Experiment 6: Amplitude Modulation, Modulators, and Demodulators

Fall 2009

Double Sideband Amplitude Modulation (AM)

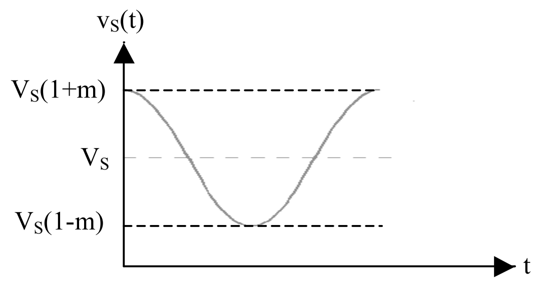

Figure 1 – Sinusoidal signal with a dc component

In double sideband modulation (the usual AM) a dc component is added to the signal voltage before the signal is multiplied by a carrier. If the signal were a simple sinusoid, it would have the form:

$$v_S(t) = V_S\,(1 + m \cos \omega_s t) \qquad (1)$$

where V_S is the dc component, $\omega_s = 2\pi f_s$ is the signal frequency, and m is known as the modulation index. This waveform is shown in Figure 1. To avoid distortion in recovering the modulating signal with a simple demodulator, the modulation index, m, is constrained to lie in the range zero to one.

In AM, the carrier signal has the form:

$$v_C(t) = V_C \cos \omega_c t \qquad (2)$$

where ω_c is the carrier frequency in radians/sec. The carrier frequency, ω_c, is usually much greater than the signal frequency.

The modulated signal is then:

$$v_m(t) = A\, v_S(t)\, v_C(t), \qquad (3)$$

where A is a scale factor that depends on the equipment used for modulation. Using equations (1) and (2) we can write

$$v_m(t) = AV_CV_S\,(1 + m \cos \omega_s t) \cos \omega_c t \qquad (4)$$

$$v_m(t) = AV_CV_S \cos \omega_c t + \frac{AV_CV_S m}{2}[\cos(\omega_c + \omega_s)t + \cos(\omega_c - \omega_s)t] \qquad (5)$$

Equation (5) was obtained from equation (4) by using the trigonometric identity for the product of two cosines.

$$v_m(t) = V_m \cos\omega_c t + \frac{V_m m}{2}[\cos(\omega_c + \omega_s)t + \cos(\omega_c - \omega_s)t] \qquad (6)$$

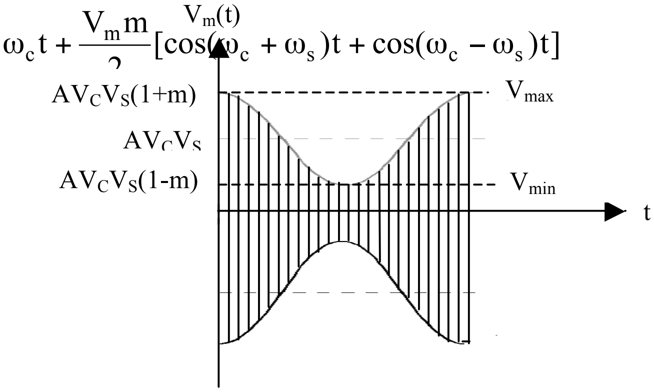

Figure 2 – Modulated signal vs. time

Figure 2 shows the modulated signal of equations (5) or (6) as a function of time. The waveform above zero is produced by the positive values of cos $\omega_c t$ while the values below zero are the result of negative values of cos $\omega_c t$. Notice that the modulation index can be obtained by measuring V_{max} and V_{min}. That is

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \qquad (7)$$

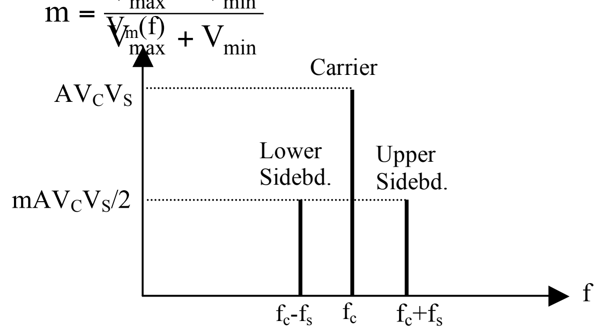

Figure 3 – Frequency components of the modulated signal

Figure 3 shows the frequency components of the modulated double sideband signal. It is evident from equation (6) that the modulated signal has a carrier component and upper and lower sidebands at the sum and difference frequencies, ($f_s + f_c$) and ($f_s - f_c$). Note that the largest values the sidebands can have relative to the carrier occurs when m = 1. This is referred to as 100% modulation and the sidebands are each half as large as the carrier.

Double Sideband Suppressed Carrier Modulation

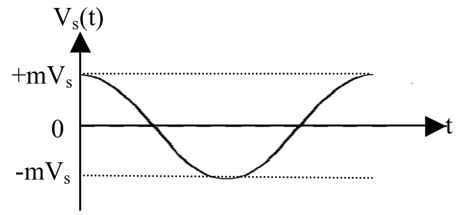

Figure 4 – Sinusoidal signal with no dc component

A double sideband suppressed carrier signal has no dc component added to the signal so that

$$v_s(t) = mV_S \cos \omega_s t \tag{8}$$

The modulated signal is the product of the modulating signal of equation (8) and the carrier with the result

$$v_m(t) = mAV_C V_S \cos \omega_s t \cos \omega_c t \tag{9}$$

or

$$v_m(t) = \frac{mAV_S V_C}{2}[\cos(\omega_c + \omega_s)t + \cos(\omega_c - \omega_s)t] \tag{10}$$

Comparing this equation to equation (6) for the case of AM with carrier, we see that equation (10) has no carrier frequency term.

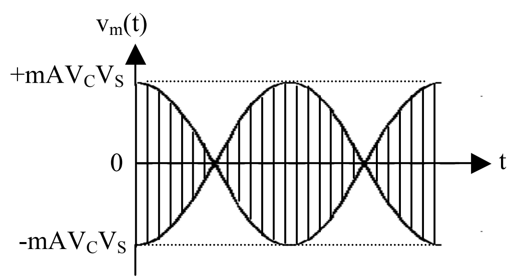

Figure 5 – Suppressed carrier modulated signal vs. time

Figure 5 shows the suppressed carrier signal of equation (10) as a function of time. The positive lobe from 0 to 90^o is produced by the product of a positive carrier and a positive signal, while the positive lobe from 90^o to 270^o is produced by the product of a negative carrier and a negative signal, etc. Notice that there is no envelope of the original modulating signal in the modulated signal as there is in double sideband AM with carrier.

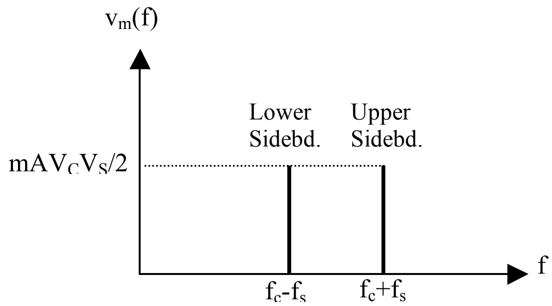

Figure 6 – Frequency components of suppressed carrier signal

The modulated signal as a function of frequency is shown in Figure 6. With no component at the carrier frequency, the transmission power requirements are lower than for AM with carrier.

Modulators

As was emphasized in the previous sections, the modulation process is essentially multiplication of one signal with another. In the earlier days of the electronic art, analog multipliers were relatively inaccurate and had limited capability and so methods were employed using non-linear circuit methods. Presently, analog multipliers can be constructed utilizing the matched characteristics of transistors fabricated with integrated circuit techniques. At low power levels, amplitude modulation can be done by straightforward multiplication of one signal by another.

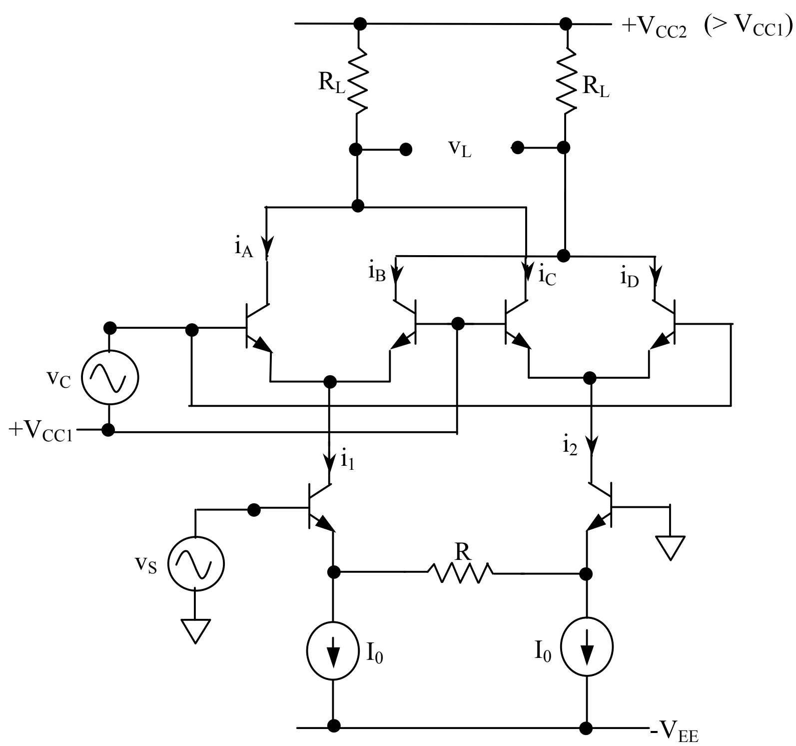

Figure 7 – Modulator based on transconductance multiplier principle

Figure 7 shows an AM modulator that uses the variable transconductance of transistors to effectively obtain multiplication.. In a transistor with collector current, i_C, the transconductance is qi_C/kT. Referring to Figure 7, the modulating signal is $v_S = V_S \cos \omega_s t$, while the carrier signal is $v_C = V_C \cos \omega_c t$. The modulating signal causes the currents i_1 and i_2 to have the values and defining transconductances g_{m1} and g_{m2}.

$$i_1 = I_0 + \frac{v_S}{R} \qquad i_2 = I_0 - \frac{v_S}{R} \tag{11}$$

$$g_{m1} = q\, i_1/kT \qquad g_{m2} = q\, i_2/kT \tag{12}$$

we have

$$i_A = \frac{I_0}{2} + \frac{g_{m1}}{2} v_C \qquad i_B = \frac{I_0}{2} - \frac{g_{m1}}{2} v_C \qquad i_C = \frac{I_0}{2} - \frac{g_{m2}}{2} v_C \qquad i_D = \frac{I_0}{2} + \frac{g_{m2}}{2} v_C \tag{13}$$

Since

$$v_L = (i_A - i_B + i_C - i_D)\, R_L = (g_{m1} - g_{m2})\ (V_C) R_L \tag{14}$$

then

$$v_L = (qV_S/kT)(V_C/R)(R_L)(\cos \omega_s t)(\cos \omega_c t) \tag{15}$$

which is a double sideband suppressed carrier AM signal. To generate a double sideband AM signal with carrier, the two dc current sources can be unbalanced (by means not shown). If the two currents are I_{01} and I_{02}, the resulting modulated signal is

$$v_L = [q(I_{01} - I_{02})/kT + (qV_S/kT)(1/R)(\cos \omega_s t)]\, (R_L)(V_C \cos \omega_c t)\ , \tag{16}$$

which is an AM double sideband signal with carrier, where

$$m = V_S/(I_{01} - I_{02})(R)\ , \quad \text{and} \quad \text{carrier amplitude} = [q(I_{01} - I_{02})/kT](R_L V_C)\ . \tag{17}$$

Other means are available to implement an AM modulator. In instrumentation applications, switches are often used. The circuit of Figure 8, for example, produces a

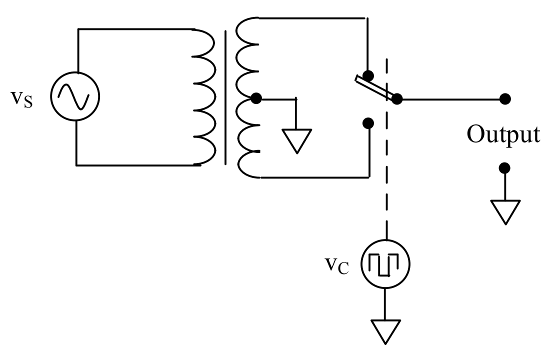

Figure 8 – Suppressed carrier modulator

suppressed carrier AM output. The function of the voltage v_C is to drive the switch to its two alternate positions at the carrier frequency rate. In the output there would be a square wave carrier instead of the usual sinusoid; however, the higher harmonics of the square wave carrier could readily be eliminated by filtering.

Demodulators

Several methods can be used to demodulate an AM double sideband signal with carrier. Perhaps the simplest is the 'peak detector'. Figure 9 shows the circuit. As is evident, the capacitor

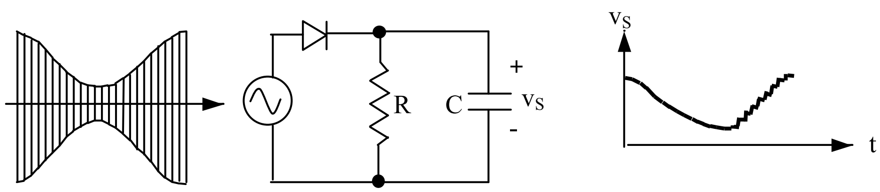

Figure 9 – Peak or envelope detector

charges on the rising part of the waveform and discharges on the falling part of the waveform. Two types of distortion that appear in the demodulated output, v_S of Figure 9, are carrier ripple on the rising edge and, possibly, an exponential decay instead of a sinusoidal variation on the falling edge if the RC time constant is too long. Nevertheless, the peak detector is widely used.

An alternative to peak detection is rectification with low pass filtering to remove the carrier and its harmonics. In this demodulation method the failure to follow distortion of the peak detector is not a problem.

If the carrier signal is available at the demodulator, AM signals, either suppressed carrier or with carrier can be demodulated by multiplying and low pass filtering. For the suppressed carrier case, for example, the product is

$$v_I(t) = AV_CV_S\, m \cos \omega_s t \cos^2 \omega_c t \tag{18}$$

or

$$v_I(t) = \frac{AV_CV_Sm}{2} \cos \omega_s t(1 + \cos 2\omega_c t) \tag{19}$$

The original signal is then recovered with appropriate filtering.

Experiment

Equipment List

1 HP 3580A Spectrum Analyzer
1 HP 33120A Function Generator
1 HP 3312A Function Generator
1 Solderless Wiring Fixture
Assorted Active Components
Assorted Passive Components

Procedure

The first thing to do is to set up the Hp 33120A function generator for external amplitude modulation. Bring up the menu. (See The Appendix to this manual for instructions about the menu-driven features of the Hp33120A.) The display should show A:MOD MENU. Use the ∨, then the > button to obtain 2:AM SOURCE. Next, press the ∨ button to display EXT/INT and then use the > button to obtain EXT on the display. Press ENTER and the unit should return to its default state. If, now, SHIFT AM is pressed, the AM Ext in small letters should show on the display and the generator can now produce an AM output by applying a modulating input from the HP 3312A function generator to the BNC connector in the center of the bottom rack panel. Note that if the generator is turned off and then turned back on, its state will be the default one and obtaining the AM Ext state will require going through the same menu commands again.

Another point to notice is that the 33120A, when in the AM Ext state, develops an output that is the product of the modulation input from the HP 3312A and the carrier which the HP33120A generates internally. So, to get a true AM output with carrier requires that the modulating signal have a DC component, which is available on the HP 3312A front panel.

Set the carrier from the HP 33120A generator at 20 kHz, 2V peak-to-peak, sine wave and apply this signal to the oscilloscope and the spectrum analyzer. The spectrum analyzer should be set on a linear frequency scale with a center frequency of 20 kHz. Set the modulation signal from the HP 3312A generator to a 500 Hz sine wave, 0V offset, and apply it to the other channel of the oscilloscope and the modulation input of the HP 33120A generator. Trigger the scope on the signal from the HP 3312A generator.

1. Double Sideband Amplitude Modulation with Carrier Set-Up

1(a). Set the modulating signal (v_S) from the HP 3312A function generator to 5V peak-to-peak and observe the modulated signal from the HP33120A on the scope. Note that it looks like the Double Sideband Modulated Signal shown in Figures 2. Use cursors to measure V_{max} and V_{min} and calculate the percent modulation per Equation (7). Note that the HP33120A is adding an offset voltage to the modulating signal coming from the HP3312A. Also observe the modulated signal on the Spectrum Analyzer and compare it to the FFT on the scope. Copy the FFT display.

1(b) Now adjust the modulating signal from the HP3312A to 10V peak-to-peak and adjust as required the DC offset from the HP 3312A to very near 0V and observe that the modulation is nearly 100%. Adjust the peak-to-peak modulating voltage until 100% modulation is achieved and estimate the offset voltage being added to the modulating signal by the HP33120A. Also observe the modulated signal on the Spectrum Analyzer and compare it to the FFT on the scope. Copy the FFT display.

2. Double Sideband Modulation with Suppressed Carrier Set-Up

At a sinusoidal modulation frequency of 500 Hz and 100 percent modulation as obtained in part 1(b), adjust only the DC Offset voltage of the HP 3312A generator so as to obtain a double sideband, suppressed carrier, modulated voltage signal as shown in Figure 5. Note that the DC offset voltage being added by the HP 33120A is the negative of the DC Offset being provided by the HP 3312A. Also observe the modulated signal on the Spectrum Analyzer and compare it to the FFT on the scope. Copy the FFT display.

3. Double Sideband Modulation Testing

3(a) Now reset the DC Offset voltage from the HP 3312A to near 0V and vary the amplitude of the modulation signal from the HP 3312A and observe how this affects the waveform of the modulated signal on the oscilloscope and the frequency components of the modulated signal on the spectrum analyzer. Observe the modulated signal on the Spectrum Analyzer and compare it to the FFT on the scope. Record and copy these observations as required.

3(b) Reset the peak-to-peak amplitude to 5V and vary the frequency of the modulation signal (200, 500, & 1000Hz) and observe how this affects the waveform and frequency components of the modulated signal. Observe the modulated signal on the Spectrum Analyzer and compare it to the FFT on the scope. Record and copy these observations as required.

3(c) Now vary the DC offset of the HP 3312A and observe the output of the HP 33120A. Take data sufficient to establish a quantitative relation between the HP 33120A peak output magnitude and the DC offset of the HP 3312A generator. Also observe the modulated signal on the Spectrum Analyzer and compare it to the FFT on the scope. Record and copy these observations as required.

4. Square Wave Modulation Testing

4(a). At a square wave modulation frequency of 1 kHz, vary the modulation amplitude to obtain 100 percent modulation. Record the waveform and frequency components of the modulated signal. Also observe the modulated signal on the Spectrum Analyzer and compare it to the FFT on the scope. Record and copy these observations as required. Repeat for 50 percent modulation.

4(b). At a square wave modulating frequency of 1 kHz and 100% modulation, change the DC offset of the HP 3312A generator to obtain a double sideband, suppressed carrier, modulated voltage. Record the waveform and FTT spectrum of the modulated voltage.

5. Demodulation of AM Signals

5(a). The circuit of Figure 10 has been made up on a solderless breadboard. This circuit functions as a precision full wave rectifier without the effects from the diode offset that occur in the conventional 4 diode bridge. We will use this circuit to demodulate the double side band amplitude modulated signal from part 1(b) above. This signal should have a carrier frequency of 20 kHz and be 100 percent modulated in the frequency range from 200 to 1000 Hz. The demodulation circuit must reproduce the amplitude and frequency of the modulation signal with minimum distortion. To do this, a low pass filter circuit is connected at the output of the precision rectifier. A resistor R = 3kΩ and a capacitor C= 0.05μF are recommended. The output of the low pass filter circuit should ideally be the original modulating signal with maximum amplitude and minimum carrier ripple. For 100% amplitude modulation of a sinusoidal signal, record and compare the modulation signal and the resulting demodulation waveform at 200, 500 and 1000 Hz.

5(b). Repeat for triangle wave modulation.

5(c). Repeat for square wave modulation.

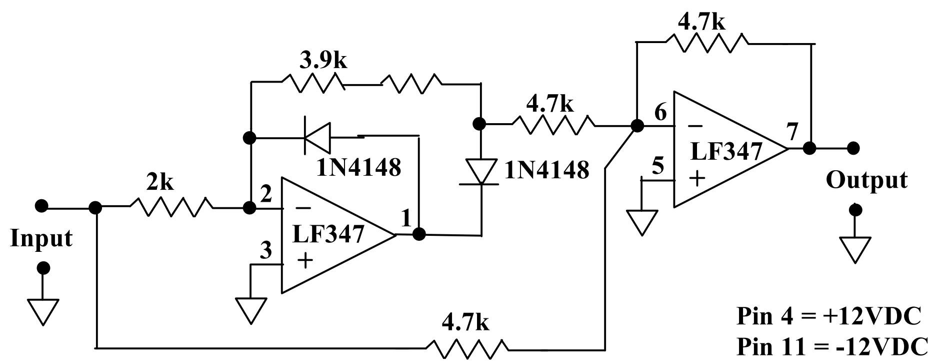

Figure 10 – Precision full wave rectifier

Report

1. Double Sideband Modulation with Carrier Set-Up

1(a) Present the results for the AM signal obtained for the $5V_{p\text{-}p}$ modulation signal and also its FFT. What is its percent modulation? What are the relative amplitudes of the sideband and carrier voltages? With reference to this waveform and Figure 5, calculate the value of "A" for the HP33120A Function Generator.

1(b) Present the results for the AM signal obtained with the $10V_{p\text{-}p}$ modulation signal and also its FFT. Did you obtain 100% modulation? Did you have to adjust the modulation signal offset voltage to get a true 100% modulation? What are the relative amplitudes of the sideband and carrier voltages?

1(c) Explicitly derive a formula for the height of the sidebands relative to the carrier of a sine wave amplitude modulated signal with carrier signal. In a table, compare the theoretical values to those obtained experimentally for 50% and 100% modulation.

2. Double Sideband Modulation with Suppressed Carrier Set-Up

2(a). Present the results for the AM signal obtained with 100% modulation and also its FFT. Did you obtain 100% modulation? Did you have to adjust the modulation signal offset voltage to get a true 100% modulation? What DC offset voltage did you have to add to obtain 100% modulation.

2(b) What is the RMS value of the 100% modulated signals with carrier in part 1(b) and with suppressed carrier in part 2(a)? What can you conclude about the power required for double sideband (ordinary amplitude modulation) transmission compared to double sideband, suppressed carrier transmission?

3. Double Sideband Modulation Testing

3(a). Present the results of varying the amplitude of the modulation signal. Describe the effects on the waveform and spectrum of the modulated signal. Does the 33120A give an output that is linearly related in amplitude to the modulating input?

3(b). Present the results of varying the frequency of the modulation signal. Describe the effects on the waveform and spectrum of the modulated signal.

3(c). Present the results of varying the DC offset of the modulation signal. Describe the effects on the waveform and spectrum of the modulated signal.

4. Square Wave Modulation Testing

4(a) Present the results of varying the amplitude of the square wave modulation signal. Describe the effects on the waveform and spectrum of the modulated signal. Does the 33120A give an output that is linearly related in amplitude to the modulating input? Also, explicitly derive a formula like Equation (6) for the sideband amplitudes with square wave modulation. In a table compare your theoretical values to those obtained experimentally for 50% and 100% modulation.

4(b) Present the results of varying the DC offset of the square wave modulation signal to obtain the suppressed carrier. Describe the effects on the waveform and spectrum of the modulated signal. Also, explicitly derive a formula for the height of the sidebands of a square wave amplitude modulated double sideband suppressed carrier voltage. In a table, compare your theoretical values to those obtained experimentally.

5. Demodulation of AM Signals

5(a) Present the results for demodulation of 200, 500, and 1000Hz sinusoidal signals.

5(a) Present the results for demodulation of 200, 500, and 1000Hz triangle wave signals.

5(a) Present the results for demodulation of 200, 500, and 1000Hz square wave signals.

5(d) Compare your modulation and demodulation waveforms at 200, 500, and 1000 Hz modulation frequencies. Discuss the reasons for any difficulties you may have had in recovering the modulation signal. Neglecting carrier ripple on the demodulated signal and assuming an ideal diode with no offset, can a diode peak detector demodulate with no distortion the following AM signals?

(1) 50% sine wave modulation
(2) 100% sine wave modulation
(3) 100% triangle wave modulation
(4) 100% square wave modulation.

Explain, preferably with some analysis.

References

1. Adel S. Sedra and Kenneth C. Smith, **Microelectronic Circuits, 5th Edition,** (Oxford, New York, New York, 2004)
2. Alan V. Oppenheim and Alan S. Willsky, **Signals and Systems, 2nd Edition,** (Prentice Hall, Upper Saddle River, New Jersey, 1997)
3. M. Schwartz, **Information Transmission, Modulation, and Noise**, 2nd Ed. (McGraw-Hill, New York, 1972).
4. A. B. Carlson, **Communication Systems: An Introduction to Signals and Noise in Electrical Communication,** 2nd Ed. (McGraw-Hill, New York, 1975).
5. K. K. Clarke and D. T. Hess, **Communication Circuits, Analysis and Design,** (Addison-Wesley, Boston, 1971)