General Class License Theory II

Dick Grote

K6PBF

k6pbfdick@gmail.com

Introduction

In the first theory class we talked about basic electrical principles and components. Now we will build on this to learn about

- Practical Circuits
- Signals and Emissions

Rectifiers and Power Supplies

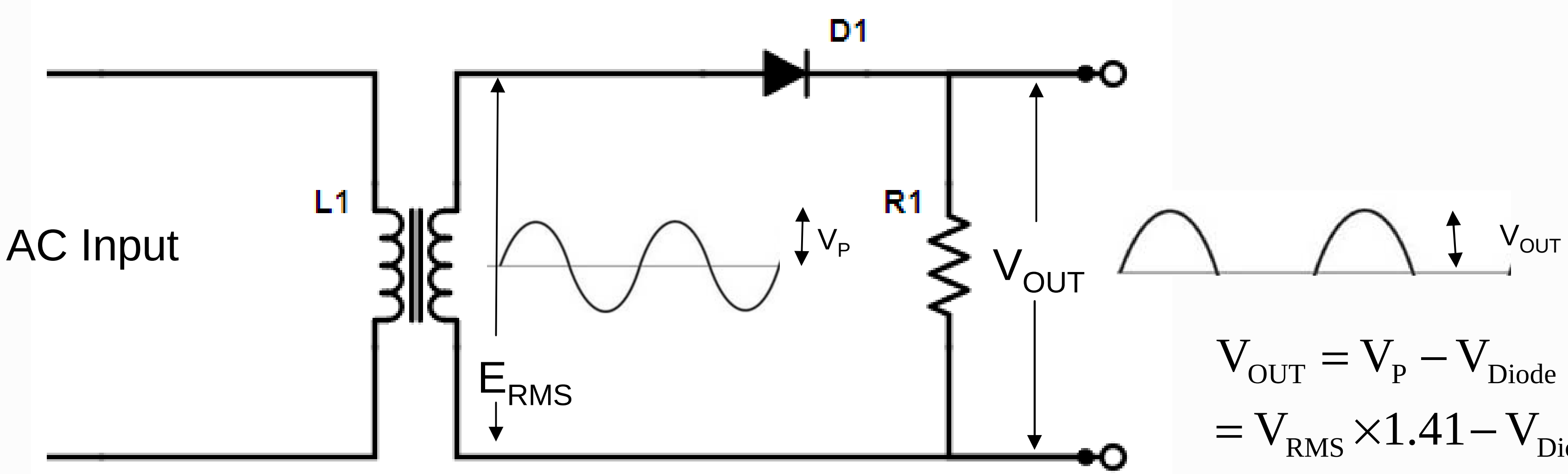
Nearly all electronics runs on DC voltage.

Need to convert AC house voltage (117 or 220V) to DC voltages almost always at different voltage levels.

Useful components to effect this:

- Transformers to change AC voltage levels
- Diode(s) to convert AC to DC
- Capacitors to store energy and "smooth out" waveforms

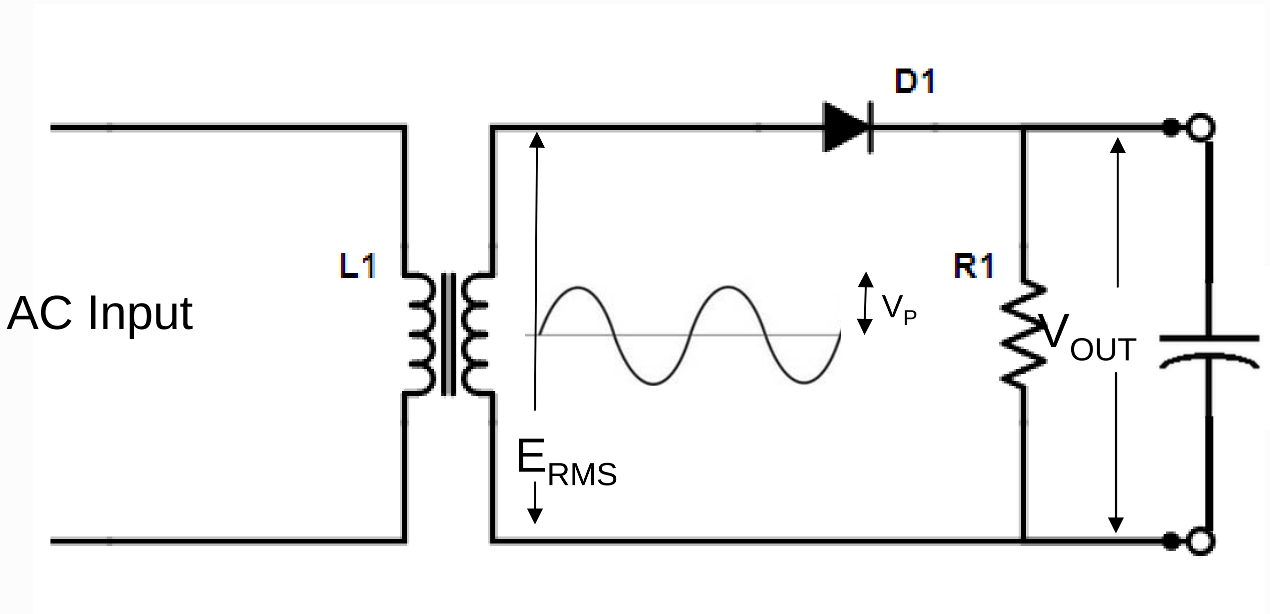
Half Wave Rectifier

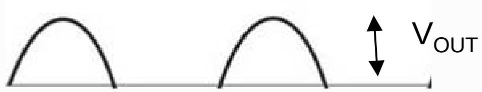


$$V_{OUT} = V_P - V_{Diode}$$
$$= V_{RMS} \times 1.41 - V_{Diode}$$
$$V_{AVE} = .45V_{RMS}$$

- Current flows through the diode during 180° of AC c ycle.

Half Wave Rectifier – Peak Inverse Voltage



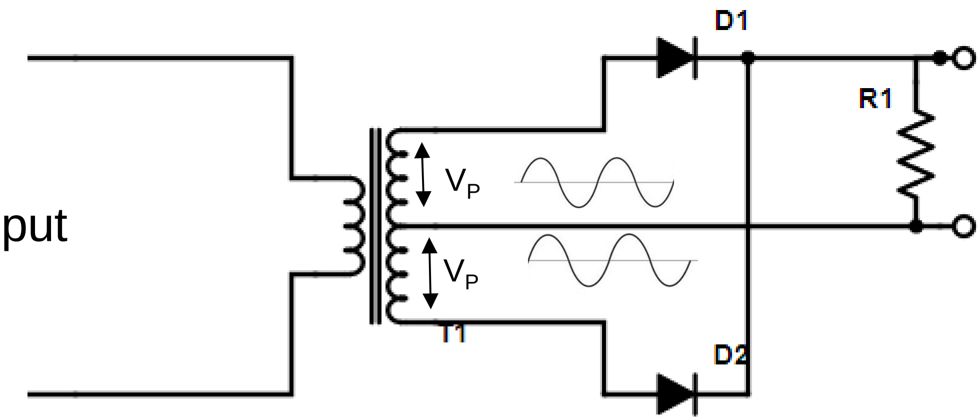


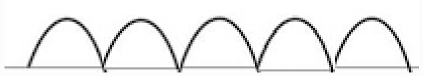
If we were to put a capacitor across the output of this rectifier then the output voltage would charge up to V_P. We can then see that during the negative half cycle:

Peak-inverse voltage across the half wave rectifier (e.g. diode) is two times the peak of the output voltage.

Full Wave Rectifier

AC Input



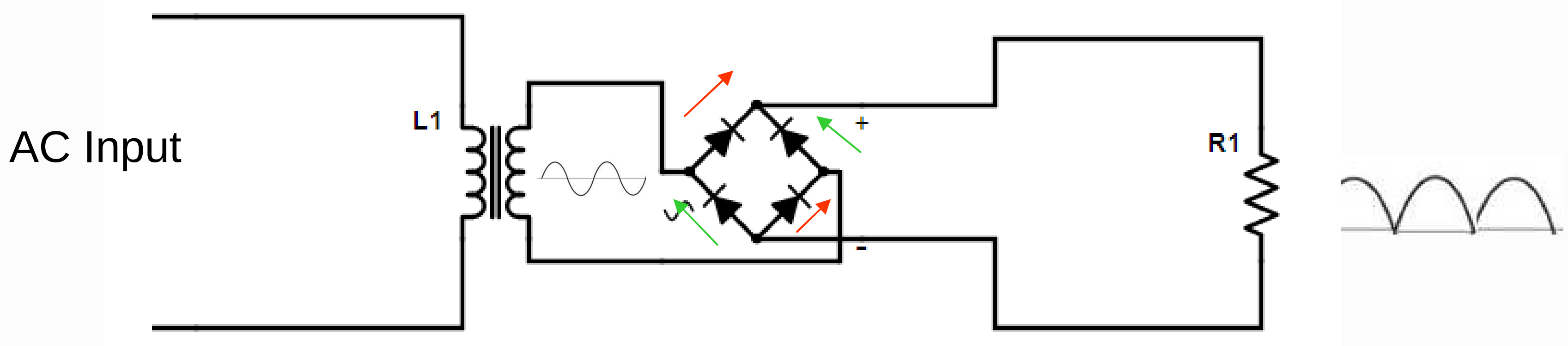


$$V_{OUT} = 2 \times V_P - V_{Diode}$$
$$= V_{RMS} \times 2.8 - V_{Diode}$$
$$V_{AVE} = .9 \times V_{RMS}$$

- Center tapped transformer allows currents to flow alternately through 2 diodes so current flows 360° of AC cycle.
- Pulses through load are a series of pulses at twice the frequency of the input.

Full Wave Bridge Rectifier

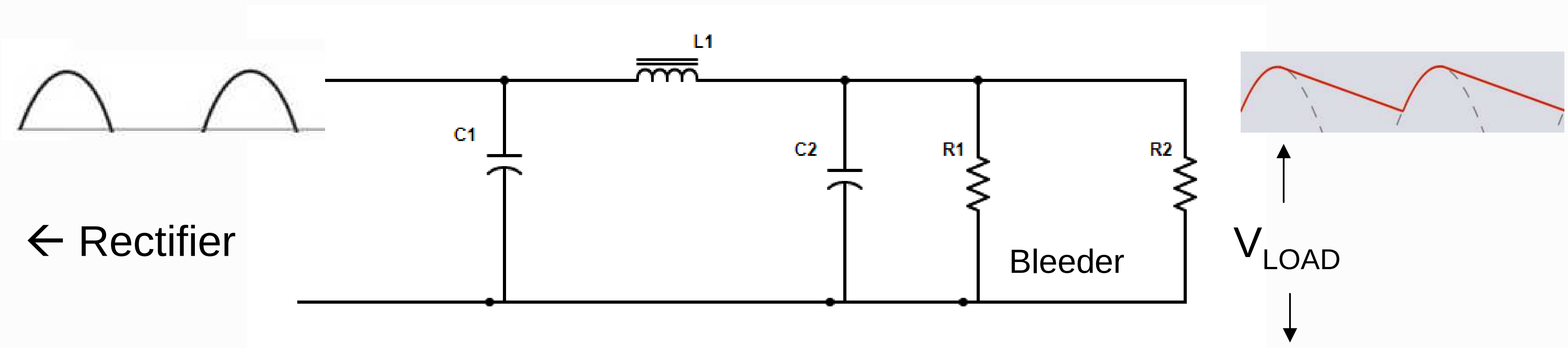
Bridge Rectifier:



- Eliminates the need for a tapped transformer at the expense of 2 additional diodes

- Peak-inverse voltage across rectifiers in a full wave bridge rectifier is equal to the normal peak (Vp) of output voltage of power supply.

Power Supply Filters



- Capacitors and inductors are used in power supply filter networks?

- Filter smoothes pulses so that V_{LOAD} approximates DC voltage

- Capacitor choices are important because they are constantly charging and discharging. It is important internal resistance of C's (termed ESR or Equivalent Series Resistance) is low.

- The Bleeder resistor ensures that discharges the filter capacitors are discharged when the power is removed.

Switch-Mode Power Supplies

A Switch-mode power supply uses a switching regulator operating at a higher frequency to control the conversion of electrical power in a highly efficient manner.

Usually are they are called switching power supply.

The advantage of switching power supply compared to linear power supplies is high frequency operation allows the use of smaller components.

Schematic symbols

During this presentation several schematic symbols have been introduced. The ARRL has a page full of them in their material. These are the ones you will need to know:

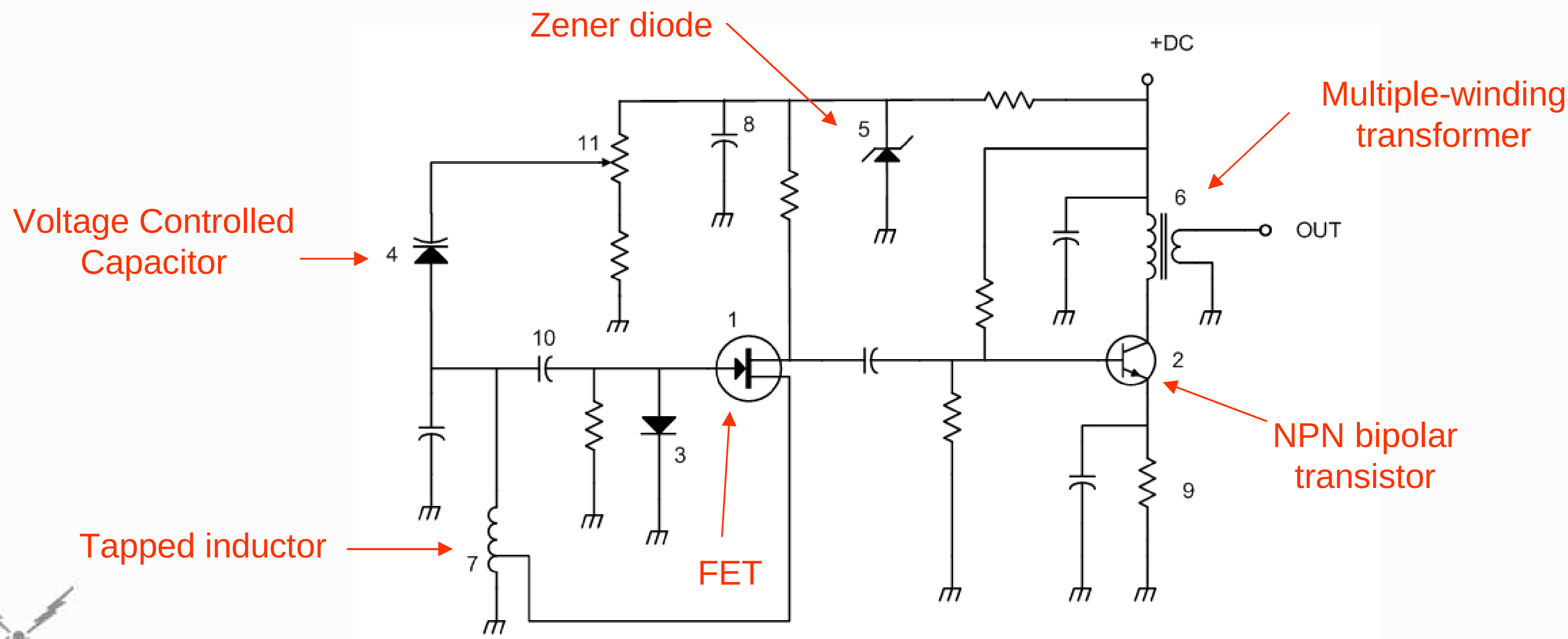


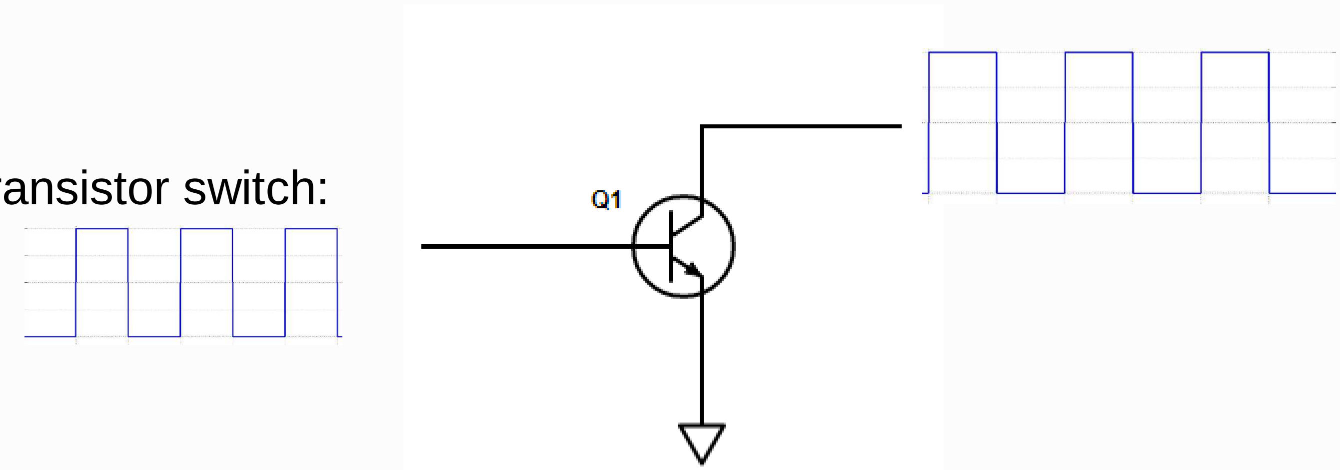
Figure G7-1

Digital Circuits

Digital circuits operate in only of two (**binary**) states:

- ON/OFF
- High/Low
- One/Zero
- True/False

Remember the transistor switch:



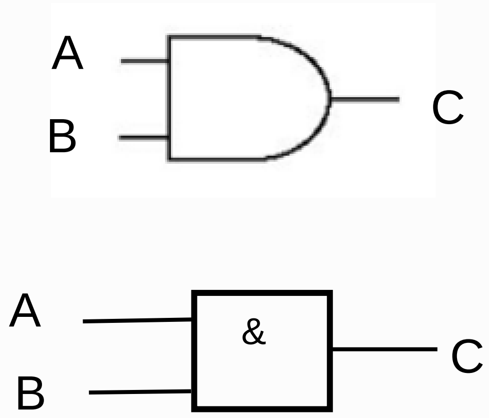
Advantages of using digital circuits: Binary “ones” and “zeros” are easy to identify with an on or off state.

Logic Symbols and Functions

AND Gate:

Truth table:

Inputs



Output

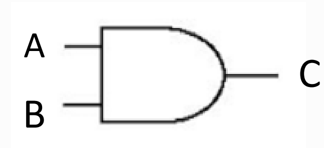
C=H when A&B are H
C=L otherwise

A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

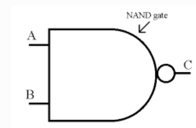
What is the function of a two input AND gate?
Output is high only when both inputs are high

Digital Logic Building Blocks

- AND — C = 1 when A&B = 1; 0 otherwise

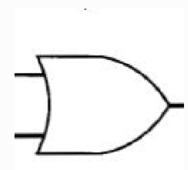


- NAND (not AND) — C = 1 when A&B=0; 0 otherwise



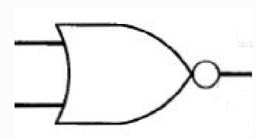
- OR — C=1 when A and/or B = 1

  C =0 when A&B = 0



- NOR — C = 0 when A and/or B = 1

  C = 1 when A&B = 0



Bits and Number of States

- One **bit** can be 1 or 0 → 2 states

- 2 bits can be 00, 01, 10, 11 → 4 states
- A byte is 8 bits and has 256 states
- In general the number of states of N number of bits is 2^N

Example: How many states does a 3 bit counter have?

$2^3 = 8$

Other Digital Devices

By combining multiple gates digital functions can be implemented. Important examples:

- Flip-flops – two stable states that are stored and can be changed in various ways.
- Counters – Flip-flops connected so that they count in binary every time they are “clocked”
- Shift registers – Sequential flip-flips connected so that data can be transferred (or shifted) from one flip-flop to the next or alternately a clocked array of circuits that passes data in steps along the array.

High Level of Integration

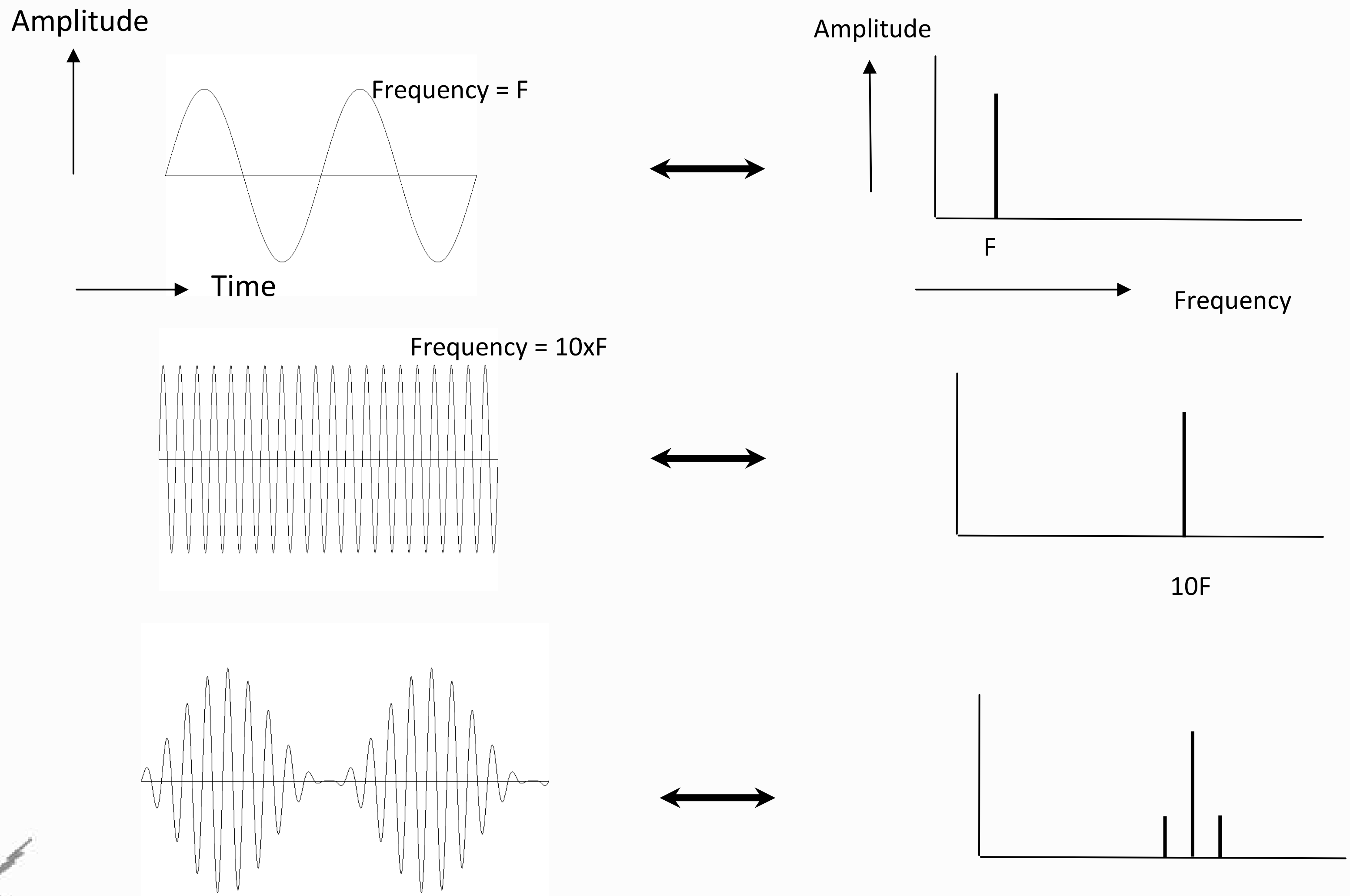
By higher levels of integration of gates very complex digital functions can be built on a chip.

Examples:

- Microprocessors
- Microcontrollers
- DSP's (Digital Signal Processors)

Complex digital circuitry can often be replaced by what type of integrated circuit? Microcontroller

Time vs. Frequency Domain



$$\mathrm{Sin}\,(F_1) \times \mathrm{Sin}\,(F_2) = \tfrac{1}{2}\,[\,\sin\,(F_1 + F_2) + \sin\,(F_1 - F_2)]$$

Radio Building Blocks

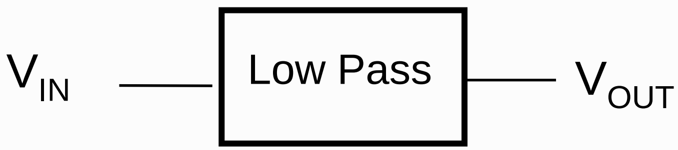
These are the basic building blocks of most radios:

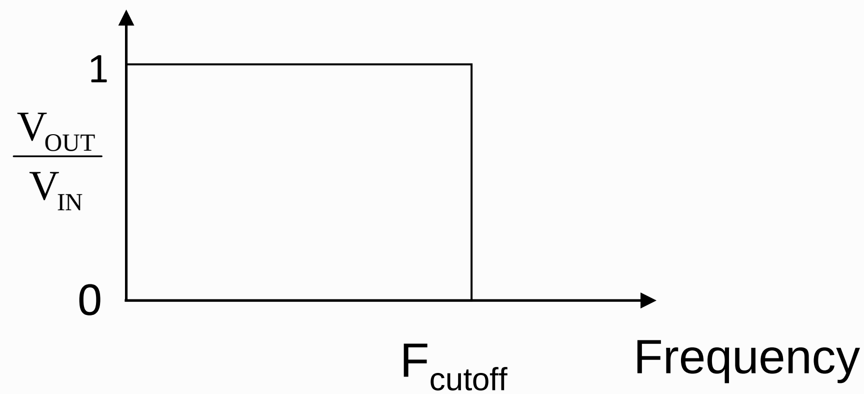
- Filters
- Oscillators
- Amplifiers
- Mixers
- Multipliers
- Modulation and modulators

We will discuss each building block and then see how they can be put together.

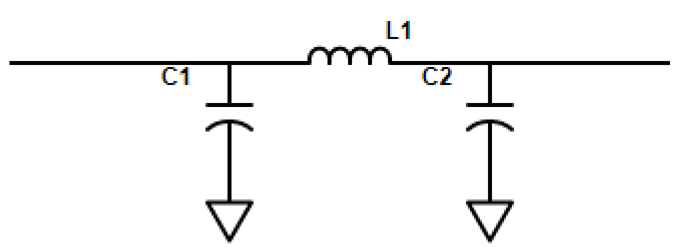
Filters

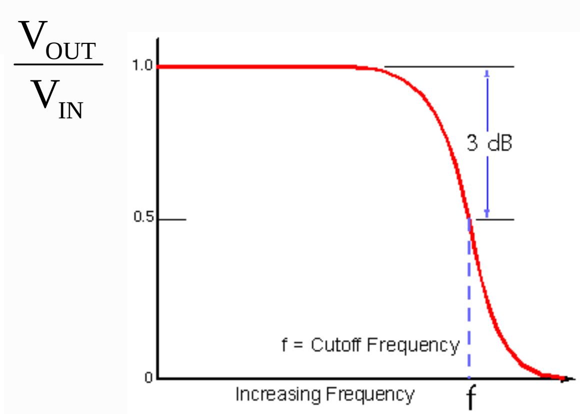
An ideal filter will pass one set of frequencies and blocks others.





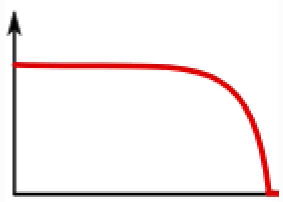
Practical Low Pass Filter



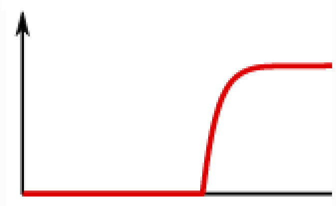


Filter Types

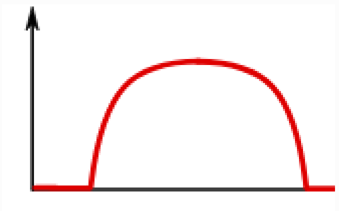
- Low Pass



- High Pass



- Band Pass



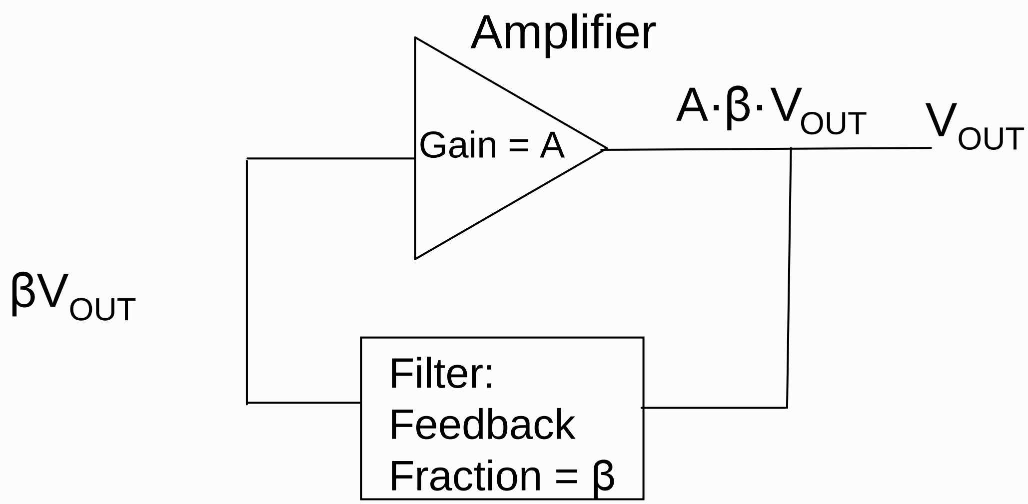
•Low pass filters are especially important for front end and out output of transceivers.

• Band pass filters are important in the intermediate frequency (IF) stages of receivers.

The impedance of a low-pass filter compared to the impedance of the transmission line into which it is inserted should be about the same.

Oscillators

An oscillator is a circuit which produces a waveform (often but not always a sine wave) at a fixed or variable frequency.



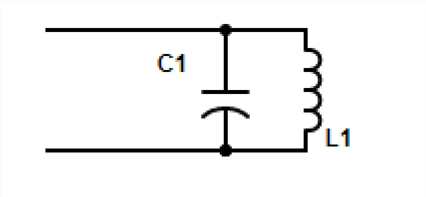
An oscillator consists of an amplifier with feedback from output to input. A filter is needed in the feedback to assure oscillation is only at one frequency

What are the basic components of an nearly every Oscillator? A filter and amplifier operating in a feedback loop.

Oscillators

Feedback (β) in an oscillator can be of various forms and configurations including L's and C's, crystals, and even light bulbs. Crystals are useful because they vibrate very accurately.

LC circuits are often configured as resonant or "tank circuits"



At the frequency where the tank circuit is at "resonance"

$$\frac{1}{2\pi FC} = 2\pi FL \qquad F = \frac{1}{2\pi\sqrt{LC}}$$

The resonance will determine the frequency of the oscillator

What determines the frequency of an LC oscillator ?
The inductance and capacity of the tank circuit.

Tunable Oscillators

Two other widely used tunable oscillators in radios are:

- Phase-locked loops (PLL)
- Direct Digital Synthesizer (DDS).

DDS is a digital device that can be programmed by a computer or microprocessor to oscillate at a specific frequency and they can be very stable. They are used in a lot of ham applications.

What is the advantage of a transceiver controller by a direct digital synthesizer? It has variable frequency with the stability of a crystal oscillator.

Amplifiers

Amplifiers increase the strength (e.g amplitude) of signals.

The term **Linear Amplifier** or "linear" is used usually to describe the equipment that amplifiers the output of a transmitter up as much as the legal limit – 1500 watts

Linear amplifiers operate so that the output preserves the input waveform.

$$\text{Amplifier efficiency} = \frac{\text{RF Power Output}}{\text{DC Power Input}}$$

Amplifier Linearity

Linearity is a measure of how well the amplifier it preserves the input signal without creating signal distortion.

In general amplifier linearity is inversely proportional to efficiency: Efficiency↑ → Linearity ↓

Amplifier Efficiency

- **Class A** – most linear, low distortion (output transistors always in active region)
- **Class B** – efficiency good and linearity can be good (output transistors push-pull each operating during half cycle)
- **Class AB** – Between A and B in operation
- **Class C** – Very un-linear, but highest efficiency (output transistors are being switched off and on) Suitable only for CW

Amplifier Neutralization

In vacuum tube linear amplifiers parasitic capacity can create enough positive feedback to cause oscillations.

A solution is provide some addition negative feedback in the circuit to cancel the positive feedback.

This is call **neutralization** and is implemented by connecting a small variable capacitor from output to input of the circuit to provide negative feedback.

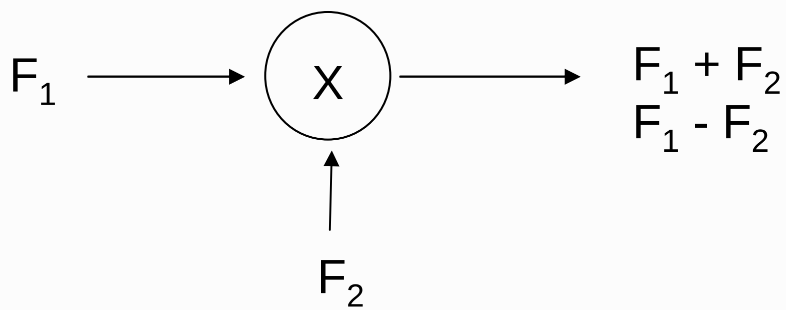
What is the reason for neutralizing the final stage of a transmitter? To eliminate self-oscillation.

Mixer

The **Mixer** is a circuit that multiplies two signals which creates sum and difference frequencies. This mixing process is called **heterodyning**.

The mathematical basis of mixing is the trigonometric property:

$$\sin(a) \times \sin(b) = \frac{1}{2}[\sin(a+b) + \sin(a-b)]$$



In Radio circuits, F_1 is usually the RF input and F_2 the local oscillator

Example To shift frequencies to a 455 Khz IF:

F_1 = 14.250Mhz
F_2 = 13.795Mhz

F_2-F_1 = 455 Khz
F_2+F_1 = 28.045Mhz

Remove this frequency with a low pass filter.

Mixer Operation and Interference

What receiver stage combines 14.250 Mhz input signal with a 13.795 MHz oscillator to produce a 455 kHz intermediate frequency (IF) signal?

--Mixer

If a receiver mixes a 13.800 Mhz VFO with a 14.255 received signal to produce a 455 KhZ intermediate frequency (IF) signal, what type of interference will a 13.345 Mhz signal produce in the receiver?

--Mixer interference.

(13.800-13.345=455 → two input frequencies mix.

Multiplier

A Multiplier circuit operates in a similar manner to a mixer but instead of creating sum and differences of the input, it creates harmonics of an input frequency.

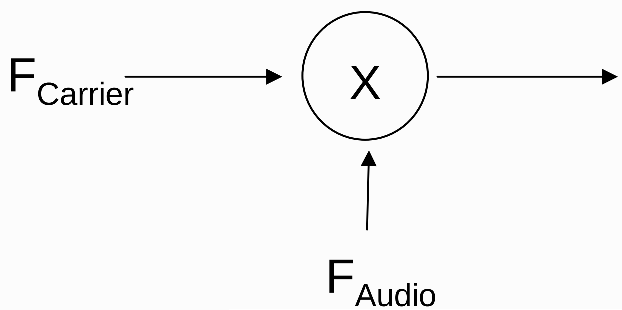
Multipliers are often used in VHF and UHF radios to create a higher frequency signal.

What is the stage in a VHF FM transmitter that generates a harmonic of a lower frequency signal to reach the desired operating frequency?

--Multiplier

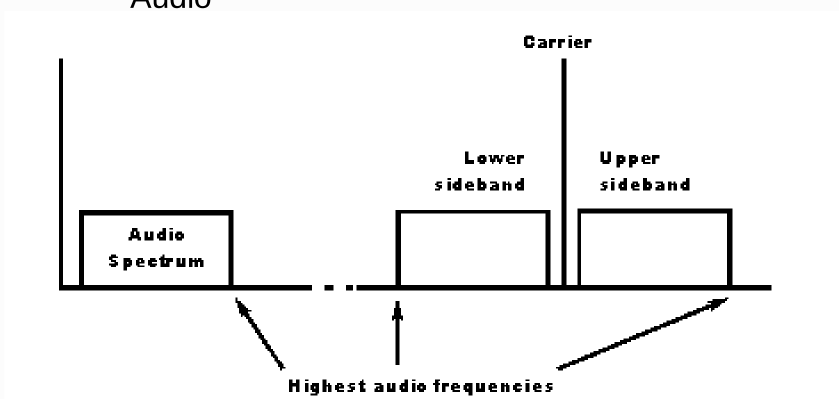
Modulation

Modulation is the process of adding information to an RF signal (i.e. the carrier) by varying frequency, amplitude or phase. Amplitude modulation:



$F_{Carrier} + F_{Audio}$ Upper Side Band (USB)

$F_{Carrier} - F_{Audio}$ Lower Side Band (LSB)



AM Modulation

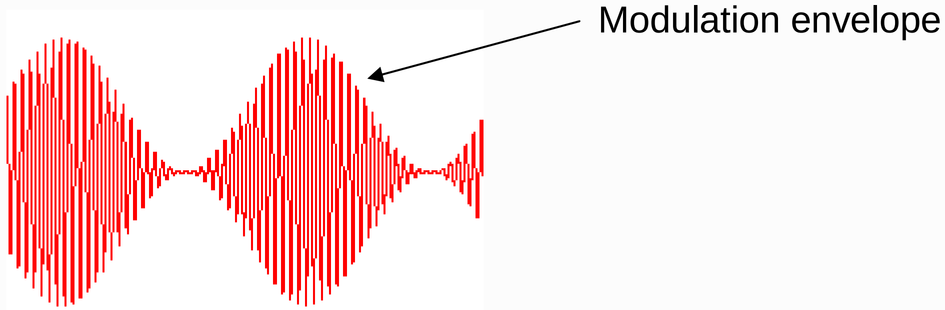
- AM – Amplitude Modulation: phone transmission in which the voice signal modulates the carrier.

What type of modulation varies the instantaneous power level of the RF Signal?

--Amplitude modulation

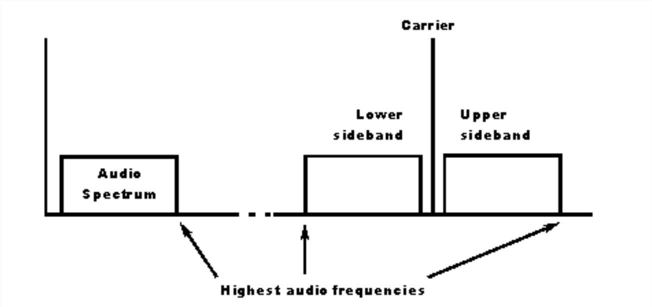
What is the modulation envelope of an AM signal?

--The waveform created by connected the peak values of the modulated signal



SSB Modulation

SSB – Single Side Band, only one of the two sidebands is transmitted; one sideband and the carrier are suppressed



What is the advantage of carrier suppression in a single sideband phone transmission versus full carrier amplitude modulation?

--Available transmitter power can be used more effectively

Which phone emission uses the narrowest bandwidth:

-- Single sideband

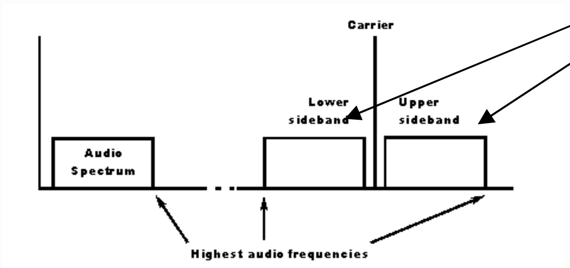
What control is typically adjusted for proper ALC setting on a signal sideband phone transmission.

-- Transmitter audio or microphone gain

Modulation and Transmission Issues

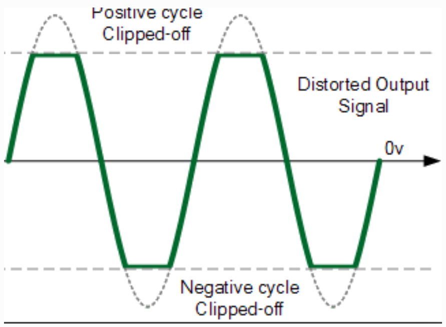
What is the effect of over modulation?

--Excessive bandwidth



With over-modulation the sidebands will start to extend and use more than the desired bandwidth.

Amplifiers which are over-driven product an output that saturates or “flat-tops” and so produce a distorted output

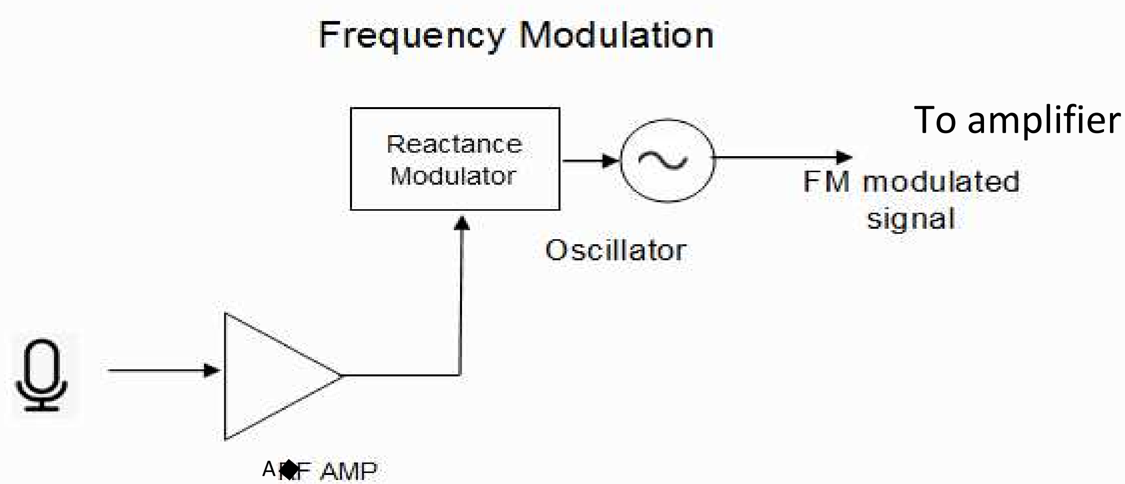


What is meant by the term flat-topping when referring to a single side band transmission?

--Signal distortion caused by excess drive

Frequency Modulation

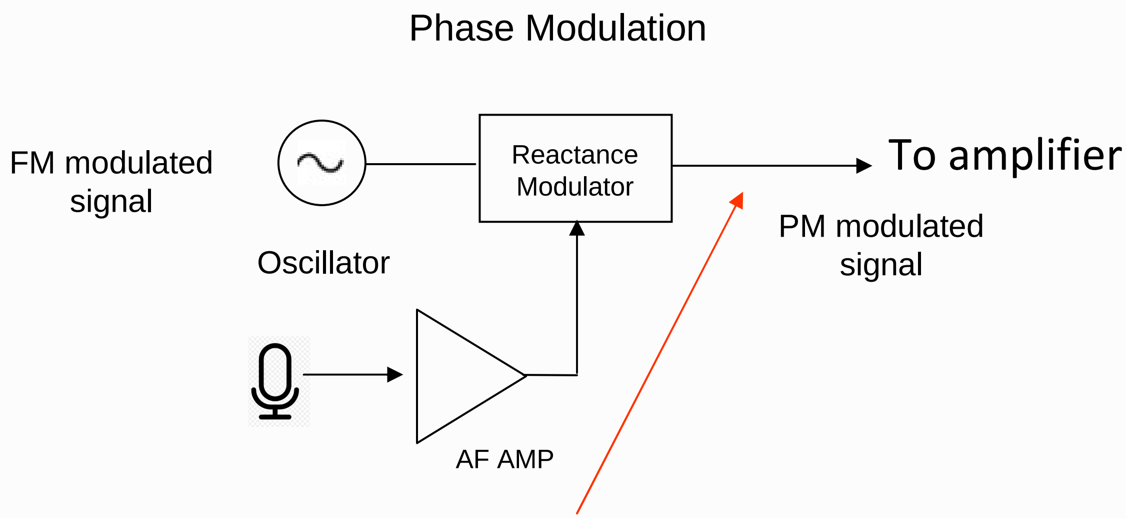
FM – frequency modulation, changes instantaneous frequency of RF to convey information



A reactance modulator changes its reactance as a function of the signal that controls it.

Phase Modulation

PM – phase modulation, changes phase angle of the RF wave to convey information

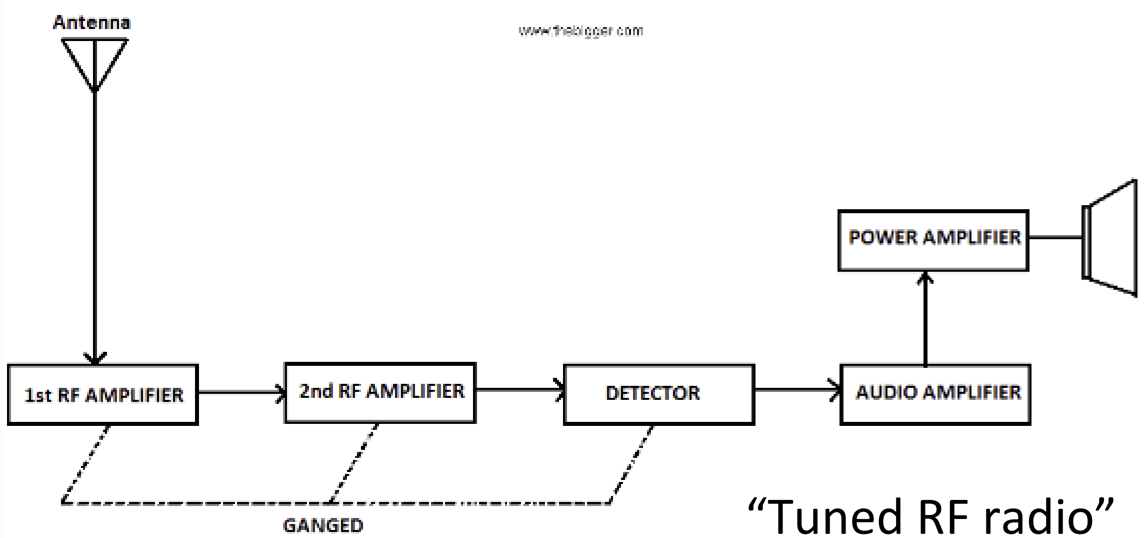


What emission is produced by a reactance modulator connected to the transmitter RF amplifier stage? --Phase Modulation

How Does a Receiver Work?

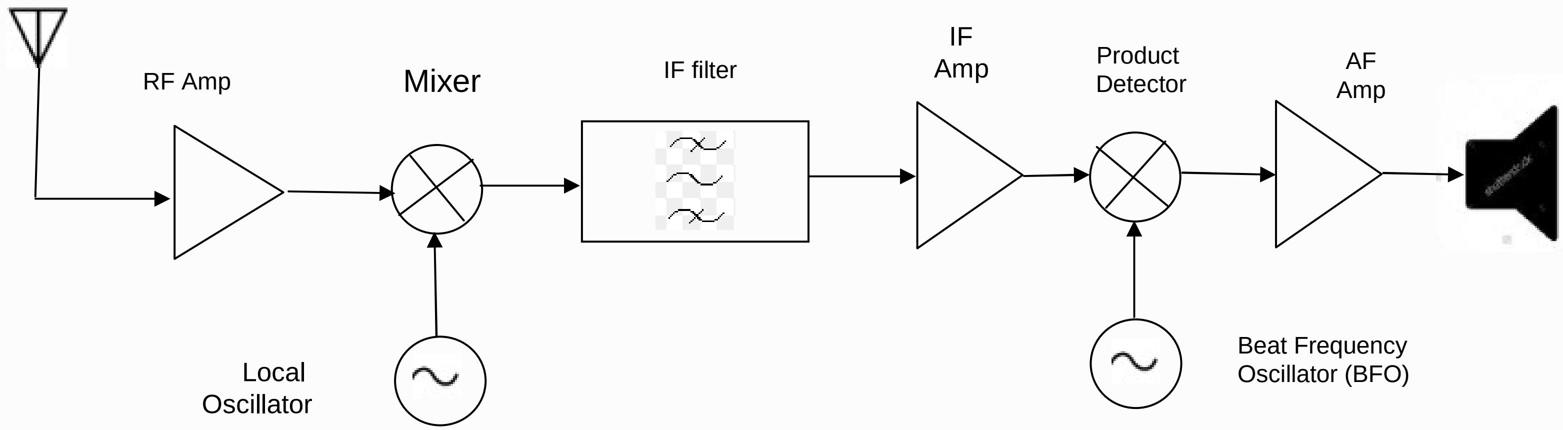
A radio receiver need to

1. capture a signal
2. provide gain and filtering
3. Detect or demodulate
4. Drive a speaker or headphones.



"Tuned RF radio"

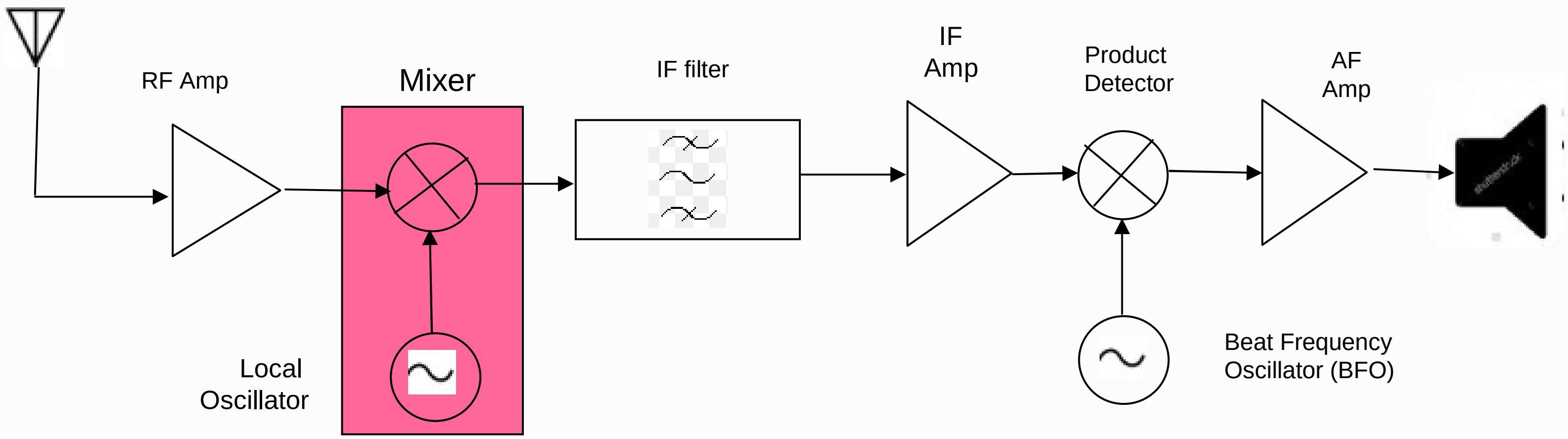
The Superheterodyne Receiver



The Superheterodyne

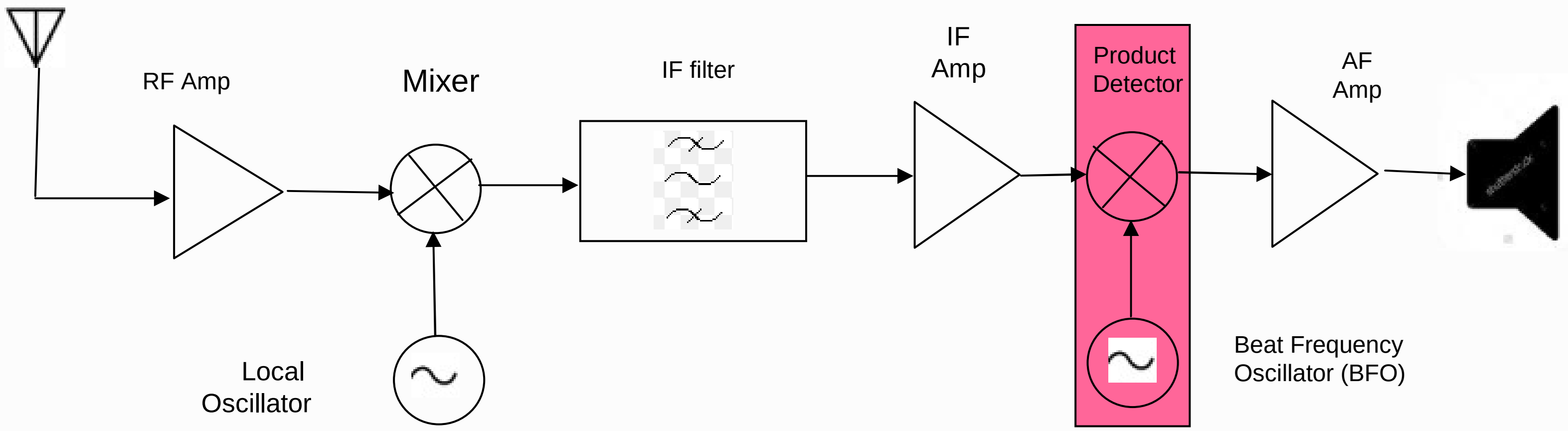
- Receives and amplifies the RF signal
- Mixes the RF signal to the IF frequency
- Processes and filters the signal in the IF section
- Amplifies the IF signal
- With the BFO and Product detector generates an audio signal
- Amplifies and outputs this audio signal and with a little luck you can hear New Zealand calling.

The Superheterodyne Receiver



The function of the Mixer in a Superheterodyne is to shift frequencies from the RF frequency to an intermediate frequency (IF) for filtering and processing. Together with the Local Oscillator it generates the mixing products that are processed by the IF filter.

Product Detector and BFO

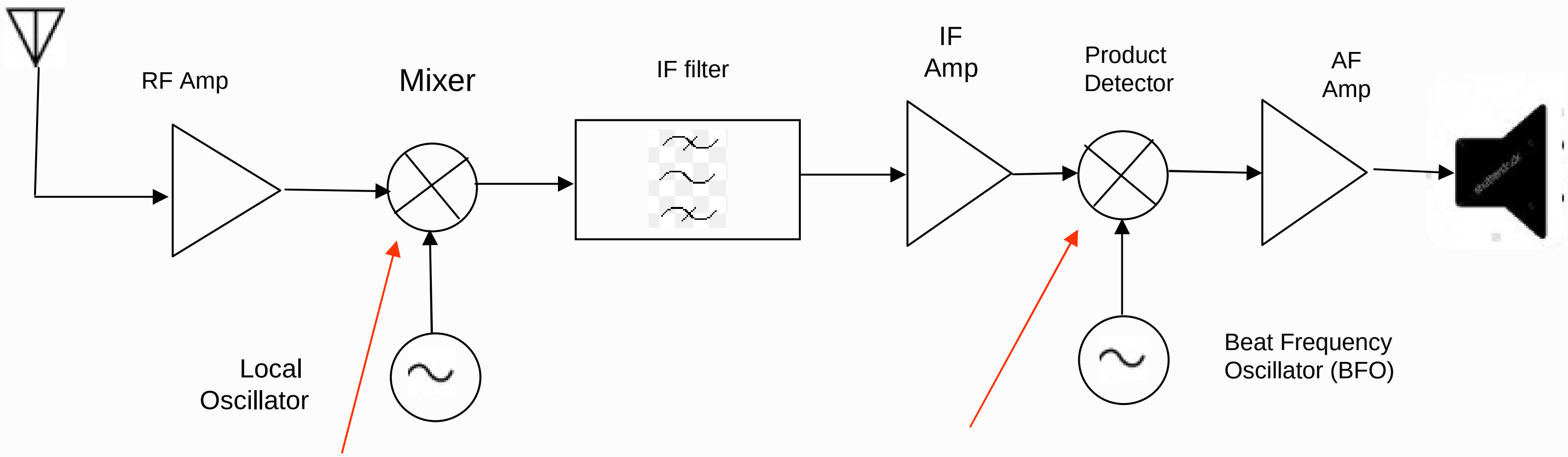


A Product Detector is a type of mixer that allows a receiver to demodulate CW and SSB signals

A Beat Frequency Oscillator (BFO) produces a sine wave which mixes in the product detector to demodulate the IF output and generate the received audio signal.

Other detectors are used for AM (envelope detector) and FM (discriminator)

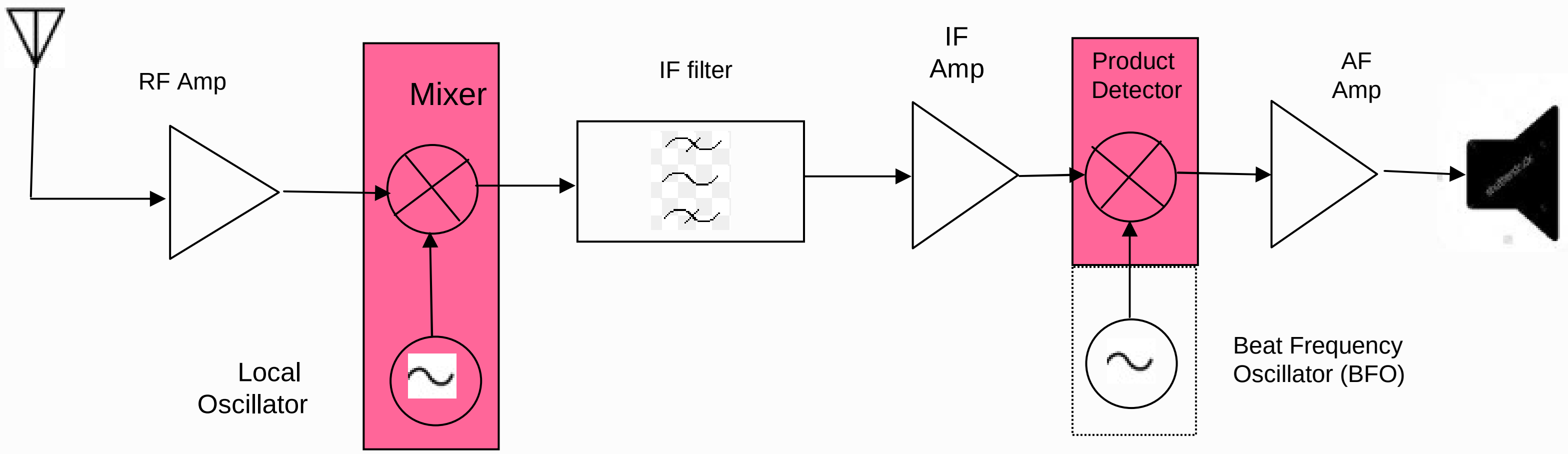
The Superheterodyne



What circuit is used to process the RF signals from the RF amplifier and send them to the IF filter in a superheterodyne receiver?   Mixer

What circuit is used to combine signals from the IF amplifier and BFO and send the result to the AF amplifier in some single sideband receivers?   Product Detector

The Simplest Superheterodyne

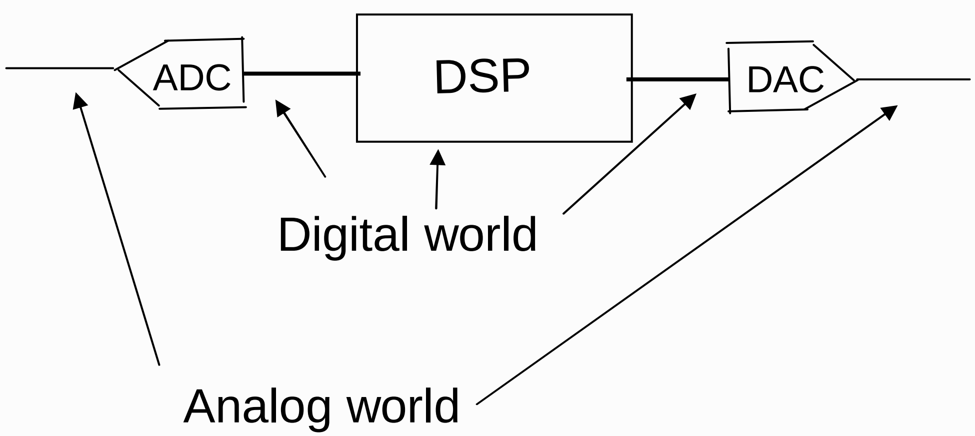


The simplest combination of stages that implement a superheterodyne receiver are:

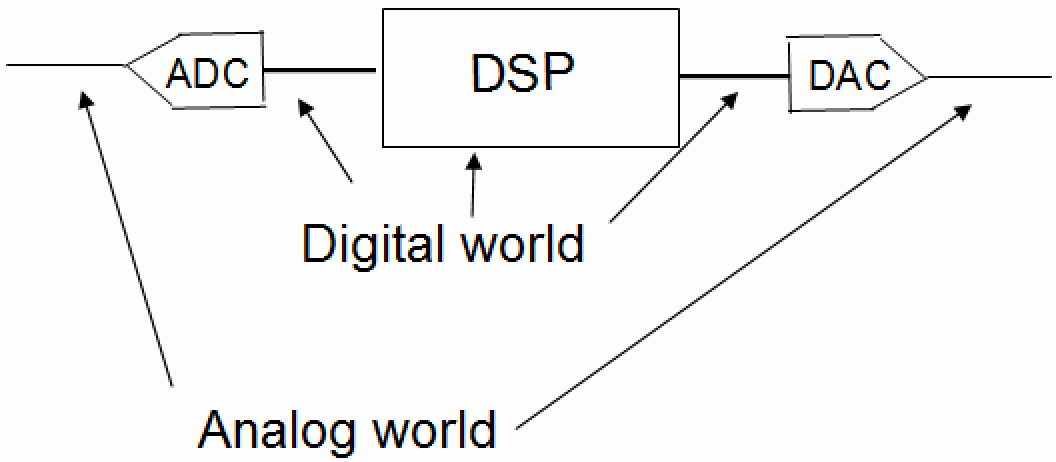
- HF oscillator (aka local oscillator)
- Mixer
- Product detector.

Digital Signal Processing

•DSP's are special purpose processors which do signal processing that once was done entirely by analog circuits.
•They are found in the IF section of most modern radios to do programmable band pass and notch filtering and in the audio section to do equalization and noise reduction.
•Many new radios called Software Defined Radios (SDR's) are almost completely based on DSP's and associated control IC's and most singal processing functions are performed by software.



Digital Signal Processing



How is Digital Signal Processing Accomplished?

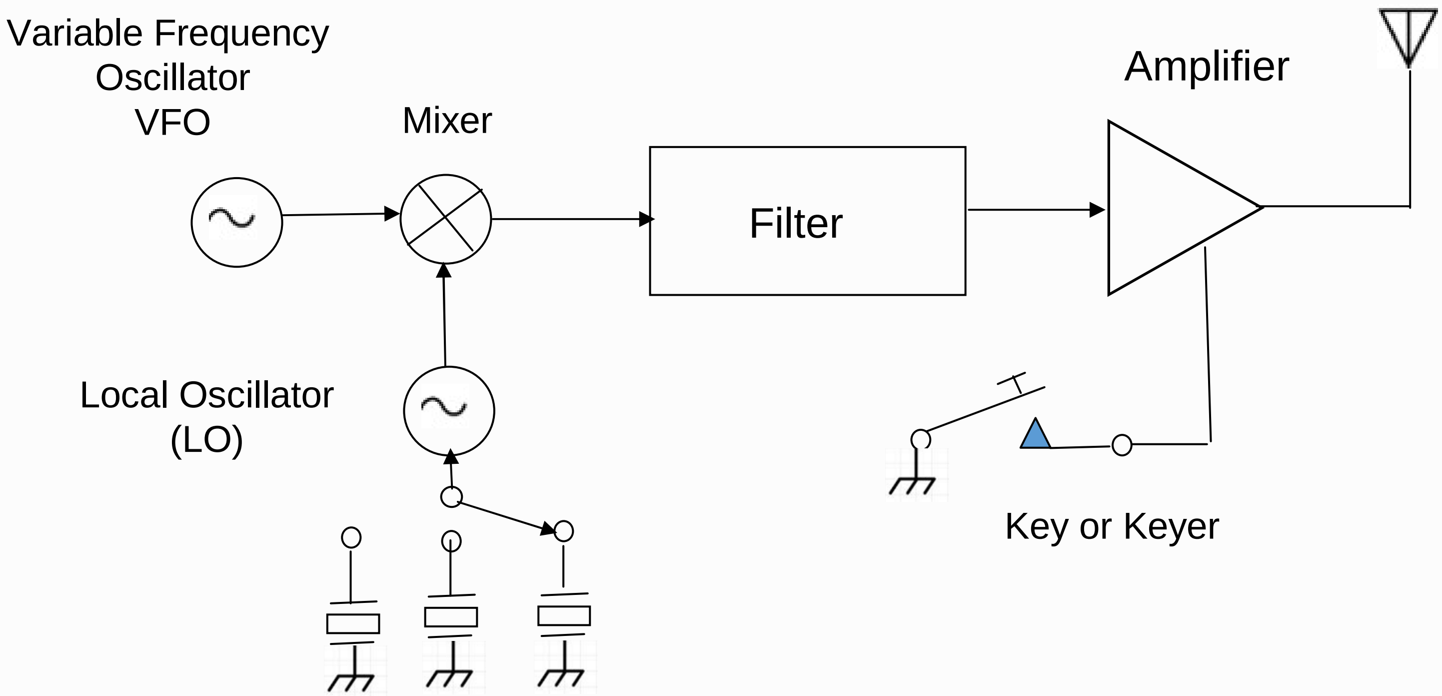
By converting the signal from analog to digital and then using digital processing.

What is necessary for a Digital Signal Processor IF:

- ADC – Analog to digital converter
- DAC – Digital to analog converter
- Digital Processor chip

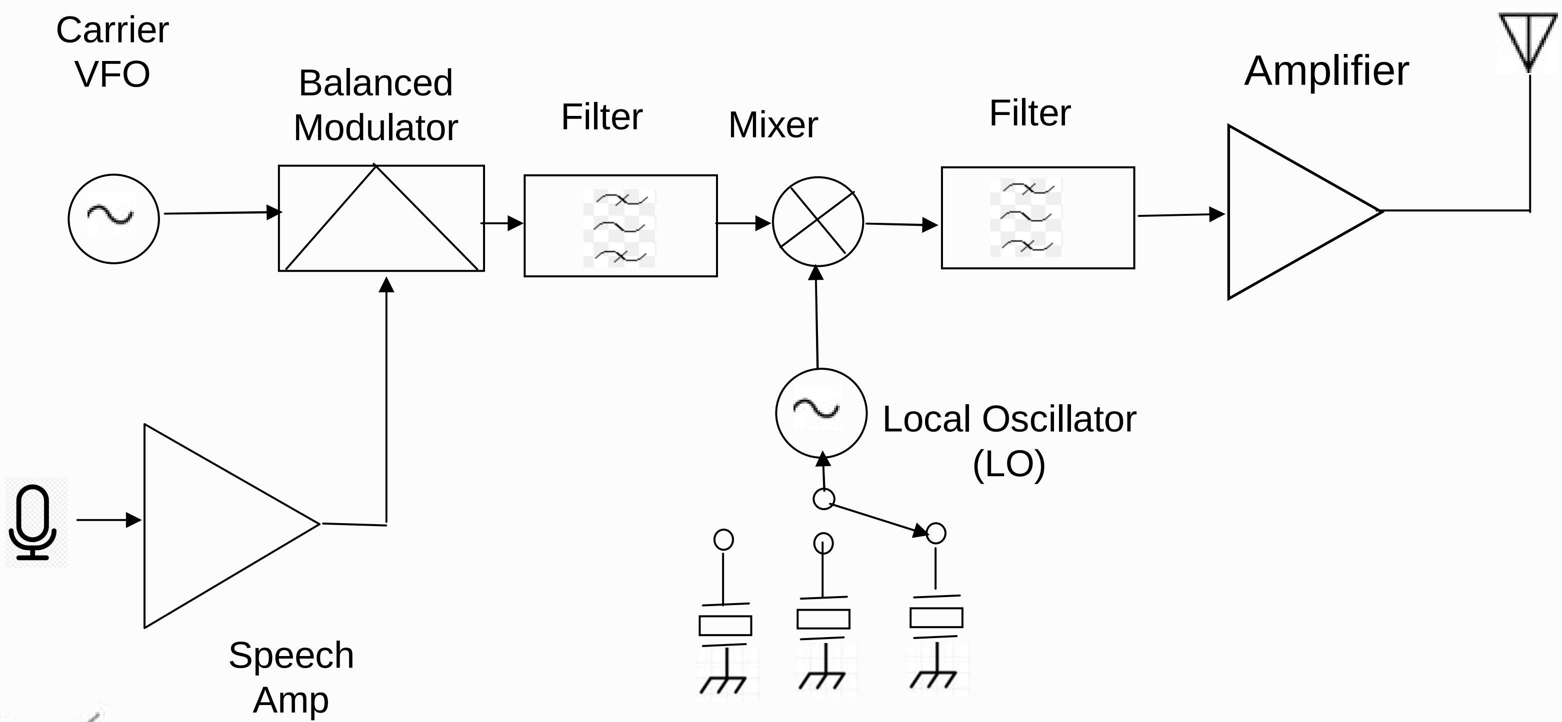
CW Transmitter

The CW transmitter takes sine wave (constant waveform—CW) mixes it to the transmission frequency, filters out harmonics, and sends it out through an amplifier that is turned on and off by a key hence creating dits and dahs.

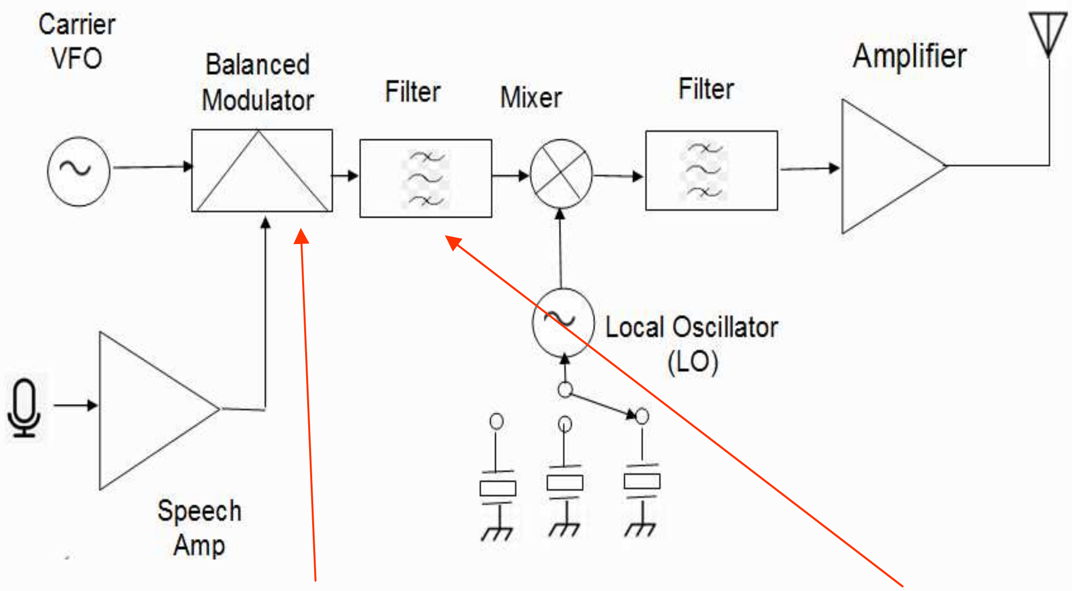


SSB Transmitter

A SSB transmitter mixes an audio signal with a carrier sine wave in a balanced modulator, filters the output to eliminate one of the two side bands, mixes to a transmission frequency, filters the result to reduce harmonics, and provides amplification for transmission.



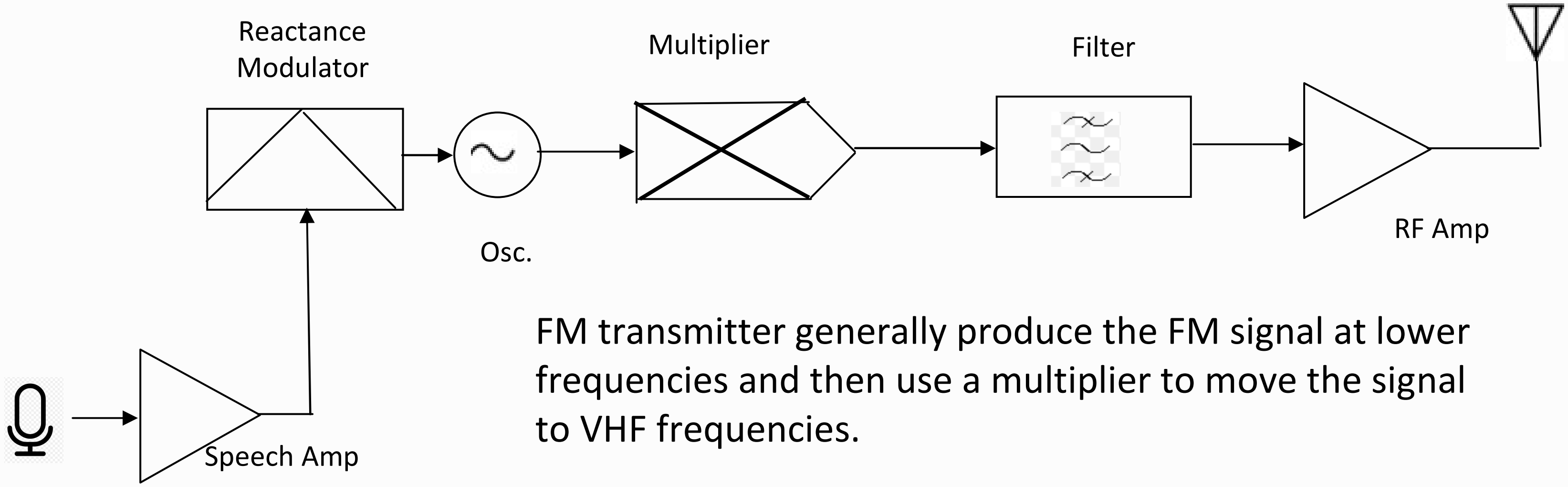
SSB Transmitter



What circuit is used to combine signals from the carrier oscillator and speech amplifier then send them to the filter in some single sideband phone transmitters?
--Balanced Modulator

What circuit is used to process signals from the balanced modulator then send them to the mixer in some single sideband phone transmitters?
--Filter

VHF FM Transmitters



FM transmitter generally produce the FM signal at lower frequencies and then use a multiplier to move the signal to VHF frequencies.

If we want a transmitter to operate on the 2 meter band and the multiplier is 12, then the oscillator must operate at 146.52 Mhz/12 = 12.12 Mhz.

The frequency deviation of the FM is multiplied also by 12 in this example.

If 5 khz deviation is desired at the output, then deviation of the reactance modulator must be

5kHz/12 = 416.7Hz

Digital Modes

There is an ever increasing number of digital modes used in ham radio and and often in DX:

- RTTY – important for contests and DX
- PSK31 – useful for casual QSO's and occasional DX
- Pactor and Winmor – more of a legacy mode
- JT65 and J9 – great in bad band conditions, some DX

--Operate at extremely low signal strength on HF bands

- FT8– brand new mode that is becoming important, DX

Bandwidths of Transmission Modes

One of the advantages digital modes is that they often use very little bandwidth.

Mode	Bandwidth (HZ)
→ PSK31	50
FT8	50
CW	~100
→ RTTY	200
MFSK15	300
JT65	350
→ PACTOR	2300
SSB	3000
FM	16000 (assuming 5KHz deviation and 3kHz modulating frequency

It is good to match the receiver bandwidth to that of the operating mode?

It results in the best signal to noise ratio. *

* not necessary or desirable on many digital modes.

PSK31

PSK or Phase Shift Keying is a very low bandwidth mode that still performs well in bad conditions. It is computer generated and decoded (for example FLDIGI program) and the interface to the radio is a sound card.

PSK coding scheme is **varicode** – the number of bits being varies and depends on the specific letter

Uppercase letters use more bits and slow transmission slightly

The "31" in PSK stands for the transmitted symbol rate which is 31.25. A good typist can out-type PSK transmission.

Symbol rates is the rate at which individual data symbols are transmitted.

Higher symbol rates require higher bandwidths.

RTTY

RTTY transmission moves between two tones called mark and space. The difference between the two tones is called the "shift".

The most common shift is 170Hz

FSK signal is generated by changing an oscillators frequency directly with a digital control signal.

The modulation scheme is called Frequency shift keying (FSK).

The underlying code is called Baudot code—a 5 bit code with additional start and stop bits.

RTTY has a very characteristic sound on the air that you will quickly identify

RTTY

The RTTY code is generated and decoded in a computer (for example MMTTY program). There are two ways for the computer to talk to the radio:

- FSK -- the computer directly instructs the radio to shift back and forth between mark and space frequencies.
- AFSK -- a (sometime specialized) soundcard generates audio signals and they are transmitted on SSB or FM

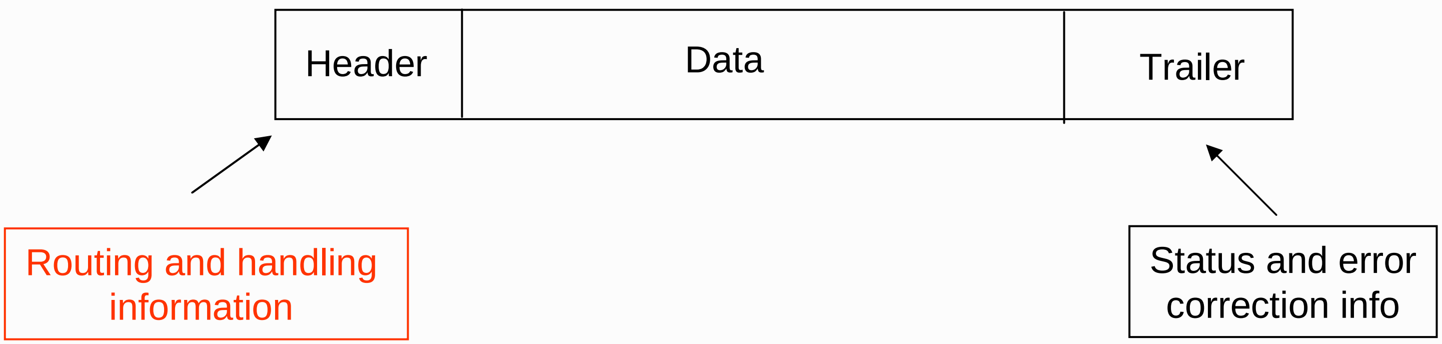
RTTY usually uses the LSB. Often if you can't decode a RTTY signal you (or your contact) may be on the other sideband.

RTTY is a nearly 100% duty cycle mode when transmitting and care must be taken not to overload your amplifier. It is important to know the duty cycle of the mode so to not overload the amplifier.

Packet Modes

Packet modes transmit data (packets) rather than bits and often include error detection and correction.

Typical packet format (string of bits):



Packet communication is only a two way protocol. If errors are detected in the received message, a new request for a new packet is made. If there are too many re-transmission requests, the connection is dropped

Packet Protocols

PACTOR and WINMOR protocol messages:

NAK response (not acknowledges) – the receiver requests a re-transmission of information

ARQ – automatic repeat on request mode. If receiving station responds to ARQ data mode containing errors, it requests the packet to be re-transmitted

FEC – (Forward error correction) allows the receiver to correct errors in received data packets by transmitting redundant information with the data

Packet

- Pactor is a two way communication scheme so it is impossible to join an existing communication.
- Pactor bandwidth is 2300Hz

Thank you

You should now be prepared to pass the General Class license test Subelements 7 and 8