(WIDEBAND FREQUENCY MODULATION)

Laboratory Project Report submitted for

COMMUNICATION SYSTEM-1

(EET3061)

Submitted by

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(April, 2018)

Declaration

We, the undersigned students of B. Tech. of Electronics and Communication Engineering Department hereby declare that we own the full responsibility for the information, results etc. provided in this PROJECT titled "**(WIDEBAND FREQUENCY MODULATION FROM NARROW BAND FREQUENCY MODULATED WAVE WITH HELP OF SUITABLE FREQUENCY MULTIPLIER)**" submitted to **Siksha 'O' Anusandhan, Bhubaneswar** for the partial fulfillment of the subject **COMMUNICATION SYSTEM-1 (EET3061)**. We have taken care in all respect to honor the intellectual property right and have acknowledged the contribution of others for using them in academic purpose and further declare that in case of any violation of intellectual property right or copyright we, as the candidates, will be fully responsible for the same.

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DATE: 9|04|2018

PLACE:ITER,Bhubaneswar

Abstract

In this design project our objective is to design an experimental set up for generating WBFM signal by virtue of suitable frequency multiplier and verify the signal power of a received signal, which has undergone with frequency modulation at the transmitter and mixed with an AWGN of zero mean and 0.2 variance during transmission.
We took a sine wave as a message signal and a carrier signal to generate a frequency modulationsignal. An AWGN signal is added to it. And the power was measured before and after the addition of noise to it.

Contents

1. Introduction

Transmission of information by the communication systems over large distances is quite a feat of human ingenuity. Communication systemshas used a very clever technique called Modulation to increase the reach of the signals. In the modulation process, two signals are used namely the modulating signal and the carrier. The modulating signal is nothing but the baseband signal or information signal while the carrier is a high frequency sinusoidal signal .

In the modulation process, some parameter of the carrier wave (such as amplitude, frequency or phase) is varied in accordance with the modulating signal . This modulated signal is then transmitted by the transmitter.

The receiver demodulates the received modulated signal and gets the original information signal back.

Additive white Gaussian noise (AWGN) is a basic noise model used in Information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics:

- *Additive* because it is added to any noise that might be intrinsic to the information system.
- *White* refers to the idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emissions at all frequencies in the visible spectrum.
- *Gaussian* because it has a normal distribution in the time domain with an average time domain value of zero.

AWGN is often used as a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude.

2. Need Recognition and Problem definition

Modulation is used to facilitate transmission.

ADVANTAGES OF MODULATION:

1. Reduction in the height of antenna

For many baseband signals, the wavelengths are too large for reasonable antenna dimensions. This long wavelength would necessitate an impractically large antenna. By modulating a high frequency carrier, we effectively translate the signal spectrum to the neighborhood of a carrier frequency that corresponds to a much smaller wavelength.

2. Avoids mixing of signal

If the baseband sound signals are transmitted without using the modulation by more than one transmitter, then all the signals will be in the same frequency range i.e. 0 to 20 kHz . Therefore, all the signals get mixed together and a receiver can not separate them from each other.

3. Increases the range of communication

The frequency of baseband signal is low, and the low frequency signals can not travel long distance when they are transmitted . They get heavily attenuated. The modulation process increases the frequency of the signal to be transmitted . Therefore, it increases the range of communication.

4. Multiplexing is possible

The multiplexing allows the same channel to be used by many signals . Hence, many TV channels can use the same frequency range, without getting mixed with each other or different frequency signals can be transmitted at the same time .

The AWGN channel is a good model for many satellite and deep space communication links. It is not a good model for most terrestrial links because of multipath.

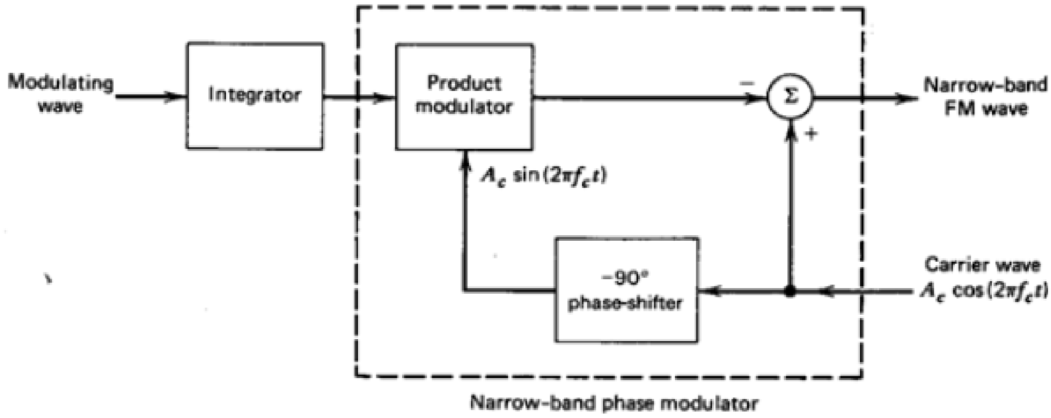
Frequency modulation is preferred because here, the message information is contained in varying frequency of modulated signal, not the amplitude so additive noise does not have any effect on this modulation.So here we will design a cicuit in which the received signal is undergone with frequency modulation at the transmitterand an AWGN(Additive white Gaussian Noise) is added to it through a noise generator circuit.

As with any form of modulation there are several advantages and disadvantages to its use. These need to be considered before making any decision or choice about its use:

Advantages of frequency modulation, FM:

- ***Resilience to noise:*** One particular advantage of frequency modulation is its resilience to signal level variations. The modulation is carried only as variations in frequency. This means that any signal level variations will not affect the audio output, provided that the signal does not fall to a level where the receiver cannot cope. As a result this makes FM ideal for mobile radio communication applications including more general two-way radio communication or portable applications where signal levels are likely to vary considerably. The other advantage of FM is its resilience to noise and interference. It is for this reason that FM is used for high quality broadcast transmissions.
- ***Easy to apply modulation at a low power stage of the transmitter:*** Another advantage of frequency modulation is associated with the transmitters. It is possible to apply the modulation to a low power stage of the transmitter, and it is not necessary to use a linear form of amplification to increase the power level of the signal to its final value.
- ***It is possible to use efficient RF amplifiers with frequency modulated signals:*** It is possible to use non-linear RF amplifiers to amplify FM signals in a transmitter and these are more efficient than the linear ones required for signals with any amplitude variations (e.g. AM and SSB). This means that for a given power output, less battery power is required and this makes the use of FM more viable for portable two-way radio applications.
- ***FM has poorer spectral efficiency than some other modulation formats:*** Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission than frequency shift keying, a form of frequency modulation. As a result, most data transmission system use PSK and QAM.
- ***Requires more complicated demodulator:*** One of the minor disadvantages of frequency modulation is that the demodulator is a little more complicated, and hence slightly more expensive than the very simple diode detectors used for AM. However this is much less of an issue these days because many radio integrated circuits incorporate a built in frequency demodulator .
- ***Some other modes have higher data spectral efficiency:*** Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission that frequency shift keying, a form of frequency modulation. As a result, most data transmission system use PSK and QAM.
- ***Sidebands extend to infinity either side:*** The sidebands for an FM transmission theoretically extend out to infinity. They are normally significant for wideband frequency modulation transmissions, although small for narrow band FM. To limit the bandwidth of the transmission, filters are often used, and these introduce some distortion of the signal. Normally this is not too much of an issue although care has to be taken to include these filters for wideband FM and to ensure they are properly designed.

3.Function Decomposition



Then the signal is passed through a group of frequency multipliers to generate a wideband FM. In electronics, a **frequency multiplier** is an electronic circuit that generates an output signal whose output frequency is a harmonic (multiple) of its input frequency. Frequency multipliers consist of a nonlinear circuit that distorts the input signal and consequently generates harmonics of the input signal. A subsequent bandpass filter selects the desired harmonic frequency and removes the unwanted fundamental and other harmonics from the output.

Frequency multipliers are often used in frequency synthesizers and communications circuits. It can be more economical to develop a lower frequency signal with lower power and less expensive devices, and then use a frequency multiplier chain to generate an output frequency in the microwave or millimeter wave range. Some modulation schemes, such as frequency modulation, survive the nonlinear distortion without ill effect (but schemes such as amplitude modulation do not).

Mathematical Expression for the FM modulation:

$$S_{FM}(t) = A_c \cos(2\pi f_c t + \beta \sin(2\pi f_m t))$$

Modulation index in FM (β)=$\frac{k_f A_m}{f_m} = \frac{\Delta f}{f_m}$.

NBFM EQN

$$e_{FM}(t) = s(t) = \underbrace{E_c sin\omega_c t}_{\text{Carrier}} + \frac{m_f E_c}{2}\underbrace{\sin(\omega_c + \omega_m)t}_{\text{USB}} - \frac{m_f E_c}{2}\underbrace{\sin(\omega_c - \omega_m)t}_{\text{LSB}}$$

WBFM EQN

$$eFM = s(t) = E_c\{J_0(m_f)sin\omega_c t + J_1(m_f)[sin(\omega_c + \omega_m)t - \sin((\omega_c - \omega_m)t] + J_2(m_f)[sin(\omega_c + 2\omega_m)t - \sin((\omega_c - 2\omega_m)t + J_3(m_f)[sin(\omega_c + 3\omega_m)t - \sin((\omega_c - 3\omega_m)t + J_4(m_f)[sin(\omega_c + 4\omega_m)t - \sin((\omega_c - 4\omega_m)t \ldots\ldots\ldots..(1)$$

Looking at equation (1), we can conclude the following points:

1. The FM wave consists of carrier. The first term in equation(1) represents the carrier.
2. The FM wave ideally consists of infinite number of sidebands. All the terms except the first one are sidebands.
3. The amplitudes of the carrier and sidebands is dependent on the J coefficients.
4. As the values of J coefficients are dependent on the modulation index m_f, the modulation index determines how many sideband components have significant amplitudes as shown in fig.2 below.
5. Some of the J coefficients can be negative. Therefore, there is a 180^o phase shift for that particular pair of sidebands.
6. The carrier component does not remain constant. As $J_0(m_f)$ is varying the amplitude of the carrier will also vary. However, the amplitude of FM wave will remain constant.
7. For certain values of modulation index, the carrier component will disappear completely. These values are called eigen values.
8. In FM, the total transmitted power always remains constant. It is not dependent on the modulation index. The reason for this is that the amplitude of the FM signal i.e. E_c is always constant. AND the power transmitted is given by,

$$P_t = \frac{\left(\frac{E_c}{\sqrt{2}}\right)^2}{R} = \frac{{E_c}^2}{2R}$$

4. Concept Generation

In our experiment we have to generate a sinusoidal signal that undergoes with frequency modulation. For this reason we use a 8038 Ic because this generates a carrier signal of high frequency in astablemultivibrator mode. The input i.e the message signal is applied to it for which we get a FM modulated signal at the output.

A narrow band FM is the FM wave with a small bandwidth .The modulation index m_f of narrow band FM is small as compared to one radian . Hence, the spectrum of narrow band FM consists of the carrier and upper sideband and a lower sideband .

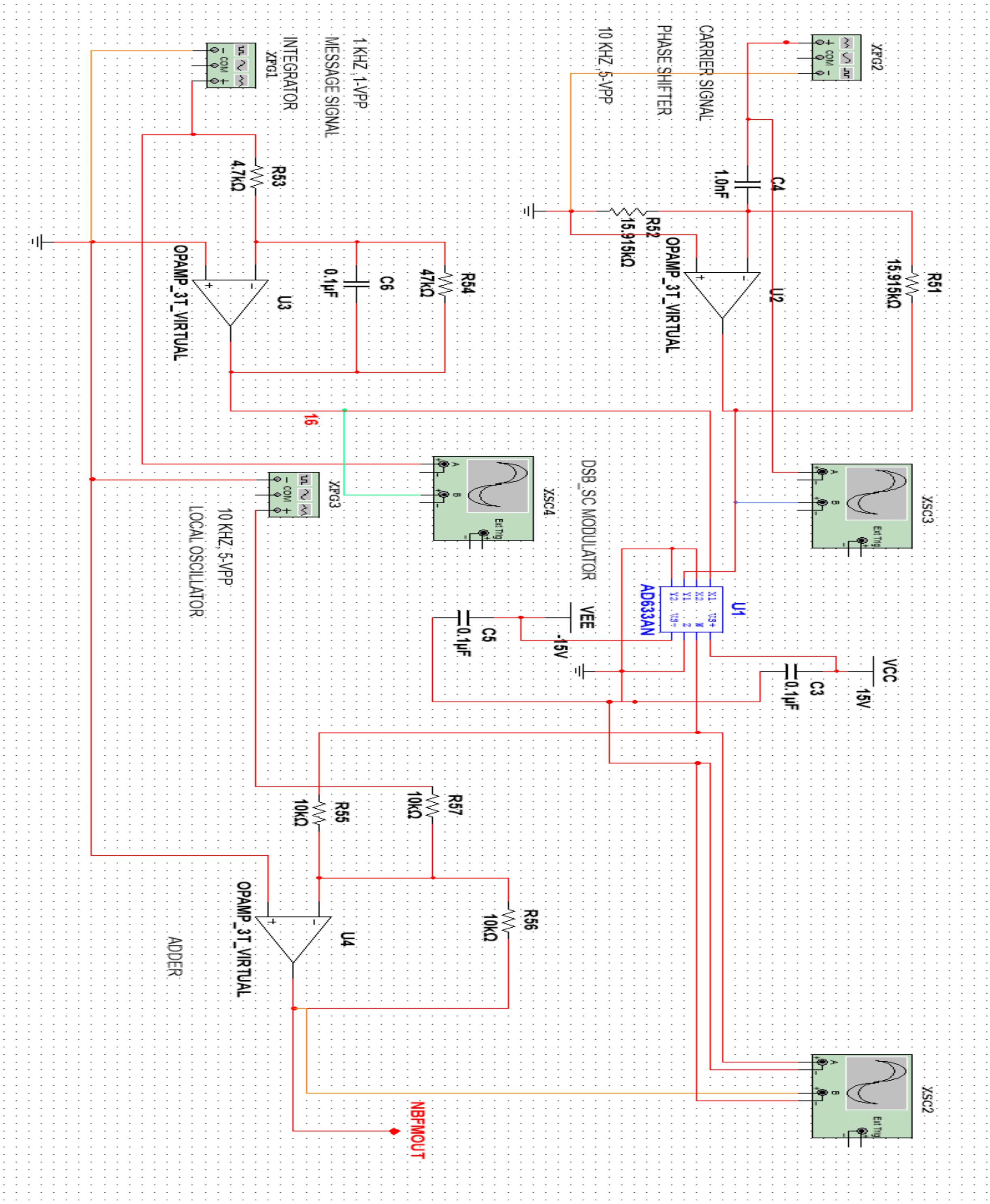
For large values of modulation index m_f , the FM wave ideally contains the carrier and an infinite number of sidebands located symmetrically around the carrier.Such a FM wave has infinite bandwidth and hence called as wideband FM.The modulation index of wideband FM is higher than 1.
The maximum permissible deviation is 75 kHz and it is used in the entertainment broadcasting applications such as FM radio, TV etc.

The next part of our experiment is we have to add an AWGN signal for which we used the noise black box.The noise needs to beadded and the output of the FM needs to verified to check the power.

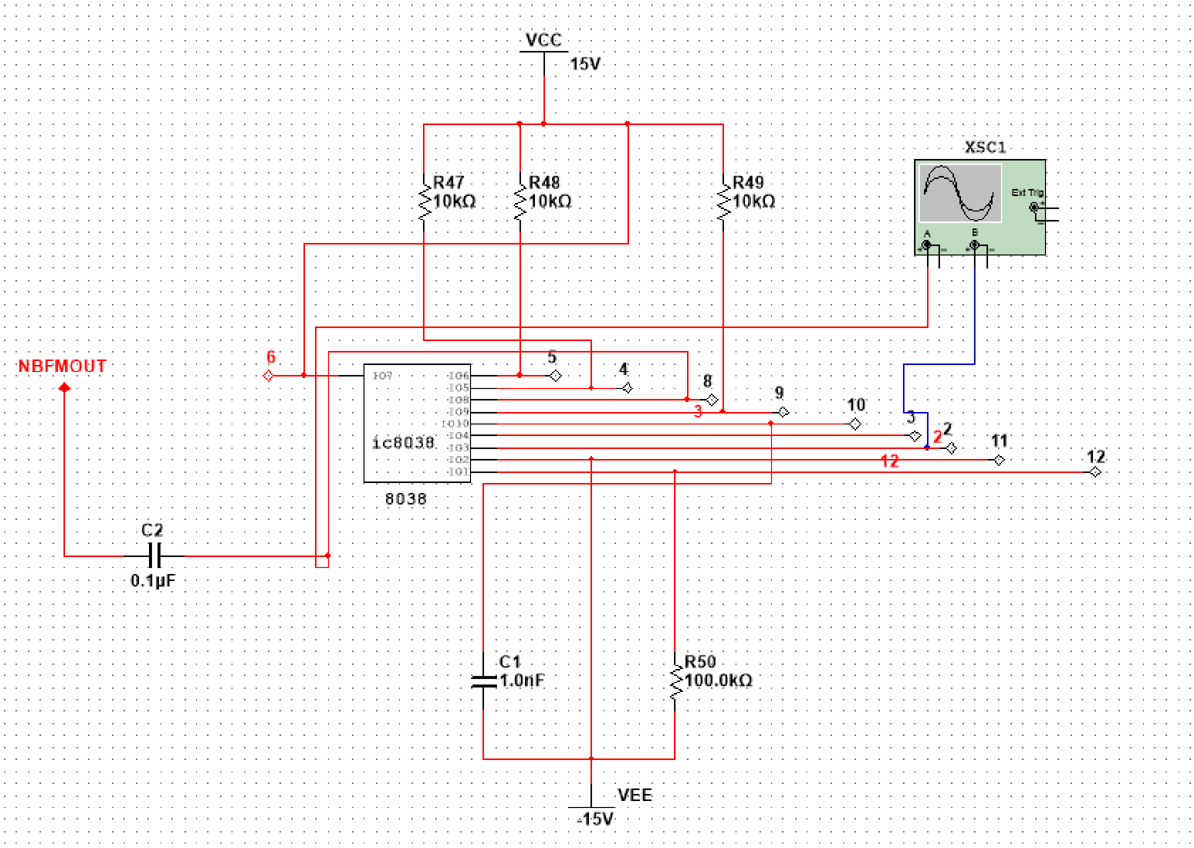
5. Concept Selection

Software purpose:

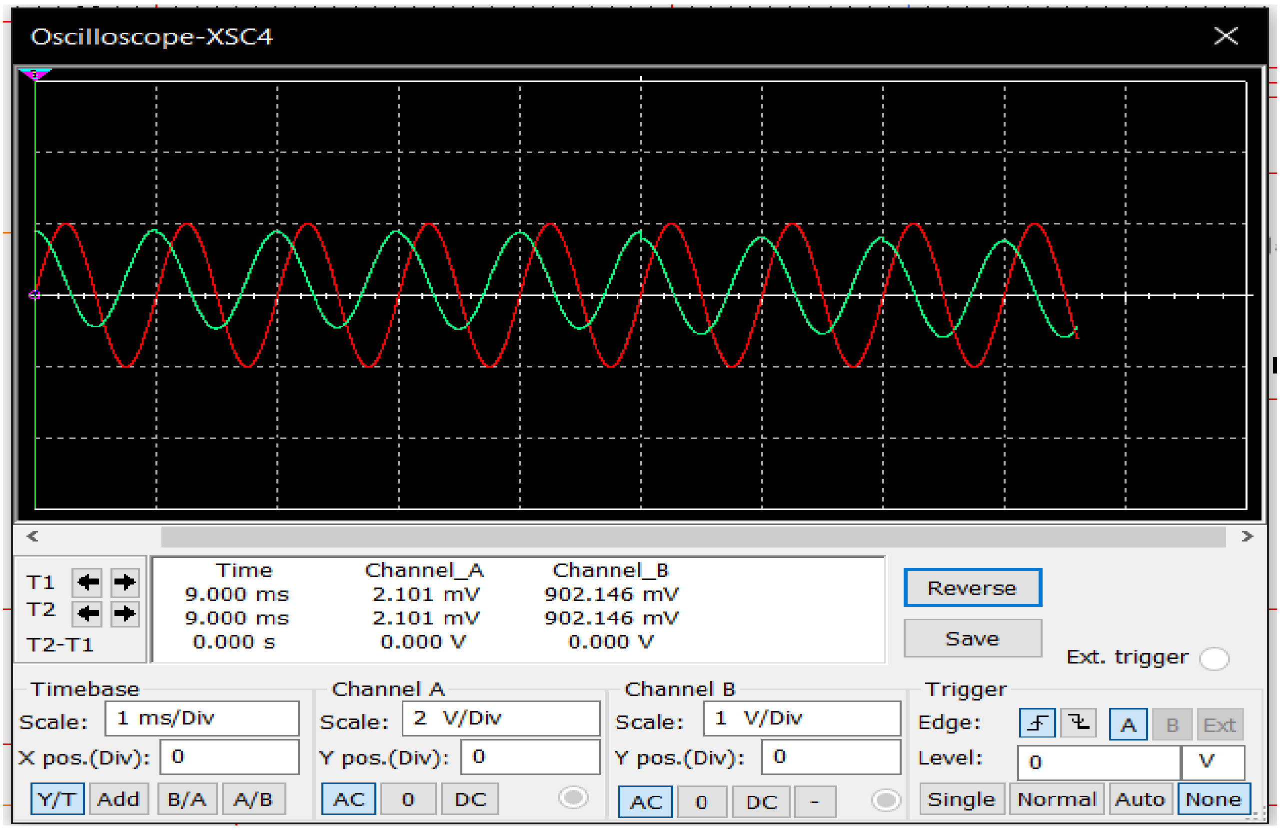
NBFM GENERATION



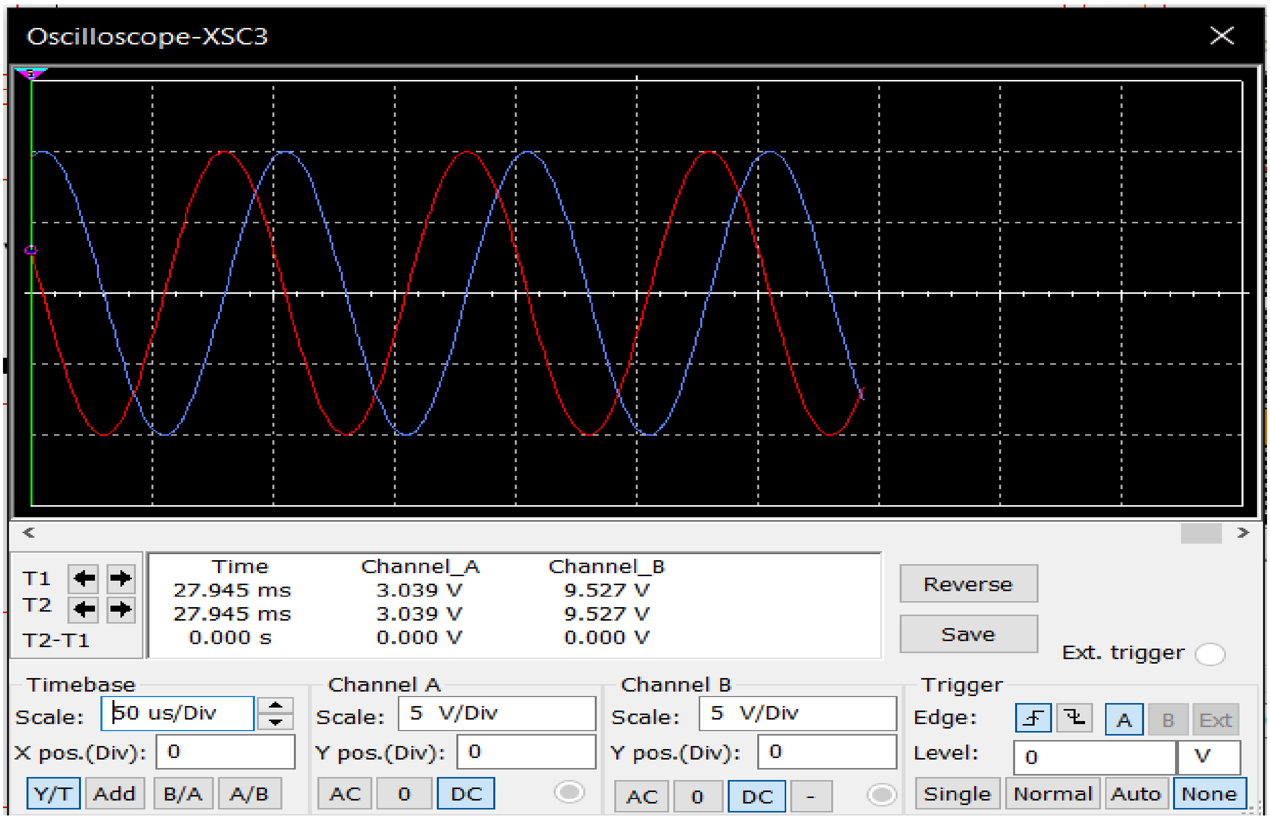
WBFM GENERATION USING ICL 8038



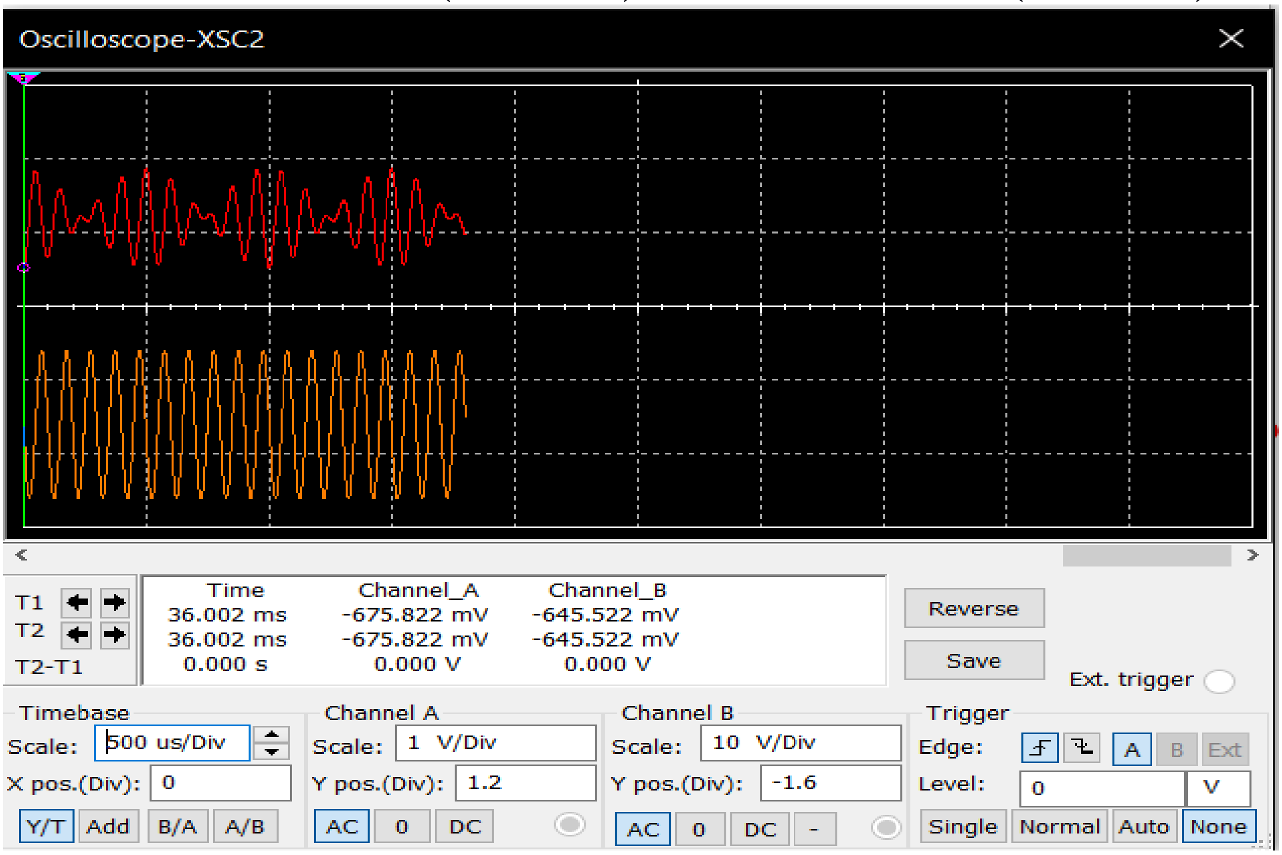
INTEGRATOR OUTPUT



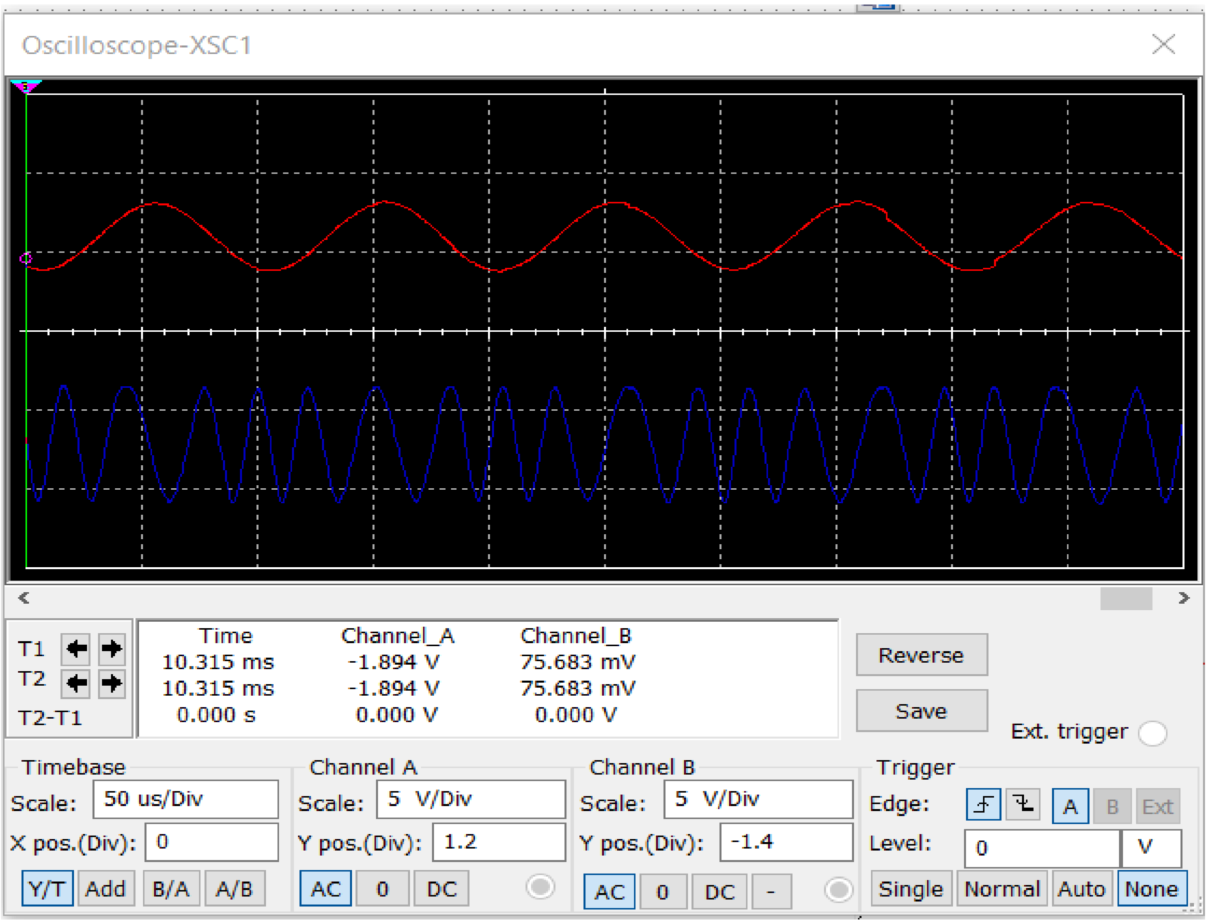
PHASE SHIFTER OUTPUT



DSB-SC MODULATOR OUTPUT (CHANNEL A) ADDER OUTPUT (CHANNEL B)



ICL 8038 OUTPUT



Hardware purpose:

We used ICL8038 instead of a frequency multiplier because we needed a sinusoidal output at the end of modulation. And the design of frequency multiplier includes designing a set of atleast 5-10 LC resonance circuit with different LC values which is difficult to implement.

The **ICL8038** waveform generator was an Integrated circuit by Intersil designed to generate accurate sine, square & triangular waveforms based on bipolar monolithic technology involving Schottky barrier diodes. Triangular waves were produced by charging and discharging a capacitor with constant currents. The triangular waves were converted to sine waves involving a non-linear network of transistors and thin-film resistors.The output frequency was set by resistors or capacitors and covered a range from 0.001 Hz to more than 300 kHz. An external control voltage would accomplish frequency sweeping or frequency modulation. The temperature drift could be optimized to less than 250ppm/°C by combining it with a PLL

Instead of performing the noise circuit and the adder on the breadboard, we used a noise black box which consisted of the above 2 things.

So our hardware consisted of our ICL8038 and the noise part. The rest was connected with the noise box.

6. Analysis

MATLAB

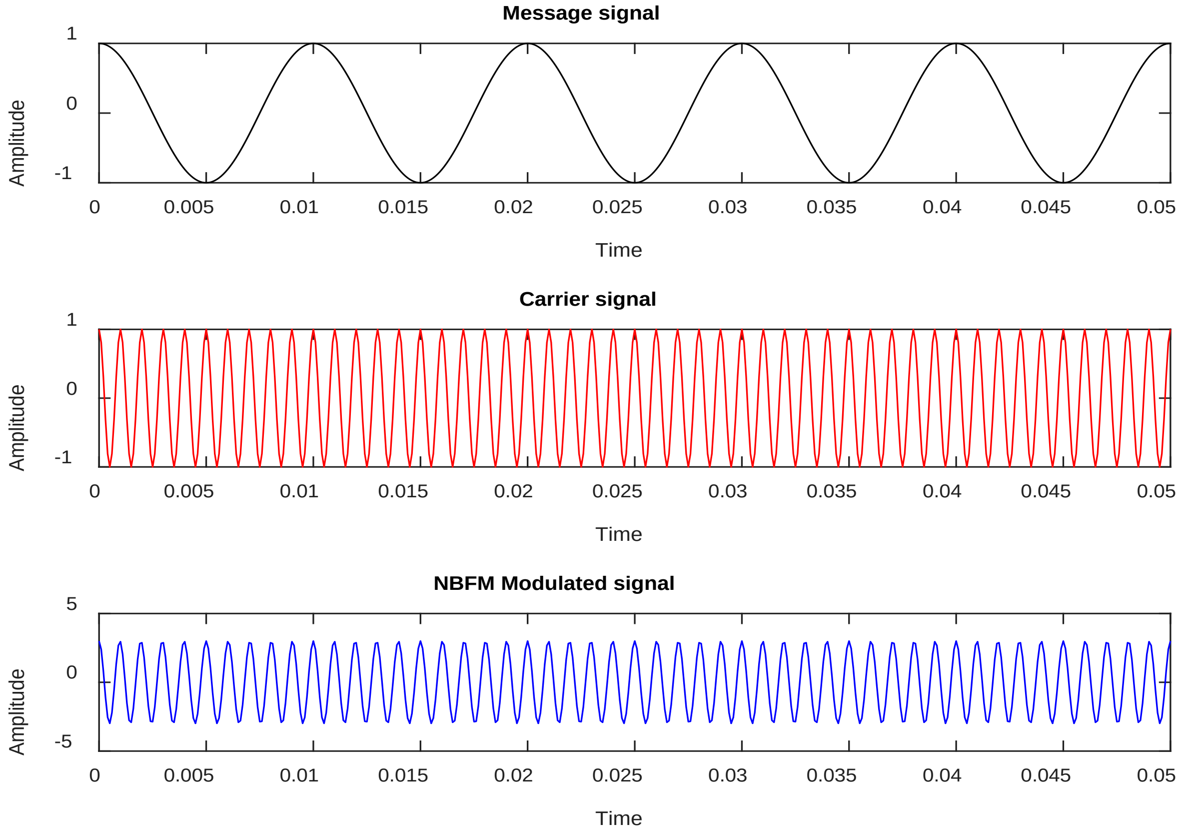
```
clc;
clear all;
close all;

fs=10000;
ts=1/fs;
fm=100;
t=0:1/fs:5/fm;
Am=1;

m=Am*cos(2*pi*fm*t);            %message
figure
subplot(3,1,1);
plot(t,m,'black');xlabel('Time');ylabel('Amplitude');
title('Message signal')

Ac=3;
fc=1000;
c=Am*cos(2*pi*fc*t);            %carrier
subplot(3,1,2);
plot(t,c,'r');xlabel('Time');ylabel('Amplitude');
title('Carrier signal')

b=0.3;
mod=Ac*cos((2*pi*fc*t)+(b*sin(2*pi*fm*t))); %NBFM modulated signal
subplot(3,1,3);
plot(t,mod,'b');
title('NBFM Modulated signal');xlabel('Time');ylabel('Amplitude');

figure
FN=10;              %multiplier constant
b=FN*0.3;
mod=Ac*cos((2*pi*fc*t)+(b*sin(2*pi*fm*t))); %WBFM modulated signal
subplot(3,1,1);
plot(t,mod,'blue');
title('WBFM Modulated signal');xlabel('Time');ylabel('Amplitude');

noise=sqrt(0.4)*randn(1,length(mod)); %AWGN  noise with varianc 0.4 and mean 0

Z=mod+noise; %adding the noise to the FM modulated signal
subplot(3,1,2);
plot(t,Z,'r');
title('Modulated signal plus noise');;xlabel('Time');ylabel('Amplitude');

power=(norm(mod)^2)/length(mod) %calculating the signal power
power1=(norm(Z)^2)/length(Z) %calculating the signal power + noise
```

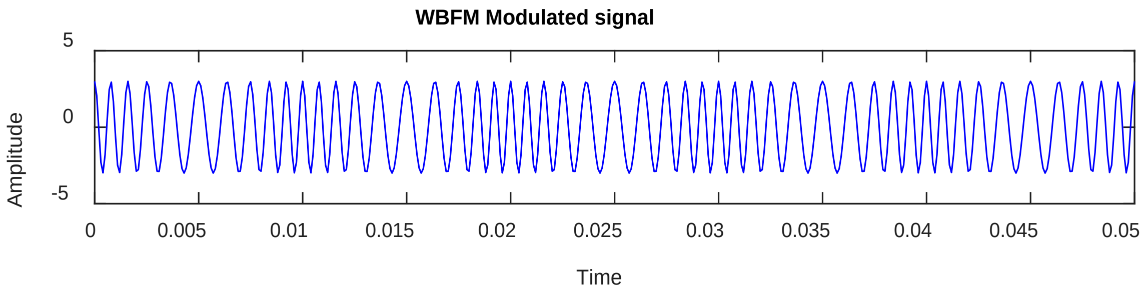
```
Z_diff=diff([Z(1) Z])/(ts)*b;      %differentiation
Z_rec=Z_diff.*(Z_diff>0)          %rectification
h=fir1(70,[100*(ts)])             %filter
Z_de=filter(h,1,Z_rec)            %filtered output

subplot(3,1,3);
plot(t,Z_de,'k');
title('Demodulated signal');xlabel('Time');ylabel('Amplitude');
power2=(norm(Z_de)^2)/length(Z_de) %calculating the demodulated signal power
```

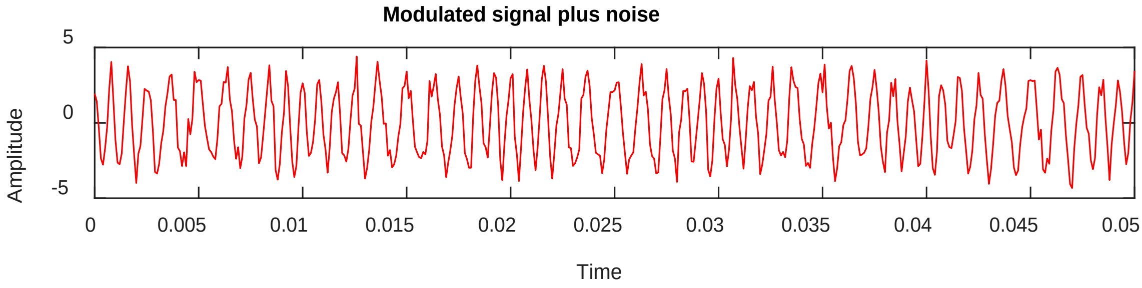
Output:

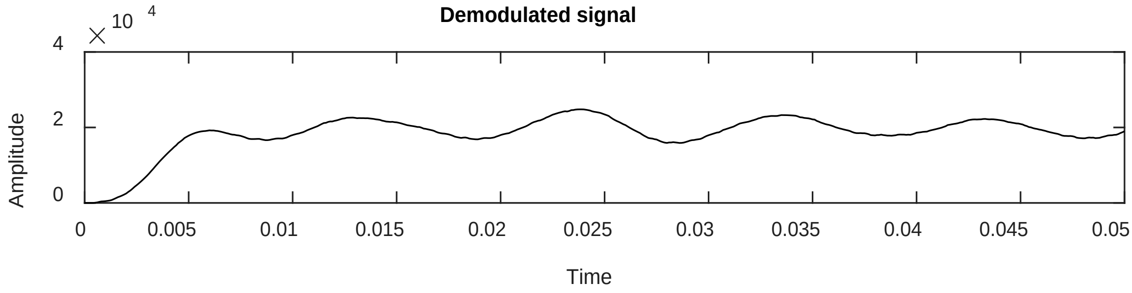
According to the question, we need to add an AWGN noise of mean 0 and variance 0.2. From this MATLAB program we can prove the mean and variance to be 0 and 0.2 respectively by using the commands as follows:-

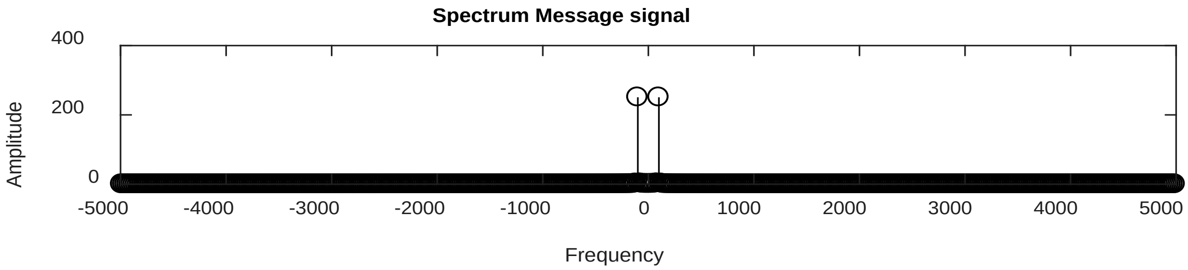
```
>> var(noise)

ans =0.1902

>> mean(noise)

ans = 0.0473
```

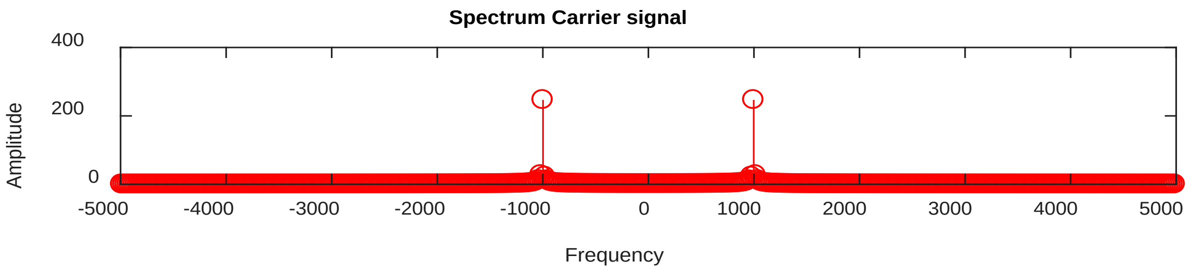


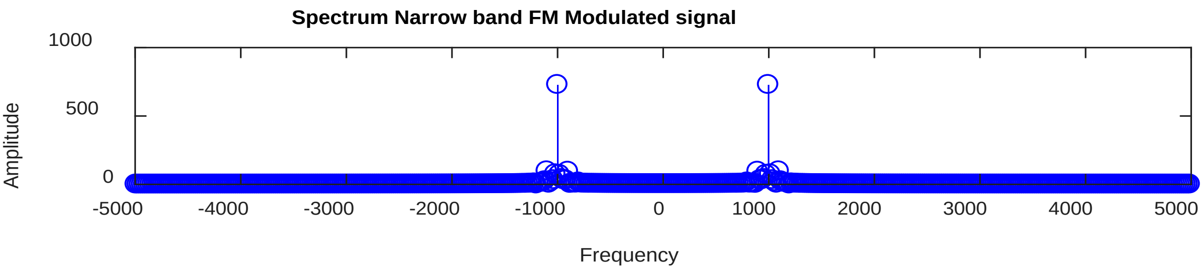

WBFM Modulated signal
5
0
-5
Amplitude
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Time

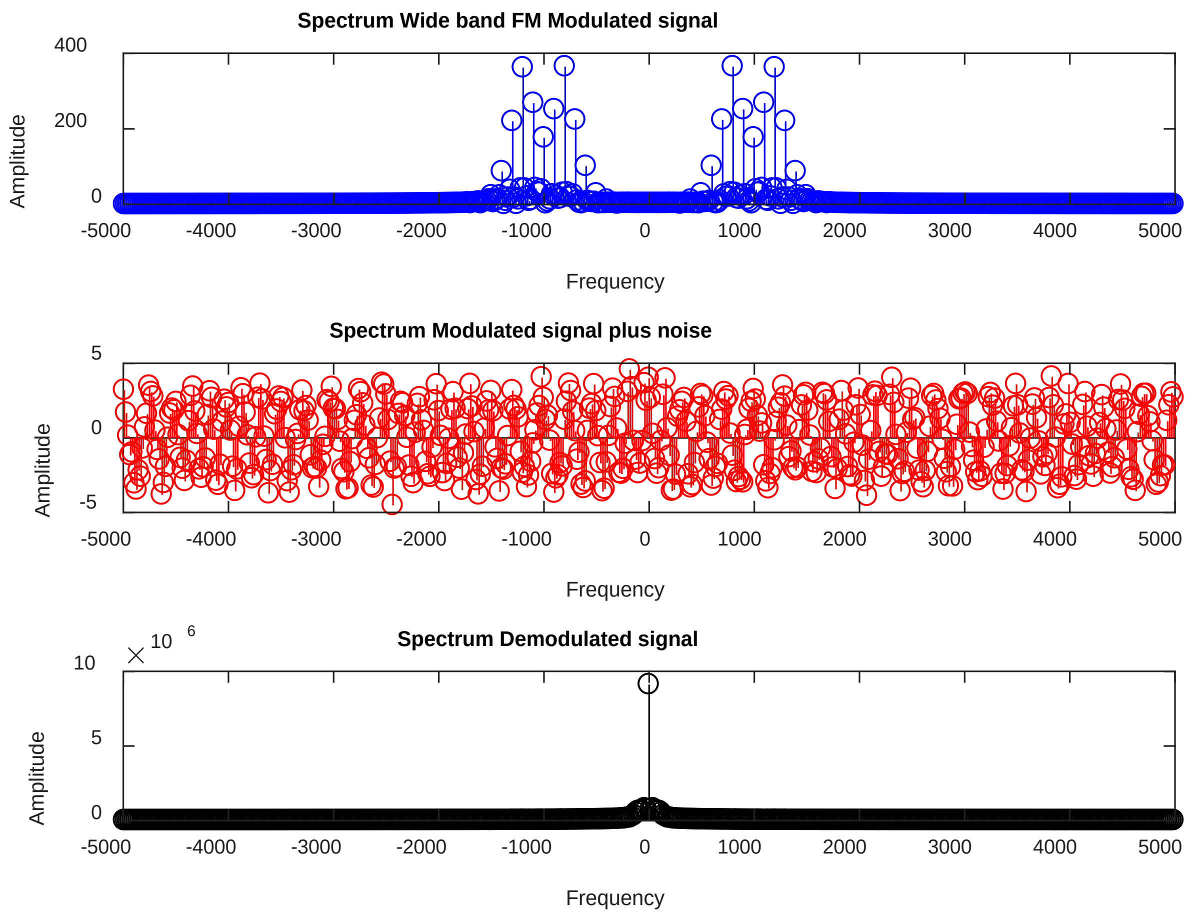

Modulated signal plus noise
5
0
-5
Amplitude
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Time


Demodulated signal
× 10 4
4
2
0
Amplitude
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Time


Spectrum Message signal
400
200
0
Amplitude
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
Frequency


Spectrum Carrier signal
400
200
0
Amplitude
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
Frequency

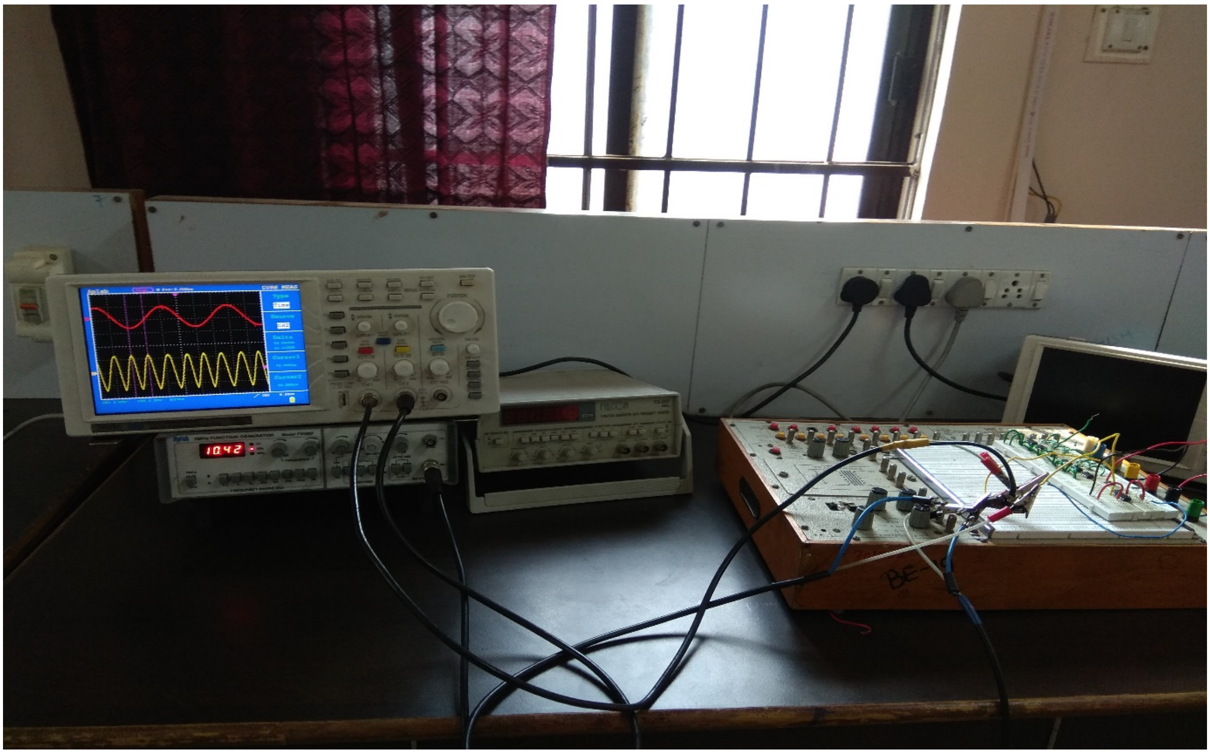

Spectrum Narrow band FM Modulated signal
1000
500
0
Amplitude
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
Frequency



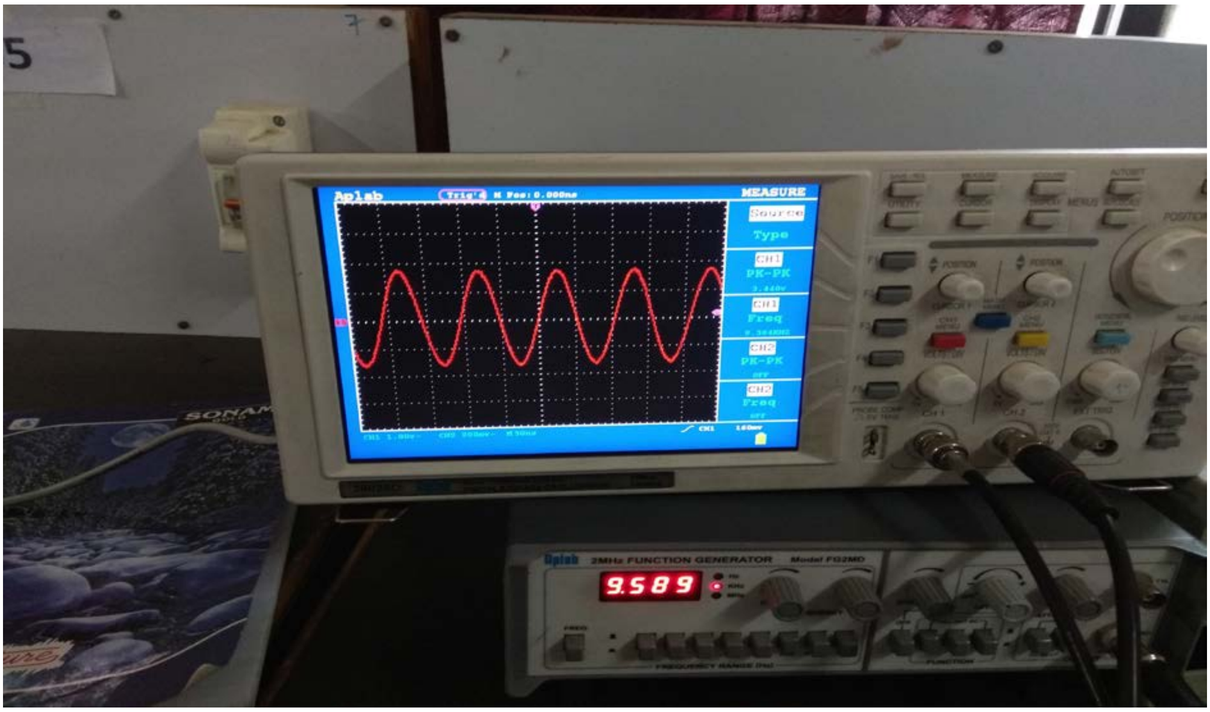
Spectrum Wide band FM Modulated signal
400
200
0
Amplitude
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
Frequency
Spectrum Modulated signal plus noise
5
0
-5
Amplitude
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
Frequency
× 10 6
Spectrum Demodulated signal
10
5
0
Amplitude
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
Frequency

7. Testing and Improvement

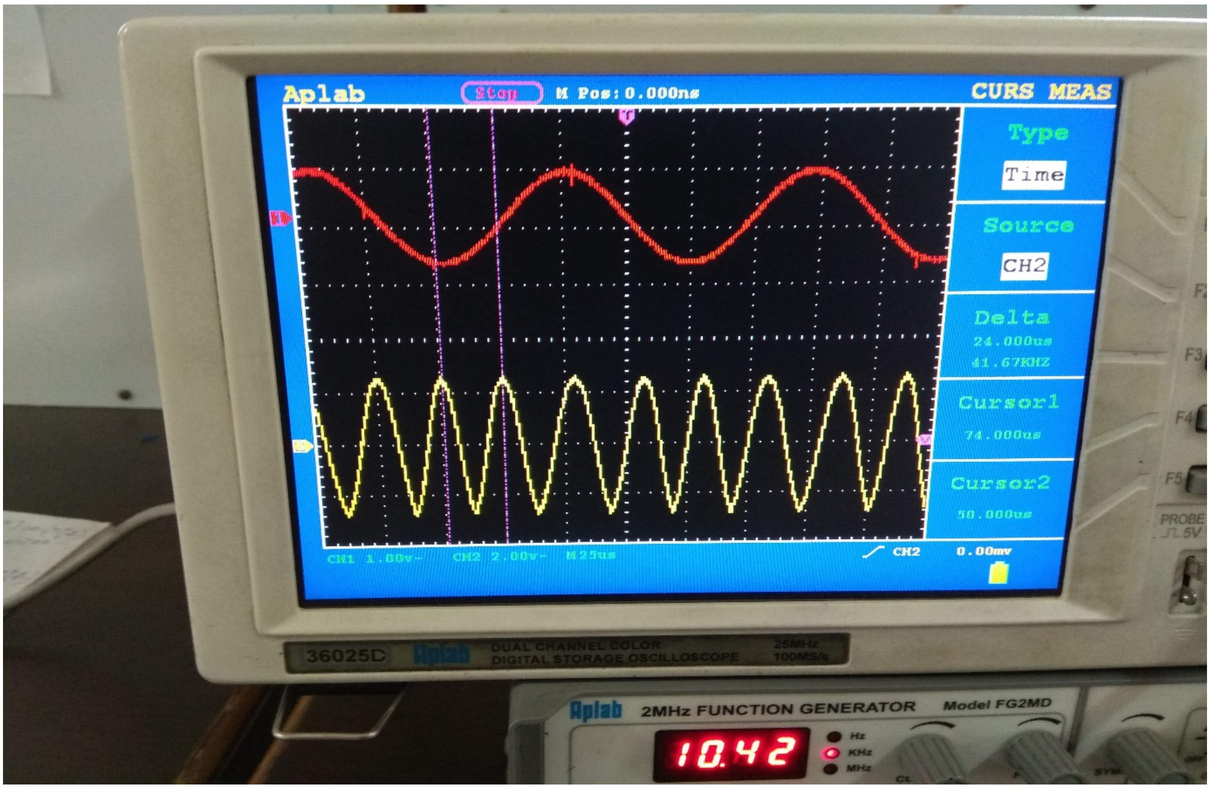
Narrow Band FM



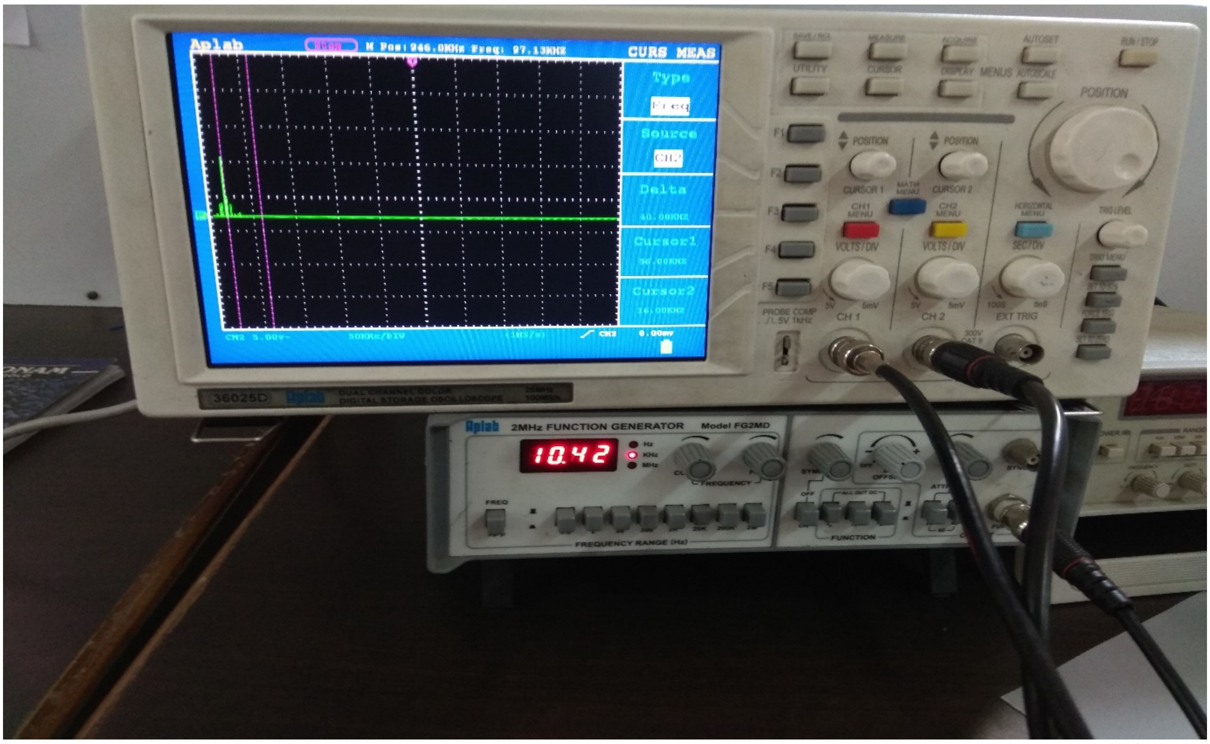
MESSAGE 10 KHZ



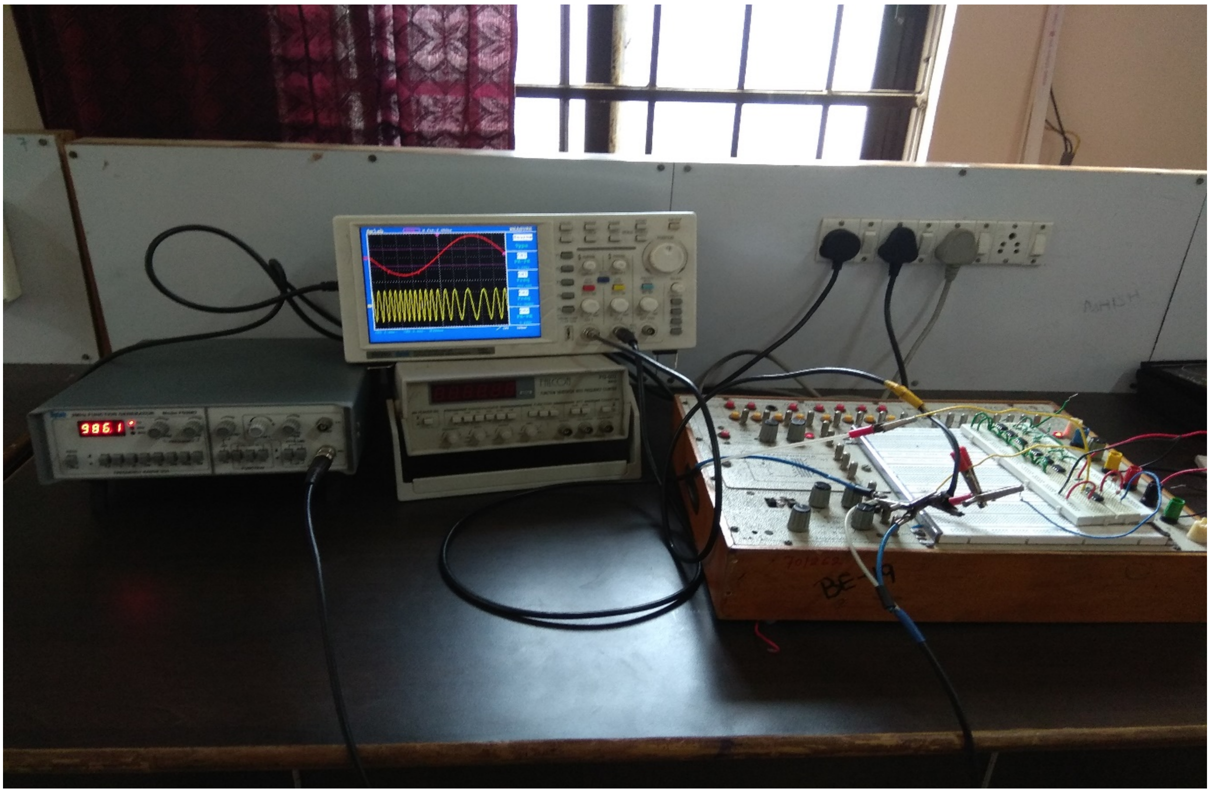
MESSAGE SIGNAL AND MODULATED SIGNAL



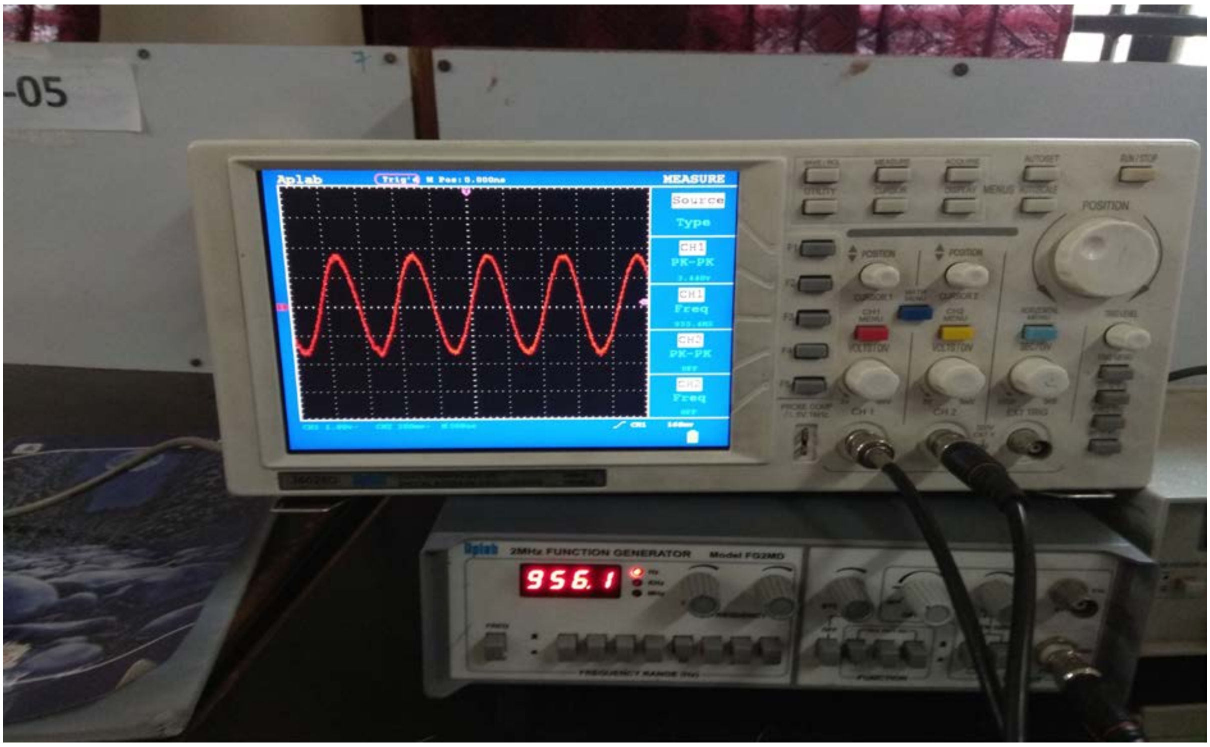
SPECTRUM (CARRIER + TWO SIDEBANDS SAME AS AM)



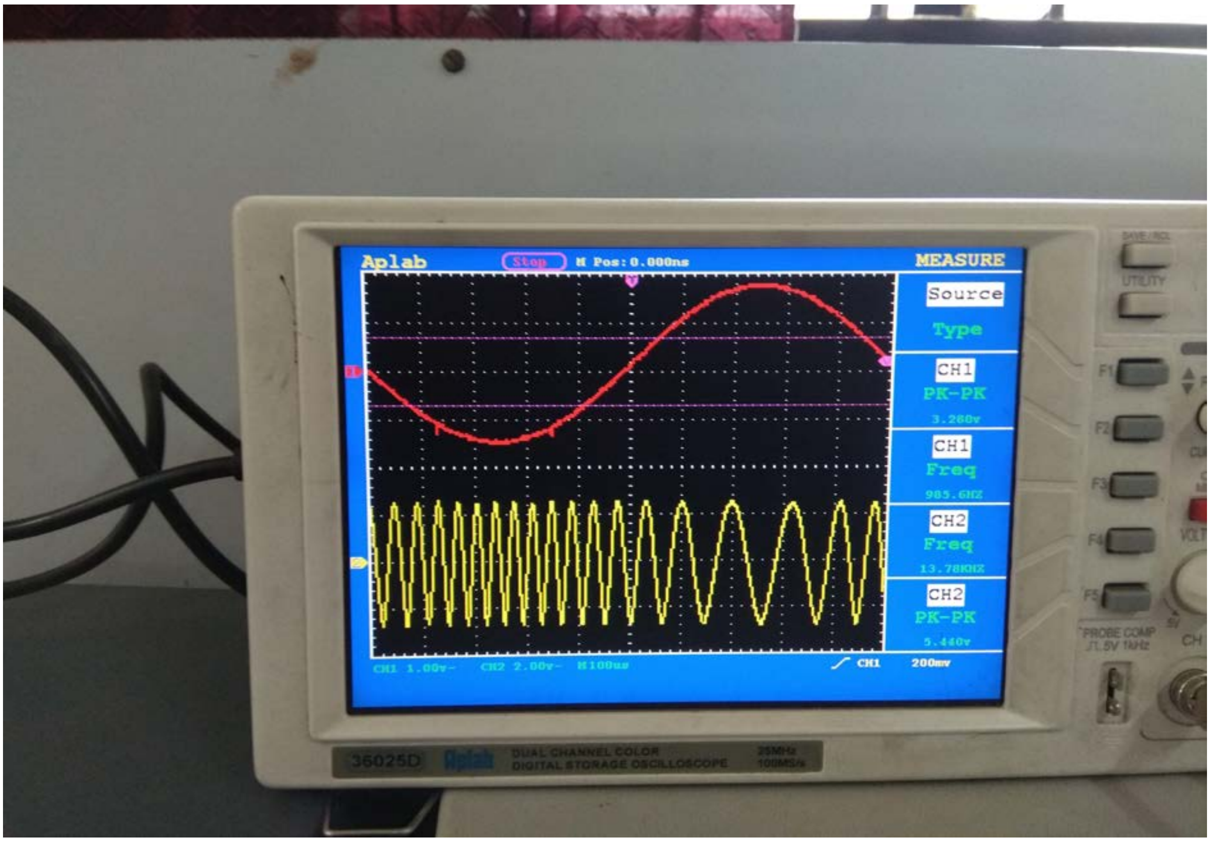
Wideband FM



MESSAGE 1 KHZ



MESSAGE SIGNAL AND MODULATED SIGNAL



We can notice that the high frequency part is present where the signal amplitude is low and vice versa where as in reality it should be reversed from this we can conclude that the ICL 8038 delays the output due to some of its design faults or specifications.

8. Discussions and Conclusion

In this report the theory of frequency modulation and Additive white Gaussian noise was covered. We added the output of the FM modulation to the AWGN noise. Block-by-block design and construction of FM modulation, noise creation and addition of the two signals was carried out in MULTISIM

A detailed description of how the design works is given here, along with why the design was chosen. The final design was discussed in full along with details of construction and assembly. The parts used are very rare and costly and the circuit was very difficult to constructed especially the multiplier part. In the circuit the first part was to generate a FM modulated signal and the second part was to pass it through a AWGN noise and then compare the power of the two signals.

We found out that the difference between the power of the original signal and the power of the signal to which noise was added and had undergone demodulation , is very less.We came to conclusion that addition of additive white Gaussian noise (AWGN) decreases the power of the signal but the difference is less.

We also become familiar with the benefits and limitations of each stage and could optimize them. The main achievement of this project is the successful construction of the system. Finally we got the results of the tests used on the design.

9. References

1. https://www.electronics-notes.com/articles/radio/modulation/frequency-modulation-fm.php

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10. Appendices

1. IC 8038

HARRIS Semiconductor

ICL8038

September 1998 File Number 2864.3

Precision Waveform Generator/Voltage Controlled Oscillator

The ICL8038 waveform generator is a monolithic integrated circuit capable of producing high accuracy sine, square, triangular, sawtooth and pulse waveforms with a minimum of external components. The frequency (or repetition rate) can be selected externally from 0.001Hz to more than 300kHz using either resistors or capacitors, and frequency modulation and sweeping can be accomplished with an external voltage. The ICL8038 is fabricated with advanced monolithic technology, using Schottky barrier diodes and thin film resistors, and the output is stable over a wide range of temperature and supply variations. These devices may be interfaced with phase locked loop circuitry to reduce temperature drift to less than 250ppm/°C.

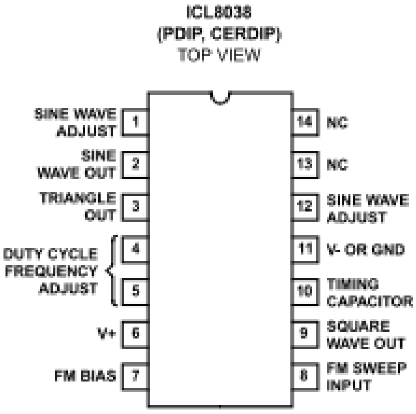
Features

- Low Frequency Drift with Temperature . . . . . . .250ppm/°C
- Low Distortion. . . . . 1% (Sine Wave Output)
- High Linearity . . . . .0.1% (Triangle Wave Output)
- Wide Frequency Range . . . . 0.001Hz to 300kHz
- Variable Duty Cycle . . . . 2% to 98%
- High Level Outputs. . . . . TTL to 28V
- Simultaneous Sine, Square, and Triangle Wave Outputs
- Easy to Use - Just a Handful of External Components Required

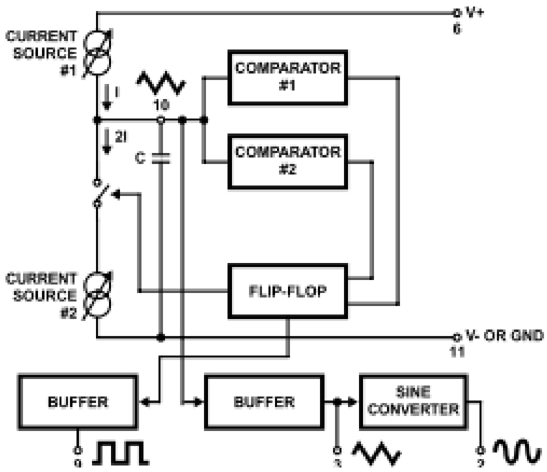
Ordering Information

PART NUMBER	STABILITY	TEMP. RANGE (°C)	PACKAGE	PKG. NO.
ICL8038CCPD	250ppm/°C (Typ)	0 to 70	14 Ld PDIP	E14.3
ICL8038CCJD	250ppm/°C (Typ)	0 to 70	14 Ld CERDIP	F14.3
ICL8038BCJD	180ppm/°C (Typ)	0 to 70	14 Ld CERDIP	F14.3
ICL8038ACJD	120ppm/°C (Typ)	0 to 70	14 Ld CERDIP	F14.3

Pinout



Functional Diagram



Absolute Maximum Ratings

Supply Voltage (V- to V+). 36V
Input Voltage (Any Pin) . . . . V- to V+
Input Current (Pins 4 and 5). 25mA
Output Sink Current (Pins 3 and 9) 25mA

Operating Conditions

Temperature Range
ICL8038AC, ICL8038BC, ICL8038CC . . . . 0^oC to 70^oC

Thermal Information

Thermal Resistance (Typical, Note 1)	θ_{JA} ($^oC/W$)	θ_{JC} ($^oC/W$)
CERDIP Package	75	20
PDIP Package	115	N/A

Maximum Junction Temperature (Ceramic Package) . . . . 175^oC
Maximum Junction Temperature (Plastic Package) . . . . 150^oC
Maximum Storage Temperature Range. . . . . -65^oC to 150^oC
Maximum Lead Temperature (Soldering 10s) . . . . 300^oC

Die Characteristics

Back Side Potential . . . . V-

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

NOTE:

1. θ_{JA} is measured with the component mounted on an evaluation PC board in free air.

Electrical Specifications $V_{SUPPLY} = \pm10V$ or $+20V$, $T_A = 25^oC$, $R_L = 10k\Omega$, Test Circuit Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	ICL8038CC			ICL8038BC			ICL8038AC			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Supply Voltage Operating Range	V_{SUPPLY} V+	Single Supply	+10	-	+30	+10	-	+30	+10	-	+30	V
	V+, V-	Dual Supplies	±5	-	±15	±5	-	±15	±5	-	±15	V
Supply Current	I_{SUPPLY}	$V_{SUPPLY} = \pm10V$ (Note 2)		12	20	-	12	20	-	12	20	mA
FREQUENCY CHARACTERISTICS (All Waveforms)												
Max. Frequency of Oscillation	f_{MAX}		100	-	-	100	-	-	100	-	-	kHz
Sweep Frequency of FM Input	f_{SWEEP}		-	10	-	-	10	-	-	10	-	kHz
Sweep FM Range		(Note 3)	-	35:1	-	-	35:1	-	-	35:1	-	
FM Linearity		10:1 Ratio	-	0.5	-	-	0.2	-	-	0.2	-	%
Frequency Drift with Temperature (Note 5)	$\Delta f/\Delta T$	0^oC to 70^oC	-	250	-	-	180	-	-	120		ppm/^oC
Frequency Drift with Supply Voltage	$\Delta f/\Delta V$	Over Supply Voltage Range	-	0.05	-	-	0.05		-	0.05	-	%/V
OUTPUT CHARACTERISTICS												
Square Wave Leakage Current	I_{OLK}	$V_9 = 30V$	-	-	1	-	-	1	-	-	1	μA
Saturation Voltage	V_{SAT}	$I_{SINK} = 2mA$	-	0.2	0.5	-	0.2	0.4	-	0.2	0.4	V
Rise Time	t_R	$R_L = 4.7k\Omega$	-	180	-	-	180	-	-	180	-	ns
Fall Time	t_F	$R_L = 4.7k\Omega$	-	40	-	-	40	-	-	40	-	ns
Typical Duty Cycle Adjust (Note 6)	ΔD		2		98	2	-	98	2	-	98	%
Triangle/Sawtooth/Ramp Amplitude	$V_{TRIANGLE}$	$R_{TRI} = 100k\Omega$	0.30	0.33	-	0.30	0.33	-	0.30	0.33	-	- xV_{SUPPLY}
Linearity			-	0.1	-	-	0.05	-	-	0.05	-	%

Electrical Specifications V_{SUPPLY} = ±10V or +20V, T_A = 25°C, R_L = 10kΩ, Test Circuit Unless Otherwise Specified **(Continued)**

PARAMETER	SYMBOL	TEST CONDITIONS	ICL8038CC			ICL8038BC			ICL8038AC			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Sine Wave												
Amplitude	V_{SINE}	R_{SINE} = 100kΩ	0.2	0.22	-	0.2	0.22	-	0.2	0.22	-	xV_{SUPPLY}
THD	THD	R_S = 1MΩ (Note 4)	-	2.0	5	-	1.5	3	-	1.0	1.5	%
THD Adjusted	THD	Use Figure 4	-	1.5	-	-	1.0	-	-	0.8	-	%

NOTES:

2. R_A and R_B currents not included.
3. V_{SUPPLY} = 20V; R_A and R_B = 10kΩ, f ≅ 10kHz nominal; can be extended 1000 to 1. See Figures 5A and 5B.
4. 82kΩ connected between pins 11 and 12, Triangle Duty Cycle set at 50%. (Use R_A and R_B.)
5. Figure 1, pins 7 and 8 connected, V_{SUPPLY} = ±10V. See Typical Curves for T.C. vs V_{SUPPLY}.
6. Not tested, typical value for design purposes only.

Test Conditions

PARAMETER	R_A	R_B	R_L	C	SW_1	MEASURE
Supply Current	10kΩ	10kΩ	10kΩ	3.3nF	Closed	Current Into Pin 6
Sweep FM Range (Note 7)	10kΩ	10kΩ	10kΩ	3.3nF	Open	Frequency at Pin 9
Frequency Drift with Temperature	10kΩ	10kΩ	10kΩ	3.3nF	Closed	Frequency at Pin 3
Frequency Drift with Supply Voltage (Note 8)	10kΩ	10kΩ	10kΩ	3.3nF	Closed	Frequency at Pin 9
Output Amplitude (Note 10)						
Sine	10kΩ	10kΩ	10kΩ	3.3nF	Closed	Pk-Pk Output at Pin 2
Triangle	10kΩ	10kΩ	10kΩ	3.3nF	Closed	Pk-Pk Output at Pin 3
Leakage Current (Off) (Note 9)	10kΩ	10kΩ		3.3nF	Closed	Current into Pin 9
Saturation Voltage (On) (Note 9)	10kΩ	10kΩ		3.3nF	Closed	Output (Low) at Pin 9
Rise and Fall Times (Note 11)	10kΩ	10kΩ	4.7kΩ	3.3nF	Closed	Waveform at Pin 9
Duty Cycle Adjust (Note 11)						
Max	50kΩ	~1.6kΩ	10kΩ	3.3nF	Closed	Waveform at Pin 9
Min	~25kΩ	50kΩ	10kΩ	3.3nF	Closed	Waveform at Pin 9
Triangle Waveform Linearity	10kΩ	10kΩ	10kΩ	3.3nF	Closed	Waveform at Pin 3
Total Harmonic Distortion	10kΩ	10kΩ	10kΩ	3.3nF	Closed	Waveform at Pin 2

NOTES:

7. The hi and lo frequencies can be obtained by connecting pin 8 to pin 7 (f_{HI}) and then connecting pin 8 to pin 6 (f_{LO}). Otherwise apply Sweep Voltage at pin 8 ($^2/_3$ V_{SUPPLY} +2V) ≤ V_{SWEEP} ≤ V_{SUPPLY} where V_{SUPPLY} is the total supply voltage. In Figure 5B, pin 8 should vary between 5.3V and 10V with respect to ground.
8. 10V ≤ V+ ≤ 30V, or ±5V ≤ V_{SUPPLY} ≤ ±15V.
9. Oscillation can be halted by forcing pin 10 to +5V or -5V.
10. Output Amplitude is tested under static conditions by forcing pin 10 to 5V then to -5V.
11. Not tested; for design purposes only.

IC AD633

Data Sheet **AD633**

SPECIFICATIONS

$T_A = 25°C$, $V_S = \pm 15$ V, $R_L \geq 2$ kΩ.

Table 1.

Parameter	Conditions	AD633J, AD633A Min	Typ	Max	Unit
TRANSFER FUNCTION		$W = \frac{(X1-X2)(Y1-Y2)}{10\ V} + Z$			
MULTIPLIER PERFORMANCE					
Total Error	−10 V ≤ X, Y ≤ +10 V		±1	±2[1]	% full scale
T_{MIN} to T_{MAX}			±3		% full scale
Scale Voltage Error	SF = 10.00 V nominal		±0.25%		% full scale
Supply Rejection	V_S = ±14 V to ±16 V		±0.01		% full scale
Nonlinearity, X	X = ±10 V, Y = +10 V		±0.4	±1[1]	% full scale
Nonlinearity, Y	Y = ±10 V, X = +10 V		±0.1	±0.4[1]	% full scale
X Feedthrough	Y nulled, X = ±10 V		±0.3	±1[1]	% full scale
Y Feedthrough	X nulled, Y = ±10 V		±0.1	±0.4[1]	% full scale
Output Offset Voltage[2]			±5	±50[1]	mV
DYNAMICS					
Small Signal Bandwidth	V_O = 0.1 V rms		1		MHz
Slew Rate	V_O = 20 V p-p		20		V/μs
Settling Time to 1%	ΔV_O = 20 V		2		μs
OUTPUT NOISE					
Spectral Density			0.8		μV/√Hz
Wideband Noise	f = 10 Hz to 5 MHz		1		mV rms
	f = 10 Hz to 10 kHz		90		μV rms
OUTPUT					
Output Voltage Swing		±11[1]			V
Short Circuit Current	R_L = 0 Ω		30	40[1]	mA
INPUT AMPLIFIERS					
Signal Voltage Range	Differential	±10[1]			V
	Common mode	±10[1]			V
Offset Voltage (X, Y)			±5	±30[1]	mV
CMRR (X, Y)	V_{CM} = ±10 V, f = 50 Hz	60[1]	80		dB
Bias Current (X, Y, Z)			0.8	2.0[1]	μA
Differential Resistance			10		MΩ
POWER SUPPLY					
Supply Voltage					
Rated Performance			±15		V
Operating Range		±8[1]		±18[1]	V
Supply Current	Quiescent		4	6[1]	mA

[1] This specification was tested on all production units at electrical test. Results from those tests are used to calculate outgoing quality levels. All minimum and maximum specifications are guaranteed; however, only this specification was tested on all production units.
[2] Allow approximately 0.5 ms for settling following power on.