuned perfectly within the required range of 28MHz to 29.7MHz with almost no loss in signal strength.

MIXER

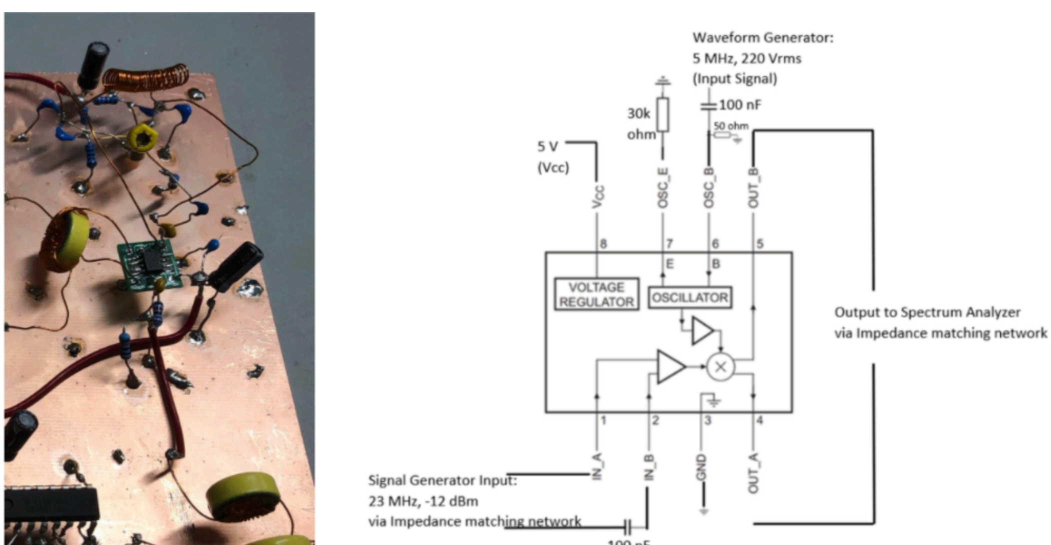


Figure 13: SA602A Mixer. The Figure shows the physical build of the SA602A [6] mixer and its connections. The mixer connects directly with the Colpitts Oscillator on the pin IN_A and the output frequency from the VCO goes into pin OSC_B. The frequency there is 6MHz instead of 5MHz as showed.

The Mixer being used is the SA602. The Mixer adds the frequency from the VCO to the frequency from the Local Oscillator (Colpitts Oscillator). So, the Mixer will effectively add the 6 MHz carrier frequency to the 22 to 23.7 MHz from the Colpitts Oscillator essentially resulting in the carrier frequency to be 28 to 29.7 MHz. This is the output from the Mixer which then passes through the Band-Pass Filter to omit any harmonics outside the range. The output from the Colpitts Oscillator is input into the Mixer through the IN_A pin. The output signal from VCO is input into the Mixer through the OSC_B pin. The output from the Mixer is tested on the Spectrum Analyzer.

MIXER TESTING

Figure 14: Mixer Testing. This is the output signal from the Mixer as it mixes the signals from both the VCO (5MHz) and Colpitts Oscillator (22-23.7MHz) during the original design stage. For this test, there were to amplifications or filtering applied. As a result, numerous harmonics can be observed.

Frequency and Corresponding power readings:

24 MHz at -23.72 dBm

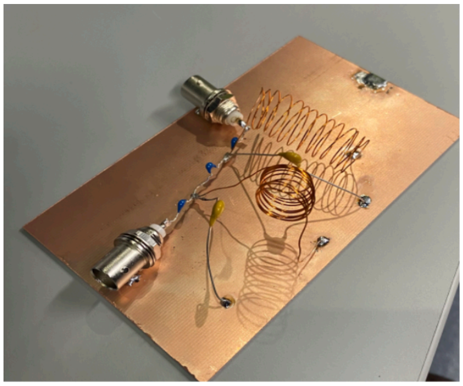
28 MHz at -40 dBm

Output bandwidth of the mixed signal is 2(3kHz +5kHz) = 16 kHz. The range of the VCO and frequency tuning can be used to widen the Bandwidth. Band-Pass Filters are used to filter out the harmonics.

FILTERS & AMPLIFIERS

The Transmitted signal has a lot of harmonics and very low signal strength. As a result, multiple stages of amplifiers are required to increase the signal strength to our required level, and same number of stages of band-pass filters are used to suppress the amplified harmonic signals.

BAND-PASS FILTERS



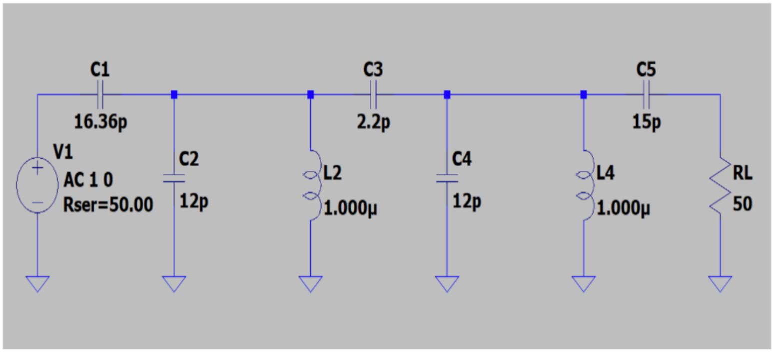


Figure 15: Band-Pass Filter Circuit. The Figure shows the Band-Pass Filter circuit and its schematic.

The Band-Pass Filter was used to suppress the frequency output from the Mixer within 27 MHz to 30 MHz to cancel out any harmonics that are outside that range. The Band-Pass Filter is a second Order Butterworth Filter. The Band-Pass Filter limits the frequency output of the system within the required tunable range of 28 to 29.7 MHz. Three stages of this Band-Pass Filter are used paired with a power amplifier for filtering and amplification purposes.

BAND-PASS FILTER TESTING

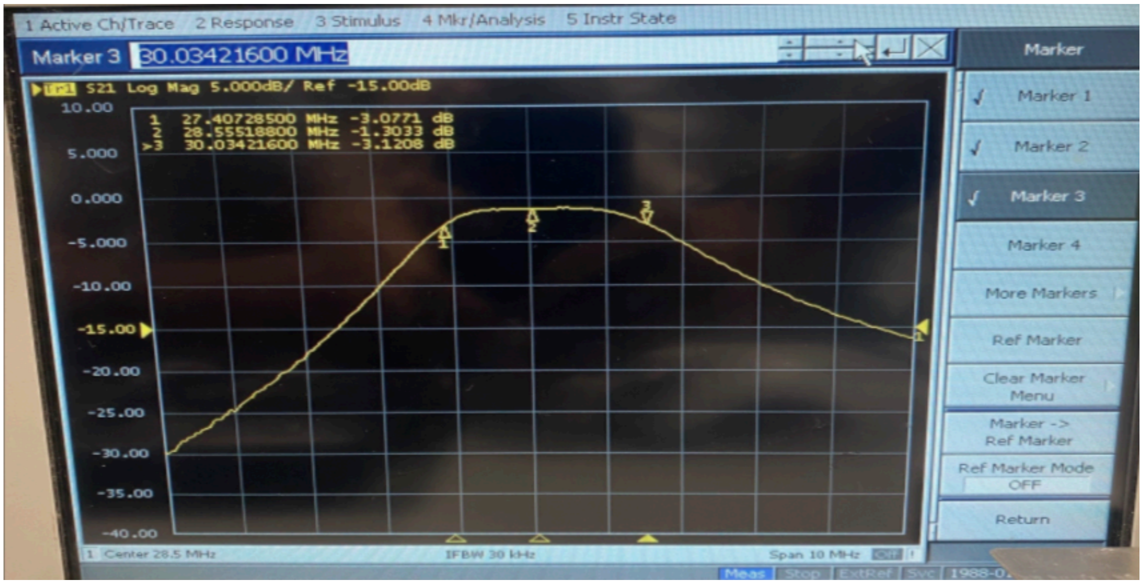


Figure 16: Band-Pass Filter Testing. The above figure is for the testing of the Band-Pass Filter on the Network Analyzer. The results show that the Band-Pass Filter works to the project requirement. Filter is successful at keeping the frequency range between 27 to 30 MHz. Therefore, markers were set up on the frequency intervals of 27 MHz, 28.5 MHz and 30 MHz and the dB loss for each interval was observed. The dB loss for each marker were observed to be -3 dB, -1.3 dB and -3.1 dB respectively.

POWER AMPLIFIER

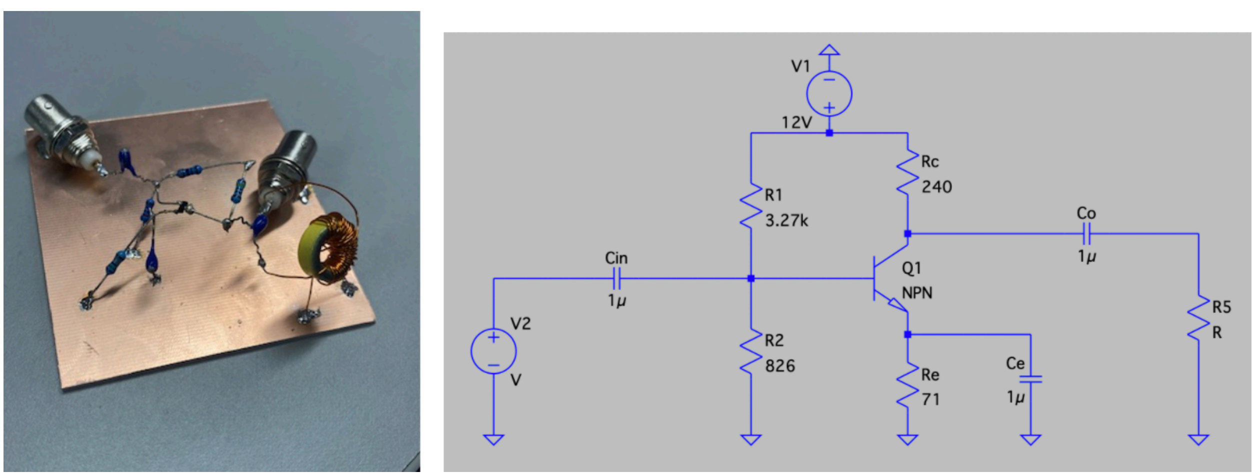


Figure 17: Power Amplifier Circuit. The Figure shows the power amplifier circuit to the left and its circuit schematic to the right. The BFS20 [7] transistor is used for the power amplification purposes.

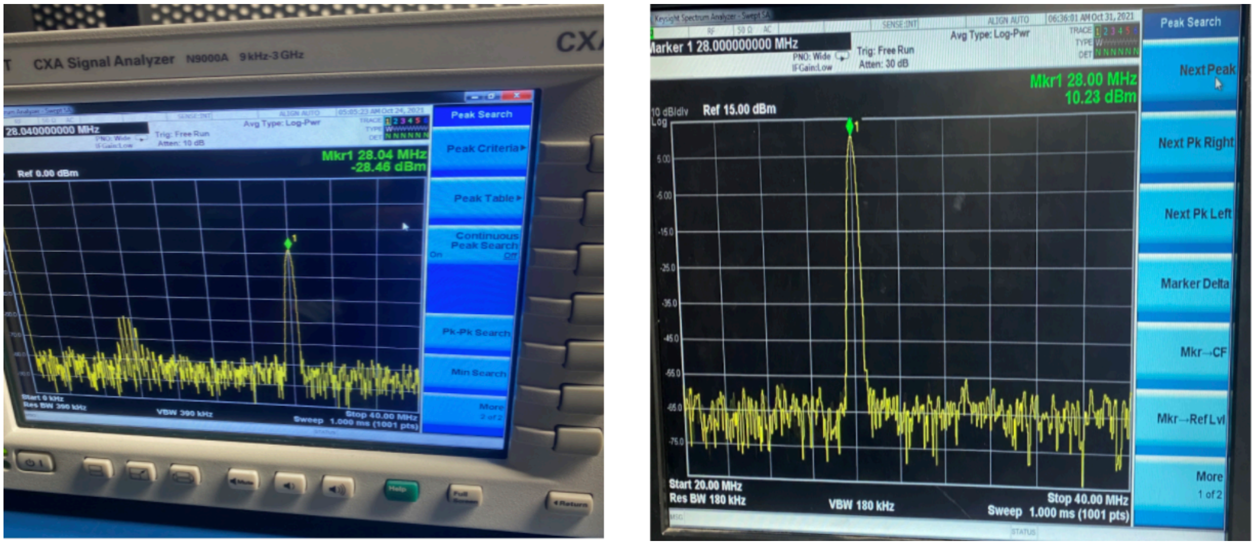


Figure 18: Power Amplifier Testing. The power amplifier was connected to the spectrum analyzer and tested. The result on the left is before amplification. The result to the right is after amplification. It was observed that the power amplifier has the ability to read a power level of +10.23dBm which is required for project specifications.

LOW-PASS FILTER

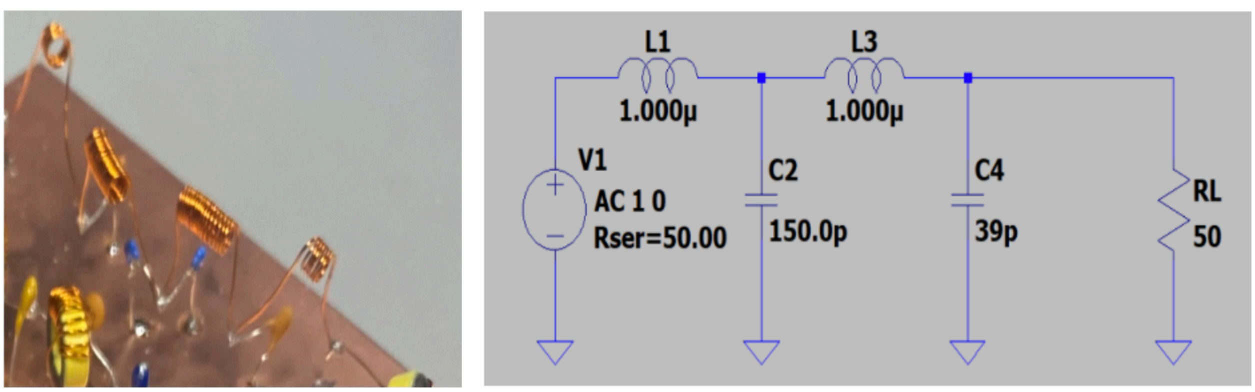


Figure 19: Low-Pass Filter Circuit. The picture on the left is the Low-Pass Filter Circuit and the one on the right is its circuit schematic. The Low-Pass Filter being used is a fourth order Butterworth Filter.

The Low-Pass Filter is used to suppress the frequency on the transmitted signal. The Low-Pass Filter has a cutoff at 30 MHz. So, any harmonics above that level are cancelled out by the filter.

LOW-PASS FILTER TESTING

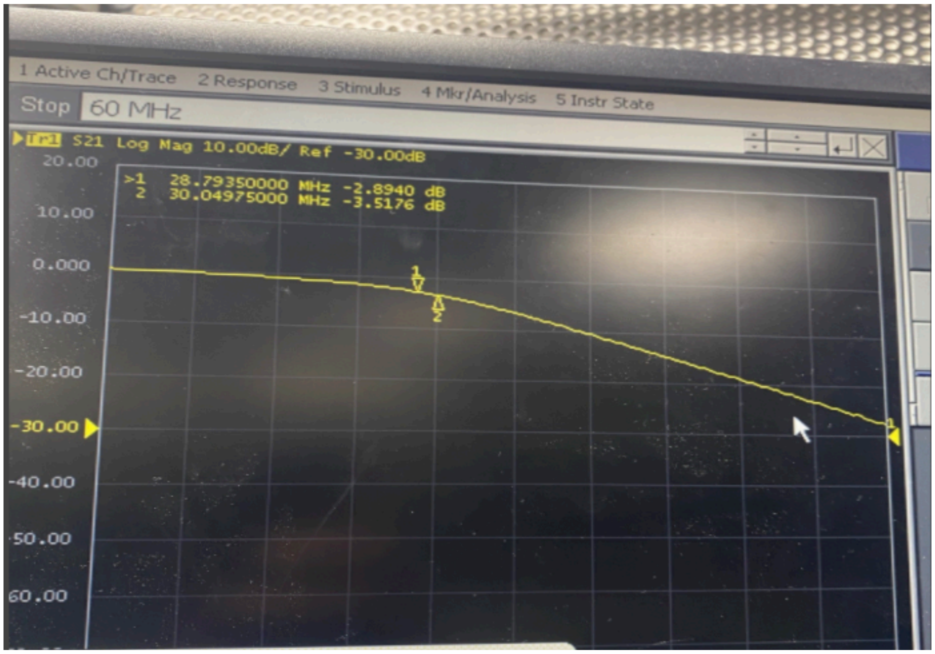


Figure 20: Low-Pass Filter Testing. The LPF was tested on the Network Analyzer. The markers on the network analyzer were set at 28.79 MHz and 30 MHz and the corresponding power values were obtained. At 28.79 MHz, the power is -2.89 dB and at 30 MHz the power is -3.5 dB. From the analysis it can be observed that any harmonics outside the 30 MHz range were cancelled out.

TRANSMITTED SIGNAL WITH FILTERS AND AMPLIFIERS

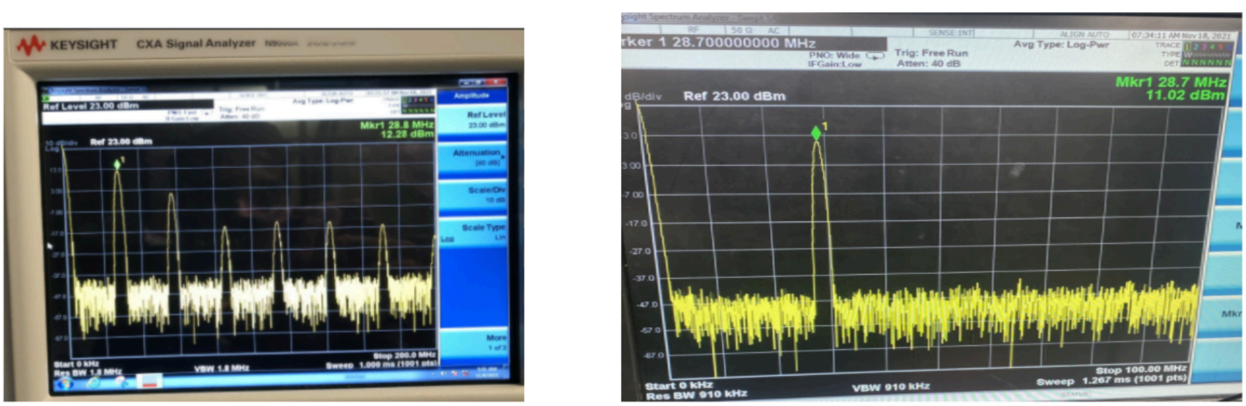


Figure 21: Transmitted signal testing with filters and amplifiers. The Figure shows how the transmitted signal changed after adding three stages of Band-Pass Filters, and one Low-Pass Filter in the output. All spurious outputs and harmonics were suppressed, and the signal strength also remained at +10dBm as per the project requirements.

FINAL SET UP OF THE ENTIRE SYSTEM

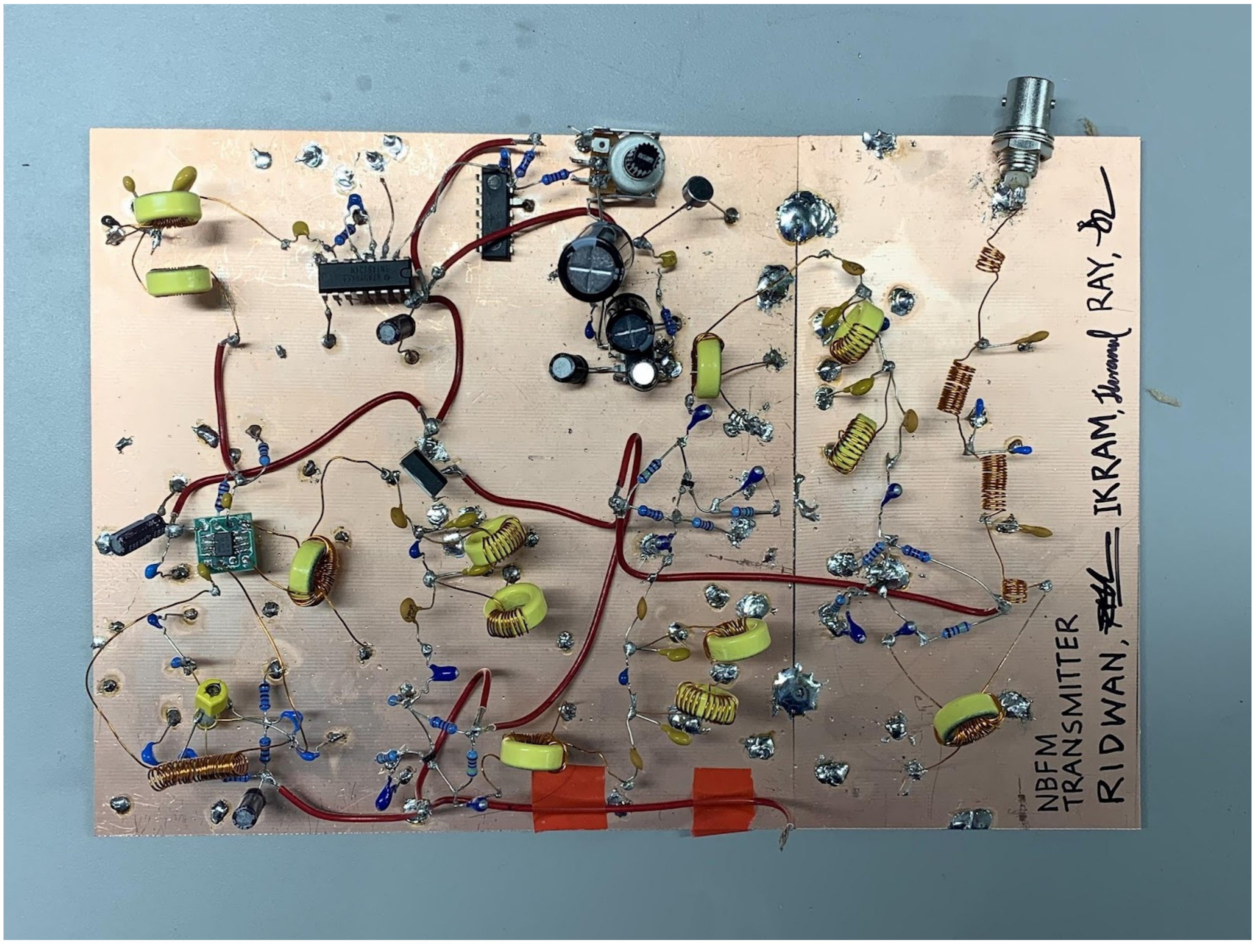


Figure 22: NBFM Transmitter Final Setup

CONCLUSION

In conclusion, the Narrow Band FM Transmitter was able to meet all its project requirements. The CMEJ-0627-42-P Electret Microphone which works as the input of the system works perfectly when applied with audio input signals within the range of 200Hz to 3000Hz. The signal is amplified using an LM386 audio amplifier, and then a LM348N summing amp is used to apply a DC voltage for the VCO. The 100kΩ potentiometer on the output of the microphone allows us to not only control the Vpp going into the VCO, but also the Bandwidth of the modulated signal so that we can keep it within 5kHz deviation. The SN74S124 VCO generates a carrier frequency of 6MHz which adds with the tunable carrier frequency range of 22 MHz to 23.7Mhz from the Colpitts Oscillator. The SA602A mixer adds the two frequencies and generates an output signal. This modulated signal however has very low signal strength and has a lot of harmonics outside the required range. As a result, three stages of band-pass filters and power amplifiers are added to suppress all harmonic within -60dBc and amplify the signal strength to +10dBm. As all the project specifications were met, it is safe to conclude that the project was an overall success.

APPENDIX

BUDGET

Project Lab 3	*Running Total*			*Total Estimate*			Start Date	9/6/21
Direct Labor:							Today	11/22/21
Category or individual:	*Rate/Hr*	*Hrs*		*Rate/Hr*	*Hrs*			
MD Ridwan Rahman	20	170	$3,400.00	15	200	$3,000.00	End Date	1/22/21
Mir Ikramul Haque	20	167	$3,340.00	15	200	$3,000.00		
Levonia Ray	20	163	$3,260.00	15	200	$3,000.00		
DL Subtotal (DL)		Subtotal:	$10,000.00		Subtotal:	$9,000.00		
Labor Overhead	*rate:*	100%	$10,000.00	*rate:*	100%	$9,000.00		
Total Direct Labor (TDL)			$20,000.00			$18,000.00		
Contract Labor:								
Lab Assistant	40	0	$0.00	40	25	$1,000.00		
Classmate	20	4	$80.00	15	20	$300.00		
Instructor	200	1	$200.00	200	15	$3,000.00		
Total Contract Labor (TCL)			$280.00			$4,300.00		
Direct Material Costs:			$69.19			$800.00		
(from Material Cost worksheet)								
Total Direct Material Costs: (TDM)			$69.19			$800.00		
Equipment Rental Costs:	Value	Rental Rate		Value	Rental Rate		Date begin	Date end
Keysight Spectrum Analyzer	$25,101.00	0.20%	$3,765.15	$25,101.00	0.20%	$3,765.15	9/6/21	11/21/21
Oscilloscope	$259.00	0.20%	$39.89	$259.00	0.20%	$39.37	9/6/21	11/21/21
Power Supply	$60.00	0.20%	$9.24	$60.00	0.20%	$9.12	9/6/21	11/21/21
Function Generator	$310.00	0.20%	$47.74	$310.00	0.20%	$47.12	9/6/21	11/21/21
Soldering Iron	$125.00	0.20%	$19.25	$125.00	0.20%	$19.00	9/6/21	11/21/21
Multimeter	$95.00	0.20%	$14.63	$95.00	0.20%	$14.44	9/6/21	11/21/21
Total Rental Costs: (TRM)			$690.56			$3,894.20		
Total TDL+TCL+TDM+TRM			$21,039.75			$26,994.20		
Business overhead		55%	$11,571.86		55%	$14,846.81		
Total Cost:		**Current**	$32,611.61		**Estimate**	$41,841.01		

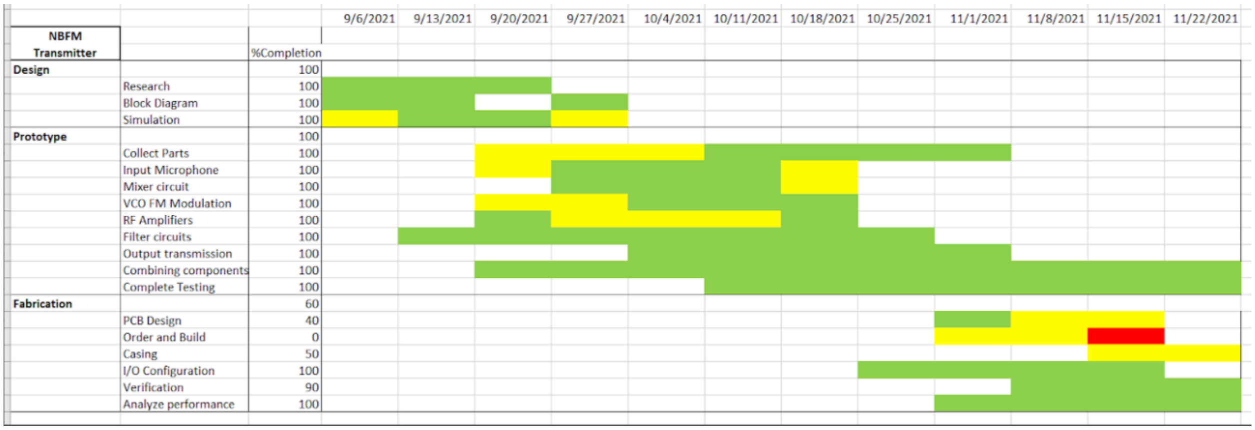
Name	Cost	quantity	notes/website	purchase date	total		TOTAL
Electret Microphone	$0.61	7	mouser.com	9/15/21	$4.27		$69.19
30 MHz crystal	$0.65	2	mouser.com	9/18/21	$1.30		
595-SN74S124N VCO	$6.71	6	mouser.com	9/18/21	$40.26		
584-LTC6990ISGTRMPBF VCC	$4.61	1	mouser.com	9/18/21	$4.61		
SA602 Mixer	$3.35	5	mouser.com	9/18/21	$16.75		
BFS20215 RF Transistors	$0.40	5	mouser.com	10/15/21	$2.00		

The overall budget for the project shows the hours of each member and hours of additional help obtained from classmates and the instructor. The Direct Material Cost is added for each component ordered through stockroom throughout the project, and Equipment Rental Costs were added for each equipment borrowed from the stockroom or used in the lab. At the end of the project, the Cost of Production was at $32,611.61, which is $9229.4 under the estimated budget.

The cost of each unit is measured by taking the cost of each component used on the final setup and adding all their prices. Through that system, cost of each unit is $48.99

Approximately 667 units will need to be sold in order to breakeven and then eventually start to generate profit.

GANTT CHART



From the Gantt Chart it can be seen that we are currently on track with the weekly progress of the project. As the project was a success, all project requirements were met in a timely manner except for the PCB design requirement for better professionalism.

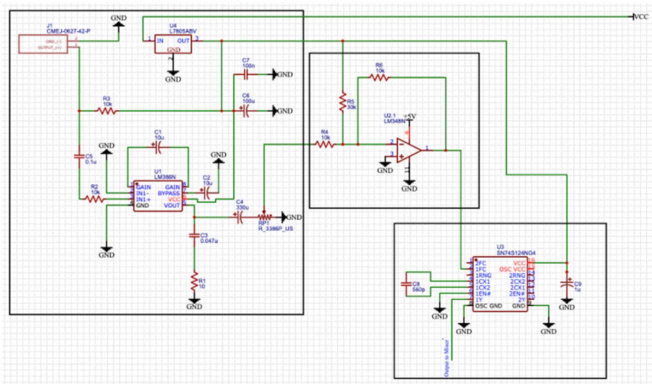
ETHICAL CONCERNS

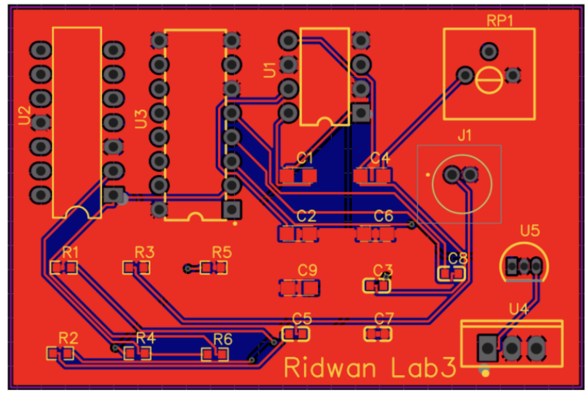
The projects worked at the ECE labs have certain ethical concerns. All the components used for the development of this project were either obtained from the ECE stockroom or ordered through the ECE stockroom. There was no third-party involvement of any manner on the overall project. The project was worked on by the members of the group with advice and help from the instructor Dr Jacob Stephens and occasional help from fellow classmates. The project has been worked on with utmost commitment and integrity by each member of the group to ensure that the project meets its completion in an ethical standard that falls under the code of conduct.

POTENTIAL ENHANCEMENTS

There are certain improvements that can be made to better our overall project.

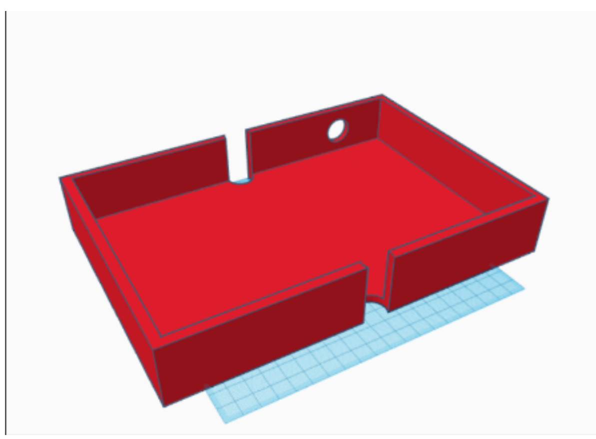
For starters the whole setup can be constructed into a PCB for a more refined build and greater stability for the signals.





A PCB idea was entertained by the group. But it was not created due to lack of time.

Other potential enhancements can be implemented by putting the setup on an enclosure to easily carry the setup and make it more compact and portable.



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2. **LM386 op-amp: https://www.ti.com/lit/ds/symlink/lm386.pdf**

3. **Microphone Circuit with op-amp: http://www.learningaboutelectronics.com/Articles/Microphone-amplifier-circuit.php**

4. **LM348N Summing amp: https://www.ti.com/lit/ds/symlink/lm248.pdf?ts=1638216727747&ref_url=https%253A%252F%252Fwww.google.com%252F**

5. **SN74S124 VCO: https://www.ti.com/lit/ds/symlink/sn74s124.pdf?ts=1634407263895&ref_url=https%253A%252F%252Fwww.google.com.mx%252Furl%253Fesrc%253Ds%2526q%253D%2526rct%253Dj%2526sa%253DU%2526url%253Dhttps%253A%252F%252Fwww.ti.com%252Flit%252Fgpn%252Fsn74s124%2526ved%253D2ahUKEwjb0rqdwc_zAhXTmGoFHQTmB_kQFnoECAkQAg%2526usg%253DAOvVaw1PRN6kB-9lr1ZYuE4GTGEr**

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7. **Power Amplifier (BFS20): https://www.digchip.com/datasheets/parts/datasheet/539/BFS20-pdf.php**

8. **RF Tools: https://rf-tools.com/lc-filter/**

9. **Dr. Jacob Stephens**

10. **Texas Tech University, ECE Stockroom**