EC3092D

COMMUNICATION ENGINEERING LAB

MINI PROJECT REPORT

FM TRANSMISSION AND RECEPTION USING FDM

GROUP A18

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AIM:

1. To design and implement an FM transmitter and receiver capable of transmitting more than one signal using frequency division multiplexing.
2. To find the effect of guard band in reducing interference.
3. To determine the effect of multiplexing on SNR.

COMPONENTS

1. LTC6990 VCO
2. AC power supply (for carrier and message signals)
3. DC power supply
4. Capacitor
5. Resistors
6. Diode (IN5818)
7. OPAMP (AD549)

THEORY

Frequency Modulation:

Frequency Modulation is the process of varying the frequency of the carrier signal linearly with the message signal. Hence, in frequency modulation, the amplitude and the phase of the carrier signal remains constant. The frequency modulation method of transmitting signals, especially in radio broadcasting, in which the value of the signal is given by the frequency of a high-frequency carrier wave. In FM radio transmission, for example, the signal to be carried is a sound wave, and its increasing and decreasing value is reflected in the increasing and decreasing frequency of a radio frequency carrier wave.

The frequency of a carrier (fc) will increase as the amplitude of modulating (input) signal increases. The carrier frequency will be maximum (fc max) when the input signal is at its peak. The carrier deviates maximum from its normal value. The frequency of a carrier will decrease as the amplitude of the modulating (input) signal decreases.

The carrier frequency will be minimum (fc min) when the input signal is at its lowest. The carrier deviates from its normal value. The frequency of the carrier will be at its normal value (free-running) fc when the input signal value is 0V. There is no deviation in the carrier. The figure shows the frequency of the FM wave when the input is at its max, 0V, and at its min.

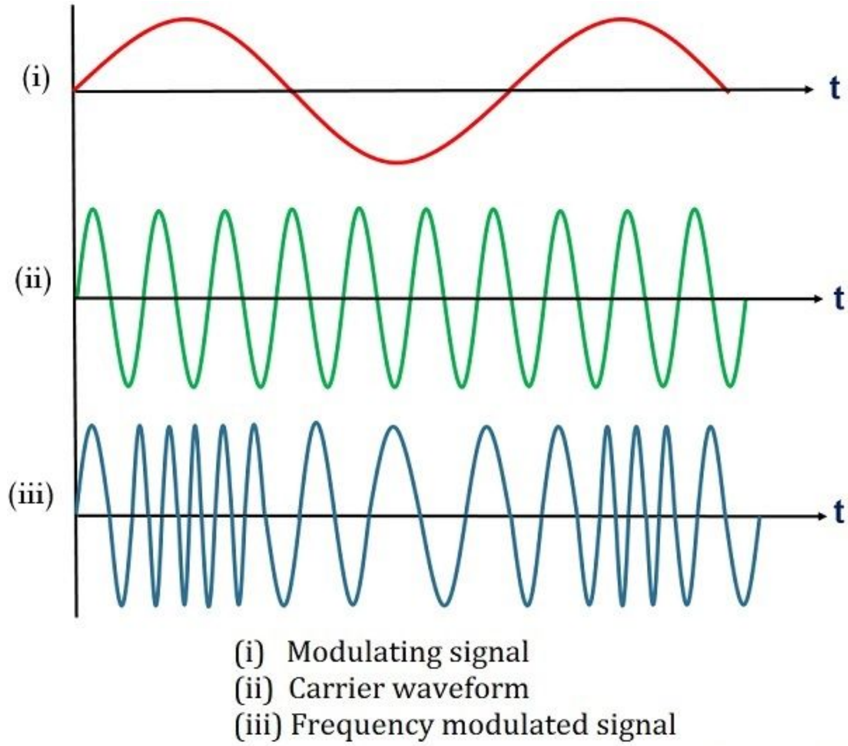


Fig 1: Frequency modulation

Mathematical Expression:

$$y(t) = A_c \cos\left(2\pi f_c t + \frac{f_\Delta}{f_m}\sin(2\pi f_m t)\right)$$

where f_c is the carrier frequency
f_m is message signal frequency
f_Δ is the frequency deviation;
$\frac{f_\Delta}{f_m}$ is the modulation index.

Modulation Index:

The modulation index of an FM wave is defined as under :

$$h = \frac{\Delta f}{f_m} = \frac{f_\Delta \left|x_m(t)\right|}{f_m}$$

The modulation index is very important in FM because it decides the bandwidth of the FM wave. The modulation index also decides the number of sidebands having significant amplitudes.

In AM, the maximum value of the modulation index m is 1 . But, for FM, the modulation index can be greater than 1.

Bandwidth

Bandwidth is one of the main elements of FM signal. In FM signal, the sidebands will extend either side which will extend to infinity; however, the strength of them drops away. Auspiciously, it is the potential to restrict the BW of an FM signal without changing its value excessively.
Recall, the bandwidth of a complex signal like FM is the difference between its highest and lowest frequency components and is expressed in Hertz (Hz). Bandwidth deals with only frequencies. AM has only two sidebands (USB and LSB), and the bandwidth was found to be 2 fm.
In FM it is not so simple. FM signal spectrum is quite complex and will have an infinite number of sidebands as shown in the figure. This figure gives an idea, how the spectrum expands as the modulation index increases. Sidebands are separated from the carrier by fc ± fm, fc ± 2fm, fc ± 3fm, and so on.

If $h << 1$, the modulation is called narrowband FM (NFM), and its bandwidth is approximately $B \approx 2f_m$

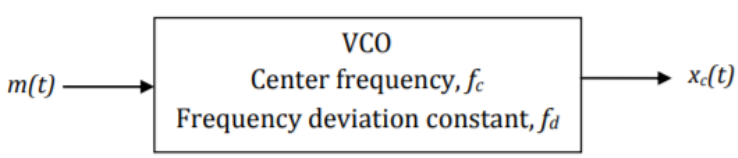
For wideband FM we use Carson's rule which states that nearly all (≈98 percent) of the power of a frequency-modulated signal lies within a bandwidth B of:

$$B = 2(\Delta f + f_m)$$

$$B = 2(\beta + 1)f_m$$

Voltage Controlled Oscillator (VCO):

The voltage-controlled oscillator (VCO) is a device whose frequency changes linearly with an input voltage. It is used to perform direct frequency modulation on signals. VCO has a center frequency f_c and the input (control) voltage m(t) modulates the instantaneous frequency around this center frequency.



$f_i(t) = f_c + f_d m(t)$ – Instantaneous frequency of FM signal

$x_c(t) = A_c\left(2\pi f_c t + 2\pi f_d \int_{-\infty}^{t} m(\tau)d\tau\right)$ – Modulated signal

A_c = Amplitude of modulated signal

Fig 2: FM generation using VCO

The mean frequency of these oscillators is determined by an RC circuit. The controllable part of the VCO is its frequency, which may be varied about a mean by an external control voltage. The variation of frequency is close to linear, with respect to the control voltage, over a large percentage range of the mean frequency.

LTC6990 Oscillator

The LTC6990 is a precision silicon oscillator with a programmable frequency range of 488Hz to 2MHz. It can be used as a fixed-frequency or voltage-controlled oscillator (VCO).

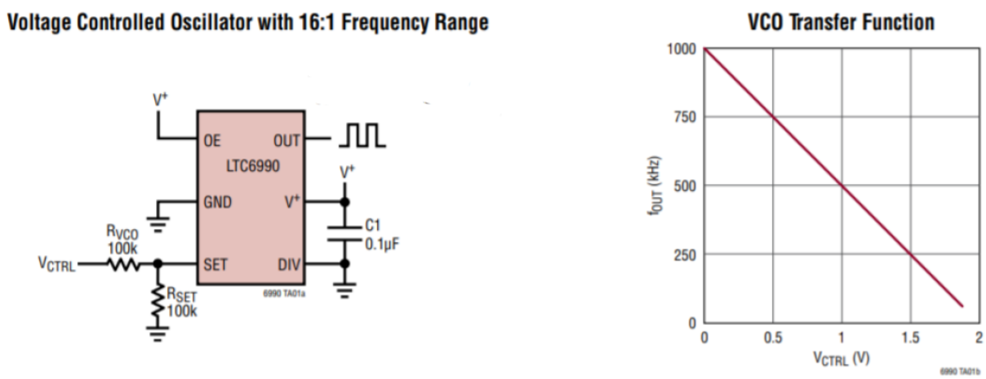


Fig 3: LTC6990 VCO

The output signal frequency expressed as

$F_{OUT} = 1MHz - 0.5V_{CTRL}\,MHz/V$

We can use the LTC6990 as a VCO to generate an FM wave by using the message signal as V_{CTRL}. A DC offset is also given to ensure that the Carrier frequency is as desired.

Frequency Demodulation

FM demodulation is a key process in the reception of a frequency modulated signal. Once the signal has been received, filtered, and amplified, it is necessary to recover the original modulation from the carrier. It is this process that is called demodulation or detection.

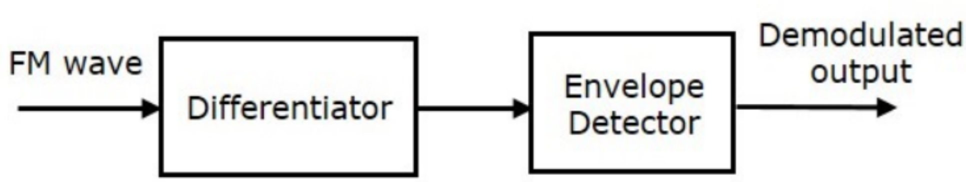


Fig 4: FM demodulation

Op-Amp based differentiator:

An op-amp differentiator is an inverting amplifier configuration that produces output voltage amplitude which is proportional to the rate of change of the input voltage with respect to time. This means that the faster change in the input voltage signal, the greater the output voltage change in response. It uses a capacitor in series with the input voltage. Normally, differentiating circuits are usually designed to respond to triangular and rectangular input waveforms.
It is used to convert the FM wave into a combination of AM wave and FM wave. This means it converts the frequency variations of FM waves into the corresponding voltage(amplitude) variations of AM waves. In this case, the output of the differentiator will be an AM modulated signal. The AM modulated signal can be then demodulated using an envelope detector.

Fig 5: The Differentiator

We know that the equation of FM wave is

$$s(t) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt\right)$$

Differentiate the above equation with respect to 't'.

$$\frac{ds(t)}{dt} = -A_c\left(2\pi f_c + 2\pi k_f m(t)\right)\sin\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt\right)$$

We can write, -*sin*θ as *sin*(θ − 180°)

$$\Rightarrow \frac{ds(t)}{dt} = A_c\left(2\pi f_c + 2\pi k_f m(t)\right)\sin\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt - 180^0\right)$$

$$\Rightarrow \frac{ds(t)}{dt} = A_c\left(2\pi f_c\right)\left[1 + \left(\frac{k_f}{k_c}\right) m(t)\right]\sin\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt - 180^0\right)$$

The Envelope detector:

An envelope detector is an electronic circuit that takes a (relatively) high-frequency amplitude modulated signal as input and provides an output, which is the demodulated envelope of the original signal.

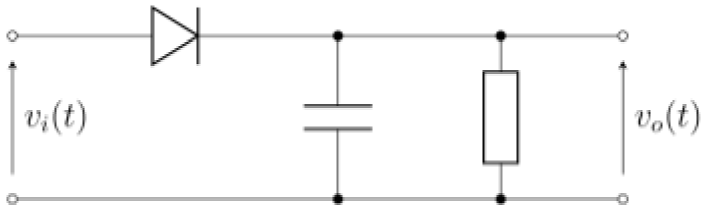


Fig 6: Envelope Detector

The capacitor in the circuit above stores charge on the rising edge and releases it slowly through the resistor when the input signal amplitude falls.
The diode in series rectifies the incoming signal, allowing current flow only when the positive input terminal is at a higher potential than the negative input terminal.

In the above equation, the amplitude term resembles the envelope of the AM wave and the angle term resembles the angle of the FM wave. Here, our requirement is the modulating signal m(t). Hence, we can recover it from the envelope of the AM wave using an envelope detector.

Finally, it is passed through a low pass filter to remove high-frequency components.

Multiplexing
Multiplexing is the process of combining multiple signals into one signal, over a shared medium. So basically it is a technique that allows the simultaneous transmission of multiple signals through a single channel. This, therefore, ensures the efficient utilization of channel bandwidth and channel resources.
The device that does multiplexing can be called a Multiplexer or MUX.

There are mainly two types of multiplexers, namely analog and digital.
They are further divided into Frequency Division Multiplexing (FDM), Wavelength Division Multiplexing (WDM), and Time Division Multiplexing (TDM)

Frequency division multiplexing
Frequency division multiplexing (FDM) is a technique of multiplexing that means combining more than one signal over a shared medium. In FDM, signals of different frequencies are combined for concurrent transmission

Concept and process

In FDM, the total bandwidth is divided into a set of frequency bands that do not overlap. Each of these bands is a carrier of a different signal that is generated and modulated by one of the sending devices. Each signal to be transmitted modulates a different carrier. The frequency bands are separated from one another by strips of unused frequencies called the guard bands, to prevent overlapping of signals.

The spectrum of composite FDM signals has been shown.

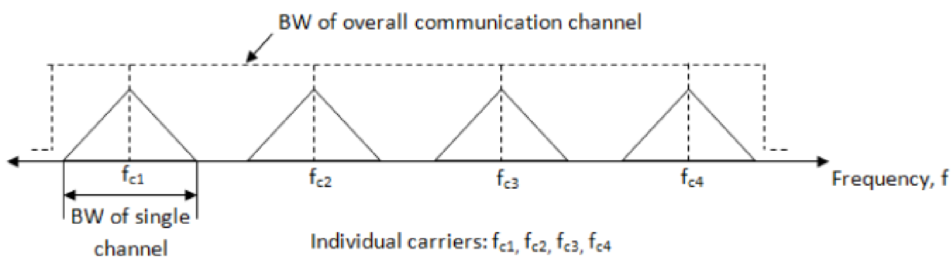


Fig 7: FDM

Different signals are thus added together in the time domain but they have a separate identity in the frequency domain.

The modulated signals are combined together using a multiplexer (MUX) in the sending end. The combined signal is transmitted over the communication channel, thus allowing multiple independent data streams to be transmitted simultaneously.

At the receiving end, the individual signals are extracted from the combined signal by the process of demultiplexing (DEMUX). The composite signal is applied to a group of bandpass filters (BPF). Each BPF has a center frequency corresponding to one of the carriers. The BPFs have an adequate bandwidth to pass all the channel information without any distortion. Each filter will pass only its channel and reject all the other channels. The channel demodulator then removes the carrier and recovers the original signal back.

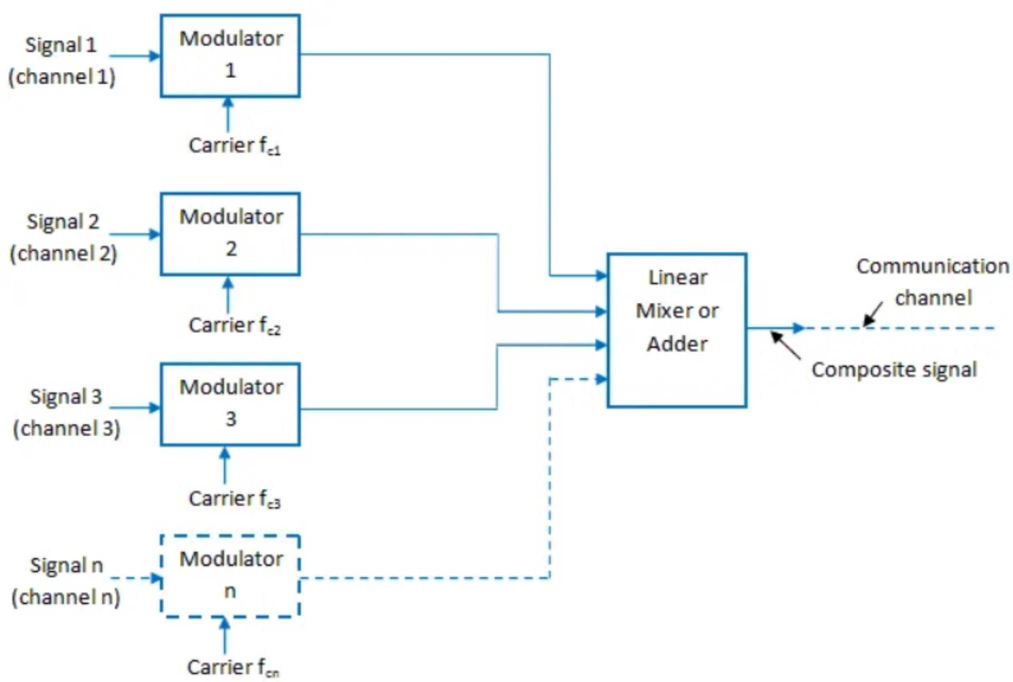


Fig 8: FDM Multiplexing process

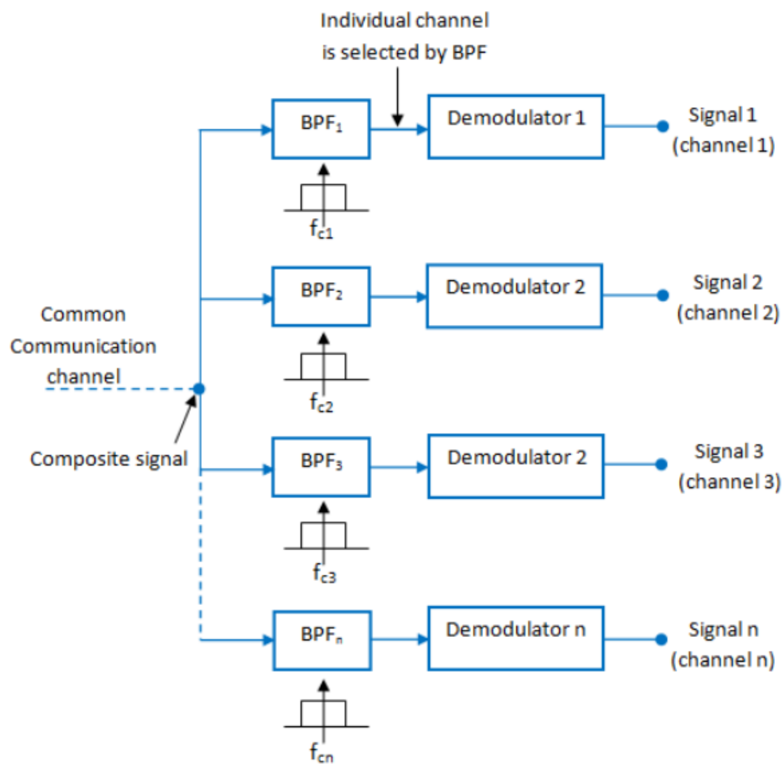


Fig9: FDM Demultiplexing process

Linear Adder

The summing Amplifier is one variation of inverting amplifiers. In an inverting amplifier there is only one voltage signal applied to the inverting input. This simple inverting amplifier can easily be modified to a summing amplifier if we connect several input terminals in parallel to the existing input terminals.

However, if all the input impedances, (R_{IN}) are equal in value, we can simplify the above equation to give an output voltage of:

$$-Vout = \frac{R_F}{R_{IN}}\left(V1 + V2 + V3....etc\right)$$

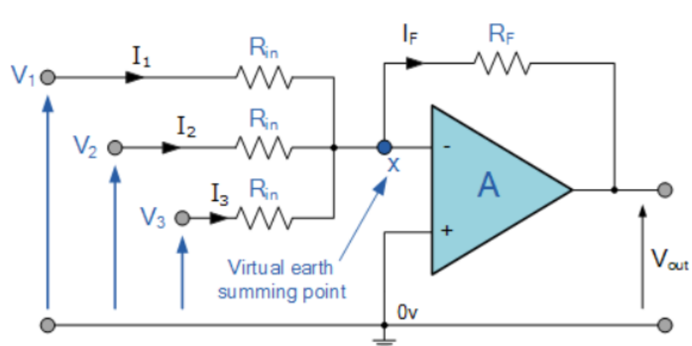
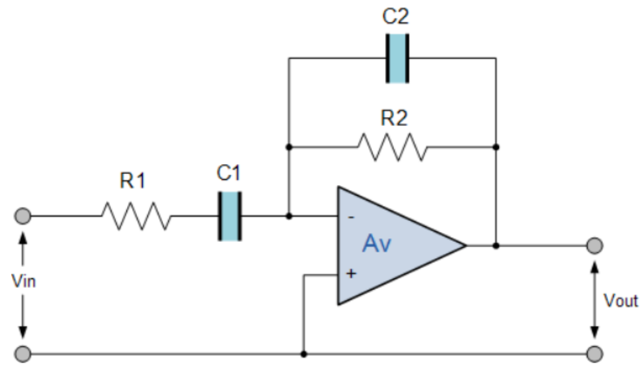


Fig 10: Summing Amplifier

Bandpass Filter

Band Pass Filter is a frequency selective filter circuit used in electronic systems to separate a signal at one particular frequency, or a range of signals that lie within a certain "band" of frequencies from signals at all other frequencies. The cut-off or corner frequency of the low pass filter (LPF) is higher than the cut-off frequency of the high pass filter (HPF) and the difference between the frequencies at the -3dB point will determine the "bandwidth" of the bandpass filter while attenuating any signals outside of these points.



$$Voltage\ Gain = -\frac{R_2}{R_1},\quad fc_1 = \frac{1}{2\pi R_1 C_1},\quad fc_2 = \frac{1}{2\pi R_2 C_2}$$

Fig 11: Bandpass Filter

Guard Band

A guard band is a narrow frequency range that separates two ranges of wider frequency. This ensures that simultaneously used communication channels do not experience interference, which would result in decreased quality for both transmissions.

Guard bands are used in frequency division multiplexing (FDM). In FDM, a number of signals are sent simultaneously on the same network, allocating separate frequency bands or channels to each signal. Guard bands are used to avoid interference between two successive channels.

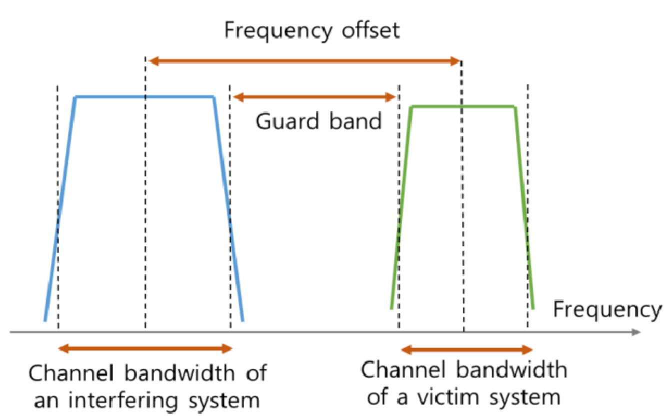
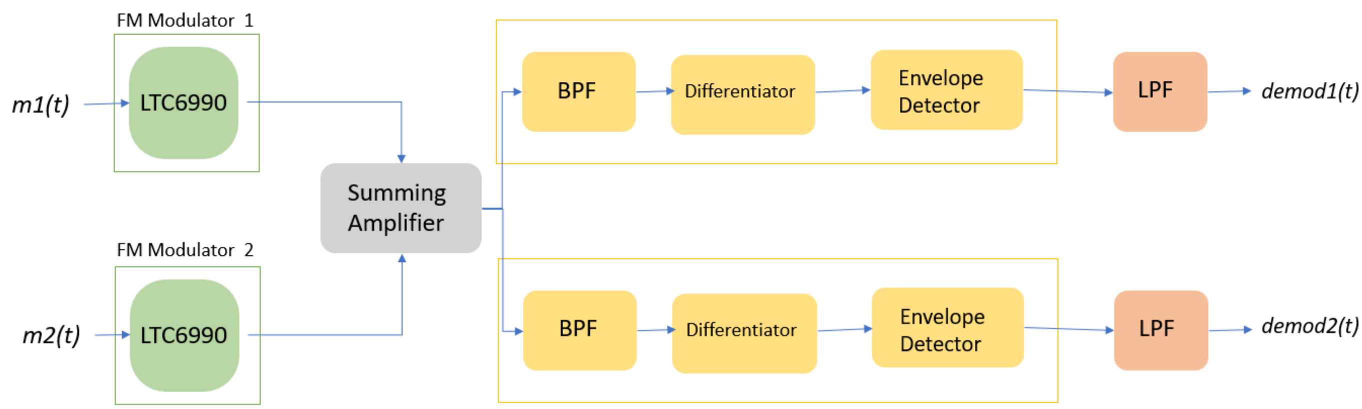


Fig 12: Guard Band

CIRCUIT BLOCK DIAGRAM



CIRCUIT DESIGN

$$f_{out} \text{ with } 1V\ V_{CTRL} = f_d = 1 - 0.5(1)$$
$$= 0.5\ MHz/V$$
$$= 500\ kHz/V$$

SIGNAL 1

$$\beta = \frac{f_d |x_m(t)|}{f_m} = \frac{500\times10^3 \times 0.25}{5\times10^3}$$

$$\beta = 25$$

$$B = 2(\beta+1)f_m = 2(25+1)5\times10^3$$
$$= 260\ kHz$$

SIGNAL 2

$$\beta = \frac{f_d |x_m(t)|}{f_m} = \frac{500\times10^3 \times 0.25}{10\times10^3}$$

$$\beta = 12.5$$

$$B = 2(\beta+1)f_m = 2(12.5+1)10\times10^3$$
$$= 270\ kHz$$

	Carrier frequency (f_c)	Message frequency (f_m)
Signal 1	280kHz	5kHz
Signal 2	780kHz	10kHz

Therefore f_{max} of Signal 1 = 280+130 = 410kHz and f_{min} of Signal 2 = 780-135 = 645kHz

FM MODULATOR

Signal 1

$f_c = 280kHz = 0.28MHz$

$f_c = 1 - 0.5\,V_{CTRL}$

$V_{CTRL} = (1-0.28)2 = \underline{\underline{1.44V}}$

Signal 2

$f_c = 780kHz = 0.78MHz$

$f_c = 1 - 0.5\,V_{CTRL}$

$V_{CTRL} = (1-0.78)2 = \underline{\underline{0.44V}}$

BANDPASS FILTER

Signal 1

$f_H = 160\,kHz$; $f_L = 400k$ from graph

High pass part

$f_H > \frac{1}{2\pi R_H C}$; Let $C = 10pF$

$\therefore R_H > 99.47k\Omega$

Low pass part

$f_L < \frac{1}{2\pi R_L C}$, let $C = 10pF$

$\therefore R_L < 39.8k\Omega$

Signal 2

$f_H = 640\, kHz$; $f_L = 900k$ from graph

High pass part

$f_H > \frac{1}{2\pi R_H C}$; let $C = 10pF$

$\therefore R_H > 24.87 k\Omega$

Low pass part

$f_L < \frac{1}{2\pi R_L C}$, let $C = 10pF$

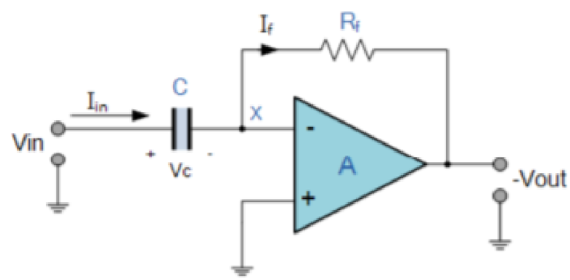
$\therefore R_L < 17.7 k\Omega$

DIFFERENTIATOR

Inorder for the op-amp to act as differentiator frequency of operation, f

$f < f_{cut\text{-}off}$

Signal 1



$f = f_c = 280 kHz$

let $C = 10pF$

$280 \times 10^3 < \frac{1}{2\pi RC}$

$\Rightarrow \underline{\underline{R < 56.84 k\Omega}}$

Signal 2

$$f = f_c = 780\ kHz$$

Let $C = 10pF$

$$780 \times 10^3 < \frac{1}{2\pi RC}$$

$$\Rightarrow \underline{\underline{R < 20.4\ k\Omega}}$$

ENVELOPE DETECTOR

Signal 1

$$T_m = \frac{1}{f_m} = \frac{1}{5000} = 200\mu s$$

$$T_c = \frac{1}{f_c} = \frac{1}{280000} = 3.5\mu s$$

$$T_c \ll \tau \ll T_m$$

Let $\tau = 50\mu s$ & $C = 10nF$

$$\therefore RC = \tau$$

$$\Rightarrow \underline{\underline{R = 5k\Omega}}$$

Signal 2

$$T_m = \frac{1}{f_m} = \frac{1}{10000} = 100\mu s$$

$$T_c = \frac{1}{f_c} = \frac{1}{780000} = 1.3\mu s$$

$$T_c \ll \tau \ll T_m$$

Let $\tau = 30\mu s$ & $C = 10nF$

$$\therefore RC = \tau$$

$$\Rightarrow \underline{\underline{R = 3k\Omega}}$$

LOW PASS FILTER

Signal 1

$f_m = 5 kHz$

$f_m \leq \frac{1}{2\pi RC}$, let $C = 1nF$

$\Rightarrow$ $\underline{\underline{R \leq 31.83 k\Omega}}$

Signal 2

$f_m = 10 kHz$

$f_m \leq \frac{1}{2\pi RC}$, let $C = 1nF$

$\Rightarrow$ $\underline{\underline{R \leq 15.9 k\Omega}}$

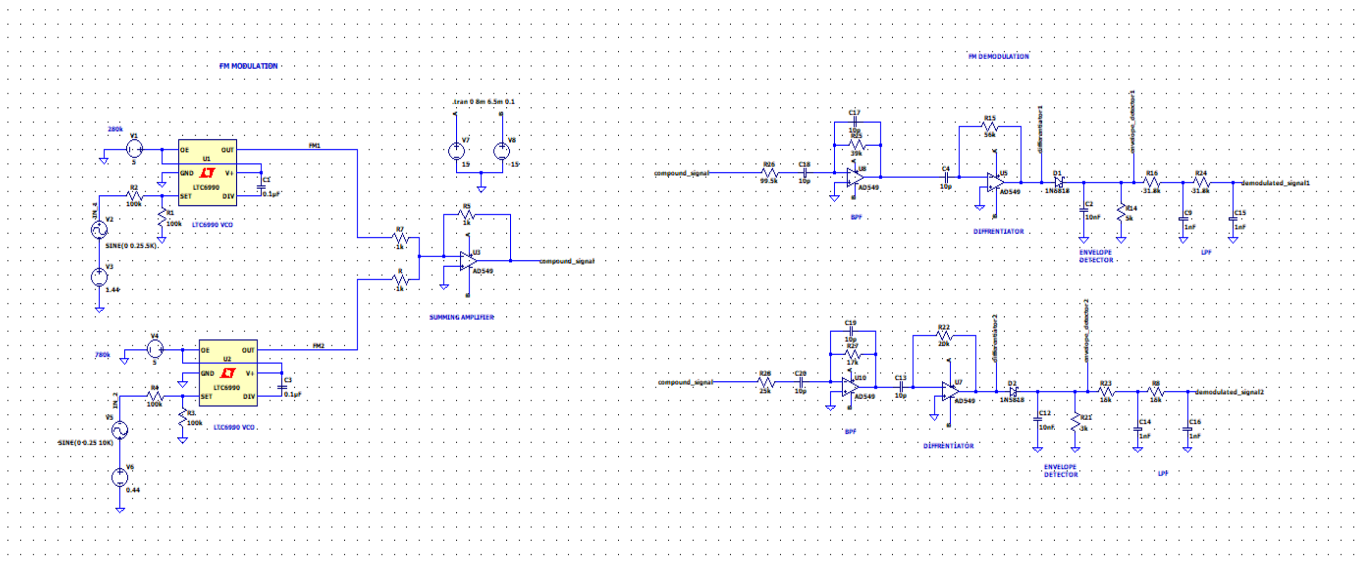
DESCRIPTION OF INPUT

For modulation, we are taking a sinusoidal message signal of frequency 5kHz and 0.5V amplitude. Another message signal is also given as input of frequency 10kHz and 0.5V amplitude. The carrier frequencies are 280kHz and 780kHz respectively which are used to calculate the Vctrl given to the SET pin of LTC6990.

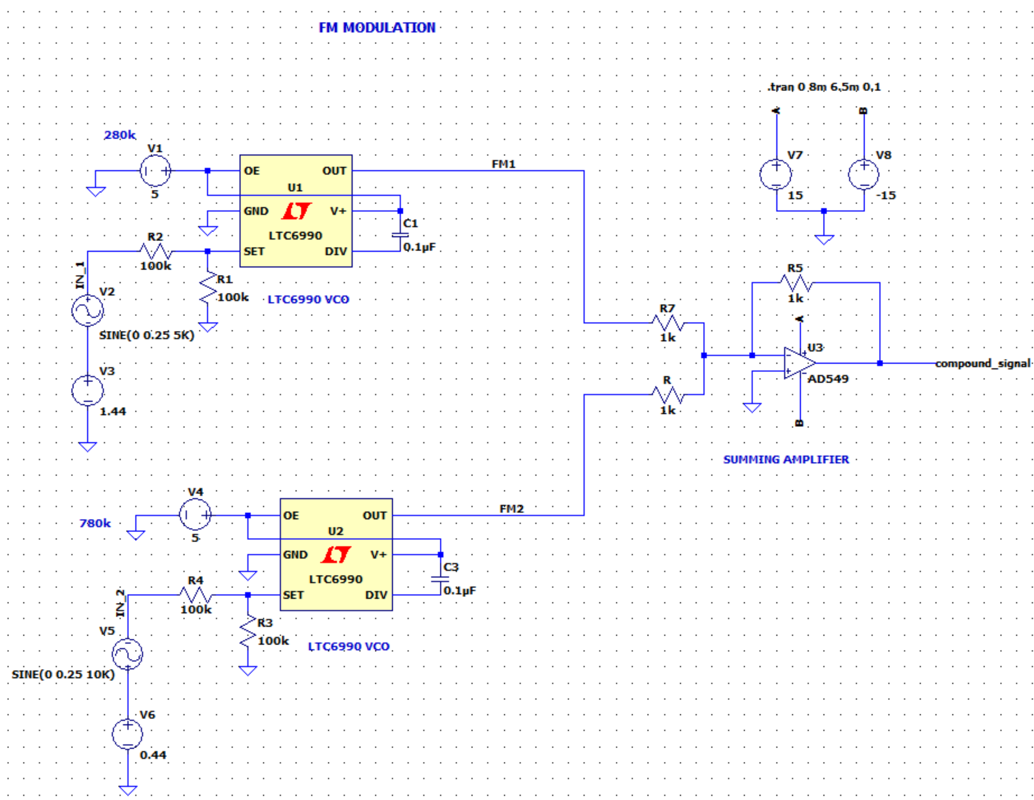
DESCRIPTION OF OUTPUT

The output obtained at VCO output pins for corresponding input message signals are the modulated waveforms. Plots of signals at the output of the summing amplifier, differentiator, envelope detector were also generated as shown below and finally we obtained our demodulated signal at the output of the low pass filter.

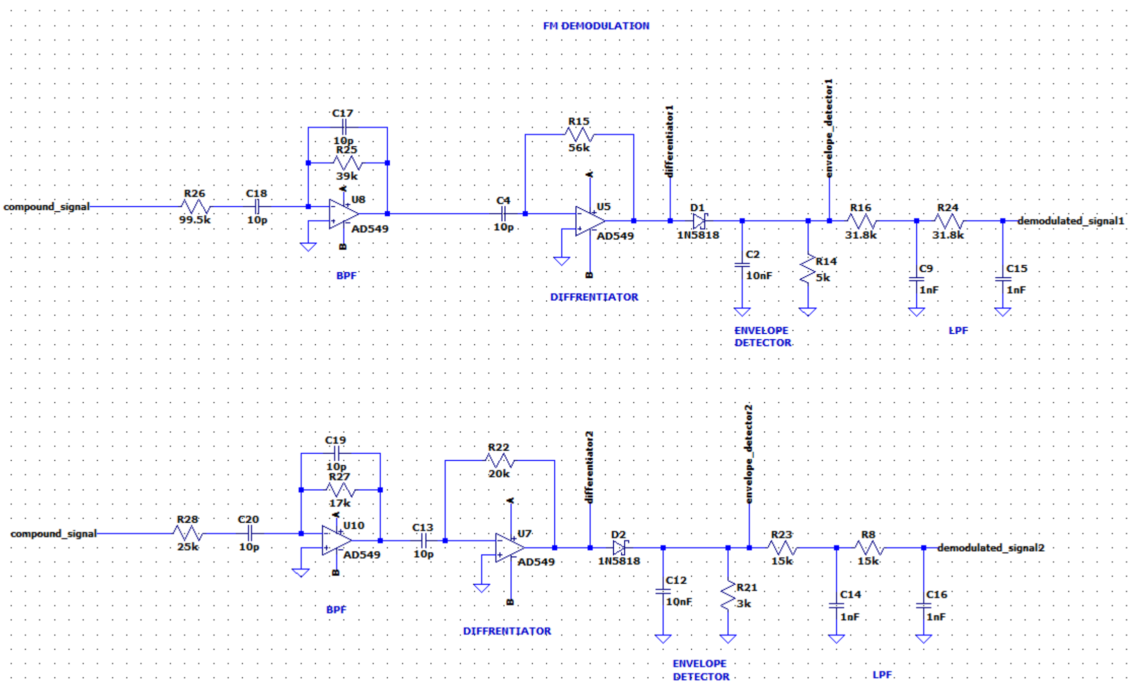
CIRCUIT DIAGRAM



FM Modulation and Demodulation with Frequency Division Multiplexing



FDM Transmitter



FDM Receiver

WAVEFORMS

With Guard band

1. Input

<table>
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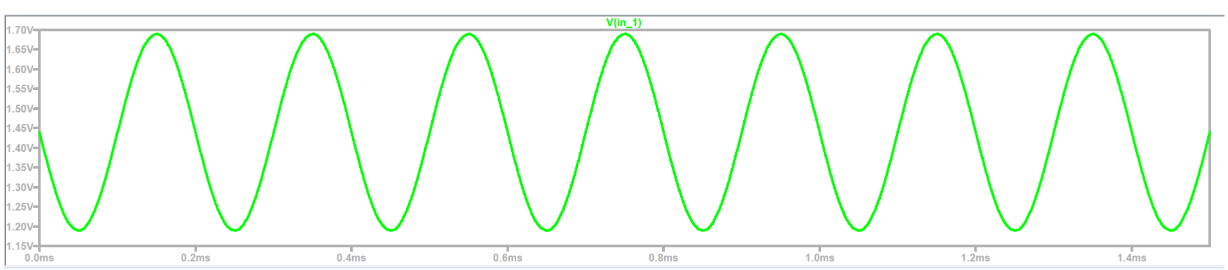
<tr><td>
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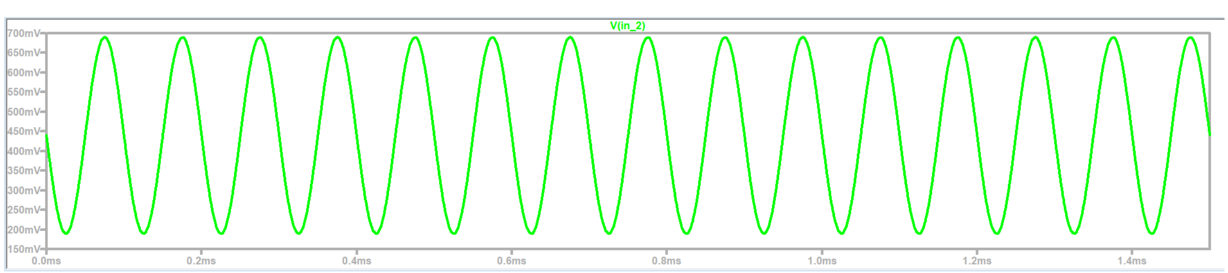
<tr><td>Message Signal 2</td></tr>
<tr><td>
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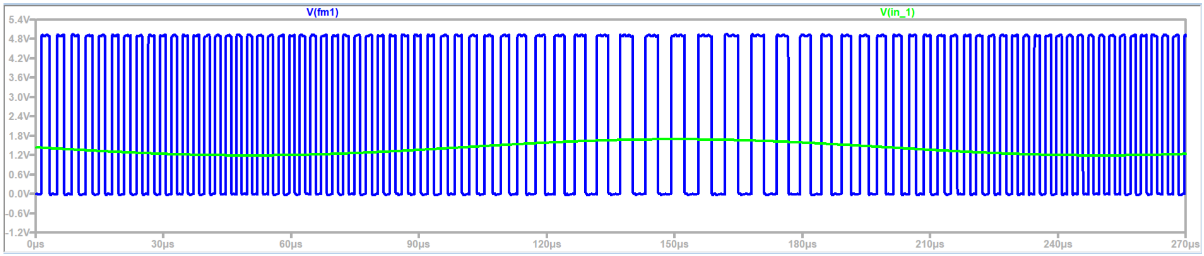
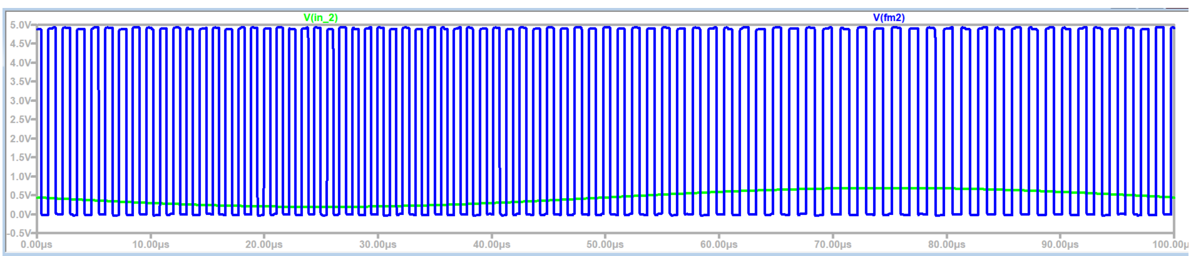
2. FM Waves

FM Signal 1

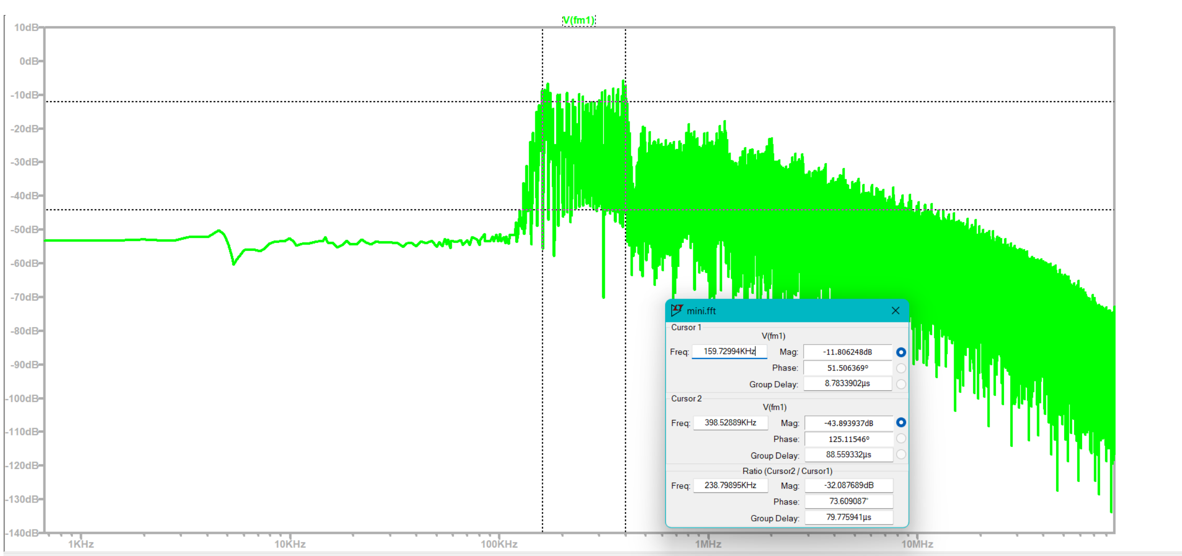


FM Signal 2

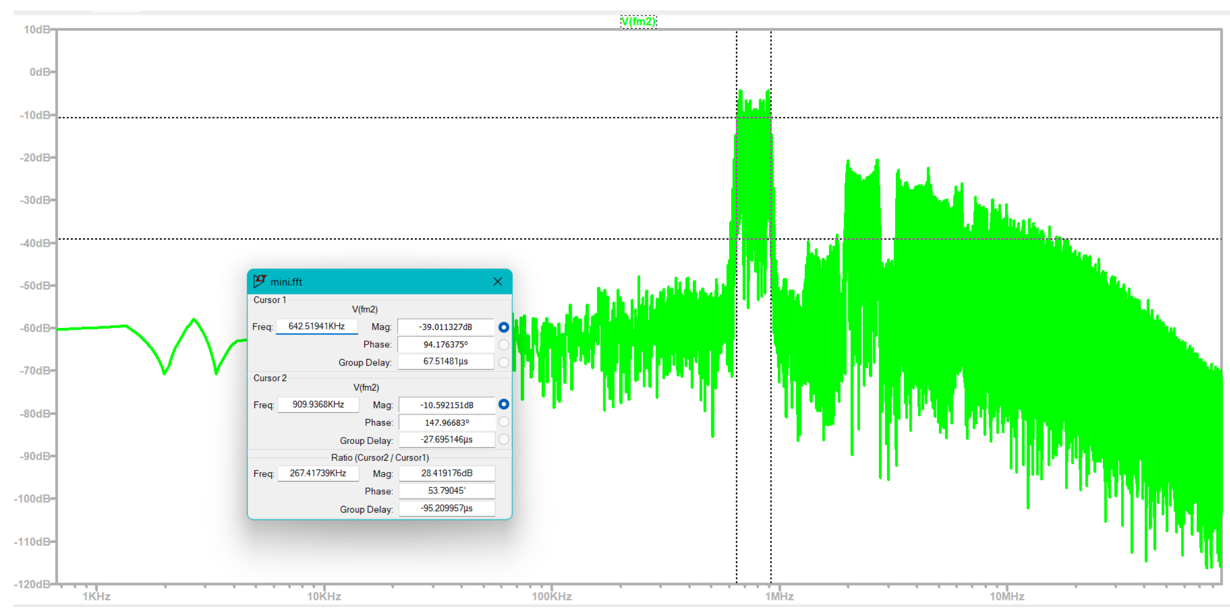


3. FM Waves FFT

FM Signal 1 FFT

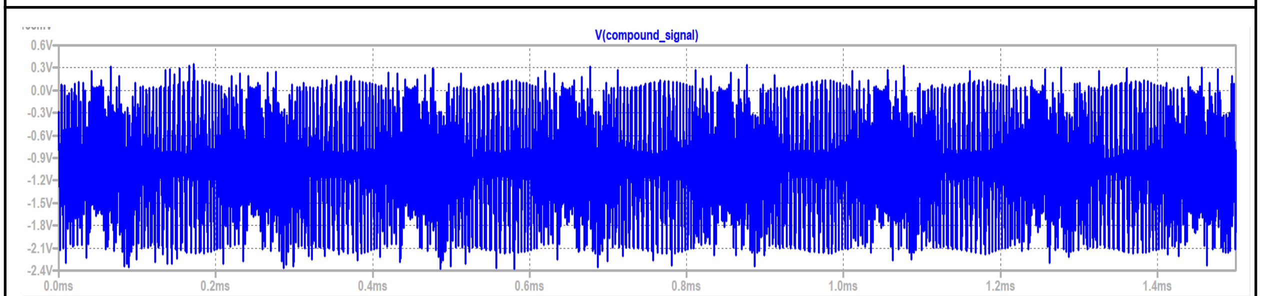


FM Signal 2 FFT



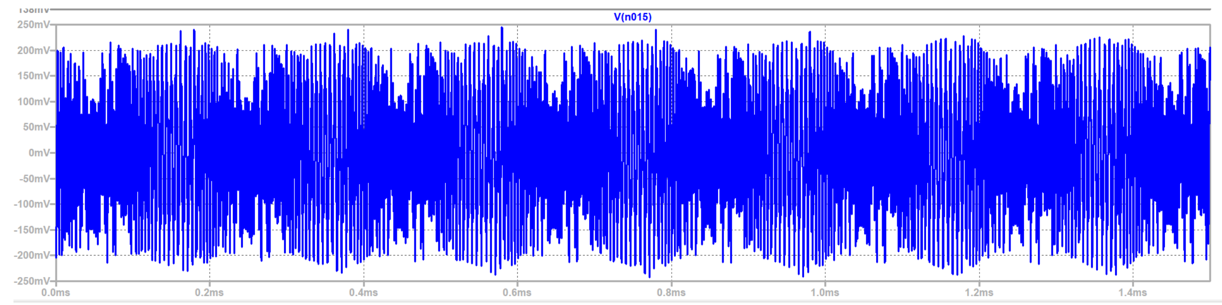
4. After Passing through Summing amplifier (Linear Adder)

Composite Signal

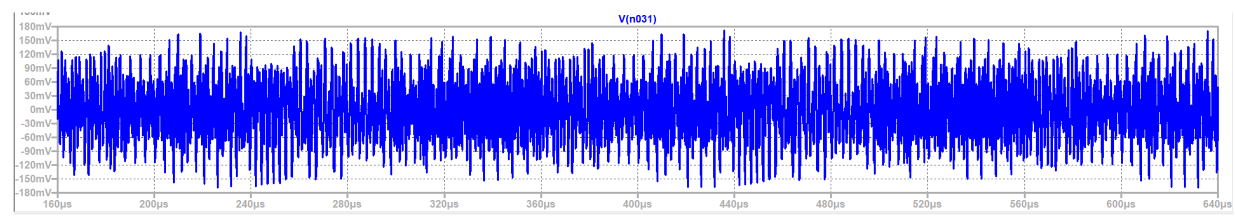


5. At Receiver After BPF

Bandpass Filtered Signal 1

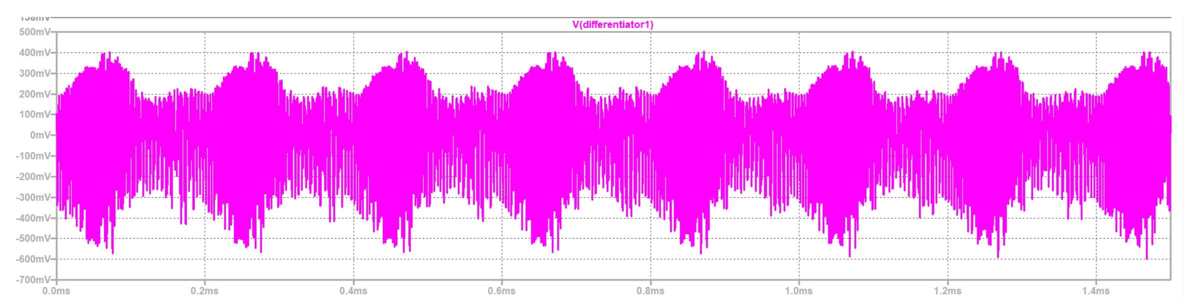


Bandpass Filtered Signal 2

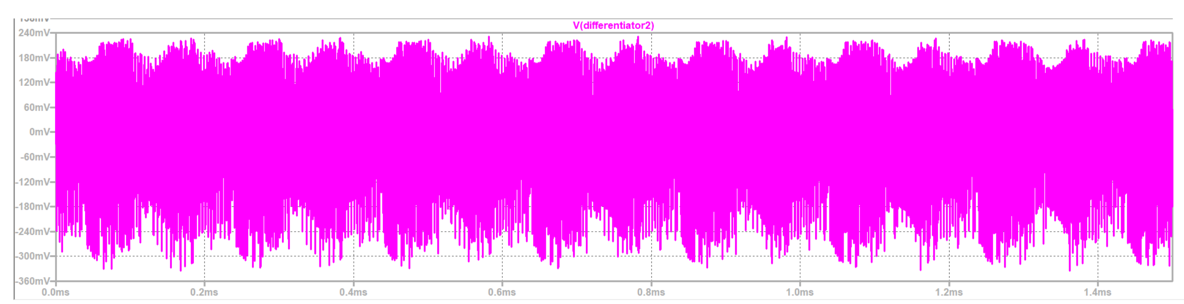


6. Differentiator Output

Differentiated Signal 1

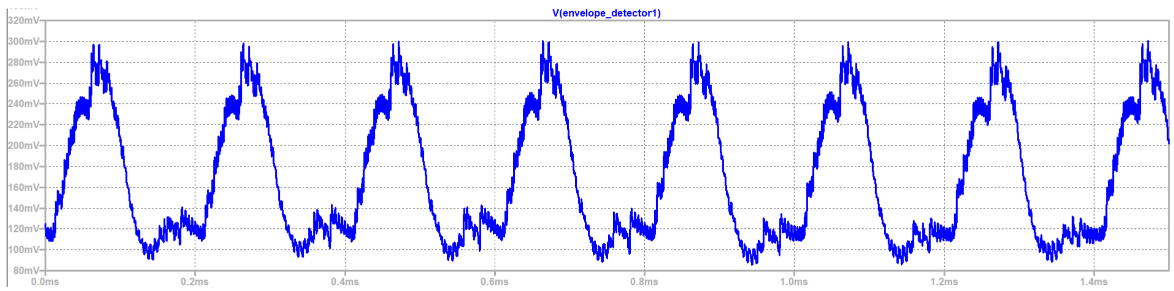


Differentiated Signal 2

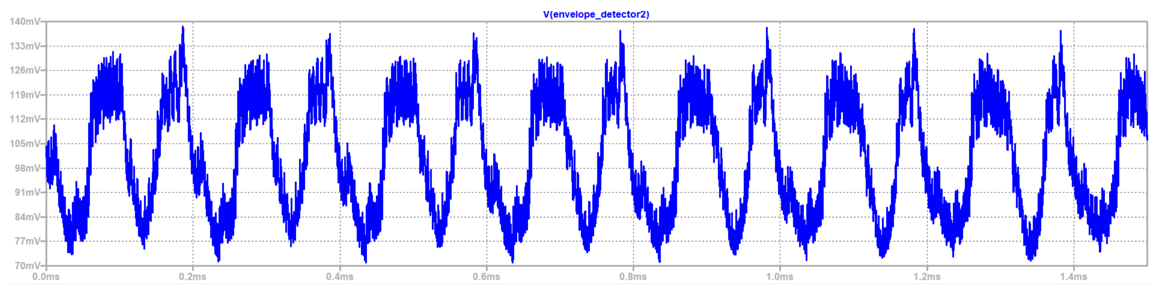


7. Envelope Detector Output

Envelope Detector Signal 1

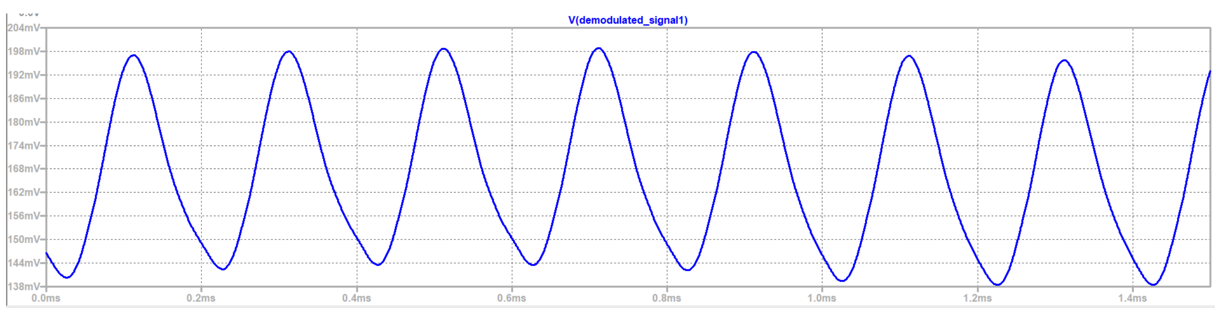


Envelope Detector Signal 2

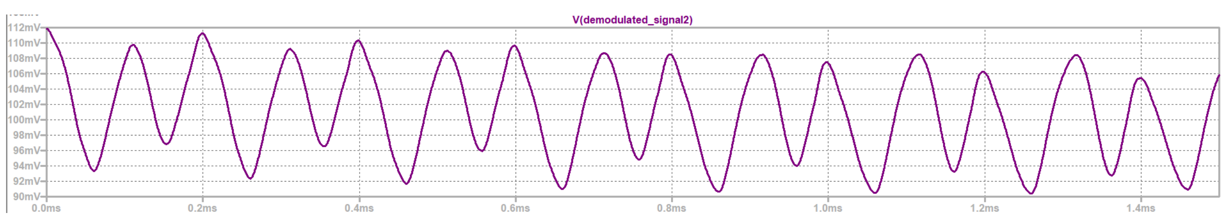


8. Output Signal

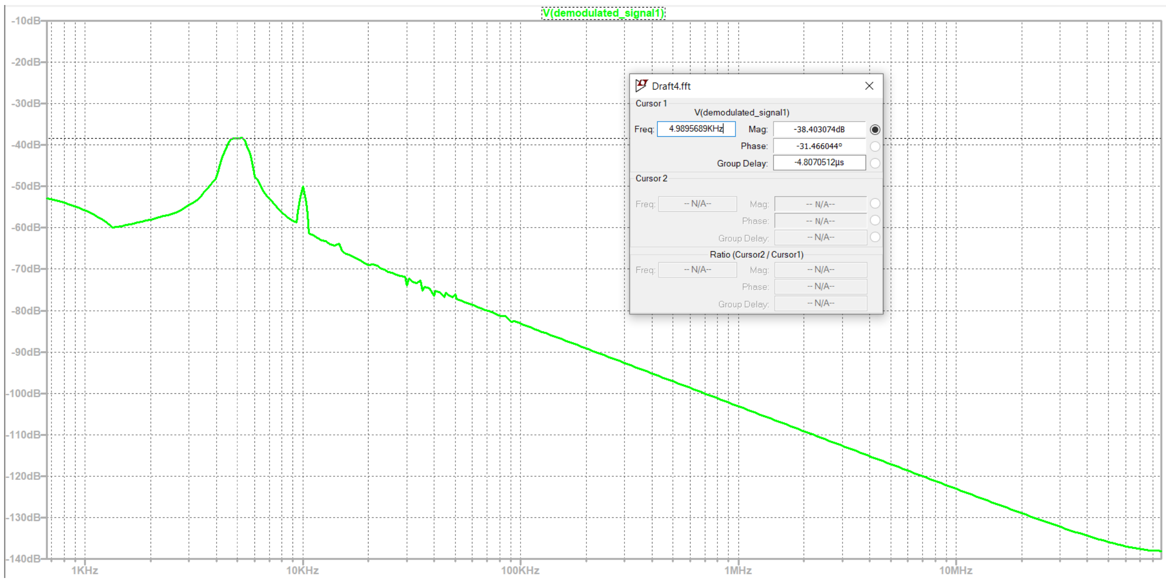
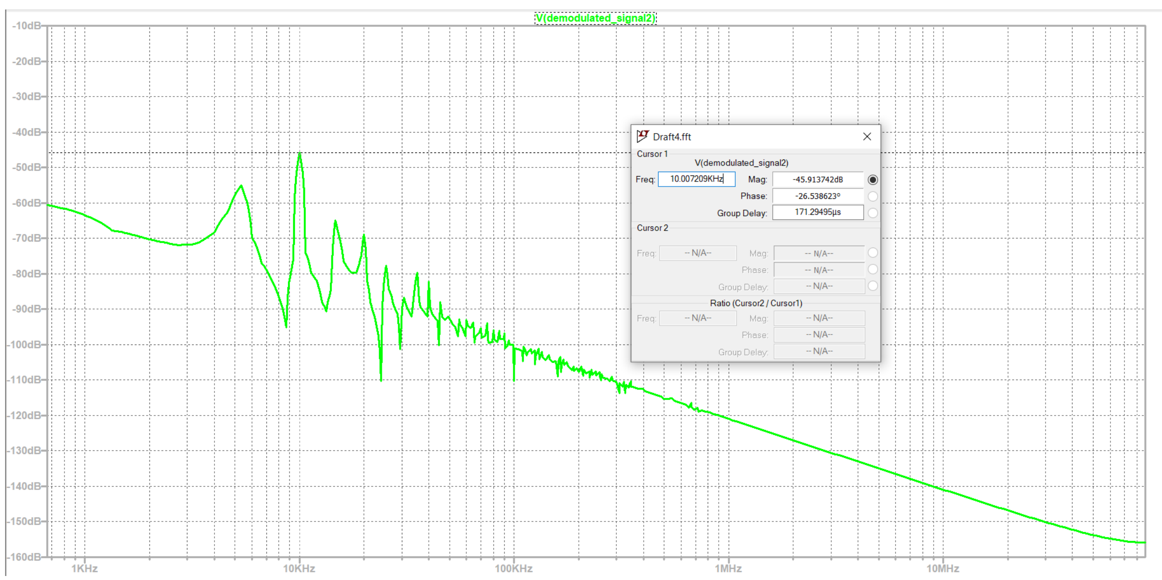
Demodulated Signal 1



Demodulated Signal 2



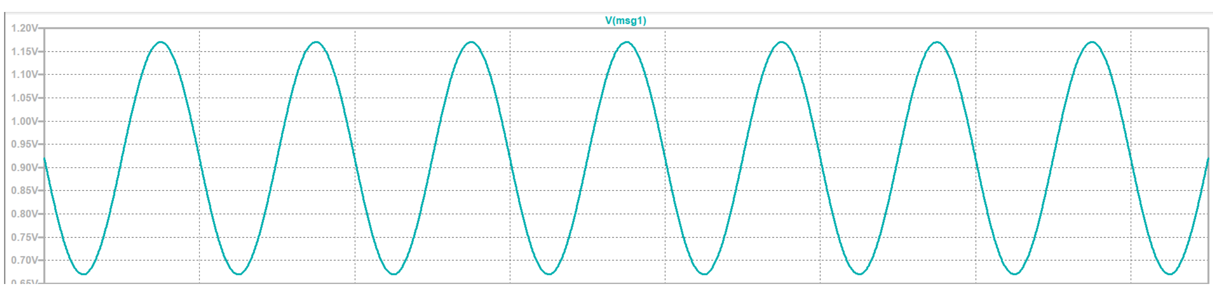
9. Output Signal FFT

Demodulated Signal 1 FFT

Demodulated Signal 2 FFT


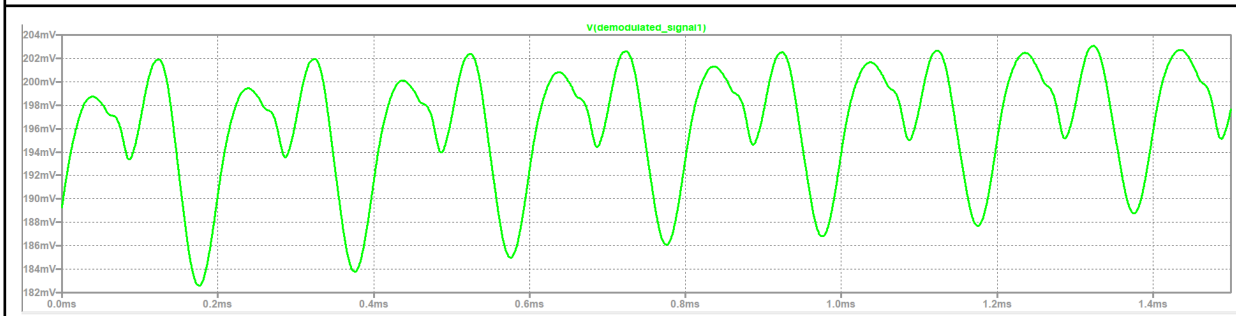
Without guard band

	Signal 1		Signal 2	
f_c	540kHz		780 Khz	
V_{CTRL}	0.92V		0.44V	
BPF	LPF Part	HPF Part	LPF Part	HPF Part
	R = 24kΩ C = 10pF	R = 38kΩ C = 10pF	R = 17kΩ C = 10pF	R = 25kΩ C = 10pF
Differentiator	R = 29kΩ	C = 10pF	R =20 kΩ	C = 10pF
Envelope detector	R = 5kΩ	C = 10nF	R =3 kΩ	C = 10nF
LPF	R = 31.8kΩ	C = 1nF	R = 15kΩ	C = 1nF

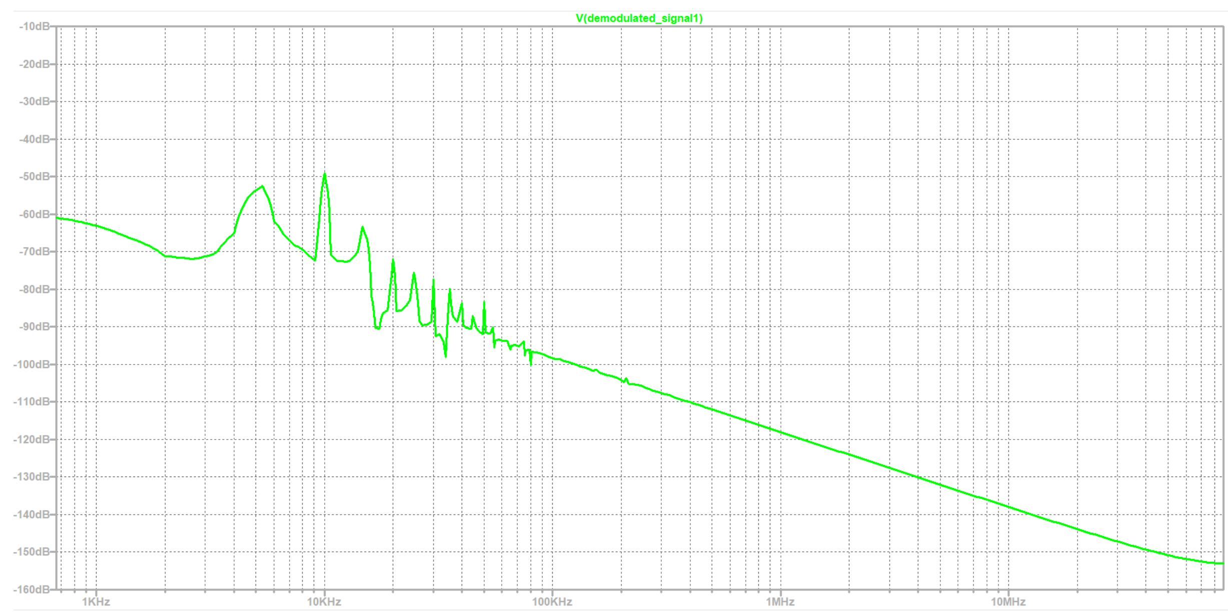
Message signal 1



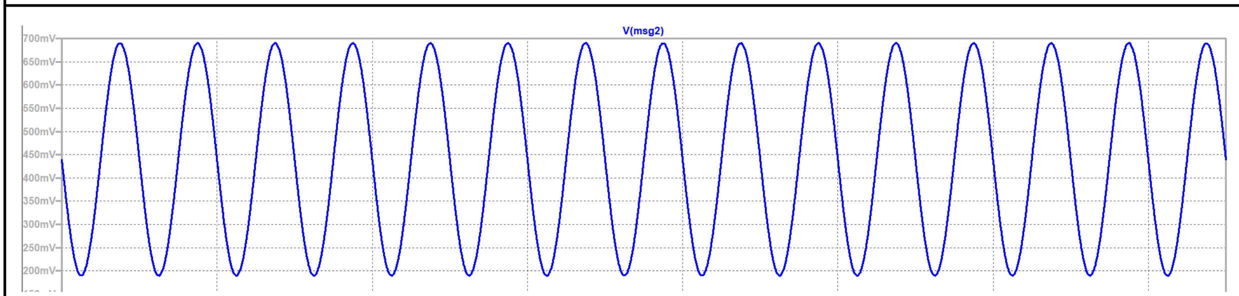
Demodulated signal 1



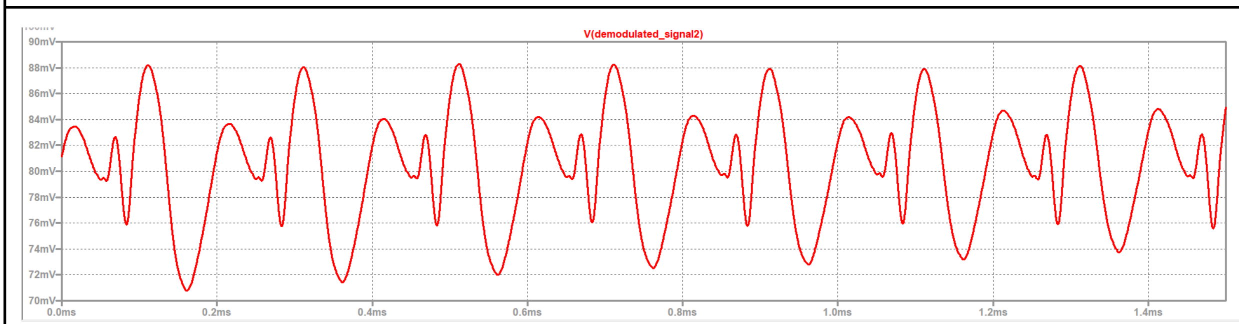
Demodulated signal 1 FFT



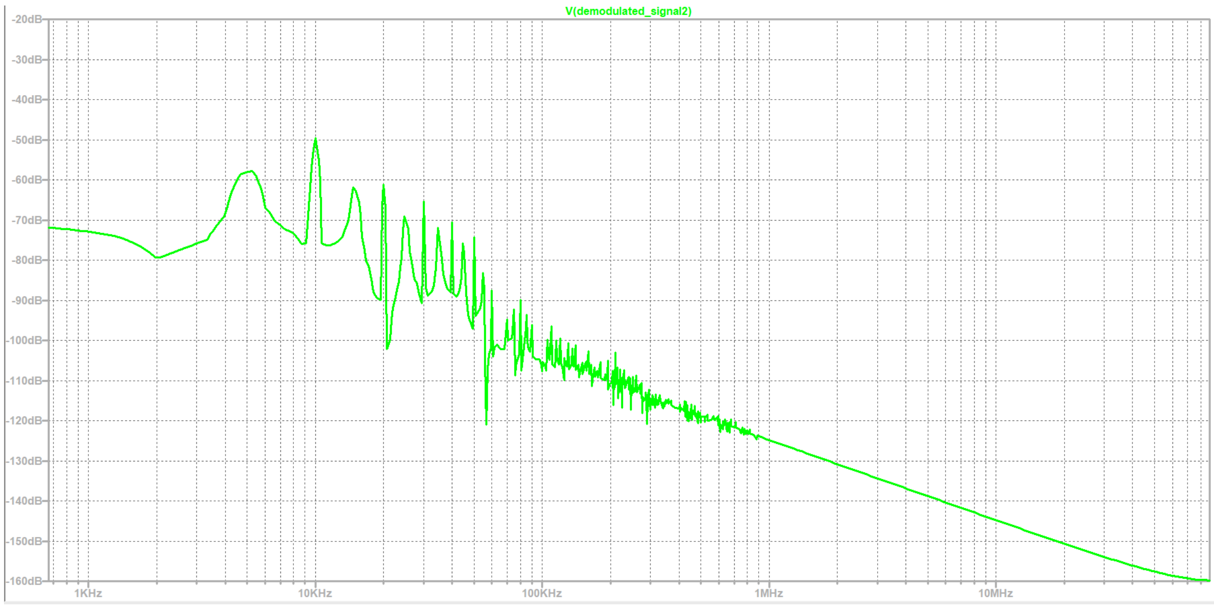
Message signal 2



Demodulated signal 2



Demodulated signal 2 FFT



SNR USING MATLAB:

With Guard Band

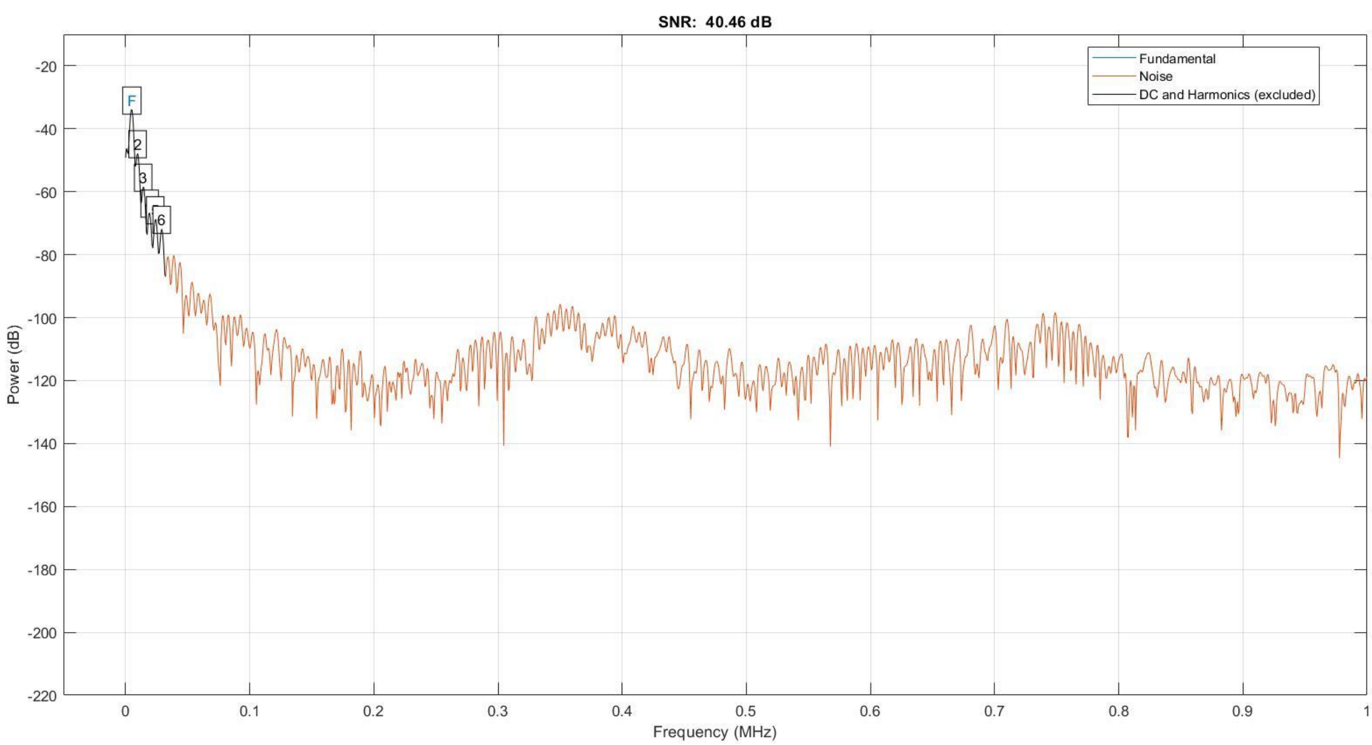
Code:

```
%The data  for each of the input and outputs was exported from LTSpice into .txt files - op1.txt,op2.txt,inp1.txt,inp2.txt and is used here

%Import data into Matlab variables (struct and from it arrays)
signal1=importdata('inp1.txt')
output1=importdata('op1.txt')
 %Extracting the data from struct signal1 which corresponds to the message ip1
ip1=signal1.data(:,2);
 %Extracting the data from struct output1 which corresponds to the demodulator output op1
op1=output1.data(:,2);
%Extracting discrete time instants
 t_ip1=signal1.data(:,1);
t_op1=output1.data(:,1);
%Extracting the sampling frequency used
T1=t_op1(80000)-t_op1(30000);
fs1=50000/T1;

%Plot the SNR
figure(1);
snr(op1,fs1);
xlim([-0.05,1]);

%Repeat Above steps for second input and output
signal2=importdata('inp2.txt')
output2=importdata('op2.txt')
%Extracting the data from struct signal2 which corresponds to the message ip2
ip2=signal2.data(:,2);
%Extracting the data from struct output2 which corresponds to the demodulator output op2
op2=output2.data(:,2);
 %Extracting discrete time instants
t_ip2=signal2.data(:,1);
t_op2=output2.data(:,1);
```

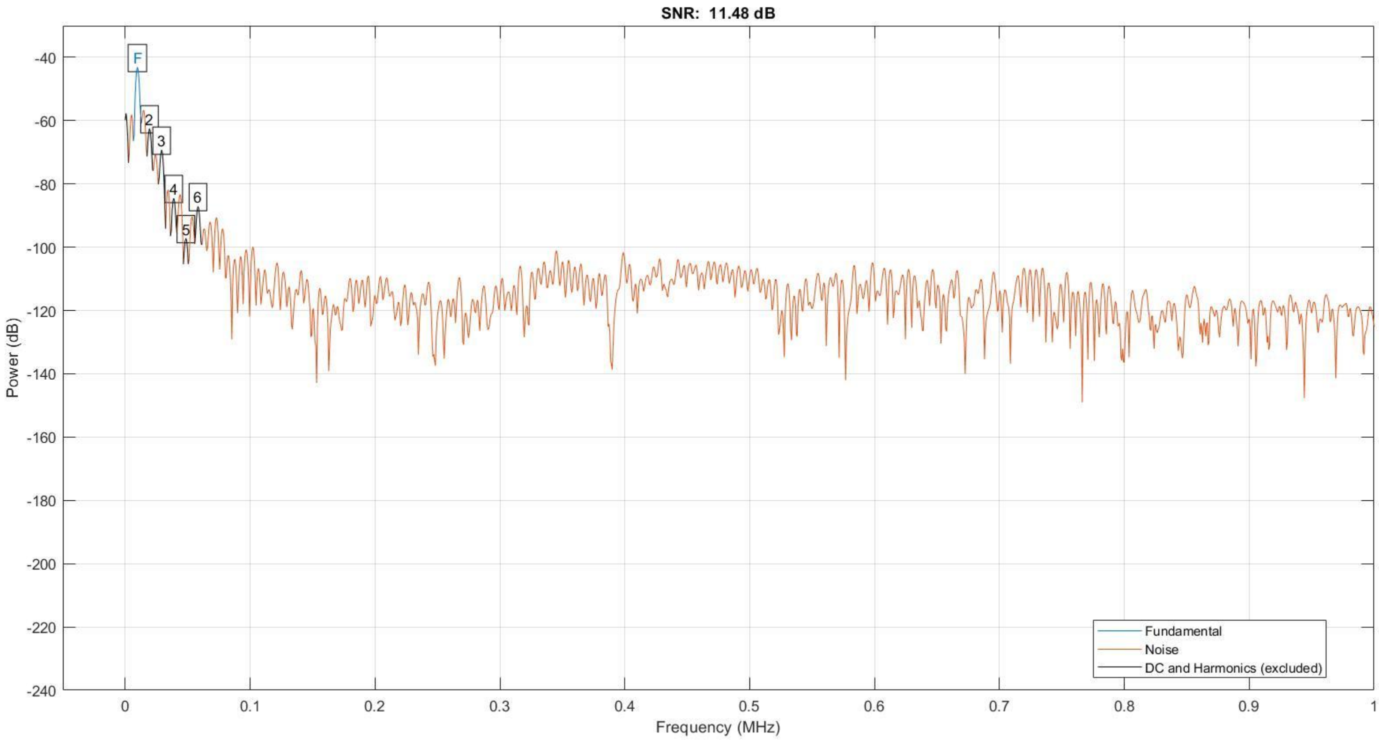
```
%Extracting the sampling frequency used
T2=t_op2(80000)-t_op2(30000);
fs2=50000/T1;

%Plot the SNR
figure(2);
snr(op2,fs2);
xlim([-0.05,1]);
```

Output:

SNR #1



SNR #2



Without Guard Band

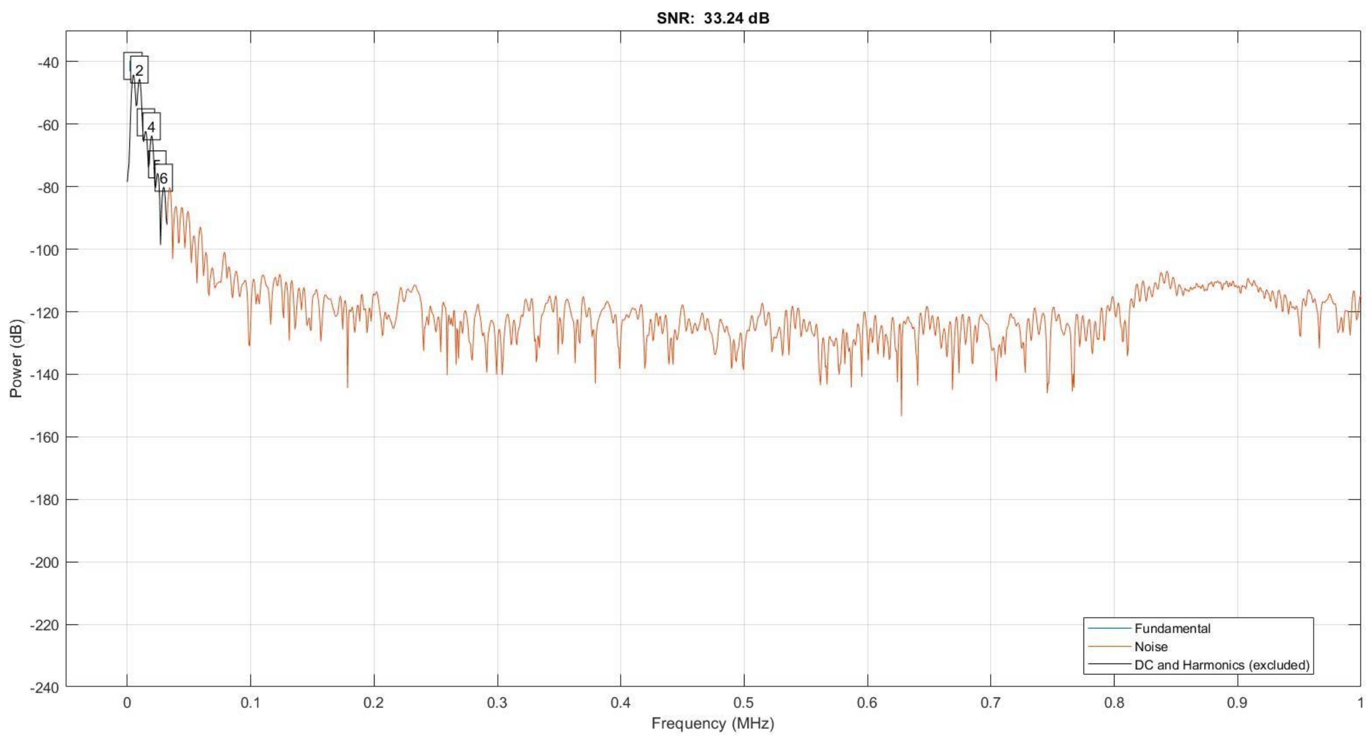
Code:

```
%The data  for each of the input and outputs was exported from LTSpice into
.txt files - op1.txt,op2.txt,inp1.txt,inp2.txt and is used here

%Import data into matlab variables (struct and from it arrays)
output1=importdata('op1_wogb.txt')
op1=output1.data(:,2);
t_op1=output1.data(:,1);
T1=t_op1(80000)-t_op1(30000);
fs1=50000/T1;

%Plot the SNR
figure(1);
snr(op1,fs1);
xlim([-0.05,1]);
```

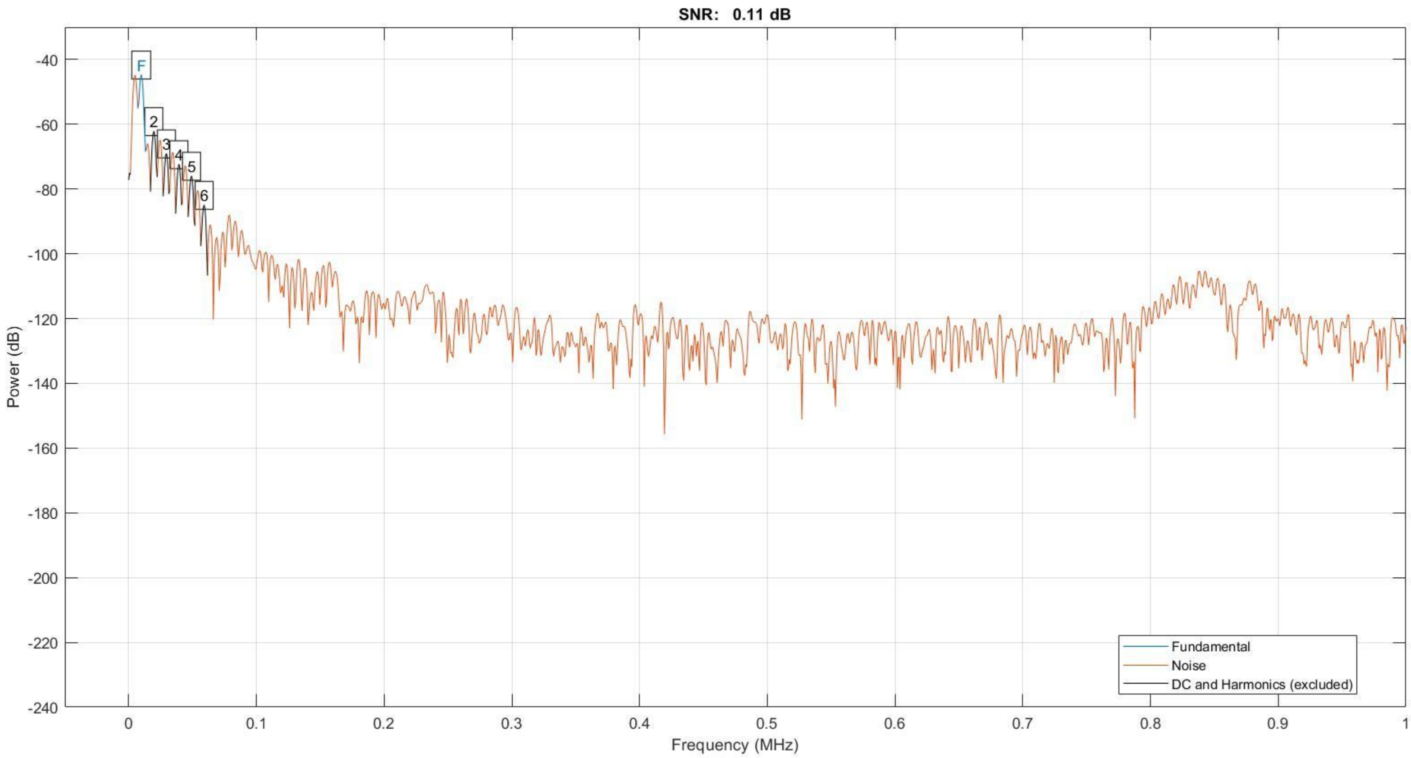
```
%Repeat Above steps for second input and output
output2=importdata('op2_wogb.txt')
op2=output2.data(:,2);
t_op2=output2.data(:,1);
T2=t_op2(80000)-t_op2(30000);
fs2=50000/T1;

%Plot the SNR
figure(2);
snr(op2,fs2);
xlim([-0.05,1]);
```

Output:

SNR #1



SNR #2


SNR: 0.11 dB
F
2
3
4
5
6
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
Power (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Frequency (MHz)
Fundamental
Noise
DC and Harmonics (excluded)

CONCLUSION

FM transmitter and receiver were designed for given message and carrier signals and two FM signals were transmitted simultaneously using Frequency Division Multiplexing.
The FM signals were generated and then multiplexed into a composite signal. This signal is then transmitted across the channel and is received. Bandpass filters are used to separate the signals and then they are demodulated to obtain the output.

The absence of guard bands leads to a lot of distortions as crosstalk occurs and there is interference between the channels. This mainly occurs due to the ideality of practical filters.

The SNR of the FM signals sent via Frequency Division Multiplexing was found using Matlab.
The SNR of the second signal was lower due to the presence of crosstalk amongst channels.
SNR of signals without a guard band was lower than those with a guard band.

Advantages of FDM:

- It does not need synchronization between its transmitter and receiver.
- Frequency division multiplexing (FDM) is simpler and easy to demodulate.
- It is used for analog signals.
- A large number of signals (channels) can be transmitted simultaneously.

Disadvantages of FDM

- It suffers from the problem of crosstalk.
- Intermodulation distortion takes place.
- Large bandwidth is required.

Applications of FDM:

- It is used in public telephones and in cable TV systems.
- It is used in AM and FM broadcasting.