NIDA SERIES 130E

ELECTRICITY AND ELECTRONICS

LESSON 3

FREQUENCY AND PHASE MODULATION (FM & PM)

OBJECTIVES

Upon completion of this lesson, the student will be able to:

1. Describe the characteristics of Frequency Modulated (FM) signals.
2. Compare Frequency Modulation to Phase Modulation (PM).
3. Describe FM modulator circuits.
4. Describe FM demodulator circuits.
5. Generate FM signals using a function generator.
6. Construct a basic FM modulator and demodulator circuit.

PREREQUISITES

None

EQUIPMENT REQUIRED

Nida Model 130E Test Console
Nida Series 130 Experiment card: PC130-130X
Nida Model 440 Function Generator or equivalent
Nida Model 470 Oscilloscope or equivalent
Nida Model 480 Multimeter or equivalent
FM Parts Kit:
1 - 1 kΩ, 1/4 W Resistor
2 - 2.2 kΩ, 1/4 W Resistor
1 - 10 kΩ, 1/4 W Resistor
1 - 47 kΩ, 1/4 W Resistor
1 - 100 kΩ, 1/4 W Resistor
1 - 220 kΩ, 1/4 W Resistor
4 - .001 μF Capacitor
1 - .005 μF Capacitor
2 - .05 μF Capacitor
2 - .01 μF Capacitor
1 - 4.7 μF Capacitor
3 - 1 mH Inductor
1 - 500 μH Inductor
1 - 1N34A Diode
1 - 2N3823 FET Transistor
1 - 2N3565 Transistor
1 - 455 kHz AM IF Transformer
20 - 2" 24 Gauge Hookup Wire
(2) BNC to BNC Cables
Nida Model 410 Frequency Counter or equivalent (OPTIONAL)

OVERVIEW

This lesson teaches the signal processing technique of Frequency Modulation (FM) and Phase Modulation (PM). Characteristics of FM signals are first covered and then PM signals are compared to FM signals noting the differences and similarities.

The lesson continues with discussions of typical FM modulator and demodulator circuits. The included four part experiment has students generating an FM signal with a function generator to study the characteristics covered in the theory. This is followed by the construction of a basic FM modulator and demodulator circuit. The final two parts of the experiment covers the operation and troubleshooting of various FM transmitters and receivers including a phase-locked loop demodulator.

INTRODUCTION

Frequency Modulation, FM for short, is another method of signal processing. FM was developed around 1936 and its use has grown steadily. Today, most all home radios have the capability to receive both AM and FM signals. FM communication systems have several advantages over AM systems. For example, FM is less noisy, as you probably already know from listening to both AM and FM radio stations.

Phase Modulation, PM for short, is also a signal processing technique. PM modulation is almost identical to FM, you can not change the phase of a signal without some frequency change and you can not change the frequency of a signal without some phase change. In fact, some texts refer to FM and PM as Angle Modulation, lumping FM and PM together.

In this lesson you will learn about the characteristics of FM signals and a few of the circuits that are used (PM will only be compared to FM, no circuits will be discussed). However, as in the AM lesson, no attempt is made to cover every circuit designed for FM. Knowledge of the operation of a few typical circuits is all that is needed, even the complex IC circuits should not pose a problem.

In the experiment you will observe the characteristics of an FM signal along with constructing a very basic modulator and demodulator circuit.

FREQUENCY MODULATION (FM)

Frequency modulation is used for the same reason amplitude modulation is used, to send information from a source to a destination. FM normally uses air as the transmission medium but, other types of mediums can be used (the principles are the same). Signal processing using FM allows the information signal to be sent over longer distances.

Recall from the AM lesson that amplitude modulation is a signal processing method that changes the amplitude of a carrier signal according to the amplitude of the information signal. Well, frequency modulation is a signal processing method that changes the frequency of a carrier signal according to the amplitude of the information signal. When the information signal amplitude is increased, the carrier signal frequency is increased.

When the information signal amplitude is decreased, the carrier signal frequency is decreased. In other words, the change in frequency of the carrier signal contains the information signal.

Figure 1 illustrates the signals associated with frequency modulation. Notice how the FM waveform has both higher and lower frequencies than the carrier signal.

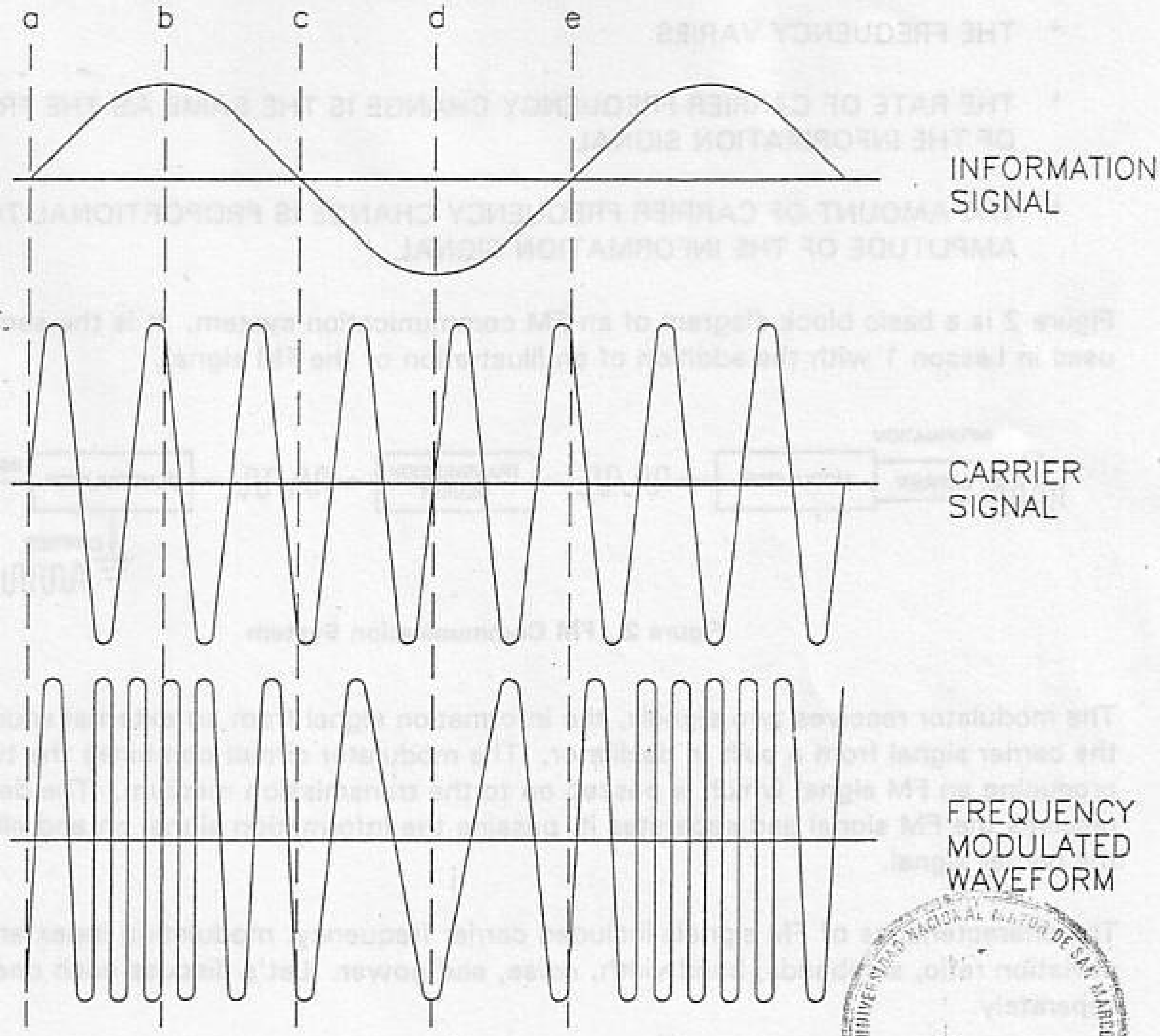


Figure 1. Frequency Modulated Signals

Look at the reference points in Figure 1. Points a, c, and e are where the information signal is at 0, point b is where the information signal is at the maximum positive amplitude, and point d is where the information signal is at the maximum negative amplitude.

During the time from point a to point b, notice how the FM signal increases in frequency to the maximum high frequency at point b (where the information signal has the maximum positive amplitude). From points b to c, the FM signal frequency decreases until reaching the frequency of the carrier signal, which is called the center frequency, at point c (where the information signal is 0). Then from point c to point d, the FM signal decreases in frequency to the maximum low frequency at point d (where the information signal has the maximum negative amplitude). From points d to e, the FM signal increases until reaching the center frequency again at point e (were the information signal is at 0).

The important features about FM waveforms are:

* THE AMPLITUDE IS CONSTANT

* THE FREQUENCY VARIES

* THE RATE OF CARRIER FREQUENCY CHANGE IS THE SAME AS THE FREQUENCY OF THE INFORMATION SIGNAL

* THE AMOUNT OF CARRIER FREQUENCY CHANGE IS PROPORTIONAL TO THE AMPLITUDE OF THE INFORMATION SIGNAL

Figure 2 is a basic block diagram of an FM communication system. It is the same diagram used in Lesson 1 with the addition of an illustration of the FM signal.

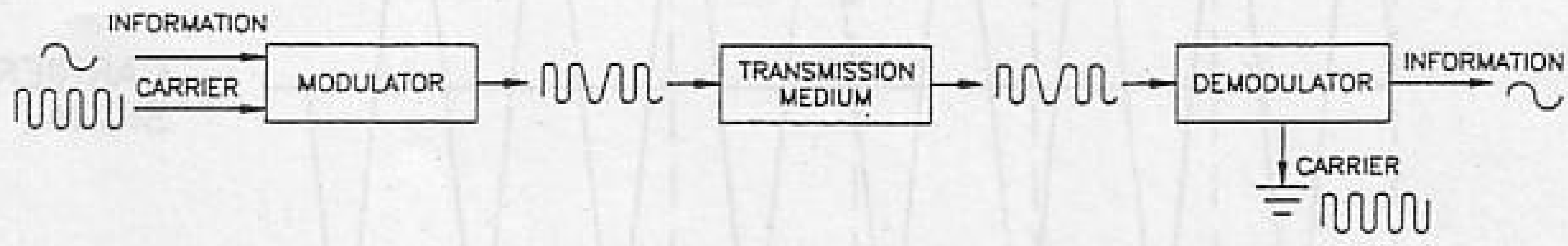


Figure 2. FM Communication System

The modulator receives two signals, the information signal from an external source and the carrier signal from a built in oscillator. The modulator circuit combines the two signals producing an FM signal which is passed on to the transmission medium. The demodulator receives the FM signal and separates it, passing the information signal on and eliminating the carrier signal.

The characteristics of FM signals included carrier frequency, modulation index and deviation ratio, sidebands, bandwidth, noise, and power. Let's discuss each one separately.

CARRIER FREQUENCY

As in AM systems, the carrier frequency in FM systems must be higher than the information signal frequency for the same reasons. Unlike AM systems, there is no rule of thumb to follow. The frequency of the carrier signal has to be able to handle the bandwidth and sidebands of the FM waveform. And as you will learn, the sidebands of an FM waveform can theoretically be infinite.

The carrier frequency for FM systems is usually 5 MHz and higher. This is not a problem because the lower frequencies are used for AM communications. For example, FM radio uses carrier frequencies between 88 and 108 MHz, and television uses frequencies of 54 to 88 MHz, 174 to 216 MHz, and 470 to 890 MHz.

MODULATION INDEX AND DEVIATION RATIO

The modulation index of a frequency modulated signal determines the extent and the rate of modulation. This is a little different from the percent modulation used in amplitude modulated systems. While AM systems normally range from 0% to 100%, or 0 to 1, FM systems normally have much higher values.

The formula for modulation index is: $m = \frac{f_d}{f_m}$

Where: f_d is the frequency deviation, or the amount of frequency change, and

f_m is the modulating frequency

For example, FM broadcast stations are allowed a frequency deviation of 75 kHz. If a 4 kHz (highest voice frequency) audio signal causes full deviation (maximum amplitude of information signal) then the modulation index is 18.75.

$$m = \frac{f_d}{f_m} = \frac{75\text{ kHz}}{4\text{ kHz}} = 18.75$$

Notice that the modulation index changes according to the modulating frequency (for a 2 kHz information signal, m is 37.5; for a 1 kHz information signal, m is 75). Modulation index only gives you a value for one particular information signal frequency and if the information signal is varying, the modulation index will vary.

Another measure of frequency modulation is the deviation ratio. The deviation ratio does not change for different information signal frequencies. The formula for deviation ratio is:

$$\text{Deviation ratio} = \frac{f_{dMAX}}{F_{mMAX}}$$

Where: f_{dMAX} is the maximum deviation, and

f_{mMAX} is the maximum frequency of the information signal

For example, if a voice signal is used for modulation, the maximum frequency is 4 kHz and using the limit of 75 kHz for the deviation, the deviation ratio equals 18.75. If the modulation frequency is 3 kHz, the deviation ratio does not change because the maximum information frequency is still 4 kHz.

$$\text{Deviation ratio} = \frac{f_{dMAX}}{f_{mMAX}} = \frac{75\text{ kHz}}{4\text{ kHz}} = 18.75$$

Example 1: Modulation Index and Deviation Ratio.

If a 210 MHz carrier signal is frequency modulated (maximum deviation of 120 kHz) with a video signal that ranges from 10 kHz to 30 kHz, what is the:

a. Maximum modulation index? ____________

For this part of the question, use the formula for modulation index and a modulation frequency of 30 kHz. m equals 120 kHz/30 kHz or 4.

b. Minimum modulation index? ____________

For this part of the question, use the formula for modulating index and a modulation frequency of 10 kHz. m equals 120 kHz/10 kHz or 12.

c. Deviation Ratio? ____________

For this part of the question, use the formula for deviation ratio and the maximum modulation frequency of 30 kHz. The deviation ratio equals 120 kHz/30 kHz or 4.

SIDEBANDS

FM waveforms also have sidebands just like AM waveforms. The major difference is that FM has many and AM has only two, upper and lower.

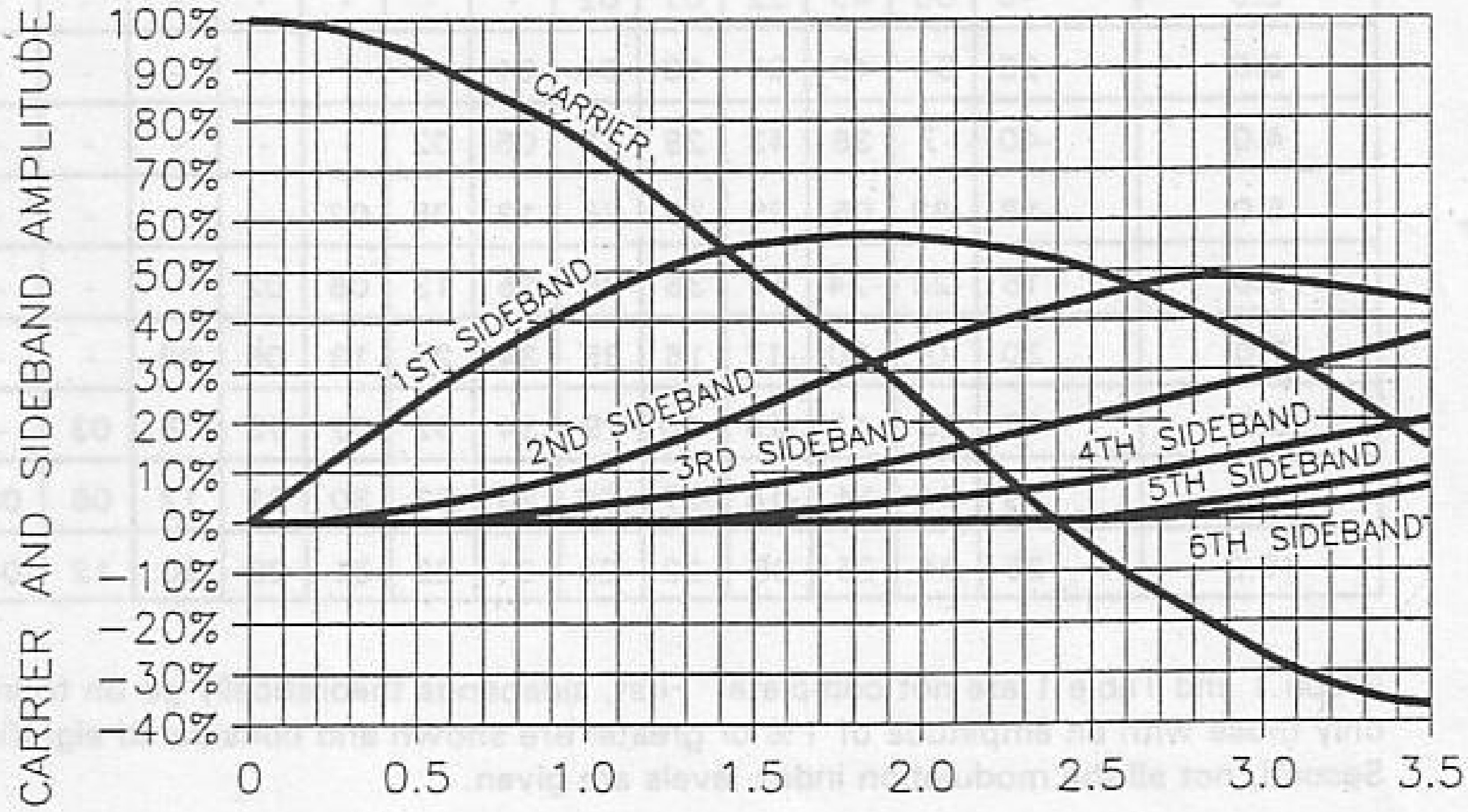
The many sidebands in FM waveforms is due the numerous frequency shifts produced by the modulation frequency. Consequently, in theory, FM waveforms can have an infinite number of sidebands. But you are in luck, many of the higher order sidebands contain a very small amount of energy and can be ignored.

Continuing the comparison of AM and FM sidebands, in AM, the sidebands add and subtract from the constant amplitude carrier signal which results in the positive and negative envelops -- amplitude variations or amplitude modulation. However in FM, the amplitude of the carrier frequency remains constant. This means that as the number of sidebands increases (or decreases) and the amplitude of the sidebands increases (or decreases), the carrier signal amplitude must change to keep a constant level FM waveform. What this boils down to is that the modulation index, maximum deviation divided by modulating signal, determines the number of significant sidebands, their amplitude, and the carrier's amplitude.

A graph comparing the modulation index and signal amplitude is shown in Graph 1 (the relationship between modulation index and amplitude levels was developed by a man name Bessel and it is called Bessel Function). At a modulation index of 0, no modulation, the carrier's amplitude is 100% and, of course, there are no sideband frequencies. When the modulation index starts to increase from 0, the carrier signal amplitude starts to decrease while the first sideband signal begins to increase. The net result is that the combined signal remains at a constant level. Notice that the second sideband signal starts out at 0% level and does not start to increase until a modulation index of 0.2. Even though the second sideband many be present at lower values of the modulation index; the level is not enough to consider. The third sideband does not come into play until a modulation index of about 0.8.

Look at the carrier frequency amplitude at a modulation index of 2.4! Does the carrier frequency disappear? Not really. At a modulation index of 2.4, the amplitude of the carrier signal is zero percent but, the combination of the first through fourth sideband levels still maintain a constant amplitude FM waveform. Also, remember that the carrier frequency contains no information, the information is in the frequency changes or sidebands of the waveform.

Graph 1. Modulation Index and Signal Levels



Also note that for modulation indices above 2.4, the carrier signal's amplitude is shown as a negative percent. This indicates that the carrier signal is 180 degrees out of phase from the sidebands above the 0% level. Also, sideband frequencies may be out of phase as shown with negative signs in Table 1. Table 1 expands Graph 1 and puts it in table format.

Table 1. Modulation Index and Signal Levels

MODULATION INDEX	CARRIER (%)	SIDEBANDS (PAIR) PERCENT													
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th
0.00	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.25	98	12	-	-	-	-	-	-	-	-	-	-	-	-	-
0.5	94	24	03	-	-	-	-	-	-	-	-	-	-	-	-
1.0	77	44	11	02	-	-	-	-	-	-	-	-	-	-	-
1.5	51	56	23	06	01	-	-	-	-	-	-	-	-	-	-
2.0	22	58	35	13	03	-	-	-	-	-	-	-	-	-	-
2.5	-5	50	45	22	07	02	-	-	-	-	-	-	-	-	-
3.0	-26	34	49	31	13	04	01	-	-	-	-	-	-	-	-
4.0	-40	-7	36	43	28	13	05	02	-	-	-	-	-	-	-
5.0	-18	-33	05	36	39	26	13	05	02	-	-	-	-	-	-
6.0	15	-28	-24	11	36	36	25	13	06	02	-	-	-	-	-
7.0	30	0	-30	-17	16	35	34	23	13	06	02	-	-	-	-
8.0	17	23	-11	-29	-10	19	34	32	22	13	06	03	-	-	-
9.0	-9	24	14	-18	-27	-06	20	33	30	21	12	06	03	01	-
10.0	-25	04	25	06	-22	-23	-01	22	31	29	20	12	06	03	01

Graph 1 and Table 1 are not complete. First, sidebands theoretically go on to infinity but only those with an amplitude of 1% or greater are shown and considered significant. Second, not all the modulation index levels are given.

Another way to see the amplitude levels for different modulation indices is shown in Figure 3. Here, a spectrum analysis is done for five different modulation indices.

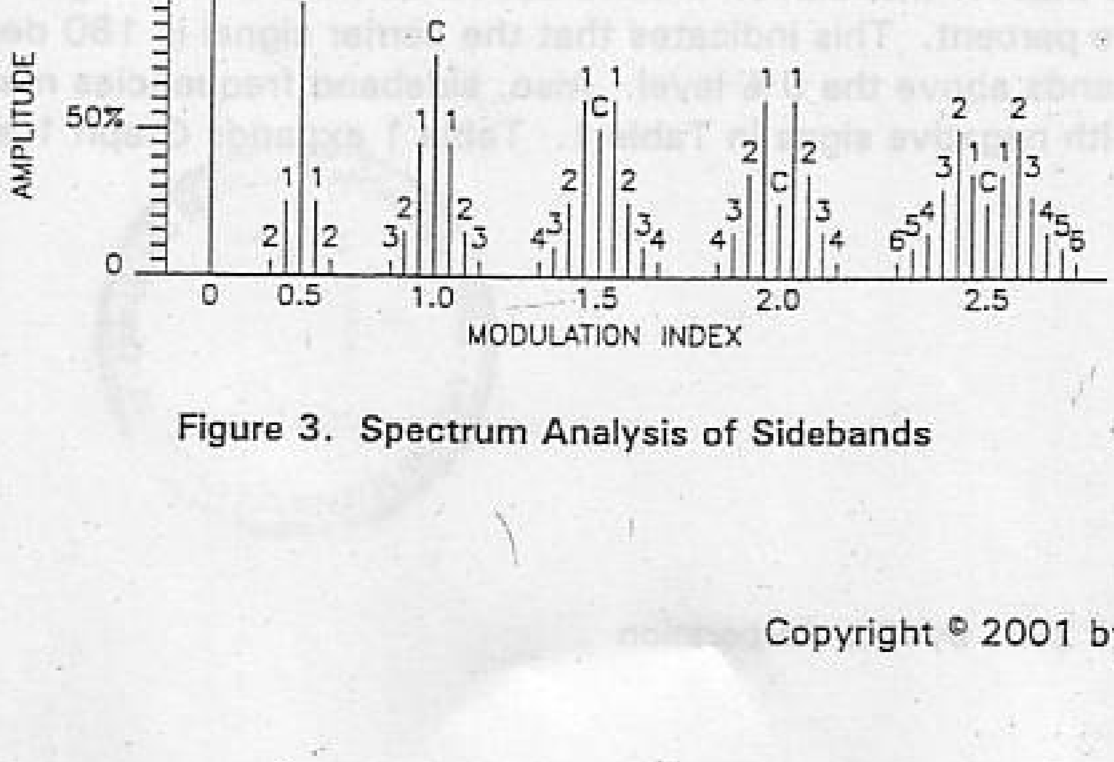


Figure 3. Spectrum Analysis of Sidebands

Example 2: Sidebands.

If an FM waveform has an amplitude of 10 Vpp and is made up from a 40 kHz information signal and a 100 MHz carrier signal, what are the number of significant sidebands generated and what are the levels of the all signals for a maximum deviation of 80 kHz?

In this question, you must first determine the modulation index and then use Table 1 to find the answers requested.

The modulation index equals the maximum deviation frequency, 80 kHz divided by the modulation frequency, 40 kHz, or 2.

$$m = \frac{f_d}{f_m} = \frac{80 \text{ kHz}}{40 \text{ kHz}} = 2$$

Refer to Table 1. A modulation index of 2 produces four sidebands.

Also in reference to Table 1, the amplitude levels are:

CARRIER SIGNAL	22%, or 0.22 x 10 Vpp = 2.2 Vpp
FIRST SIDEBAND	58%, or 0.58 x 10 Vpp = 5.8 Vpp
SECOND SIDEBAND	35%, or 0.35 x 10 Vpp = 3.5 Vpp
THIRD SIDEBAND	13%, or 0.13 x 10 Vpp = 1.3 Vpp
FOURTH SIDEBAND	3%, or 0.03 x 10 Vpp = 0.3 Vpp

BANDWIDTH

As has been mentioned several times, the bandwidth of a communication system is the highest frequency used in the information signal.

However, AM and FM waveforms also have bandwidth. In AM, the range of frequencies of the waveform is twice the modulating frequency or the range of frequencies between the upper and lower sidebands. FM is a little more complicated since there are normally more than two sidebands.

The bandwidth of an FM waveform is determined by the number of sidebands in the signal. The first sideband is like AM sidebands, $f_c + f_m$ and $f_c - f_m$. The second order sidebands are $f_c + 2f_m$ and $f_c - 2f_m$, and the process continues for each higher order of sidebands. The bandwidth, therefore, depends on the number of significant sidebands. And of course, the number of significant sidebands is determined by the modulation index (using Table 1).

The formula for the bandwidth of an FM waveform is:

BW = f_m x number of sidebands x 2 Where: f_m is the modulating frequency

Example 3: Bandwidth.

What is the bandwidth of an FM waveform at 100 MHz modulated with a 18.75 kHz signal and that has a maximum deviation of 75 kHz?

In this question, you must first determine the modulation index.

$$m = \frac{f_d}{f_m} = \frac{75\ \text{kHz}}{18.75\ \text{kHz}} = 4$$

Refer to Table 1. The number of sidebands for a modulation index of 4 is 7.

$$\begin{aligned} BW &= f_m \times \text{number of sidebands} \times 2 \\ &= 18.75\ \text{kHz} \times 7 \times 2 \\ &= 262.5\ \text{kHz} \end{aligned}$$

The bandwidth is therefore 262.5 kHz

NOISE

As you know by now, noise causes variation in amplitude. This is one of the big advantages in using FM. Amplitude variations due not affect the information signals.

The noisy FM signal shown in Figure 4 can be limited in amplitude to eliminate the noise. The limiting action does not affect the information contained in the signal as it would in an AM waveform. The information is contained in frequency variations, not amplitude variations.

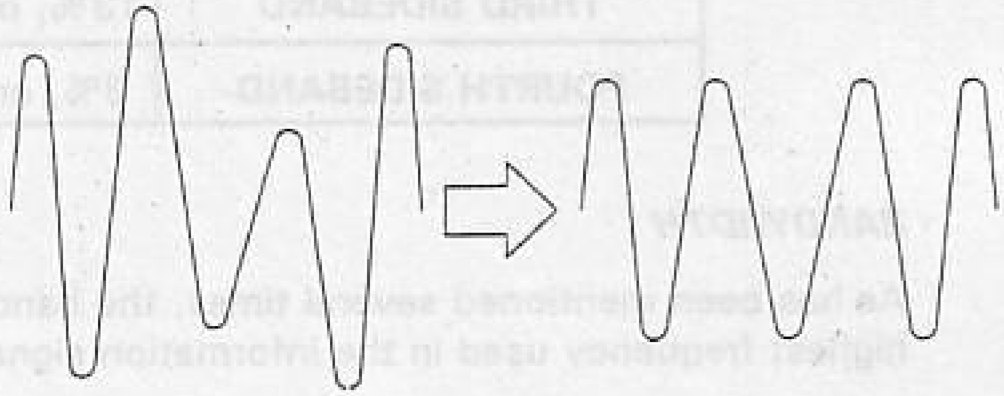


Figure 4. Noisy FM Waveform

There are many types of circuits that can limit the amplitude of waveforms, common diode limits are usually used because of the inexpensive cost.

POWER

In AM signals, only 25% of the available power is each one of the sidebands and since only one sideband is used to recover the information signal, only 25% of the available power is used. FM signals also have the available power divided among the sidebands and carrier signal.

However in FM systems, as seen in Figure 3, Table 1, and Graph 1, the power in the carrier signal can be very small depending on the modulation index. This is another advantage of FM, special circuits are not required to increases the available power in the information signal. The following points highlight the power in FM signals.

* THE CARRIER POWER DIMINISHES DURING MODULATION
* THE ENERGY TAKEN FROM THE CARRIER GOES INTO THE SIDEBANDS WHERE THE INFORMATION SIGNAL IS LOCATED
* ONE OR MORE SIDEBANDS CAN CONTAIN MORE POWER THAN THAN THE CARRIER SIGNAL.

Exercise 1: Characteristics of FM Signals.

Write the answers to questions1 through 5 in the blank spaces provided. Use the FM signal illustrated in Figure 5.

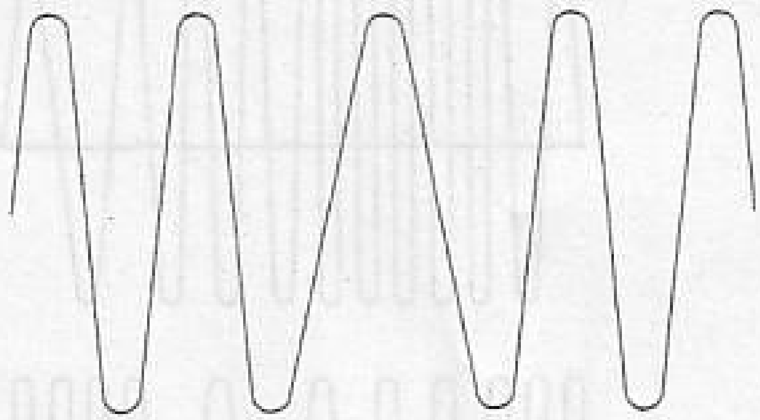


Figure 5. FM Waveform

1. What is the modulation index?

____

2. How many significant sidebands are produced? (Refer to Table 1.)

____

3. What is the percent amplitude of the carrier signal and the phase? (Refer to Table 1.)

____

4. Which sideband is the highest level and what is the level? (Refer to Table 1.) _______________

5. What is the bandwidth? (Refer to Table 1.) _______________

PHASE MODULATION (PM)

In phase modulation, the carrier's phase angle is changed according to the amplitude variations of the information signal. However, a phase change cannot occur without a frequency change. Therefore, phase modulation also produces frequency modulation (frequency modulation also produces phase modulation). It is for this reason, the PM is sometimes called indirect FM. Figure 6 illustrates the difference between FM and PM for two different types of modulating signals.

Looking at the sine wave modulating signal in Figure 6, in FM, the maximum deviation is when the modulating signal's amplitude is maximum in the positive or negative direction. In PM, the maximum deviation is when the modulating signal crosses the 0 reference, or when the signal changes polarity. Changing from – to + produces the higher frequency deviations and changing from + to – produces the lower frequency deviations. Comparing the two sine wave modulated signals shows very little difference; only the PM signal is shifted. When sine wave information signals are used, FM and PM are basically the same.

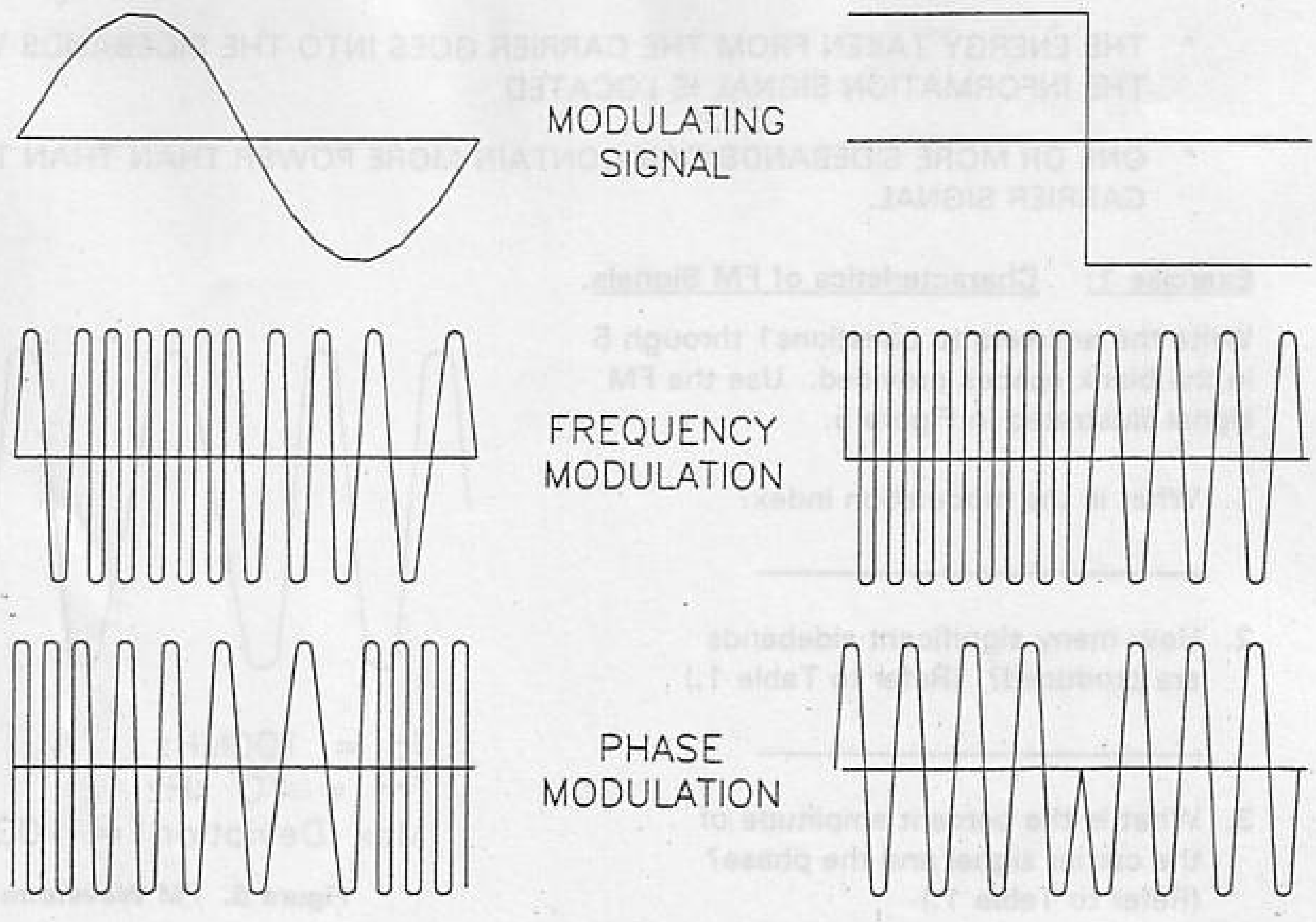


Figure 6. FM and PM Waveforms

Looking at the square wave modulating signal in Figure 6, the difference between FM and PM is readily apparent. A square wave has an abrupt change between positive and negative maximum values and between polarities. The predominant change in the FM waveform is the frequency (there is a small phase change). The predominant change in the PM waveform is the phase (there is a small frequency change).

Phase modulation is being increasingly used in communication systems that use digital or coded data as will be covered in Lesson 7 on phase shift keying. This is because the abrupt changes in phase are easily detected while small changes are not (due to hardware limitations). Small changes are probably noise or other unwanted signals in digital or coded data that will not be detected in the demodulator circuits. Because phase modulation can not detect small phase changes, PM is not used to transmit voice of music signals.

MODULATOR CIRCUITS

The modulator circuit, located in the transmitter, is the circuit that produces the frequency modulated signal. The circuit uses two inputs, carrier and information signals, and generates one output, the FM waveform. FM modulator circuits are a little more complex than AM circuits but, the basic operating principles are as simple. Two discrete component modulators are covered along with one integrated circuit modulator.

REACTANCE MODULATOR

The first type of modulator discussed is the reactance modulator. Reactance modulators operate on the principle of changing a circuits impedance to change the frequency of an oscillator. Figure 7 is a typical example of a reactance modulator using a FET transistor. You will construct this circuit in the experiment.

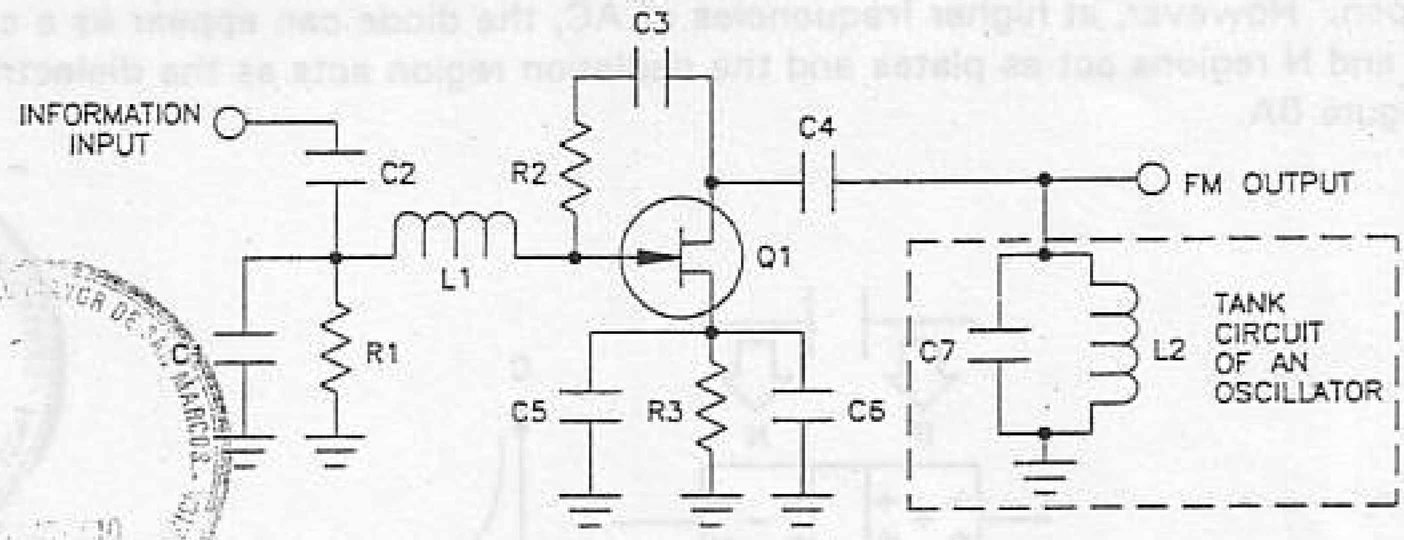


Figure 7. Reactance Modulator Circuit

The circuit operation is based on changing the total impedance of C3/R2 and the resistance of Q1's source to drain (C3/R2 and Q1 are in parallel) by applying an information signal input. The Q1 circuit is placed in parallel to the tank circuit of an oscillator (entire oscillator circuit not shown) and by changing the impedance of the Q1 circuit, the resonant frequency of the oscillator's tank changes causing a frequency change. With no input signal applied, the impedance of C3/R2 and Q1 adds to the impedance of C6 and L3 producing a carrier signal output at a center frequency. When an input signal is applied, the impedance of C3/R2 and Q1 changes, changing the oscillators frequency. In other words, frequency modulation.

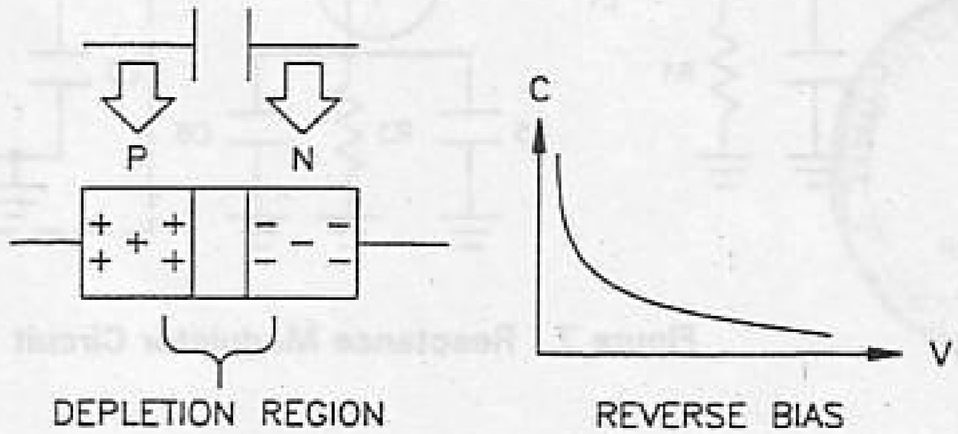
The value of C3 is such that its reactance is much higher than the resistance of R2 at the circuit's operating frequencies. Consequently, the impedance of C3 and R2 is capacitive. This capacitive reactance is in parallel to the source to drain resistance of Q1. The entire circuit for Q1 appears as a capacitance across the tank circuit and sets the oscillating frequency. When a positive voltage input is applied to the modulator, the drain current in Q1 increases in proportion to the amplitude of the input signal (normal transistor operation). This is the same as saying the source to drain resistance of Q1 decreased. Decreasing the resistance in a parallel RC circuit (C3/R2 and Q1) which is capacitive, causes the impedance to become more capacitive. The increased capacitance of C3/R2 and Q1 causes the tank circuit to resonant at a lower frequency. When the input signal is negative, the resistance of Q1 increases causing the capacitance to decrease and raising the frequency of the oscillator circuit.

C2 and C5 are coupling capacitors. L2 allows most of Vcc to reach Q1's drain and at the same time blocks AC signals from reaching the power supply. L1 allows most of the low frequency information signal to pass while blocking the higher carrier frequency from the information source.

VARACTOR MODULATOR

A varactor modulator is based around a varactor diode and is commonly called a voltage controlled oscillator or VCO for short. A quick review of varactor diodes is given but, if a more in depth study is needed, additional references are required.

When a diode is reversed biased, its resistance is very large and can be considered as an open. However, at higher frequencies of AC, the diode can appear as a capacitor. The P and N regions act as plates and the depletion region acts as the dielectric as shown in Figure 8A.



A. B.

Figure 8. Reversed Biased Diode As A Capacitor

And as you know, the more reverse voltage applied to a diode, the bigger the depletion region becomes. This is the same as saying that the dielectric of a capacitor increases, or decreases, depending on the amount of reverse bias voltage applied to the diode. Therefore, as the reverse bias voltage increases, the depletion region increases lowering the capacitance and as the reverse bias voltage decreases, the depletion region decreases raising the capacitance as shown in Figure 8B. In other words, a varactor diode is a voltage controlled variable capacitor. Diodes specifically designed to operate in this manor are called varactor diodes.

A varactor modulator, or VCO modulator, is shown in Figure 9. The circuit is nothing more than an oscillator which has its frequency determining circuit variable by means of a varactor diode, D1. Note the symbol used for a varactor diode.

Q1 is the oscillator circuit and uses R2, R3, L3, R4/C5 for biasing, and R1 for feedback. L1 blocks AC voltages from reaching the input source and L3 blocks AC voltages from reaching the power supply. C1 blocks DC voltages from Q1's collector (via R1) from affecting the varactor diode. C4 blocks the base bias voltage and C6 blocks the collector bias voltage.

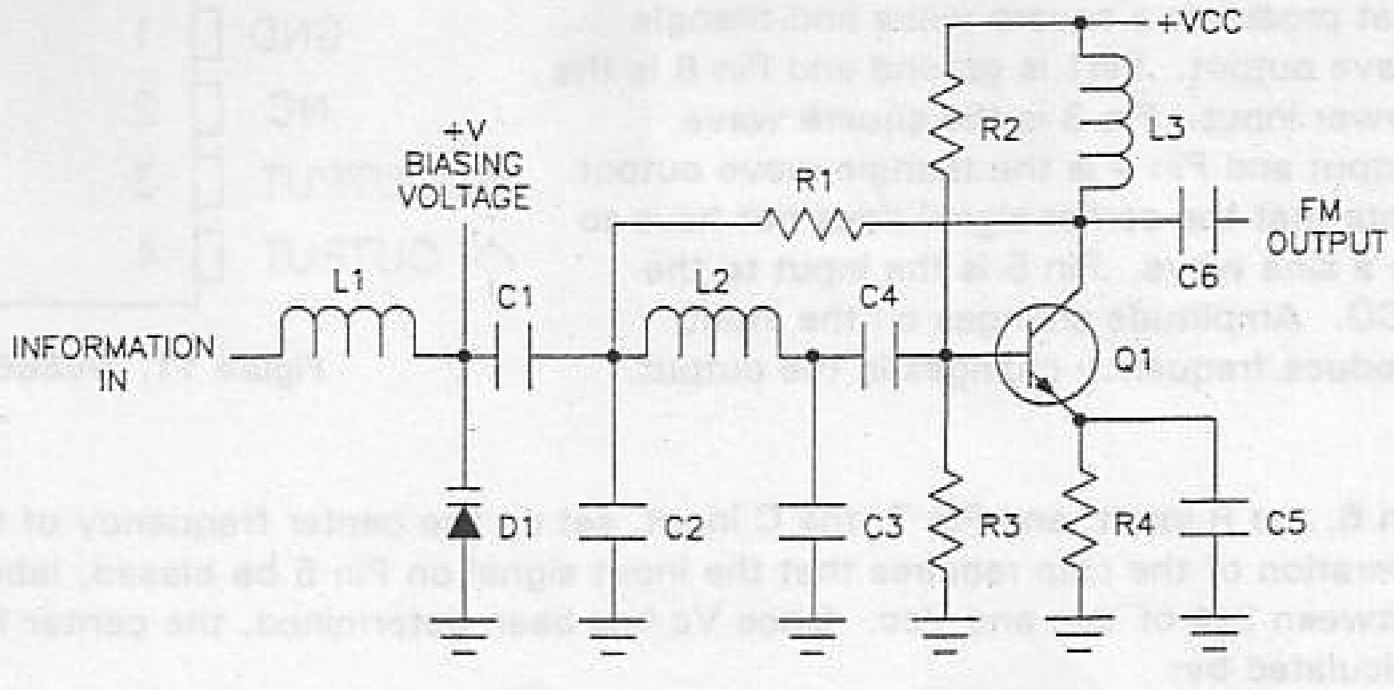


Figure 9. Varactor (VCO) Modulator Circuit

C2, C3, L2 form the frequency determining circuit. D1 is the varactor diode supplied with a reverse bias and is in parallel to C2 as shown in the re-drawn circuit in Figure 10. C2/D1 and C3 are in parallel to L2 and form the tank circuit. The circuit will oscillate at a carrier frequency determined by the value of the components and the bias applied to D1 (sets the initial capacitance). When an input signal is applied, the bias on D1 changes, changing D1's capacitance. This action changes the oscillator's frequency.

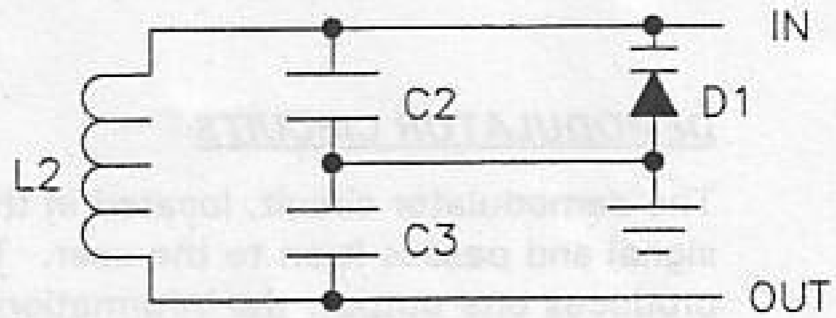


Figure 10. Tank Circuit

The information signal amplitude causes the capacitance of D1 to change. This causes the capacitance in the tank circuit to change there by changing the oscillator's frequency -- Frequency modulation.

INTEGRATED CIRCUIT VCO

The varactor modulator in Figure 9 is made up of discrete components and is a basic circuit. Additional components are normally used to improve the circuit performance but was not shown to simplify circuit description.

However, most FM modulators found in modern transmitters are in Integrated Circuit, IC, form. IC's reduce the amount of space and circuit connections even though the circuits are more complex.

The NE566 Voltage Control Oscillator is an example of an FM modulator in IC form. The circuits inside the chip contain 20 transistors, 10 diodes, and numerous resistors but the circuit connections are limited to seven as shown in Figure 11.

The chip is a voltage controlled oscillator that produces a square wave and triangle wave output. Pin1 is ground and Pin 8 is the power input. Pin 3 is the square wave output and Pin 4 is the triangle wave output. Note that the carrier signal does not have to be a sine wave. Pin 5 is the input to the VCO. Amplitude changes on the input produce frequency changes in the output.

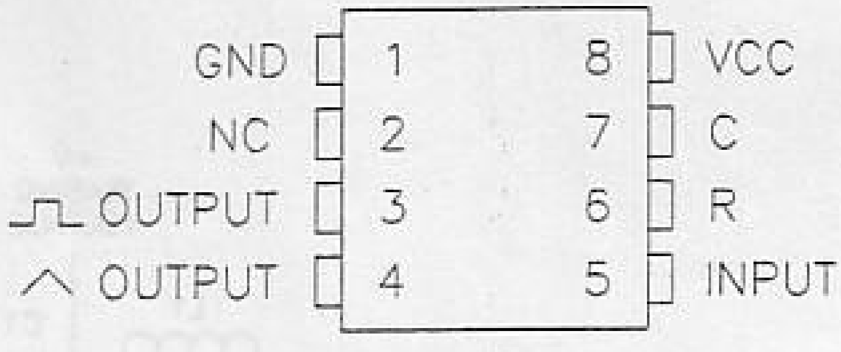


Figure 11. NE566 VCO

Pin 6, the R input, and Pin 7, the C input, set up the center frequency of the VCO. The operation of the chip requires that the input signal on Pin 5 be biased, labeled Vc, between 3/4 of Vcc and Vcc. Once Vc has been determined, the center frequency is then calculated by:

$$f_c = \frac{2\,(Vcc - Vc)}{R\ C\ Vcc}$$

Where: R is the resistance connected to Pin 6, and

C is the capacitance connected to Pin 7

DEMODULATOR CIRCUITS

The demodulator circuit, located in the receiver, is the circuit that recovers the information signal and passes it on to the user. The circuit has one input, the FM waveform, and produces one output, the information signal. FM demodulator circuits are more complex than AM circuits and three typical discrete demodulator circuits are covered. Also covered is a block diagram and chip description of a Phase-Locked Loop demodulator (PLL) circuit that uses an IC. PLL circuits are not normally constructed from discrete components due to their complexity.

SLOPE DEMODULATOR

The simplest FM demodulator is the slope detector as shown in Figure 12. The action of the circuit is based on tuning the carrier frequency to the mid point on a response curve of two tuned circuits. You will construct this circuit in the experiment.

The circuit consists of two tuned circuits and an AM detector! C1/L1 and C2/L2 are the tune circuits that produce a response curve as shown in Figure 12 . The circuits are tuned so that the carrier frequency, f_c, falls on the front slope of the response curve approximately half way up. When the FM signal input is at the center frequency, no modulation, the output to D1 is an average level. When the FM signal frequency increases, due to modulation, the output to D1 increases because the increased frequency approaches the peak of the response curve. When the FM signal frequency decreases, the output to D1 decreases because the decreased frequency is further down on the response curve. The action simply amplitude modulates the FM input signal.

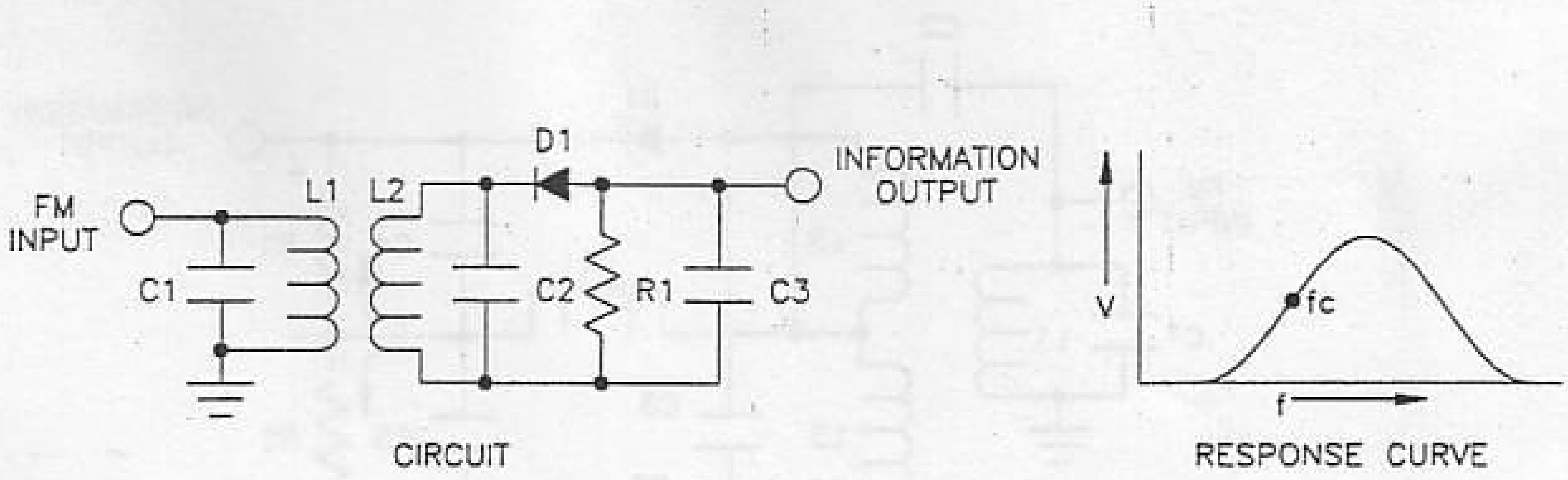


Figure 12. Slope Demodulator Circuit

D1, R1, and C3 operate as an AM diode detector or demodulator. Therefore, the output of the slope demodulator is the information signal that is passed on to the user. The disadvantage to this type of circuit is that the gain is reduced and it is very hard to achieve a linear slope response curve.

DISCRIMINATOR DEMODULATOR

A better method to demodulate an FM signal is to use a discriminator circuit as shown in Figure 13. The circuit in Figure 13 is called a Foster-Seeley discriminator and has one major disadvantage. Amplitude variations, which do not contain any information, are coupled to the output signal as noise or static. Normally, a limiter circuit is used before the demodulator which reduces this problem.

The basic circuit operation revolves around the conduction of D1 and D2 producing a voltage across R1 and R2 that varies in amplitude (information signal) as the frequency of the FM signal changes. When D1 and D2 conduct the same amount, the voltage across R1 and R2 will be equal and opposite, since their polarities are opposite, and cancel each other. The output voltage taken across R1 and R2 is therefore 0 volts. If D1 conducts harder, the voltage drop across R1 is larger than the voltage drop across R2 producing a positive output. If D2 conducts harder, the voltage drop across R2 is larger than the voltage drop across R1 producing a negative output. D1 conducts more when the FM input is above center frequency (remember, center frequency is the carrier frequency with no modulation) and D2 conducts more when the FM input is below the center frequency by the action of L2, L3 and L4.

L2 and L3 act as center tapped secondaries of a transformer with L1 acting as the primary. Thus the voltage across L2 is 180 degrees out of phase with the voltage across L3 but, by design, the voltage across L2 and L3 are equal in amplitude. L4 is capacitor coupled from L1 producing a 90 degree phase shift, thus the voltage across L4 is 90 degrees out of phase to both the voltages on L2 and L3.

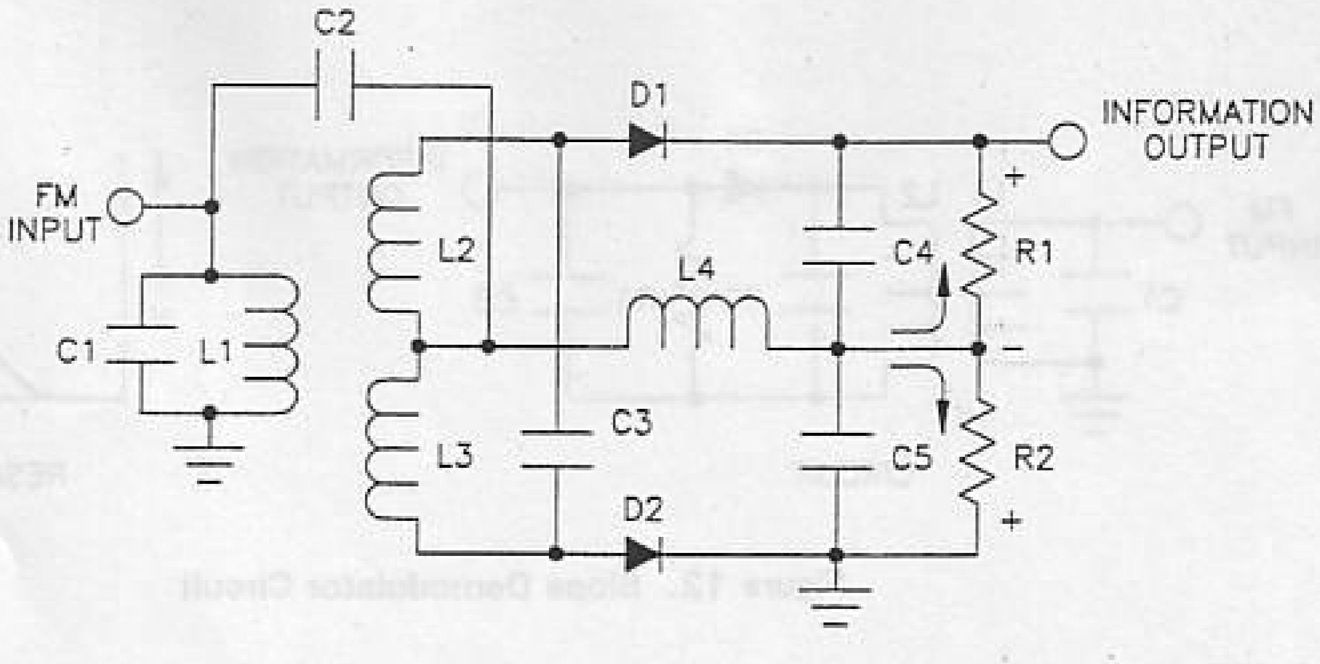


Figure 13. Discriminator Demodulator Circuit

When the FM signal input is at center frequency, the reactances of L2/L4 and C4 are equal (in the circuit for D1) and the reactances of L3/L4 and C5 are equal (in the circuit for D2). Thus the diode circuits do not produce a phase shift and the 90 degree phase shift across L4 subtracts from the voltages across L2 and L3 equally as shown in Figure 14A. The voltage drops across R1 and R2 are therefore equal and the output is 0 volts.

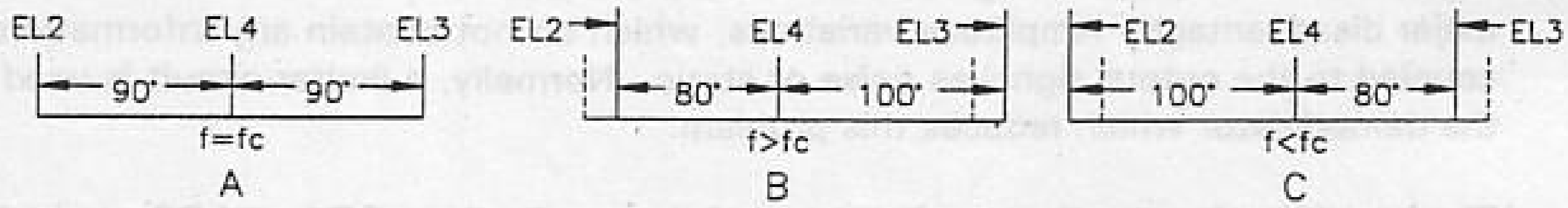


Figure 14. Voltage Phase of L2, L3, and L4

When the FM signal input is above center frequency, the inductive reactance of D1 and D2 circuits become larger than the capacitive reactance or, the circuits become inductive causing the voltage across L2 and L3 to shift phase as shown in Figure 14B. The result is that the voltage across L2 becomes more in phase with the voltage across L4 producing a larger voltage. Also, the voltage across L3 becomes less in phase with the voltage across L4 producing a smaller voltage -- remember, the phase difference between L2 and L3 is always 180 degrees. Since the D1 circuit has a larger voltage, D1 conducts more producing a positive output. The amount that D1 is larger than D2, which determines the output amplitude, depends on the frequency of the input signal due to the reactances of the circuit, the higher the frequency is above the center frequency, the more that the voltage of L2 is in phase with L4 producing a higher, more positive, output voltage.

When the FM signal input is below center frequency, the circuits become capacitive causing the voltage across L2 and L3 to shift phases in the opposite direction as shown in Figure 14C. The result is the voltage across L3 becomes more in phase with the voltage across L4 producing a larger voltage. The voltage across L2 becomes less in phase with the voltage across L4 producing a smaller voltage. Since the D2 circuit has a larger voltage, D2 conducts more producing a negative output. The amount that D2 is larger than D1 is determined by the frequency of the input signal due to the reactances of the circuit. The lower the frequency is from the center frequency, the more that the voltage across L3 is in phase with the voltage across L4 producing a higher, more negative output voltage.

In summary, the circuit produces an output that has a frequency of the deviation rate and has an amplitude based on the amount of deviation of the FM signal input.

RATIO DEMODULATOR

The ratio demodulator, or detector, is an improvement of the discriminator demodulator shown in Figure 13. The circuit has its own limiting, thus doing away with a limiting circuit preceding the demodulator. A typical ratio demodulator is shown in Figure 15. Compare the discriminator circuit in Figure 13 to the ratio demodulator in Figure 15.

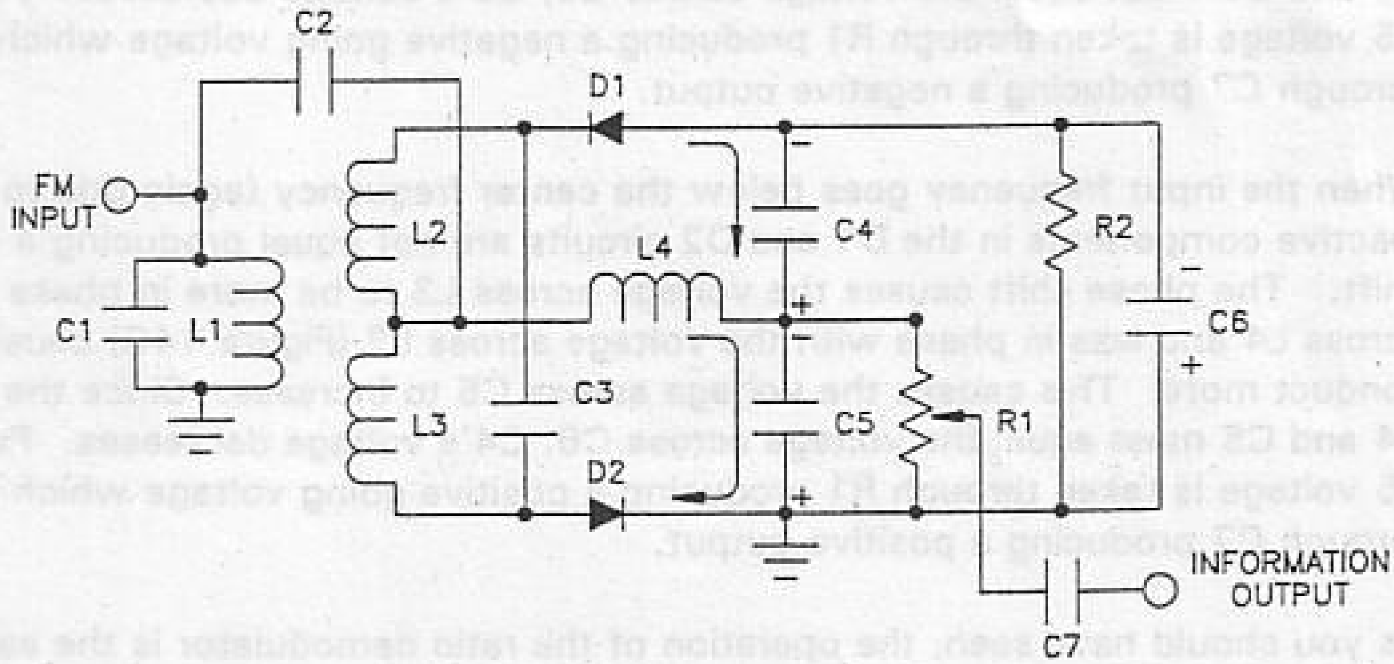


Figure 15. Ratio Demodulator Circuit

Notice that in the ratio demodulator, Diode D1 is reversed from D1 in the discriminator demodulator. Also, the ratio demodulator is different by the addition of C6/R2 and how the output is taken. However, the operation of the ratio demodulator is similar to the discriminator demodulator.

First, C6 will charge to the average received signal strength because it is across L2 and L3, the charge does not depend on the conduction of D1 and D2. Due to the size of C6, the voltage is held constant across R2 which in turn holds the voltage across C4 and C5 constant. Only increases and decreases in the signal strength change the voltage across C4/C5, R2, and C6. This action limits the signal for amplitude variations caused by noise. Noise variations, which are high frequency, do not change the charge on C6, thus the voltage across C4/C5 remains constant.

Second, D1 and D2 are in series with L2 and L3, thus producing current flows and polarities across C4 and C5 as indicated in Figure 15.

Third, assuming a constant signal strength, the charges on C4 and C5 depend on the conduction of D1 and D2 respectively -- just like in the operation of the discriminator circuit.

When the input frequency is at the center frequency, the reactive components in the D1 and D2 circuits are equal producing no phase shift. The voltage across L4 (which is 90 degrees shifted) then combines equally with the voltages on L2 and L3 causing the conduction of D1 and D2 to be equal (Figure 14A). Therefore, the voltage across C4 and C5 are equal. Also, due to the action of C6, the voltages across C4 and C5 will equal the voltage across C6. Part of the voltage across C5 is taken through R1 producing a negative DC voltage which is block by C7 producing a 0 volt output.

When the input frequency goes above the center frequency (due to modulation), the reactive components in the D1 and D2 circuits are not equal producing an inductive phase shift. The phase shift causes the voltage across L2 to be more in phase with the voltage across L4 and less in phase with the voltage across L3 (Figure 14B) causing D1 to conduct more. This causes the voltage across C4 to increase. Since the voltage across C4 and C5 must equal the voltage across C6, C5's voltage decreases. Part of the lower C5 voltage is taken through R1 producing a negative going voltage which is passed through C7 producing a negative output.

When the input frequency goes below the center frequency (again due to modulation), the reactive components in the D1 and D2 circuits are not equal producing a capacitive phase shift. The phase shift causes the voltage across L3 to be more in phase with the voltage across L4 and less in phase with the voltage across L2 (Figure 14C) causing D2 to conduct more. This causes the voltage across C5 to increase. Since the voltage across C4 and C5 must equal the voltage across C6, C4's voltage decreases. Part of the higher C5 voltage is taken through R1 producing a positive going voltage which is passed through C7 producing a positive output.

As you should have seen, the operation of the ratio demodulator is the same as the discriminator demodulator for developing the voltages across C4 and C5, which produce the output signal. Only the direction of D1 and the output circuit is different. Also, do not forget about the limiter action of C6.

PHASE-LOCKED LOOP (PLL) DEMODULATOR

The three demodulator circuits covered operate on tuned circuits. Even though variable reactive components where not used in the circuit schematics given, most demodulator circuits use tunable inductors so that circuit operation can be adjusted. You will see tunable inductors used on the discriminator and ratio demodulator circuits in the experiment. This is a disadvantage because the demodulators require frequent alignment and are not perfectly linear.

An alternative is to use a phase-locked loop system for demodulating FM signals. PLL circuits are very complex so consequently the circuits are normally in IC form. Since you cannot measure signals in an IC or repair an IC, only a block diagram of the operation of PLL circuits is required.

The block diagram of a PLL demodulator is shown in Figure 16. Notice that it only contains four circuits, a phase comparator, a low pass filter, an op-amp, and a VCO.

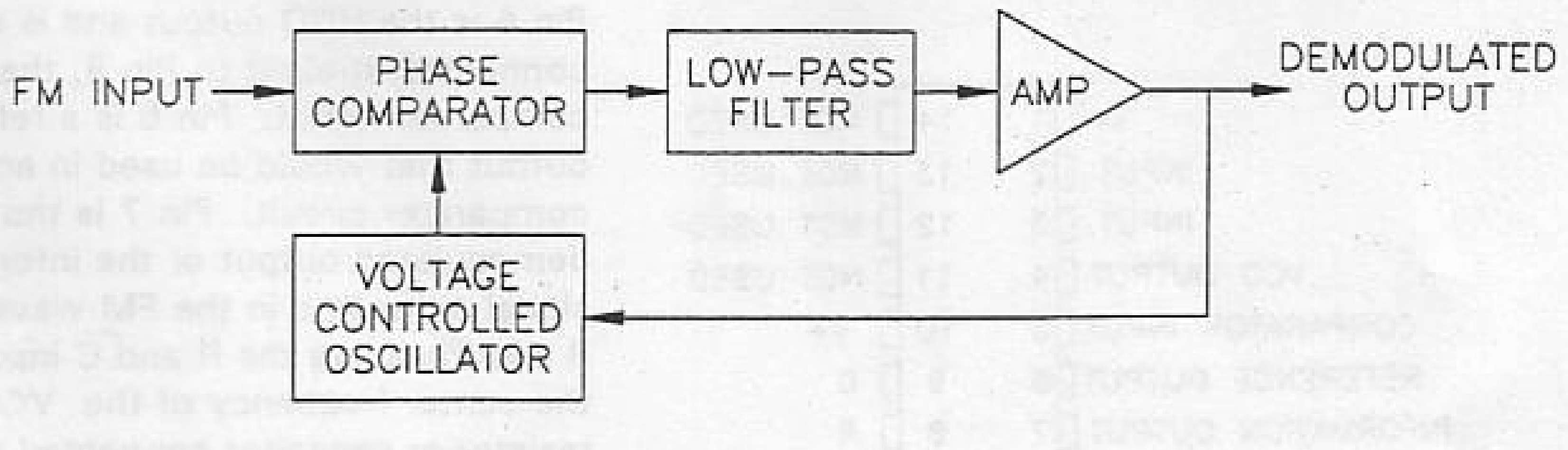


Figure 16. Block Diagram of PLL Circuit

Look closely at the diagram in Figure 16. Notice that it is a continuous loop. This makes the system dynamic and you can start signal tracing anywhere in the circuit. So, let's start with the VCO.

The VCO circuit is designed to produce, with an input voltage of 0 volts, an output frequency that is equal to the center frequency of the FM input. The output of the VCO is applied to the phase comparator along with the incoming FM signal. If there is any difference between the two signals (phase or frequency), a DC error voltage proportional to the amount and direction of the difference is produced. The output of the comparator is then filtered and amplified and sent to the VCO. The error voltage then raises or lowers the frequency of the VCO until the output of the comparator is 0, or no difference between the VCO and incoming FM signal frequency.

However, remember that the incoming FM signal is modulated, that is, it is always changing frequency. Therefore, the VCO output frequency can never exactly match the incoming instantaneous frequency, but it tracks it. This means that there is always a DC error voltage on the output of the amplifier which is constantly changing. The error voltage amplitude is changing according to the frequency changes in the FM signal, thus the FM signal is demodulated. PLL circuits directly demodulate FM signals.

The only frequency dependent circuit is the VCO, and referring back to Figure 11, the integrated circuit VCO uses only two inputs that can be variable to adjust circuit operation, R and C. Normally, only one is made variable.

A typical PLL circuit used as a demodulator is the NE565 chip as shown in Figure 17. The chip contains approximately 28 transistors, 13 diodes, and numerous resistors. There are fourteen pins, four are not used. Also, the chip allows controlling the VCO frequency by R and C inputs along with separating the output of the VCO from the input to the phase comparator. This allows additional external circuits for frequency multiplication applications. Due to the wide variety of uses for this chip, some pins are not used for a standard FM demodulator. Some of the other uses are in frequency shift keying, modems, tone decoders, data synchronizers, tracking filters, signal restoration, and frequency multiplication and division.

Pin 1 is the negative input voltage used to set up a constant current source if required. Pins 2 and 3 are the FM signal inputs to the phase comparator, two inputs are used for different applications.

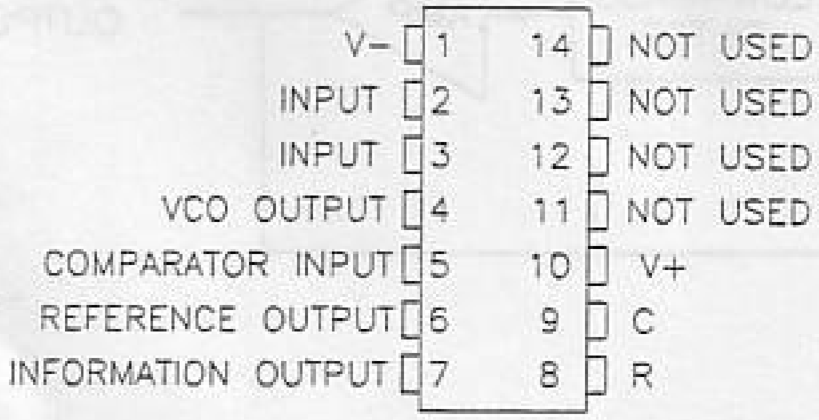


Figure 17. NE565 PLL

Pin 4 is the VCO output and is normally connected straight to Pin 5, the comparator input. Pin 6 is a reference output that would be used in an external comparator circuit. Pin 7 is the demodulated output or the information signal contained in the FM waveform. Pin 8 and Pin 9 are the R and C inputs to set the center frequency of the VCO, the resistor or capacitor connected to the pins can be made variable for chip adjustments. Pin 10 is the positive supply voltage that operates the chip. Pins 11 through 14 are not used.

The center frequency of the VCO is determined by the values of the resistor and capacitor connected to Pins 8 and 9 and is calculated by:

$$f_c \text{ is approximately } = \frac{1.2}{4\,RC}$$

<u>Exercise 2</u>: <u>FM Modulator and Demodulator Circuits.</u>

Write the answers to questions 1 through 5 in the blank spaces provided. Use the figures in the lesson as given in each question.

_________ 1. Refer to Figure 7. How is the frequency of the tank circuit varied?

a. The resultant capacitance of C1, R1, and Q1 is changed by the information signal input.
b. The capacitance of the varactor transistor Q1 is changed by the information signal input.
c. The variation in Vcc caused by the information signal changes the resonant frequency of the tank circuit.
d. The varying voltage applied from the drain of Q1 cause the tank circuit to change frequency.

_________ 2. Refer to Figure 9. How is the frequency of the oscillator varied?

a. The capacitance of the varactor transistor Q1 is changed by the information signal input.
b. The capacitance of the varactor diode D1 is changed by the information signal input.
c. The variation in Vcc caused by the information signal changes the resonant frequency of the oscillator.
d. The inductance of the varactor diode D1 is changed by the information signal input.

Exercise 2: FM Modulator And Demodulator Circuits, continued

______ 3. Refer to Figure 12. Which components determine where the center frequency of the FM signal will fall on the response curve?

a. C2 and R1
b. C2 and D1
c. D1, R1, and C3
d. C1/L1 and C2/L2

______ 4. Refer to Figure 13. What action causes the voltage across R1 to be larger than the voltage across R2?

a. D1 conducts less.
b. D2 conducts more.
c. The phase of the voltage across L4 is less than 90 degrees from the voltage across L2 and more than 90 degrees from the voltage across L3.
d. The phase of the voltage across L4 is less than 90 degrees from the voltage across L3 and more than 90 degrees from the voltage across L2.

______ 5. Refer to Figure 15. What action causes the output voltage to decrease?

a. D1 conducting more causing an increase in the voltage across C4.
b. D2 conducting more causing a decrease in the voltage across C5.
c. C6 charging to the level that is equal to the voltages across C4 and C5.
d. The phase of the voltage across L4 is less than 90 degrees from the voltage across L3 and more than 90 degrees from the voltage across L2.

EXPERIMENT

In this experiment, you will build prototypes of an FM modulator and demodulator circuit as you did in the AM lesson.

The experiment is divided into two parts:

PART 1. FM SIGNALS

PART 2. MODULATOR AND DEMODULATOR CIRCUITS

PART 1. FM SIGNALS

In this part of the experiment, you will use a function generator to generate FM signals and an oscilloscope to observe the results. If not using the Nida Model 440 Function Generator, ensure that the generator you are using can produce an FM modulated output signal. Note that some generators have modulating capability but require a second generator to produce the modulating signal input. If the function generator you are using cannot frequency modulate a carrier signal, see your instructor before continuing.

Part 1 Equipment Required

Function Generator
Oscilloscope
(2) BNC to BNC Cables

Part 1 Preparation

The Nida Model 440 Function Generator contains two different oscillator outputs, MAIN and MODULATION. The MAIN output of the generator can be frequency modulated by the MODULATION section. The modulating signals can range from 0.01 Hz to 10 kHz sine wave, square wave, or triangular wave.

Part 1 Procedure

1-1. Connect the main output of the function generator to Channel 1 of the oscilloscope.

1-2. Set the function generator for a sine wave output of 100 kHz at 8 Vpp as viewed on the oscilloscope. Ensure that the MODULATION oscillator is off, all modulating buttons out. (See Figure 18.)

Observe the carrier signal on the oscilloscope.

1-3. Set the MODULATION section of the function generator as follows. (Refer to Figure 18.)

a. Frequency RANGE - 100
b. FREQUENCY - Mid range
c. SYM - CAL
d. MOD - Mid range
e. MODULATION - FM, sine wave (two buttons used)

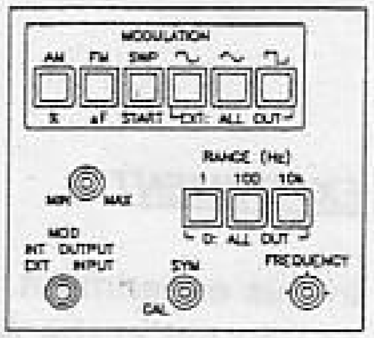


Figure 18. Modulation Section

1-4. Set the TIME/DIV control on the oscilloscope to 2 μs and adjust the trigger controls for the best stabilized display.

The signal seen on the oscilloscope is a frequency modulated waveform. Notice how the frequency is changing. Also, if using the Nida Model 440 Function Generator, notice that the frequency display on the generator is also varying around the 100 kHz carrier signal.

1-5. Rotate the FREQUENCY control on the MODULATION section of the function generator CW and CCW.

Looking closely at the waveform on the oscilloscope, you should see the rate of deviation change (how fast the frequency changes) and the amount of frequency deviation remain constant (how far off from 100 kHz). As you increase the modulating frequency the deviation rate increases and as you decrease the modulating frequency the deviation rate decreases.

1-6. Return the FREQUENCY control to max position.

1-7. Rotate the MODULATION control on the MODULATION section of the function generator CW and CCW.

Notice that the amount of deviation changes. As the amplitude (controlled by the MODULATION control) increases and decreases, the amount of frequency deviation increases and decreases. You should also observe that the rate of deviation does not change. It may appear that it does because the waveform on the oscilloscope changes from one extreme to the other faster or slower and gives an appearance of a rate change. Of course, with the MODULATION control fully CCW, no modulation, you observe no frequency change.

1-8. Change the frequency of the carrier signal in the MAIN section of the function generator along with the FREQUENCY and MODULATION controls in the MODULATION section.

Observe the results on the oscilloscope.

1-9. Change the shape of the modulating signal by pressing either the square wave or triangle wave buttons on the MODULATION section of the function generator.

Observe the results on the oscilloscope.

1-10. Set the function generator as follows:

a. MAIN generator: 100 kHz, 8 Vpp sine wave

b. MODULATION generator:

MODULATION - Sine wave, FM
MODULATION control - fully CW or MAX
RANGE - 10k
FREQUENCY -1 kHz (Use an oscilloscope, frequency counter, or Model 440 internal counter.)

1-11. Ensure that the MAIN output of the function generator is still connected to the oscilloscope.

You should be viewing a 100 kHz signal that is frequency modulated with a 1 kHz signal.

Now, let's calculate some of the characteristics of the waveform. The Nida Model 440 Function Generator allows a maximum deviation of 5% of the MAIN generator output frequency. Since the frequency is set to 100 kHz, the maximum deviation is therefore 5 kHz. (If not using the Nida Model 440 function generator, use 5 kHz anyway for the maximum deviation.)

By rotating the MODULATION control fully CW in Step 10b, you adjusted the amplitude of the modulating signal to produce the maximum deviation. With this in mind, calculate the values called for in Step 12.

1-12. Calculate the following characteristics of the displayed waveform. Use the formulas in the lesson and Table 1.

a. What is the modulation index? ____________

b. How many sidebands are produced? ____________

c. What is the bandwidth of the FM signal? ____________

d. Which sideband has the most power? ____________

1-13. Turn off power to the function generator and oscilloscope and disconnect cables. Return all equipment to the designated storage area if not continuing on to Part 2.

Part 1 Analysis

In this part of the experiment, you have observed an FM modulated signal and calculated some of its characteristics. You should have seen that:

- An FM signal is a carrier signal that is frequency modulated.
- The modulating signal is the information.
- Changing the frequency of the modulating signal only changes the deviation rate.
- Changing the amplitude of the modulating signal only changes the amount of deviation.

PART 2. MODULATOR AND DEMODULATOR CIRCUITS

In this part of the experiment, you will construct a prototype modulator and demodulator circuit. The function generator will be used to input a modulating signal. The modulator circuit produces the center frequency.

Part 2 Equipment Required

Test Console
PC130-130X
Function Generator
Oscilloscope
FM Parts Kit
BNC to BNC Cable
Frequency Counter (Optional)

Part 2 Preparation

Figures 19 and 20 are the circuits that you will construct on the PC130-130X card. Notice that these circuits are identical to the ones studied in the lesson, only this time component values are added. Refer to Figures 19 and 20 during the experiment steps.

Figure 19 is a basic reactance modulator circuit. The center frequency of the carrier signal is developed by the Hartley oscillator circuit consisting of Q2 and the tank circuit of C7 and L2/L3 along with the capacitance of the reactance circuit developed by C3, R2, and Q1. The information signal is applied to Pin E on PC130-130X and is used to change the capacitance of the C3, R2, Q1 circuit that is in parallel to the oscillator. This action changes the resonant frequency producing frequency modulation.

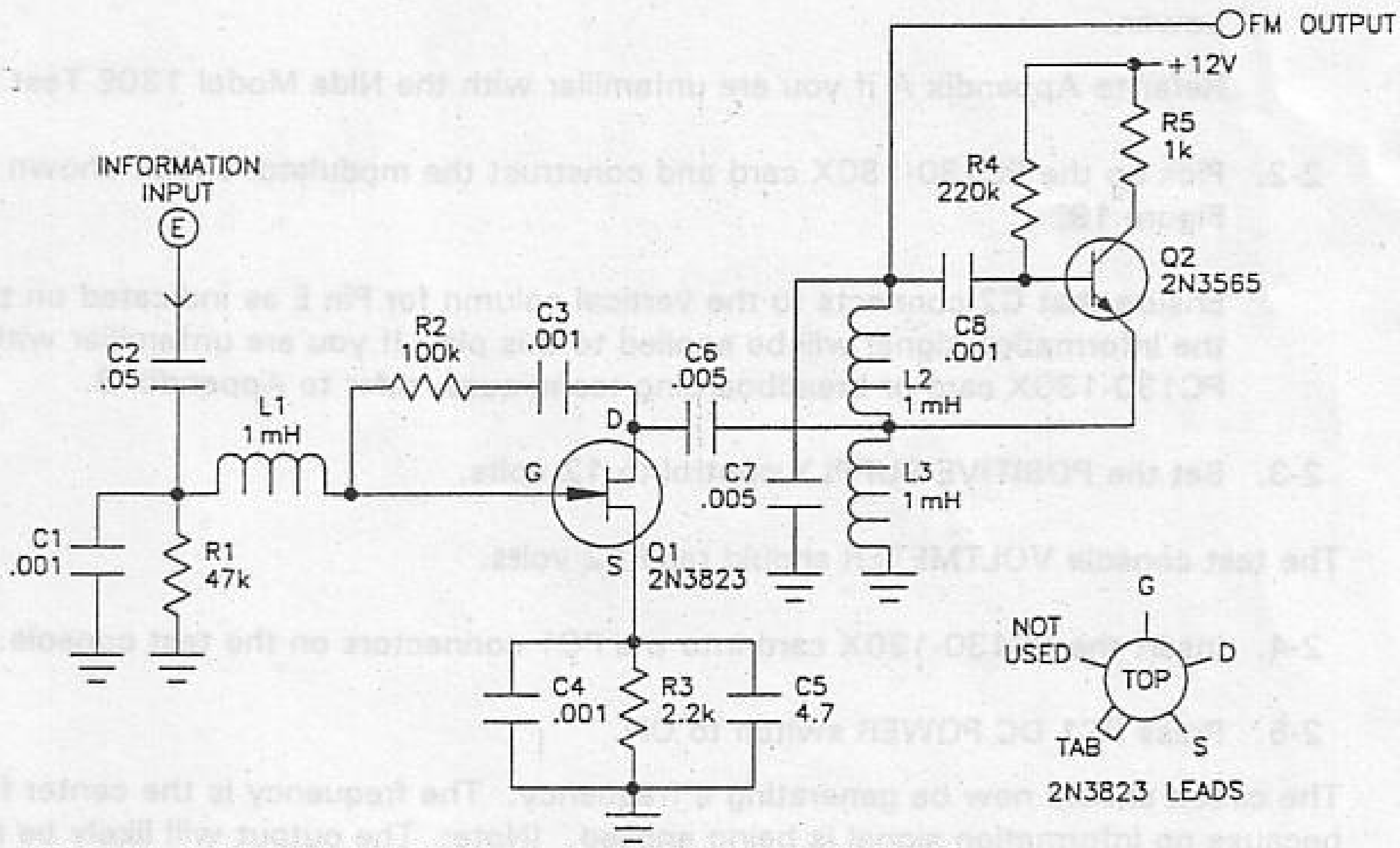


Figure 19. Reactance Modulator Circuit

Figure 20 is a basic slope demodulator circuit. T1 is a 455 kHz transformer used as C1/L1 and C2/L2 in Figure 12. C2 is used to change the frequency of T1 to match the output frequency of the modulator circuit. T1 was used because this part is inexpensive and readily available. C2 is also used to place the carrier frequency at the mid point of the response curve. Components D1, R2, and C3 operate as an AM diode demodulator which recovers the information signal.

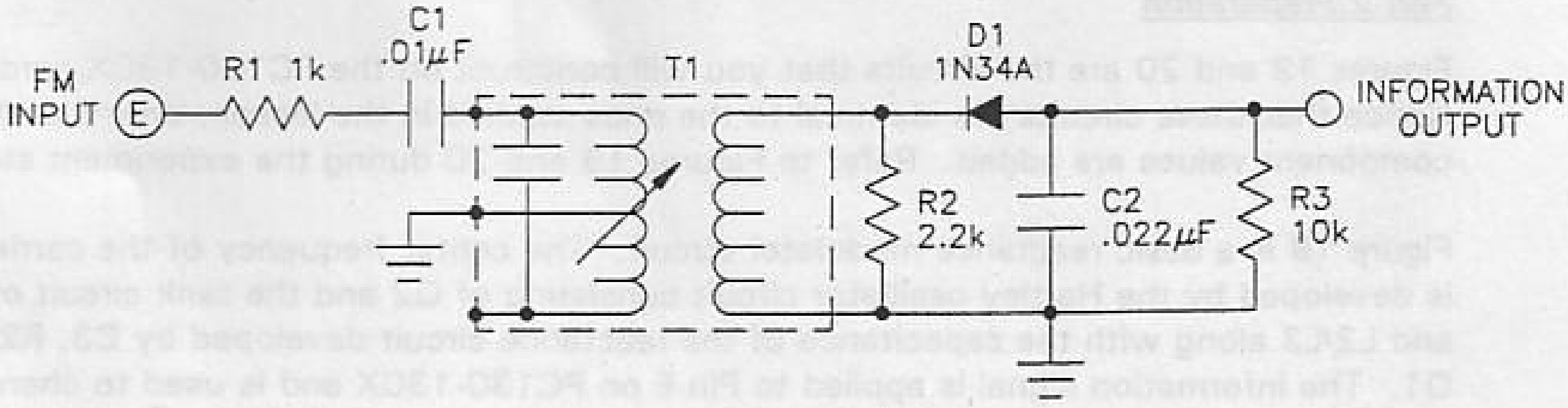


Figure 20. Slope Demodulator Circuit

Part 2 Procedure

2-1. Set the test console POSITIVE and NEGATIVE controls to OFF and turn on the main power.

Refer to Appendix A if you are unfamiliar with the Nida Model 130E Test Console.

2-2. Pick up the PC130-130X card and construct the modulator circuit shown in Figure 19.

Ensure that C2 connects to the vertical column for Pin E as indicated on the card, the information signal will be applied to this pin. If you are unfamiliar with the PC130-130X card or breadboarding techniques, refer to Appendix B.

2-3. Set the POSITIVE SUPPLY control to 12 volts.

The test console VOLTMETER should read 12 volts.

2-4. Insert the PC130-130X card into the PC1 connectors on the test console.

2-5. Press PC1 DC POWER switch to ON.

The circuit should now be generating a frequency. The frequency is the center frequency because no information signal is being applied. (Note: The output will likely be noisy due to the lack of input signal, but this will not affect the center frequency.)

2-6. Measure and record the output frequency using an oscilloscope or frequency counter if available.

f_c = ______________

The signal present on the output should be a sine wave at a center frequency determined by the component values -- no information signal applied. If there is no output frequency, check your circuit construction against the schematic shown in Figure 19. Ensure that there are no shorts or opens and ensure that you have connected the transistors to the circuit correctly. If there is a center frequency but it is not very close to the frequency given in the answer guide, do not worry! Component tolerances can cause shifts in the frequency and the frequency given in the answer guide is nominal.

2-7. Disconnect the output of the reactance circuit from the Hartley oscillator. (Remove C6 from the circuit.)

Notice that the carrier frequency changed. By disconnecting the reactance circuit, you removed some parallel capacitance from the tank circuit of the oscillator. You are observing how the reactive circuit affects the frequency output of the entire modulator.

2-8. Re-connect the output of the reactance circuit to the Hartley oscillator. (Place C6 back into the circuit.)

The signal observed should be the same frequency as you measured in Step 6.

2-9. Set up the function generator MAIN output for a 1 kHz sine wave output. Ensure that all the MODULATION controls are disengaged.

2-10. Connect the main output of the function generator to the INPUT SIGNAL BNC on the test console. Use a BNC to BNC cable.

2-11. Using the oscilloscope, observe the signal on the output of the modulator circuit.

The signal is now an FM waveform. Notice how the frequency is changing. Ensure that the amplitude control on the function generator has no attenuation and is above the minimum setting.

2-12. Vary the output amplitude of the function generator and observe the change in the output waveform.

You should see that the frequency deviation changes according to the amplitude of the information signal.

2-13. Vary the output frequency of the function generator and observe the change in the output waveform.

You should see that the frequency deviation stayed the same but the deviation rate changes.

Notice how this circuit operates just like the function generator did in Part 1 of this experiment. The reactance modulator caused the parallel capacitance of the tank circuit to change according to the amplitude of an information signal input. The more positive the input, the harder Q1 conducts decreasing the internal resistance. Decreasing the resistance increases the capacitance of the C3, R2, Q1 circuit. This increase in capacitance increased the capacitance of the tank circuit, lowering the frequency from the center frequency.

2-14. Turn off the function generator and disconnect the oscilloscope.

2-15. Press PC1 DC POWER to off and carefully remove PC130-130X card from the PC1 position.

2-16. Disassemble the modulator circuit and construct the demodulator circuit as shown in Figure 20.

Construct the circuit with a connecting wire between the output of T1 and the input to D1. Also, place T1 between the upper and lower section of the breadboard card. This will make circuit construction easier. Also, make sure that the input to the circuit connects to Pin E.

2-17. Insert the PC130-130X card into the PC1 connectors on the test console.

2-18. Turn on the function generator. Set the main output to a frequency of 450 kHz.

The resonant frequency of the transformer is approximately 455 kHz. Setting up the output of the function generator for 450 kHz allows tuning T1 to place 455 kHz on the mid point of the response curve.

2-19. Disconnect the output of T1 to the AM detector circuit (input to D1).

2-20. Connect the oscilloscope to the output of T1.

2-21. Adjust T1 for a peak output at the function generator's output frequency.

A peak indication is obtained by adjusting T1 to the maximum signal amplitude, where any further adjustment causes a decrease in signal amplitude.

2-22. Vary the frequency of the function generator around the set frequency.

You should see the amplitude of the output signal increase when the frequency of the function generator approaches 455 kHz and decrease as the frequency of the function generator rises above or falls below 455 kHz. This illustrates that the carrier signal has been adjusted to the mid point of T1's response curve.

2-23. Re-connect the output of T1 to the AM detector circuit, D1.

2-24. Adjust the frequency of the function generator to 455 kHz.

2-25. Frequency modulate the output signal by placing the generator's controls as follows:

a. RANGE - 10k
b. MOD - mid position
c. FREQUENCY - mid position
d. MODULATION - FM, sine wave

2-26. Connect the oscilloscope to the output of the detector.

You should see a sine wave output at the low modulating frequency.

2-27. Vary the MOD and FREQUENCY controls in the modulation section of the function generator. Observe the results.

You should observe the same results as you did in Part 1 of this experiment. Notice that when the information input signal frequency increased, the output information signal frequency increased. This is due to the increase of the deviation rate when frequency modulation is used. Also, when the amplitude of the information input signal increased, the output information signal amplitude increased. This is due to the amount of frequency deviation when frequency modulation is used.

2-28. Disconnect the oscilloscope and function generator.

2-29. Remove PC130-130X from the PC1 position.

2-30. Disassemble the demodulator circuit. Retain all components for further use.

2-31. Return the test console POSITIVE and NEGATIVE SUPPLY controls to OFF and turn main power off. Return all equipment to the designated storage areas.

Part 2 Analysis

In this part of the experiment, you constructed an FM modulator and demodulator circuit. You should have seen that:

- A modulator circuit combines two signals to produce an FM waveform.
  - The high frequency signal is the carrier and is used to send the information.
  - The lower frequency is the information or modulation signal, it is used to frequency modulate the carrier signal.
  - The center frequency is generated in the modulator circuit.
  - The amplitude of the information signal changes the capacitance of a tank circuit producing frequency modulation.

- A demodulator circuit separates the information, or modulating, signal from the carrier signal.
  - The FM signal is changed to an AM signal in a slope demodulator.
  - The AM signal is then passed to a AM diode demodulator where the information signal is recovered.

SUMMARY

This lesson introduced you to the principles and circuits of frequency modulation, FM. Here are some of the major points about the lesson that you should remember and review.

- Frequency modulation is a signal processing technique.
- Frequency modulation changes a carrier signals frequency according to the amplitude variations of an information, modulating, signal.
- The information signal is contained in the sidebands of the carrier signal.
- The characteristics of FM waveforms are:
  - Carrier frequency - must be larger than the information signal highest frequency. Must be able to include the multiple sideband frequencies.
  - Modulation Index and Deviation Ratio - is a different method to measure modulation as compared to AM's percent modulation.

$$\text{Modulation Index} = \frac{f_d}{f_m}$$

Where: f_d is the frequency deviation or amount of frequency change, and f_m is the modulating frequency

$$\text{Deviation ratio} = \frac{f_{dMAX}}{f_{mMAX}}$$

Where: f_{dMAX} is the maximum deviation, and f_{mMAX} is the maximum frequency of the modulating signal

  - Sidebands - the FM waveform is actually made up of many frequencies, the number of sidebands depend on the modulation index. The carrier frequency can have less power than certain sideband frequencies. Refer to Figure 3, Table 1, and Graph 1.
  - Bandwidth - The bandwidth of an FM signal depends on the number of significant sidebands. Table 1 lists some of the significant sidebands for each modulation index.

$$BW = f_m \times \text{number of sidebands} \times 2$$

Where: BW is bandwidth and f_m is the modulating frequency

  - Noise - FM is less noisy than AM because the information is in frequency variations not amplitude variations.
  - Power - There is more information power in FM waveforms because of the power levels of sidebands as shown in Figures 3, 4, and 5.

- Phase Modulation is almost identical to frequency modulation. You cannot have a phase change without a frequency change and you can not have a frequency change without a phase change.
  - Figure 6 compares two types of modulating signals for frequency modulation and phase modulation.
  - Phase modulation is used in digital circuits but not used for voice or music transmissions due to the inability to detect small phase difference (hardware limitation).

- Modulator Circuits
  - Located in the transmitter. Causes frequency variations in a carrier signal according to amplitude variations in an information signal.
  - Reactance - uses a parallel capacitance circuit that capacitance is changed by an information signal amplitude. The change occurs because of the internal resistance of a transistor in the parallel circuit. The capacitance is part of an oscillator circuit.
  - Varactor or VCO - works on same principle of the reactance modulator but uses a varactor component. A varactor diode changes capacitance based on the reverse bias voltage. Changing the reverse bias voltage changes the capacitance which is part of an oscillator.
  - Integrated Circuit VCO - same as a discrete component VCO but constructed in a chip.

- Demodulator Circuits
  - Located in the receiver and used to separate the carrier signal from the information signal.
  - Slope - Uses the frequency response curve of a LC circuit to change a frequency modulated signal into an amplitude modulated signal. Then a AM detector is used to recover the information signal.
  - Discriminator - Uses the amount of conduction of two diodes to set an output voltage. Conduction of diodes depends on the frequency of the input signal. When at f_c, two diodes conduct the same. The difference in voltages across two resistors determines information signal.
  - Ratio - Uses the same principle of operation as the discriminator but output circuit is different, a capacitor holds the output voltage to a constant level and the charges on two capacitors develop the information signal.

♦ Demodulator Circuits, continued

- Integrated Circuit Phase-Locked Loop - this circuit uses the advantages of integrated circuits to construct a very complex circuit in a simple package. PLL circuits contain a phase comparator, filter, amplifier, and a VCO. The VCO frequency is compared to the incoming FM signal and any difference is used to develop an error voltage. This voltage is filtered and amplified and applied to the VCO, which will then change its frequency. The process continues since an FM signal is always changing frequency and the result is that the error signal is a representation of the information signal.

♦ Troubleshooting transmitter and receiver circuits is no more difficult than troubleshooting other circuits.

TEST

Read each question carefully. Write the correct answer in the blank space provided.

_________ 1. What characteristic of a carrier signal is changed for FM signal processing?

a. Phase
b. Frequency
c. Amplitude
d. Modulation

_________ 2. What characteristic of a carrier signal is changed for PM signal processing?

a. Phase
b. Frequency
c. Amplitude
d. Modulation

_________ 3. What is the modulation index of an FM signal that has a deviation of 25 kHz and an information signal of 10 kHz?

a. 250
b. 25
c. 10
d. 2.5

_________ 4. If an FM signal has a modulation index of 4.0, how many significant sidebands are there? (Refer to Table 1.)

a. 5
b. 6
c. 7
d. 8

_________ 5. If an FM signal has a modulation index of 5.0 and a modulating frequency of 4 kHz, what is the bandwidth?

a. 64 kHz
b. 32 kHz
c. 8 kHz
d. 4 kHz

________ 6. If an FM signal has a modulation index of 6.0, which sideband produces the most power? (Refer to Table 1.)

a. 3rd
b. 4th and 5th
c. 5th and 5th
d. 1st and 9th

________ 7. What type of modulator circuit uses a component that changes its capacitance according to the voltage applied?

a. Ratio
b. Slope
c. Reactance
d. Varactor

________ 8. What type of modulator circuit uses a circuit that changes its capacitance according to the voltage applied?

a. Ratio
b. Slope
c. Reactance
d. Varactor

________ 9. What type of demodulator circuit uses the phase difference between two signals to develop the information signal?

a. PLL
b. Slope
c. Ratio
d. Discriminator

________ 10. What type of demodulator circuit uses the response curve of a tuned circuit to develop the information signal?

a. PLL
b. Slope
c. Ratio
d. Discriminator