PRACTICAL ELECTRICITY AND ELECTRONICS

Fundamentals For Analog Communication: Frequency Division Multiplex

Volume 10

by

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Laboratory Exercise **1**

FREQUENCY DIVISION MULTIPLEXING TRAINER FAMILIARIZATION

Performance Objectives

A. Demonstrate the operation of the FREQUENCY DIVISION MULTIPLEXING TRAINER.

B. **Investigate the fundamentals of synchronous detection for amplitude modulation.**

Basic Concepts

1. Multiplex is the transmission of two or more channels of information by a single, composite signal.
2. A beat frequency oscillator (BFO) signal is a reference signal for a synchronous detector.
3. Frequency division multiplex channels occur at the same time but at different locations in the frequency spectrum.
4. Frequency division multiplex systems use separate subcarriers for each channel in a primary group.
5. Subcarriers in a primary group are suppressed.
6. A primary group consists of two or more channels of information. Each channel has a subcarrier with a different frequency.
7. A *mixer* adds and subtracts the *frequencies* of two signals applied to it.
8. A *summer* adds the *amplitudes* of two signals applied to it.

Introductory Information

Multiplex operation is the transmission of two or more signals separated by either frequency, phase, or time. There are two basic categories of multiplex operation: time division and frequency division multiplex.

Time division multiplex systems send two or more sets of information in tandem over a common channel: one set of information is sent at a time. The amount and how often the information is sent varies widely and depends upon the needs of the system. The *chop* mode on an oscilloscope is an example of time division multiplexing where channel 1 and channel 2 alternately control the trace. Electronic switching between channels is rapid, so that gaps in the trace caused by the off times are not observable.

Frequency division multiplex systems send two or more sets of information over the same channel at the same time. Figure 1-1 illustrates a telephone system using frequency division multiplex techniques to send multiple voice channels over a single pair of wires. Here, each voice channel is used to modulate a separate carrier. The first carrier is 8140kHz. The frequency of each additional carrier increases in 4kHz increments. The use of balanced modulators

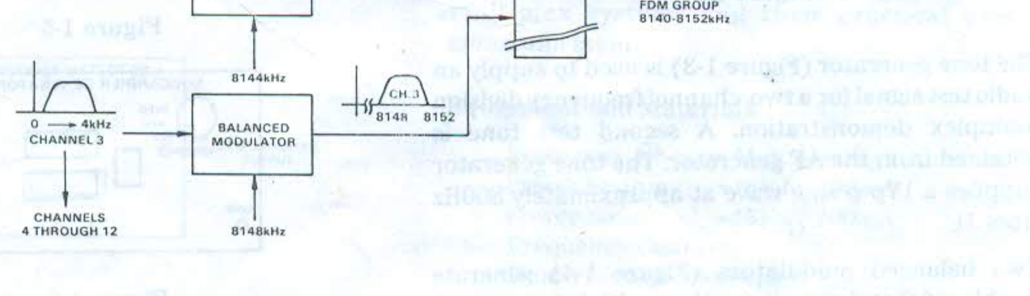

Figure 1-1

eliminates the carrier from the modulated signals. If the lower sideband is eliminated from the balanced modulator output as well, all that remains for each channel is a single, 4kHz-wide sideband. The three sidebands, which make up the three-channel FDM signal, will appear between 8140kHz and 8152kHz after the individual channels are combined in a summing amplifier.

A basic frequency division multiplex telephone system has twelve separate voice channels in its primary group. Fifty primary groups can be multiplexed together into one master group for a total of 600 voice channels. By expanding these basic multiplexing techniques, tens of thousands of voice channels are sent over a single transmission link.

In order to send thousands of channels over the same transmission link, primary groups of 12 channels are shifted in frequency and placed within larger groups. Techniques that shift multiplexed signals without distrubing their intelligence use mixers. Figure 1-2 shows the three-channel frequency division multiplexed signal from Figure 1-1 being down-converted (from its 8140- to 8152-kHz range) to between 96 and 108 kilohertz.

The FREQUENCY DIVISION MULTIPLEXING TRAINER consists of nine different circuits in eleven different blocks. Because multiplexing requires multiple channels of information, many circuits are repeated. For example, two balanced modulators, two product detectors, two post detection filters, and two predetection filters are located on the trainer. In addition to the preceding primary circuits and the SUMMING IF AMPLIFIER, support circuits are included on the trainer. These consist of a TONE GENERATOR, an FM GENERATOR, an FM DETECTOR, and a SUBCARRIER GENERATOR.

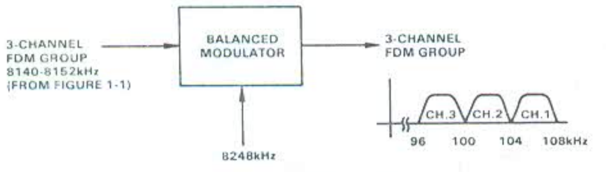

Figure 1-2

The tone generator (Figure 1-3) is used to supply an audio test signal for a two-channel frequency division multiplex demonstration. A second test tone is obtained from the AF generator. The tone generator supplies a 1Vp-p sine wave at approximately 800Hz from J1.

Two balanced modulators (Figure 1-4) generate double sideband signals for the multiplex system. A modulation signal applied to J2 will modulate a carrier applied to J3. The CARRIER ADJ control can be varied to cancel the carrier so that only sidebands of the carrier appear in the output at J4. For balanced modulator 2, a modulation signal can be applied to J5, the carrier to J6, and the output taken from J7.

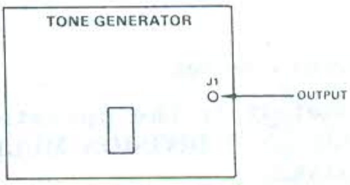

Figure 1-3

The summing amplifier (figure 1-5) is a summer. It is used to *add* (not multiply) the signals from the balanced modulators together. Input jacks J8 and J9 accept the AM or DSB (double sideband) signals, and their sum appears at J10.

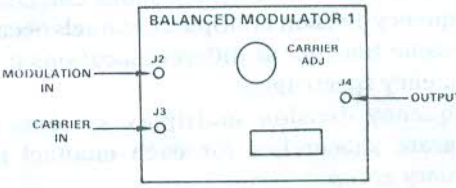

Figure 1-4

A subcarrier generator (Figure 1-6) supplies carriers for the balanced modulators. These square wave signals are available at J31, J32, and J33. The signal at J31 is always twice the frequency of the signals at J32 and J33. The phase between the signals at J32 and J33 is always 90 degrees, but their frequency is always the same. Experiments in this student manual use 10kHz and/or 20kHz carriers. The FREQ ADJ control is used

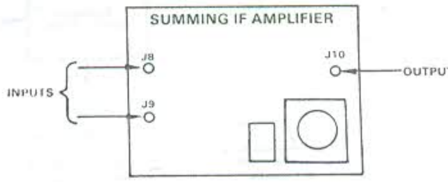

Figure 1-5

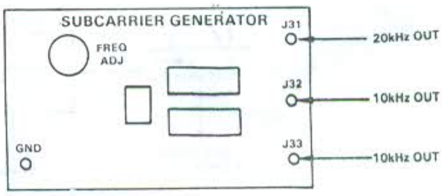

Figure 1-6

to set the output of the generator at J31 to 20kHz. J32 and J33 are the 10kHz signal outputs which are 90 degrees apart in phase but identical in frequency.

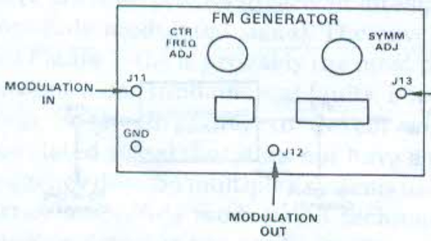

Figure 1-7

An FM generator (Figure 1-7) modulates a carrier by varying the frequency of that carrier. The modulation signal is applied to J11 and a modulated sine wave carrier is taken from J13. Carrier frequency is a nominal 200kHz and can be adjusted by the FREQ ADJ control. Another control, the SYMM ADJ, is used to adjust the carrier for minimum sine wave distortion. J12 is a test point for the amplified modulation signal.

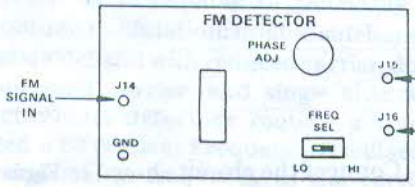

Figure 1-8

The FM detector (Figure 1-8) is a phase-locked loop circuit. It accepts a frequency modulated carrier from the FM generator circuit and demodulates it. The FM detector has a dual frequency range selected by the FREQ SEL slide switch. A high (HI) position centers the phase-locked loop free-running frequency around 200kHz. The low (LO) position places the center frequency at approximately 10kHz. The only other control is the PHASE ADJ potentiometer. It is used in the LO frequency range to shift the phase of a 10kHz test signal at its input (J14) approximately 20 to 160 degrees. The shifted signal is at J16. Frequency modulated input signals at J14 will be demodulated and appear at J15.

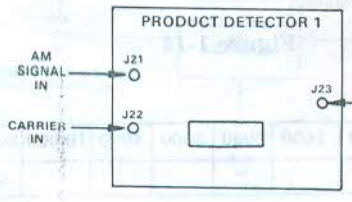

Figure 1-9

The FM generator and FM detector are used to send a frequency division multiplex signal over an RF link. They are the final two of the four support circuits on the frequency division multiplex trainer.

A pair of product detectors (Figure 1-9) are used to demodulate the 10kHz and 20kHz subcarrier signals. A modulated signal is applied to J21 and a carrier to J22. The demodulated output is available at J23. Note that a product detector can demodulate both AM and double- or single-sideband signals.

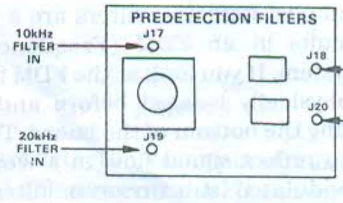

Figure 1-10

Predetection filters (Figure 1-10) are bandpass filters which are tuned to pass one of the subcarriers and reject the other. These filters have a gain of four for signals within their passband. The signal input is J17. The output is J18.

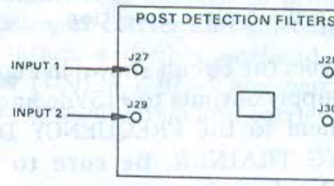

Figure 1-11

Post detection filters (Figure 1-11) are low pass filters used to remove high frequency noise and other products of detection from a product detector output. These active low pass filters attenuate frequencies above 4kHz.

Additional Reading

See the bibliography at the back of this manual for additional reading material on frequency division multiplex systems and their practical uses in communication.

Equipment and Materials

- Frequency Division Multiplexing Trainer
- Power Source *+15Vdc, 100mA*
- Power Source *–15Vdc, 100mA*
- Frequency Counter
- Dual Trace Oscilloscope
- AF Generator

Exercise Procedure

Objective A. Demonstrate the operation of the FREQUENCY DIVISION MULTIPLEXING TRAINER.

Preparatory Information

Before beginning an in-depth study of frequency division multiplex systems using the frequency division multiplexing trainer, you will become familiar with the trainer by investigating some characteristics of *predetection* and *post detection* filters.

Both pre- and post-detection filters are a part of the receiver circuits in an FDM (Frequency Division Multiplex) system. If you look at the FDM trainer, the filters are physically located before and after the detectors along the bottom of the board. These filters are placed to reflect signal flow in a working FDM circuit: a modulated subcarrier is filtered before detection (predetection); a demodulated signal is filtered after detection (post detection).

The predection filter is a bandpass filter designed to pass a subcarrier and/or its sidebands. There are two filters.— one for each subcarrier in the FDM system you will develop on this board.

The post detection filter is a low-pass filter designed to pass a detected signal and block any of the sum signal that may remain after detection.

☐ 1. a) Connect the circuit shown in Figure 1-12. Set the power supply outputs to +15Vdc and -15Vdc and connect them to the FREQUENCY DIVISION MULTIPLEXING TRAINER. Be sure to observe polarity. The plus lead from the power supply is connected to the terminal marked +15. The common lead for both power supplies is connected to the GND terminal located between the +15 and -15 terminals.

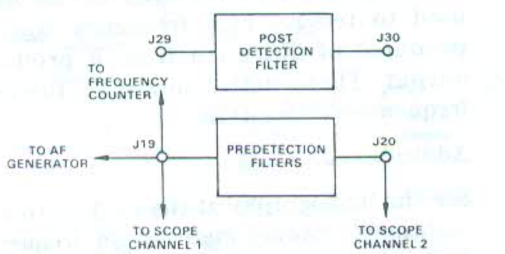

Figure 1-12

☐ b) Trigger the oscilloscope on channel 1. Set the AF generator for 4Vp-p at approximately 20kHz. Vary the frequency control for maximum output from the predetection filter. What is the frequency of this bandpass filter, and what can you conclude about the frequency of the subcarrier?

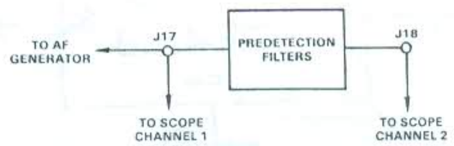

Figure 1-13

☐ c) Connect the circuit shown in Figure 1-13. Vary the frequency control for maximum output from the predetection filter. What is the center frequency of this bandpass filter, and what can you conclude about the frequency of the subcarrier?

☐ d) Connect the circuit shown in Figure 1-14. Set the AF generator to 300Hz at 1Vp-p. Measure the output level at J28 and enter it in Table 1-1. Repeat the procedure for each frequency in Table 1-1. What can you conclude about the characteristics of the post detection filter from this experiment?

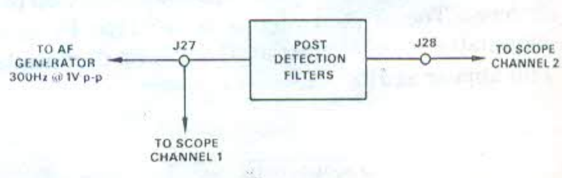

Figure 1-14

f(Hz)	300	1000	2000	3000	4000	10,000	20,000
Vout(p-p)	1.7						0.05

Table 1-1

Objective B. Investigate the fundamentals of synchronous detection for amplitude modulation.

Preparatory Information

There are several ways to recover intelligence from an amplitude modulated signal. The envelope detector (see Figure 1-15) is probably the most popular, but it contains some fundamental faults. Foremost among them is the inability to detect an amplitude modulated signal that does not have a carrier. Since frequency division multiplex systems use suppressed-carrier amplitude modulation techniques, a simple envelope detector can not be used.

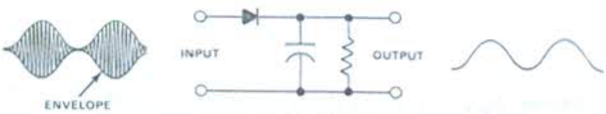

Figure 1-15

A solution to the problem of demodulating suppressed-carrier AM signals is found in the synchronous detector. It is capable of detecting *any* type of amplitude modulation: double sideband with carrier, double sideband with reduced carrier, double sideband suppressed carrier, and single sideband. However, synchronous detectors require a reference signal, called a BFO (Beat Frequency Oscillator), that must be identical in frequency to the carrier of the AM signal being demodulated (refer to Figure 1-16). But because synchronous detectors are the only means of demodulating suppressed carrier signals, and because they produce considerably less distortion in the demodulated signal, synchronous detectors are in widespread use. In order for a synchronous detector to work, the frequency of the BFO must equal the carrier frequency of the signal being demodulated. When detecting AM signals without carriers, the frequency of the BFO must still equal the frequency of the suppressed carrier. Also, the phase of the BFO must match the phase of the carrier exactly; that is, the amplitude of the BFO signal must rise and fall in perfect synchronization with the carrier. If it does not, the demodulated output will distort or be entirely suppressed. The product detector in this trainer is a type of synchronous detector.

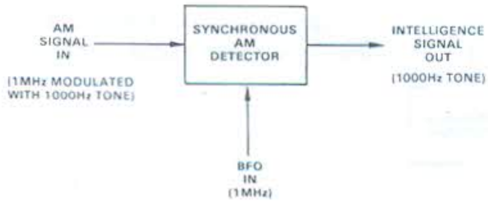

Figure 1-16

When BFO and carrier signals are mixed, the output is the sum and difference of the two frequencies (see Figure 1-17). Since the two signals are the same frequency, the difference between them is zero. The demodulation process is shown in Figure 1-18 as it occurs on the frequency division multiplexing trainer, where the low-pass filter is an external part of the detector. When an AM signal is applied to the input of

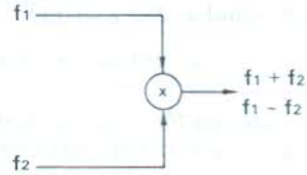

Figure 1-17

a product detector, its output signals are equal to the sum and difference of the BFO and carrier frequencies *and* the BFO and any AM sideband frequencies which may be present. The post detection filter is a low pass filter which removes the sum frequencies of 19, 20, and 21kHz; therefore, the only signal left is the 1kHz intelligence signal.

On the frequency division multiplexing trainer, an amplitude modulated signal is generated from a carrier signal and an intelligence signal by a balanced modulator. It is possible to produce an AM signal consisting of carrier and sidebands at 100 percent modulation, a double sideband signal without its carrier (DSB-SC), or at any percentage of the two variables: modulation and carrier suppression.

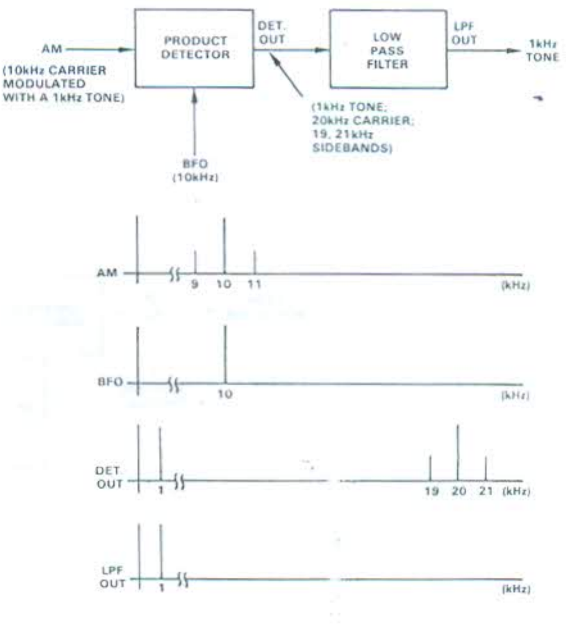

Figure 1-18

In this objective, a balanced modulator and a product detector will be used. One will generate an AM signal consisting of a carrier modulated by lkHz, and the second will be operated as a synchronous detector to recover the lkHz.

☐ 2. a) Connect the frequency counter to J31. Apply power to the trainer. Use the FREQ ADJ control on the subcarrier generator to set the frequency of the signal at J31 to 20kHz. Measure and record the frequency of the signal at J32 and J33.

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☐ b) Connect the circuit shown in Figure 1-19. Adjust the AF generator for a 1kHz sine wave at 1Vp-p. Trigger the oscilloscope on channel 1 and set the sweep speed to 0.5ms/cm. Use the CARRIER ADJ control to adjust the output of the balanced modulator for a 100 percent modulated AM waveform from J4. Describe the waveform.

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☐ c) Move the oscilloscope channel 2 probe from J4 to J23. Describe the signal. Explain.

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☐ d) Remove the connection between J22, the BFO input, and J31. Describe the signal at J23, the output of the product detector, and explain your observation.

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☐ e) Replace the connection between J22 and J31 and confirm the return of the 1kHz intelligence signal. What happens when the wire between J22 and J31 is moved from J31 to J32? Explain.

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Summary

In this Laboratory Exercise you examined the Frequency Division Multiplexing Trainer and investigated some of its circuits. You learned that FDM systems send two or more channels of information over one transmission link at the same time. This is

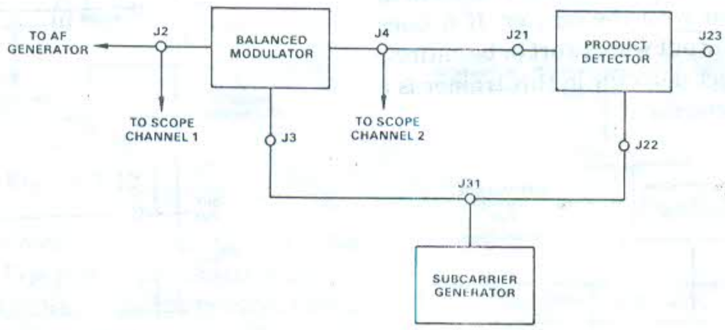

Figure 1-19

accomplished by placing each channel at a different location in the frequency spectrum. Each channel has a separate subcarrier which is modulated and combined with other subcarriers into a group. You discovered that predetection filters are bandpass filters tuned to pass one subcarrier from a group of FDM subcarriers. You also discovered that a post detection filter blocks subcarrier frequencies but can pass a demodulated signal. And finally, you investigated a synchronous detector and discovered that a BFO signal is a reference signal which must be equal in frequency to the modulated carrier being detected.

Quiz

1. Frequency division multiplex systems separate channels

   a. within specific periods of time.
   b. in tandem over a common channel.
   c. Both a and b.
   d. Neither a nor b.

2. A post detection filter used in FDM systems

   a. filters demodulated signals from subcarriers.
   b. passes subcarrier frequencies to a detector.
   c. filters FM from the linear mixer output.
   d. passes demodulated signals from detectors.

3. The subcarrier generator on the frequency division multiplex trainer

   a. is readjusted for each FDM channel.
   b. supports a two-channel FDM system.
   c. does not supply balanced modulators.
   d. provides multiple modulation signals.

4. A post detection filter is an effective filter for blocking subcarrier frequencies.

   a. This statement is false.
   b. The statement would be true if it referred to predetection filters.
   c. The statement would be false if it referred to predetection filters.
   d. The statement can only be made true if it names subcarrier frequencies.

5. Describe the function of a summer.

   a. To multiply signals from product detectors.
   b. To divide signals from the subcarrier generator.
   c. To add signals from balanced modulators.
   d. To subtract signals from the summing amplifier.

6. A synchronous detector

   a. demodulates AM signals.
   b. requires a reference signal.
   c. Both a and b.
   d. Neither a nor b.

Laboratory Exercise 2

FDM TRAINER SUPPORT CIRCUITS

Performance Objectives

A. **Demonstrate and test the operation of the SUBCARRIER GENERATOR and TONE GENERATOR.**

B. **Demonstrate and test the POST DETECTION FILTER.**

Basic Concepts

1. Subcarrier generators used in frequency division multiplex systems generate a different frequency for each channel in the *primary* group.
2. A primary group is a basic FDM unit, or set of channels, from which larger groups of channels are assembled.
3. Subcarrier generator output signals are all derived from a common oscillator.
4. Frequency division multiplex systems are aligned or tested with signals from tone generators.
5. Post detection filters pass intelligence frequencies but block FDM subcarrier frequencies.

Introductory Information

A typical FDM signal contains a group of sidebands whose carriers were suppressed during the modulation process. These sidebands occupy carefully controlled segments of the spectrum so that many sidebands can be packed into as little spectrum space as possible. To accomplish this high-density packaging of FDM sidebands, frequency division multiplex systems require precise subcarrier signals.

The *location* of FDM subcarriers within the frequency spectrum is important. Frequency *stability* of subcarrier signals is important in the demodulation process. Many FDM telephone systems use single sideband signals. During demodulation, the frequency of the signal used as the BFO (beat frequency oscillator, see Figure 2-1) must be typically within 15Hz of the subcarrier used to generate the SSB signal. Figure 2-1 shows the same SSB signal applied to two product detectors. When properly demodulated, as shown on Figure 2-1(a), a 1kHz tone results. If the BFO is shifted up in frequency by 100Hz (8140kHz to 8140.1kHz) as shown in Figure 2-1(b), the pitch of the demodulated signal is reduced by a proportional amount. Without a close frequency tolerance between the BFO and the subcarrier used to generate the SSB signal, the pitch of a demodulated voice wave shifts, becomes unnatural, and difficult to understand. When a double-sideband suppressed-carrier FDM system is considered, both frequency *and* phase of the BFO signal become critical. They must be identical to the frequency and phase of the original carrier. Without phase coherence between the BFO and the subcarrier used to generate the DSB signal, proper demodulation is impossible. Therefore, the subcarriers in an FDM system are generated with attention to frequency accuracy and stability.

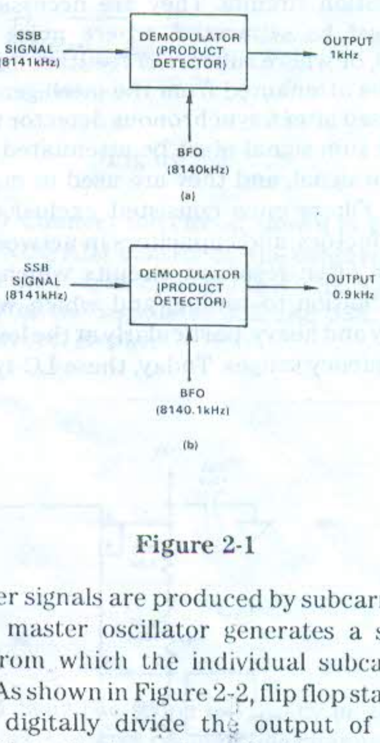

Figure 2-1

Subcarrier signals are produced by subcarrier generators. A master oscillator generates a stable frequency from which the individual subcarriers are derived. As shown in Figure 2-2, flip flop stages can be used to digitally divide the output of a master oscillator into the two subcarrier frequencies, 10kHz and 20kHz. Locking the individual subcarrier frequencies to a single oscillator insures that the subcarriers will keep their relative positions to one another even though the master oscillator drifts within its limits. If every subcarrier had its own oscillator, individual drifting among the oscillators would make large FDM systems impractical.

Figure 2-1 showed a typical FDM system using single sideband. It contained an 8141kHz SSB signal which was produced by a 8140kHz carrier and a 1kHz intelligence signal. Often, communications systems are tested and aligned using test signals rather than the intelligence signals they ordinarily carry. This is because the intelligence signals are often random in frequency and amplitude, and, therefore, make poor signals for alignment or troubleshooting. A tone generator on the frequency division multiplex trainer produces an audio test tone.

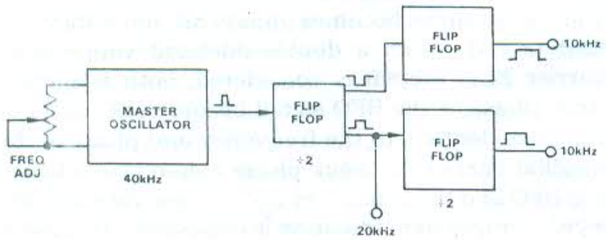

Figure 2-2

Filters play an important roll in analog and digital communication circuits. They are necessary where signals must be separated, where noise must be eliminated, or where subcarrier feedthrough or leakage must be attenauted from the intelligence signal. They are used after a synchronous detector where the subcarrier sum signal must be attenuated from the intelligence signal, and they are used in many other locations. Filters once consisted exclusively of resistors, inductors, and capacitors in networks. These were quite often resonant circuits which required careful attention to tuning, and which were often quite bulky and heavy, particularly at the low and mid audio frequency ranges. Today, these LC-type filters can be replaced with *active* filters which rely on simple resistor-capacitor networks working in conjunction with operational amplifiers. These filters, particularly in the audio range used by communication systems, are much less expensive, do not require difficult tuning procedures, are stable under varying environmental conditions, and are small and light. In addition, they can be designed to provide gain, something that LC-type filters could not do. Active filters are used on the frequency division multiplexing trainer to separate and filter subcarrier signals.

Additional Reading

See the bibliography at the back of this manual for additional reading material related to frequency division multiplex subcarrier circuits and post detection filters.

Equipment And Materials

Power Supply *+15Vdc, 100mA*
-15Vdc, 100mA
AF Generator
Dual-trace Oscilloscope
Frequency Division Multiplexing Trainer

Exercise Procedure

Objective A. Demonstrate and test the operation of the SUBCARRIER GENERATOR and TONE GENERATOR.

Preparatory Information

The circuit schematic of the subcarrier generator is shown in Figure 2-3. Integrated circuit U6 is a 555-type timer used in a 40kHz oscillator circuit. Resistors R28, R29, and R30 control the charge and discharge

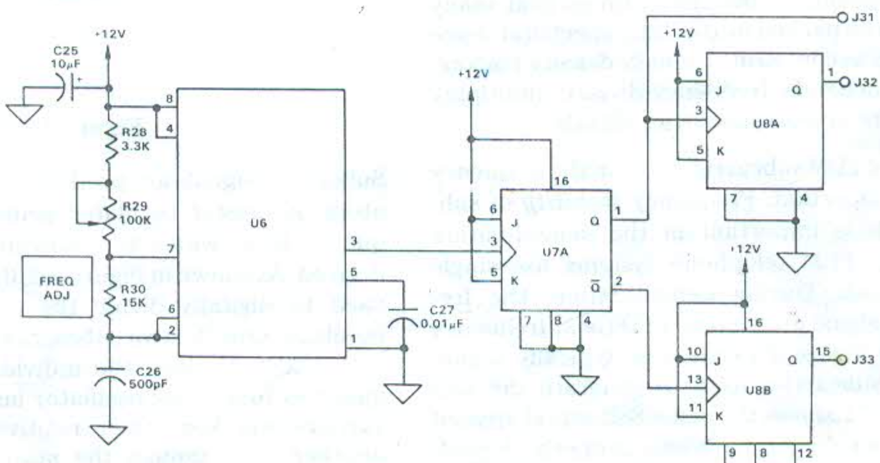

Figure 2-3

time of capacitor C26 to set the basic frequency of oscillation. Resistor R29 is made variable to serve as a frequency adjust (FREQ ADJ) control to set the subcarrier oscillator to the desired frequency. Capacitor C25 decouples the power supply from the oscillator, and C27 keeps the unused control voltage pin 5 at ground for ac. The output of the timer oscillator is applied to the clock input of flip flop U7A. All the flip flops trigger on a positive edge only; refer to Figure 2-4

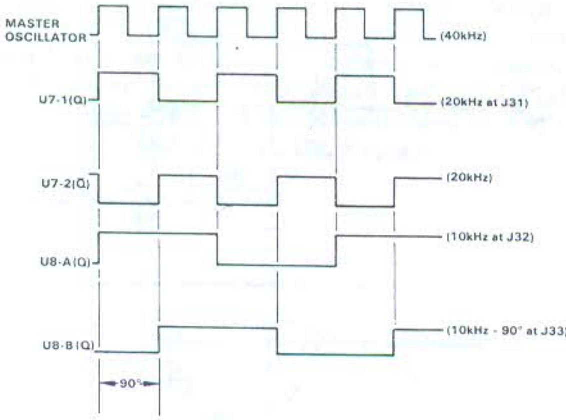

Figure 2-4

also. A 20kHz square wave at pin 1, the Q output, results from the divide-by-two action of the flip flop. This 20kHz signal is applied to J31 to serve as one of the subcarrier signals, and to the clock input of flip flop U8A. A second flip flop, U8B is triggered by the inverted 20kHz signal at pin 2 of U7A. As a result of the two-out-of-phase signals from U7A, one of the U8 flip flops is triggered every 180 degrees. This results in 10kHz signals that are 90 degrees out of phase with each other. These signals are applied to J32 and J33 as the 10kHz quadrature subcarrier signals.

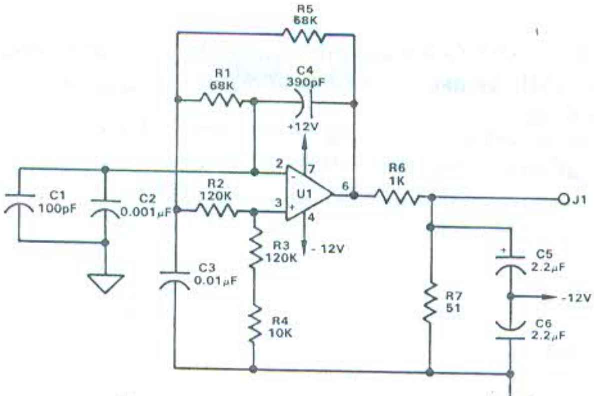

Figure 2-5

A schematic diagram of the tone generator is shown in Figure 2-5. Integrated circuit U1 is an operational amplifier operated at slightly above unity gain. The frequency of oscillation of this sine wave oscillator is determined by capacitors C3 and C4, and resistors R1 and R5. To insure reliable oscillation, the total series resistance of R3 and R4 is slightly larger than R2, and capacitor C2 is padded slightly with C1. It is these extra components that place the op amp slightly above unity gain and insure reliable operation. Resistors R6 and R7 divide the oscillator output to approximately 1Vp-p, and capacitors C5 and C6 form a low-pass filter to shape the output sine wave. The capacitors are electrolytic and, therefore, are polarity sensitive. Because the output of the oscillator circuit is bipolar, the electrolytic capacitors are returned to -12Vdc to prevent them from being back biased by the output signal.

☐ **1. a)** Adjust the power supplies to +15Vdc and -15Vdc, then connect them to the trainer. Be sure to observe polarity. The plus lead from the power supply is connected to the terminal marked +15. The common lead for both power supplies is connected to the GND terminals located between the +15 and -15 terminals.

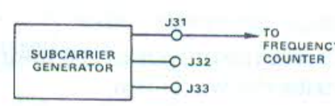

Figure 2-6

☐ **b)** Connect the circuit shown in Figure 2-6. Use the FREQ ADJ control on the subcarrier generator to set the frequency at J31 to 20kHz. Measure the frequency of the signals at J32 and J33. Are your results correct? Explain.

☐ **c)** Sync the scope externally on the 20kHz signal at J31. Connect oscilloscope channel 1 to J31 and channel 2 to J32. What can you observe about the two signals? Explain.

☐ **d)** Connect the circuit shown in Figure 2-7. Observe, measure, and record any phase difference between the 10kHz signals.

☐ **e)** Connect the circuit shown in Figure 2-8. Use the oscilloscope to confirm the output frequency and amplitude of the tone generator at J1.

☐ **f)** Observe the output of the tone generator at J1 and describe the waveform.

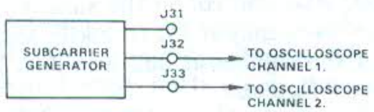

Figure 2-7

Objective B. Demonstrate and test the POST DETECTION FILTER.

Preparatory Information

The circuit schematic of the post detection filter is shown in Figure 2-9. Integrated circuit U15 is an operational amplifier used in an active low-pass filter circuit. Resistors R66 and R67, and capacitors C50 and C51 contribute to the cut-off frequency. Resistors

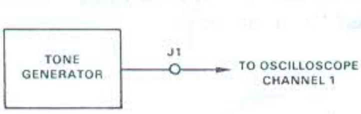

Figure 2-8

R68 and R69 are the input and feedback resistors which set the gain of the op amp to approximately 1.75. An input signal applied to J27 is dc coupled to the noninverting input of the op amp. The output is also dc coupled and appears at J28. The second post detection filter input is at J29 and its output is J30. Both circuits are electrically identical; only the input and output jacks and reference designations change.

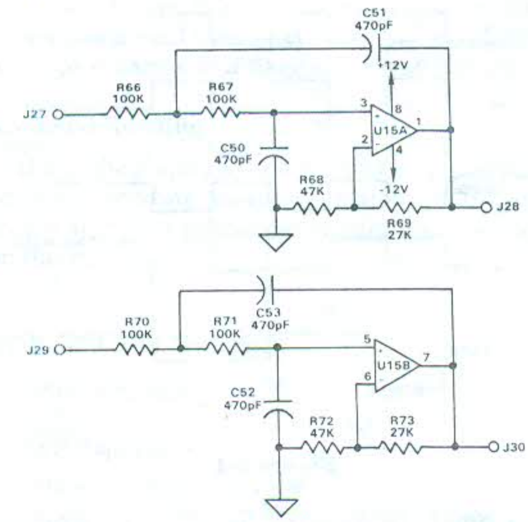

Figure 2-9

☐ **2. a)** Connect the circuit shown in Figure 2-10. Set the AF generator to 1000Hz at 1Vp-p. Measure the output of the post detection filter at J28.

☐ **b)** Calculate the voltage gain (G) of the filter at 1kHz by using the ratio of output voltage to input voltage.

☐ **c)** Set the AF generator to 1000Hz and adjust the AF LEVEL control for 1Vp-p at J28. Increase the frequency of the AF generator until the output of the filter (J28) drops to 0.7Vp-p, the 3dB-down point. Record the frequency. Explain.

☐ d) Reset the AF generator frequency control to 1kHz and check the AF GAIN control adjustment for a 1Vp-p output at J28. Increase the frequency of the AF generator to 10kHz (switch the MULTIPLIER control from ×10 to ×100). Measure and record the amplitude of the signal at J28. Explain.

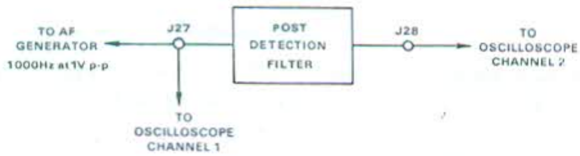

Figure 2-10

☐ e) Remove the AF generator from the input of the filter and connect the tone generator in its place (J1 to J27). Describe the signal on channel 2 of the oscilloscope. Explain.

Summary

In this laboratory Exercise you examined and demonstrated the operation of the subcarrier generator, the tone generator, and the post detection filter on the frequency division multiplexing trainer. You observed the output signals of the subcarrier generator that were derived from a master oscillator. You adjusted the frequency of the master oscillator and measured the frequency of the subcarrier generator output. The phase difference between the 10kHz subcarrier signals was measured and found to be 90 degrees. The output signal waveform and frequency of the tone generator was determined to be a sine wave at approximately 770Hz. Finally, you demonstrated the operation of the post detection filter and saw that this circuit blocked subcarrier frequencies, passed audio signals, and had a 3dB-down point of approximately 4kHz.

Quiz

1. The subcarrier generator master oscillator is adjusted for

   a. 5kHz at the output.
   b. 10kHz + 90 degrees at the output.
   c. 10kHz or 20kHz at the appropriate output.
   d. 40kHz at the output.

2. The 10kHz outputs from the subcarrier generator are

   a. synchronized.
   b. in quadrature.
   c. 90 degrees apart.
   d. All of the above.

3. The output of the tone generator

   a. is not attenuated by the post detection filter.
   b. contains square waves.
   c. is a subsonic signal.
   d. serves as a third subcarrier.

4. Post detection filters

   a. are used to separate and filter subcarrier signals.
   b. become unworkable at audio frequencies.
   c. are used to no particular advantage in FDM systems.
   d. become efficient at subcarrier frequencies.

5. To eliminate subcarrier sum signals from detected intelligence signals use a

   a. predetection filter.
   b. linear summing amplifier.
   c. post detection filter.
   d. nonlinear mixer.

6. The subcarrier generator used on the frequency division multiplexing trainer maintains phase relationships among its outputs with

   a. phase locked loop techniques.
   b. stable free running oscillators.
   c. flip flop circuits.
   d. digital phase detectors.

Laboratory Exercise 3

TRANSMITTER CIRCUITS

Performance Objectives

A. **Determine the operating characteristics of a balanced modulator.**

B. **Determine the operating characteristics of a summing amplifier.**

C. **Determine the operating characteristics of the FM Generator and demonstrate its operation.**

Basic Concepts

1. Balanced modulators generate suppressed carrier DSB signals from a carrier signal and a modulation signal.
2. A linear summing amplifier adds a pair of signals together without generating the sum and difference frequency components that occur with a nonlinear mixer.
3. A summing amplifier is used to combine the separate carrier frequencies used in an FDM system.
4. A phase locked loop FM generator is a method of producing frequency modulation.
5. A double sideband suppressed carrier signal exists only under conditions of modulation.

Introductory Information

In theory, any type of modulation scheme can be used for FDM systems. The subcarrier can employ amplitude, frequency, phase, double-sideband suppressed carrier, or single sideband modulation. The main carrier can also use any of the modulation methods. Frequency modulation is often used in telemetry for both the sub-carrier and main carrier modulation. A television station sends the color portion of its signal on two DSB (double sideband suppresse carrier) signals. Stereo FM broadcast stations send a suppressed carrier AM signal containing the stereo information.

The trainer has three basic transmitter circuit functions used in frequency division multiplex systems. The double sideband, suppressed carrier modulators (BALANCED MODULATOR 1 and 2), a summing circuit (SUMMING IF CIRCUIT) which linearly mixes two or more subcarrier signals, and an FM generator (FM GENERATOR) for the main carrier signal.

Figure 3-1 is a simplified diagram of the balanced modulator integrated circuit. It includes a four quadrant multiplier (a bipolar balanced modulator), an operational amplifier, and a buffer amplifier. All three functions are independent. When used as a

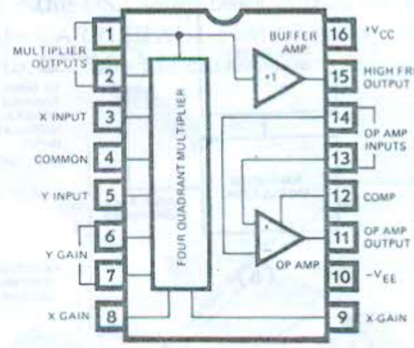

Figure 3-1

balanced modulator, the IC works similarly to the simple diode balanced modulator shown in Figure 3-2. In a balanced condition, equal carrier current flows through diodes A and D, or when carrier polarity reverses, equal carrier current flows through B and C. As a result, magnetic fields at the primary of transformer TOUT cancel each other, so nothing is

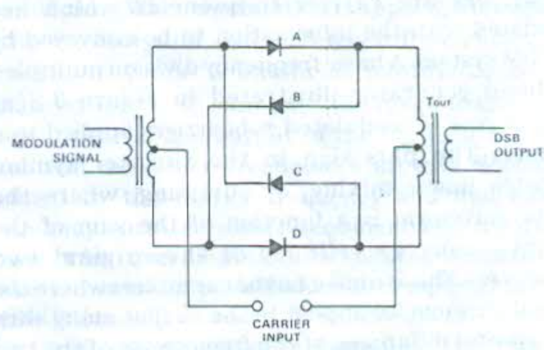

Figure 3-2

induced into the output circuits. With modulation, diodes C, D (or, when the modulation polarity is reversed, B, A) will conduct the modulation signal. This will unbalance the carrier current flow through diodes A, D (or B, C) since both modulation current and carrier current flow through diode D (or A). As a result of the unbalance, a signal will appear at the output. However, the signal that appears is not the carrier, the carrier is still suppressed. The presence of a modulation signal results in *sideband* signals that are the sum and difference of the inputs. This is analagous to an AM signal. When there is no modulation signal, there are no sidebands. In both regular (with carrier) AM and DSB suppressed carrier, the presence of a modulation signal results in sidebands at the output.

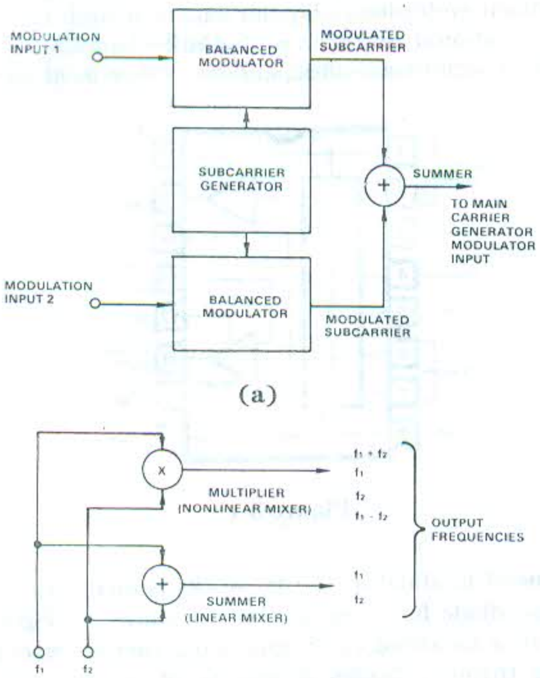

Figure 3-3

Subcarriers are carrier frequencies which are modulated with the information to be conveyed by the FDM system. A basic frequency division multiplex baseband generator illustrated in Figure 3-3(a) shows a pair of modulated subcarriers applied to a summer. The plus sign in the summer symbol indicates linear mixing, or summing, where the output waveform is a function of the sum of the instantaneous *amplitudes* of the original two frequencies. This is unlike nonlinear mixers where the original frequencies appear in the output along with the sum and difference of the *frequencies* of the two original frequencies. See Figure 3-3(b). If the nonlinear mixer is balanced, only the sum and difference frequencies appear in the output. Nonlinear mixers are indicated symbolically by a multiplication sign within the circle. A summer is used to combine the individual subcarrier frequencies in an FDM system to prevent products of nonlinear mixing from appearing.

The FM generator is used to produce a main carrier signal which contains the individual modulated subcarrier frequencies. A block diagram of the precision waveform generator IC used in the trainer to generate an FM signal is shown in Figure 3-4. A

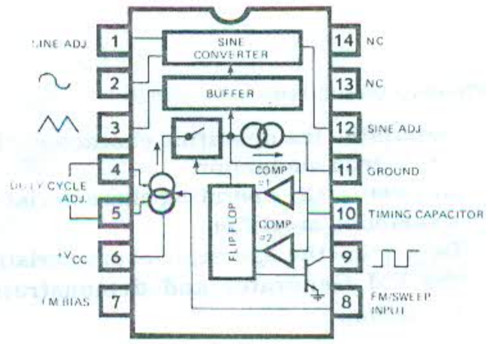

Figure 3-4

timing capacitor connected to IC pin 10 governs the basic period of oscillation in conjunction with the Duty Cycle Adjust resistance network at pins 4 and 5. A dc level or ac signal applied to the FM sweep input will alter the frequency.

On the trainer, a center frequency adjust (CTR FREQ ADJ) potentiometer adjusts the dc level, and a modulation signal at J11 varies the ac level at IC pin 8, the FM Sweep Input. This is accomplished in a summing amplifier whose output is connected to pin 8 of the IC.

Refering to Figure 3-4, the waveform generator IC produces a triangular wave across the timing capacitor. The waveform is then buffered internally and applied to a triangle-to-sine converter with an output at IC pin 2. The sine wave is made available at J13 of the trainer.

Additional Reading

See the bibliography at the back of this manual for additional reading material related to frequency division multiplex transmitter circuits.

Equipment and Materials

Power Source *+15Vdc, 250mA*
Power Source *-15Vdc, 250mA*
AF Generator
Frequency Counter
Dual-trace Oscilloscope
Frequency Division Multiplex Trainer

Exercise Procedure

Objective A. Determine the operating characteristics of a balanced modulator.

Preparatory Information

Practical frequency division multiplexing systems use suppressed-carrier AM signals for each channel of information. Also known as double sideband (DSB) and DSB suppresed carrier (DSB-SC), the circuit most often used to achieve DSB modulation is the balanced modulator.

Balanced modulators produce an output signal proportional to the product of a modulating signal and a carrier. Lowest distortion in a simple balanced modulator occurs when the modulating signal is much smaller than the carrier. Because the balanced modulator output is the product of the input signals, the modulator is also called a multiplier. When a multiplier (balanced modulator) is combined with an operational amplifier in the same integrated circuit, the combination is called an operational multiplier.

Balanced Modulators 1 and 2 on the frequency division multiplexing trainer use operational multipliers. In addition to built-in buffer and operational amplifiers, the gain of the multiplier can be externally adjust. Figure 3-5 shows a simplified block diagram of the operational multiplier and the method used to vary the gain. As resistance between pins 8 and 9 is increased, gain of the modulation input is decreased. Notice the short between pins 6 and 7. This sets the gain of the carrier input to maximum. The carrier can be either a sine wave or a square wave. The carrier input of the operational multiplier is operating in the saturated mode. In this circuit, the carrier is a square wave; the gain of the carrier input has been raised to maximum for optimum saturated mode sensitivity.

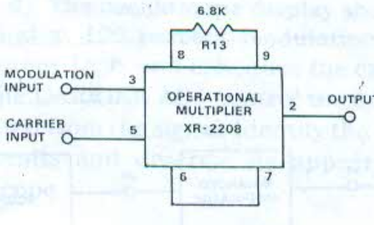

Figure 3-5

Simply stated, the output of a multiplier is a *scaled* product of the two input voltages. In other words, the output voltage is the product of the two input voltages *times* a scaling factor such as 0.1, 0.5, 0.01, etc. As shown in Figure 3-6, an operational multiplier with two-volt modulating and four-volt carrier signals would have an output of not eight, but 0.8 volts if the multiplier had a 0.1 scale factor (2 x 4 x 0.1 = 0.8). The figure shows the actual *transfer** characteristics of one quadrant of a type XR-2208 4-quadrant multiplier IC with a scale factor of 0.1. In practice, more than one quadrant is used when the bipolar signals are applied to the multiplier IC.

When an AM signal is demodulated, there are two signals which result: a dc output proportional to the carrier strength, and the original modulating signal recovered from the sidebands. In double sideband suppressed carrier systems, the absence of a carrier eliminates the dc component from the demodulated signal, which then consists of only the original modulation signal.

Balanced modulators used for generating DSB-SC communication signals incorporate some method of adjusting the circuit balance. The trainer uses a potentiometer to apply a variable dc level to the modulation input of the operational multiplier. By observing the DSB modulator output on an oscilloscope, the CARRIER ADJ control can be used to add carrier to, or eliminate carrier from, the output.

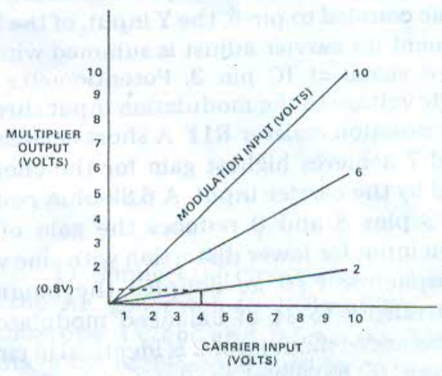

Figure 3-6

When a balanced modulator is adjusted to suppress the carrier, there will be no output when there is no modulation. When modulation is applied, the balance is upset, and sum and difference frequencies are generated. Since a balanced modulator is not balanced for these sum and difference frequencies, they appear at the output of the modulator. These sum and difference frequencies are the sidebands defined by the carrier frequency and modulation frequency. An interesting phenomenon occurs if only the *carrier* of an amplitude-modulated signal from a balanced modulator is reduced: the percentage of modulation will increase. Even though the absolute sideband power remains constant, the relative percentage of power in the sidebands increases in proportion to the carrier power decrease.

* A plot showing an input-output relationship.

A characteristic double-sideband, suppressed-carrier oscilloscope display results as the carrier is reduced to where only the modulation envelope of the AM signal remains. As the carrier is reduced, the envelope appears to fall in upon itself, see Figure 3-7, until only the overlaping envelope remains.

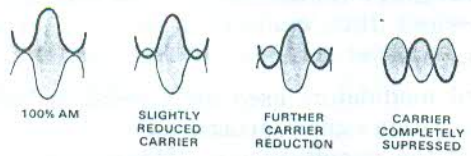

Figure 3-7

A schematic of a balanced modulator used on the trainer is shown in Figure 3-8(a). The modulation input at J2 is ac coupled to pin 3, the X input, of the type XR-2208 operational multiplier. Similarly, the carrier is ac coupled to pin 5, the Y input, of the IC. A dc component for carrier adjust is summed with the modulation signal at IC pin 3. Potentiometer R12 applies a dc voltage to the modulation input through 100k-ohm isolation resistor R11. A short between IC pins 6 and 7 achieves highest gain for the chopper mode used by the carrier input. A 6.8k-ohm resistor between IC pins 8 and 9 reduces the gain of the modulation input for lower distortion with sine wave inputs. Capacitor C10 ac couples the balanced modulator output to J4 of balanced modulator 1. Note that balanced modulator 2 is identical in circuit and function to balanced modulator 1. Only the reference designations change as shown in Figure 3-8(b).

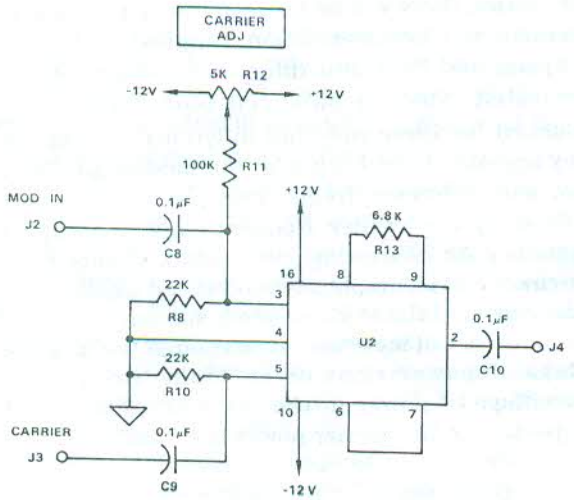

Figure 3-8(a)

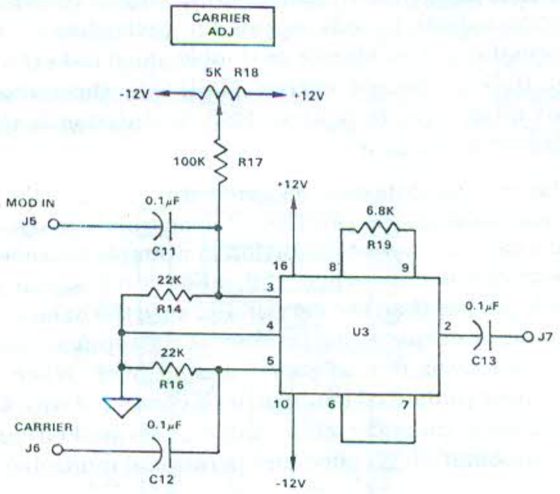

Figure 3-8(b)

☐ 1. a) Connect the circuit shown in Figure 3-9. Set the AF generator to 1kHz at 1Vp-p. Set the oscilloscope vertical sensitivity to 1V/cm and the sweep to 0.5ms/cm. Turn trainer power on and turn the CARRIER ADJ control completely counter clockwise. Set the FREQ ADJ on the subcarrier generator fully clockwise. Adjust the AF generator slightly if necessary to stabilize the waveform. What does the waveform at J4 represent?

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....

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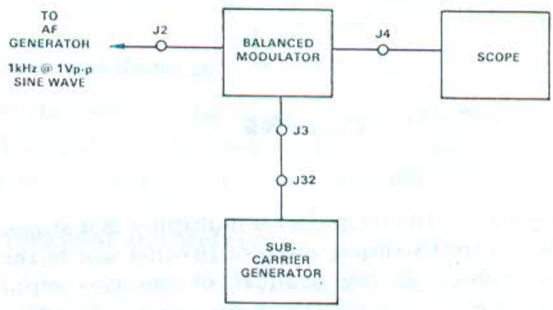

Figure 3-9

☐ b) Slowly turn the carrier adjust control clockwise, stopping when the valleys of the wave-forms touch. What does the waveform at J4 now represent and why?

☐ c) Reduce the AF level to zero while observing the waveform on the oscilloscope. Then restore the system to one hundred percent modulation using the AF level control. Describe the effect your actions had on the signal.

☐ d) The oscilloscope display should show an AM signal at 100 percent modulation. If it is not, repeat steps 1a, b, and c. Reduce the carrier further using the CARRIER ADJ control until the carrier is eliminated from the signal. Identify the type of signal that results and describe its appearance on the oscilloscope.

☐ e) Sketch an AM signal (100% modulation) and a DSB-SC as they are represented on an oscilloscope.

☐ f) Connect the circuit shown in Figure 3-10. Set the AF generator to 1kHz at lVp-p, and the oscilloscope 1V/cm and 0.5ms/sec. The vertical inputs of the oscilloscope must be dc coupled. What does this circuit accomplish?

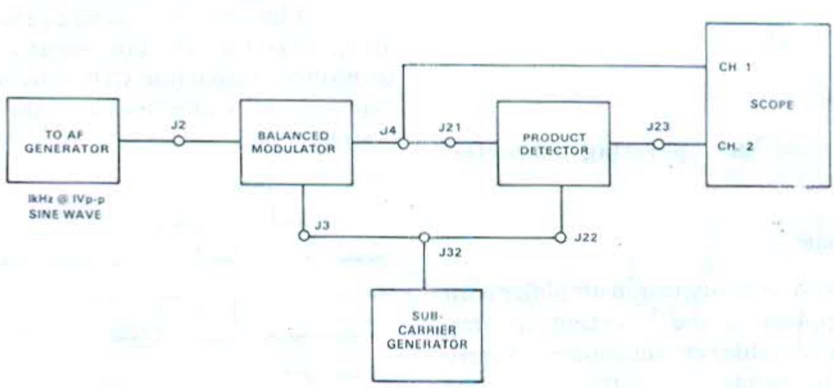

Figure 3-10

☐ **g)** Use the CARRIER ADJ control to obtain a DSB suppressed carrier signal. Identify and describe the signal at J23.

☐ **h)** Use the vertical position control to place the demodulated waveform at a convenient reference point. Rotate the CARRIER ADJ control to observe a dc level shift in the demodulated waveform. What is the approximate range of the dc level shift and why does the dc level shift occur?

Object B. Determine the operating characteristics of a summing amplifier.

Preparatory Information

A linear mixer consists of an operation amplifier with multiple inputs applied to the inverting op amp input. A simple resistor adder circuit shown in Figure 3-11 is used to add the inputs together. Since the input signals are combined in a circuit which uses only linear devices, sum and difference signals which occur when signals are mixed in non-linear mixers, are not generated.

The operational amplifier is used as a buffer-amplifier for the already mixed input signals. The amplifier has a 68k-ohm feedback resistor (This will be seen in Figure 3-13 later in this exercise.) which sets the gain in conjunction with each input resistor to approximately 1.4 ($G = R_{FB}/R_{IN} = 68K/47K = 1.4$).

Signals are added in a resistive mixer as shown in Figure 3-12. The resultant signal developed across the load resistor, which is common to both input resistors, is shown. Notice that when a signal is present at each input at the same time, the output voltage is equal to the sum of the amplitude at each input.

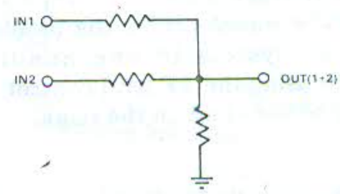

Figure 3-11

Two sine waves of different frequency such as 100Hz and 1000Hz will have their instantaneous values added algebraically when mixed in a linear device. When applied to a non-linear mixer, the same two signals appear on an oscillocope as the familiar AM modulation envelope.

The ability of the linear mixer, or adder, found in your trainer to combine a wide range of frequencies is governed by the response of the operational amplifier used as a buffer-amplifier. This device is a JFET input op amp with wideband, low noise, and low drift characteristics.

A schematic of the summing amplifier used on the trainer is shown in Figure 3-13. An input at J8 or J9 is ac coupled to an input resistor by C14 or C15, respectively. A 47k-ohm input resistor (R20 or R21) in conjunction with feedback resistor R22 provide a gain of approximately 1.4 for an input signal. The summed inputs are applied to the inverting input of an op amp (U4). The non inverting input is returned to ground. Capacitor C16 rolls off the gain of the summer for frequencies above the useful range of the system.

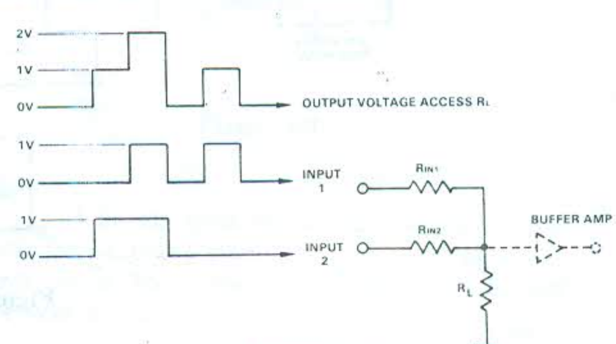

Figure 3-12

☐ **2. a)** Connect the circuit shown in Figure 3-14. Set the AF generator to 1kHz at 1Vp-p.

☐ **b)** Use the oscilloscope to measure the output versus the input amplitude for each input (J8 and J9). What is the gain of the summing amplifier?

☐ **c)** Connect input J9 to J8. What is the gain of the summing amplifier in this configuration?

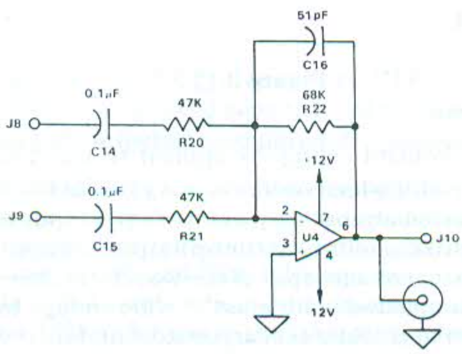

Figure 3-13

☐ **d)** Remove the jumper between inputs J8 and J9. Measure the bandwidth of the summing amplifier at the 3dB down points by noting the frequency at which the output voltage drops to 70.7 percent of its 1kHz value.

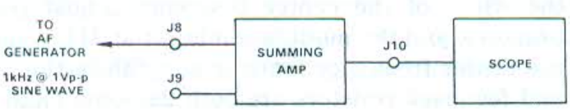

Figure 3-14

☐ **e)** Connect input J8 to the 20kHz signal source at J31, and connect J9 to 10kHz at J32. Complete the waveform of the J10 output signal shown in Figure 3-15(a). The actual signal at J10 is inverted by the summing amplifier. *Ans. on pg. 3-11*

☐ **f)** Connect input J8 to J1, the 770Hz, 1Vp-p output of the tone generator, and connect J9 to a 10kHz, 1Vp-p sine wave from the AF generator. With the oscilloscope set for a 0.5ms/cm sweep rate, carefully adjust the AF generator frequency if necessary to stabalize the pattern shown in Figure 3-15(b). Does the waveform illustrate addition of these two frequencies? Explain.

NOTE: It may be helpful to use the 770Hz signal to externally trigger the oscilloscope.

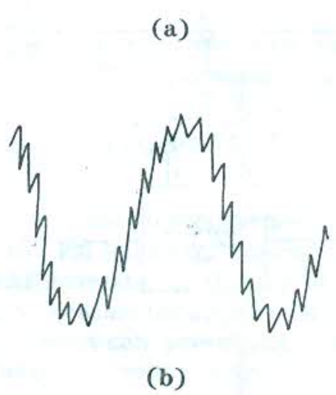

Figure 3-15

Objective C. Determine the operating characteristics of the FM Generator and demonstrate its operation.

Preparatory Information

Frequency division multiplex system *baseband* signals are used to modulate a higher-frequency carrier signal. In this system, two double-sideband suppressed carrier signals centered around 10kHz and 20kHz are the baseband signal. The FM Generator section of the trainer uses a precision waveform generator IC to produce a sine wave that serves as the carrier for the baseband signal. The frequency of the generator is directly proportional to a control voltage. By altering this voltage, frequency modulation is performed. In addition, a dc control voltage from the center frequency adjust (CTR FREQ ADJ) potentiometer is added to the modulation input to control the carrier frequency.

This precision waveform generator IC has provision for minimizing distortion of the output waveform. A potentiometer (SYMM ADJ) supplies a positive voltage to each timing resistor, R29 and R30 (see Figure 3-16). The potentiometer is adjusted for best waveform symmetry as viewed on an oscilloscope. Since timing resistors R29, R30 and timing capacitor C20 form an RC circuit which sets the center frequency of oscillation, any adjustment of symmetry also shifts the output waveform frequency.

When timing resistors are equal in value, the frequency of oscillation is f = 0.3/RC. For example, if the potentiometer (SYMM ADJ) is set to its center, total resistance is 7.2k-ohms (2.5 + 4.7). Therefore,

$$\begin{aligned} f &= 0.3/RC \\ &= 0.3/7.2 \times 10^{3} \times 1.5 \times 10^{-10} \\ &= 0.3/10.8 \times 10^{-7} \\ &= 2.77 \times 10^{5} \\ &= 277\text{kHz} \end{aligned}$$

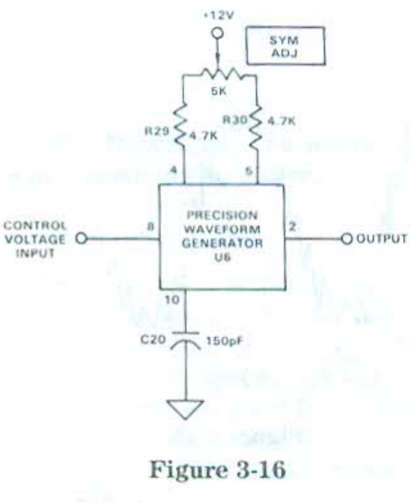

Figure 3-16

A modulating voltage is summed with the CTR FREQ ADJ dc control voltage in an operational amplifier, then applied to the control voltage input of the waveform generator. Figure 3-17 shows a simplified diagram of the summer circuit. The modulation is applied to a 33k-ohm input resistor which, in conjunction with the 22k-ohm feedback resistors, provides a gain of 2/3. The dc voltage for carrier frequency control of approximately 4 to 10 volts is developed between the wiper and ground of a center-frequency adjust (CTR FREQ ADJ) potentiomenter.

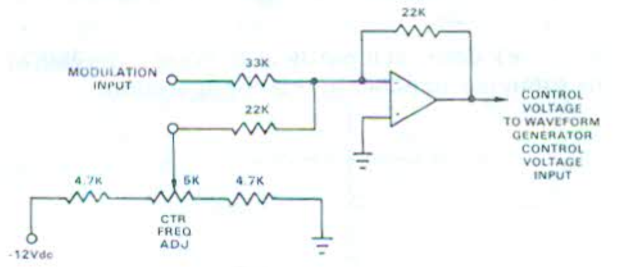

Figure 3-17

This dc control voltage is applied to the 22k-ohm input resistor which results in unity gain at this input. The inverted algebraic sum of these two input signals appears at the output of the op amp and is applied to the control voltage input of the waveform generator. The op amp bandwidth must be wide enough to pass the 10kHz and 20kHz subcarrier sidebands of the FDM signal. Also, the frequency response of the op amp is modified to increase gain at higher modulating frequencies to compensate for a lower sensitivity at the modulation input of the waveform generator IC.

A schematic of the FM generator used on the trainer is shown in Figure 3-18. Integrated circuit U6, a precision waveform generator, is capable of producing sine, square, triangular, sawtooth and pulse waveforms up to 1MHz. The generator can be frequency modulated with an external control voltage at pin 8. The frequency of oscillation if set by an RC network consisting of C20 and the resistance of the potentiometer circuit R29, R30, and R31 connected to IC pins 4 and 5. An 82k-ohm fixed resistor between pin 12 and -12Vdc serves to reduce sine wave distortion.

Op amp U5 drives the FM sweep input. Two voltages are summed at the inverting input: a dc voltage from the wiper of the center frequency adjust potentiometer, and the modulation input at J11. Gain for the center frequency input is unity since the input and feedback resistors are both 22k-ohm (R26 and R28). Gain is slightly above unity at this modulation input. Resistor R27, the 33k-ohm input resistor, and the 22k-ohm feedback resistor, R28, provide a

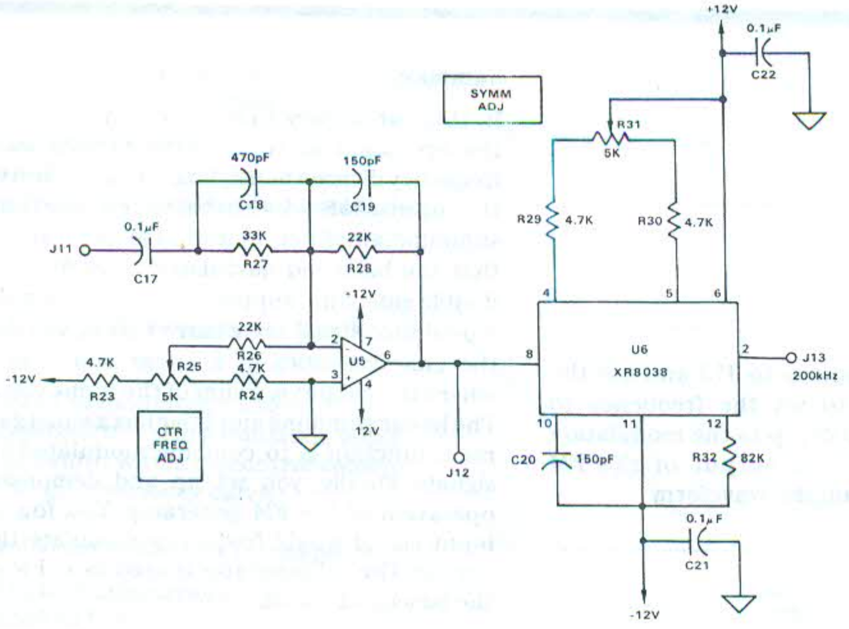

Figure 3-18

nominal gain of 0.67. Capacitors C18 and C19 compensate for reduced sensitivity of the waveform generator IC at higher modulation frequencies.

Capacitors C21 and C22 are power supply decoupling capacitors. The IC output at pin 2 is connected to J13 of the trainer. The frequency determining RC network consisting of C20 and R29, R30, and potentiometer R31 allows the user to adjust the output sine wave to a nominal 200kHz for use in the laboratory exercises.

☐ **3. a)** Connect channel 2 of the oscilloscope to J13 of the FM GENERATOR. Vary the symmetry adjust (SYMM ADJ) control for best symmetry of the sine wave. Once this control is set, it should not be readjusted since it affects the center frequency control in the next step.

☐ **b)** Connect a frequency counter to J13. Connect frequency control voltage test point J12 to channel 1 of the dc-coupled oscilloscope. Rotate the CTR FREQ ADJ (center frequency adjust) control fully counterclockwise and place a point on the graph of Figure 3-19 at the intersection of the voltage and frequency values as read on the scope and counter respectively. Complete the graph using control voltage increments of 1 volt. What does the graph show?

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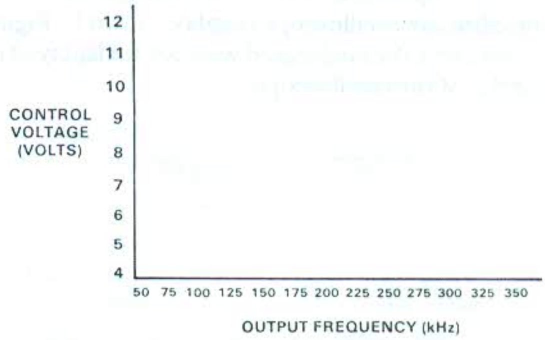

Figure 3-19

☐ **c)** Determine the input versus output characteristic of the FM Generator control voltage stage. Adjust the AF generator to 0.5Vp-p at J11 for each frequency and measure the output at J12 to complete Table 3-1. What can you conclude about the response of the control voltage stage.

☐ d) Connect the counter to J13 and use the CTR FREQ ADJ control to set the frequency to 200kHz. Apply 1000Hz at 0.2Vp-p to the modulation input jack J11. Observe the output of the FM generator at J13 and explain the waveform.

☐ e) Increase the modulation frequency to 100kHz. Increase the AF generator output to approximately one volt. Carefully adjust the AF generator frequency and AF level slightly if necessary to stabalize the oscilloscope display shown in Figure 3-20. Interpret the modulated waveform displayed on channel 2 of the oscilloscope.

Summary

In this Laboratory Exercise you were introduced to the operation of transmitter circuits used in the frequency division multiplexing trainer. You examined the operation of the balanced modulator, the summing amplifier, and the FM generator. You saw that the balanced modulator is used to generate a double sideband, suppressed-carrier signal from the modulation signal and a carrier. Next, you determined the characteristics of a linear summing amplifier where the output is a sum of the input voltage levels. The linear summing amplifier has a small gain, and its main function is to combine modulated subcarrier signals. Finally, you set up and demonstrated the operation of the FM generator. You found that an input signal would frequency modulate the 200kHz carrier. The FM generator is used as an FM carrier for the baseband signal.

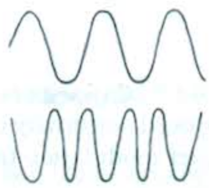

Figure 3-20

QUIZ

1. With AM and DSB signals, the presence of a modulation signal results in
   a. linear mixing.
   b. carrier suppression.
   c. sideband generation.
   d. phase modulation.

2. A frequency division multiplex generator produces
   a. triangular waveforms.
   b. modulated subcarrier signals.
   c. the main carrier signal.
   d. unmodulated products of nonlinear mixing.

3. The carrier input to an operational multiplier used as a balanced modulator can be a
   a. square wave.
   b. sine wave.
   c. Both a and b.
   d. Neither a nor b.

	20Hz	500Hz	1000Hz	10kHz	20kHz	50kHz	100kHz	200kHz
Vpp @ J11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vpp @ J12	___	___	___	___	___	___	___	___

Table 3-1

4. A summing circuit used in frequency division multiplex systems does not generate
   a. sum and difference signals.
   b. linear mixing.
   c. algebraically added instantaneous amplitude values.
   d. None of the above.

5. Frequency division multiplex system baseband signals
   a. are never used to modulate carriers.
   b. are directly proportional to modulation index.
   c. control bandwidth with a dc control voltage.
   d. modulate a high frequency carrier.

The frequency division multiplex technique is
   a. restricted to DSB subcarriers.
   b. not restricted to DSB.
   c. only a laboratory curiosity.
   d. not suited to telemetry applications.

RECEIVER CIRCUITS

Performance Objectives

A. **Determine the lock range of the PLL FM demodulator and demonstrate its operation.**

B. **Determine the operating characteristics of predetection filters.**

C. **Determine the operation of product detectors and determine the effect a reference phase change has on the demodulated signal.**

Basic Concepts

1. A phase locked loop can be used to directly demodulated an FM signal.
2. The phase locked loop FM detector output is a sample of the VCO control voltage.
3. Predetection filters are active bandpass filters tuned to help recover individual FDM channels from a baseband signal.
4. Active filters use operational amplifiers and RC networks in efficient filter circuits that do not require bulky LC circuits.
5. Voltage gain in decibels is equal to twenty times the log of the output voltage divided by the input voltage (dB = 20 log Eout/Ein).
6. Product detectors mix a modulated carrier with an unmodulated carrier of equal frequency and phase.
7. Product detectors are also known as synchronous or heterodyne detectors.
8. Quadrature multiplexing places two FDM subcarriers on the same frequency but displaced in phase by ninety degrees.

Introductory Information

A frequency division multiplex system (FDM system) will have at least two channels of information. When two or more of these information channels are combined into one composite signal, it is called a *baseband* signal. The reception of FDM signals requires a minimum of two separate detection circuits, one for each channel as shown in Figure 4-1(a). If this 2-channel (baseband) system is used to modulate a third carrier, then a baseband detector is needed to recover the baseband signal containing the two original channels. The FM detector on the trainer is used to recover a baseband signal as shown in Figure 4-1(b).

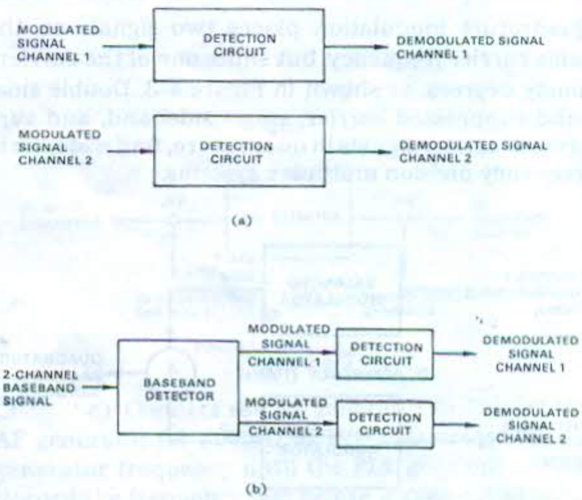

Figure 4-1

It is the function of the product detectors to separate the baseband signal into its two separate channels *and* to demodulate each channel to recover the intelligence it contains. Actual separation of the individual channels from the baseband signal is accomplished with product detectors. Predetection filters aid the product detectors by filtering noise from baseband channels. There is one product detector for each channel in the system. As shown in Figure 4-2, the baseband signal (which contains the two channels of information) and a separate reference signal are input to each product detector.

The product detector is a mixer. The result of mixing is sum and difference signals. If the reference signal and one of the two information channels are the *same* frequency when they are mixed, the difference frequency will be zero. What remains is the information and the sum signal. The sum signal can be easily removed with a low pass filter.

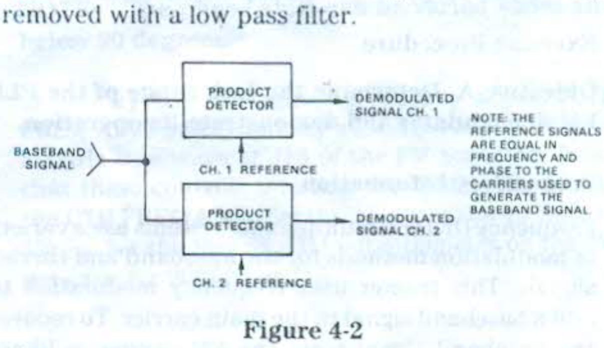

Figure 4-2

This trainer uses double sideband suppressed carrier (DSB-SC) baseband channels. It is possible to use other types of modulation, but modulation systems *without* a carrier have certain advantages over those with carriers, such as more efficient use of power. An AM carrier contributes no information, yet contains two-thirds the energy of a 100-percent modulated AM signal. In addition, two signals can be multiplexed in quadrature when carriers are suppressed.

Quadrature modulation places two signals on the same carrier frequency, but shifts one of the carriers ninety degrees, as shown in Figure 4-3. Double sideband suppressed carrier, single sideband, and suppressed carrier signals in quadrature, find wide use in frequency division multiplex systems.

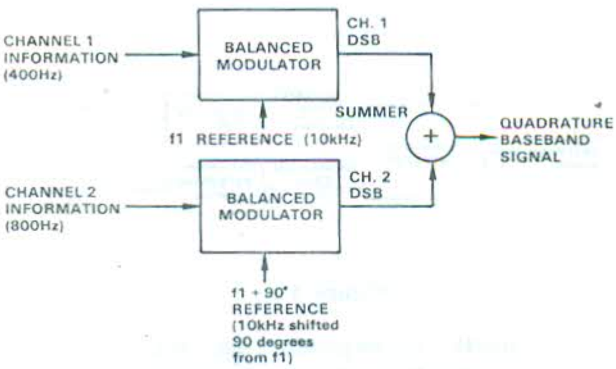

Figure 4-3

Additional Reading

See the bibliography at the back of this manual for additional reading material related to frequency division multiplex receiver circuits.

Equipment And Materials

Power Source *+15Vdc, 100 mA*
Power Source *-15Vdc, 100 mA*
AF Generator
RF Generator
Frequency Counter
Dual-trace Oscilloscope
Frequency Division Multiplexing Trainer

Exercise Procedure

Objective A. Determine the lock range of the PLL FM demodulator and demonstrate its operation.

Preparatory Information

Frequency Division Multiplexing systems use a variety of modulation methods for the baseband and carrier signals. This trainer uses frequency modulation to add a baseband signal to the main carrier. To recover the baseband signal from the FM carrier, a Phase Locked Loop (PLL) FM detector is used. A block diagram of a phase locked loop used to detect an FM signal is shown in Figure 4-4.

The comparator develops an error signal only if the VCO and carrier phases are different. Under normal PLL operation, a difference between the VCO and carrier phase occurs only when modulation shifts the carrier frequency. The greater the frequency shift, the greater the error signal. The faster the frequency shift, the faster the error signal shift.

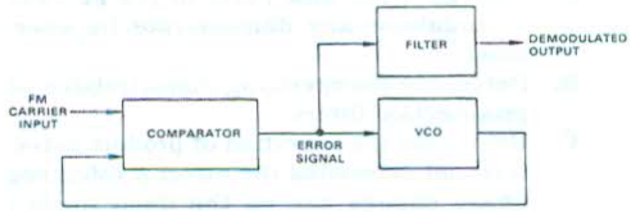

Figure 4-4

The result of this action is an error signal that varies in direct proportion to the modulation. However, the comparator error signal is not an analog recreation of the modulation. Rather, it is a rectangular wave whose duty cycle changes with the modulation. A low-pass filter must be used to recreate the original analog modulation signal by integrating the changing duty cycle. The time constant of a filter is chosen so the output voltage is the dc average of the input signal. Refer to Figure 4-5. The average (dc) value of the waveform is

$$V_{av} = (t1/T)V$$

Duty cycle is defined as the ratio of time t1 to total period T

$$D = t1/T$$

The average dc value of a pulse train is directly proportional to its duty cycle.

$$V_{av} = DV$$

The average value of the error signal from the PLL phase comparator is equivalent to the original modulating signal.

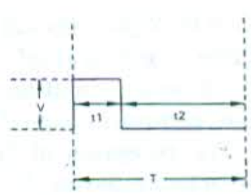

Figure 4-5

A schematic of the FM detector used on the trainer is shown in Figure 4-6. The input signal is ac coupled to the PLL input at pin 14 by C22. Capacitor C21 provides power supply decoupling. The VCO frequency is set to its low range by switching capacitor

C20 in parallel with C23. Without C23 in the circuit, the VCO high frequency range is set by C23 alone. The actual VCO frequency is determined by: the voltage at VCO IN pin 9, the capacitance between pins 6 and 7, and by the resistance at pin 11. Variable resistor R27 in series with R24 will adjust the VCO phase approximately 90 degrees.

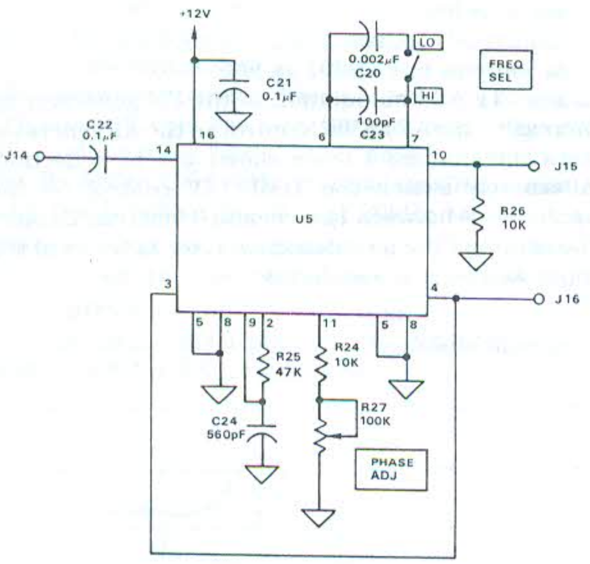

Figure 4-6

The output of the internal phase comparator appears at pin 2 where an external low pass filter (the loop filter), consisting of R25 and C24, provides the error signal to the VCO input (VCO IN, at pin 9). The VCO output at pin 4 is externally connected to the comparator input at pin 3. This point is made available on the trainer at J16 as a signal for externally synchronizing an oscilloscope and for use in a phase-shift experiment. And finally, the output of the FM detector at pin 10 is developed across R26 and made available at J15 on the trainer.

☐ 1. a) Connect J14 to GND. Set the FREQ SEL switch to HI and adjust the PHASE ADJ potentiometer for 200kHz at J16. Connect the circuit shown in Figure 4-7. Set the RF generator to 200kHz at 1Vp-p. Does the phase locked loop appear to be locked? Explain.

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☐ b) Confirm the lock range of the FM detector PLL: Increase the RF generator frequency until the PLL goes out of lock. Determine and note the RF generator frequency at the point just before the loop goes out of lock.

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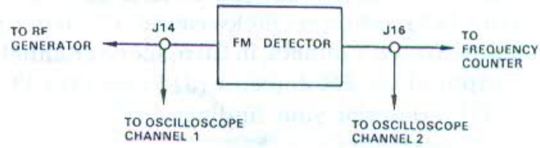

Figure 4-7

☐ c) Connect the AF generator to J14. Set the AF generator for 200kHz at 1Vp-p. Decrease the AF generator frequency until the PLL goes out of lock. Record the frequency just before it goes out of lock.

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☐ d) Change the FREQ SEL switch to LO. Set the AF generator to 10kHz at 1Vp-p. Trigger the oscilloscope on the VCO output at J16. Rotate the PHASE ADJ and describe what happens.

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NOTE: The phase shift can be varied above and below 90 degrees.

☐ e) Use the center frequency adjust (CTR FREQ ADJ) and symmetry adjust (SYMM ADJ) for a 200kHz sine wave at J13 of the FM generator (note that these controls interact: the SYMM ADJ affects the CTR FREQ ADJ). Set the AF generator to 1kHz at 1Vp-p. Set the PHASE ADJ potentiometer on the FM detector for 200kHz at J16.

☐ f) Connect the circuit shown in Figure 4-8. Describe the operation of the system.

☐ g) Turn the AF LEVEL control on the AF generator fully counterclockwise to reduce the modulation to zero. Connect, in turn, scope channel 1 to the output of the FM detector (J15), and the VCO output (J16). Describe your findings.

☐ h) Connect channel 1 of the oscilloscope to J28, the output of the post detection filter. Connect channel 2 of the oscilloscope to J27, the input to the post detection filter. Set the oscilloscope trigger to channel 2, the sweep speed to 1μs/cm, and set the vertical sensitivity of channel 1 to 0.1V/cm and channel 2 to 1V/cm (using X10 probes). Explain the input and output waveforms of the post detection filters.

☐ i) Add modulation to the FM generator by increasing the AF LEVEL control on the AF generator until the channel 1 trace shows a 1cm deflection. Alternately switch the TIME/DIV control on the oscilloscope between 1μs/cm and 0.5ms/cm. Explain the action of the post detection filter in terms of the input and output waveforms.

☐ j) Set the oscilloscope trigger to channel 1 and the sweep speed to 0.5ms/cm. Adjust the AF generator to 2000Hz, then use the AF LEVEL control to set the level at J28 to 1Vp-p. Find the 3dB-down point by increasing the AF generator frequency until the output signal drops to 0.7 times its original amplitude.

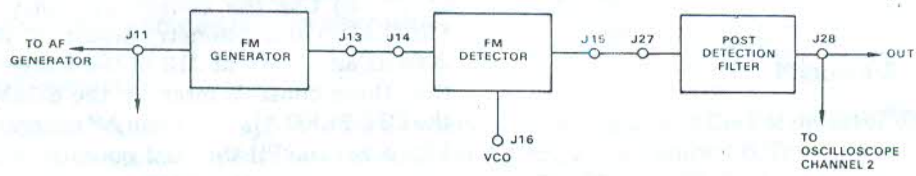

Figure 4-8

Objective B. Determine the operating characteristics of predetection filters.

Preparatory Information

Predetection filters are bandpass filters (see Figure 4-9), which peak at one frequency and roll off on either side of peak. They are used in frequency division multiplex systems to filter noise and separate a subcarrier from its baseband signal. The trainer uses two subcarriers: one at 10kHz and another at 20kHz. There are, therefore, two predetection filters. See Figure 4-10. One has a center pass frequency of 10kHz, and the other has a center pass frequency of 20kHz. By design, the 10kHz filter has maximum gain for the 10kHz subcarrier. But at 20kHz, the 10kHz filter has less than one-half as much gain. The result is an output from the 10kHz predetection filter which consists predominately of the 10kHz subcarrier signal. Similiarly, the output from the 20kHz filter is predominately the 20kHz subcarrier.

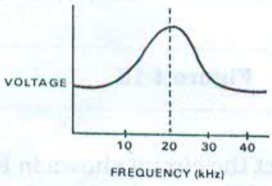

Figure 4-9

A schematic of the predetection filters used on the trainer is shown in Figure 4-11. It is a noninverting active bandpass filter. Its center frequency is set by the time constant of an RC network consisting of R45, R46, R47, C38, and C39. (See Figure 4-11(a)). Doubling the time constant of the network will lower the center frequency of the filter by one half. The values shown in Figure 4-11(a) result in a center frequency

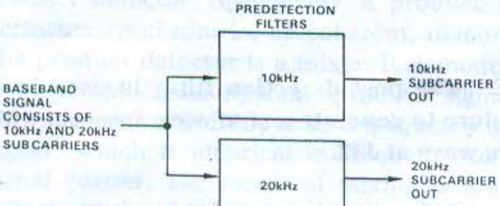

Figure 4-10

of 20kHz. Doubling the value of each resistor *or* each capacitor in the time constant network will double the time constant. The center frequency of the 20kHz filter was lowered to 10kHz when the value of C38 and C39 was doubled by adding a second capacitor of equal value in parallel as shown in Figure 4-11(b).

Resistors R48 and R49 serve as input and feedback resistors to set the gain of the filter. Because the time constant network and the gain network resistors interact in this type bandpass filter, gain of the filters is not equal to Rout/Rin. There is controlled positive feedback from the output to the input of U12 via R47 which results in a center frequency gain of four.

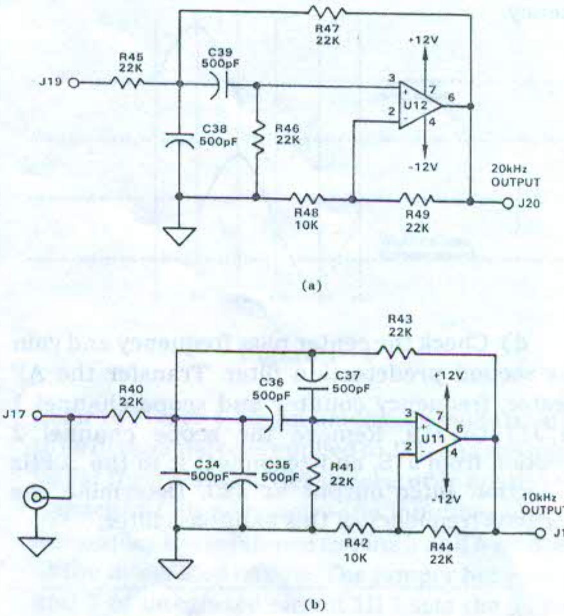

Figure 4-11

Except for the extra set of 500pF capacitors to lower the center frequency to 20kHz, only the reference designations change for the 10kHz predetection filter as shown in Figure 4-11(b).

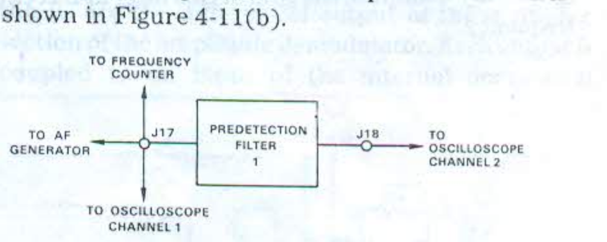

Figure 4-12

☐ 2. a) Connect the circuit shown in Figure 4-12.

☐ b) Set the AF generator for approximately 10kHz at 1Vp-p. Adjust the AF generator frequency for maximum amplitude of the output signal at J18. Describe the characteristics of this filter by observing the amplitude of the filter output as you adjust the frequency above and below the peak amplitude.

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☐ **c)** Compute the gain of the filter at its center frequency.

☐ **d)** Check the center pass frequency and gain of the second predetection filter. Transfer the AF generator, frequency counter and scope channel 1 from J17 to J19. Remove the scope channel 2 connection from J18, and reconnect it to the 10kHz predetection filter output at J20. Determine the center pass frequency of this bandpass filter.

☐ **e)** Compute the gain of this filter at its center frequency.

☐ **f)** Increase the AF generator output to 4Vp-p. Compute the probable output of the predetection filter at J20 and verify your results with the oscilloscope.

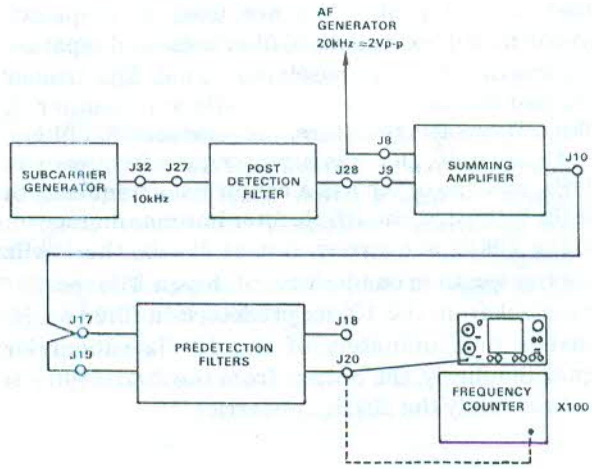

Figure 4-13

☐ **g)** Connect the circuit shown in Figure 4-13. Measure and record the amplitude of the 10kHz sine wave at J9. Set the AF generator to 20kHz *at the same level you measured at J9.* Measure the frequency of the predominate waveform at J20.

NOTE: The post detection filter is used in this procedure to generate a sine wave from the 10kHz square wave at J32.

☐ **h)** Remove the connection at J28. Describe the input to the predetection filters.

☐ **i)** Use the oscilloscope to measure the 20kHz signal amplitude at the output of each predetection filter (J18, J20 respectively). Explain.

☐ j) Replace the connection between J28 and J9. Use the oscilloscope to measure and record the frequency of the signals at J18 and J20. Explain.

Objectvie C. Determine the operation of product detectors and determine the effect a reference phase change has on the demodulated signal.

Preparatory Information.

A *product detector* can be used to demodulate all types of amplitude modulation. A regular AM carrier with two sidebands, double sideband supressed-carrier modulation, and single sideband modulation can all have their intelligence recovered with a product detector. Specifically, a product detector performs synchronous, or coherent, demodulation. The product detector is a mixer. It demodulates all types of AM signals by mixing the AM signal with a reference signal (a BFO, or beat frequency oscillator signal) which is identical in frequency to the AM signal carrier. The result of mixing is a sum and difference signal. When the two signals (the AM and reference) are the same frequency, their difference is zero. The sum signal is easily removed by a simple low pass filter. What remains is the intelligence signal.

Product detectors can also be used to recover intelligence signals which are modulated in quadrature. That can occur when two intelligence-carrying signals occupy the same spectrum space because their carriers are at precisely the same frequency but shifted in phase by ninety degrees. One of its signals is called *in-phase;* the other, the *quadrature* signal, as shown in Figure 4-14. When an in-phase reference signal is applied to the product detector, the quadrature component will be ignored, but the in-phase signal will be demodulated. Similarly, the quadrature signal can be demodulated by a quadrature reference signal which ignores the in-phase signal.

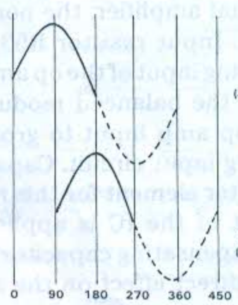

Figure 4-14

Refer to Figure 4-15. An amplitude modulated signal to be demodulated is applied to J21, and the reference signal from a subcarrier generator is applied to J22. Capacitor C40 ac-couples the input signal and C41 ac-couples the reference to pins 3 and 5 respectively, of the integrated circuit. The jumper between pins 6 and 7 of integrated circuit U13 sets the gain of the reference input to maximum, while the gain of the input signal channel is reduced somewhat by the 22 kilohm resistor (R55) between pins 8 and 9. The reference input is operating in its saturated mode as did the balanced modulators (Laboratory Exercise 3) which use the same integrated circuit. Pins 2 and 1 of the IC are the differential output of the multiplier section of the amplitude demodulator. Each output is coupled to an input of the internal operational

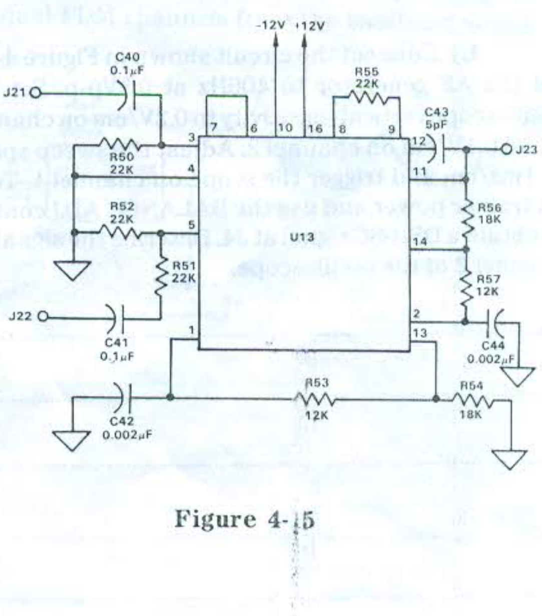

Figure 4-15

amplifier which is part of the operational multiplier IC. Resistor R57 serves as the input resistor for the inverting input of the op amp at pin 14 of the IC, and R56 is the feedback resistor which is connected between IC pins 14 and 11, the op amp output. Capacitor C44 operates in conjunction with an internal 6 kilohm resistor to form a low pass filter to reduce ripple at the subcarrier frequency. The second input to the operational amplifier, the noninverting input, is at IC pin 13. Input resistor R53 connects between the noninverting input of the op amp and the differential output of the balanced modulator. Resistor R54 from the op amp input to ground completes the noninverting input circuit. Capacitor C42 acts as the low pass filter element for this noninverting input. The output of the IC is applied to J23. Capacitor C43 is a compensating capacitor for the IC and, as such, has no direct effect on the amplitude demodulator function.

☐ 3. a) Check the frequency of the subcarrier oscillator at J32 with the frequency counter. Set the period of the waveform if necessary to 100μs (10kHz) with the FREQ ADJ control. What is the frequency of the subcarrier at J31 and J33 as discussed in Laboratory Exercise 2?

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☐ b) Connect the circuit shown in Figure 4-16. Set the AF generator to 400Hz at 0.5Vp-p. Set the oscilloscope vertical sensitivity to 0.2V/cm on channel 1 and 0.1V/cm on channel 2. Adjust the sweep speed to 1ms/cm and trigger the scope on channel 1. Turn on trainer power and use the BALANCE ADJ control to obtain a DSB-SC signal at J4. Describe the signal on channel 2 of the oscilloscope.

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☐ c) Remove the oscilloscope channel 2 probe from J4 and connect it to J23. Explain the waveform. What is it composed of?

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☐ d) Connect J23 to J27 on the post detection filter. Connect the oscilloscope channel 2 probe to J27 and then J28. Explain what function the post detection filter serves in this circuit.

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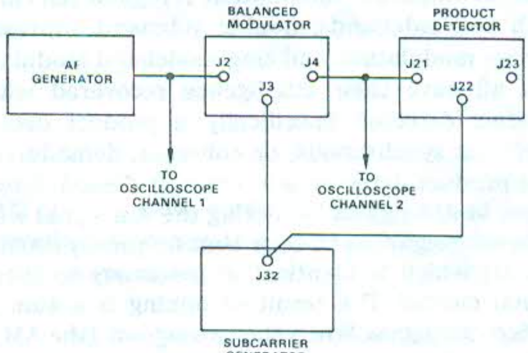

Figure 4-16

☐ e) Shift the connections at J32 to J33 and then to J31. What effect is there on the demodulated 400Hz output of the post detection filter at J28?

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NOTE: There is slightly less ripple at the 20kHz reference because a low pass filter is more efficient at the higher frequency.

☐ f) Separate the reference signals to the system by connecting the balanced modulator (J3) to J32 (10kHz) and by connecting the product detector (J22) to J33 (10kHz shifted 90 degrees from J32). What is the effect on the demodulated 400Hz output at J28 of the post detection filter?

☐ g) Connect the circuit shown in Figure 4-17. What effect does the PHASE ADJ control have on the demodulated output of the product detector? Explain.

☐ h) Use the PHASE ADJ control on the FM detector to place the product detector reference signal in quadrature with the DSB input signal. Explain.

Summary

In this Laboratory Exercise you examined and demonstrated the operation of receiver circuits used in frequency division multiplex systems. These circuits included FM demodulators for recovering frequency-modulated baseband signals, product detectors, and predetection filters used to both reduce noise and separate baseband signals before they are applied to a demodulator. You first determined the lock range of a PLL FM demodulator and observed VCO control and output voltages generated by the PLL when it is locked. Next, you investigated the characteristics of active bandpass filters used as predetection filters that reduce noise before the FDM channels are demodulated. The filters also aid in separating the individual FDM channels from the baseband signal.

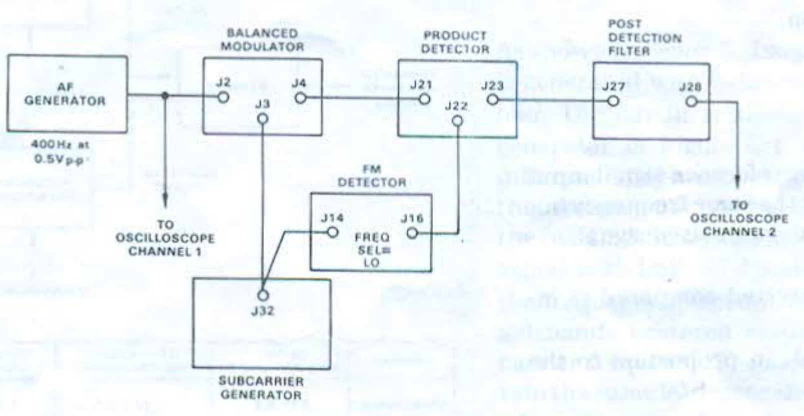


Figure 4-17

And finally, you operated the product detector as it is configured to separate and demodulate an FDM channel. You found that the output of a product detector can be reduced to zero simply by swinging its reference signal 90 degrees from the FDM channel carrier. This fact can be employed to separate two channels that occupy the same place in the frequency spectrum, but which are separated by 90 degrees. The unwanted channel will not appear in the output since its phase is 90 degrees displaced from the phase of the channel you wish to demodulate. This is known as quadrature modulation and demodulation.

Quiz

1. A predetection filter

   a. passes one sideband.
   b. filters noise.
   c. rejects the carrier.
   d. reduces carrier ripple.

2. Important elements of quadrature modulation are

   a. carrier suppression and phase shift.
   b. bandwidth and variable phase shift.
   c. baseband and modulation frequencies.
   d. mixing and efficient use of power.

3. The error signal from the phase detector of the PLL used in FM detection

   a. is a waveform whose duty cycle changes with modulation.
   b. is applied to a post-detection filter.
   c. Neither a nor b.
   d. Both a and b.

4. Product detectors can be used to demodulate

   a. frequency modulation.
   b. in-phase reference signals.
   c. phase modulation.
   d. quadrature signals.

5. If a DSB-SC signal and the reference signal input to a product detector are the same frequency but not the same phase, the demodulated signal

   a. will be amplitude distorted compared to in-phase conditions.
   b. will change amplitude in proportion to the phase difference.
   c. Both a and b.
   d. Neither a nor b.

6. Frequency division multiplex systems recover signals with a

   a. linear detector.
   b. product detector.
   c. envelope detector.
   d. asynchronous detector.

Laboratory Exercise 5

FDM AND QM COMMUNICATIONS

Performance Objectives

A. **Demonstrate the operation of a two-channel frequency division multiplex (FDM) baseband circuit.**

B. **Demonstrate the operation of a two-channel quadrature modulation (QM) baseband circuit.**

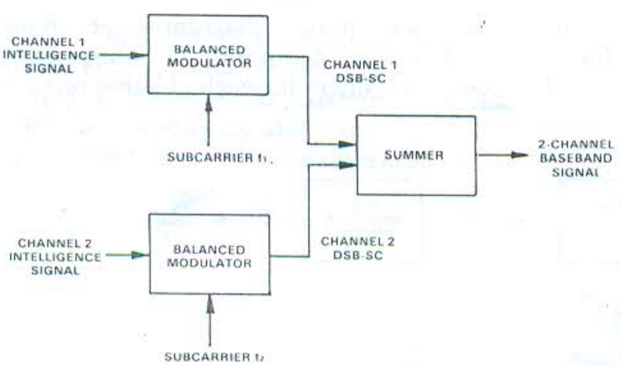
C. **Demonstrate the operation of an FM transmission link modulated with an FDM baseband signal and with a QM baseband signal.**

Basic Concepts

1. Baseband signals contain all the information that modulates a given carrier.
2. A baseband signal can consist of just the intelligence signal or of an encoded signal such as FDM or QM.
3. The basic quadrature modulation system contains two channels.
4. The basic frequency division multiplex system can contain more than two channels.

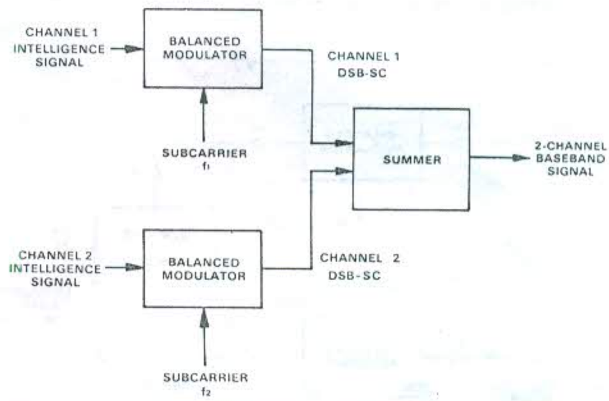
Introductory Information

Frequency division multiplexing systems send two or more channels of information at the same time over one circuit. As shown in Figure 5-1, two different intelligence signals (800Hz and 1600Hz, see table in Figure 5-1) are modulated by separate subcarriers, f1 and f2. The result is two sets of sidebands — one centered around subcarrier f1 containing channel 1 intelligence and the second containing channel 2 intelligence centered around f2. These sidebands (9.2, 10.8, 18.4, and 21.6kHz) are combined by adding them in a linear mixer. The resulting baseband signal consists of only sidebands whenever an intelligence signal is present; the carriers are suppressed by the balanced modulators in each channel.



CHANNEL	INTELLIGENCE SIGNAL (Hz)	SUBCARRIER FREQUENCY (kHz)	DSB-SC SIDEBANDS (kHz)	CARRIER
1.	800	$f_1 = 10$	9.2, 10.8	SUPPRESSED
2.	1600	$f_2 = 20$	18.4, 21.6	SUPPRESSED

Figure 5-1



CHANNEL	INTELLIGENCE SIGNAL (Hz)	SUBCARRIER FREQUENCY (kHz)	DSB-SC SIDEBANDS (kHz)	CARRIER
1.	800	$f_1 = 10$	9.2, 10.8	SUPPRESSED
2.	1600	$f_2 = 10 + 90°$	8.4, 11.6	SUPPRESSED

Figure 5-2

As shown in Figure 5-2, a quadrature basebase signal is generated with balanced modulators and a summer. The circuit is identical to the FDM baseband generator in Figure 5-1. Only the subcarriers are different. They must be the same frequency (10kHz in this system), but one is shifted by 90 degrees. When the two DSB-SC signals are combined into a baseband signal, both DSB-SC signals occupy the same place in the frequency spectrum. And, both signals have their sidebands centered around the suppressed 10kHz carrier frequency. The sidebands do, however, maintain the same 90 degree shift to which their suppressed carriers were held. As a result, although the sidebands overlap in frequency, they are separated by phase which makes them recoverable. The special characteristic of synchronous detectors, which allows them to demodulate only those signals that are the same frequency and phase as the BFO signal, is used to recover the original intelligence signal.

Frequency division multiplexing is used to transmit a large group of channels simultaneously. Major telephone systems utilize FDM to transmit thousands of telephone conversations over one transmission link at the same time. Transmission links include fiber optic and coaxial cables, microwave relay systems, and communication satellites. Once the desired number of channels have been combined, any one of the modulation techniques can be used. Pulse modulation is used for fiber optic links. Frequency modulation is used for the communications link in this trainer. The FDM or QM baseband signal will frequency modulate a 200kHz carrier. The FM signal will be aplied to a phase locked loop FM detector which recovers the baseband signal for the FDM or QM demodulation circuitry.

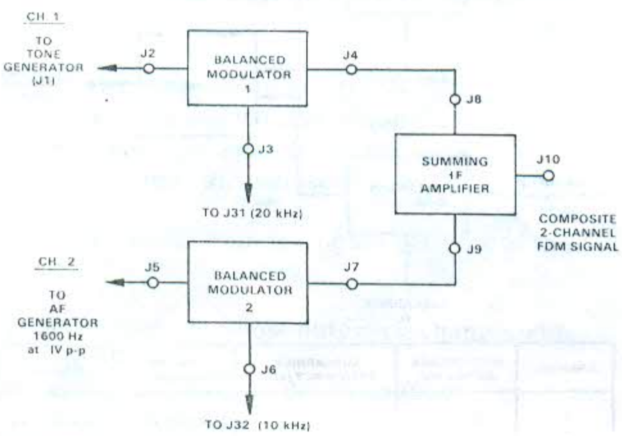


Figure 5-3(a)

Additional Reading

See the bibliography at the back of this manual for additional reading material related to frequency division multiplex receiver circuits.

Equipment And Materials

Power Source	*+15Vdc, 100mA*
Power Source	*-15Vdc, 100mA*
AF/RF Generator	
Dual-trace Oscilloscope	
Frequency Counter	
Frequency Division Multiplexing Trainer	

Exercise Procedure

Objective A. Demonstrate the operation of a two-channel frequency division multiplex (FDM) circuit.

Preparatory Information

Individual elements of a frequency division multiplex system have been investigated and demonstrated in earlier laboratory exercises. Now you will connect a complete FDM system and explore its operation. Figure 5-3 represents a two-channel FDM system that can be constructed with the trainer. Modulating intelligence signals can be in the voice frequency range of approximately 300 to 4000Hz. Subcarriers of 10kHz and 20kHz are applied to balanced modulators along with a modulation signal. As shown in Figure 5-3(a), the tone generator provides the intelligence signal for channel 1 and an AF generator provides the intelligence signal for channel 2. The result is a set of double sideband suppressed carrier signals. A linear mixer, or summer, combines the two sets of sidebands into a composite signal which includes upper and lower sidebands for each channel.

Figure 5-3(b) is a connection diagram of the circuit that demodulates the composite 2-channel FDM signal. Predetection filters for each channel remove

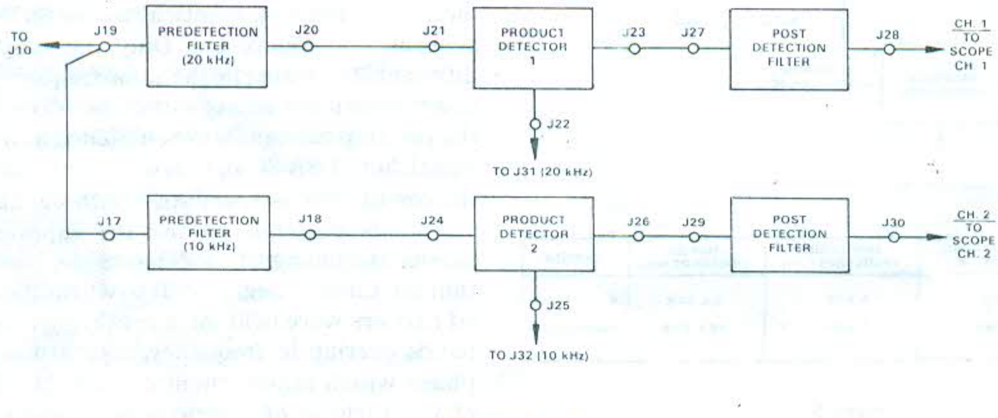


Figure 5-3(b)

noise and unwanted sidebands from the input of each product detector. Separate BFO signals (to J22 and J25) for each product detector match a channel carrier frequency of either 10kHz or 20kHz. The post detection filters pass the detected intelligence signal but not the sum component from the product detector, which is twice the subcarrier frequency.

The purpose of any multiplex system is to send multiple channels of information from one place to another *without* using multiple transmission paths. This trainer sends two channels of information from one place on the board to another using a single wire between J10 and J17. Two independent intelligence inputs are available: channel 1 at J2 and channel 2 at J5. The system multiplexes the input signals, sends them by wire to J17, demultiplexes them and makes channel 1 information available at J28 and channel 2 at J30.

☐ **1.** **a)** Set the power supply outputs to +15Vdc and -15Vdc and connect them to the trainer. With the frequency counter connected to J31, use the FREQ ADJ control to set the subcarrier frequency at J31 to 20kHz. Connect J3 to J32 and use the oscilloscope and the CARRIER ADJ control to balance the carrier from the output of balanced modulator 1 at J4. Connect J6 to J32 and balance the carrier from the output of balanced modulator 2 at J7. Describe the oscilloscope waveform at J4 and J7.

☐ **b)** Connect the circuit shown in Figure 5-3(a). For convenience, set the AF generator for a 1Vp-p sine wave at approximately double the tone generator frequency, about 1600Hz. Observe the output of the balanced modulators at J4 and J7. Explain.

☐ **c)** Connect the oscilloscope probe to J10. Describe the signal. Explain.

☐ **d)** Trigger the oscilloscope on channel 1. Connect channel 1 of the oscilloscope to J7 and channel 2 to J10. Remove the connection between J4 and J8. Observe and explain the oscilloscope display.

☐ **e)** Replace the connection between J4 and J8. Again observe the complex waveform at the output of the summing amplifier at J10, then remove the connection between J1 and J2. Explain the oscilloscope display.

☐ **f)** Add the circuit shown in Figure 5-3(b) to the existing circuit. Trigger the oscilloscope on channel 2 and observe the waveform. Explain.

☐ g) Remove the channel 2 oscilloscope probe from J30 and connect it to J29, the input of the post detection filter. Observe and explain the waveform.

NOTE: A sum signal consists of sidebands whose frequencies are equal to the sideband frequency plus the BFO frequency, which is, in this example, 10kHz.

☐ h) Return the channel 2 oscilloscope probe to J30. Connect J1 to J2. Observe and explain the oscilloscope display.

Objective B. Demonstrate the operation of a two-channel quadrature modulation (QM) baseband circuit.

Preparatory Information

The operation of a *quadrature* multiplex system is quite different from the *frequency division* multiplex system demonstrated in the last exercise procedure, although their circuits are quite similar.

Figure 5-4 represents a two-channel QM system that can be constructed with the trainer. Note the similarity between the circuit used to generate the composite two-channel FDM signal in Figure 5-3(a) and its QM counterpart in Figure 5-4(a). The circuit is identical. Only the frequency of the balanced modulator reference signals is different. As shown in Figure 5-4(a), the 10kHz reference signal from J32 of the subcarrier generator is still connected to J6 of balanced modulator 2. However, the reference signal input to balanced modulator 1, which was 20kHz in the FDM system, is now a 10kHz signal from J33 of the subcarrier generator. The phase between these two 10kHz signals is the only significant difference between them. As discussed in the Introductory Information, it is a 90 degree phase shift.

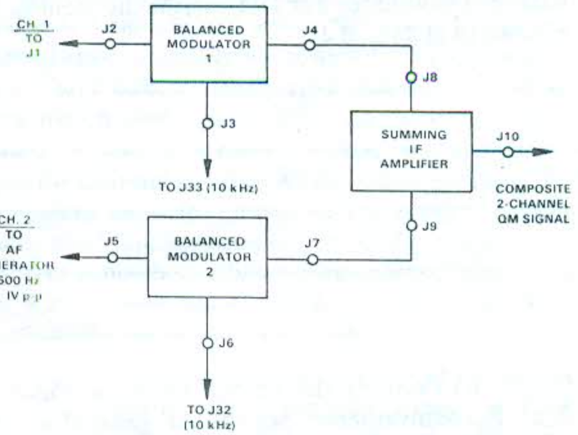


Figure 5-4(a)

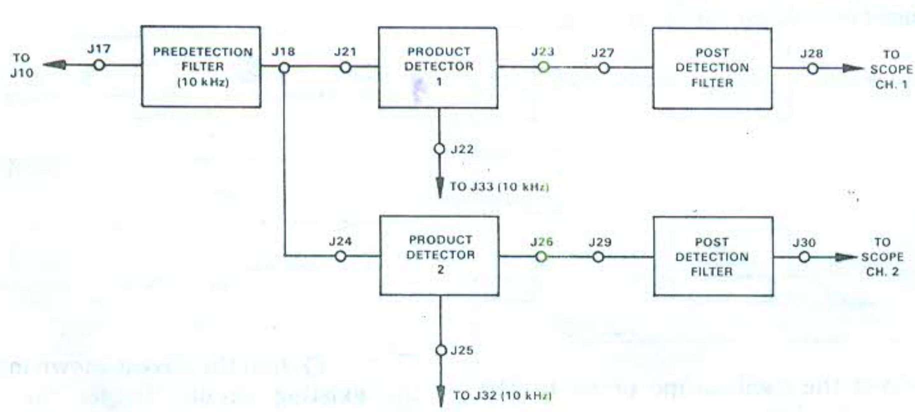


Figure 5-4(b)

Figure 5-4(b) is a connection diagram of the circuit that demodulates the composite 2-channel QM signal. Because both sets of sidebands share the same spectrum space, 10kHz in this system, only the 10kHz predetection filter is required.

Both product detectors receive the same QM signal from a common source — the 10kHz predetection filter. A product detector will demodulate sidebands that have the same phase as the BFO signal. Sidebands that are not the same phase as the BFO will not be demodulated. Full suppression of the unwanted sidebands occurs at 90 degrees, and the demodulated intelligence signal from a product detector is maximum when the phase difference is exactly zero. Between the two extremes, the suppression or demodulated signal amplitude is proportional to the actual phase shift.

As the phase of one of the quadrature signals changes, the unwanted intelligence signal begins to be detected and appears in the unwanted channel, while, at the same time, the desired information begins to be suppressed. The gradual loss of the desired information and the concomitant appearance of unwanted information is crosstalk.

Post detection filters perform the same function in this system as they did in the FDM system. They pass the detected intelligence signal but not the sum component from the product detector.

☐ 2. **a)** Set the power supply outputs to +15Vdc and –15Vdc and connect them to the trainer. With the frequency counter connected to J31, use the FREQ ADJ control to set the subcarrier frequency at J31 to 20kHz. Connect J3 to J32 and use the oscilloscope and the CARRIER ADJ control to balance the carrier from the output of balanced modulator 1 and J4. Connect J6 to J32 and balance the carrier from the output of balanced modulator 2 at J7. Describe the oscilloscope waveform at J4 and J7.

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☐ **b)** Connect the circuit shown on Figure 5-4(a). For convenience, set the AF generator for a 1Vp-p sine wave at approximately double the tone generator frequency, about 1600Hz. Observe the output of the balanced modulators at J4 and J7. Explain.

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☐ **c)** Connect the oscilloscope probe to J10. Describe the signal. Is there an obvious difference between this signal and the FDM signal viewed in step c of the last exercise?

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☐ **d)** Add the circuit shown in Figure 5-4(b) to the existing circuit. Trigger the oscilloscope on channel 1 and trim the FREQ ADJ control on the subcarrier generator for best symmetry and stability of the channel 1 waveform. Explain the waveforms displayed on the oscilloscope.

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☐ **e)** Remove the connection between J33 of the subcarrier oscillator and J22 of product detector 1.

NOTE: The connection between J3 and J33 must remain in place.

☐ f) Connect a wire between J32 and J14. Connect another wire between J16 and J22. Figure 5-5 illustrates these changes which control the phase of the 10kHz subcarrier before it is applied to product detector 1.

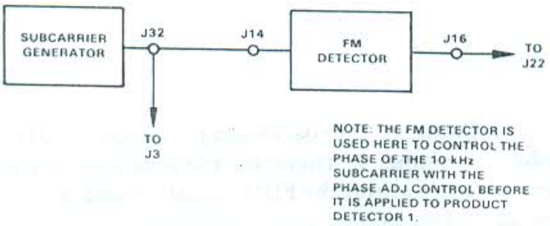

Figure 5-5

☐ g) Set the FREQ SEL switch on the FM detector to LO. While monitoring channels 1 and 2 on the oscilloscope, vary the PHASE ADJ control on the FM detector. Describe and explain the results.

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☐ h) Return the circuit to its original state as shown in Figure 5-4(b). Confirm that the intelligence signals applied to J2 and J5 of the balanced modulators appear, respectively, at J28 and J30 of the post detection filters.

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☐ i) Reverse the subcarriers applied to the product detectors (interchange the plug at J22 with the plug at J25). Describe and explain the results as seen on the oscilloscope.

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Objective C. Demonstrate the operation of an FM transmission link modulated with an FDM baseband signal and with a QM baseband signal.

Preparatory Information

The multiplex signals generated by the trainer are complex waveforms that contain two channels of information. As more channels are added to a multiplex system, that system becomes more efficient. But for a system to be useful, the complex multiplex waveform must be sent from where it is generated to where it will be demodulated and used.

In this exercise, the complex multiplex waveform will be generated and carried by a wire to the demultiplexer on another part of the board. When it is confirmed that the system is working correctly, an FM link will be inserted between the two parts of the multiplex system as shown in Figure 5-6. The FM carrier containing the multiplex signal can be sent over wire, used as a radio link, or used as a subcarrier. If used as a subcarrier, it could modulate a microwave transmitter for relay by communications satellite to other parts of the world.

☐ **3.** a) Apply power to the trainer and connect the oscilloscope to J13 of the FM generator. Vary the symmetry adjust (SYMM ADJ) control for best symmetry of the sine wave. Once this control is set, it should not be readjusted since it affects the center frequency control in the next step.

☐ b) Connect the frequency counter to J13. Use the CTR FREQ ADJ control to set the FM generator carrier frequency to 200kHz.

☐ c) Connect the frequency counter to J16. Connect J14 to ground. Set the FREQ SEL switch on the FM detector to HI. Use the PHASE ADJ control on the FM detector to set the frequency to 200kHz. What have you accomplished in these three exercise steps?

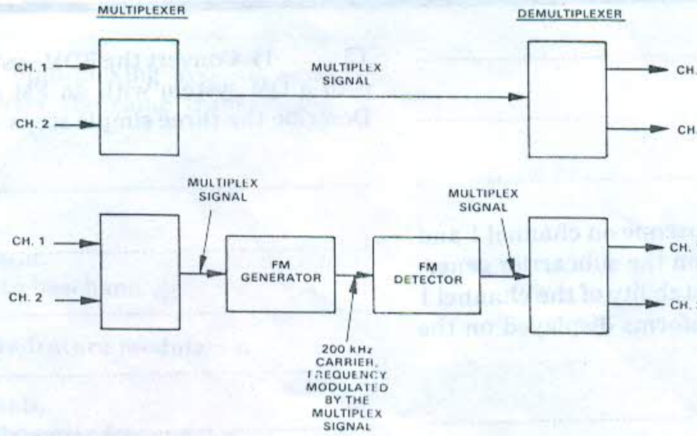

Figure 5-6

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☐ **d)** Connect the circuit shown in Figure 5-7. Describe the operation of the system.

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☐ **e)** Connect the frequency division multiplex system shown in Figure 5-8. This is identical to the FDM circuit you constructed for Objective A. Briefly explain the operation of the circuit and the oscilloscope display.

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☐ **f)** Remove the wire between J10 and J19. Connect it between J13 and J14.

☐ **g)** Connect a wire between J10 and J11. Connect another wire between J15 and J19. Describe the change made to the FDM circuit.

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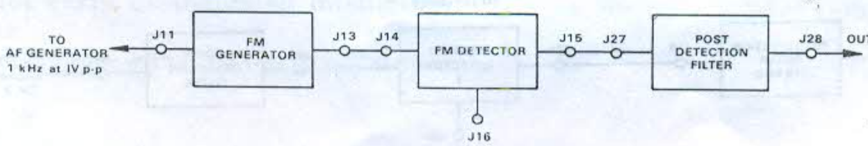


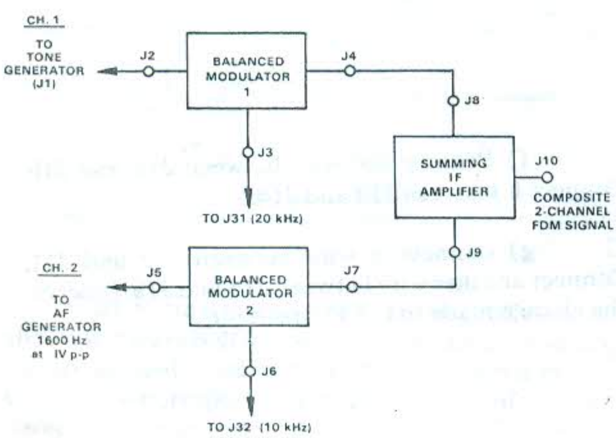
Figure 5-7

☐ h) Trigger the oscilloscope on channel 1 and trim the FREQ ADJ control on the subcarrier generator for best symmetry and stability of the channel 1 waveform. Explain the waveforms displayed on the oscilloscope.

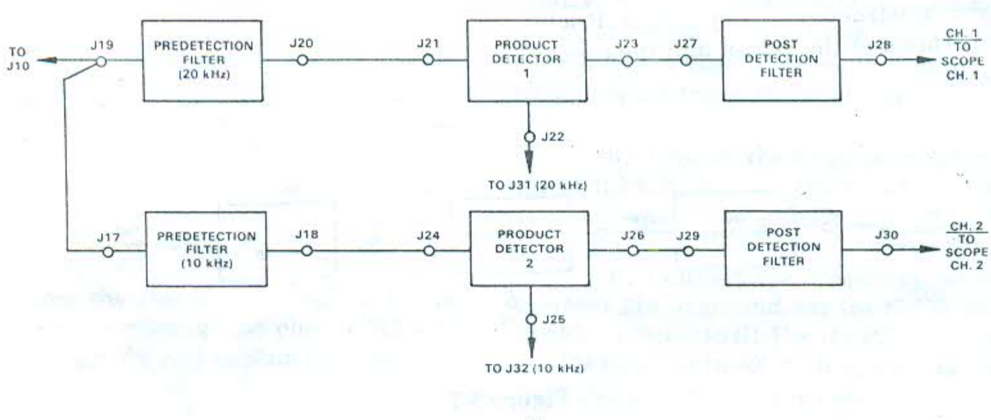
☐ i) Convert the FDM system operated in step *h* to a QM system with an FM communication link. Describe the three simple steps.

Summary

In this Laboratory Exercise you connected and investigated a two-channel frequency division multiplex system. You demonstrated that multiple channels of intelligence can be transmitted without multiple transmission paths using FDM or QM. Frequency division multiplex uses a *different* subcarrier frequency and modulator for each channel in the basic system. The quadrature modulation system uses the *same* subcarrier frequency for each channel in the system, but they are separated by a 90 degree phase shift. A multiplex generator turns multiple transmission paths into one path. A demultiplexer returns the single path back to multiple paths. You also used an FM communication link consisting of an FM generator and FM detector to demonstrate that FDM and QM baseband signals can be sent over other types of transmission links.



(A)



(B)

Figure 5-8

Quiz

1. Frequency division multiplexing systems send multiple channels over the same transmission link

   a. in tandem.
   b. at the same time.
   c. to an FM generator.
   d. without regard to baseband.

2. Systems that use quadrature modulation

   a. develop FM signals.
   b. use common subcarrier frequencies.
   c. develop phase coherent sidebands.
   d. use dual subcarrier frequencies.

3. An FDM system uses a summing amplifier to

   a. remove noise.
   b. detect intelligence.
   c. mix subcarriers.
   d. combine sidebands.

4. Multiple transmission paths can be reduced to a single transmission path

   a. with a multiplex generator.
   b. under conditions of double subcarrier frequencies.
   c. with submultiple sidebands.
   d. under conditions of single quadrature frequencies.

5. Microwave relay, coaxial cable, and communications satellite are examples of FDM

   a. BFO generators.
   b. baseband signals.
   c. transmission links.
   d. complex waveforms.

6. The FM communication link demonstrated in this Laboratory Exercise

   a. will carry only demodulated intelligence signals.
   b. will operate only with QM subcarrier signals.
   c. did not carry demodulated intelligence signals.
   d. did not operate with FDM subcarrier signals.

ANSWERS TO PROCEDURE QUESTIONS

LABORATORY EXERCISE 1

Objective A

b. Maximum output of the filter occurred at approximately 20kHz. Therefore, the frequency of one of the subcarriers in this FDM system must also be 20kHz.

c. Maximum output of the filter occurred at approximately 10kHz. Therefore, the frequency of one of the subcarriers in this FDM system must also be 10kHz.

d. The post detection filter is an effective filter for blocking the subcarrier frequencies. It will pass detected signals up to approximately 4kHz.

Objective B

a. The frequency of the signals at J32 and J33 is 10kHz.

b. The valleys of a 100-percent modulated amplitude-modulated waveform touch but do not overlap.

c. The signal at J23 is a 1kHz sine wave. It is the intelligence signal recovered from the AM waveform by the product detector.

d. The output of the product detector no longer contains the detected 1kHz intelligence signal because the BFO signal was removed. The signal consists of the undetected AM waveform.

e. The product detector no longer detects the intelligence component because the BFO signal (now 10kHz) is no longer the same frequency as the modulated carrier (still 20kHz).

LABORATORY EXERCISE 2

Objective A

b. Yes. The signals at J32 and J33 are correct if each is 10kHz. Each 10kHz signal is derived from the 20kHz signal that appears at J31.

c. The signals at J31 and J32 are synchronized. The signal at J32 is the output of a flip flop triggered by the 20kHz signal at J31.

d. The circuit maintains a constant 90 degree phase difference between the two 10kHz signals.

e. The frequency of the signal at J1 is nominally 770Hz, and its amplitude is nominally 0.9Vp-p.

f. The waveform at J1 is a sine wave.

Objective B

a. The output of the post detection filter at J28 is approximately 1.7Vp-p.

b. The voltage gain is typically 1.7. $G = V_{out}/V_{in} = 1.7/1 = 1.7$.

c. The 3dB-down frequency is typically 4kHz. This is the upper cutoff frequency of the post detection filter.

d. The 10kHz signal at J28 is typically 0.15Vp-p under the stated conditions. For a given input level, the output of the post detection filter is much less for a 10kHz signal than for a 1kHz signal. The 10kHz signal is suppressed because it is outside the bandpass of the post detection filter.

e. The signal at J28, the output of the post detection filter, is an amplified version of the input signal from the tone generator. This 770Hz signal is not suppressed by the post detection filter because it is within the 4kHz bandpass of the filter.

LABORATORY EXERCISE 3

Objective A

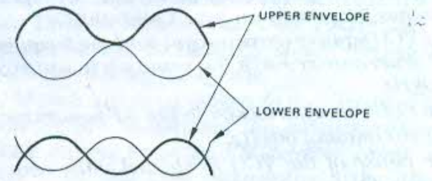
a. The waveform at J4 is an AM signal modulated to something less than one hundred percent.

b. The waveform at J4 represents an AM signal at one hundred percent modulation. The carrier adjust control was used to reduce the carrier power until the fixed, modulating signal power was adequate to modulate the carrier to one hundred percent.

c. Reducing the AF level lowered the modulation percentage from one hundred to zero in the traditional way; that is, by reducing the power of the modulating signal while the carrier power remained constant.

d. The type of signal is double sideband with suppressed carrier (DSB-SC). When the carrier is reduced to zero, all that remains of an AM signal are the sidebands; these are depicted on an oscilloscope as overlapping upper and lower limits of the AM envelope.

e.



f. The circuit converts a signal at J4 to a DSB-SC equivalent, and then demodulates the DSB-SC signal to recover the original, modulating signal.

g. The waveform at J23 is the demodulated double-sideband suppressed carrier signal that was generated by the AM/SSB modulator circuit. The waveform is a result of the 1kHz modulation signal from the AF generator. The demodulated 1kHz signal exhibits ripple at the carrier frequency.

h. There is approximately a 0.5 volt shift in the demodulated output dc level above and below the point of carrier balance. The dc level is a result of the demodulation process and is proportional to the amount of carrier present.

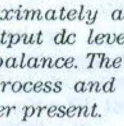
Objective B

b. The output voltage of the summing amplifier is 1.4 times the input.

c. The gain is nearly double when the inputs are tied together.

d. The 3dB-down bandwidth of the summing amplifier is from approximately 25Hz to between 50kHz and 75kHz.

e.



f. Yes. The oscilloscope display shows the high frequency signal "riding" on the low frequency signal. This is the characteristic oscilloscope display of signals which have been added rather than multiplied.

Objective C

b. The graph is relatively straight and covers a frequency ratio of at least 2:1. The straight area of the graph shows a linear voltage-to-frequency relationship. The upper frequency value depends upon the setting of the SYMM ADJ control as well as the CTR FREQ ADJ control.

c. The gain of the control voltage stage gradually increases with frequency over its useful frequency range up to about 50kHz.

d. At a scope sweep speed of 2μs/cm, the 200kHz carrier can clearly be seen under the influence of 1000Hz modulating signal. The change in frequency of the carrier is evident by a gradual thickening of the waveform from left to right.

e. Each half cycle of the 100kHz modulating frequency affects the frequency of one cycle of the 200kHz carrier waveform. Therefore, one cycle of the carrier will be raised in frequency and the next cycle will be lowered in frequency in a repeating pattern.

LABORATORY EXERCISE 4

Objective A

a. Yes. The square wave at J16 is the VCO output. As the RF generator frequency is varied, the square wave changes frequency an equal amount.

b. The VCO square wave output and the frequency of the RF generator remain the same up to approximately 300kHz.

c. The PLL remains locked to the AF generator down to approximately 60kHz.

d. The phase of the VCO is shifted with respect to the comparator input.

f. A 1000Hz sine wave modulates a 200kHz carrier from the FM generator. The FM signal is demodulated by the FM detector and filtered to recover the 1kHz sine wave.

g. The output of J13 is the 200kHz unmodulated carrier wave. The waveform at J15 is the filtered output of the PLL phase comparator. The square wave at J16 is the VCO output waveform generated by the PLL.

h. The input of the post detection filter is the VCO control voltage waveform which results from detecting the unmodulated FM generator carrier. The duty cycle of this waveform under no modulation is constant, and so the output of the post detection filter is zero.

i. The input waveform is the VCO control waveform which is varying in step with the modulation and contains some of the 200kHz carrier frequency. The post detection filter removes the carrier and passes only the 1kHz modulation frequency.

j. The 3dB-down point of the post detection filter is approximately 4kHz.

Objective B

b. A filter whose output peaks at one frequency and drops off above and below that peak, as this one does, has the characteristics of a bandpass filter. This bandpass filter has a center pass frequency of approximately 10kHz.

c. $$\begin{aligned} gain &= V_{out}/V_{in} \\ &= 4/1 \\ &= 4 \end{aligned}$$

d. The center pass frequency of this predetection bandpass filter is approximately 20kHz.

e. $$\begin{aligned} gain &= V_{out}/V_{in} \\ &= 4/1 \\ &= 4 \end{aligned}$$

f. The input signal amplitude of 4Vp-p times a filter gain of four results in a verifiable 16 volts p-p at the predetection filter output.

g. A 20kHz sine wave appears at J20. The center pass frequency of this predetection bandpass filter is approximately 20kHz.

h. The input to the predetection filters at J17 and J19 is a 20kHz sine wave from the AF generator.

i. The output of the 20kHz predetection filter at J20 is two to three times as great as the 10kHz filter output at J18. The gain of a predetection filter is maximum only at its center frequency. Other frequencies are attenuated.

j. The frequency at J18 is 10kHz and at J20 it is 20kHz. The predetection filters separate the baseband signal into its individual 10kHz and 20kHz components.

Objective C

a. The frequency of the subcarrier at J31 is double the frequency at J32, and the signal at J33 is the same frequency as the signal at J32 but shifted in phase by 90 degrees.

b. The waveform at J4 is a double sideband suppressed carrier signal. With the carrier suppressed, only the characteristic overlapping-envelope display remains.

c. The waveform at the output of the product detector consists of two frequencies: the 400Hz intelligence signal, which results from the difference between the two input signals, and the sum of the two signals.

d. The post detection filter removes the high frequency sum signal component with a low pass filter. The 400Hz intelligence signal is not affected by the low pass filter.

e. There is no change in the demodulated 400Hz intelligence signal when the reference frequency changes between 10kHz and 20kHz (J31) or the phase changes 90 degrees (J32, J33).

f. There is no 400Hz output since the reference signal to the product detector is 90 degrees from the phase of the DSB input signal.

g. The output of the product detector changes amplitude in proportion to the phase difference between the DSB input signal and the reference signal.

h. The PHASE ADJ control is varied until the 400Hz intelligence signal at J28 of the post detection filter is reduced to zero. At that point, the DSB input signal and the reference signal to the product detector are separated by 90 degrees.

LABORATORY EXERCISE 5

Objective A

a. There is no significant output from the balanced modulators at J4 and J7. When balanced, there is no carrier at the output of the balanced modulator.

b. The output at J4 and J7 is the characteristic overlapping envelope display of a double-sideband suppressed-carrier signal.

c. The signal at J10 is a complex waveform. It is a composite of upper and lower sidebands generated by the balanced modulators from the two subcarriers and two intelligence signals.

d. The output of the summing amplifier at J10 is the same as the input to the summing amplifier at J9. Removing the connection between J4 and J8 *eliminated one of the two DSB-SC signals from the output of the summing amplifier.*

e. *The output of the summing amplifier at J10 is again identical to the input at J9. When a balanced modulator is balanced and the intelligence input is removed, there is no output. Therefore, one of the DSB-SC signals was again eliminated from the output of the summing amplifier.*
f. *The waveform on channel 2 is the intelligence signal applied to J5 of balanced modulator 2. There is no signal on channel 1 of the oscilloscope because the intelligence signal input was removed in an earlier step.*
g. *The input to the post detection filter is the output of the product detector. It contains both the intelligence signal and the sum signal. NOTE: A sum signal consists of sidebands whose frequencies are equal to the sideband frequency plus the BFO frequency, which is, in this example, 10kHz.*
h. *The oscilloscope displays the two intelligence signals. The complete 2-channel frequency division multiplex system is in operation.*

Objective B

a. *There is no significant output from the balanced modulators at J4 and J7. When balanced, there is no carrier at the output of the balanced modulator.*
b. *The output at J4 and J7 is the characteristic overlapping envelope display of a double-sided suppressed-carrier signal.*
c. *The signal at J10 is a complex waveform. It is a composite of upper and lower sidebands. Only the phase of one of the suppressed subcarriers is different, which is not obvious in a complex oscilloscope waveform.*
d. *The waveform on channel 1 is the intelligence signal applied to J2 of balanced modulator 1. The channel 2 waveform is the intelligence signal applied to J5 of balanced modulator 2. A complete quadrature modulation system is in operation.*
g. *As the phase of the 10kHz subcarrier used as a BFO signal for product detector 1 is varied, the shape of the demodulated signal on channel 1 of the oscilloscope also varies. The demodulated signal becomes distorted by crosstalk as the subcarrier shifts out of its normal quadrature condition.*
h. *With the connections shown in Figure 5-4, the nominal 800Hz signal at J2 appears at J28. The nominal 1600Kz signal at J5 appears at J30.*
i. *When the subcarriers are reversed, the demodulated signals appear on the opposite channel. A product detector demodulates the DSB-SC signal that is in phase with its BFO. Each detector has a signal to demodulate since sidebands of both channels are applied to each balanced modulator.*

LABORATORY EXERCISE 5

Objective C

c. *The FM generator and FM detector have been adjusted to operate at a carrier frequency of 200kHz.*
d. *A 1kHz sine wave modulates a 200kHz carrier at the FM generator. The FM signal is demodulated by the FM detector and filtered to recover the 1kHz sine wave.*
e. *The circuit develops an FDM signal at J10 consisting of two DSB-SC signals based on 10kHz and 20kHz subcarriers. The oscilloscope shows the intelligence signals carried by the system.*
g. *An FM link has been added to the circuit. The FDM signal at J10 modulates the FM generator whose 200kHz output feeds the FM detector input. The FM signal is demodulated and applied to the input of the predetection filters.*
h. *The waveform on channel 1 is the intelligence signal applied to balanced modulator 1. Channel 2 is the intelligence signal applied to balanced modulator 2. A complete FDM system with an FM communication link is in operation.*
i. *(1) Make the subcarriers equal in frequency but phase shifted 90 degrees by moving the two wires from J31 to J33. (2) Apply the QM signal to both product detectors by moving the wire at J20 to J18. (3) Trim FREQ ADJ control on subcarrier generator for best symmetry of the demodulated waveforms.*

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