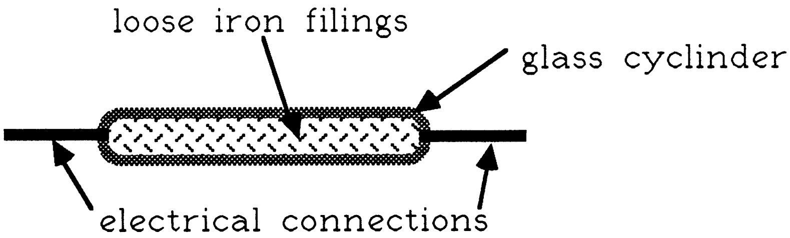
HISTORY OF RADIO

All studies of radio communications must begin with the early radio pioneers who transformed Maxwell's equations into the reality of wireless communications. The earliest deliberate[1] radio receiver was the coherer, a glass cylinder filled with loose iron filings, which operated as a r.f. detector. In the presence of strong electromagnetic fields such as would be generated by a primitive spark generator the circuit resistance of the coherer would drop. Basically, the first radio was a coherer connected to an electric doorbell. This was the state of the art in 1891.

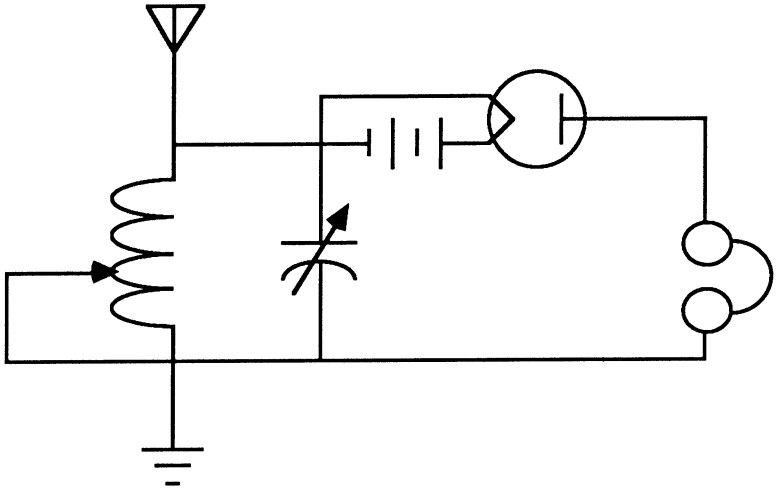


In 1906 the crystal detector was introduced to replace the coherer. The crystal detector was the famous "cat whisker" formed by a very small, sharp wire touching a hunk of galena crystal. The metal–crystal interface formed a primitive diode junction and, when connected to a resonant circuit tuned to the frequency of a r.f. transmitter, formed a radio which could demodulate amplitude modulated broadcasts.

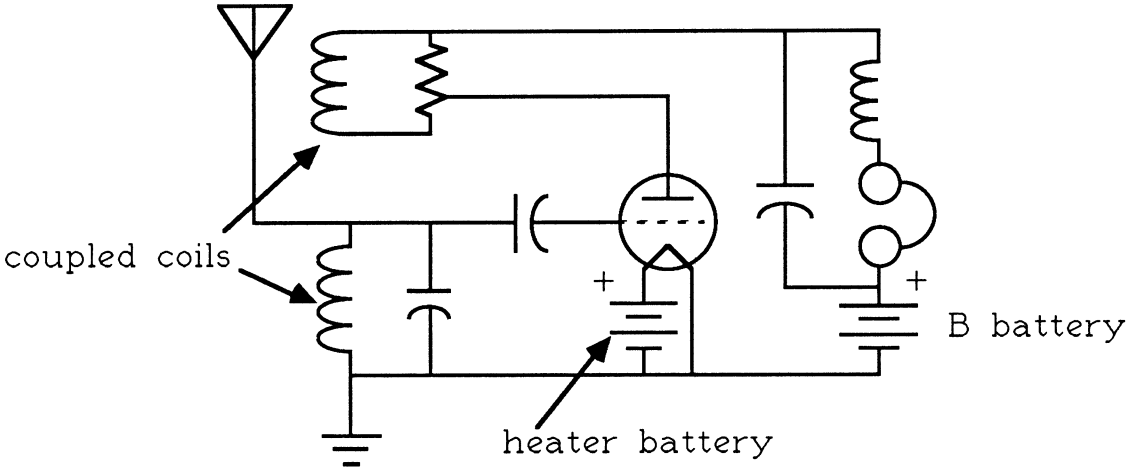
In 1907 the "cat whisker" was replaced by a Fleming valve (one of the first diode vacuum tubes).

---

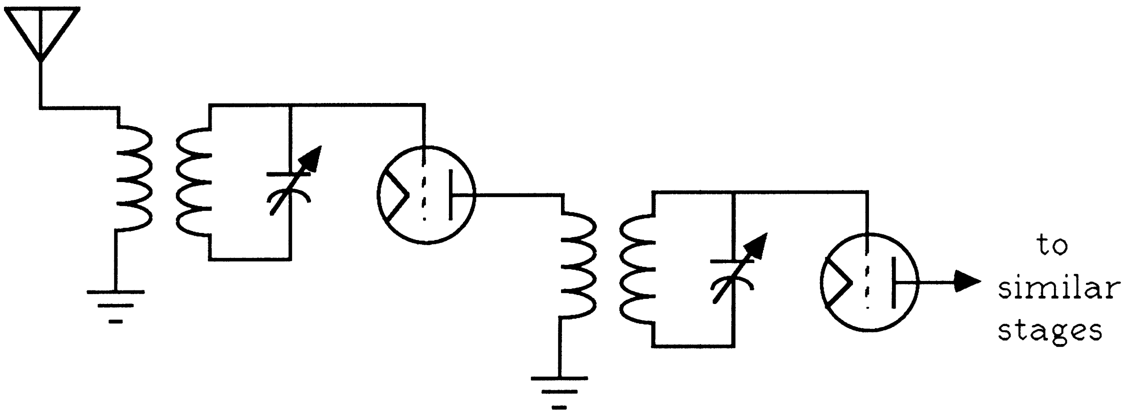
[1] The first radio receivers were actually dew–covered clotheslines in the vicinity of Marconi's original spark gap radio transmitters. The dew made a good electrical conductor, i.e. an antenna, and housewifes hanging up laundry to dry would often act as detectors drawing sparks from the clothesline.



Tubes were first used for amplification in radios in 1908. The first such radio circuit based upon amplification was the regenerative radio which used feedback to further increase the sensitivity of the radio. The regenerative circuit became the standard for radio receivers for over a decade.

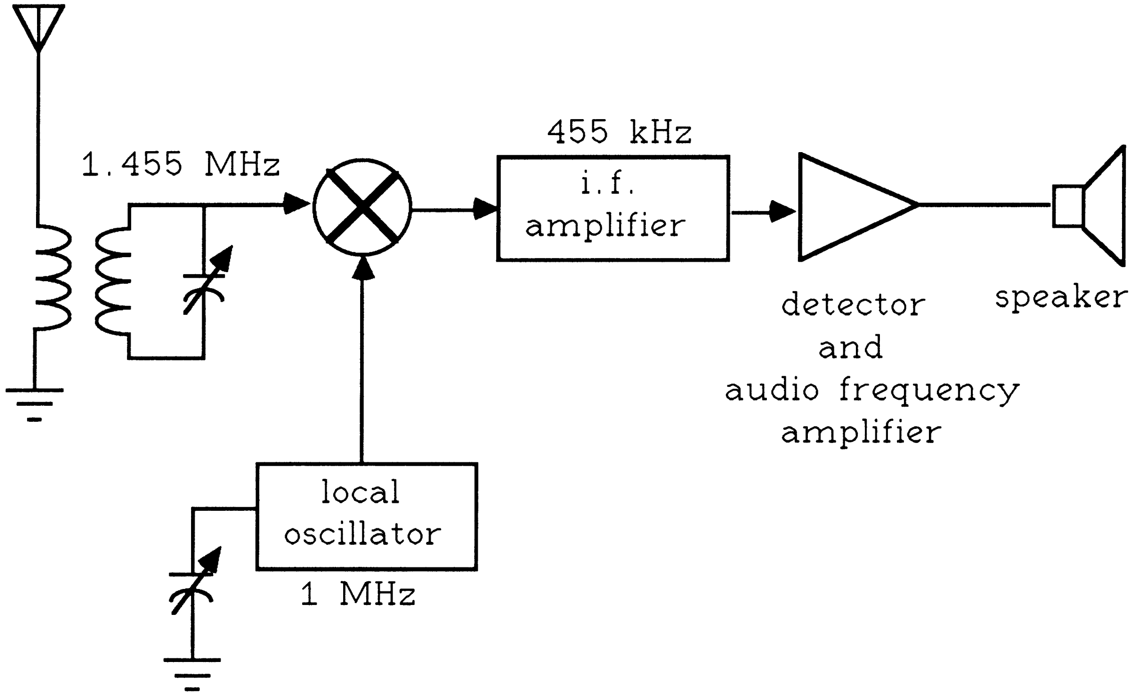


The regenerative circuit was best suited for experimenters as it usually required continuous readjustment to prevent the circuit from oscillating. To avoid readjustment the tuned radio frequency (or TRF) radio was developed. The TRF radio was nothing more than a radio with several tuned amplifier stages. The TRF radio did not require continuous readjustment but required the coordinated tuning of as many as ten resonant circuits. Radios of this time period were famous for their mechanical ingenuity using levers and cams to simultaneously tune a large number of resonant circuits.



The modern radio came into being with Armstrong's patent of the superheterodyne radio circuit in 1918. This patent was assigned to RCA which held a tight monopoly on it for nearly ten years. The superheterodyne radio essentially breaks the radio into two components: a front end which is <u>tuned</u> to the frequency of the radio station of interest and the intermediate frequency and detection section which operates at a <u>fixed</u> frequency. Because these latter stages operate at a fixed frequency they can be factory adjusted and need never be readjusted. This was a radical breakthrough and shifted the emphasis in radio engineering from the mechanical engineering of the TRF radios back to electrical engineering.

The most important component of the superheterodyne radio is how the variable received frequency is converted to a fixed intermediate frequency. This frequency translation is done by multiplying, or mixing, the incoming radio frequency with a signal from a variable frequency oscillator resulting in sum and difference frequency signals. In general, radios use the difference frequency as the intermediate frequency. In most modern radios the intermediate frequencies are 455 kHz for AM radios and 10.7 MHz for FM radios. About 1930 there was so much pressure on RCA for their monopolistic exploitation of the superheterodyne radio that they begin to license it to other manufacturers.

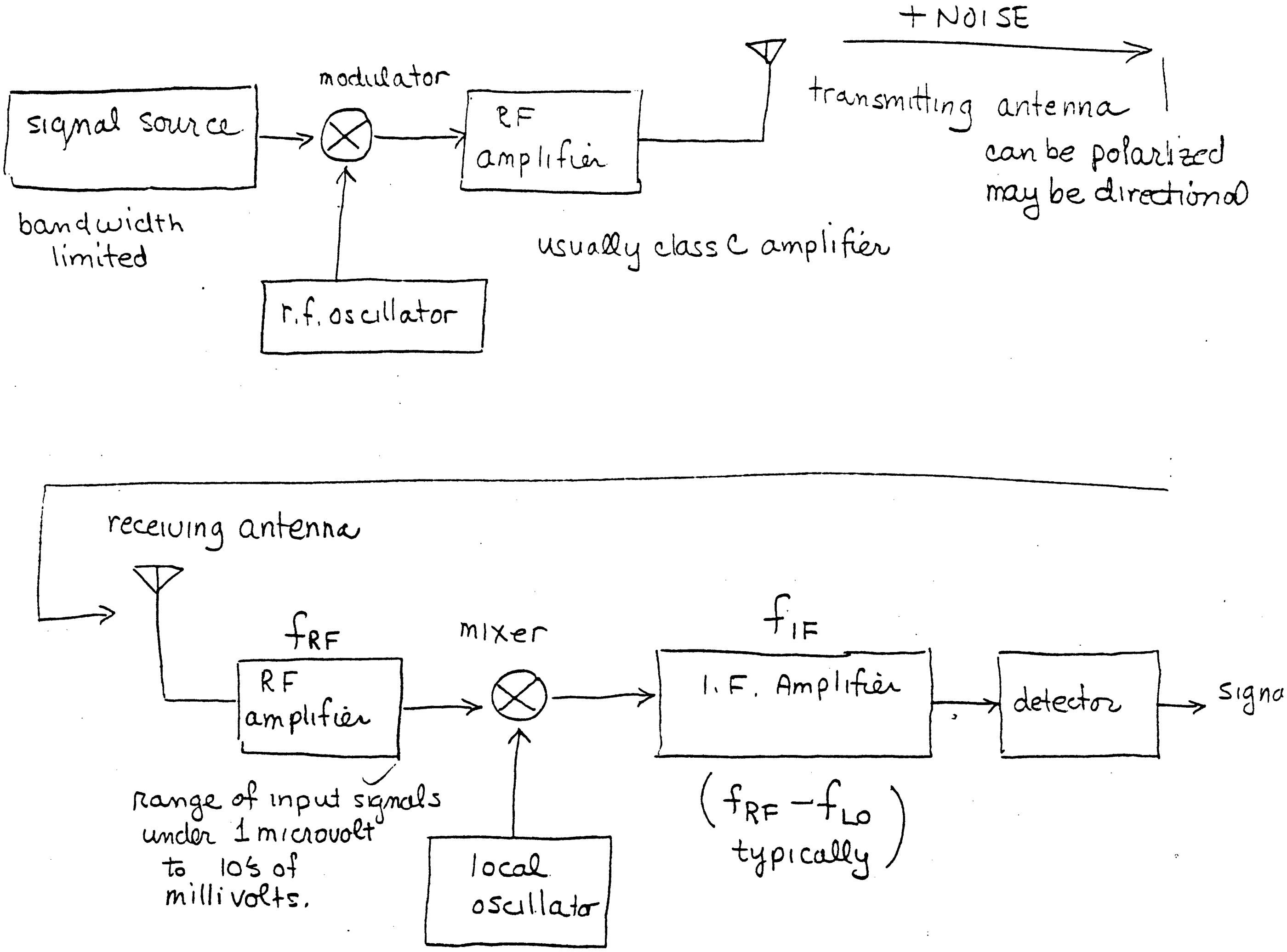


Very little fundamental development occurred after these hectic first years of radio. Improvements occurred: tubes were replaced by solid state transistors and diodes, devices became better, and radio sensitivities were improved. But these were not the fundamental changes of earlier years.

Stereo sound was introduced in the 1950's and 60's but this was not a change in communications, but rather a change in the modulation method. Even the recent introduction of AM stereo is more the development of agreed upon standards rather than the introduction of fundamental concepts.

Now television on the other hand...

Superheterodyne radio concepts:



bandwidth limited

usually class C amplifier

can be polarized
may be directional

range of input signals
under 1 microvolt
to 10's of
millivolts.

($f_{RF} - f_{LO}$
typically)

$$f_{LO} = f_{RF} \pm f_{IF}$$

mixer is non-linear circuit

general introduction to modulation

carrier (unmodulated) signal $v(t) = A(t)\cos\phi(t)$
$= A(t)\cos\left(\omega_c t + \Theta(t)\right)$

amplitude modulation

$$A(t) = V_c\left[1 + \underset{\substack{\uparrow \\ \text{modulation index} \\ \text{(constant)}}}{m_a}\,\underset{\substack{\nwarrow \\ \text{modulating signal}}}{F(t)}\right]$$

angle modulation

phase modulation

$$\Theta = k_\theta F(t) = k_\theta V_{max}\, v(t)$$

We usually define V_{max} to be the maximum of $F(t)$, thus we can normalize $\Theta(t)$,

k_θ has units of radians/volt.

$k_\theta V_{max} \triangleq$ modulation index $= m_p$

Note that m_p does not mean the same thing as m_a.
m_p is not restricted to $[0, 1]$.

Example: $v_{PM}(t) = A\cos\left[\omega_c t + m_p v(t)\right]$

$$\Theta(t) = m_p v(t)$$

$$\omega(t) = \omega_c + \frac{d\Theta(t)}{dt} = \omega_c + m_p\frac{dv(t)}{dt}$$

frequency modulation

$$v_{FM}(t) = A\cos\left[\omega_c t + k_\omega\int_0^t v_m(t)\,dt\right]$$

The deviation $\delta\omega$ of the instantaneous frequency $\omega(t)$ from the carrier frequency ω_c is directly proportional to the instantaneous amplitude of the modulating voltage.

$$\delta\omega(t) = \omega(t) - \omega_c = \omega_c + \frac{d\Theta(t)}{dt} - \omega_c = \frac{d\Theta(t)}{dt}$$

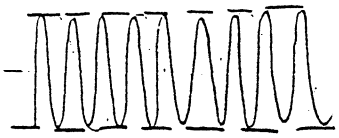
Let $\delta\omega(t) = k_\omega v_m(t) = \dfrac{d\Theta}{dt}$

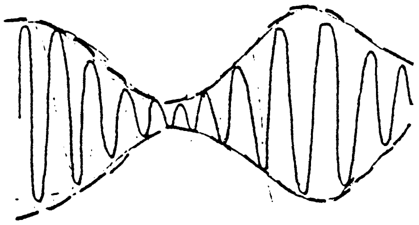
$$\therefore\quad \Theta(t) = \int_0^t k_\omega v_m(t')\,dt' + \Theta(0) \longleftarrow \text{usually } \Theta(0) = 0$$

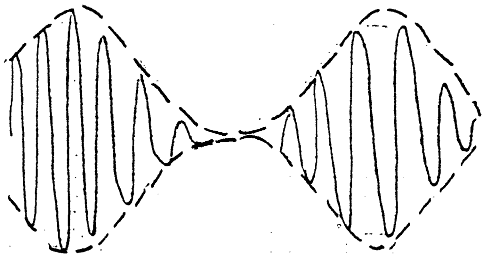
For FM we define a modulation index $m_f = \frac{\Delta\omega}{\omega_m}$

Spectra of modulated signals

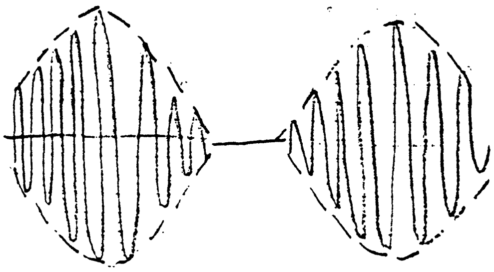
AM modulated waveforms



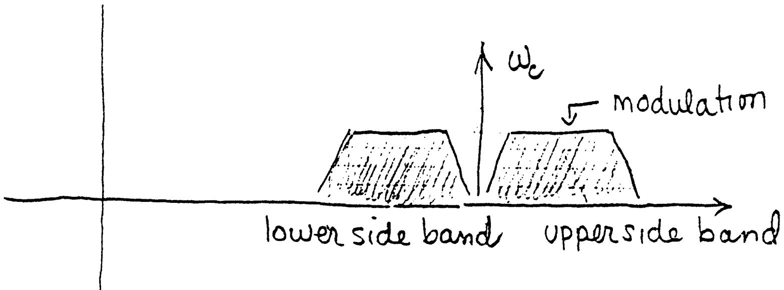




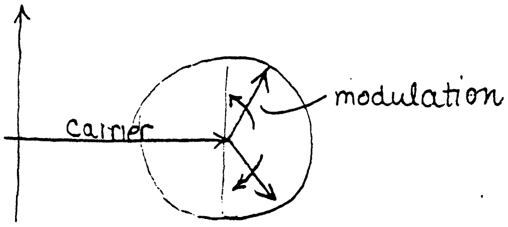
when $m_a > 1$ the signal may or may not be present during certain parts of the modulating waveform.



spectra



phasor diagram



$$F(t) = V_c \cos \omega_c t + \frac{V_c m_a}{2} \cos(\omega_c \pm \omega_m) t$$

Spectra of angulated signals

sinusoidal modulation

$$F_\theta(t) = V_c \cos(\omega_c t + m_\theta \sin \omega_m t)$$

$$m_\theta = \frac{\Delta\omega}{\omega} \quad \text{for FM}$$

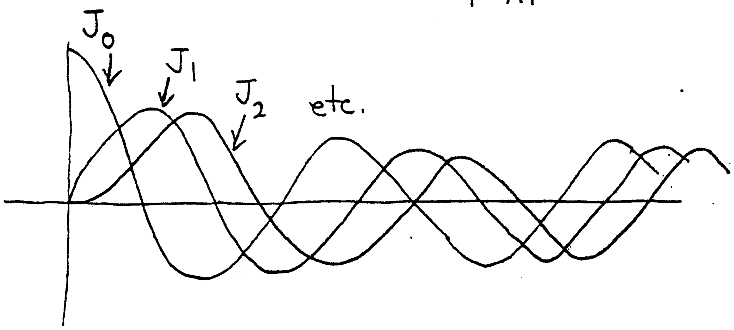
$$m_p = k_\theta V_m \quad \text{for PM}.$$

These look mathematically the same.

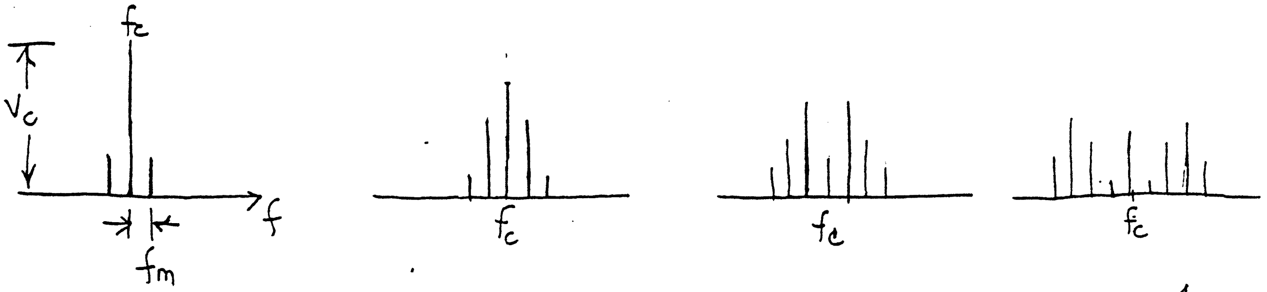
Using Fourier-Bessel series expansion of the above equation

$$F_\theta(t) = V_c \left\{ J_0(m_\theta)\cos\omega_c t + J_1(m_\theta)\left[\cos(\omega_c+\omega_m)t - \cos(\omega_c-\omega_m t)\right] + J_2(m_\theta)\left[\cos(\omega_c+2\omega_m)t - \cos(\omega_c-2\omega_m)t\right] \right\}$$

$$+ \dots$$

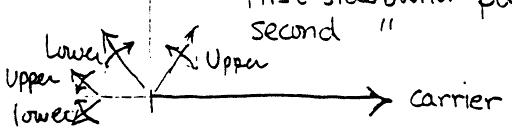


note that a proper choice of m_θ can make a particular sideband go to zer

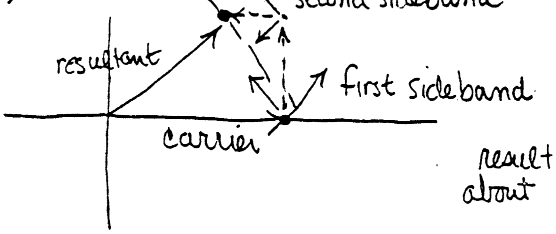


$m_\theta = 0.5$ $m_\theta = 1$ $m_\theta = 2$ $m_\theta = 4$

Phasor diagram



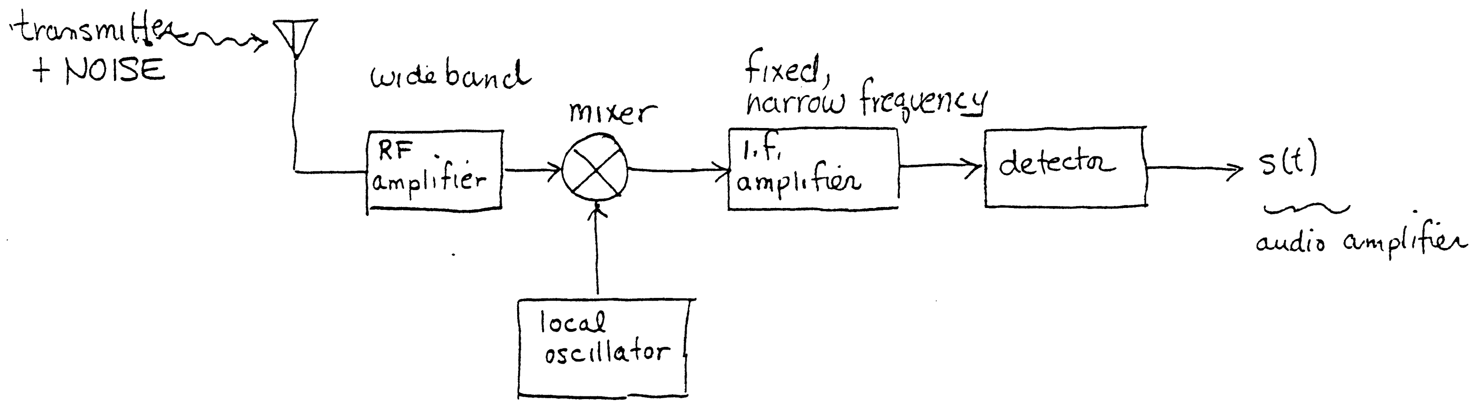
first sideband pair is 90° out of phase with carrier
second " is 180° "



do vector sum of all

result swings ±Δ about carrier.

receiver performance



overall performance.

sensitivity	minimum carrier signal that produces a given signal/noise power ratio (SNR) at i.f. output. Can be specified for a given modulation level
noise figure	how much noise is added by the electronics between the RF amplifier and IF output
selectivity	
image rejection	image input/carrier input that gives equal mixer outputs. A measure of r.f. amplifier rejection
i.f. rejection	i.f. input/carrier input that gives equal mixer outputs.

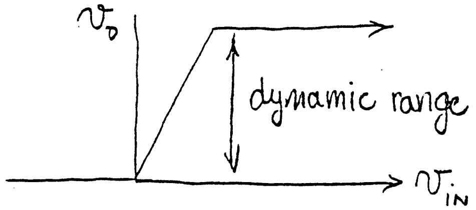
If $f_{RF} - f_{LO} = f_{IF}$
image frequency is
$f_{RF} + f_{LO}$

r.f. amplifier

1) high power gain

2) low noise (r.f. amplifier dominates receiver performance)

3) linear transfer function with wide dynamic range.



(don't want intermodulation distortion (IMD)
cross - modulation distortion (CMD)

4) <u>low</u> reverse transfer admittance
(isolate antenna from oscillator)

5) sufficent selectivity to reject i.f., image and other spurs from mixer input.

FET's usually have wider dynamic range and less IMD, CMD than BJT's.

cross modulation	3rd order distortion products from a undesired signal can modulate desired signal. usually important when trying to receive a weak signal near a strong signal

The mixer :

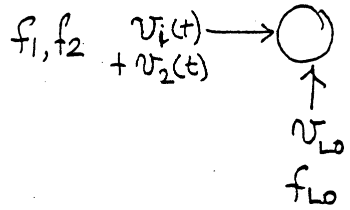
1) square law characteristic

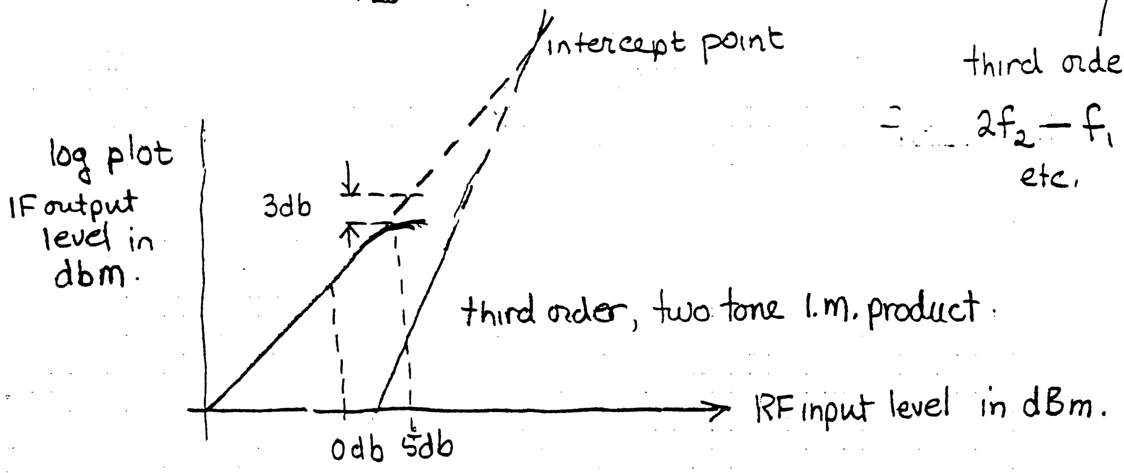
input output $$i_o(t) = I_o + a v_i(t) + \underbrace{b[v_i(t)]^2}_{\text{generates sum and difference terms called 2nd order intermodulation products}} + \underbrace{c[v_i(t)]}$$

third order produ

$= 2f_2 - f_1 \pm f_{LO}$

etc.





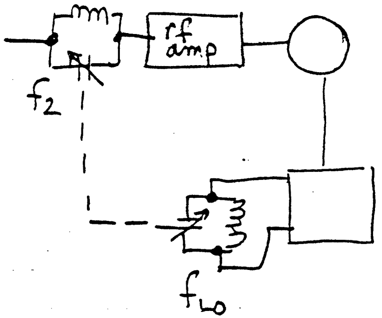
an outstanding mixer intercept of +40 dbm
noise figure of 10 db
lo power +13 dbm

typical mixer intercept of +20 to +25 dbm.

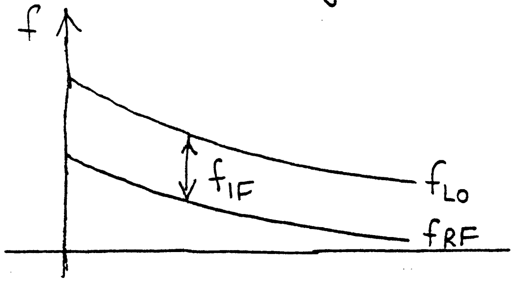
2) wide dynamic range for input signals
3) conversion gain (often a loss)
4) low noise figure
5) complete isolation of LO, RF and IF from each other

Local oscillator

1) should be free of harmonics
2) should be stable.



should be tuned together

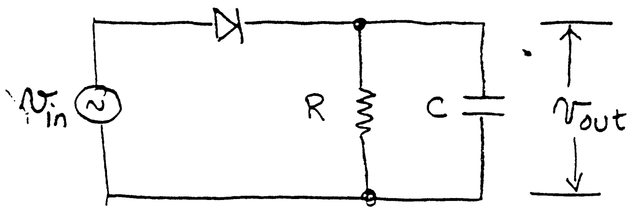


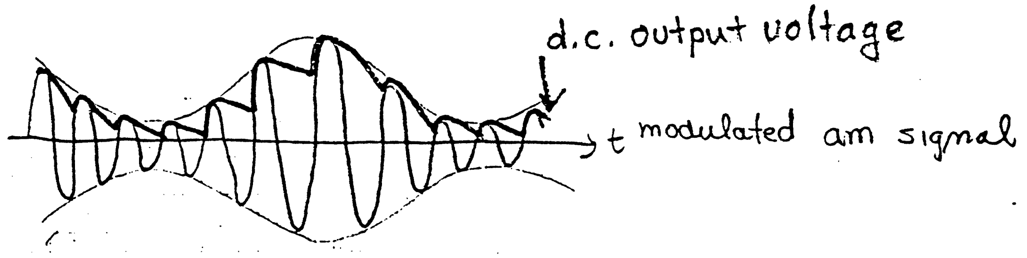
I.F. Amplifier

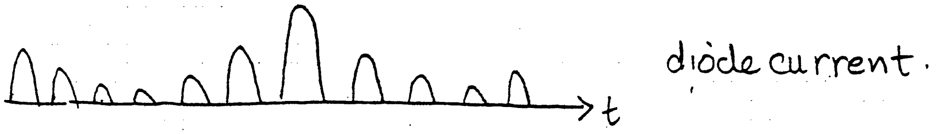
provides most of the gain in a radio
provides high adjacent channel selectivity (i.e. narrow bandwidth)
typically needs an output of 1-2 volts

455 kHz for AM
10.7 MHz for FM

} tend to give poor image rejection since the sum (or difference) is still in the range of the radio diode envelope detectors.







The choice of RC controls the slope ("decay") of the voltage pulse in the diode output, i.e. the amount of filtering. R also determines the load impedance the source sees.

If $v_{in} = V_c \cos \omega t$

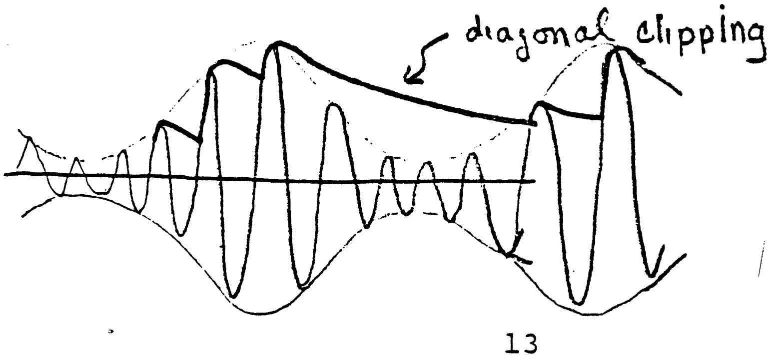
$v_{out} = v_{od}$ — a d.c. value

The detector efficiency $\eta \triangleq \dfrac{v_{od}\ (\text{d.c.})}{v_{IN}\ (\text{a.c.})}$

The input impedance will be approximately $R_{in} \cong \dfrac{R}{2\eta}$.

Design procedure ① pick R to give desired R_{in}

② pick C to prevent diagonal clipping



RC is too large to allow voltage to decay thus causing distortion