BSc in Computer Engineering
CMP4204
Wireless Technologies

Lecture 1

Radio Principles

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1. Introduction

Radio or wireless communications started at the tail end of the 20th century from a garden to a nearby hill in Italy. It is principled on the fact that electromagnetic energy can pass through space. Information can be modulated on the radiated wave by altering some property of it, its amplitude, its frequency or its phase. As a receiving station the wave induces small currents in a wire antenna and with a receiver these currents can be amplified and the original modulating signal extracted from the radiated wave.

1.1 The Sine Wave and Hertz

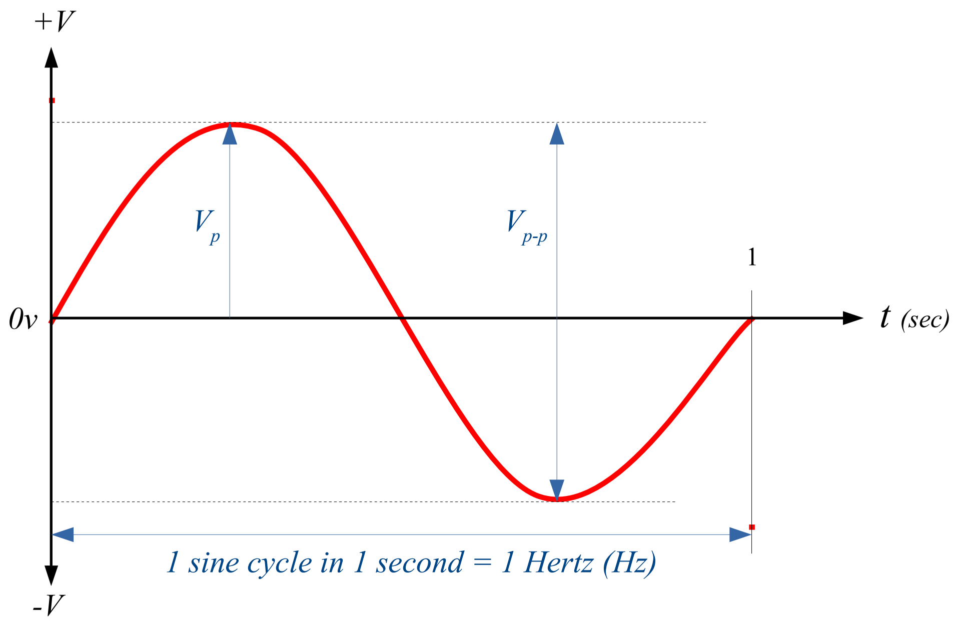

Illustration 1: Sine wave and Hertz

A sinusoidal alternating voltage, or sine wave is the typical representation of a radio signal. It is an Alternating Current (AC) much like that found in the home electrical service. The period of the sine wave is the completion is a cycle from 0v to a peak, back to 0v, down to a trough and back to 0v. If such a cycle is completed in 1 second it is said to have a frequency of 1 Hz. The parts of the cycle are Peak voltage (V_p) and the Peak to Peak Voltage ($V_{p\text{-}p}$). The effective voltage, oer in other words the equivalent Direct Current (DC) voltage is called the Root Mean Square (RMS) and is equal to 0.707 x Vp.

At higher frequencies AC exhibits the property that it can be radiated into the air in the form of electro-magnetic radiation.

While the signal shown above is 1 Hz the mains electricity operated at 60 Hz, or 60 cycles per second. An audio signal over the phone, i.e. voice transmits between 300 – 3,,400 Hz, while music on a home stereo can be heard at up to 2,000 Hz or 20 kHz. The radio signal most familiar is the FM radio and it operates from 88 – 106 MHz.

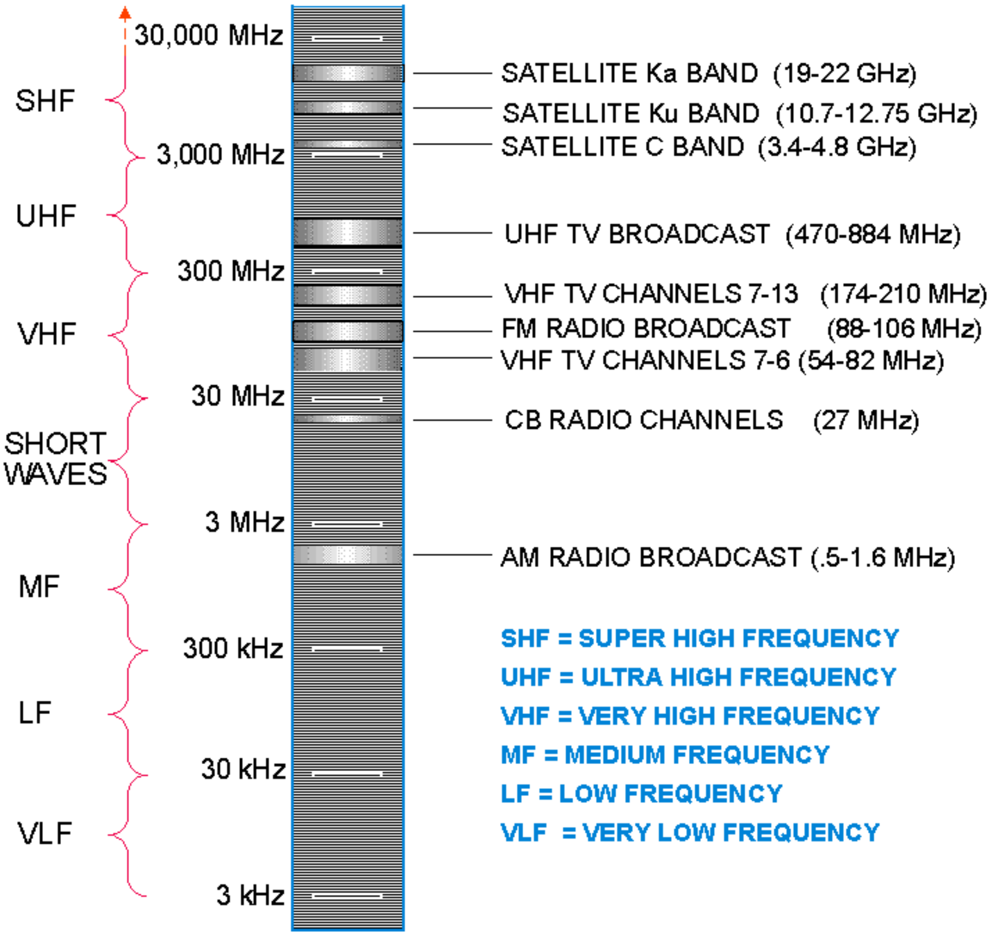

Illustration 2: The electro-magnetic spectrum

Illustration 2 Shown the map of the full radio spectrum and the various uses for each portion of that spectrum. Portions of the band exhibit different properties and are therefore more suited to particular applications.

Illustration 3 Shows the complete frequency band map.

1.2 The frequency map

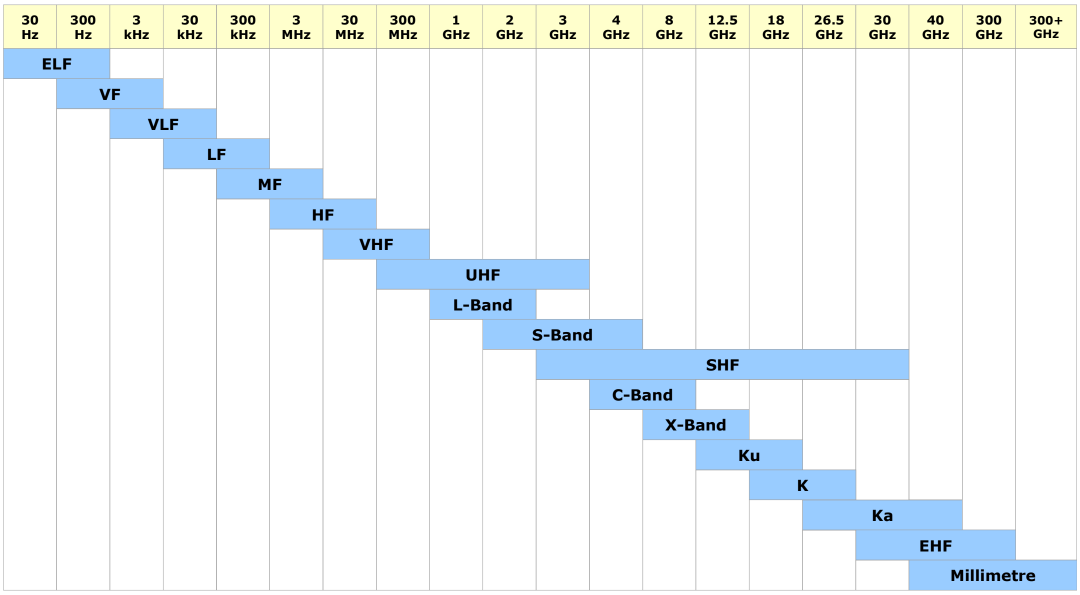

Illustration 3: Frequency bands

2. The Marconi experiments

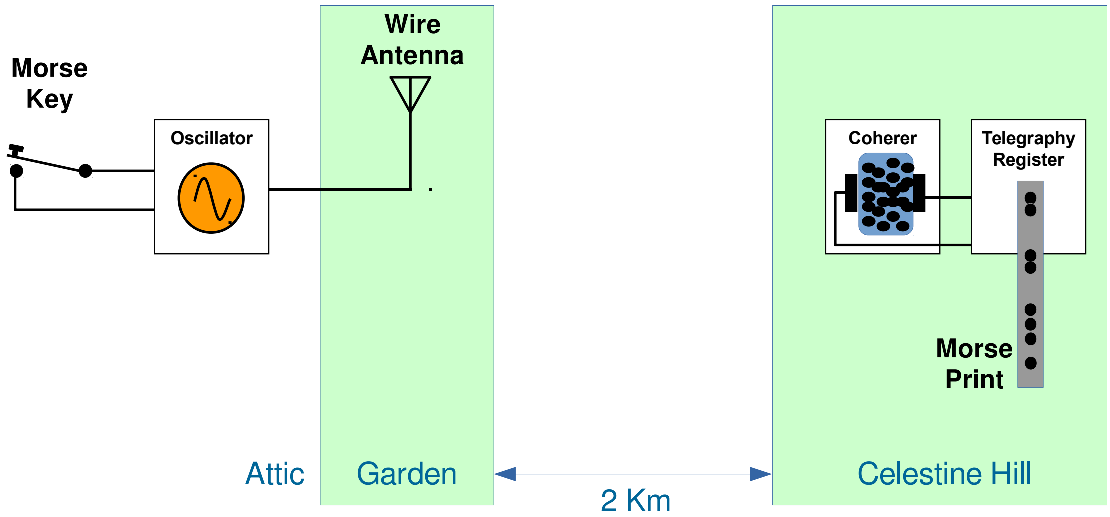

Illustration 4: Marconi radio system in 1895

Guglielmo Marconi is widely regarded as the inventor of radio communications. At his home at Villa Griffone in Italy, Guglielmo Marconi carried out experiments in the years 1894 and 1895.

He connected a spark-producing radio oscillator with a morse key in the attic, known as the Silkworm Room to a long wire antenna suspended in the garden of the villa.

He transmitted a signal to and beyond Celestine Hill which was a full 2 Km away.

On the hill he had a coherer receiver, basically a tube filled with iron filings, connected to a telegraphy register, a device that prints Morse code on paper to receive the transmitted signal. He actually had a gunshot signal that his first message had arrived.

2.1 Coherer receiver

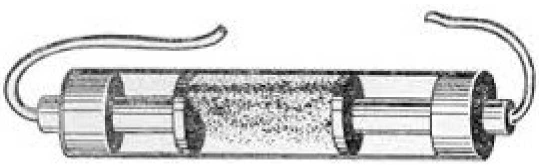

Illustration 5: Coherer receiver

The core of the marconi receiver was a coherer receiver. This is a tube containing a pair of electrodes spaced a small distance apart with metal filings between them.

When a radio signal is received the metal particles cling together (cohere). This reduces the resistance between the electrodes thereby permitting a signal to pass.

This signal triggers the telegraphy register to make a 'dit'.

3. Modulation

3.1 History

As can be seen with Marconi, initial early work on radio was telegraphy based. In 1900, five years after Marconi made the first radio transmission, Reginald Fessenden passed the first voice transmission over 1.5 Km using Amplitude Modulation (AM).

His first transmitted words were, "Hello. One, two, three, four. Is it snowing where you are, Mr. Thiessen?".

3.2 Introduction

So what exactly is modulation ?

Modulation describes a range of techniques for encoding information on a carrier signal (f_c), typically a sine-wave signal. A device that performs modulation is known as a modulator.

Basic modulation techniques include:

- Amplitude modulation (AM)
- Frequency modulation (FM)
- Single SideBand modulation (SSB)

4. Amplitude Modulation (AM)

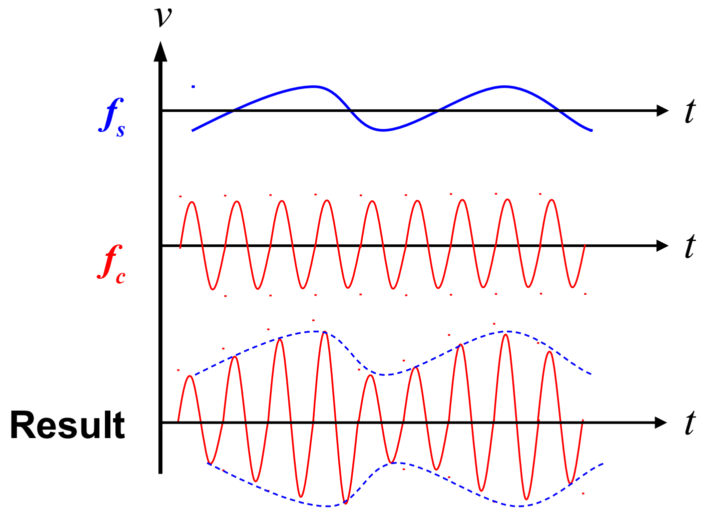

Illustration 6: Amplitude Modulation (AM)

Amplitude Modulation (AM) is a method used to transfer a signal (f_s) from a point A to a point B, typically using radio waves. In the case of an analogue signal being transmitted, the amplitude of the radio wave is modulated to be directly proportional to the value of the analogue signal at the time. This can be compared to FM (FM), which modulates the frequency rather than the amplitude of the carrier.

The working principles of AM radio are as follows:

- A carrier wave introduces an alternating positive and negative electrical voltage in the receiving antenna.
- Modulating the wave causes the amplitude of these electrical voltages to be increased or decreased in equal and opposite amounts.
- The receiver uses a diode to remove either the positive or negative part of the electrical signal, leaving a signal which when filtered with a Low Pass Filter (LPF) and amplified produces an audible sound. Because f_c is significantly greater than f_s it is possible to use a capacitor to smooth or filter the waveform to remove the carrier.

One of the attractions of AM is that decoding the signal at the receiver is quite simple. This was significant for the early days of commercial radio when electronic components were still quite expensive. It was one of the most popular methods for sending voice and music over radio during the 20th century.

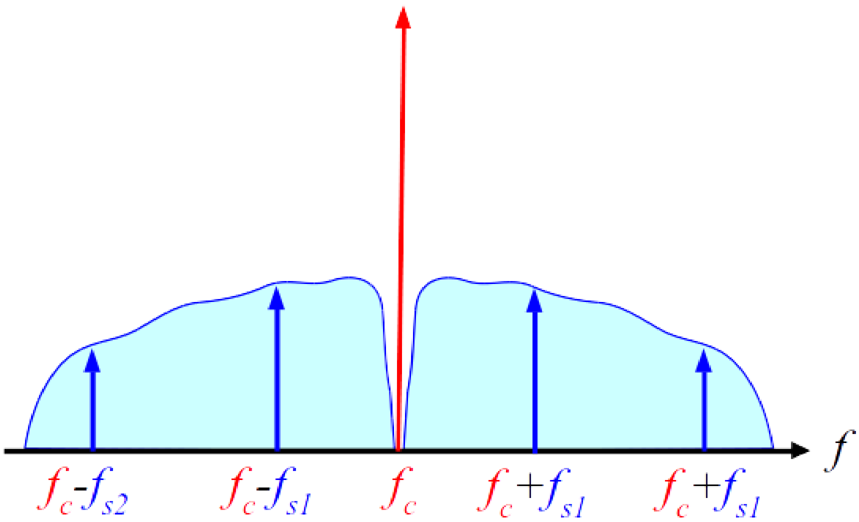

Illustration 7: Amplitude Modulation (AM)

AM typically produces a modulated output signal that has twice the bandwidth of the modulating signal, with a significant power component at the original carrier frequency. SSB is a technique that improves this, at the cost of extra complexity.

4.1.1 Single sideband modulation (SSB)

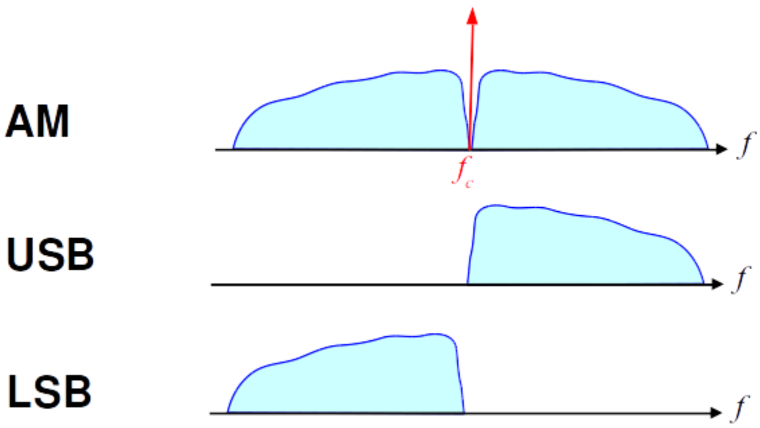

Illustration 8: Single SideBand (SSB)

SSB is a refinement of the technique of AM designed to be more efficient in its use of power and bandwidth.

AM typically produces a modulated output signal that has twice the bandwidth of the modulating signal, with a significant power component at the original carrier frequency. SSB improves this, at the cost of extra complexity.

The best way of considering SSB modulation is to first consider an AM signal. This will have two frequency-shifted copies of the modulated signal (the lower one is frequency-inverted) on either side of the remaining carrier signal.

To produce an SSB signal, a filter is applied to remove one of the sidebands, and remove the carrier signal. What remains still contains the entire information content of the AM signal, using substantially less bandwidth and power, but cannot now be demodulated by a simple envelope detector. Depending on which sideband remains the new signal is called either Upper SideBand (USB) or Lower SideBand (LSB)

To recover the original signal from an SSB signal, the carrier must be replaced with an extra 'false carrier' signal, prior to sending the signal to a standard envelope detector.

For this to work, the false carrier must be accurately adjusted to match the frequency of the original carrier.

4.2 AM Transmitter

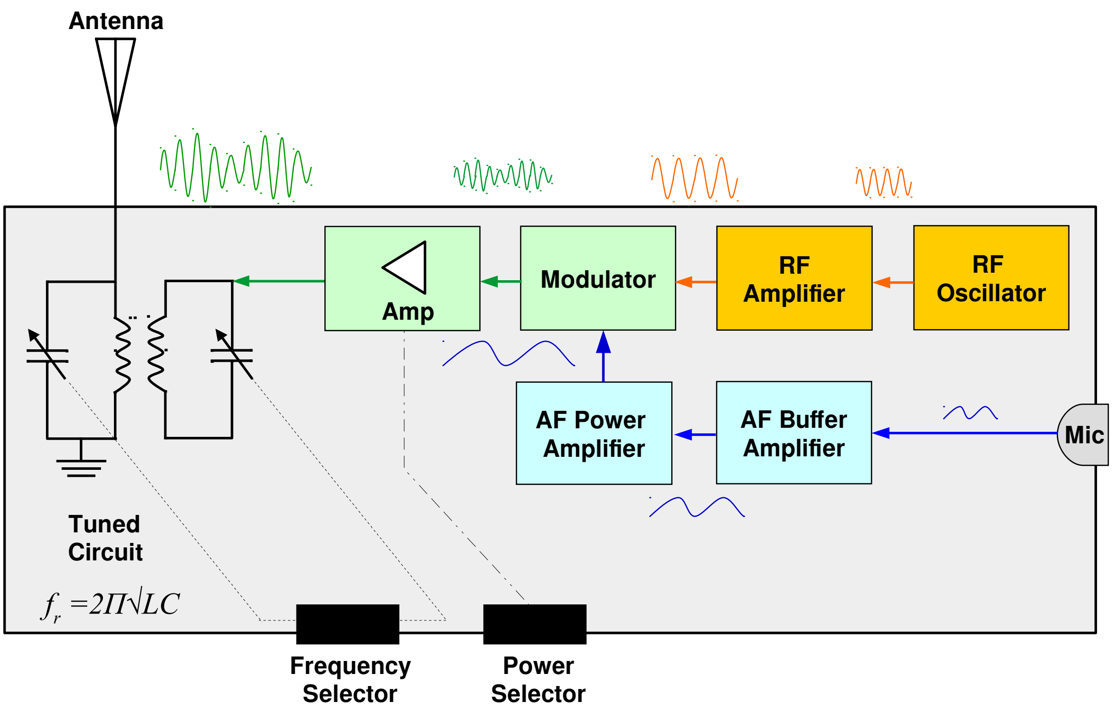

Illustration 9: AM Transmitter

A radio wave is a complex signal that contains the carrier wave f_c of the broadcast station and the audio output f_s of the microphone or audio amplifier source.

It begins with the RF oscillator circuit, which is in affect a signal generator that is tuned to the precise operating frequency of that particular station.

The generator output is applied to the final output stage of the transmitter, made up of several tuned tank circuits.

The block diagram shows how the oscillator and tank circuit are connected to the broadcast antenna where the signal is radiated into the atmosphere over long distances. Before it is broadcast, the audio signal is modulated with the RF carrier so that it becomes part of the transmitted signal.

In AM broadcast, this is achieved by changing the instantaneous amplitude of the RF carrier signal with a circuit called the modulator. A modulator is a circuit that combines two signals together to form one signal, but the characteristics of both are retained. This means that a modulated radio wave contains the carrier frequency and the audio signal when it is transmitted. The transmitted signal can than travel over thousands of miles to a radio receiver.

Referring to Illustration 9, you can see that the audio signal is connected in such a way as to change the amplitude (voltage level) of the radio frequency sine wave. This signal contains the frequency of the transmitter and its amplitude is changing at the audio rate of the audio circuit. If a radio station has a broadcast frequency of 1080 on the dial, then the frequency of the oscillator is set to 1.080.

4.3 AM Superheterodyne Receiver

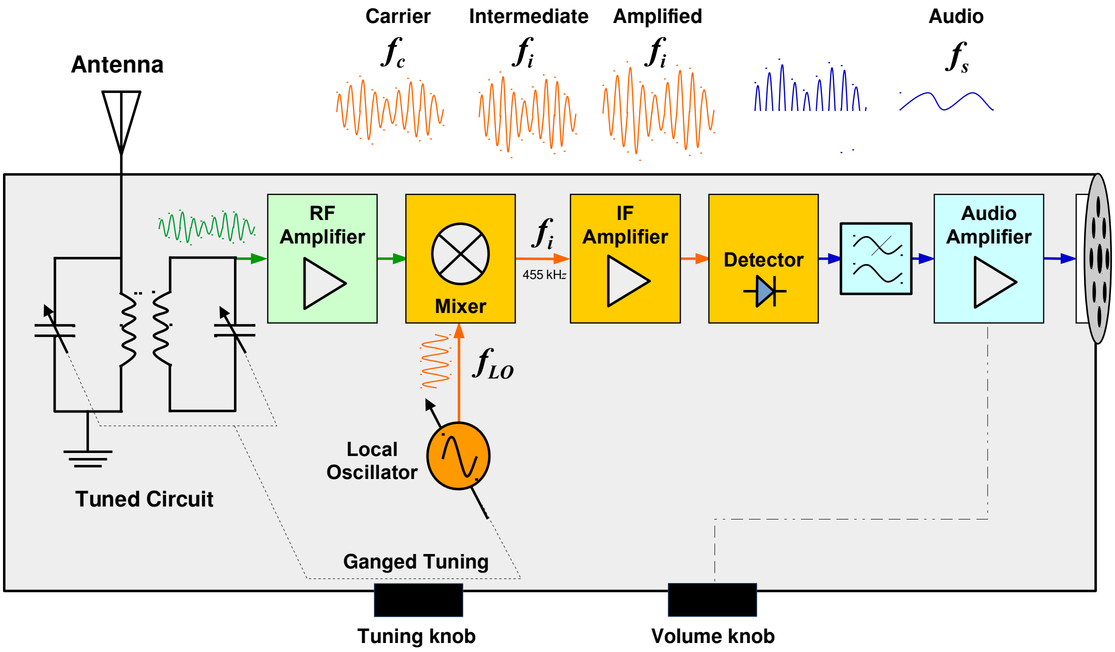

Illustration 10: AM Superheterodyne receiver

The function of the radio receiver is to recover the audio signal f_s that was modulated onto the RF carrier f_c at the radio station, and apply it to the speaker, reproducing the sounds of the announcer.

The standard AM receiver is the Superheterodyne receiver.

The source of the radio signal starts at the receiver antenna, which is a length of wire exposed to the atmosphere.

When the RF energy passes by the wire, a small voltage and current will be induced that will change in step with the RF energy striking it. RF energy will induce voltage and current in any kind of conductor that gets in it's path, that is why a radio won't work well when inside a steel building. (The radio waves will be absorbed by the steel).

The other end of the antenna is connected to a tank circuit inside the radio and it is tuned to only one resonance frequency using the variable capacitors in a ganged tuning mechanism (i.e. one control adjusts both capacitors).

Even though there are hundreds of radio stations transmitting signals at the same time and they are all hitting the antenna inducing currents, only one of them will cause enough current to be of any use.

The tank circuit used in this radio is a series connected tank, which means the current will be maximum at the resonance frequency (f_r).

If we make one of the reactance, inductance L or capacitance C variable, we can select or tune any one of the stations passing by the antenna wire by adjusting the reactance to a new resonance frequency. This frequency can be determined by the formula:

$$f_r = 2\Pi\sqrt{LC}$$

All other non resonant RF signals will pass to earth via the earth connection.

The signal is then mixed with a locally generated signal from a Local Oscillator (LO) to create an Intermediate Frequency (IF).

The LO is adjusted with a ganged tuning mechanism such that the output of the mixer will always be the same frequency.

This is necessary so the rest of the circuitry of the radio is manufactured for only one frequency even though the radio can handle a large spread of frequencies.

The detector or demodulator circuit is made up of a diode and a capacitor on the output of the diode.

The diode can only conduct current in one direction and the signal from the IF stage is connected directly to the anode of the diode so that any positive voltage applied to it will cause current flow.

The output of the diode will be only half of the IF signal.

Since we are only interested in the audio signal, the high frequency portion of the signal is shunted to ground through a capacitor.

5. Frequency Modulation (FM)

Frequency modulation (FM) is the encoding of information into a carrier wave by variation of its instantaneous frequency in accordance with an input signal.

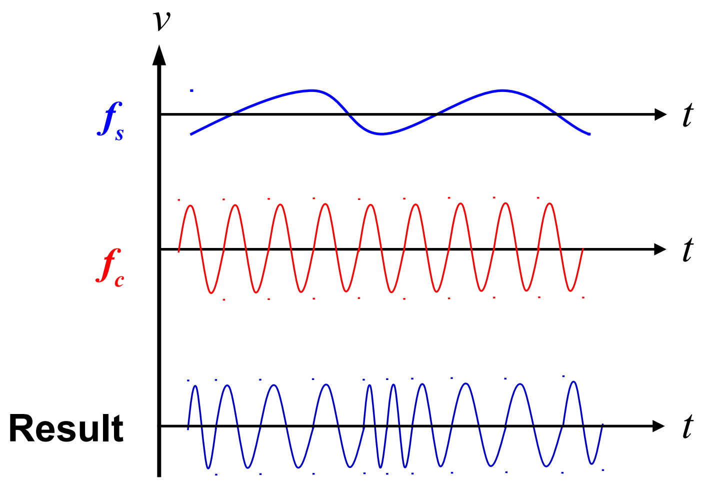

Illustration 11: Frequency Modulation (FM)

FM requires a wider bandwidth than AM by an equivalent modulating signal, but this also makes the signal more robust against interference. FM is also more robust against simple signal amplitude fading phenomena. As a result, FM was chosen as the modulation standard for high frequency, high fidelity radio transmission: hence the term "FM radio".

The harmonic distribution of a simple sine wave signal modulated by another sine wave signal can be represented with Bessel functions - this provides a basis for a mathematical understanding of FM in the frequency domain.

A rule of thumb, Carson's rule states that nearly all the power of an FM signal lies within a bandwidth of:

$$2(\Delta f + f_m)$$

where Δf is the peak instantaneous deviation of the carrier from the centre frequency and f_m is the highest modulating frequency.

5.1 FM Transmitter

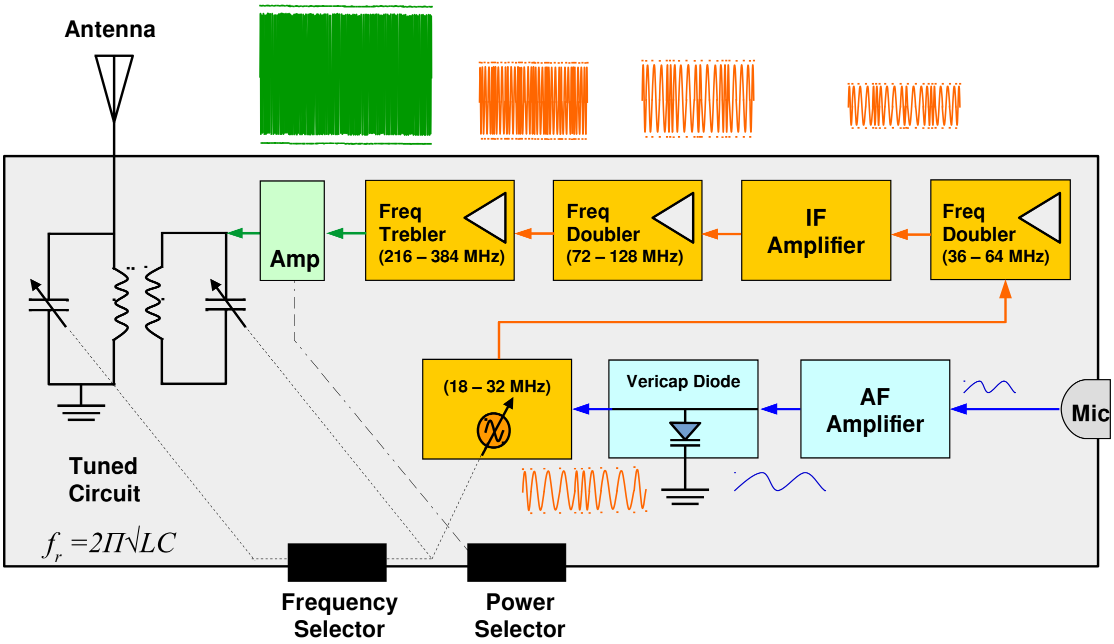

Illustration 12: FM Transmitter

Audio received from the microphone are amplified and then used to control a variable capacitance (Varicap) diode. The capacitance of a varicap diode varies with the voltage applied to it, i.e. from the audio signal. This capacitance now varies at the rate of the input audio signal (f_s) and applied to the LO varies the instantaneous frequency generated. It has been agreed that the maximum deviation from the carrier (f_c) caused by the modulating signal is 75 kHz.

Designing and building a stable crystal oscillator is difficult so as the operating frequency increases, the crystal must be ground so thin that it often cracks while vibrating. To avoid this the oscillating frequency is maintained at comparatively low frequencies, sometimes as low as 1/100 of the output frequency. Special power amplifiers are used post the oscillator to double and treble the frequency.

The required output frequency band will determine the number and type of power amplifier stages, doublers, treblers or even quadruplers that need to be employed.

5.2 FM Receiver

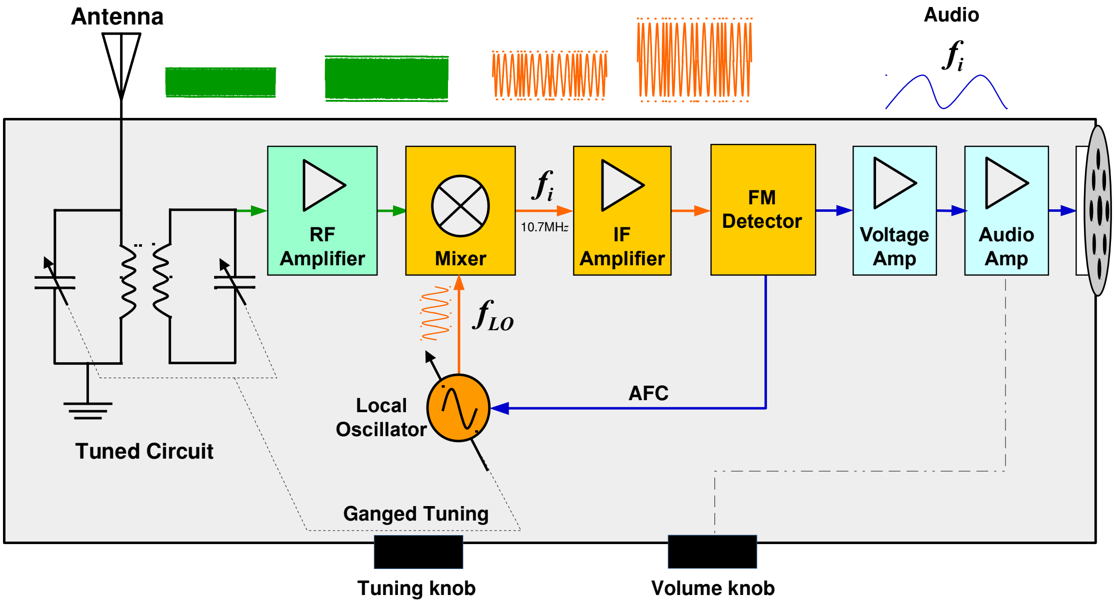

Illustration 13: FM Receiver

There are many forms of FM detector and as Integrated Circuits (IC) took over from descrete components the popularity of the types changed, for example the PLL FM detector and the Quadrature FM detector were more suited to application in ICs.

Basic FM detector: As an FM signal carries no amplitude variations, a demodulator block that senses frequency variations is required. It should also be insensitive to amplitude variations as these could add extra noise. Simple FM detectors such as the Foster Seeley or ratio detectors can be made from discrete components although they do require the use of transformers.

PLL FM detector: A phase locked loop can be used to make a very good FM demodulator. The incoming FM signal can be fed into the reference input, and the VCO drive voltage used to provide the detected audio output.

Quadrature FM detector: This form of FM detector block is widely used within ICs. IT is simple to implement and provides a good linear output.

Assuming that a receiver is nearly tuned to the desired frequency, the Automatic Frequency Control (AFC) circuit in the receiver develops an error voltage proportional to the degree to which the receiver is mistuned. This error voltage is then fed back to the tuning circuit in such a way that the tuning error is reduced. In most frequency modulation (FM) detectors, an error voltage of this type is easily available.

6. Self-test Quiz

1. Describe the difference between the following modulation methods:
   - AM
   - USB
   - LSB
2. Contrast the difference between AM and FM.
3. With the aid of a diagram describe how a superheterodyne receiver works.
4. How does the superheterodyne receiver keep the circuitry simple considering the wide band of frequencies it is capable of receiving from?
5. By agreement what is the maximum deviation from f_c allowed?