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Lesson 11

OSCILLATORS, PLL and SIGNAL MODULATION

ACMA Syllabus February 2024 Chapters 3.6 and 3.7

Contents

Oscillators

An oscillator is a circuit that produces a continuous, repeated, alternating waveform without any input. The oscillator relies on feedback to keep the oscillator in frequency and phase.

Oscillators can be fixed frequency or variable.

The most-common linear oscillator in use is the crystal oscillator, in which the output frequency is controlled by a piezo-electric resonator consisting of a vibrating quartz crystal. Crystal oscillators are ubiquitous in modern electronics, being the source for the clock signal in computers and digital watches, as well as a source for the signals generated in radio transmitters and receivers. As a crystal oscillator's "native" output waveform is sinusoidal, a signal-conditioning circuit may be used to convert the output to other waveform types, such as the square wave typically utilized in computer clock circuits.

Overview

Oscillation Circuit

This is the primary source of the oscillations. The circuit may be discrete components or a quartz crystal.

The most-common oscillator in use is the crystal oscillator. Crystal oscillators are common in modern electronics. They are the oscillator source for the clock signal in computers, digital watches and the signals generated in radio transmitters and receivers.

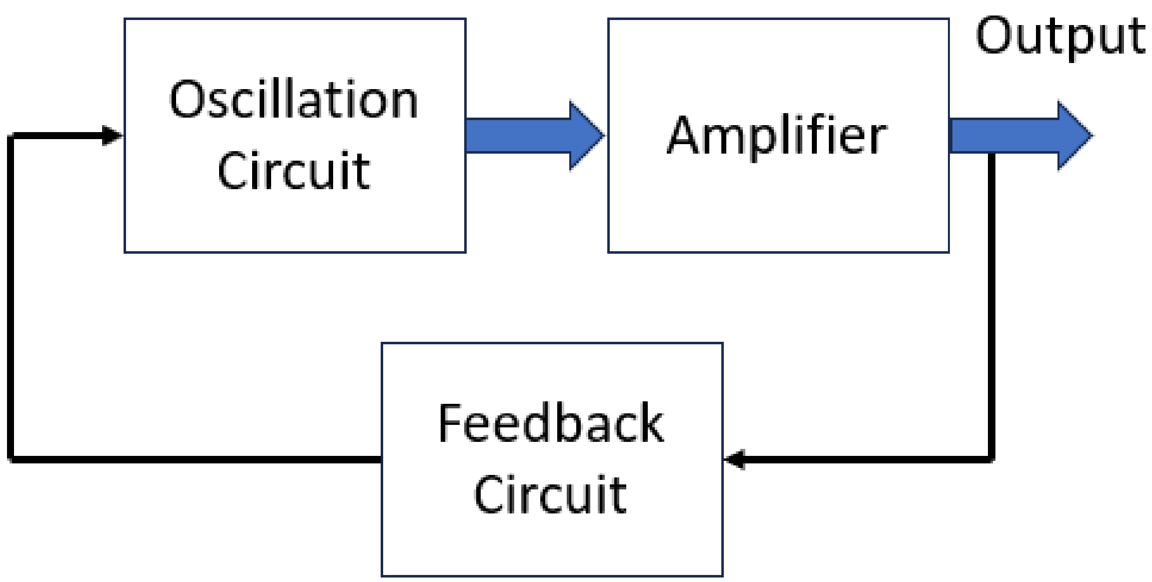
Amplifier

The source signal is usually weak, and this signal needs to be amplified. The amplifier would need to be a very high input impedance to prevent overloading the oscillations.

Feedback

Feedback is essential as it sustains the oscillator and keeps the oscillator on frequency.

Signal feedback from output in phase with the input signal is termed *positive feedback.* Signal feedback that is out of phase by 180° with respect to the input signal is termed *negative feedback.*



Oscillators are grouped in two categories.

- The linear or harmonic oscillator produces a sinusoidal output.
- The nonlinear or relaxation oscillator which produces square or other wave shape outputs.

Oscillators can be fixed frequency or variable.

Oscillators are often characterised by the frequency of their output signal:

- A low-frequency oscillator generates a frequency below 20 Hz.
- An audio oscillator produces frequencies in the audio range from 20 Hz to 20 kHz.
- A radio frequency oscillator produces signals in the range of 100 kHz to 100 GHz.

Oscillator Stability Essentials

Oscillator frequency output can be unstable if the following issues are not controlled.

Feedback

Feed back is needed to sustain the oscillations and ensure accuracy of the output.

Temperature Change

Temperature changes can alter the parameters of crystals, resistors, capacitors and inductors.

A Temperature Compensated Crystal Oscillator (TCXO) provides a more precise and stable output. An Oven-Controlled crystal oscillator (OCXO) keeps crystals at a consistent elevated temperature.

Mechanical Vibrations

External vibrations can cause short-term phase fluctuations in the output signal, known as phase noise. The ideal oscillator should have a combination of mechanical isolation and electrical compensation to reduce phase noise.

Power Supply

A regulated and well filtered power supply is essential for a stable oscillator.

Control Parasitic Oscillations

Parasitic oscillation is undesirable feedback in the oscillator and can be caused by feedback in the oscillator amplifier. An example of parasitic oscillations is if a mic is held too close to the speaker and the amplifier goes into uncontrolled oscillation.

Oscillator Types

Beat Frequency Oscillators

A beat frequency oscillator (BFO) is a dedicated oscillator used to create an audio frequency signal from Morse code radiotelegraphy (CW) transmissions. The signal from the BFO is mixed with the received signal to create a heterodyne or beat frequency which is heard as a tone in the speaker. BFOs are also used to demodulate single-sideband (SSB) signals by restoring the carrier that was suppressed at the transmitter.

Overtone Oscillator

This is an oscillator running at a harmonic of the original frequency. An overtone oscillator frequency allows a crystal oscillator to run at an odd multiple of the main crystal frequency and is a simple way to frequency multiplication in crystal oscillators.

Voltage Controlled Oscillator (VCO)

A VCO is an oscillator whose output frequency is controlled by an input voltage.

Variable Frequency Oscillator (VFO)
A Variable Frequency Oscillator (VFO) is an integral part of transmitters and receivers.

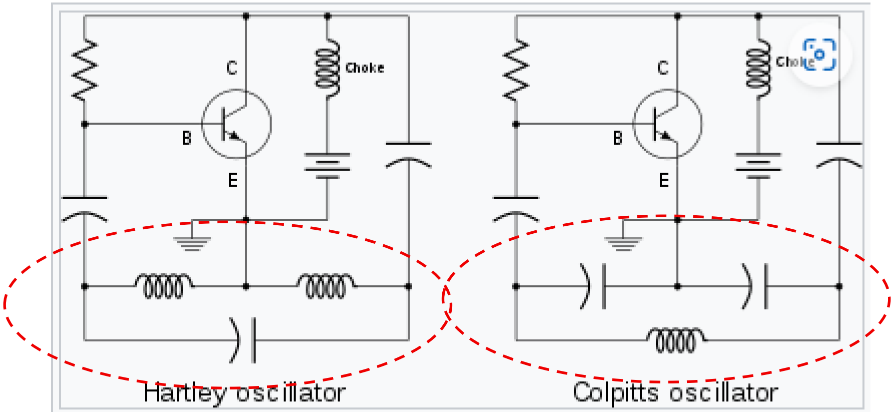
Discrete component Oscillators
Non digitised or packaged oscillators using discrete components such as inductors and capacitors.

Common Oscillators

Discrete Component Oscillators

Colpitts' Oscillator
A Colpitts oscillator is an LC oscillator for a certain frequency. The distinguishing feature of the Colpitts oscillator is the two capacitors (C for Colpitts) in parallel across the inductor.

The Colpitts oscillator is highly valued for producing pure, stable sinusoidal waveforms, particularly in the high-frequency and radio frequency (RF) ranges (1 to 60+ MHz).



Two common LC oscillator circuits, the Hartley and Colpitts oscillators

Wikipedia

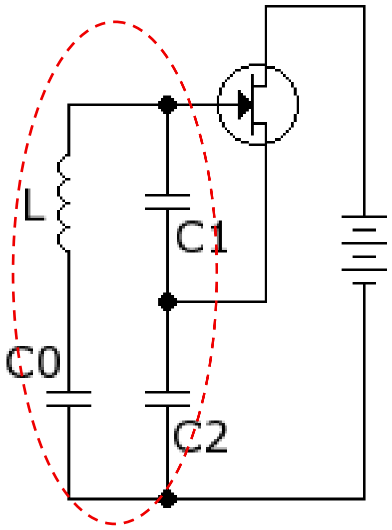
Hartley Oscillator
The Hartley oscillator is an oscillator in which the oscillation frequency is determined by a tuned circuit. The distinguishing feature of the Hartley oscillator is that the tuned circuit consists of a single capacitor in parallel with two inductors (H for Hartley) in series (or a single tapped inductor), and the feedback signal is taken from the center connection of the two inductors.

The Hartley oscillator is a popular LC circuit used for generating radio frequencies (up to 30 MHz) due to its simplicity

Clapp Oscillator
The Clapp oscillator is an LC oscillator using a particular combination of an inductor and three capacitors and a positive feedback network. The oscillator has good frequency stability.

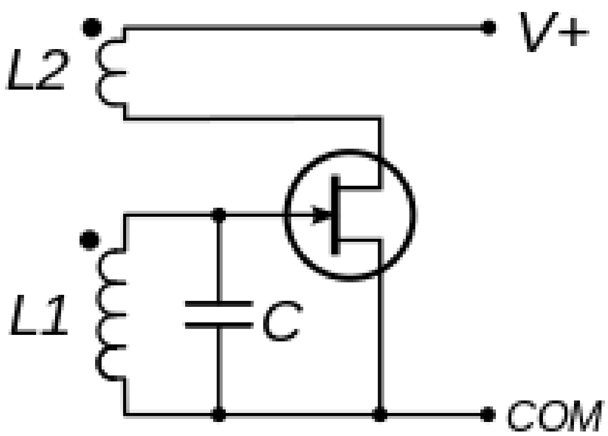
The Clapp oscillator is a modified Colpitts oscillator featuring an additional capacitor (Co) placed in series with the inductor to improve frequency stability.

The Clapp oscillator offers better precision for high frequency applications.



Armstrong Oscillator

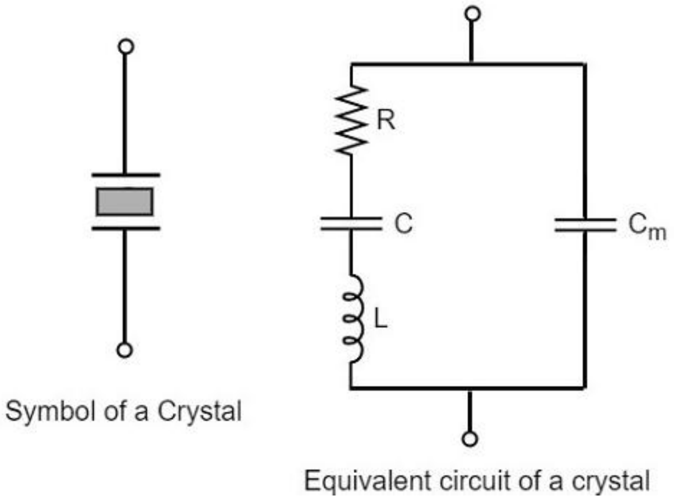
The Armstrong oscillator is an oscillator circuit which uses an inductor and capacitor to generate oscillation and is the earliest oscillator circuit. This oscillator was used in the first vacuum tube radio transmitters. It is also called a “tickler oscillator” because its distinguishing feature is that the feedback signal is magnetically coupled into the tank inductor "tickler coil" in the output circuit.



Crystals

Piezoelectric crystals are specialized devices that convert mechanical stress (pressure) directly into electrical energy (voltage) and voltage into movement. The voltage induced movement is at a frequency defined by the size and shape of the crystal.

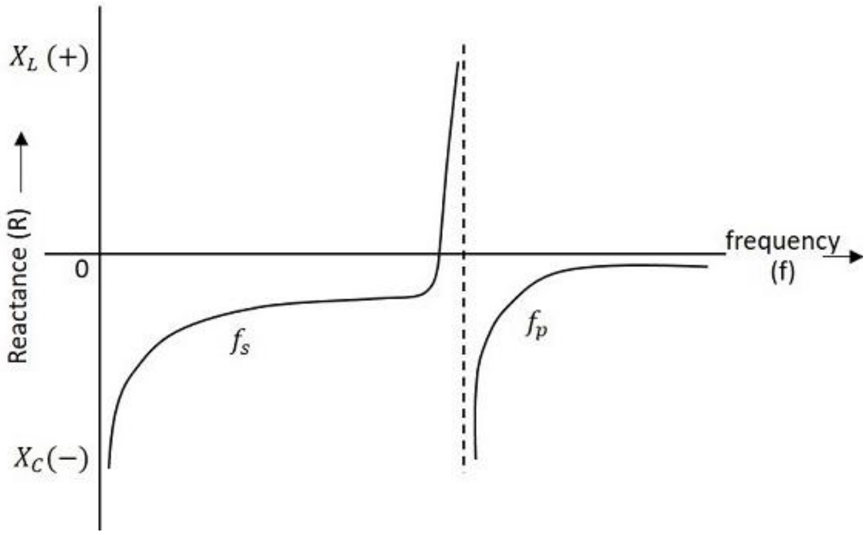
A quartz crystal equivalent circuit is shown below.



A piezoelectric crystal can operate in both series and parallel resonant modes depending on the circuit design and frequency.

When the crystal is not vibrating, the device looks like a capacitor C_M. When vibrating, the circuit is a series LCR configuration or a parallel LCR circuit.

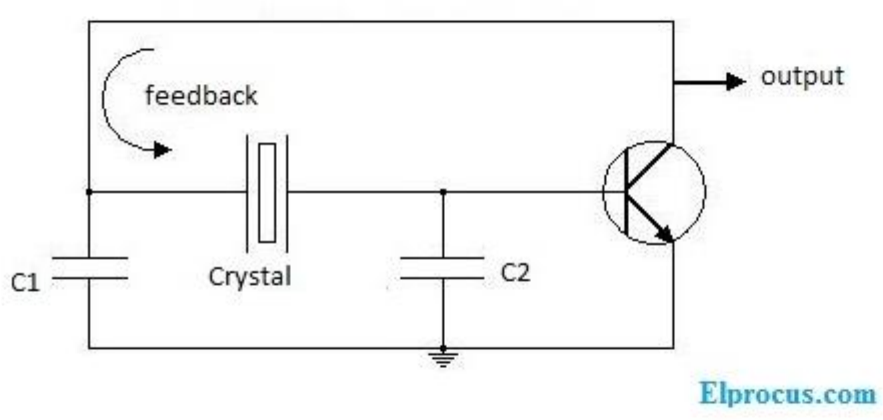
A quartz crystal provides both series and parallel resonance as shown in the graph below.



fs is the series frequency and f_p is the parallel frequency response.

Pierce Oscillator

The Pierce oscillator is an oscillator well-suited for use in piezoelectric crystal circuits. Virtually all digital IC clock oscillators are of Pierce type, as the circuit can be implemented using a minimum of components. The low manufacturing cost of this circuit and the outstanding frequency stability of the quartz crystal give it an advantage over other designs in many consumer electronics applications. The most-common linear oscillator in use is the crystal oscillator where the output frequency is regulated by a piezo-electric quartz crystal.



Hints (Know the oscillators)

- Hartley oscillator has feedback from tapped inductors. *(H)artley = Henries = inductors*
- Colpitts oscillator has feedback from tapped capacitors. *(C)olpitts = capacitance*
- Clapp oscillator has feedback from tapped capacitors but in parallel with series tuned circuit.
- The Armstrong oscillator has feedback from a tapped transformer. *Strong arm to lift the transformer.*
- Pierce oscillator has a crystal.

Frequency Multiplier

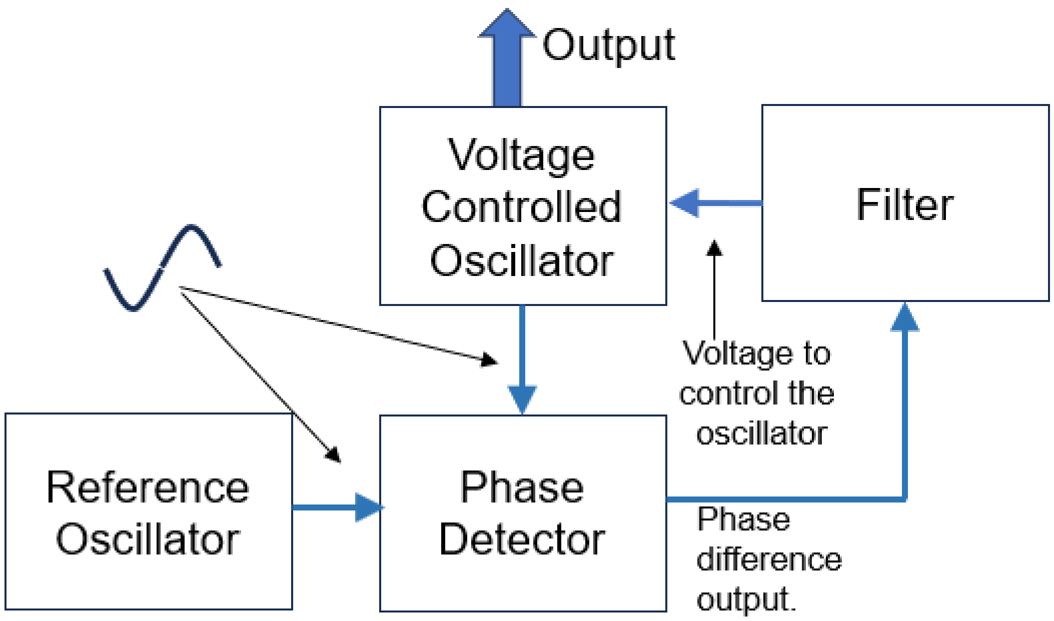
A frequency multiplier transforms the input frequency to an output frequency which is a multiple (harmonic) of the input frequency. Frequency multipliers consist of a nonlinear circuit that distorts the input signal and consequently generates harmonics of the input signal. A subsequent bandpass filter selects the desired harmonic frequency and removes the unwanted fundamental and other harmonics from the output.

Phase Locked Loop [PLL] Oscillator

A Phase-Locked Loop (PLL) is a feedback-controlled system generating an output matching an input reference signal. A PLL is used for precise frequency synthesis.

A phase-locked loop compares the phase of a reference oscillator to the phase of an adjustable oscillator. When the comparison is in steady state, the phase of the output frequency and the phase of the incoming frequency are in sync. This is called “locked”. See diagram below.

The PLLs are used in many applications from frequency synthesizers to FM demodulators and signal reconstitution.



Phase Locked Loop (PLL)

A PLL consists of three key components:

1. **Phase detector,** AKA phase comparator or mixer, compares the phases of two signals and generates a voltage according to the phase difference.
2. **Loop filter** that attenuates the high-frequency component of the input signal to smoothen and flatten the signal to make it DC.
3. **Voltage-controlled oscillator** (VCO)is regulated by the voltage from the filter. The VCO generates a sinusoidal signal.

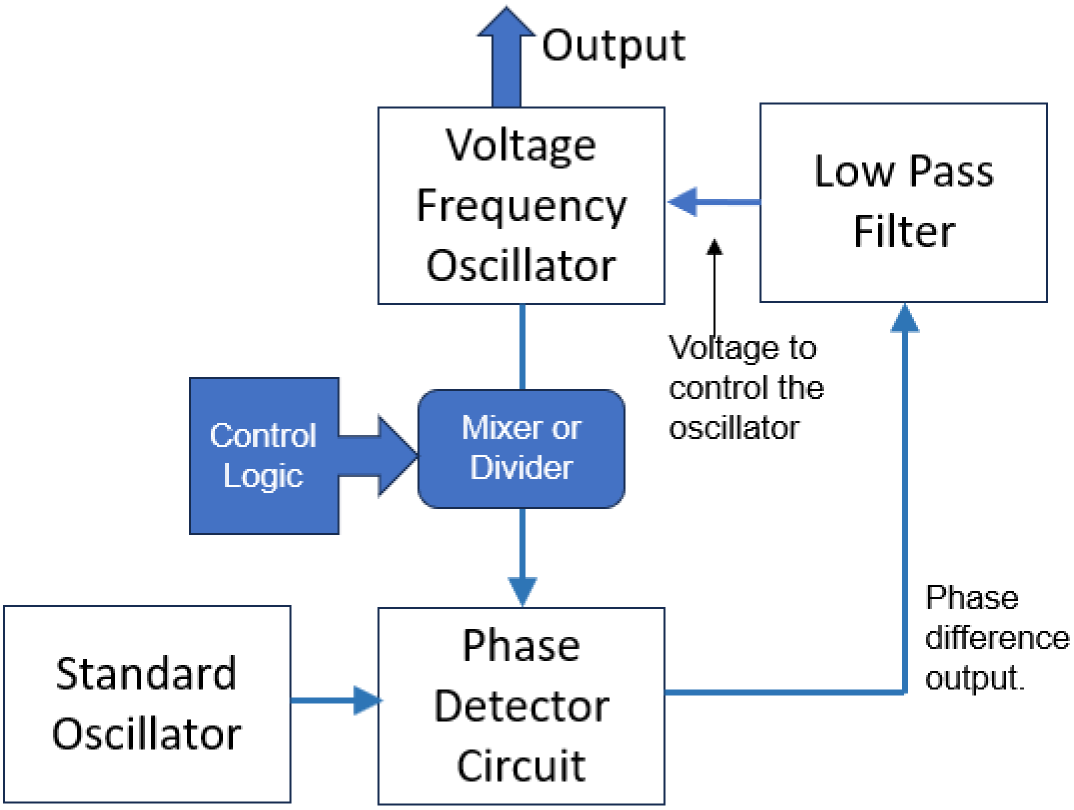
PLL Frequency Synthesis

A frequency synthesizer allows the designer to generate a variety of output frequencies as multiples of a single reference frequency.

If the PLL feedback from the VCO to the phase comparator is controlled, the output frequency would be changed.

The **Analogue PLL synthesiser** has a mixer between the VCO and the phase detector.

The **Digital PLL synthesiser** inserts a digital divider in the loop between the VCO and the phase detector. The VCO frequency will be divided and run at the divided times the standard oscillator frequency. Programming the division ratio of the divider changes the output frequency. This makes the frequency synthesizer programmable.



Phase Locked Loop (PLL) Synthesiser

Signal Modulation

A carrier wave, at a frequency for long distance transmission, is not much use unless the carrier includes some form of information. Adding the information to the carrier is called “modulation”.

Modulation is defined as the process of including information (data, voice, or video) onto a carrier signal for transmission.

Removing the information from the carrier in the receiver is called “demodulation.”

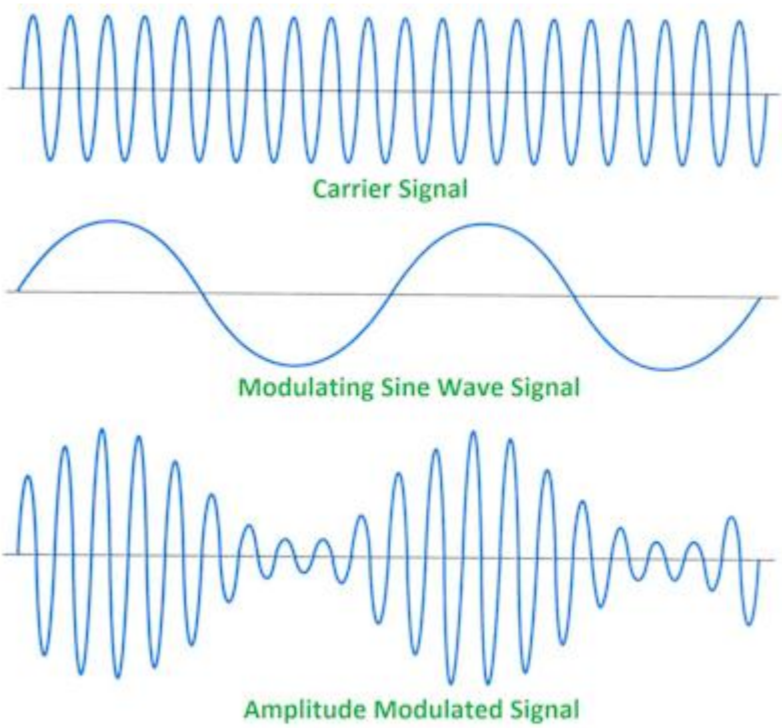
Analogue Modulation

In the amateur radio arena, there are five primary methods of modulating a carrier with an analogue signal.

These primary modulation methods used by radio amateurs are AM, SSB, CW, FM and PM.

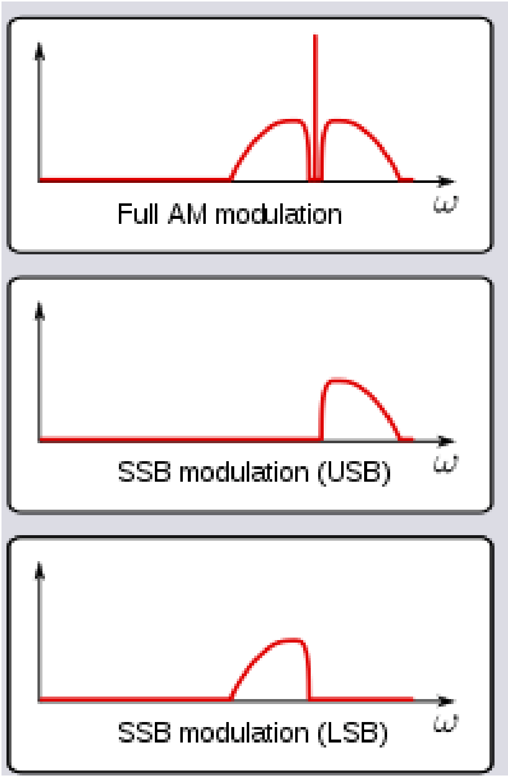
Amplitude modulation (AM)

AM is a modulation technique where the amplitude of the carrier varies in proportion to the message signal. AM is also referred to as double side band.



Single-Sideband modulation (SSB)

SSB is a refinement of amplitude modulation (AM). SSB refers to a modulation format in which one sideband of a double-sideband signal and the carrier are removed. This reduces the occupied bandwidth and improves spectral efficiency. On amateur radio frequencies above 10 MHz, the upper side band (USB) is used. Frequencies below 10 MHz use the lower side band (LSB).

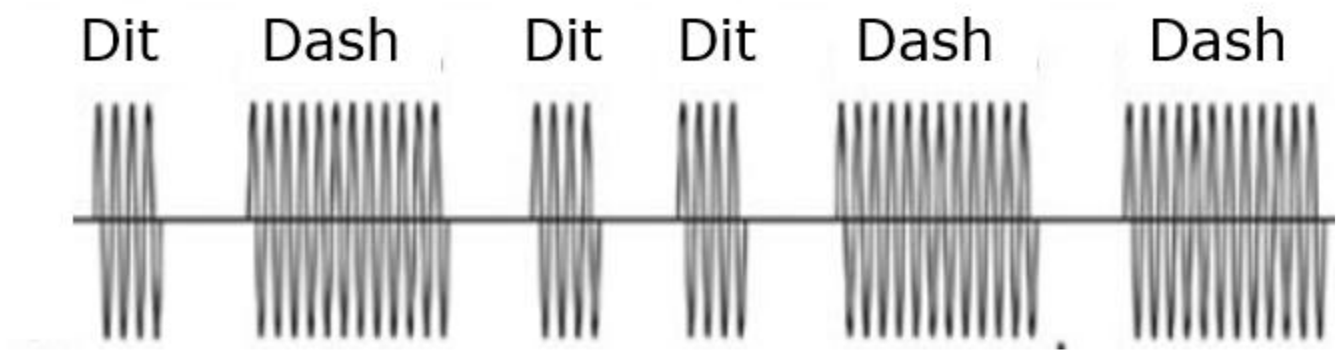


Wikipedia [Single-sideband modulation - Wikipedia]

Continuous Wave (CW)

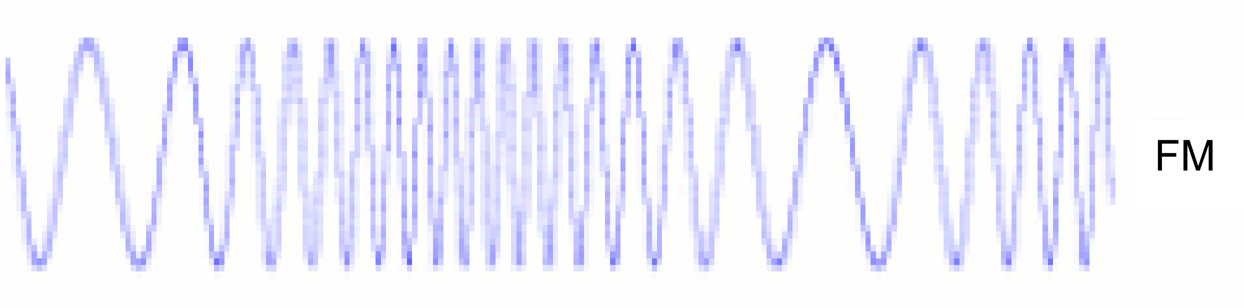
The term continuous wave refers to a method of radio transmission in which a sinusoidal carrier wave is switched on and off as in Morse code.

CW is not a binary digital transmission as it has three states: Dit, Dash and off.



Frequency modulation (FM)

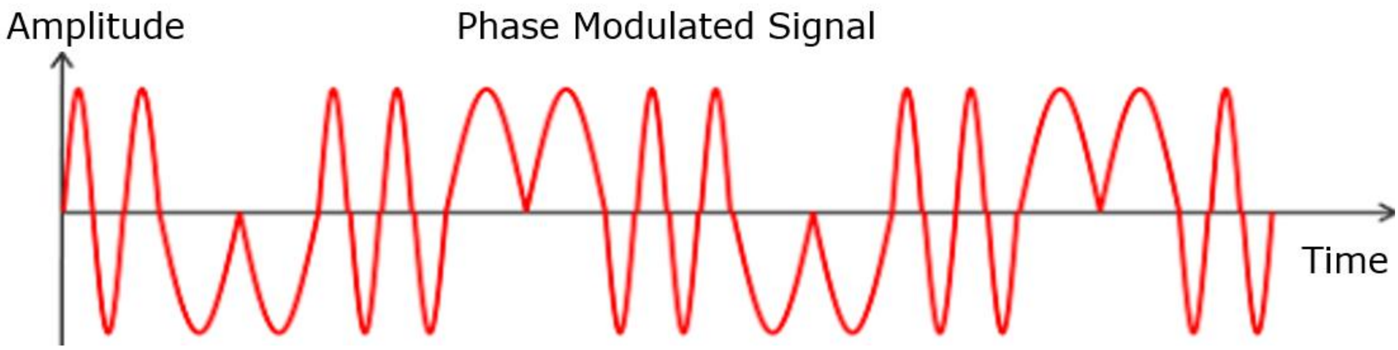
FM is a modulation technique where the frequency of the carrier wave is varied by the message signal.



Phase Modulation (PM)

Phase modulation (PM) is a modulation technique where the phase of the carrier wave is varied by the message signal.

PM requires more complex receivers compared to frequency modulation (FM).

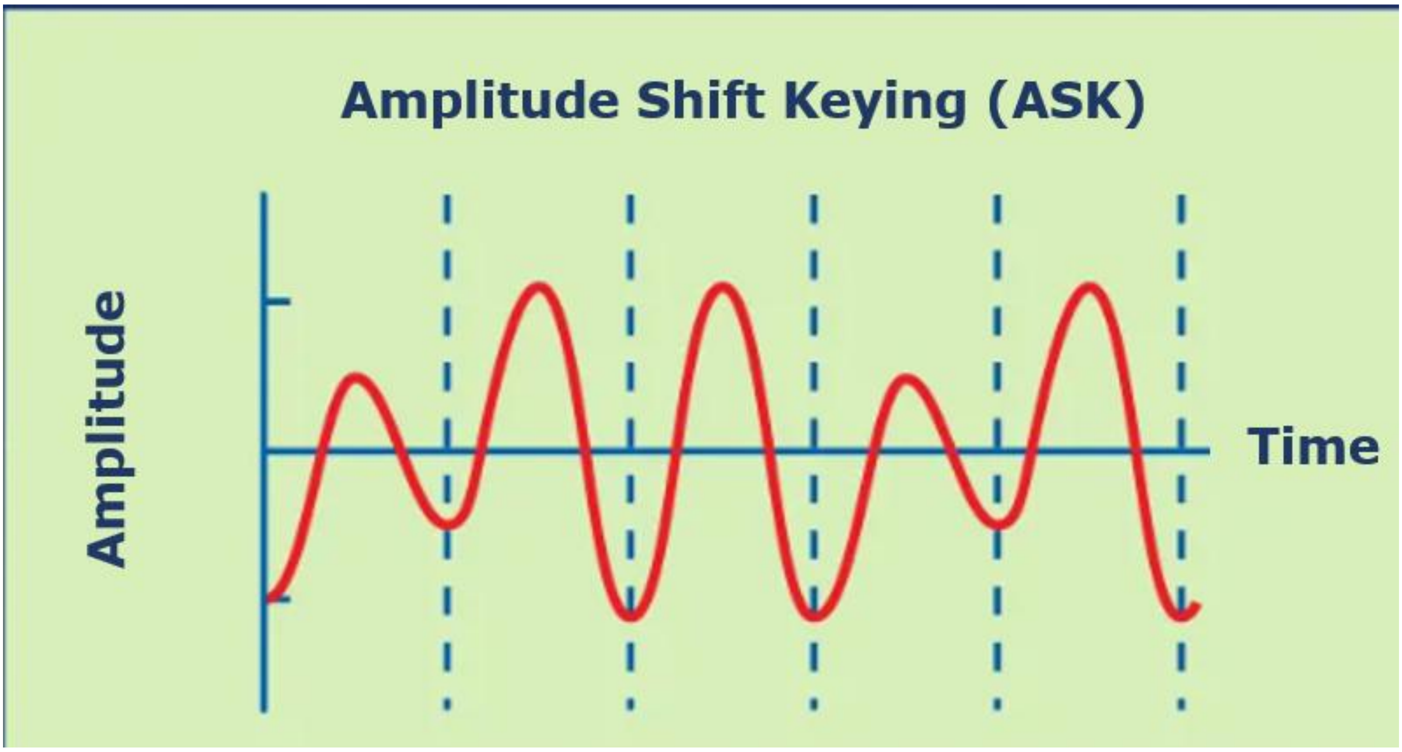


Digital Modulation

Digital modulation of the carrier wave is where digital data is superimposed on an analog carrier.

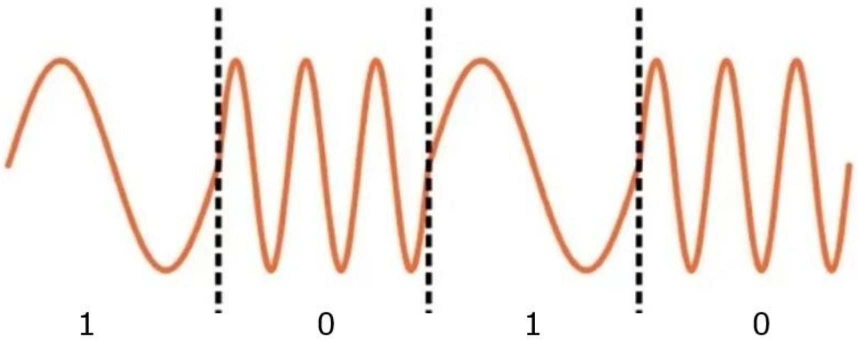
Amplitude Shift Keying (ASK)

ASK uses different amplitude levels that are assigned to different binary values. The carrier wave's instantaneous amplitude is modified based on the digital signal's value.



Frequency Shift Keying (FSK)

FSK, the carrier frequency is switched between two predetermined frequencies, one representing a binary 0 and the other representing a binary 1.

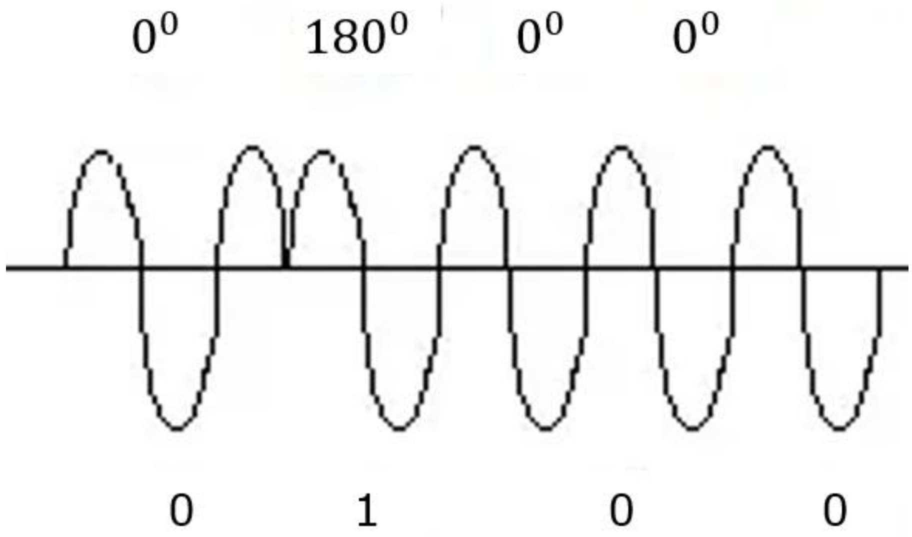


Phase Shift Keying (PSK)

For PSK, the phase of the carrier wave is adjusted at specific intervals based on the digital signal being transmitted. There are two subsets of PSK

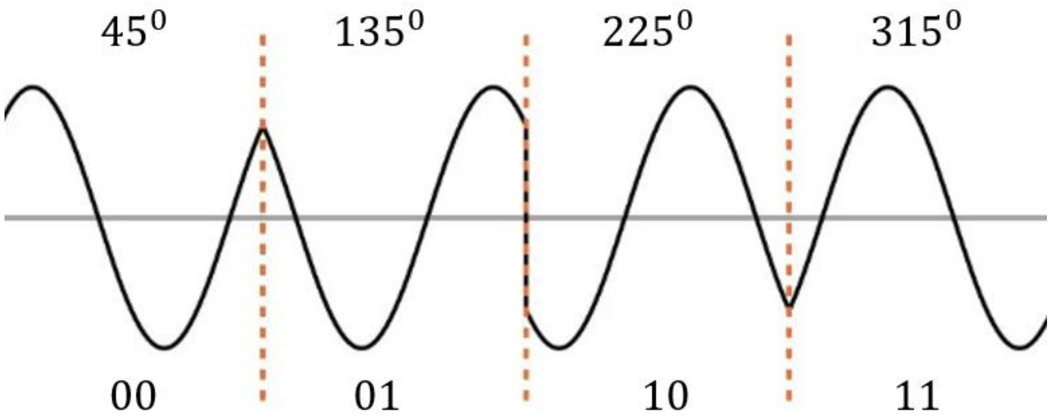
2PSK

2PSK, Binary Phase Shift Keying (BPSK) or Phase Reversal Keying. The carrier has two phase reversals such as 0° and 180° representing a one or a zero.



4 PSK or Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying (QPSK) is a digital modulation technique that transmits two bits of data simultaneously per symbol by varying the phase of a carrier wave among four distinct values. 4PSK doubles the data rate of 2PSK within the same bandwidth.

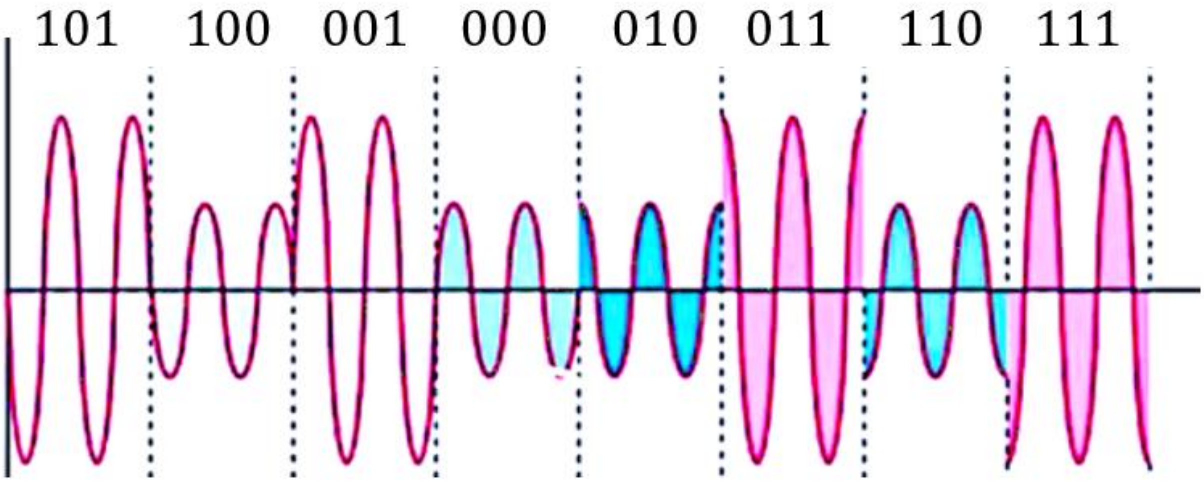


Quadrature Amplitude Modulation (QAM)

QAM used in digital telecommunications modulates by using both the phase and amplitude of two carrier waves (90° out of phase).

QAM is widely used in Wi-Fi, cable internet, and cellular networks to transmit more data per symbol.

QAM's higher data rate capabilities and robustness to noise and interference make it a preferred choice for various digital communication systems.



Data Checking

Cyclic Redundancy Check (CRC)

Cyclic Redundancy Check (CRC) is an error-detecting code used in network protocols to ensure data integrity. Used in protocols like TCP.

When a receiver detects a CRC mismatch, the packet is discarded and a request for retransmission is sent. This method ensures reliable transmission but can reduce throughput and increase latency.

Forward Error Correction (FEC)

FEC is a digital signal processing technique used to control errors in data transmission over noisy or unreliable communication channels. FEC adds error-correcting codes to the original data stream. The receiver can detect and correct a limited number of errors without needing to request retransmission.

Bits and Bauds

Bit rate is the number of bits (0s and 1s) transmitted per second, i.e. bits per second (bit/s).

Baud rate is the number of signal units (symbols or characters) transmitted per second.

Baud Rate vs. Bit Rate

1:1 or Simple Coding.

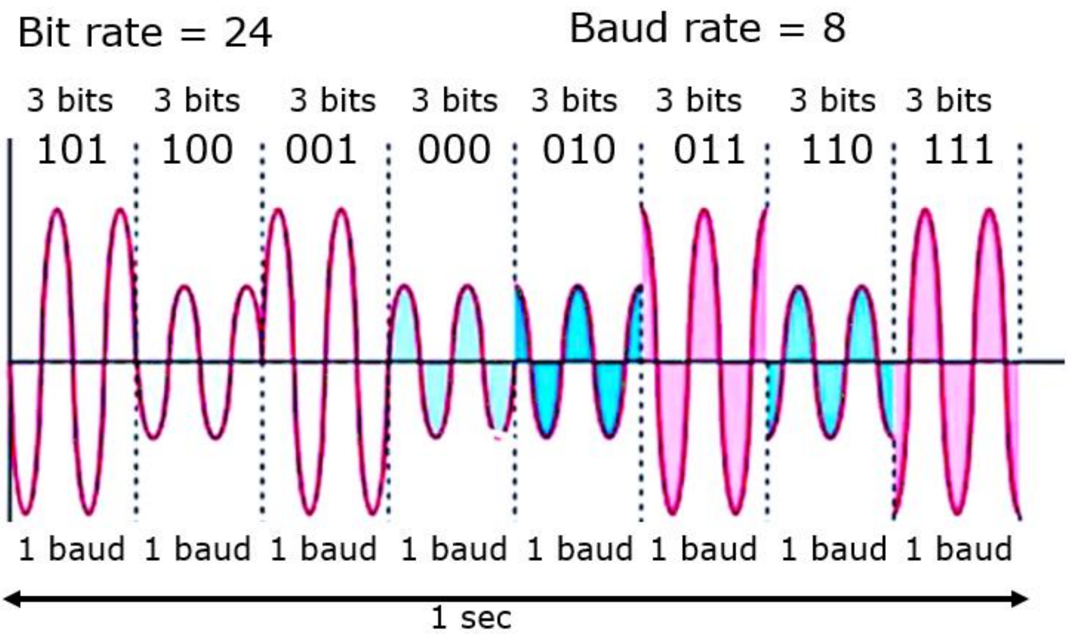
If 1 symbol = 1 bit. e.g. 9600 baud = 9600 bps. This simple coding would only send a one or a zero.

1:N or Complex Modulation.

If 1 symbol = 4 bits e.g. QAM 1000 baud = 4000 bps. In this case, 4 bits would represent a more complex character. So, 1000 complex characters are sent at a rate of 4000 bits per second.

In the figure, 24 bits are sent every second. Bit Rate = 24

3 bits represent one character. Baud Rate = 8



AMTOR

AMTOR (Amateur Teleprinting Over Radio) is telecommunications between two or more electromechanical teleprinters in different locations.

AMTOR was developed in 1978 by Peter Martinez, G3PLX, with the first contact taking place in September 1978 with G3YYD on the 2m Amateur band.

The AMTOR protocol utilizes a 7-bit code for each character, with each code-word having four mark and three space bits. If the received code does not match a four-to-three (4:3) ratio, the receiver assumes an error has occurred.

AMTOR utilizes FSK, with a frequency shift of 170 Hz, and a symbol rate of 100 Baud.

AMTOR has now fallen out of use as improved PC-based data modes such as PSK31 take over.

Packet Radio

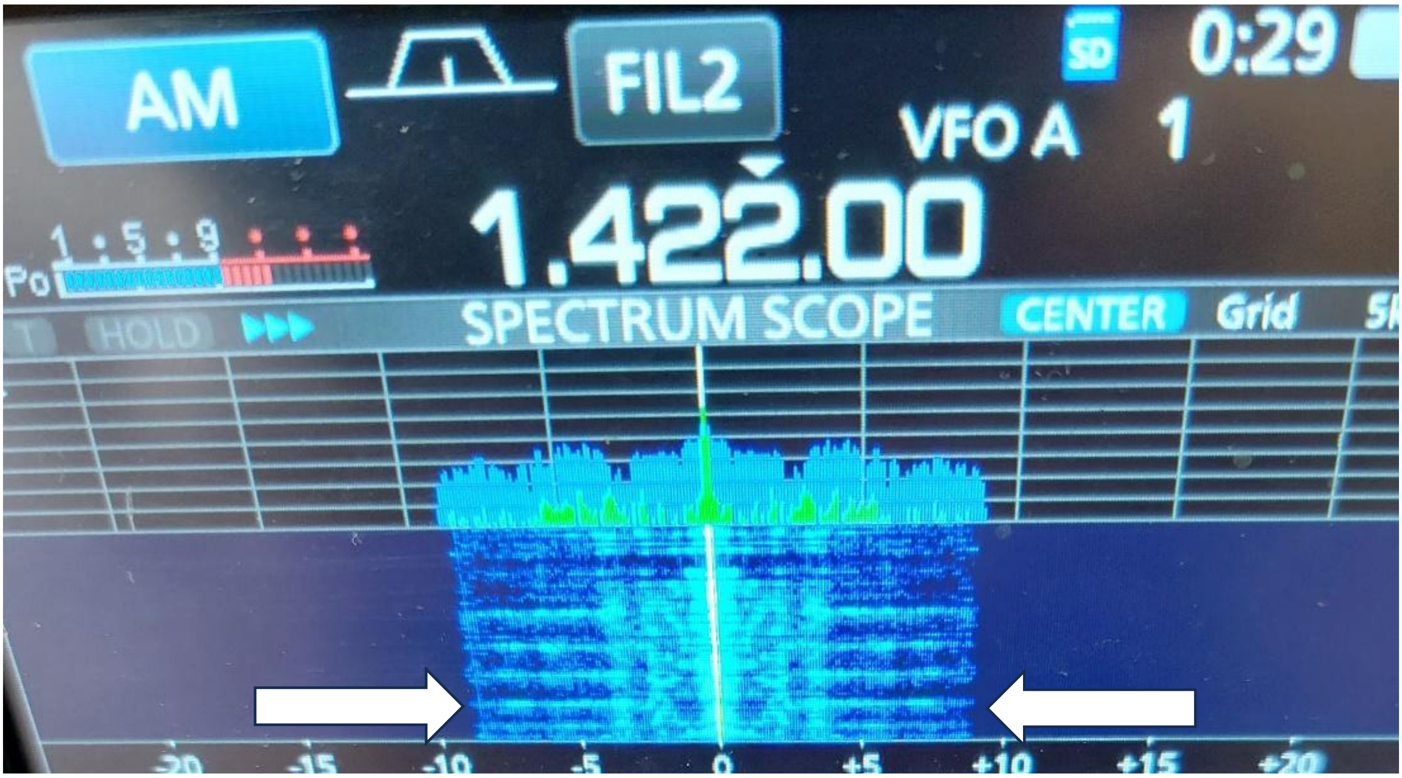
Packet radio uses packet switching techniques for digital radio communications and is frequently used by amateur radio operators.

Data is broken into "packets," which include station callsigns for identification. The Terminal Node Controller (TNC), or software like Direwolf, converts digital computer data into audio tones (AFSK) for the radio to transmit, ensuring high-accuracy data transfer.

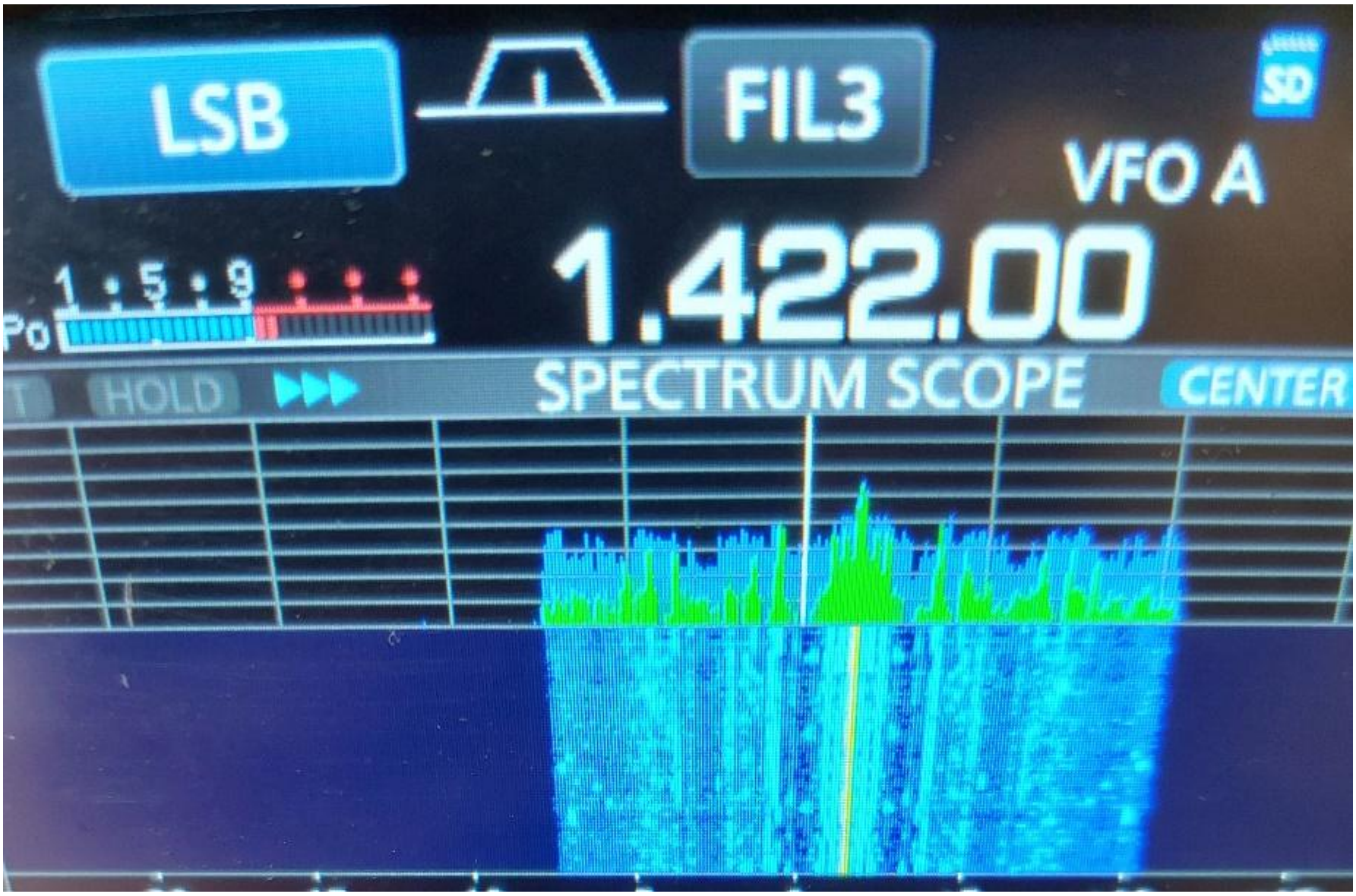
Computers, connected to transceivers, send data using the AX.25 protocol for reliable, node-to-node communication over VHF/UHF/HF bands.

Signal Spectrum Images

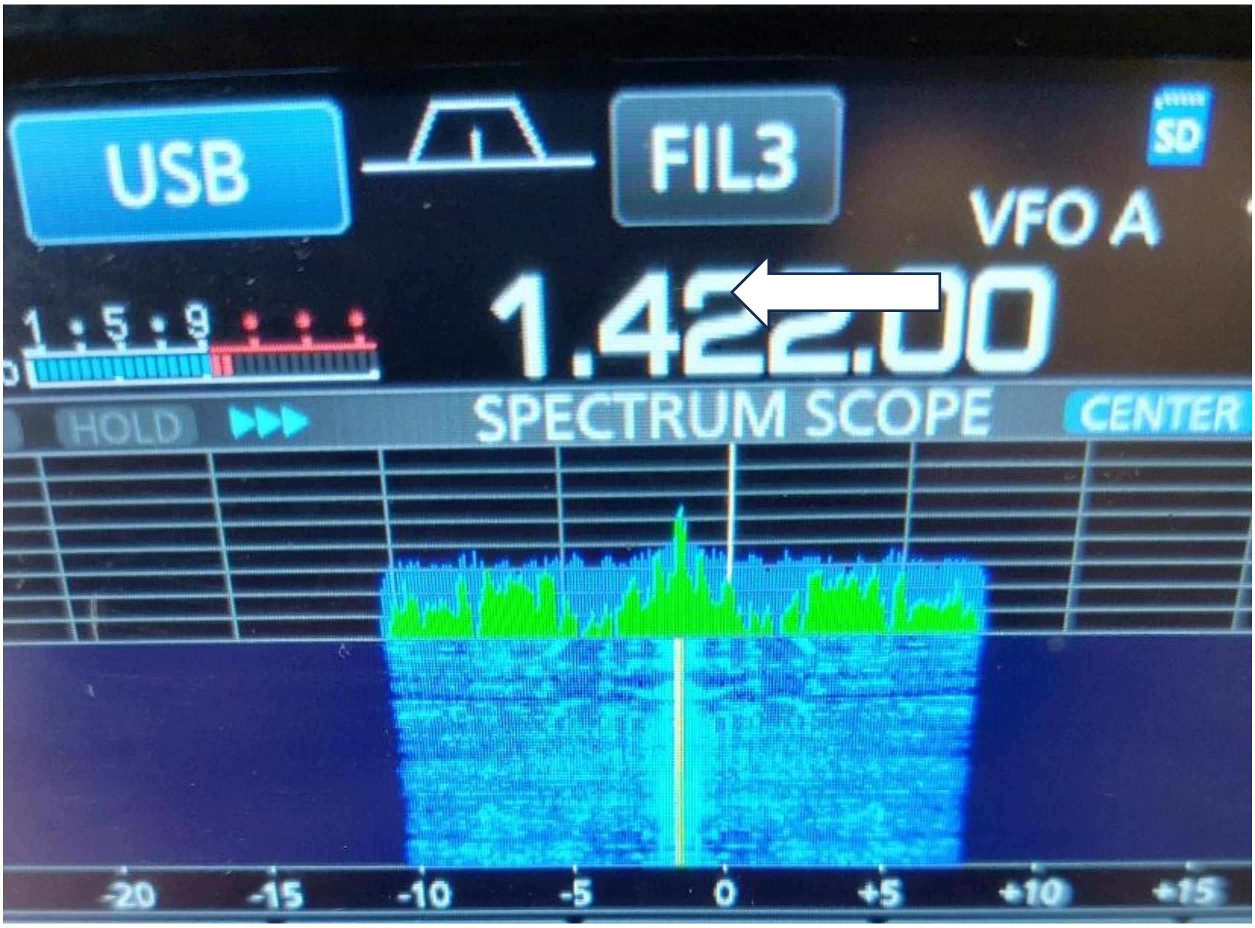
A double-sided AM signal with the centre carrier at 1.422 MHz.



The total bandwidth for the station's signal occupies 18 kHz.



A Lower Side Band (LSB) signal.



An Upper Side Band (USB) signal.

Go to Lesson 11 questions.