ADVANCED

Lesson 13

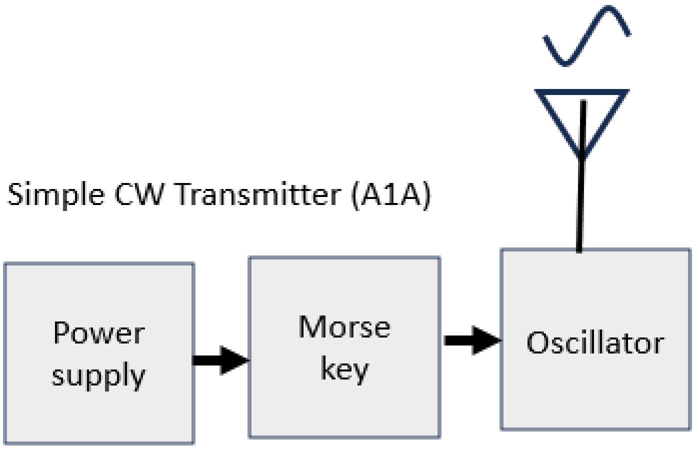
TRANSMITTERS

ACMA Syllabus February 2024 Chapters 5, 1.7, 1.8 and 1.9

Contents

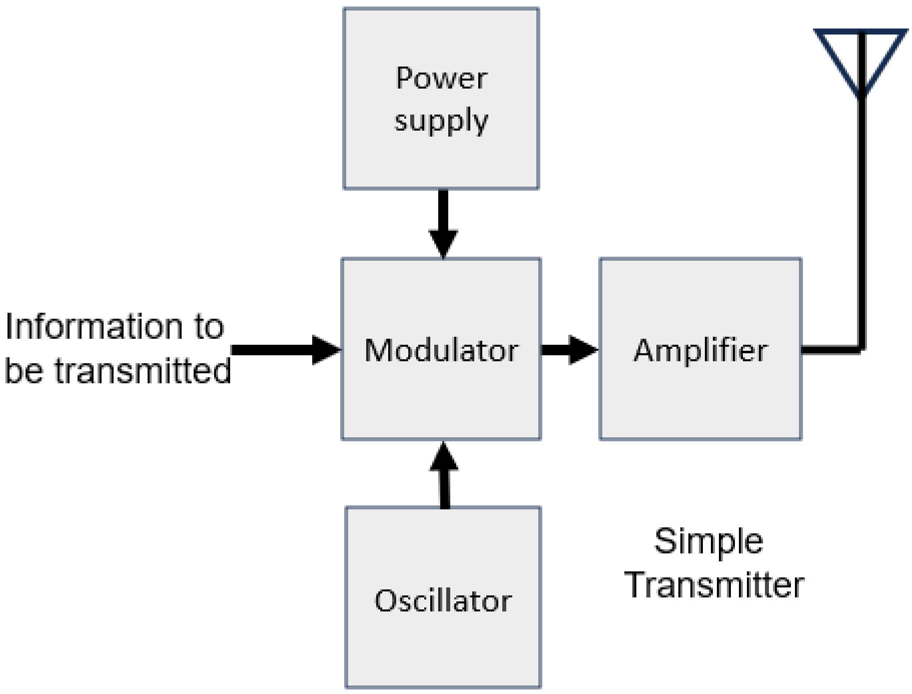
Transmitters

A radio transmitter or just transmitter (often abbreviated as XMTR or TX) is an electronic device which produces radio waves in an antenna with the purpose of signal transmission to a radio receiver. The transmitter itself generates a radio frequency alternating current, which is applied to the antenna. When excited by this alternating current, the antenna radiates radio waves.



In this simplest transmitter, the oscillator which is running at the carrier frequency is turned on and off by the morse key. The signal would be weak making this transmitter ineffective.

A simple audio transmitter needs a method to superimpose the 300 Hz audio signal onto the carrier signal.



The information to be transmitted is modulated with an oscillator at the carrier frequency. This modulated signal is amplified and sent the antenna. The power supply will not be shown in future block diagrams.

Oscillator

An oscillator circuit generates the radio frequency signal which is usually a sine wave of constant amplitude. This is called the carrier wave because it produces the radio waves which "carry" the information. In modern transmitters, the oscillator is precisely controlled by the vibrations of a quartz crystal. The frequency of the carrier wave is considered the frequency of the transmitter.

Varying the frequency of the oscillator allows the transmitter to cover a broad band of frequencies.

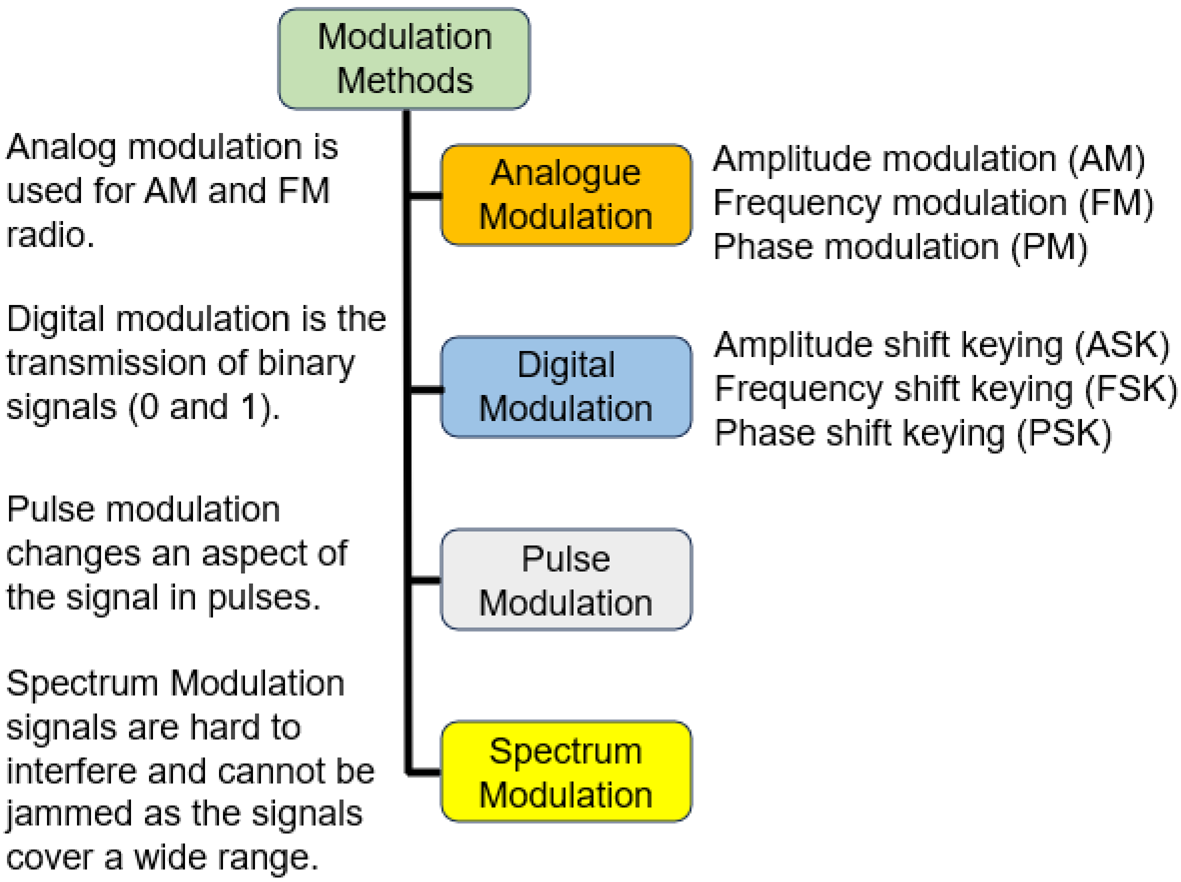
Modulator

A modulator superimposes a low-frequency (information) signal onto a high-frequency (carrier) signal for the purpose of transmission. This is achieved by varying some aspect of the carrier wave. The information is provided to the transmitter as an electronic signal called the modulation signal. The modulation signal may be an audio, video or data. Different types of transmitters use different modulation methods to transmit information:

High level modulation is where the modulator is connected to the power amplifier.

Low level modulation is where the modulator is connected a few stages prior to the power amplifier.

Modulation Methods



Types of Modulation

Amplitude modulation (AM)	In an AM transmitter, the amplitude of the carrier wave varies in proportion to the modulation signal.
FSK (frequency-shift keying)	A FSK transmitter for data, the frequency of the carrier is shifted between two frequencies which represent the two binary digits, 0 and 1.
Morse code (CW)	A carrier wave is turned on and off, corresponding to dots and dashes for Morse code.

Frequency modulation (FM)	A FM transmitter the frequency of the carrier is varied by the modulation signal.
Single Side Band (SSB)	Is a variation of amplitude modulation signal.
Phase modulation (PM)	Phase modulation (PM) encodes a message signal as variation in the instantaneous phase of a carrier wave. Phase modulation is one of the two principal forms of angle modulation, together with frequency modulation. The phase of a carrier signal is modulated to follow the changing signal level (amplitude) of the message signal. The peak amplitude and the frequency of the carrier signal are maintained constant and the phase of the carrier changes correspondingly. Phase modulation is an integral part of many digital transmission coding schemes in technologies like Wi-Fi, GSM and satellite television. However, it is not widely used for transmitting analog audio signals via radio waves.

Modulation Methods

Low-level generation
Low-level modulation is performed prior to the output element of the final stage of transmitter.

High-level generation
High-level generation is performed in the final element of the final stage of transmitter.

AM
High-power AM transmitters for broadcasting are modulated by varying the supply voltage to the power amplifier stages.

FM
FM signals can be generated using either direct or indirect frequency modulation:

Direct FM modulation is performed by feeding the message into the input of a voltage-controlled oscillator.

Indirect FM modulation is performed when the message signal is integrated to generate a phase-modulated signal. This is used to modulate a crystal-controlled oscillator, and the result is passed through a frequency multiplier to produce an FM signal.

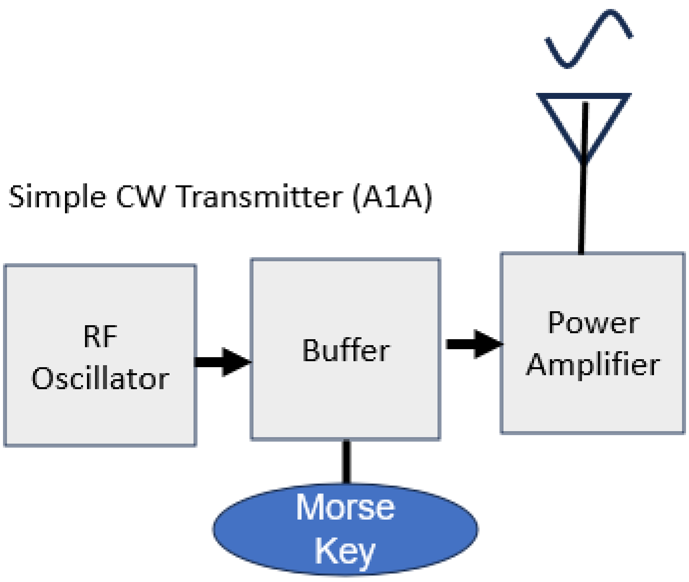
Reactance Modulator
Reactance modulators are for indirect modulation of a FM or PM signal. The reactance modulator do not have very good frequency stability and uses an electrically variable inductance or capacitance to produce the signals. Commonly a varactor diode is used to provide variable capacitance.

Amplifier

A radio frequency (RF) amplifier to increase the power of the signal, to increase the range of the radio waves.
An impedance matching (antenna tuner) circuit to transform the output impedance of the transmitter to match the impedance of the antenna.

Transmitter Block Diagrams

CW transmitter



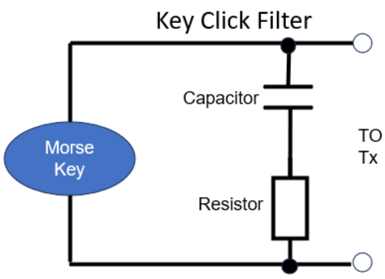
The CW transmitter is the simplest transmitter and still very effective. CW takes the least bandwidth for transmission and can be heard is the worst operating conditions.

In the CW transmitter, the oscillator generates the carrier, and the buffer separates the signal from the Power amplifier (PA). The carrier is turned on and off by the morse key. The power supply for each stage is separated to prevent one stage interfering with other stages. This is called decoupling. The method of decoupling is by using either capacitive or inductive. Capacitive coupling is cheaper, but the downside is that transient spikes can still pass through a capacitor. The alternative is inductive coupling such as a transformer with either ferrite or air core. The primary and secondary windings can be tuned to the desired frequency to eliminate unwanted signals.

A common form of keying is “block based” where the amplifier is biased on and off.

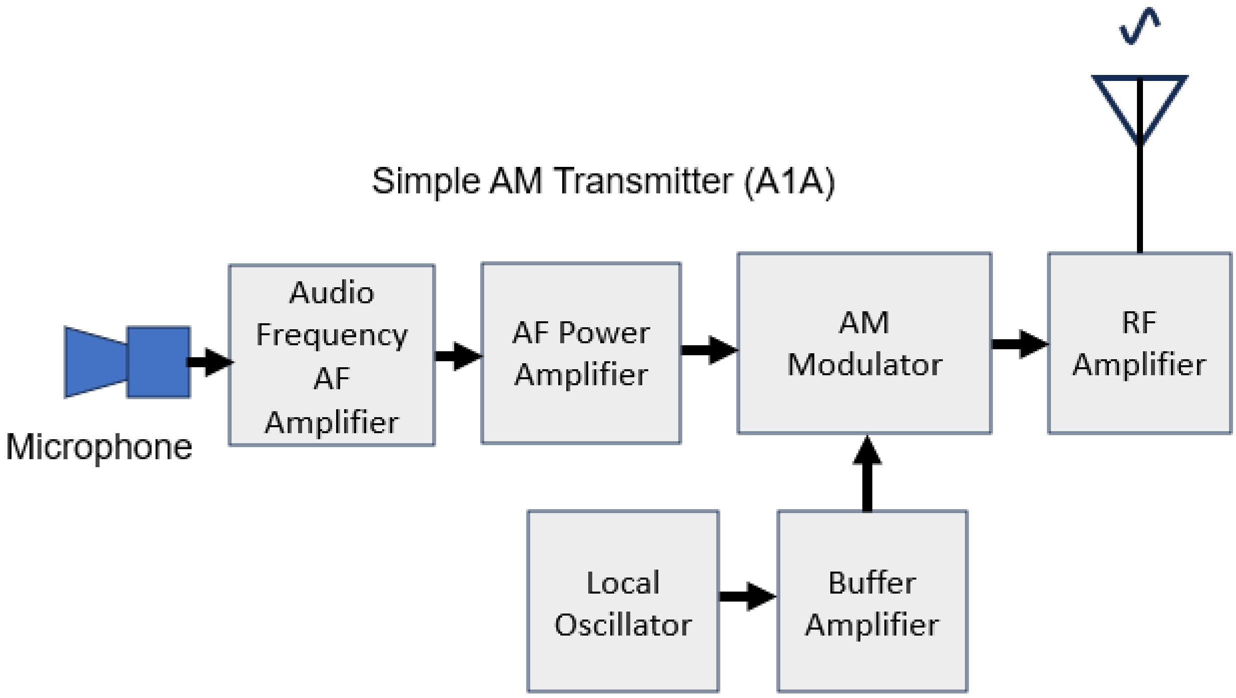
Two issues with CW transmitters are Key clicks and chirps.

- **Key Clicks**. CW transmitted with poor waveform shaping causes interference. This is heard as clicks and thumps by other CW operators on nearby frequencies. Key Clicks can be reduced by using a Key Click filter to shape the transients between transmission bursts of morse code. This filter can be a simple RC network to shape the attack and decay times of the transmissions.



- **Chirps**. Oscillator stability is essential for a clean transmission. Any variation in the frequency as the transmitter is keyed is called a chirp. This is an unpleasant signal to receive.

AM Transmitter

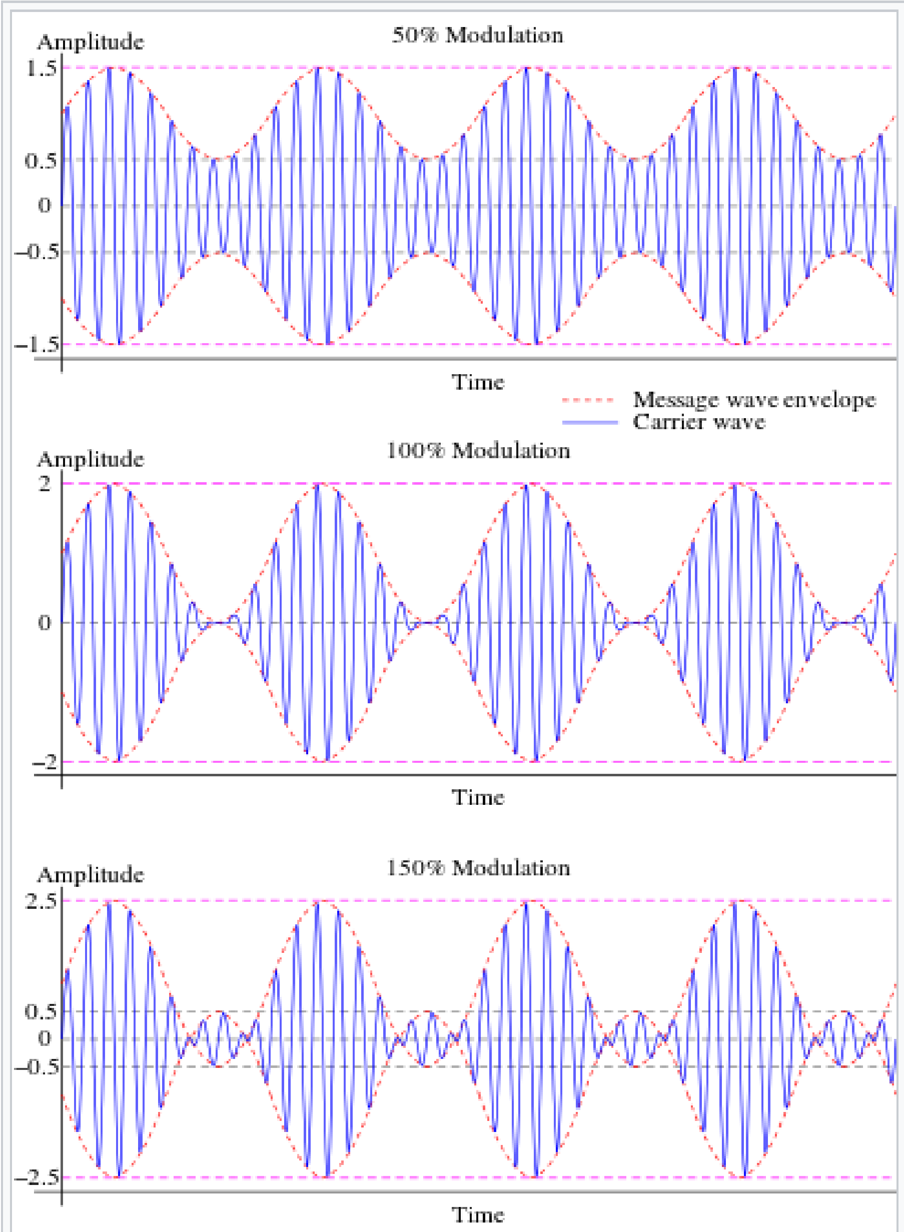


For AM transmissions, the carrier is amplitude modulated by the message being transmitted. The disadvantage with AM is that it transmits identical sidebands with the carrier. A message of 3 kHz bandwidth requires 6 kHz bandwidth plus the carrier.

The unmodulated carrier has an amplitude of 1. Best efficiency is 100% modulation as shown in the diagram below.

The power of an AM transmission is spread between the carrier and two side bands. Each side band has approximately a quarter of the transmitted power and the carrier accounts for 50 % of the power. So that a transmission of 40 W would have 20 w in the carrier and 10 W in each side band.

Overmodulation of the signal as shown in the bottom of the next diagram will cause inference in adjacent stations. Overmodulation is called splatter. The common cause of overmodulation is by excessive microphone gain.



This diagram is copied from Wikipedia at [Amplitude modulation - Wikipedia]

AM Modulation Index

The amplitude modulation index describes the amount by which the modulated carrier envelope varies about the static level. The amplitude modulation index expressed as a percentage. For a Modulation index of 0.75 would be 75% modulation.

$$m = \frac{M}{A}$$

m = Modulation Index

A = the carrier amplitude.

M = the modulation amplitude and is the peak change in the RF amplitude from its un-modulated value.

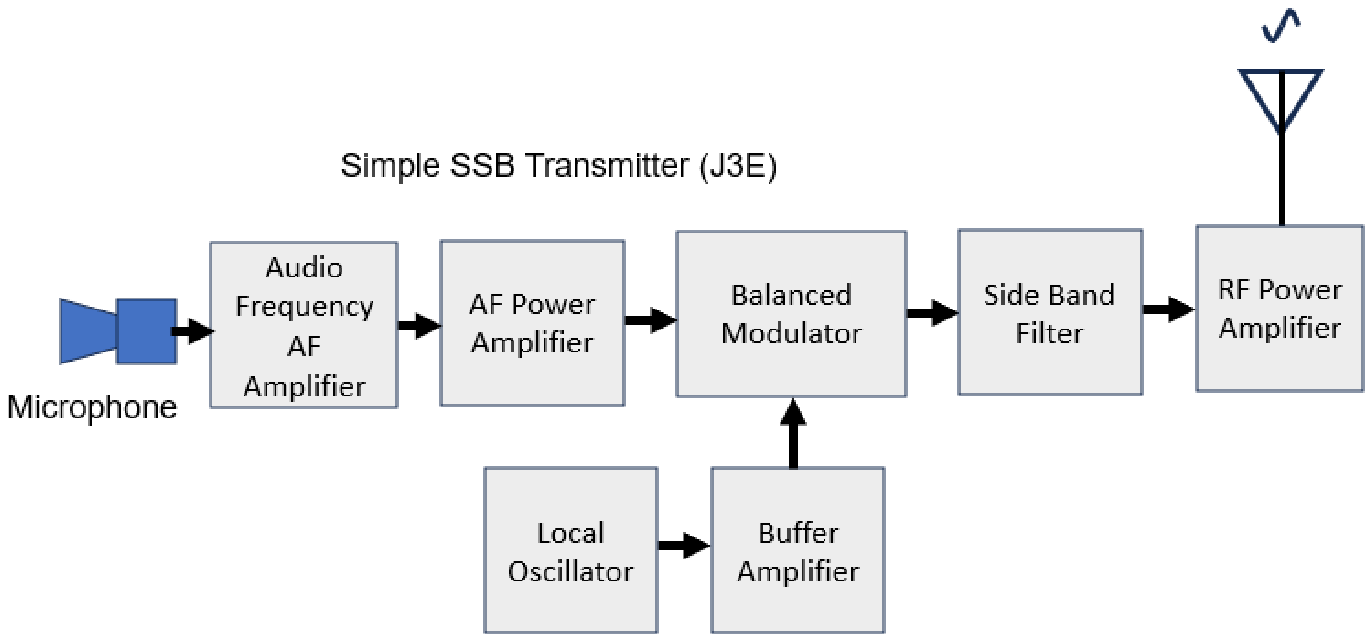
Example: An AM signal has an amplitude of 5 V peak and the modulation signal had a peak of 2 V.

$$m = M / A$$

$$m = 2/5$$

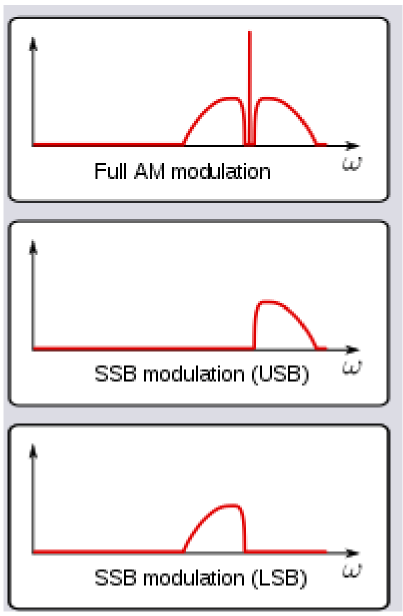
$$m = 0.4 \text{ or } 40\ \%$$

SSB Transmitter



Single sideband suppressed carrier is the correct term but the is reduced to Single Side Band or SSB. SSB is a variant of AM.

A balanced modulator adds the message to the carrier so that only the sideband signals come through the output modulator. This creates a balanced signal, as there is less noise because the carrier signal has been removed.

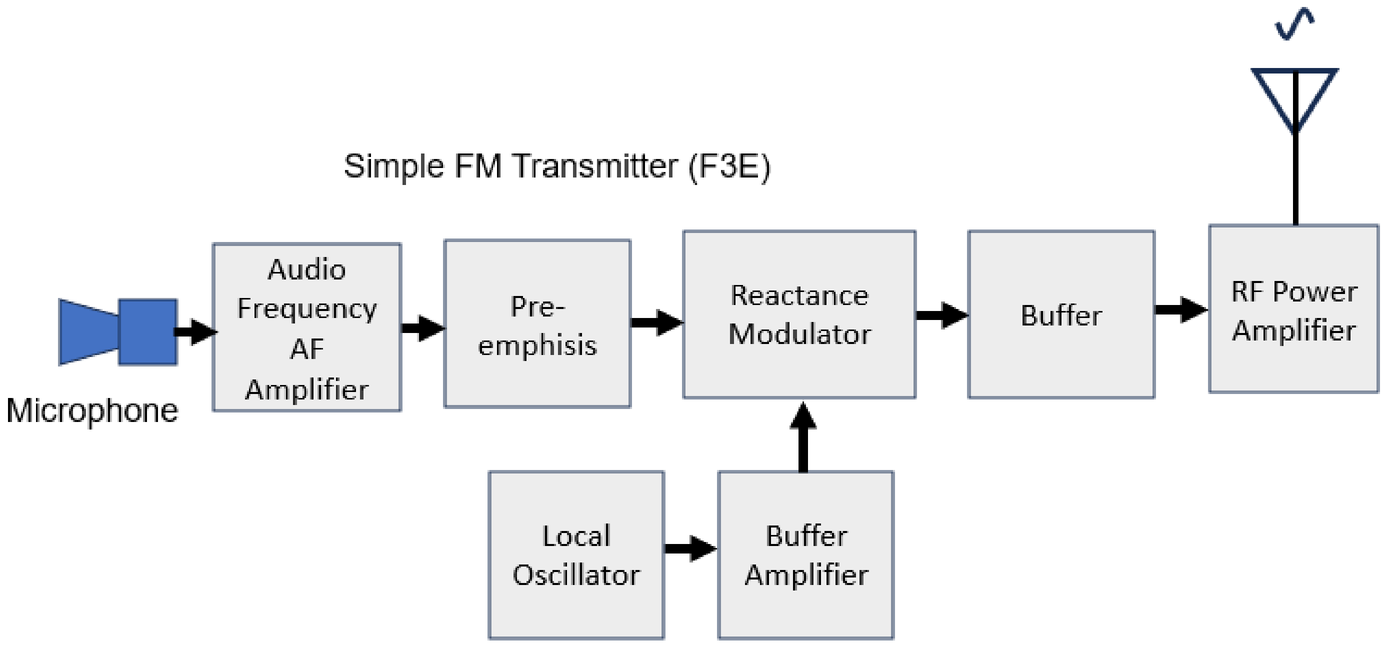


Wikipedia [Single-sideband modulation - Wikipedia]

The upper side band (USB) or lower side band (LSB) can be selected. Amateur radio convention is that for frequencies greater than 10 MHz USB is used. For frequencies below 10 MHz, LSB is used.

For a 3 kHz message using SSB, the bandwidth is half that of an AM with the same message.

FM Transmitter



The message may go through a pre-emphasis stage which boosts the higher frequencies of the audio signal to improve its transmission and reception quality. De-emphasis occurs in the receiver.

A FM transmitter has a reactance modulator where the carrier frequency is varied by the message sent.

Frequency modulation index

The frequency modulation index is equal to the ratio of the frequency deviation to the modulating frequency. The modulation index is independent of the carrier frequency.

$$m = \frac{Frequency\ deviation}{Modulation\ frequency} \quad \text{or} \quad m = \frac{\Delta F}{f\ mod}$$

Example: A signal has a deviation of ±5kHz and the modulating frequency is 1kHz.

m = Freq Deviation / Mod freq

m = 5 / 1

m = 5.

Modulation index is 5.

Bandwidth

The bandwidth required by a FM signal can be calculated.

$$BW = 2(\Delta_f + f_s)$$

BW = Bandwidth

Δf = frequency deviation

f_S = modulating frequency

Example: Delta f = 55 KHz FS = 10 KHz

. BW = 2 x (Freq change + Mod freq)

BW = 2 x (55 + 10)

BW = 2 x 65

BW = 130 KHz

Neutralisation

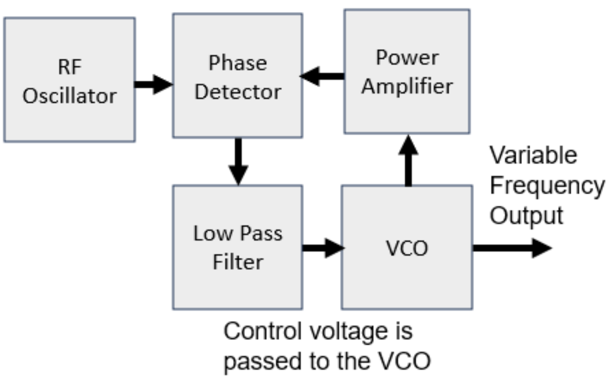
Neutralisation is a technique used to cancel feedback in bipolar junction transistors (BJTs) and field-effect transistors (FETs) that can cause instability over certain frequency ranges. This is done by introducing an additional feedback signal of equal amplitude but opposite phase to cancel the original feedback.

A completely neutralized amplifier must fulfill two conditions. The first is that the interelectrode capacitance between the input and output circuits is cancelled. The second requirement is that the inductance of the screen grid and cathode assemblies and leads be completely cancelled.

Varying The Frequency

An amateur transmitter is of little value if it can only transmit on one frequency. Being able to vary the oscillator frequency can be achieved by several methods.

- Array of crystals. This allows the transmitter to be used on several different frequencies.
- Variable-frequency oscillator (VFO) - A VFO is an oscillator whose frequency can be tuned over some range.
- Phase-locked loop (PLL) - A PLL generates an output signal whose phase is related to the phase of an input signal. The simplest PLL consists of a variable frequency oscillator and a phase detector in a feedback loop.



- Direct Digital Synthesis (DDS) - DDS is a method to generate a sine wave using digital techniques. The analogue signals are synthesized from values stored and used to recreate the signal. DDS signals can be synthesized directly without requiring the phase-locked loops. The digital bytes are converted by a Digital to Analogue Converter (DAC) then passed through a smoothing filter. The synthesized signals are repeatable and the frequencies precise.

Frequency synthesizers can output a clean stable signal up through UHF, but it was not practical to operate the oscillator at the final output frequency. Multiplying the frequency is more common up to the final required frequency.

- Frequency Doubler - A push-push frequency doubler can be tuned to two times the input frequency.
- Frequency Tripler - A push-pull frequency tripler can be tuned to three times the input frequency.

Using a multiple of the frequency driving the stage, a large harmonic output is generated. Many transmitters used this simple approach successfully.

Measuring Transmitter Output Power

This is usually performed using a power meter. Modern power meters also include and SWR meter for testing the transmission line and antenna.

Peak envelope power (PEP)

PEP is the average power over a single radio cycle. PEP is equal to steady carrier power of a FM, FSK, or RTTY transmission.

With AM, 100% modulation of a carrier (PEP) is four times its carrier PEP; in other words, a typical modern 100-watt amateur transceiver is usually rated for no more than 25 watts carrier output when operating in AM.

Average Power

PEP is equal to the average power in a steady FM, FSK, or RTTY transmission.

Typical average power of a SSB voice transmission is 10-20% of PEP.

PEP level control.

Most modern amateur transceivers use an ALC (automatic level control) system to monitor the output. Operators must be aware of this as overdriving the ALC can cause distortion in the output.

Transmitter Field Strength

Electric field strength is a quantitative measure of the intensity of an electric field at a particular location. The standard unit is the volt per meter (V/m or V·m-1). A field strength of 1 V/m represents a potential difference of 1 V between points separated by 1 meter.

Transmitter Terms

- **Automatic Level Control (ALC)** - An ALC circuit controls the signal strength at the input to the power amplifier in a ham radio transmitter. The ALC keeps the power amplifier input at the designed range for linear operation and stops the power amplifier from being driven into non-linearity. Overdriving the ALC circuit can distort the signal and cause interference.
- **Mixer** - Mixers shift signals from one frequency range to another, a process known as heterodyning. Frequency mixers are also used to modulate a carrier signal in radio transmitters.
- **Buffer** – A buffer stage matches one stage to the following stage. This may be impedance matching or circuit separation and in decoupling.
- **Duty Cycle** - The duty cycle is the ratio of the time a piece of equipment is operating to time it is off. An amateur transmitter is not designed for 100% transmission time so has a

duty cycle included in the design and should be operated within the manufacture's parameters.
  - ❖ FSK, RTTY, AFSK SSB uses a 100% (1) duty cycle.
  - ❖ Morse code uses a 40% duty cycle.
- **Driver** – Driver or output stage of the transmitter.
- **Power amplifier** - A radio-frequency power amplifier (RF power amplifier) converts a low-power radio-frequency signal into a higher-power signal and the output drives the antenna.
- **Output matching** – The transmitter output impedance must be matched to the load impedance for maximum power transfer.
- **Linier amplifier**. - Linearity refers to the ability of the amplifier to produce signals that are accurate copies of the input and at increased power levels. No amplifier can provide perfect linearity; however, the amplifying devices follow nonlinear function and rely on circuitry techniques to reduce those effects.
- **Output filter** – The output filter would have 50 ohms input and output impedance and ensure the output does not exceed the designated frequency range.
- **Crystal filter** - A crystal filter allows selected frequencies to 'pass' through while attenuating undesired frequencies. Quartz crystals can exhibit mechanical resonances with a very high Q factor (from 10,000 to 100,000 and greater – far higher than conventional resonators built from inductors and capacitors)
- **Audio-frequency range** – The human audio range is 20 Hz to 20,000 Hz is commonly referenced frequency range.
- **Output impedance** - Maximum power is transferred when the transmitter output impedance is equal to the load impedance of the antenna. Amateur standard is 50 ohms.
- Transmitter Efficiency -
- **Spurious RF radiations** – Distortion is introduced by the transmitter when the output is not an exact magnified copy of the input. Signals can get clipped leading to harmonic and sideband distortion. Overdriving the amplifier is a major cause of wide signal bandwidth and splatter.
- **Phase noise** - Phase noise is an undesired variation in the phase of the signal.
- **Cavity Resonator** - Is used at the higher frequencies. The cavity resonator has a high Q so is ideal for oscillation and amplification. The cavity is a closed compartment made of a conductor with a hollow interior. A perfect oscillator is formed when the input is provided to the cavity resonator at the high frequency. The output of the cavity resonator is higher than its input, so it also works as an amplifier.
- **Efficiency** – Efficiency can be expressed as a ratio of the power output ÷ power input. This number can also be expressed as a percentage by multiplying the ratio by 100.

Efficiency% = (Power out / Power in) x 100

Emission Modes

Emission modes are defined in Schedule 1 of the Radiocommunications Licence Conditions (Amateur Licence) Determination 2015 (LCD). The three characters are the:

- Modulation component,
- Signal nature component.
- Information nature component

These are seen in the receiver and transmitter diagrams.

A1A

A =Main carrier is amplitude modulated and uses double-sideband
1 = Signal modulating the main carrier is a single channel containing quantified or digital information without the use of a modulating subcarrier.
A = Telegraphy for aural reception

J3E

J = Main carrier is amplitude modulated and uses a single-sideband, suppressed carrier
3 = Signal modulating the main carrier is a single channel containing analogue information
E = Telephony

F3E

F = Main carrier is angle modulated and uses frequency modulation
3 = Signal modulating the main carrier is a single channel containing analogue information
E = Telephony

You can access the LCD here and go to Schedule 1.

Frequencies

The LCD Part 1 (1C) (2) states the **frequency band** is described using two frequencies and starts immediately above the lower frequency and ends at the higher frequency.

Your carrier and modulated signal cannot cross the boundary edge at the bottom of the boundary edge. Interpretation says your signal bandwidth may exceed the top frequency, but this is not advised.

Goto the frequencies sheet **HERE**

Amateur Frequencies, Bandwidths, Power and Limitations.

Always consult the LCD and Australian Band Plan.

Users	Band	Frequency	Mode	Power
A	2200m	135.7 kHz - 137.8 kHz	Any mode. BW< 2.1 kHz	As per Note 1
A	630m	472 kHz - 479 kHz	Any mode. BW< 2.1 kHz	As per Note 2
A	160m	1.8 MHz – 1.875 MHz	Any Mode BW<8 kHz	As per Note 3 & 4
F - S - A	80m	3.5 MHz – 3.7 MHz	Any Mode BW<8 kHz	As per Note 3 & 4
A		3.776 MHz – 3.8 MHz	Any Mode BW < 8 kHz	As per Note 3
	60m	Not yet available		
F - S - A	40m	7.0 MHz – 7.1 MHz	Any Mode BW < 8 kHz	As per Note 3 & 4
		7.1 MHz – 7.3 MHz	Any Mode BW < 8 kHz	As per Note 3
A	30m	10.1 MHz – 10.15 MHz	Any Mode BW < 8 kHz	As per Note 3
S - A	20m	14.0 MHz – 14.35 MHz	Any Mode BW<8 kHz	As per Note 3 & 4
A	17	18.068 MHz – 18.168 MHz	Any Mode BW<8 kHz	As per Note 3 & 4
F - S - A	15m	21.0 MHz – 21.45 MHz	Any Mode BW<8 kHz	As per Note 3 & 4
A	12m	24.89 MHz – 24.99 MHz	Any Mode BW<8 kHz	As per Note 3 & 4
F - S - A	10m	28.0 MHz – 29.7 MHz	Any Mode BW < 16 kHz	As per Note 3 & 4
A	6m	50.0 MHz - 52.0 MHz	Any Mode BW < 100 kHz	As per Note 3
S - A		52.0 MHz - 54.0 MHz	Any Mode	As per Note 3
F - S - A	2m	144.0 MHz - 148.0 MHz	Any Mode	As per Note 3
F - S - A	70cm	430.0 MHz - 450.0 MHz	Any Mode	As per Note 3
S - A	23cm	1.24 GHz -1.3 GHz	Any Mode	As per Note 3
A	13cm	2.3 GHz – 2.302 GHz	Any Mode	As per Note 3
S - A		2.4 GHz - 2.45 GHz	Any Mode	As per Note 3 & 5
A	9cm	3.3 GHz - 3.4 GHz	Any Mode	As per Note 3
		3.4 GHz - 3.6 GHz	Any Mode	As per Note 3 & 6
S - A	6cm	5.65 GHz - 5.85 GHz	Any Mode	As per Note 3
A	3cm	10.0 GHz – 10.5 GHz	Any Mode	As per Note 3
A	12 mm	24.0 GHz - 24.25 GHz	Any Mode	As per Note 3
A	6 mm	47.0 GHz – 47.2 GHz	Any Mode	As per Note 3
A	4 mm	76.0 GHz – 81.0 GHz	Any Mode	As per Note 3
A	2.5mm	122.25 GHz – 123.0 GHz	Any Mode	As per Note 3
A	2mm	134.0 GHz – 141.0 GHz	Any Mode	As per Note 3
A	1.25mm	241.0 GHz – 250.0 GHz	Any Mode	As per Note 3

Note 1 - A maximum Effective Isotropic Radiated Power (EIRP) of 1 watt pX.

Note 2 - A maximum Effective Isotropic Radiated Power (EIRP) of 5 watts pX.
Excluded from use in the "Timor Non Directional Beacon Area". Refer to LCD Part 3 (1)

Note 3
Foundation transmitter power - 10 watts pX for all modes
Standard Transmitter power - 100 watts pX for
J3E - SSB telephony
R3E - SSB variable carrier telephony
Other modes 30 watts pY
Advanced transmitter power - 400 watts pX for
C3F - Vestigial sideband television
J3E - SSB telephony
R3E - SSB variable carrier telephony
Other modes - 120 watts pY.

Note 4 - If the band width is exceeded, the Power Spectral Density (PSD) of the signal must not exceed 1 watt per 100kHz.

Note 5 - Other services must accept any harmful interference from Industrial, Scientific & Medical devices.

Note 6 - Excluded from operating in areas defined by Schedule 5 of the LCD.

pX - Peak envelope power (PEP).
pY - The average power
pZ - Carrier Power.

Go to Lesson 13 Questions.