

Analog Communications

FACET®



Student Workbook

91578-00
Edition 4



3091578000503

FOURTH EDITION

Second Printing, March 2005

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ISBN 0-86657-224-4

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Introduction

This Student Workbook provides a unit-by-unit outline of the Fault Assisted Circuits for Electronics Training (F.A.C.E.T.) curriculum.

The following information is included together with space to take notes as you move through the curriculum.

- ◆ The unit objective
- ◆ Unit fundamentals
- ◆ A list of new terms and words for the unit
- ◆ Equipment required for the unit
- ◆ The exercise objectives
- ◆ Exercise discussion
- ◆ Exercise notes

The **Appendix** includes safety information.

UNIT 1 – INTRODUCTION TO ANALOG COMMUNICATIONS

UNIT OBJECTIVE

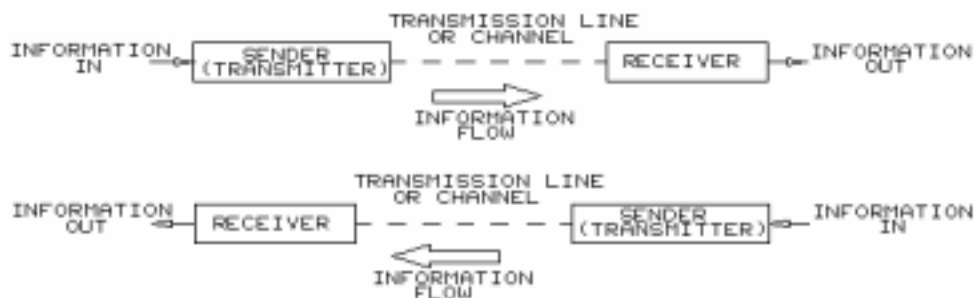
At the completion of this unit, you will be able to describe the basic principles of analog radio communications, the ANALOG COMMUNICATIONS circuit board, and the balanced modulator.

UNIT FUNDAMENTALS



A block diagram of a communication system is shown.

Communication is the transfer of information from one place to another.

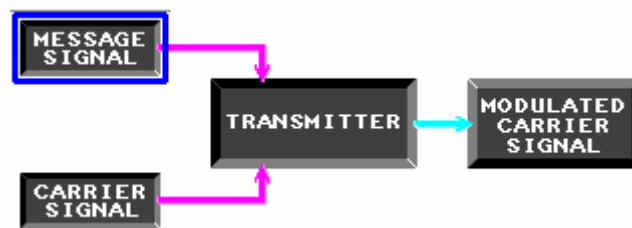


A bidirectional communication system operates in opposite directions. The receiver can respond to the sender.

Radio communication uses electrical energy to transmit information. Because electrical energy travels almost as fast as light, radio communication is essentially instantaneous.

A radio transmitter converts **audio** (sound) signals to electrical signals that are sent over wires or through space.

A radio receiver converts the **electromagnetic waves** back to sound waves so that the information can be understood.



The transmitted information is the **intelligence signal** or **message signal**

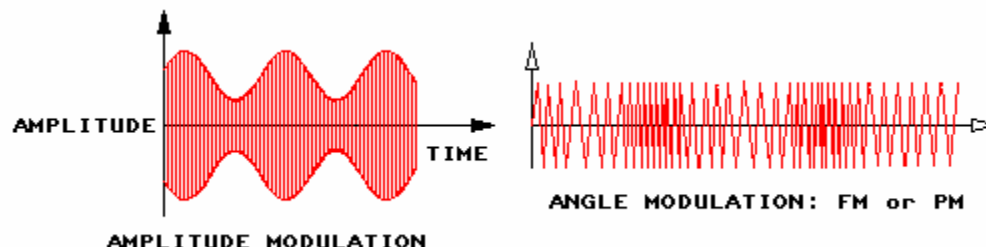
In this course, the term message signal refers to the transmitted information. Message signals are in the **Audio Frequency (AF)** range of low frequencies from about 20 Hz to 20 kHz.

The **Radio Frequency (RF)** is the **carrier signal**. Carrier signals have high frequencies that range from 10 kHz up to about 1000 GHz.

A radio transmitter sends the low frequency message signal at the higher carrier signal frequency by combining the message signal with the carrier signal.

Modulation is the process of changing a characteristic of the carrier signal with the message signal. In the transmitter, the message signal modulates the carrier signal.

The modulated carrier signal is sent to the receiver where **demodulation** of the carrier occurs to recover the message signal.



The three principal forms of modulation are the following:

- **Amplitude Modulation (AM)**
- **Frequency Modulation (FM)**
- **Phase Modulation (PM)**

FM and PM are types of **angle modulation**.

In modulation, the message signal changes the amplitude, frequency, or phase of the carrier signal.

FREQUENCY	DESIGNATION	ABBREVIATION
30 Hz – 300 Hz	EXTREMELY LOW FREQUENCY	ELF
300 Hz – 3000 Hz	VOICE FREQUENCY	VF
3 kHz – 30 kHz	VERY LOW FREQUENCY	VLF
30 kHz – 300 kHz	LOW FREQUENCY	LF
300 kHz – 3 MHz	MEDIUM FREQUENCY	MF
3 MHz – 30 MHz	HIGH FREQUENCY	HF
30 MHz – 300 MHz	VERY HIGH FREQUENCY	VHF
300 MHz – 3 GHz	ULTRA HIGH FREQUENCY	UHF
3 GHz – 30 GHz	SUPER HIGH FREQUENCY	SHF
30 GHz – 300 GHz	EXTRA HIGH FREQUENCY	EHF

To prevent interference, every radio communication transmits at its own frequency.

The designations for carrier frequency ranges are shown.

The ANALOG COMMUNICATIONS circuit board contains the following circuit blocks:

- VCO-LO
- AM/SSB TRANSMITTER
- PHASE MODULATOR
- QUADRATURE DETECTOR
- VCO-HI
- AM/SSB RECEIVER
- PHASE-LOCKED LOOP

These circuit blocks permit you to configure transmission and reception circuits for amplitude, frequency, and phase-modulated signals.

On the ANALOG COMMUNICATIONS circuit board, a versatile Integrated Circuit (IC) called a **balanced modulator** performs the following functions:

- amplitude modulation
- Double-Sideband (DSB) modulation
- mixer
- product detector
- phase detector

NEW TERMS AND WORDS

audio - signals that a person can hear.

electromagnetic waves - the radiant energy produced by oscillation of an electric charge.

intelligence signal - any signal that contains information; it is also called the message signal.

message signal - any signal that contains information; it is also called the intelligence signal.

Audio Frequency (AF) - frequencies that a person can hear. AF signals range from about 20 Hz to 20 kHz.

Radio Frequency (RF) - the transmission frequency of electromagnetic (radio) signals. RF frequencies are from about 300 kHz to the 1,000,000 kHz range.

carrier signal - a single, high-frequency signal that can be modulated by a message signal and transmitted.

Modulation - the process of combining the message signal with the carrier signal that causes the message signal to vary a characteristic of the carrier signal.

demodulation - the process of recovering or detecting the message signal from the modulated carrier frequency.

Amplitude Modulation (AM) - the process of combining the message signal with the carrier signal and the two sidebands: the lower sideband and the upper sideband.

Frequency Modulation (FM) - the process of combining the message signal with the carrier signal that causes the message signal to vary the frequency of the carrier signal.

Phase Modulation (PM) - the process of combining the message signal with the carrier signal that causes the message signal to vary the phase of the carrier signal.

angle modulation - the process of combining the message signal with the carrier signal that causes the message signal to vary the frequency and/or phase of the carrier signal.

balanced modulator - an amplitude modulator that can be adjusted to control the amount of modulation.

Double-Sideband (DSB) - an amplitude modulated signal in which the carrier is suppressed, leaving only the two sidebands: the lower sideband and the upper sideband.

mixer - an electronic circuit that combines two frequencies.

product detector - a detector whose audio frequency output is equal to the product of the Beat Frequency Oscillator (BFO) and the RF signal inputs.

phase detector - an electronic circuit whose output varies with the phase differential of the two input signals.

envelopes - the waveform of the amplitude variations of an amplitude modulated signal.

sidebands - the frequency bands on each side of the carrier frequency that are formed during modulation; the sideband frequencies contain the intelligence of the message signal.

AM - an amplitude modulated signal that contains the carrier signal and the two sidebands: the lower sideband and the upper sideband.

bandwidth - the frequency range, in hertz (Hz), between the upper and lower frequency limits.

harmonics - signals with frequencies that are an integral multiple of the fundamental frequency.

Beat Frequency Oscillator (BFO) - an oscillator whose output frequency is approximately equal to the transmitter's carrier frequency and is input to a product detector.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit

ANALOG COMMUNICATIONS circuit board

Multimeter

Oscilloscope, dual trace

Generator, sine wave

NOTES

Exercise 1 – Analog Communication Concepts

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe the basic principles of analog radio communications.
- recognize a message signal, a carrier signal, and a modulated signal.

You will use an oscilloscope to make signal measurements.

DISCUSSION

- Analog signals are continuous; they vary in amplitude, frequency, and/or phase.
- Digital signals are discontinuous; they are either high (logic 1) or low (logic 0).
- Message signals (information) have low frequencies from 20 Hz to 20 kHz.
- Carrier signals have frequencies from 10 kHz to 1000GHz.
- Modulation is where the message signal changes a characteristic (amplitude, frequency or phase) of the carrier signal so that the message can be transmitted at the higher carrier frequency.
- Radio signals are transmitted by conduction through a wire or radiated through space.
- In the receiver, demodulation is the process of recovering the message signal from the modulated carrier signal.
- Bandwidth of an AM signal is the difference between the highest and the lowest frequency on each side of the carrier

NOTES

Exercise 2 – Circuit Board Familiarization

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe analog radio communications circuits.
- locate them on the ANALOG COMMUNICATIONS circuit board.

You will use an oscilloscope to make signal measurements.

DISCUSSION

- The ANALOG COMMUNICATION circuit board contains seven circuit blocks.
- The circuit blocks include oscillators, amplifiers, modulators, mixers filters , LC networks limiters and detectors.
- The circuit blocks can be configured for the transmission and reception of AM, SSB, FM, and PM.

NOTES

Exercise 3 – Balanced Modulator

EXERCISE OBJECTIVE

When you have completed this exercise on the balanced modulator, you will be able to

- describe the circuit block.
- explain the output signal's relationship to the two input signals.
- describe the operation and applications.

You will use an oscilloscope to make measurements.

DISCUSSION

- The balanced modulator on the circuit board is an IC (1496).
- The circuit consists of a dual differential amplifier, a differential amplifier, and a current source
- The output of the balanced modulator is a full-wave multiplication of the two input signals
- The balanced modulator may have a null potentiometer to adjust the amount of modulation or suppress the carrier frequency in the output.
- The balanced modulator's output will contain the sum and difference frequencies of the inputs plus the carrier frequency if it is not suppressed.
- The balanced modulator can be used as an AM modulator, an SSB modulator, a mixer, a product detector, and a phase detector.

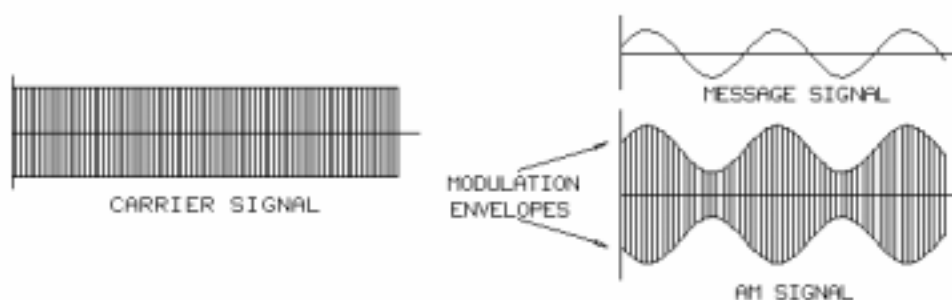
NOTES

UNIT 2 – AM TRANSMISSION

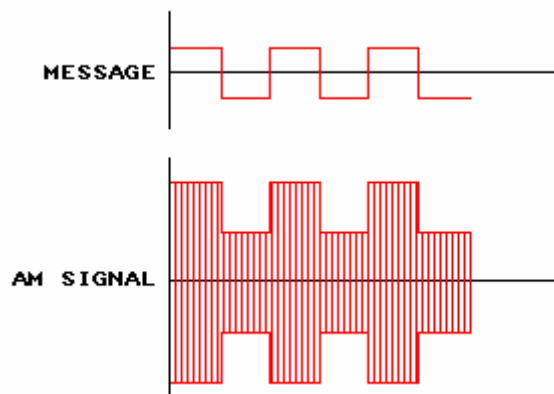
UNIT OBJECTIVE

When you have completed this unit, you will be able to describe AM transmission circuits and signals by using the AM/SSB TRANSMITTER circuit block on the ANALOG COMMUNICATIONS circuit board.

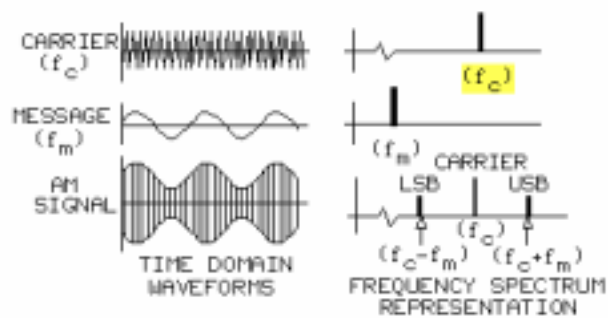
UNIT FUNDAMENTALS



Amplitude modulation (AM) produces a modulation envelope that has the same waveform as the message signal.

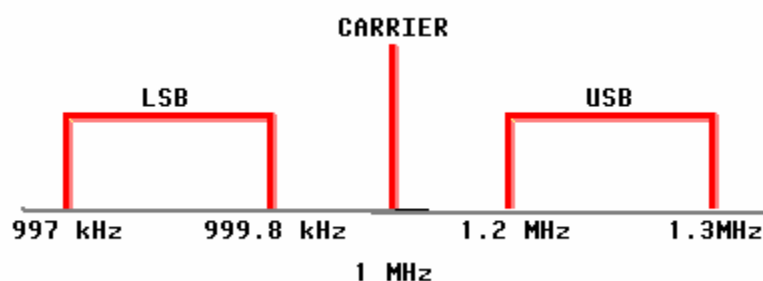


If the message signal were a square wave, the modulation envelope of the AM signal would be a square wave.



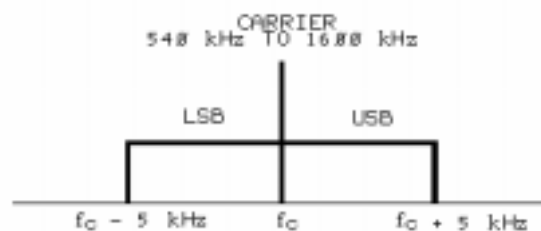
When the message signal is a sine wave, the frequency spectrum of the modulated carrier signal (AM signal) consists of three frequency components.

- the carrier (f_c)
- the upper side-band (USB) ($f_c + f_m$)
- the lower side-band (LSB) ($f_c - f_m$)



When the message signal is a more complex waveform, such as voice, the frequency spectrum is correspondingly more complex and contains many more frequency components.

Therefore, a wider **bandwidth** (frequency space) is necessary to transmit the information.



Commercial AM broadcasting, which is usually in the frequency band from 540 kHz to 1600 kHz, has a 10 kHz bandwidth.

AM **baseband** signals, which include voice and music, are limited from about 100 Hz to 5 kHz.

NEW TERMS AND WORDS

bandwidth - the frequency range, in hertz (Hz), between the upper and lower frequency limits.

baseband - the band of frequencies occupied by a message signal.

frequency translate - the process of displacing the frequency contents of a signal to another place in the frequency spectrum.

modulation index (m) - the ratio between the amplitudes of the message signal and the unmodulated carrier signal.

percentage of modulation (% Mod.) - the modulation index expressed as a percentage ($m \times 100$).

overmodulation - the term used when the modulation index is greater than 1. It occurs when the peak amplitude of the message signal is greater than the peak amplitude of the unmodulated carrier signal.

transmission efficiency - fraction of the total AM signal power that is contained in the sidebands.

splatter - adjacent-channel interference (fake sideband frequencies) due to overmodulation of carrier signal by abrupt peak message signals.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit

ANALOG COMMUNICATIONS circuit board

Oscilloscope, dual trace

Generator, sine/square wave

EQUIPMENT REQUIRED (VI)

F.A.C.E.T. base unit

ANALOG COMMUNICATIONS circuit board

Virtual Instrument

Oscilloscope, dual trace

Generator, sine/square wave

Spectrum analyzer

NOTES

Exercise 1 – Amplitude Modulation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe the generation of amplitude-modulated signals and explain how the message signal affects the shape of the AM signal,
- calculate the modulation index and percentage of modulation from AM signal parameters,
- describe 100% modulation, overmodulation, and transmission efficiency.

You will use an oscilloscope to make AM signal measurements.

DISCUSSION

- The AM signal envelope has the same shape and frequency as the message signal
- There are many ways to produce an AM signal, but all of them must allow the amplitude variations of the message signal to be impressed onto the carrier signal.
- The amplitude modulator mixes the message and carrier signals to frequency translate the message signal: it shifts the message signal to the carrier signal's frequency.

NOTES

Exercise 2 – RF Power Amplifier

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- adjust the output impedance of the RF power amplifier,
- measure circuit parameters to calculate the RF power amplifier input power, output power, and power gain,
- calculate the percentage of output power transferred to the antenna load,
- calculate the total power, carrier power, and sideband power of an AM signal.

You will measure the circuit parameters with an oscilloscope.

DISCUSSION

- The RF power amplifier is the last active stage before the transmitting antenna and provides the power amplification necessary for the antenna to radiate the RF signals over long distances.
- An antenna-matching network provides the RF amplifier with the output impedance necessary to transfer the power to the low-impedance antenna.
- In the transmission of radio signals, efficiency is the primary importance in power amplifiers because any loss of power means less power radiated.

NOTES

UNIT 3 – AM RECEPTION

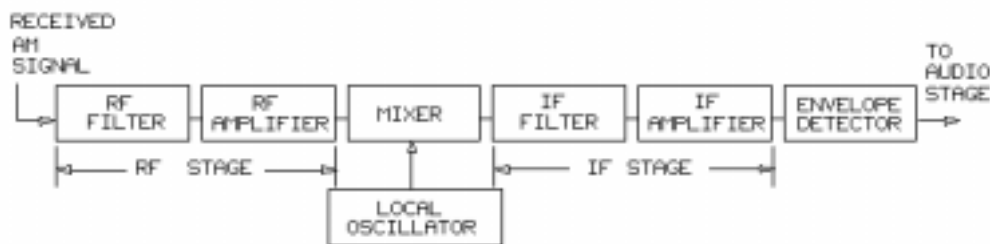
UNIT OBJECTIVE

At the completion of this unit, you will be able to describe AM reception circuits and signals by using the AM/SSB RECEIVER circuit block on the ANALOG COMMUNICATIONS circuit board.

UNIT FUNDAMENTALS

An Amplitude Modulation (AM) receiver must be able to single out, or select, a desired station and then recover the message signal that is being broadcast by that particular AM transmitter.

The ability of a radio receiver to select a desired radio signal frequency while rejecting all others is called **selectivity**.



NOTE: The IF amplifier is not included on the circuit board.

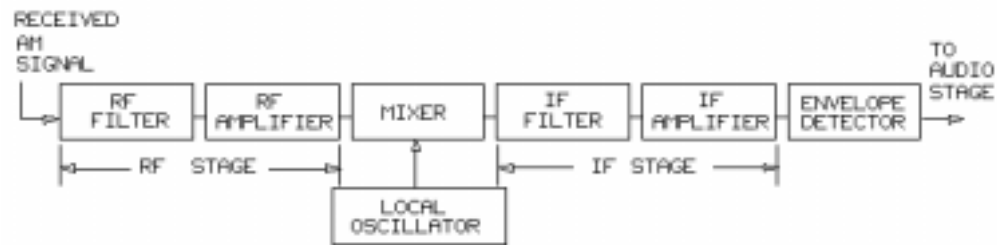
The basic sections of the AM receiver on the circuit board are shown.

By adjusting the Radio Frequency (RF) filter on the circuit board, you select a frequency range (bandwidth) that has the desired AM signal as its resonant frequency.

You tune the RF amplifier by adjusting an inductor in its collector circuit; the power level of the selected AM signal is greatly increased.

The RF filter and RF amplifier compose the **RF stage** of the receiver.

To permit the **Intermediate Frequency (IF) stage** of an AM receiver to be designed for a fixed frequency, the mixer combines the selected AM signal with a **Local Oscillator (LO)** signal to produce a 455 kHz IF signal regardless of the selected AM frequency.



NOTE: The IF amplifier is not included on the circuit board.

The IF filter is a ceramic band-pass filter with a bandwidth of 20 kHz that attenuates all frequencies below 445 kHz and above 465 kHz.

If necessary, an IF amplifier provides additional power gain. The IF amplifier is not included on the circuit board.

The IF filter and IF amplifier are components of the IF stage.

The **envelope detector** demodulates the 455 kHz IF signal to return the message signal to its original frequency.

The message signal then goes to the audio stage, which is not included on the circuit board, for further amplification and conversion to sound by the speaker.

NEW TERMS AND WORDS

selectivity - a measure of how well a receiver rejects adjacent station signals when tuned to a particular station.

RF stage - the first input stage, in which primary selection, filtering and amplification of the input RF (radio frequency) signal is performed.

Intermediate Frequency (IF) stage - that section of a receiver between the mixer and the detector. The IF stage operates at a fixed intermediate frequency (FIF) and is where most of the amplification and filtering occurs.

Local Oscillator (LO) - an oscillator in a piece of electronic equipment that is usually used as a source of electromagnetic wave frequencies for mixing with other frequencies that the equipment handles.

envelope detector - a circuit containing a diode in series with an RC network; used to perform demodulation.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit

ANALOG COMMUNICATIONS circuit board

Oscilloscope, dual trace

Generator, sine wave

NOTES

Exercise 1 – RF Stage

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- calculate the AM signal power at an RF filter input,
- describe how an RF filter is tuned to filter an AM signal,
- and calculate the power gain of an RF amplifier.

You will use an oscilloscope to make AM signal measurements.

EXERCISE DISCUSSION

- The transmitted AM signal is sent by a direct connection between the transmitter and receiver on the circuit board.
- The RF filter bandwidth is large enough to pass the upper sideband (USB) and the lower sideband (LSB) frequencies.
- The filter provides a 50Ω match for the receiving antenna.

NOTES

Exercise 2 – Mixer, IF Filter, and Envelope Detector

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- explain the operation of the mixer,
- describe the function of the IF filter,
- and describe how the envelope detector converts a 455 kHz AM signal to the message signal.

You will use an oscilloscope to make signal measurements.

DISCUSSION

- The mixer combines the 1000 kHz AM signal from the RF stage with a 1455 kHz LO signal to produce a 455 kHz difference signal and a 2455 kHz sum frequency.
- The IF filter is designed to pass a 455 kHz signal with a bandwidth (20 kHz) that includes the AM sidebands: the LSB at 445 kHz and the USB at 465 kHz.
- A diode detector is a nonlinear charging circuit formed by a diode in series with a parallel RC network.
- When an AM signal is applied to the envelope detector circuit input, the diode conducts only during the positive portion of the AM signal.

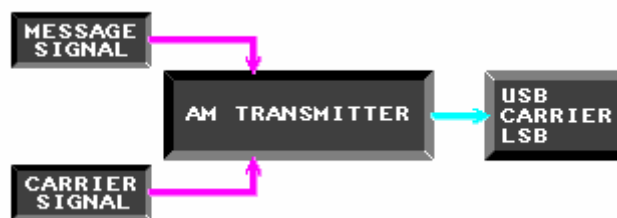
NOTES

UNIT 4 – SSB TRANSMISSION

UNIT OBJECTIVE

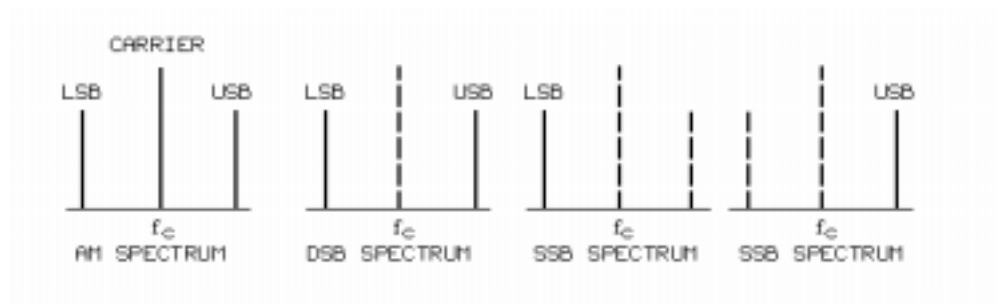
At the completion of this unit, you will be able to describe single sideband (SSB) transmission circuits by using the AM/SSB TRANSMITTER circuit block on the ANALOG COMMUNICATIONS circuit board.

UNIT FUNDAMENTALS



Unit 2 described and demonstrated Amplitude Modulation (AM) transmission.

The transmitter converts the message signal frequency to the frequency of the carrier signal and transmits the Upper Sideband (USB), Lower Sideband (LSB), and the carrier.

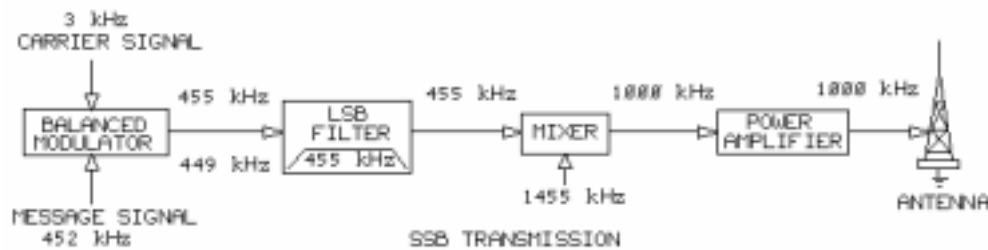


For an AM signal, the message signal is frequency translated to sidebands centered around the carrier frequency.

Double Sideband (DSB) modulation removes the carrier frequency (f_c) from the AM signal, leaving only the LSB and USB frequencies.

A DSB signal is an amplitude-modulated signal with the carrier frequency removed.

Removing one of the sideband frequencies from a DSB signal produces a **Single Sideband (SSB)** signal; either sideband may be removed because each sideband contains the complete message signal intelligence.



On the circuit board, a balanced modulator translates the 3 kHz message signal frequency and suppresses the 452 kHz carrier signal in the SSB transmitter.

The 449 kHz LSB and the 455 kHz USB are output from the balanced modulator.

A **ceramic filter** attenuates the 449 kHz LSB, and the 455 kHz USB is output as the SSB signal to the **balanced mixer**.

The **mixer**, which is a balanced modulator, increases the frequency of the 455 kHz SSB signal to the transmission frequency of 1000 kHz.

A **tuned LC network** at the output of the mixer attenuates the 455 kHz input and 1910 kHz sum frequencies; the 1000 kHz SSB signal is output from the mixer to a power amplifier.

A high gain power amplifier increases the SSB power to the antenna.

On your circuit board, the power amplifier and its antenna matching network tuned for 1000 kHz are the same circuits used for AM transmission.

NEW TERMS AND WORDS

Double Sideband (DSB) - an amplitude-modulated signal in which the carrier is suppressed leaving only the two sidebands: the lower sideband and the upper sideband.

Single Sideband (SSB) - an amplitude-modulated signal that contains only one of the sidebands: either upper sideband or lower sideband.

ceramic filter - a filter (normally constructed from lead zirconatetitanate) that derives its frequency selectivity from a mechanical deformity resulting from an electric field (Piezoelectric effect). A ceramic filter usually has a narrow bandwidth.

balanced mixer - a device that generates output frequencies equal to the sum and difference of the two input frequencies: the carrier frequency is suppressed. In an SSB transmitter, the balanced mixer performs an upconversion.

mixer - an electronic device that combines two frequencies.

tuned LC network - a circuit consisting of an inductor (L) and a capacitor (C) that passes signals within a desired frequency range (bandwidth).

up-conversion - an electronic process that increases the frequency of a signal. In an SSB transmitter, the balanced mixer performs an up-conversion.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
ANALOG COMMUNICATIONS circuit board
Oscilloscope, dual trace
Generator, sine wave

EQUIPMENT REQUIRED (VI)

F.A.C.E.T. base unit
ANALOG COMMUNICATIONS circuit board
Virtual Instrument
Oscilloscope, dual trace
Generator, sine wave

NOTES

Exercise 1 – Balanced Modulator and LSB Filter

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe how a balanced modulator produces a DSB signal.
- explain how the SSB is output from the LSB filter.
- understand why an SSB has low power consumption and a narrow bandwidth.

You will use an oscilloscope to make signal measurements.

DISCUSSION

- The balanced modulator translates a message signal to two sidebands and suppresses the carrier signal frequency to produce a DSB signal.
- With AM, only one of the sidebands is required to send the complete message signal.
- To produce an SSB signal from the DSB signal, a ceramic bandpass filter with a narrow 4 kHz bandwidth is used to remove the 449 kHz LSB signal.
- A SSB signal transmission uses only 16.5% of the total 100% modulated AM signal power and is less than half of the AM signal's bandwidth.

NOTES

Exercise 2 – Mixer and RF Power Amplifier

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe the operation of a balanced mixer.
- explain the function of the mixer's output LC network.
- describe the operation of an RF power amplifier.
- understand the advantages of SSB transmission.

You will use an oscilloscope to make signal measurements.

DISCUSSION

- The process of increasing the frequency of a signal to a higher frequency for transmission is called up-conversion.
- The mixer, which is a balanced modulator, performs the up-conversion.
- The RF power amplifier has a tuned antenna-matching network that matches the impedance of the RF amplifier to the impedance of the antenna.

NOTES

UNIT 5 – SSB RECEPTION

UNIT OBJECTIVE

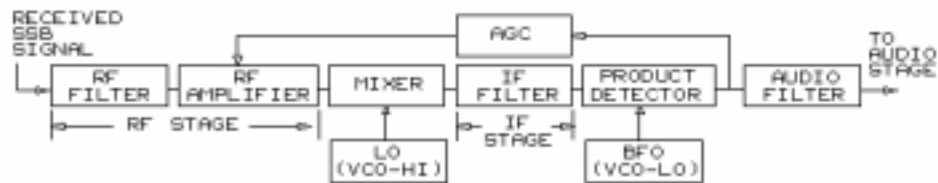
At the completion of this unit, you will be able to describe SSB reception circuits and signals by using the AM/SSB RECEIVER circuit block on the ANALOG COMMUNICATIONS circuit board.

UNIT FUNDAMENTALS

Single Sideband (SSB) is commonly used in the overcrowded frequency range of 2 MHz to 30 MHz.

The SSB receiver on the circuit board is very similar to the Amplitude Modulation (AM) receiver.

The difference is that the SSB receiver has a **product detector** and an audio filter (in place of the AM envelope detector) plus **Automatic Gain Control (AGC)**. Commercial AM receivers also have AGC circuits.

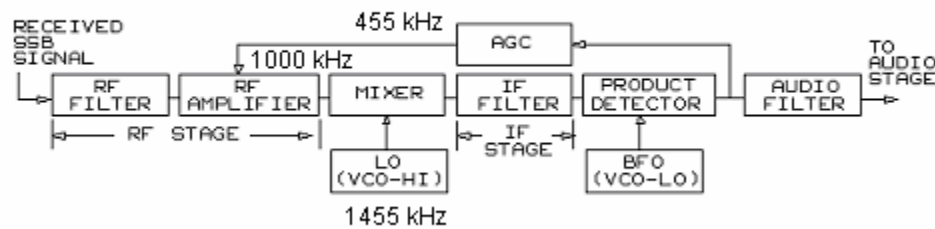


The Radio Frequency (RF) filter, RF amplifier, mixer, and Intermediate Frequency (IF) filter components are the same for both AM and SSB reception.

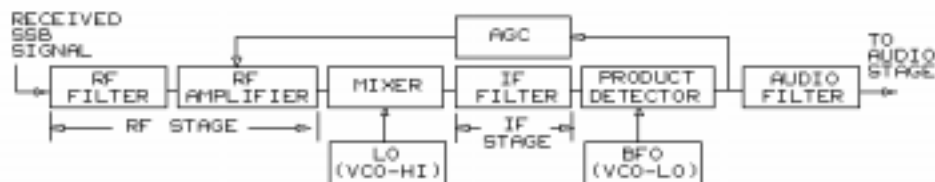
For both AM and SSB reception, these components perform the exact same functions with signals that have the same frequencies; on your circuit board, a 1000 kHz RF signal is converted to a 455 kHz RF signal.

You adjust the RF filter and RF amplifier to select the desired SSB frequency. The RF amplifier greatly increases the SSB power.

The mixer combines the selected SSB signal with a Local Oscillator (LO) signal to produce a 455 kHz IF signal regardless of the selected SSB frequency.



On the ANALOG COMMUNICATIONS circuit board, the mixer combines a 1000 kHz signal with the 1455 kHz local oscillator VCO-HI signal to produce a 455 kHz SSB intermediate frequency signal. The 1455 kHz VCO-HI is also an input to the transmitter's mixer.



The IF filter is a ceramic band pass filter with a bandwidth of 4 kHz that filters all frequencies below 453 kHz and above 457 kHz.

If necessary, an IF amplifier may be included in the receiver to provide additional power gain. The IF amplifier is not included on your circuit board.

Because an SSB signal does not have a message signal envelope like an AM signal, the SSB uses a product detector instead of an envelope detector.

The product detector is a balanced modulator that combines the IF filter's SSB 455 kHz signal with a **BFO (Beat Frequency Oscillator)** signal, whose frequency has to be exactly the same as the 452 kHz carrier signal to the transmitter's modulator.

An audio filter passes the message signal (AF signal) frequency and filters all other frequencies that are output from the product detector.

The message signal from the audio filter then goes to the audio stage, which is not included on your circuit board, for further amplification and conversion to sound by the speaker.

An SSB receiver uses the average strength of the demodulated signal as **feedback** through an AGC circuit to the RF stage.

On your circuit board, the AGC circuit maintains the audio volume when the received signal power changes by varying the gain of the RF amplifier.

NEW TERMS AND WORDS

product detector - a detector whose audio frequency output equals the product of the beat frequency oscillator (BFO) and the RF signal inputs.

Automatic Gain Control (AGC) - a circuit that maintains the output volume of a receiver, regardless of the variations in the received signal power.

BFO (Beat Frequency Oscillator) - an oscillator whose output frequency is approximately equal to the transmitter's carrier frequency and is input to product detector that recovers the message signal.

feedback - a signal derived from a circuit output signal and fed back to a previous circuit component to cause a change that controls the output.

down-converter - an electronic device that decreases the frequency of a signal. In the SSB receiver, the balanced mixer is a down-converter.

propagation path - the radiation route traveled by electromagnetic waves.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit

ANALOG COMMUNICATIONS circuit board

Multimeter

Oscilloscope, dual trace

Generator, sine wave

NOTES

Exercise 1 – RF Stage, Mixer, and IF Filter

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe how an RF filter is tuned for an SSB signal.
- calculate the power gain of an RF amplifier.
- adjust the mixer to produce a 455 kHz SSB signal from the IF filter.

You will use an oscilloscope to make SSB signal measurements.

DISCUSSION

- In a SSB receiver, the RF filter passes the desired signal and matches the antenna impedance.
- The balanced mixer is a down-convertor because it reduces the SSB frequency from 1000 kHz to 455 kHz.
- The IF filter is a ceramic filter and has a higher attenuation rate than a typical LC filter.

NOTES

Exercise 2 – Product Detector and AGC

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe the operation of a product detector and an audio filter.
- explain how the Automatic Gain Control (AGC) circuit maintains the amplitude of the recovered message signal.

You will use an oscilloscope and a multimeter to make measurements.

DISCUSSION

- An envelope detector, which demodulates an AM signal, cannot demodulate an SSB signal.
- A product detector demodulates an SSB signal to recover the message signal.
- The product detector is a balanced modulator that requires a beat frequency oscillator (BFO) to provide a reference frequency.
- The function of an AGC circuit is to vary the gain of the controlled stages so that the audio output is constant when the strength of the received signal varies.

NOTES

UNIT 6 – ANGLE MODULATION AND DEMODULATION

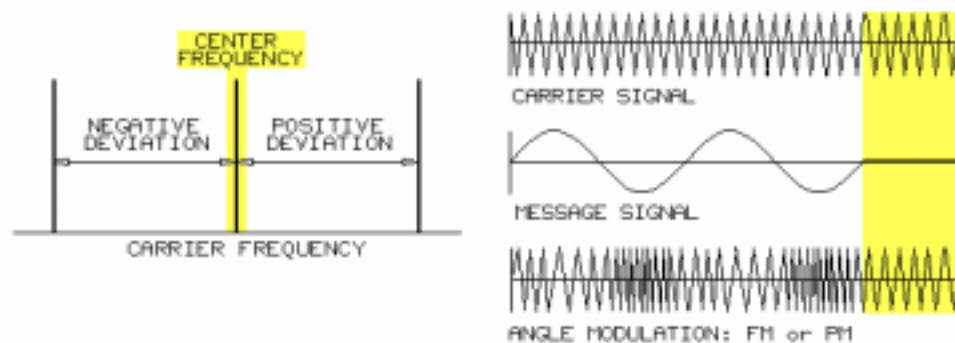
UNIT OBJECTIVE

At the completion of this unit, you will be able to describe angle modulation and demodulation by using the VCO-LO, PHASE MODULATOR, and QUADRATURE DETECTOR circuit blocks on the ANALOG COMMUNICATIONS circuit board.

UNIT FUNDAMENTALS

Angle modulation includes frequency modulation (FM) and phase modulation (PM).

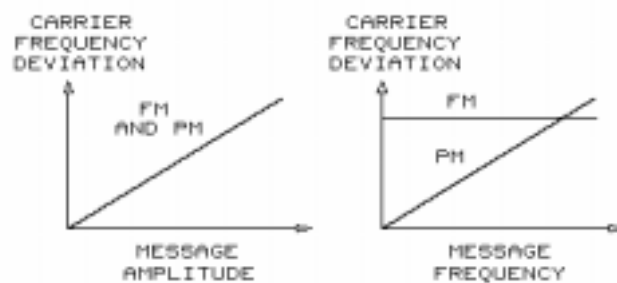
FM and PM are interrelated; one cannot change without the other changing.



When the message signal amplitude is zero, there is no change in the FM carrier frequency; the carrier is at its **center frequency**.

Frequency deviation is the positive or negative change in the carrier frequency from its center frequency.

In FM, the frequency of a sine wave carrier deviates from its center frequency by an amount that is proportional to the message signal amplitude.

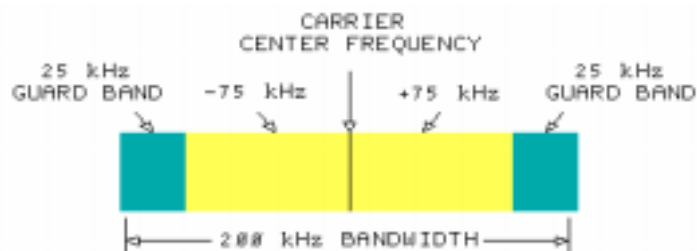


In PM, like FM, the frequency (and phase angle) of a sine wave carrier changes by an amount that is proportional to the message signal amplitude.

The message signal frequency also deviates the carrier frequency in PM.

Instead of specifically referring to FM or PM, angle modulation is commonly called FM.

FM transmission provides better random noise rejection than AM transmission. Because of better noise rejection in the receiver, FM provides a greater transmission distance than AM for the same frequency and transmitter power.



Radio stations in the broadcast band of 88 MHz to 108 MHz use FM to transmit audio on the radio frequency (RF) carrier wave.

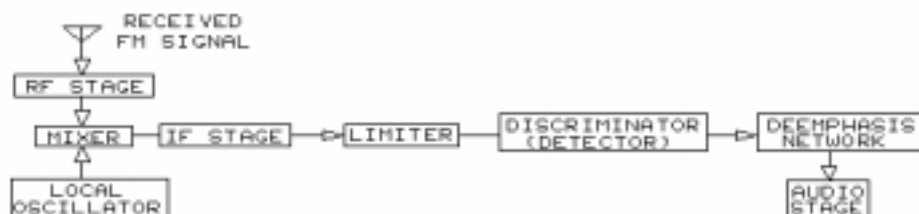
In the United States, the Federal Communications Commission (FCC) has defined 100% modulation as a deviation of 75 kHz above and below the assigned RF carrier center frequency.

To minimize possible interaction between stations, an additional "guard band" of 25 kHz is on either side of these extremes.

Broadcast FM allows for a true high-fidelity modulating signal up to 15 kHz, as opposed to 5 kHz for AM.

For strictly voice communications, used by police, aircraft, taxicabs, and private networks, the message signal bandwidth is limited to a maximum of 3 kHz.

These narrowband FM systems have FCC bandwidth allocations of 10 kHz to 30 kHz.



The front of an FM receiver is very similar to an AM or Single Sideband (SSB) receiver.

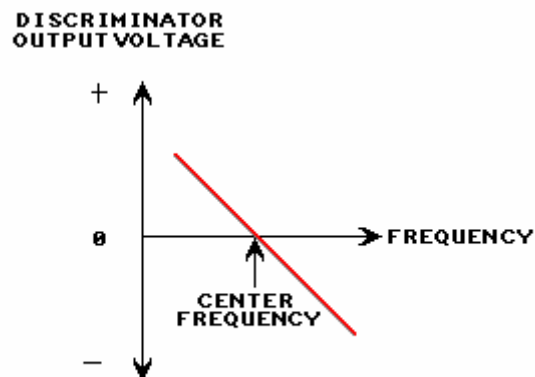
There is an RF stage, mixer, and intermediate frequency (IF) stage; an automatic gain control (AGC) circuit may or may not be present.

The standard frequency for the FM IF stage is 10.7 MHz, compared to 455 kHz for AM.

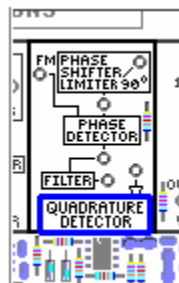
A **discriminator**, the detector of an FM receiver, is a device that extracts the message signal from frequency or phase variations of the carrier signal. **Discriminator** is the preferred term for an FM demodulator.

The de-emphasis network brings high-frequency message signals back to the proper relationship with the lower frequencies.

The audio stage provides the necessary amplification and volume control for the recovered message signal.



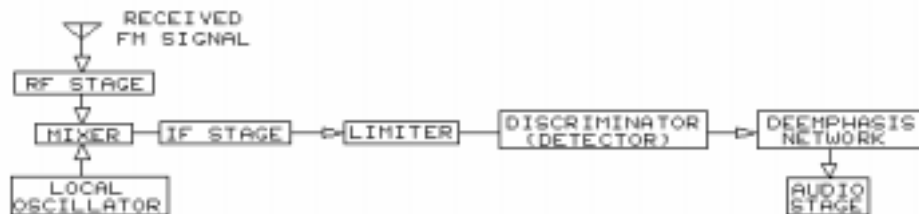
The discriminator outputs a message signal amplitude that depends on the carrier frequency deviation.



On your circuit board, the **QUADRATURE DETECTOR** circuit block is the discriminator that limits and demodulates an FM signal.

The QUADRATURE DETECTOR circuit block contains a PHASE SHIFTER/LIMITER, a PHASE DETECTOR, and a FILTER.

Other types of discriminators include the Foster-Seely discriminator, the ratio detector, and the phase-locked loop.



The FM RF stage, mixer, and IF stage are very similar to the corresponding AM reception circuits.

Since you have already studied the functions of these circuits, they are not included in this discussion of FM reception.

FM FREQUENCIES MHz	USERS
52 TO 53	NARROWBAND AMATEUR
54 TO 88	TV AUDIO
88 TO 92	NONCOMMERCIAL BROADCAST
92 TO 108	COMMERCIAL BROADCAST
108 TO 174	NARROWBAND PUBLIC SERVICE
146 TO 147.5	NARROWBAND AMATEUR
174 TO 216	TV AUDIO
216 TO 448	NARROWBAND PUBLIC SERVICE
448 TO 458	NARROWBAND AMATEUR
478 TO 886	TV AUDIO
> 886	NARROWBAND PUBLIC SERVICE
> 902	NARROWBAND AMATEUR

The table shows FM frequencies assigned by the FCC to the following users.

NARROWBAND AMATEUR

TV AUDIO

NONCOMMERCIAL BROADCAST

COMMERCIAL BROADCAST

NARROWBAND PUBLIC SERVICE

NEW TERMS AND WORDS

center frequency - the frequency of the unmodulated FM carrier signal.

Frequency deviation - the maximum frequency change between a modulated and unmodulated carrier signal.

discriminator - a device that demodulates an FM signal.

quadrature - the phase relationship between two equal frequency signals that are 90° out of phase.

percentage of modulation - the modulation index expressed as a percentage ($m \times 100$).

sideband pair - two sidebands that are spaced equally on each side of the center frequency.

FM modulation index - the ratio of frequency deviation to the message signal frequency.

significant sideband pairs - the number of sideband pairs that contain significant energy content.

signal-to-noise ratios - the ratio of the magnitude of the signal to that of noise (often expressed in decibels).

varactor diode - a diode that changes capacitance with a change in input voltage.

Schottky diodes - diodes that have a low forward voltage drop in the range of 0.2V to 0.4V.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit

ANALOG COMMUNICATIONS circuit board

Signal generator, (sine wave)

Oscilloscope, dual trace

Multimeter

NOTES

Exercise 1 – Frequency and Phase Modulation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- describe frequency modulation and an FM circuit.
- describe phase modulation and a PM circuit.

You will use an oscilloscope and a multimeter to make measurements.

DISCUSSION

- In FM, the carrier signal frequency deviates only with the message signal amplitude.
- In FM, the message signal's frequency does not deviate the carrier signal's frequency but does affect the rate of deviation.
- Amplitude variations of the FM carrier contain no message signal intelligence; only frequency deviations contain the intelligence.
- The percentage of modulation describes the extent of the carrier frequency deviations.
- Like AM, the FM carrier signal sidebands contain the message signal intelligence.
- The bandwidth required for an FM signal depends upon two factors: the message signal amplitude and frequency.
- In PM, the carrier signal changes its phase (and frequency) with the changes in the message signal amplitude and frequency.

NOTES

Exercise 2 – Demodulation (Quadrature Detector)

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- explain demodulation of an FM signal.
- describe the operation of a quadrature detector.

You will use an oscilloscope and a multimeter to make measurements.

DISCUSSION

- FM demodulators are referred to as discriminators or frequency detectors.
- An FM discriminator converts the magnitude and rate of the frequency deviations into the amplitude and frequency of the message signal.
- The phase detector outputs a signal with a frequency that is twice the FM frequency and a dc voltage that varies with the phase difference between the two inputs.

NOTES

UNIT 7 – PHASE-LOCKED LOOP

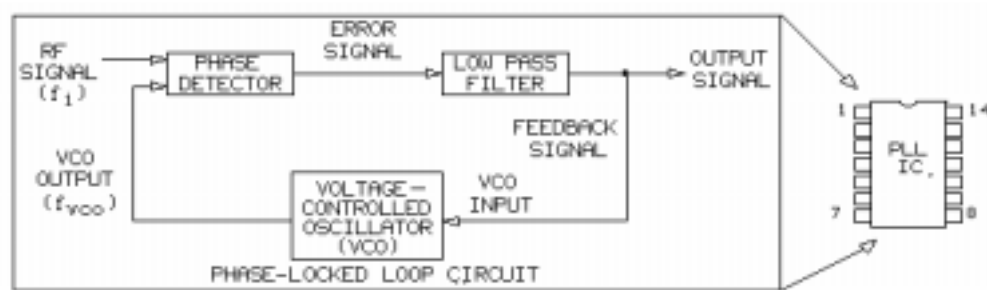
UNIT OBJECTIVE

At the completion of this unit, you will be able to describe phase-locked loop operation by using the VCO-LO and PHASE-LOCKED LOOP circuit blocks on the ANALOG COMMUNICATIONS circuit board.

UNIT FUNDAMENTALS

PHASE-LOCKED LOOP CIRCUIT

Although developed in 1932, it was not until the 1970s that the **phase-locked loop (PLL)** became widely available as a low-cost integrated circuit (IC), which led to its use in many electronic applications.



A PLL can generate, modulate, select, demodulate, and multiply signals.

Instrumentation, television, space telemetry, and many other applications requiring a high degree of noise immunity and a narrow bandwidth use PLLs.

PLLs are used in FM and AM demodulation because they do not require complex coil adjustments.

PLLs are also used for **Frequency-Shift Keying (FSK)** operations in digital communications.

A PLL operates by producing a **voltage controlled oscillator (VCO)** frequency (f_{vco}) that matches the RF frequency (f_i).

The RF signal and the VCO output signal are input to a **phase detector**.

When f_{vco} equals f_i , a PLL is in its locked condition.

A phase change between f_i and f_{VCO} causes the phase detector to change its output signal, which is an **error signal**.

The phase detector's error signal varies with the f_i and f_{VCO} phase change.

The low pass filter removes the high-frequency component and passes the low-frequency component from the phase detector's error signal.

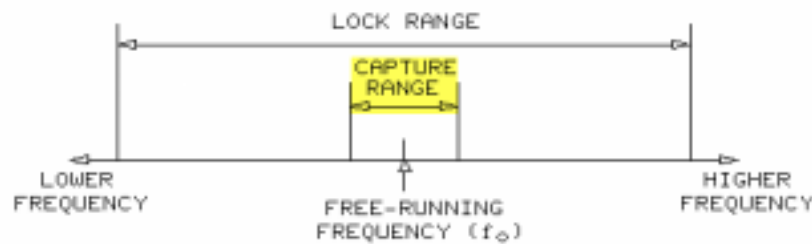
The phase detector's low-frequency component is the PLL's output signal and is also the **feedback signal** to the VCO.

If an unmodulated RF signal is the input to a locked PLL, a dc voltage is the output signal.

The feedback signal causes f_{VCO} to match f_i ; the feedback dc voltage to the VCO is constant as long as f_i remains constant.

The name "phase-locked loop" comes from the locked phase relationship between the RF and VCO signals and the feedback loop.

Once the PLL is in its locked condition, f_{VCO} **tracks**, or follows, a changing f_i .



Tracking of f_i by f_{VCO} will not occur until f_i reaches the **capture range**.

The frequency range over which the f_{VCO} tracks f_i is the **lock range** of the PLL.

When the locked range is exceeded by f_i , f_{VCO} reverts to VCO's **free-running frequency (f_0)**.

The lock range is wider than the capture range.

The VCO free-running frequency (f_0) is usually in the center of the lock and capture ranges.

NEW TERMS AND WORDS

phase-locked loop (PLL) - a circuit that locks onto a phase relationship between an input signal and a VCO signal, and produces an error signal. The error signal is fed back to control the VCO frequency so that it equals the input frequency.

Frequency-Shift Keying (FSK) - shifting an analog signal's frequency between two values to represent the binary states high and low of a digital signal. A modem uses FSK to transmit digital signals over analog telephone lines.

voltage controlled oscillator (VCO) - an oscillator that uses an input voltage to control its output frequency.

phase detector - an electronic circuit whose output varies with the phase difference of the two input signals.

error signal - an output signal that increases with the difference between two input signals; the error signal is fed back to keep the two input signals equal.

feedback signal - an output signal that controls a circuit variable by affecting the operation of a preceding circuit section.

tracks - when a signal's parameter, such as frequency, follows a change in another signal to maintain an equivalence.

capture range - the frequency range in which the RF frequency (f_i) must be for the VCO frequency (f_{VCO}) to start tracking f_i .

lock range - when a PLL is locked, the frequency range within which the VCO frequency (f_{VCO}) tracks the RF frequency (f_i).

free-running frequency (f_o) - the VCO frequency when the PLL is not locked.

closed loop - a circuit (system) that has an output signal feeding back to control a preceding circuit section.

varactor diode - a diode that changes capacitance with a change in input voltage.

open loop - a circuit (system) that does not feed back an output signal to a preceding circuit section.

cutoff frequency - (also called corner frequency) – defined by the 3 db (down) points on either side of the center frequency of a bandpass filter.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit

ANALOG COMMUNICATIONS circuit board

Virtual Instrument

Multimeter

Oscilloscope, dual trace

Generator, sine wave

NOTES

Exercise 1 – PLL Circuit and Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- determine the VCO's free running frequency.
- explain the PLL's capture and lock ranges.

You will use an oscilloscope and dc voltmeter to make measurements.

EXERCISE DISCUSSION

- The phase detector is a 1496 balanced modulator whose function is similar to that of the phase detector on the QUADRATURE DETECTOR circuit block.
- The dc voltage feedback signal controls f_{vco} to match f_i by changing the capacitance of the varactor diode in the VCO circuit.
- When f_i and f_{vco} are not equal, the sum and difference frequencies are output from the phase detector.

NOTES

Exercise 2 – FM Detection With a PLL (VI)

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to

- explain how the phase detector's input frequencies affect the output signals.
- explain how the feedback signal to the VCO varies with the phase change between the input signals.
- describe how a PLL demodulates an FM signal.

You will use an oscilloscope and dc voltmeter to make measurements.

EXERCISE DISCUSSION

- When a PLL is locked, the phase detector's input frequencies (f_i and f_{vco}) are equal but 90° out of phase.
- The output contains a sum frequency, which is twice the input frequency, and a difference component, which is a dc voltage.
- Every variation in f_i causes a phase change with f_{vco} , which then causes the dc voltage difference component to change.
- The low-pass filter removes the sum frequency, but passes the varying dc voltage difference component that is the recovered message signal.
- After capture, the bandwidth of the FM signal stays within the PLL's lock range until the FM signal becomes greater than the PLL's lock range, returning the VCO to its free-running frequency.

NOTES

APPENDIX A – SAFETY

Safety is everyone's responsibility. All must cooperate to create the safest possible working environment. Students must be reminded of the potential for harm, given common sense safety rules, and instructed to follow the electrical safety rules.

Any environment can be hazardous when it is unfamiliar. The F.A.C.E.T. computer-based laboratory may be a new environment to some students. Instruct students in the proper use of the F.A.C.E.T. equipment and explain what behavior is expected of them in this laboratory. It is up to the instructor to provide the necessary introduction to the learning environment and the equipment. This task will prevent injury to both student and equipment.

The voltage and current used in the F.A.C.E.T. Computer-Based Laboratory are, in themselves, harmless to the normal, healthy person. However, an electrical shock coming as a surprise will be uncomfortable and may cause a reaction that could create injury. The students should be made aware of the following electrical safety rules.

1. Turn off the power before working on a circuit.
2. Always confirm that the circuit is wired correctly before turning on the power. If required, have your instructor check your circuit wiring.
3. Perform the experiments as you are instructed: do not deviate from the documentation.
4. Never touch "live" wires with your bare hands or with tools.
5. Always hold test leads by their insulated areas.
6. Be aware that some components can become very hot during operation. (However, this is not a normal condition for your F.A.C.E.T. course equipment.) Always allow time for the components to cool before proceeding to touch or remove them from the circuit.
7. Do not work without supervision. Be sure someone is nearby to shut off the power and provide first aid in case of an accident.
8. Remove power cords by the plug, not by pulling on the cord. Check for cracked or broken insulation on the cord.

