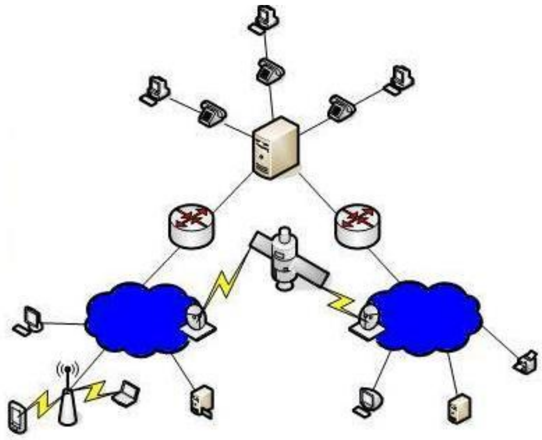
Department of Electrical and Computer Engineering
Faculty of Engineering and Architecture
American University of Beirut



EECE 442L – Communications Laboratory

Experiment on
Frequency Modulation and Demodulation

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Frequency Modulation and Demodulation

OBJECTIVES

- Review the basic concepts of frequency modulation and demodulation.
- Build and analyze the behavior of an FM modulator and demodulator.
- Perform demodulation of an FM signal from a circuit and study the effect of additive noise on the demodulated output.

PREPARATION EXERCISE FOR FREQUENCY MODULATION EXPERIMENT

A. INTRODUCTION

As preparation to the frequency modulation (FM) experiment, we will study and observe the modulation process by strictly separating the baseband modulation and upconversion steps. Using a demo VI, you can observe waveforms in the time and frequency domains as we develop the description of the FM process. Whereas in AM the amplitude of a sinusoidal function is varied with time to include information of a message signal, in FM and PM (phase modulation) we vary the phase with time. A pair of sinusoidal functions used in baseband modulation of which only the phase varies with time can be expressed as $\{A\cos(\varphi(t)), A\sin(\varphi(t))\}$. At any point in time, $\varphi(t)$ has a certain value and is therefore referred to as the instantaneous phase. The rate of change of the instantaneous phase is indicated with the instantaneous frequency. In FM, this instantaneous frequency is varied with the message signal, whereas in PM the instantaneous phase is varied with the message signal.

A.1 INSTANTANEOUS PHASE AND FREQUENCY

In the first step to obtain FM a message signal *m(t)* is used to vary the *instantaneous* frequency $f_i(t)$ of a sinusoidal function with amplitude A_c and time-variable argument, or phase. This instantaneous frequency is related to the instantaneous phase $\varphi(t)$ as follows: $\mathrm{f(t)} = \dfrac{\mathrm{d}\varphi(t)/\delta t}{2\pi}$.

The baseband modulated signal consists of a pair of sinusoidal functions of which the phase varies in a non-linear fashion with time:

$$\mathrm{s_I(t)} = \mathrm{A_c}\cos(\phi(\mathrm{t})) = \mathrm{A_c}\cos\left(2\pi\int \mathrm{f_i}(t)dt\right),$$
$$\mathrm{s_Q(t)} = \mathrm{A_c}\sin(\phi(\mathrm{t})) = \mathrm{A_c}sin\left(2\pi\int \mathrm{f_i}(t)dt\right)$$

with $f_i(t) = k_f m(t)$, $s_I(t) = \mathrm{A_c}\cos\left(2\pi k_f \int m(t)dt\right)$.

In the case of a single tone message represented as $m(t) = A_m\cos(2\pi f_m t)$ we obtain $s_I(t) = \mathrm{A_c}\cos(\frac{k_f A_m}{f_m}\sin(2\pi f_m t) = \mathrm{A_c}\cos(\beta\sin(2\pi f_m t)$ with $\beta = \frac{k_f A_m}{f_m} = \frac{\Delta f}{f_m}$. β is called the modulation index. Similarly we get $s_Q(t) = \mathrm{A_c}\sin(\beta\sin(2\pi f_m t)$. The instantaneous frequency $\mathrm{f_i}(t)$ has extreme values $\pm k_f A_m$. $k_f A_m$ is referred to as the frequency deviation Δf. It is a measure of the swing of $\mathrm{f_i}(t)$. As shown above the instantaneous phase $\varphi(t)$ is obtained through integration of $\mathrm{f_i}(t)$. The swing of $\varphi(t)$ is indicated by β.

So we must integrate the message signal and then modulate the phase. FM is equivalent to phase modulation (PM) of the integrated message signal. Before we go to the second step of upconversion to a carrier frequency we will examine the signal *s(t)* obtained in the time and frequency domain. Download and open the **"eh_Demo_FM.vi"**. Use the following settings:

Quantity/Setting	Value
Choice of message signal	freq sweep
duration (s)	0.001
Astart	1
Aend	1
k_f	5000 Hz/V
fstart, fend	5000 Hz

Work out the expression for $s_I(t)$ with these values. By how much will the phase $\varphi(t)$ in $s_I(t)$ vary?

Run the VI and observe the instantaneous frequency *f(t)* and phase $\varphi(t)$. What are the values of *Δf* and *β*? Observe at the same time the spectra of $s_I(t)$ and $s_Q(t)$. How do they differ? To which quantity can we relate the location of the impulses in the spectrum?

Increase *β*:

Quantity/Setting	Value
Astart	10

Describe the changes that you observe in *f(t)* and $\varphi(t)$. Note that the phase is mapped to the interval (-π, π). With the values used for the amplitude and the frequency sensitivity *Δφ* is more than 2π and we induce extra cycles in the first part of *s(t)*. To show the effect more clearly we also increase *Aend*:

Quantity/Setting	Value
Aend	10

For the complete duration we see that Δφ is equal to several times 2π and how cycles are induced in s(t). What are now the values of Δf and *β*? Observe the spectra and compare to the first simulation. Did the total bandwidth increase? A commonly used rule to estimate the bandwidth is Carson's rule: $B = 2f_m + 2\Delta f = 2f_m(1+\beta)$. Given a fixed value of f_m, it is clear that the bandwidth will increase with an increase in *β.* Commonly, we distinguish between narrow band and wide band FM depending on the value of *β*:

1. Narrow band FM (NBFM) $\beta<1$ rad
2. Wide band FM (WBFM) $\beta>1$ rad

The FM modulated single tone signal can be written as a pair of Fourier series:

$$s_I(t) = A_c(J_0(\beta) + 2\sum_{n=1}^{\infty} J_{2n}(\beta)\cos[2\pi(2n)f_m t])$$

$$s_Q(t) = 2A_c\sum_{n=1}^{\infty} J_{2n+1}(\beta)\sin[2\pi(2n+1)f_m t]$$

From this expression the spectra can be found as:

$$S_I(f) = A_c\sum_{n=-\infty}^{\infty} J_{2n}(\beta)\delta(f - nf_m)$$

$$S_Q(f) = A_c\sum_{n=-\infty}^{\infty} J_{2n+1}(\beta)\delta(f - nf_m)$$

A.2 UPCONVERSION

The process observed so far is a baseband operation. Before transmission we need to convert the resulting *s(t)* to a suitable frequency band. In the frequency domain this *upconversion* corresponds to shifting the spectrum *S(f)* by f_c, resulting in *U(f)* The details of this upconversion process were discussed in the preparation material of AM. Again for a single tone message we get

$$u(t) = A_c\left[\cos(2\pi f_c t)\cos(\beta\sin(2\pi f_m t)) - \sin(2\pi f_c t)\sin(\beta\sin(2\pi f_m t))\right]$$

which reduces to

$$u(t) = A_c \cos\left[2\pi f_c t + \beta\sin(2\pi f_m t)\right]$$

This is the usual expression for a single tone FM signal, where in the time domain we add a phase of $2\pi f_c$. *u(t)* can be expanded to

$$u(t) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\cos[2\pi(f_c + nf_m)t]$$

The spectrum is found to be

$$U(f) = \frac{A_c}{2}\sum_{n=-\infty}^{\infty} J_n(\beta)[\delta(f - f_c - nf_m) + \delta(f + f_c + f_m)]$$

Both *u(t)* and *U(f)* can be observed on the front panel. With the last settings observe *u(t)* and notice how the number of cycles at a certain point in time depends strongly on the magnitude of $k_f m(t)$ at that point in time. How is *U(f)* obtained from $S_I(f)$ and $S_Q(f)$?

Identify the carrier component and observe if it varies with the settings. How does this compare to AM? Run various cases and comment on the spectra observed in terms of the concepts that you have reviewed. Observe the waveforms of *f(t)*, *s(t)* and *U(f)*.

Quantity/Setting	Value
Choice of message signal	freq sweep
duration (s)	0.005
Astart	1
Aend	1
k_f	1000 Hz/V
fstart, fend	1000 Hz
carrier frequency	20 000 Hz
k_f	5000 Hz/V

A.3 IMPLEMENTATION OF MODULATION AND DEMODULATION

In the lab experiment, you are required to develop an FM modulator in LabVIEW. You will also use a circuit that can modulate a message signal at its input. It is based on a voltage-controlled oscillator (VCO). In such a circuit, a non-linear element like a diode or transistor varies its capacitance with an applied voltage and thus its oscillation frequency. When a message signal is used as the control voltage, the output signal of the VCO is frequency modulated.

A demodulator should produce an output signal that is proportional to the instantaneous frequency. Three types of FM demodulators are known:

1. Phase-locked loop
2. Slope detection/FM discriminator (easy to implement)
3. Quadrature detector

In the lab experiment, you are also required to develop an FM demodulator.

For more background information on frequency modulation and demodulation, check Section 3.3 in [1] and/or Sections 3.11-3.14 in [2].

For more background information on the impact of noise on FM demodulation, check Sections 5.2-5.3 in [1] and Sections 5.6-5.7 in [2].

EXPERIMENT DESCRIPTION

GENERAL RULES

- If you open a VI and are not asked to do any changes in it, then close it without saving changes by clicking on "Defer decision".
- Save VIs as ***[GroupID]_name of VI.vi.***
- Save plots as ***[GroupID]_Question number.jpg***. For questions with more than one plot, append extra info to the name to differentiate between the plots.
- Remember to zip and upload only the files you created without the ones given to you in "FM.zip".

PART I: PROCEDURE AND ANALYSIS: FM MODULATION/DEMODULATION

Q.1 List an advantage and a disadvantage of FM over AM.

Q.2 Write the equation of the FM modulated signal.

Q.3 State the difference between Wideband and Narrowband FM.

Build the front panel shown in Figure 1.

Build the FM modulator's Block diagram by using the following steps:

a) Use the "**Sine Waveform**" VI to generate the message wave. Create user Numeric controls in the front panel for the message frequency and amplitude. Set the Sampling frequency of the "Sine Waveform" to 1M and its record length to 10000.

b) Create Numeric controls in the front panel for the carrier frequency f_c and frequency deviation Δf. Get the instantaneous frequency $f_i(t) = f_c + k_f \cdot m(t)$, where f_c is the carrier frequency and $k_f = \dfrac{\Delta f}{A_m}$ is the frequency sensitivity.

c) Use the "**Integral x(t)**" VI to obtain the instantaneous phase angle $\theta_i(t) = 2\pi \cdot \int_0^t f_i(\tau) \cdot d\tau$. Make sure to specify the integrator's 'dt' which you can get out of the waveform components.

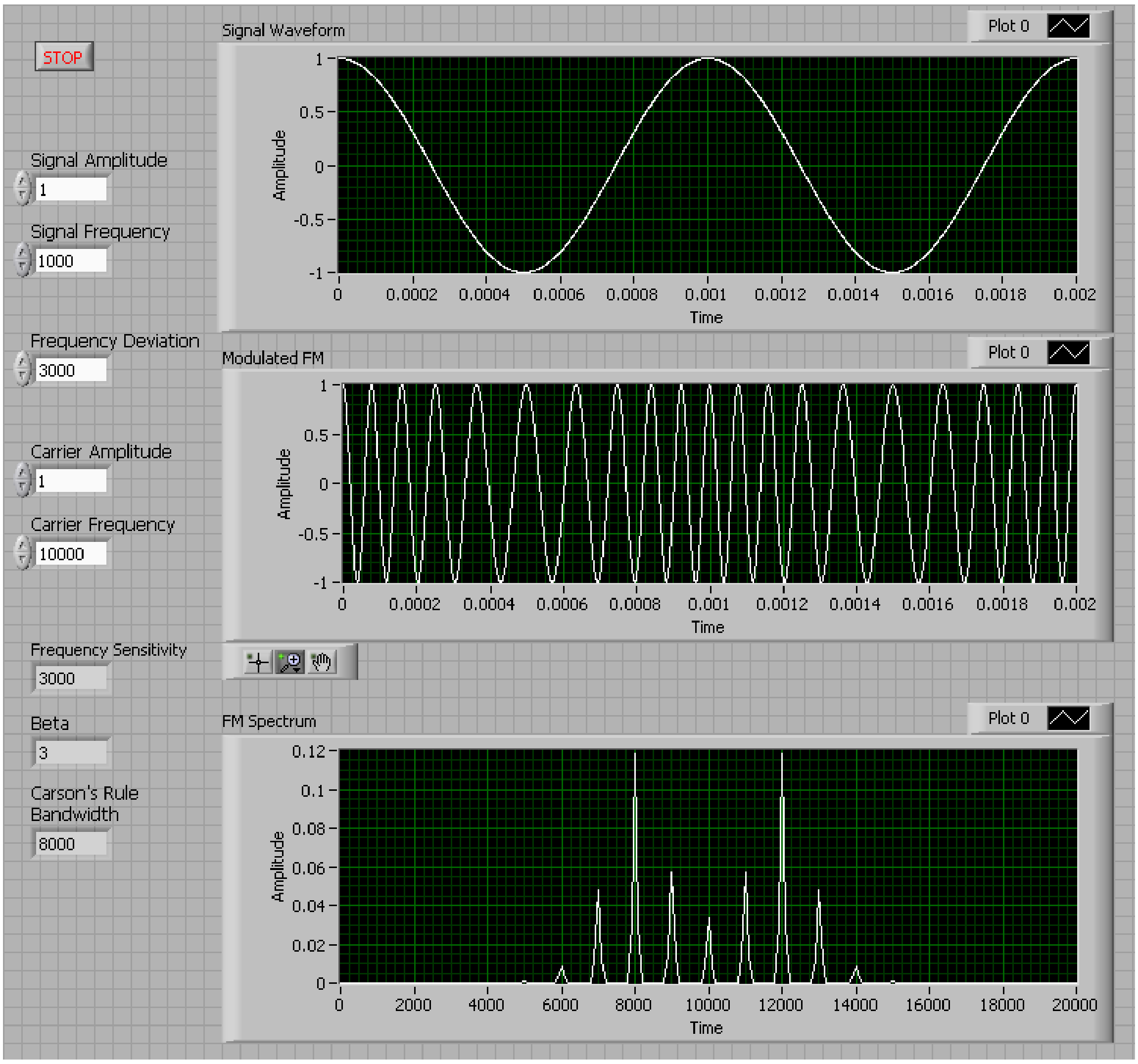

Figure 1: FM Modulation VI Front Panel.

d) Use the "Cosine" VI and create user Numeric controls in the front panel for the carrier amplitude to obtain $S_{FM}(t) = A_c \cos(\theta_i(t)) = A_c \cos(2\pi f_c t + \beta \sin(2\pi f_m t))$ which is the FM modulated signal.

e) Use the "Build Waveform" VI to build a waveform in order to plot the time and frequency domain signals of $S_{FM}(t)$.

f) Use the "FFT Mag-Phase" VI to get the frequency domain of $S_{FM}(t)$.

g) Add the necessary mathematical operations to obtain and display Beta, Frequency sensitivity and Carson's Rule Bandwidth.

Save the VI as "**FM_MOD.VI**".

Let f_m= 1 KHz and A_m =1 V.

Set the carrier frequency to 10 KHz.

Q.4 Plot and save the FM spectrum for values of Δf = 0.5, 2, and 5 KHz.

Q.5 Specify the NBFM and the WBFM signals for the cases in Q.4.

Q.6 Determine the FM bandwidth using Carson's rule in each case of Q.4.

Q.7 Comparing the values calculated in Q.6 with the observed spectra, is Carson's rule a good indicator of bandwidth?

Q.8 Fix the frequency deviation to Δf = 500 Hz. Plot and save the spectrum of the FM modulated signal for values of f_m =300, 500, and 1000Hz.

Q.9 Variations in the modulating frequency (with a fixed frequency deviation) correspond to variations in the modulation index β. Comment on the effect of varying the modulation index on the bandwidth of the FM modulated signal.

Create a blank VI and construct the FM demodulator shown in Figure 2.

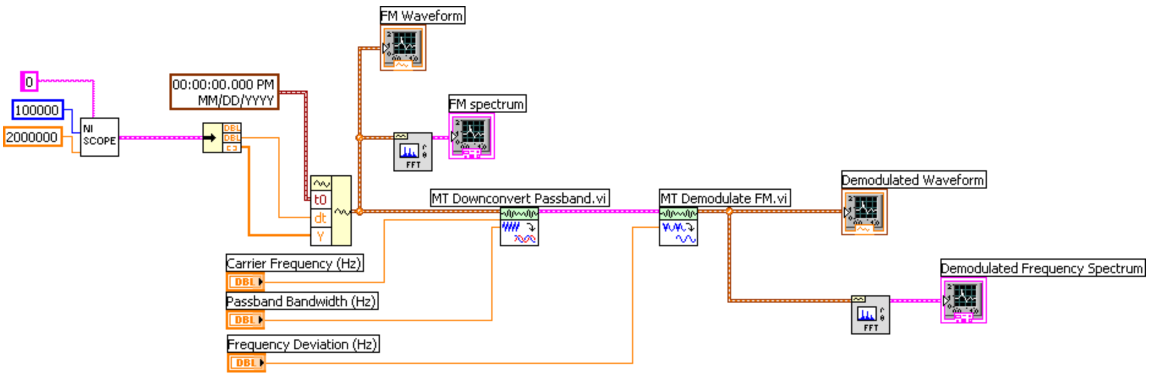

Figure 2: FM Demodulation VI Block Diagram.

You will be provided with an FM Signal Generator Board. This board is not only an FM generator but also it contains an additive noise generator. Therefore, you do not know the carrier frequency used in the board. Moreover, you do not know the frequency deviation.

Connect the FM signal generator Board to the NI function generator and to the NI data acquisition modules.

Open the (FGEN soft panel) and use it to generate the following message signal:

Fm	1000Hz
Am	10 mVolts (Pk-Pk)
Signal type	Sine wave form

Q.11 Provide a plot for the FM spectrum (show frequencies between 40 and 110 KHz)

Q.12 From the graph what is the Carrier frequency?

Now in the FGEN change the Message parameters as follows:

Fm	1000Hz
Am	1 Volts (Pk-Pk)
Signal type	Sine wave form

Q.13 Provide a plot for the FM spectrum (show frequencies between 40 and 110 KHz).

Q.14 from the graph what is the band width of the generated FM signal?

Q.15 Using Carson's rule what is the frequency deviation (Δf)?

Q.16 Find the Modulation index (β) and the Frequency sensitivity (Kf)?

Run the FM demodulator VI that you have already built in order to demodulate the FM signal.

Q.17 Provide plots for the Demodulated signal in the time domain and in the frequency domain.

Q.18 For Am=1 volt (Pk-Pk), is the FM signal WBFM or NBFM?

Q.19 For Am=10 mVolts (Pk-Pk), what does the FM signal converges to?

In the last part of this experiment, you will study the effect of noise on FM signal demodulation.

In the FGEN change the message parameters as follows:

Fm	1000Hz
Am	1 Volts (Pk-Pk)
Signal type	Sine wave form

Run the demodulator VI and gradually change the Noise Potentiometer on the FM signal generator board.

Q.20 Provide Plots for the demodulated signal with minimum and maximum noise power in the time and in frequency domains.

REFERENCES

[1] J. Proakis and M. Salehi, Communication Systems Engineering. Prentice-Hall, 2nd edition, 2002.

[2] S. Haykin, Communication Systems. John Wiley & Sons, 3rd edition, 1994.