

EE198B
Senior Project
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Transceiver for Wireless Speaker System

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Abstract

The demands of the transceiver are increasing in home entertainment uses. There are many different signals are transmitting at the same time. For the receiver to pick up the right signal, the original message signal must be modulated with a carrier signal before sending out. There are several different kinds of modulation technique available. Because of power efficient, frequency modulation is used in this project. In this project, the transceiver's abilities of transmitting and receiving are tested. If the transceiver is able to pass this test, it is considered to be a success product.

Introduction

Using wireless communication technology for home entertainment becomes popular. Wireless speaker system is not a new invention for this century; however, the goal of this project is to improve the size, quality and range of the communication system. In order to build a good communication system, a good transceiver is necessary. Generally speaking, each transceiver is designed for its own purpose and for some specific applications. A transceiver works perfectly for one application may not suit for another situation. The transceiver of this project is designed a wireless speaker system.

Theory of Modulation

There could be many signals transmitting at the same time, for example, there are many different signals transmitted by radio stations and TV stations at the same time.

Figure 1 shows that there are several signals exist at the same time, and those signals are displayed by a spectrum analyzer.

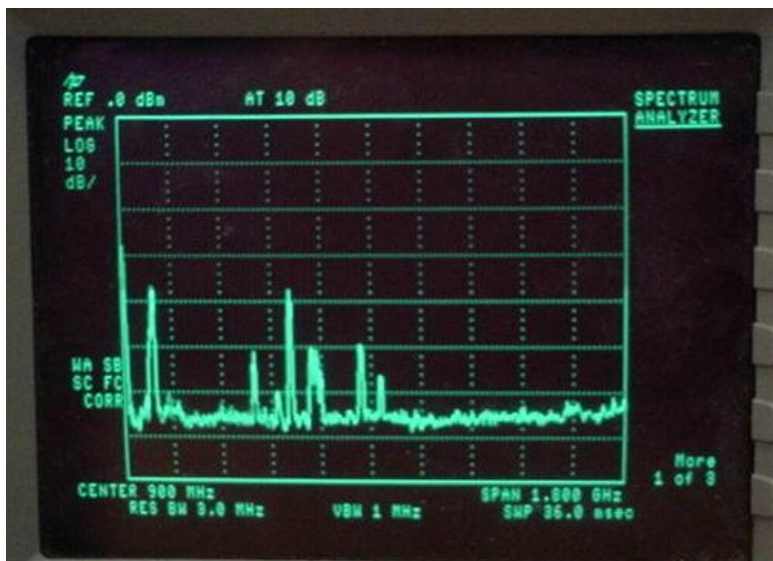


Figure 1: Several signals with different frequencies are displayed by the spectrum analyzer.

For the receiver able to receive the desired signal, the desired signal is need to be modulated before it is transmitted. Explain it in simple way, modulation is like multiplying the message signal, $m(t)$, and the carrier signal, $c(t)$, and become a modulated signal, $u(t)$. Depending on the carrier frequency, the modulated signal will be picked up by the receiver tuned at a specified channel or frequency.

There are several different modulation technologies, for instances, amplitude modulation (AM), frequency modulation (FM), pulse amplitude modulation (PAM), and frequency shift keying (FSK). The AM and FM are used for analog communication. On the other hands, PAM and FSK are used for digital communication. The concepts of the amplitude modulation and pulse amplitude modulation are similar. The amplitude of the modulated

signal varies, and different amplitudes represent different data. Vice versa, the frequency modulation and the frequency shift keying are similar. Instead of the amplitude, the frequency of the carrier signal is varies, and different frequencies correspond to different data. Certainly, there are many other different modulations like phase modulation for analog and phase shift keying for digital. Sending and receiving an audio signal is one of the analog communications. So, in this project, either amplitude modulation (AM) or frequency modulation (FM) can be used.

One of the primary advantages of FM is that the modulation is contained in carrier frequency variations and not in amplitude changes like AM, which would be susceptible to noise and interference. This means that it can remove any noise and not affecting the desired information. Using FM to send and receive the audio signal in this project is more appropriate.

In angle modulation, the spectral components of the modulated waveform are not related in any simple fashion to the message spectrum. Furthermore, superstition does not apply, and the bandwidth of the angle-modulated signal is usually much greater than twice the message bandwidth. The increase in bandwidth and system complexity is compensated for by the improved performance in the face of noise and interference.

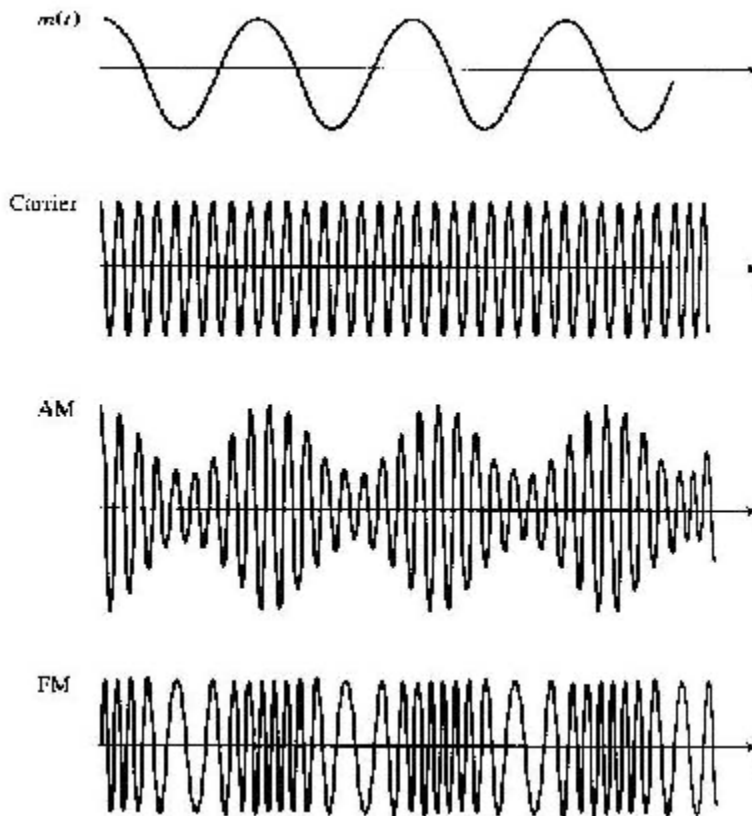


Figure 2: The typical waveform of the AM and FM signals.

The idea of frequency modulation, where the carrier frequency would be varied in proportion to message $m(t)$. The carrier frequency $\omega(t) = \omega_c + km(t)$, where k is an arbitrary constant. If the peak amplitude of $m(t)$ is m_p , then the maximum and minimum

values of the carrier frequency would be $\omega_c + km_p$ and $\omega_c - km_p$. Hence, the spectral components would remain within this band with a bandwidth $2km_p$ centered at ω_c . The bandwidth is controlled by the arbitrary constant k .

In the project, 89.90MHz had been chosen as the carrier frequency in FM radio band because using any normal FM radio can receive the signal inside the range. Both of the transmitter circuit and the receiver circuit can be tuned from 87.75MHz to 108MHz.

Advantages and Disadvantages of Frequency Modulation

Advantages:

- ◆ Frequency varies and amplitude stays same
- ◆ Another method of modulating the carrier is to vary its frequency
- ◆ during the positive portion of the audio signal the frequency of the carrier gradually increases; during the negative period the carrier frequency is decreased
- ◆ The maximum modulating frequency permitted by FM broadcast stations is 15 kHz
- ◆ slight changes in amplitude don't matter since the audio signal is conveyed through changes in frequency

Disadvantages:

- ◆ Does not have linear-modulation method
- ◆ Amplitude does not vary and frequency stays same
- ◆ Can not superimpose the sound on the carrier by varying the amplitude of the carrier
- ◆ Cannot transmit the video, or picture, signals by FM

The Major Parts of the Project

- 1) FM Transmitter.
- 2) FM Receiver.
- 3) Two Antenna Whips.
- 4) Two PC Speakers 8W 4Ω

Block Diagram of the wireless speaker system

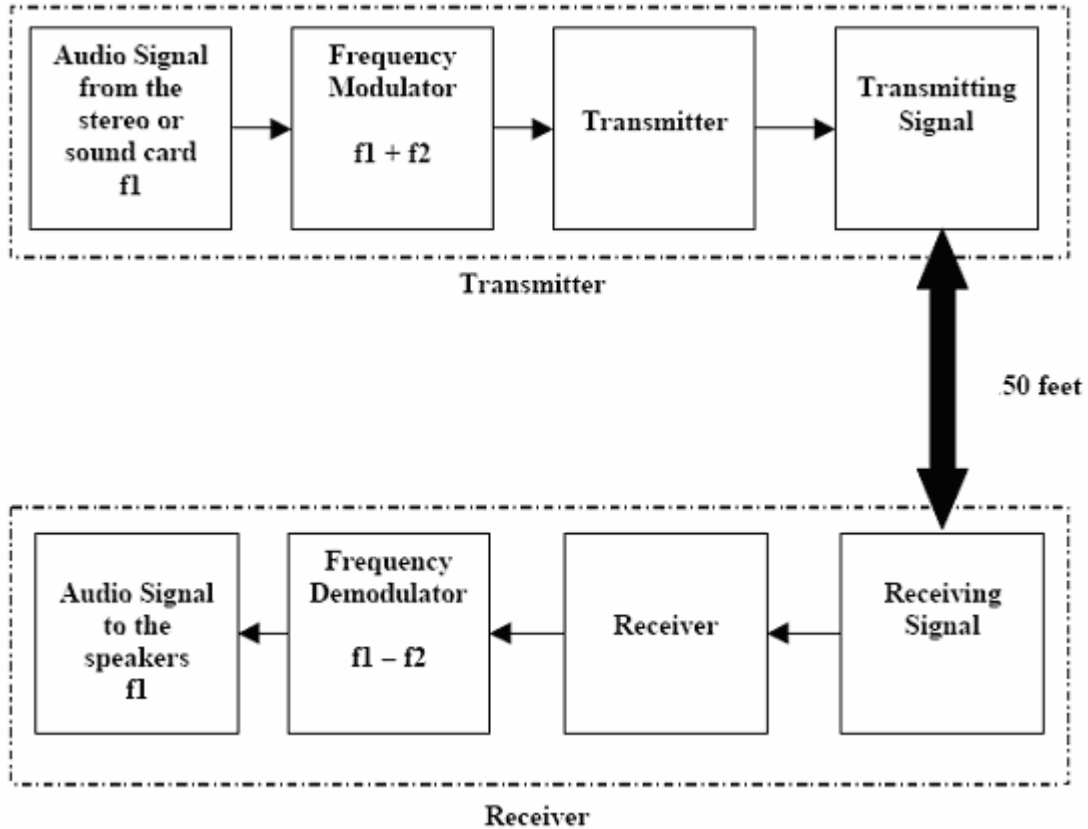


Figure 3: Block diagram of the FM wireless link

1. Transmitter Block Diagram

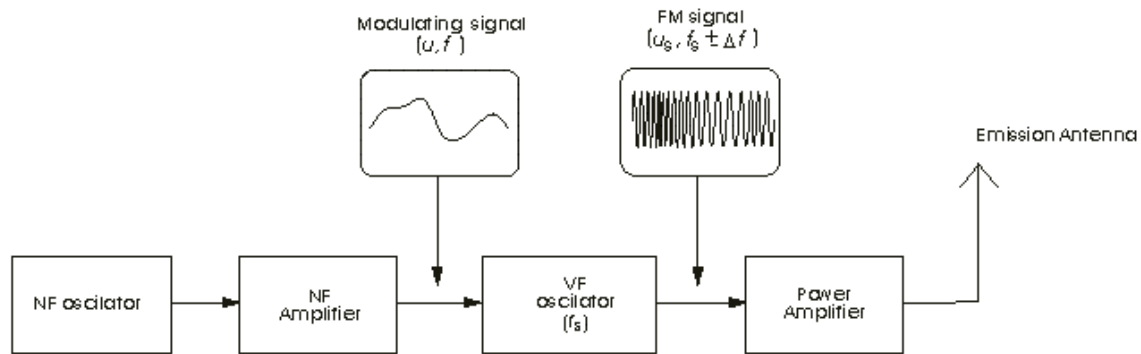


Figure 4: Block Diagram of the FM Transmitter.

Basically, there are two ways of generating FM waves: indirect generation and direct generation. In the indirect method, a narrowband angle-modulated signal is produced first and then converted to a Wideband angle-modulated signal by using frequency multipliers. Besides, in the direct method, the modulating signal directly controls the carrier frequency. Any oscillator whose frequency is controlled by the modulating signal voltage is called a voltage controlled oscillator (VCO). Indirect generation method is used in the FM transmitter because indirect generation has an advantage of frequency stability. On the other hand, the direct generation has a major disadvantage that the carrier frequency tends to drift and so additional circuitry is required for frequency stabilization. In this project, the indirect method of generating FM waves is used.

Circuit Diagram

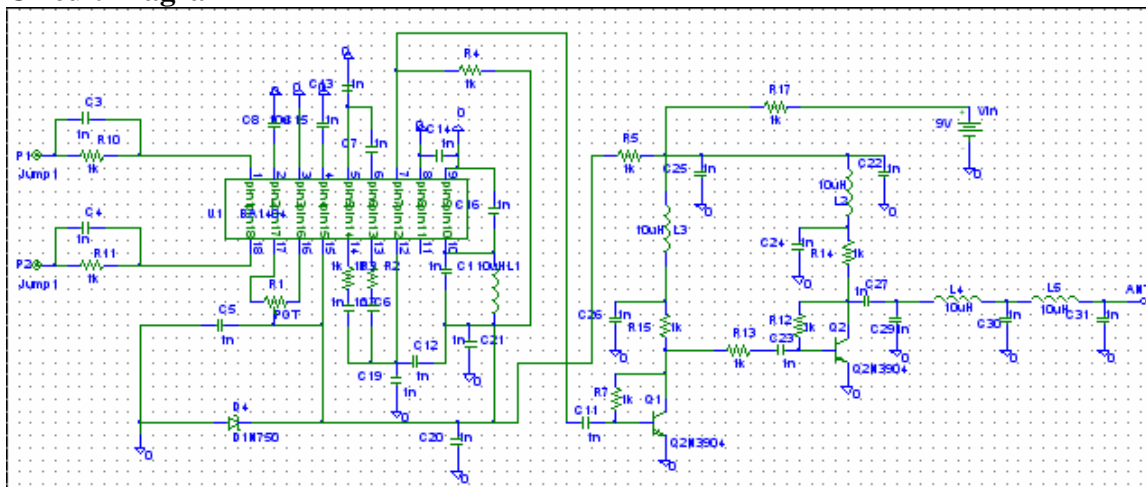


Figure 5: Circuit diagram of the FM Transmitter

Circuit Description

A quick glance at the Schematic Diagram shows that the custom FM stereo transmitter IC (U1) is at the heart of the FM10A. The control of U1 is determined by its surrounding circuitry. Potentiometers R1 and R4 allow for adjustment of input level. Resistors R3 and R6 set the pre-emphasis characteristics. R7 permits adjustment of stereo balance. L1 and

C16 form an adjustable resonant circuit to set the carrier operating frequency. Diodes D1,2 and 3 regulate the voltage to U1 at 2.1 volts DC, though Q1 may be operated safely up to 12-15 VDC. The RF output of Q1 feeds both the on-board whip antenna and J3 for an external antenna.

BA1404 FM stereo transmitter chip

The FM stereo transmitter IC BA1404 is a heart of the transmitter circuit. There are some advantages to use this chip in the design. Firstly, BA1404 required low-voltage and low power consumption. Moreover, it required few external components. Also, it has stereo modulator, FM modulator, and transmitter on a single chip. And this chip is not expensive. From the Block diagram, pin number 1 and pin number 18 are the left and right inputs of the audio signals.

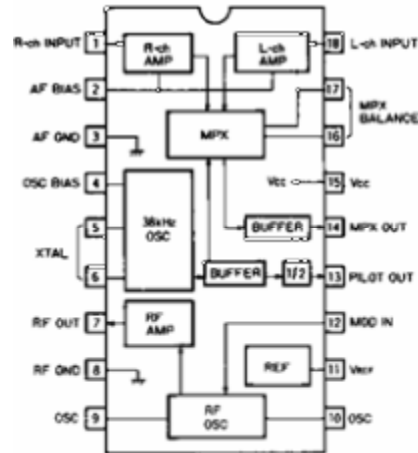


Figure 6: Block diagram of BA1404 FM stereo transmitter

BA1404 Pin description

Pin no.	Pin Name	Description
1	R-channel audio input	Connects to the pre-emphasis circuit
2	Input amplifier bypass	Connects to the bypass capacitor
3	GND	Low frequencies
4	38 kHz oscillator bypass	Connects to bypass capacitor
5	38 kHz oscillator	Connects to 38 kHz crystal oscillator
6	38 kHz OSC	Connects to load capacitor of crystal oscillator
7	RF output	Connects to LC resonator
8	GND	High frequency
9	RF oscillator	Connects to bypass capacitor
10	RF oscillator	Connects to capacitor and LC resonator
11	Voltage Supply	Connects to variable capacitor
12	Modulation signal input	Connects to bypass capacitor and modulated signal source
13	Pilot signal output	Connects to RC mixer circuit
14	Multiplexer signal output	Connects RC mixer circuit
15	Vcc	Power supply
16	Multiplexer modulator balance	Connects to trim pot resistor
17	Multiplexer modulator balance	Connects to trim pot resistor
18	L-channel audio input	Connects to pre-emphasis circuit

Table 1: Pins description of IC chip BA1404

2. Receiver Block Diagram

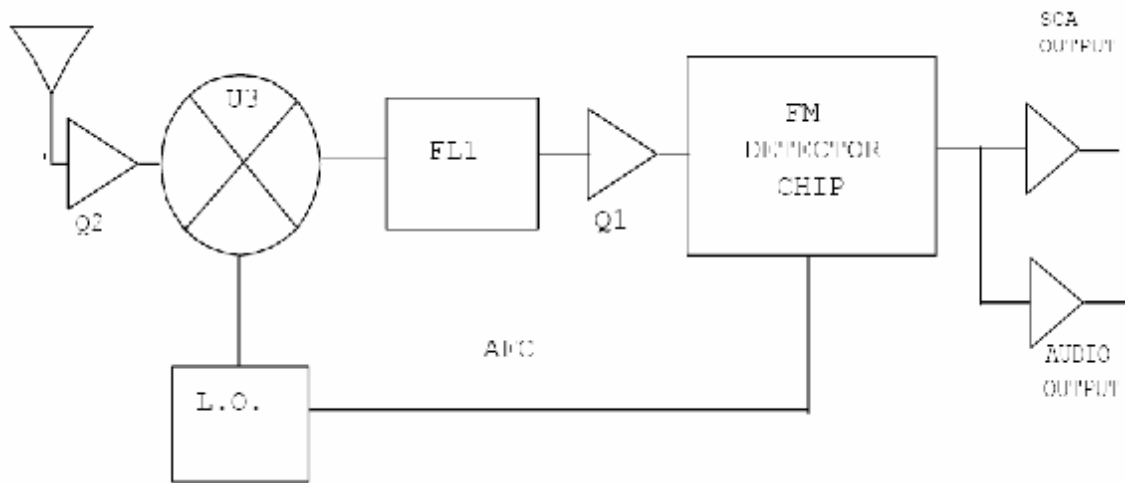


Figure 7: Block diagram of the FM receiver.

Circuit Diagram

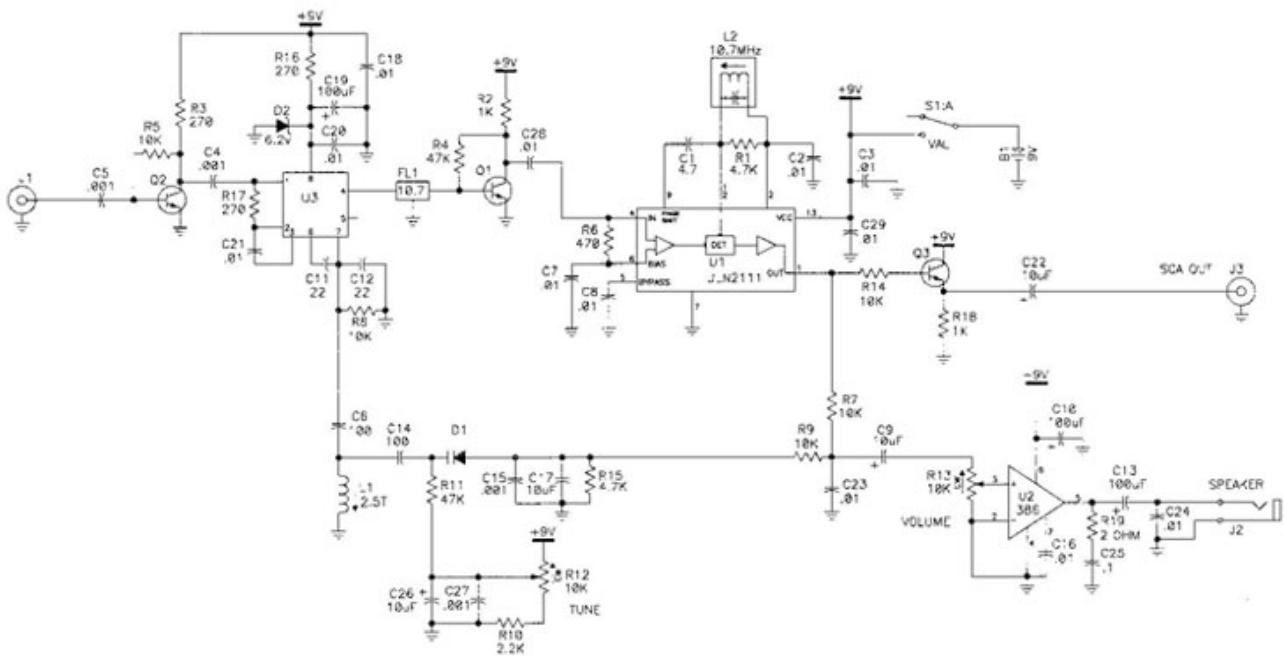


Figure 8: the circuit diagram of the FM receiver

Circuit Description

FM broadcast signals captured by the whip antenna or from the input jack are applied to the RF amplifier Q2, a high gain, low noise microwave style transistor. Signals are amplified about 20 dB, that's 100 times!

Double balanced mixer and oscillator IC SA602

After being boosted, these signals are routed to the SA602 mixer-oscillator chip for conversion down to the 10.7 MHz Intermediate Frequency (IF). The SA602 is a very popular chip used in a great variety of receivers from cellular telephones to satellite receivers. The reason for its popularity is that it contains most of a receiver's 'front end' circuitry on a single, easy to use chip. Internal to the SA602 is an oscillator tuned by an external tank circuit; C11, C12, L1 and varactor diode D1. A varactor diode acts like a voltage variable capacitor and the voltage applied across it comes from Tuning pot R12. This IF signal is an exact reproduction of the desired signal, but at 10.7 MHz. Then band-pass filters it with ceramic filter.

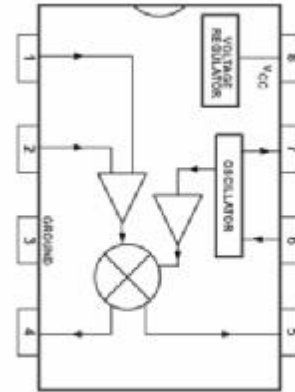


Figure 9: Block Diagram of the double-balanced mixer and oscillator

The ceramic filter allows only the desired 10.7 MHz signal to pass, rejecting any adjacent channel signals. Transistor Q1 amplifies the IF signal before it is applied to the detector chip U1. The first section of U1 performs this limiting function, providing high gain and clipping any amplitude (noise) variations.

FM is detected in the second section using a process known as quadrature detection. Capacitor C1 and coil assembly L2 comprise a phase shift network that is required by the quadrature detector. Demodulated signals are amplified and sent out through pin 1 to the; volume control, AFC circuitry and the SCA buffer amp. The AFC circuitry is used to properly keep the receiver locked on to the tuned in radio station. Resistor R9 and capacitor C17 filter out any audio voltage variations so that only major frequency changes will shift the tuning voltage to lock the frequency. Audio signals from the volume control are amplified to speaker levels by U2, an LM-386 audio amplifier chip.

Audio amplifier IC LM386

The LM386 is a power amplifier designed for use in low voltage consumer applications. The gain is internally set to 20 to keep external part count low, but the addition of an external resistor and capacitor between pins 1 and 8 will increase the gain to any value from 20 to 200. The inputs are ground referenced while the output automatically biases to one-half the supply voltage. The quiescent power drain is only 24 milliwatts when operating from a 6 volt supply, making the LM386 ideal for battery operation.

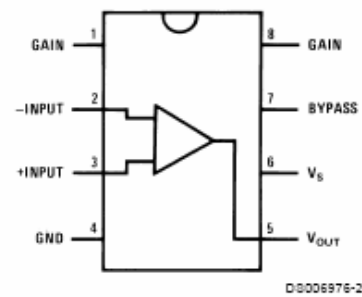


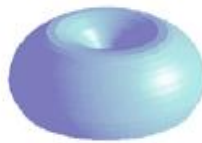
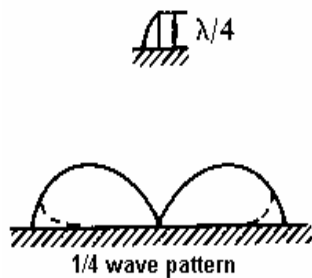
Figure 10

3. Antennas:

Two antenna telescopic whips for transmitter and receiver

In the project, two antenna telescopic whips are used for transmitter and receiver because they are easy to fabricate, easy to feed, and are lightweight. The wavelength of the FM wave is from 3.40m (88MHz) to 2.78m (108MHz). The next stage in the process is the transmission of the radio signal from an antenna as electromagnetic waves. For efficient transmission the antenna must have a length corresponding to a multiple of one half wavelength of the carrier wave thus for Classic FM an antenna of approximately 1.5 m (4 ft 6 in) should be suitable. However, having such a long antenna is not practical and it will highly increase the size of the product. So, the telescopic whip antennas have been chosen to use in the project because the length of the antenna can be adjusted.

Antenna Radiation Pattern



The following diagrams show the radiation pattern of the monopole antenna. The carrier frequency of the transmit signal is 89.90MHz and the electromagnetic wave travels with the speed of light. Therefore, the wavelength of this particular frequency is about 3.34m. ($v = f\lambda$) $\lambda/4$ is about 0.835m.

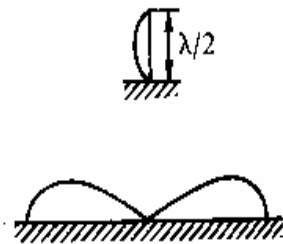


Figure 11: Radiation pattern
2D






Figure 12: Radiation pattern
3D

4. Speakers:

Two 4Ω 8W PC speakers

The output of the receiver can be connected to any headphone or speaker with 1/8" jack. In the project, two 4Ω 8W PC speakers are used.

Testing

Testing Equipment	Model	
1) Spectrum analyzer	HP 8591E	 <p data-bbox="982 562 1382 594">Figure 13: Spectrum analyzer</p>
2) Function Generator	Tektronix CFG 280	 <p data-bbox="982 888 1382 919">Figure 14: Function Generator</p>
3) Oscilloscope.	Tektronix TAS465	 <p data-bbox="982 1150 1382 1182">Figure 15: Oscilloscope</p>
4) Digital Multi-meter.	Tektronix	 <p data-bbox="982 1297 1382 1329">Figure 16: Digital Multi-meter</p>
5) Power Supply	HP	 <p data-bbox="982 1507 1382 1533">Figure 17: Power Supply</p>

(All testing equipment is provided by project adviser.)

Test One (Distance = 1.2 feet)

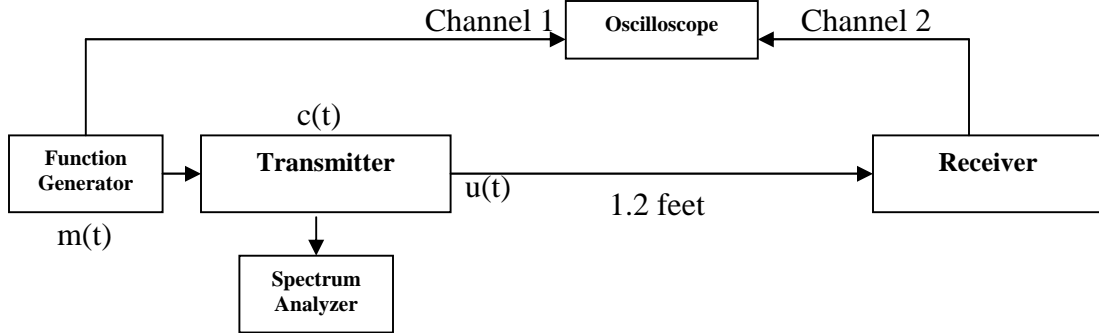


Figure 18: Setup of Test One.

Test One Result

Firstly, without any input signal, the antenna of the FM transmitter is connected to the spectrum analyzer. The carrier frequency, the output power and the spectrum of the transmitter are shown on figure 19a.

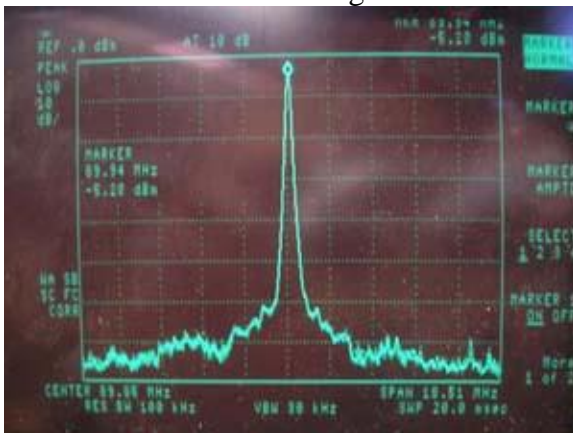


Figure 19a: The spectrum of the FM transmitter. (no input signal)

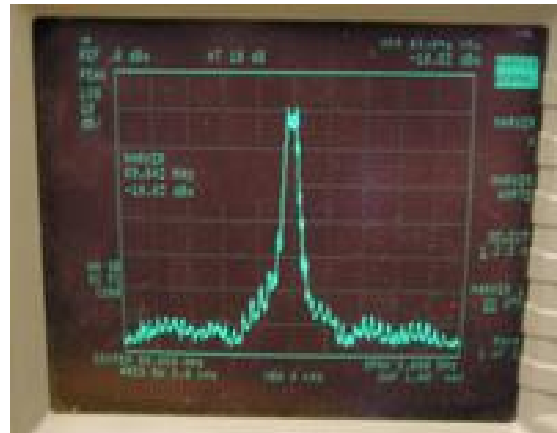


Figure 19b: The spectrum of the FM transmitter with input signal (1kHz sine wave)

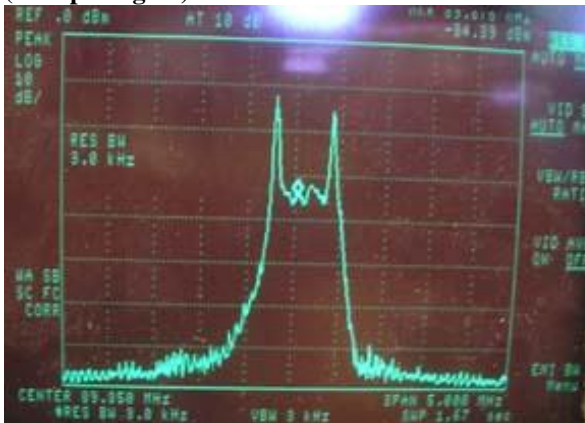


Figure 19c: The spectrum of the FM transmitter with input signal (4 kHz sine wave)

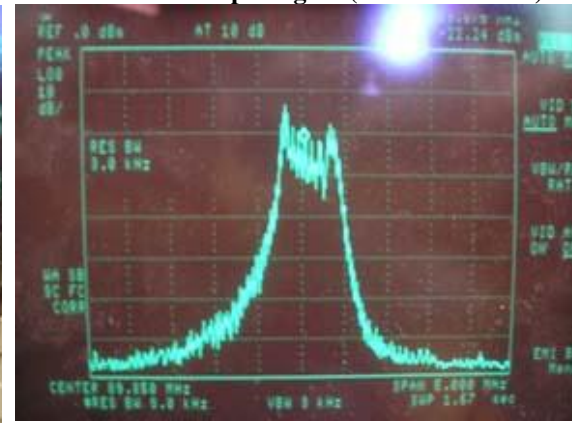


Figure 19d: The spectrum of the FM transmitter with input signal (30kHz sine wave)

From figure 19a, the spectrum analyzer shows that the carrier frequency of the transmitter is 89.90MHz, and its output power is -5.20dBm.

Next, using the function generator to generate a 4 kHz sine wave signal ($V_{p-p} = 0.5V$) as the input of the FM transmitter, the spectrum analyzer showed that the bandwidth of the FM signal had been increased due to the amplitude of the input signal. The amplitude of the input signal enlarged the bandwidth of the frequency from $f_c + km_p/2\pi$ to $f_c - km_p/2\pi$ (Figure 19c). In other word, the bandwidth is equal to km_p/π centered at f_c . Using the spectrum analyzer, it shows that the minimum frequency f_{min} is 89.84 MHz and the maximum frequency f_{max} is 89.96 MHz. Therefore, the frequency deviation of the transmitter is $\Delta f = 89.96MHz - 89.90MHz = 0.6MHz$.

Transmitter	$V_{pp}=0.5V$
input signal $m(t)$ (kHz)	BFM (kHz)
4	120
6	146
10	203
20	300
30	304
40	304

To find the arbitrary constant k for $V_{p-p} = 0.5V$ at 4 kHz,

$$\begin{aligned}
 f_{max} &= 89.96MHz \\
 f_c &= 89.90MHz \\
 m_p &= 0.25V \\
 f_{max} &= f_c + km_p / 2\pi \\
 k &= 1.5(MHz/V)
 \end{aligned}$$

The bandwidth of the FM transmitter is equal to $km_p/\pi = 0.12MHz$

Increasing the frequency of the modulating signal $m(t)$ from 20 Hz to 40 kHz also changed the spectrum of the frequency modulated signal $u(t)$. The bandwidth of the frequency modulated signal B_{FM} depends on the peak value of the modulating signal $m(t)$ and the bandwidth of the input signal (B). Therefore, the bandwidth of the FM signal will be:

$$B_{FM} = 2(\Delta f + B) \text{ where } \Delta f = km_p / 2\pi$$

In this test, the distance between the transmitter and the receiver is about 1.2 feet. And the gain of the system is about -16.67dB. As the result, the attenuation of the system is $-16.67/1.2 \text{ feet} = -13.8 \text{ dB/ft}$

This communication system is designed for audio transmitting and receiving use, so the desire frequency of the signal is between 20 Hz to 10 kHz. This is the frequency range of the human hearing. Other frequency of the signals will be rejected by the low pass filter from the FM transmitter. There is a limitation of the amplitude of input signal in the product. If the amplitude of the input signal is larger than 500mV, a lot of noise can be found in the received signal (Figure 20).

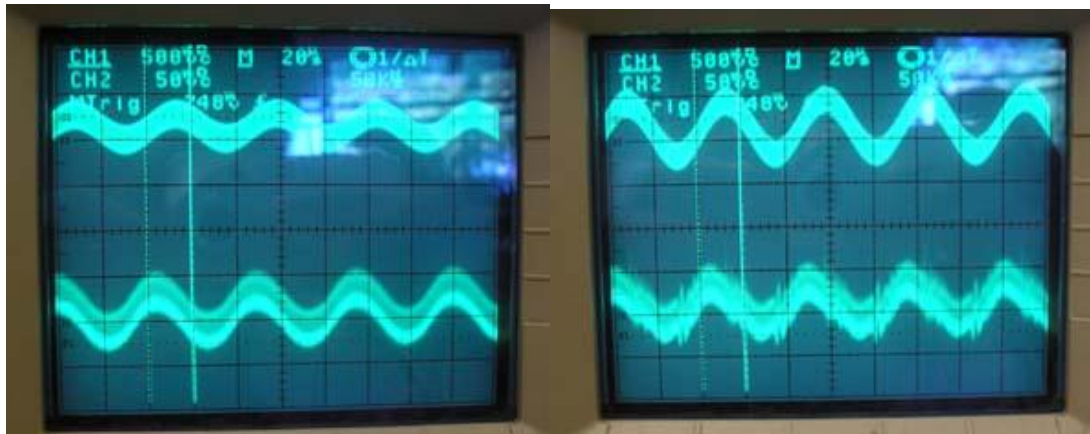


Figure 20: Top - Input signal 20 kHz $V_p = 0.5V$ and Bottom - the receive signal (left)
 Top - Input signal 20 kHz $V_p = 0.5V$ and Bottom - the receive signal with noise (right)

Result Analysis

The results in Test one clearly shows that the transceiver is working properly. Since the transceiver pass the Test One (distance = 1.2 feet), the ability of sending and receiving signal of the transceiver is proven.

Test Two (Distance = 10 feet)

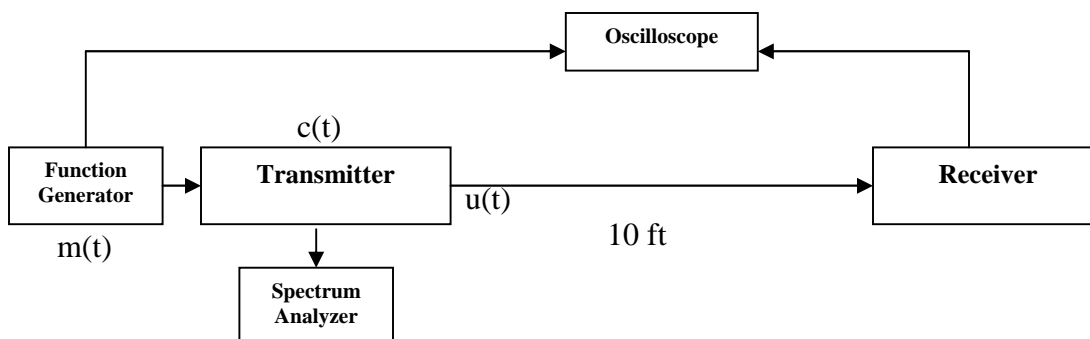


Figure 21: Setup for Test Two.

Next, separating the transmitter and the receiver about 10 feet apart and using the spectrum analyzer to see the spectrum of the receiver.

Test Two Result

The power of the signal the FM receiver can get is about -149.7dBm .

Result Analysis

The results show that the transceiver is able to communicate in 10 feet. The attenuation of the transmitting signal is shown on Table 2. The average attenuation is about -13.625dBm at 89.90MHz .

Distance (ft)	Sending Power (Reading of Spectrum Analyzer)	Receiving Power (Reading of Spectrum Analyzer)	Attenuation
1.2 ft	-15.76 dBm	-36.46 dBm	-13.8 dBm/ft
10.0 ft	-15.20 dBm	-149.700 dBm	-13.45 dBm/ft

Table 2: Test 1 and Test 2 results

Budget

Parts	Units	Cost (USD)
Transmitter	1	\$23.00
CAPACITORS 4 10 pf disc capacitor 1 18 pf disc capacitor 1 220 pf disc capacitor 8 .001 μ F disc capacitor 2 .0047 μ F disc capacitors 4 4.7 to 10 μ F electrolytic capacitors 1 470 μ F electrolytic capacitor 1 1000 μ F electrolytic capacitor		
RESISTORS 2 270 ohm 1 470 ohm 1 4.7K ohm 3 10K ohm 2 15K ohm 1 150K ohm 1 100K yellow trimmer potentiometer 2 1K yellow trimmer potentiometer		
SEMICONDUCTORS 3 Diodes 1 2SC2498 NPN VHF transistor 1 18-pin DIP Custom FM Transmitter IC with matching socket		
MISCELLANEOUS 1 38 KHz crystal 1 Shielded inductor coil 1 Ramsey FM10A Printed circuit board 1 Plastic alignment screwdriver 1 PC board mounted push-button switch 3 RCA-type PC-mount jacks 1 2.5 mm phone jack 1 9-volt battery snap connector		
Receiver	1	\$22.00
CERAMIC DISC CAPACITORS: 4 .001 uf disc 12 .01 uf disc 1 .1 uf disc 1 4.7 or 5 pf disc 2 22 pf disc 2 100 pf disc		
ELECTROLYTIC CAPACITORS: 4 4.7 or 10 uf 3 100 to 220 uf		
RESISTORS AND POTENTIOMETERS: 2 10K ohm 1 2 ohm 3 270 ohm 1 470 ohm 2 1K resistor 1 2.2K ohm 2 4.7k ohm 5 10K resistor 2 47K ohm		

INDUCTORS AND FREQUENCY COMPONENTS: 1 10.7 Mhz ceramic filter 1 slug tuned plastic molded coil 1 10.7 Mhz shielded can style IF transformer		
SEMICONDUCTORS: 1 varactor diode, 33pf 1 Zener diode, 6.2 volt 1 SA602 IC 1 LM386 IC 1 ULN2111 IC 1 2SC2498 NPN transistor 2 2N3904 NPN transistor		
Antenna Whips	2	\$2.00
PC Speakers	2	\$10.00
Total		\$62.00

Table 3: Cost of the FM transceivers

Specification

Transmitter

Power Supply	9V battery
Input Voltage	1.5V - 3V
Output Voltage	500mV
Input Audio Jack	Accepts 1/8" stereo phone jack
Carrier Frequency	89.90MHz
Frequency Response	20Hz – 24kHz
Frequency Deviation	100kHz
Modulation Method	Frequency Modulation
Bandwidth	200kHz
Application	Transmits audio signal from stereo to receiver or FM radio.

Table 4: Specification of FM transmitter

Receiver

Power Supply	9V battery
Input Voltage	1.5V - 3V
Output Voltage	500mV
Signal to Noise Ratio	13dB
Output Audio Jack	Accepts 1/8" stereo phone jack
Demodulation Method	Frequency Demodulation
Application	Receive the signal from the transmitter and convert to audio signal.

Table 5: Specification of FM receiver

Conclusion

The transceiver of this project is for home stereo application. The carrier frequency is 89.90 MHz and its frequency deviation is 100 kHz. Choosing of frequency modulation can make the better sound quality rather than AM. The product was first tested to prove its abilities of sending and receive signals. The distance between the transceivers is 1 feet long. Then, the second test is to test the transceivers can communicate in some distance. The main reason for the longer distance is not tested because all the equipment is locked up on the stations not allow to move. The size of the transmitter is small. The dimension of the FM transmitter is 2" x 3". It is obvious that the size has been improved. The size of the receiver (3.5" x 5") is bigger than the transmitter; however, it still can be reduced the size by using more compact board. The total cost of the product is about \$62.00 (including the PC speakers). Comparing with other brands of similar product, it is low cost and high quality.

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Adel S. Sedra and Kenneth C. Smith, Microelectronic Circuit, Fourth Edition, Oxford University Press, 1998.

Radio Receivers

<http://www.mikroelektronika.co.yu/english/product/books/rrbook/rrbook.htm>

Data Sheet of FM stereo transmitter IC (BA1404)

<http://www.radiochips.com/images/ba1404v1.pdf>

Data Sheet of double balanced mixer and oscillator IC SA602

Data Sheet of audio amplifier LM386