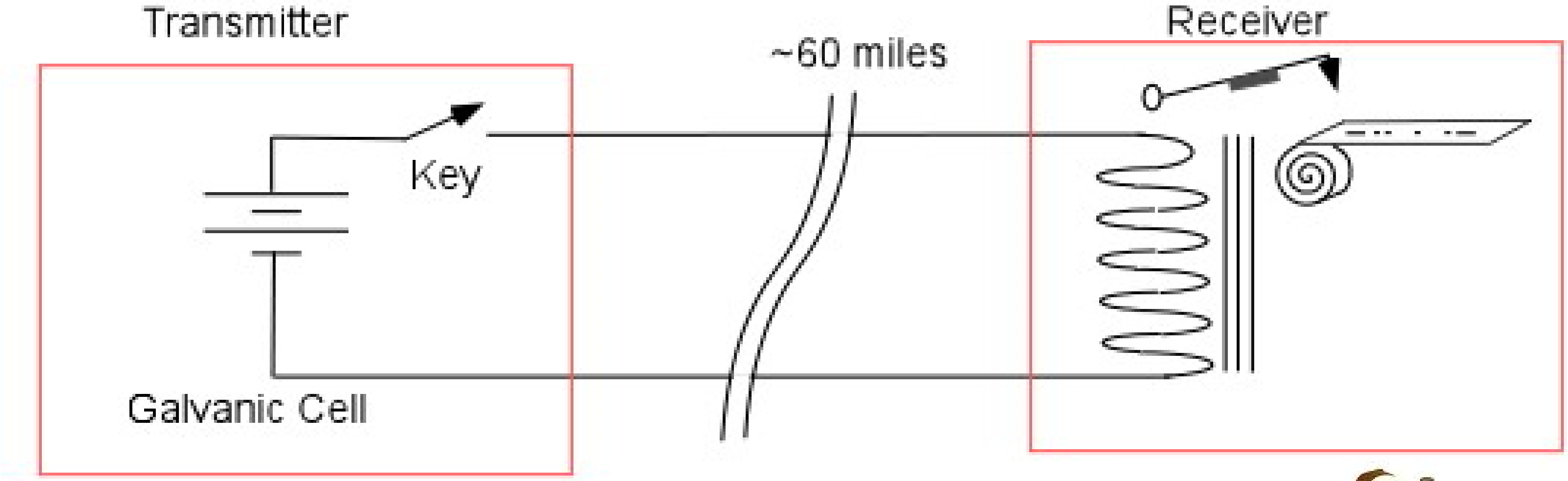
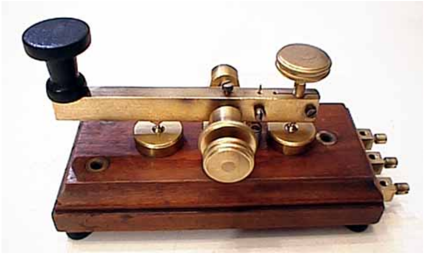
Basic Architecture of a Telegraph link





The birth of the telecommunication Network

Ezra Cornell installed the lines for the Baltimore-Washington telegraph demonstration, and became enamored by the telegraph and its potential. He (and others) started creating city-to-city links. Cornell worked to bring them all together under Western Union, the first large telecom network.

Trans-Atlantic Cable: the birth of EE

- Transatlantic cable was installed in 1850s
- It required large voltage and operated very slowly (91 word message from Queen Victoria took 16 hours to send.
- After a few days it failed. Investors were furious, and demanded an investigation!
- Lord Kelvin led the panel, the designers had no clues about resistance, inductance, capacitance, nor how to build wires.
- Standards were created, i.e. the Volt, the Ampere, the Ohm, and so forth.
- Electrical Science was born

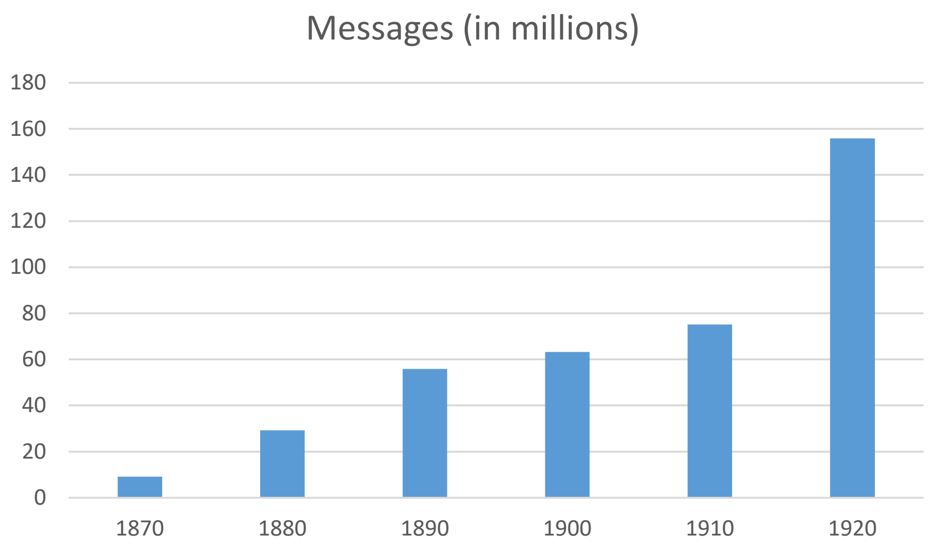
First Electrical Engineering School starts at Cornell 1883

- It was located in Franklin Hall, now Tjaden Hall, over by the Art museum

- The mission was to develop the technology for Electrical Engineering
  - Power generation
  - Electric power transmission
  - Wire insulation
  - HV transformers
  - Basic circuit theory

The telecommunication boom began

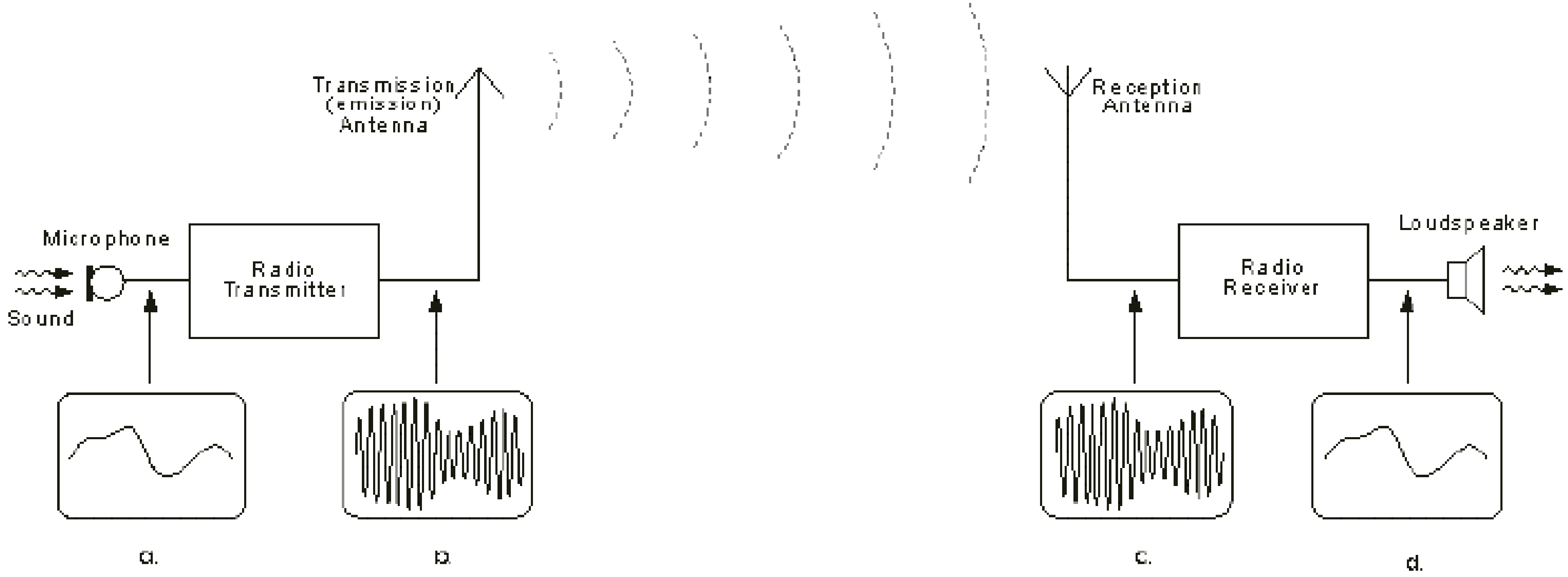
Telegraph messages sent per year in the USA through 1920



Compare to today

- 6 Billion phone calls per day in USA
- 250 Billion e-mails per day in the world
- 6 Billion text messages per day in USA

The drive for wireless telegraph connections motivated radio



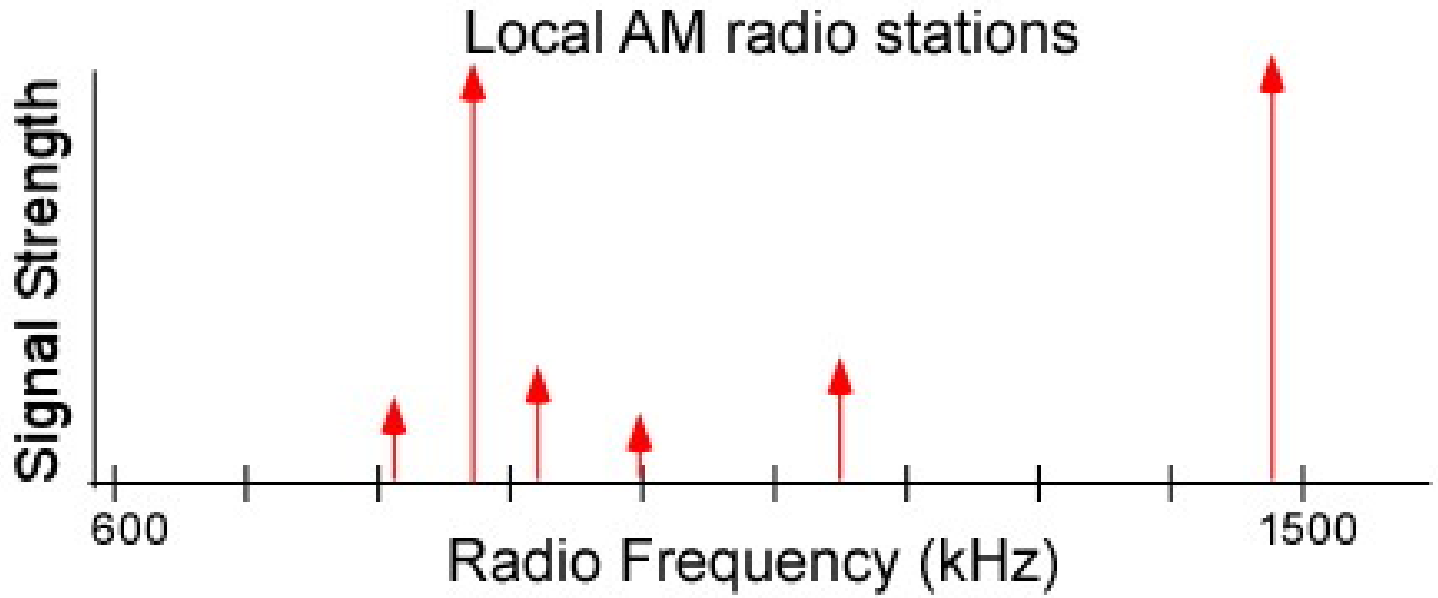
Information (voice, text, etc.) modulates a radio frequency signal.

The radio frequency current i(t) drives an antenna, creating an electromagnetic wave

A receiving antenna couples the wave, the radio amplifies and demodulates the signal

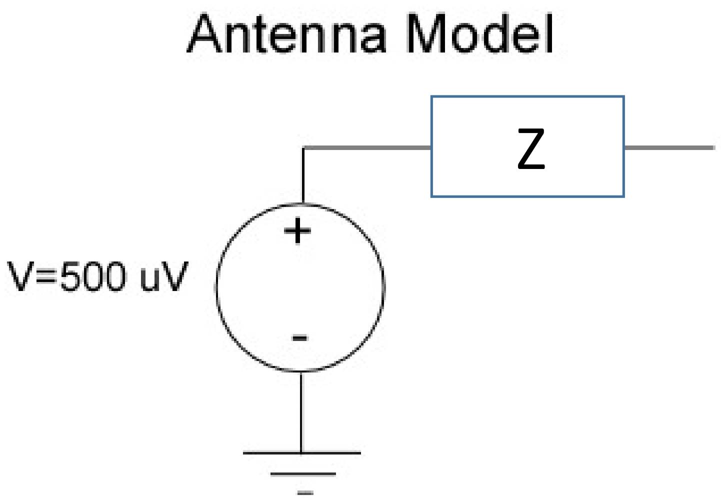
ECE 2100 view on radio receivers

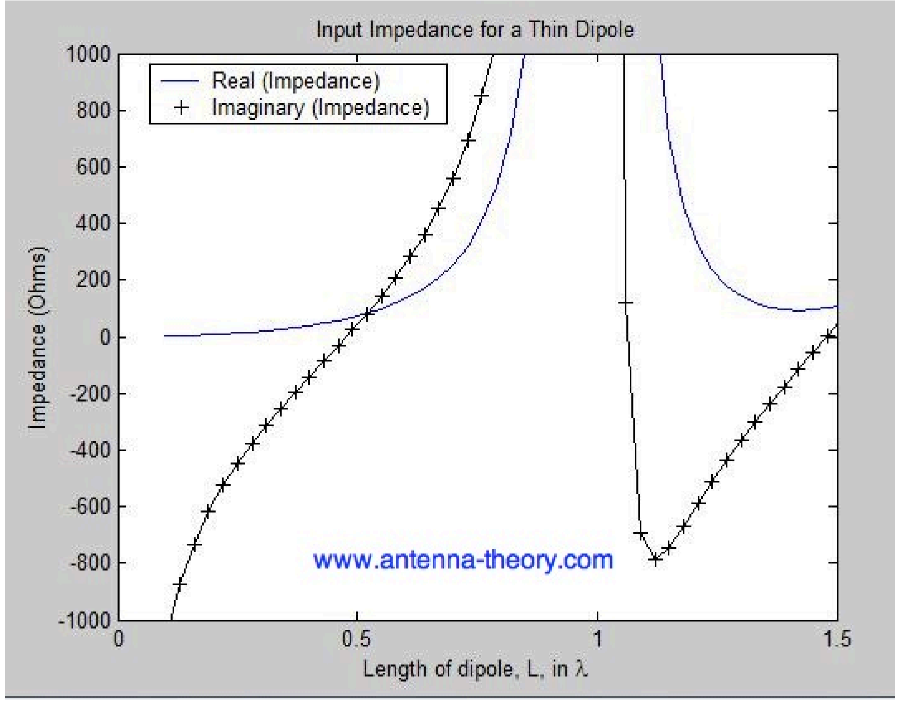
Scenario: we want to build a radio to receive music from a local station.



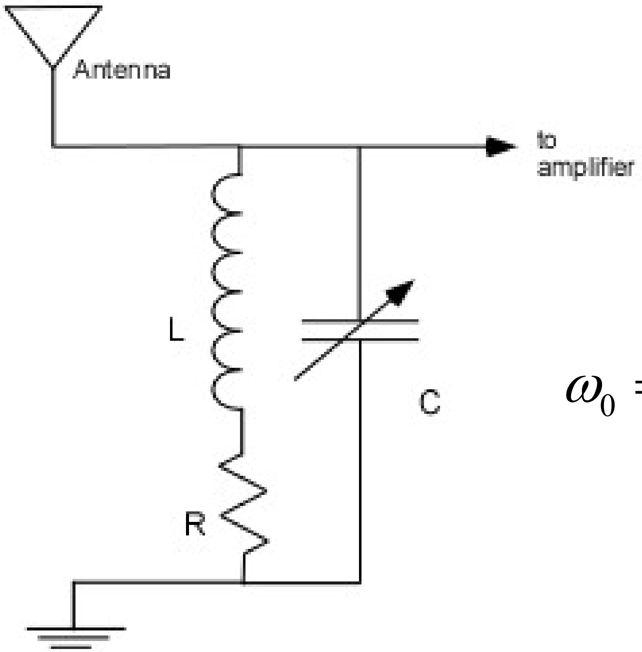
Step 1. Set up an antenna

- A radio wave amplitude will have magnitude of 1μV/M to 500μV/m, depending on power of station and distance.
- An antenna can be a simple wire, oriented vertically typically. The voltage on the antenna is a product of the RF field strength and the length of the antenna
- Example: a field with 50 μV/m will create a 500 μV signal on a 10 m antenna



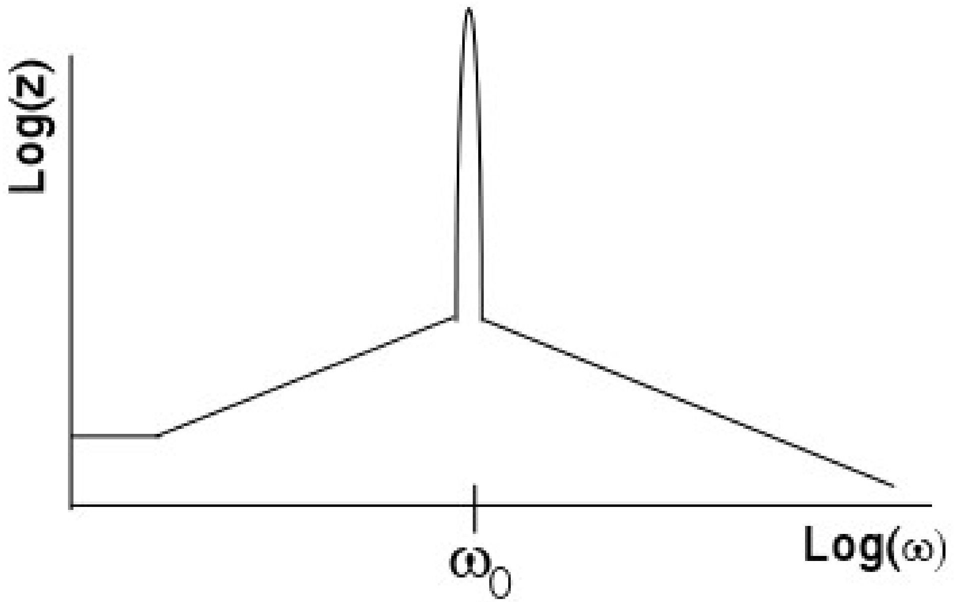


Step 2: Filter the input



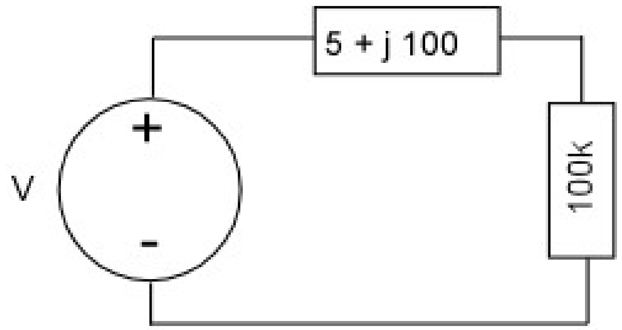
$$\omega_0 = \sqrt{\frac{1}{LC}}$$

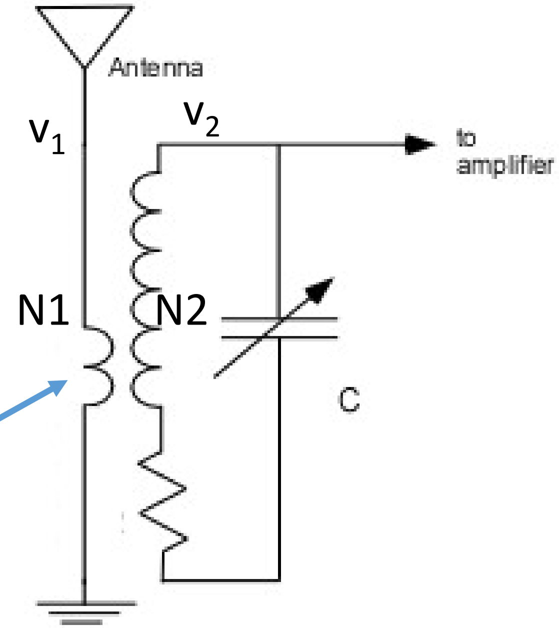
The impedance of the tuned circuit depends on frequency, reaching a maximum value of z=QωL at the resonance.



Step 3: Maximum Power Transfer

- The resonant circuit has an impedance of 100s of kΩ. Will the antenna transfer its power efficiently?





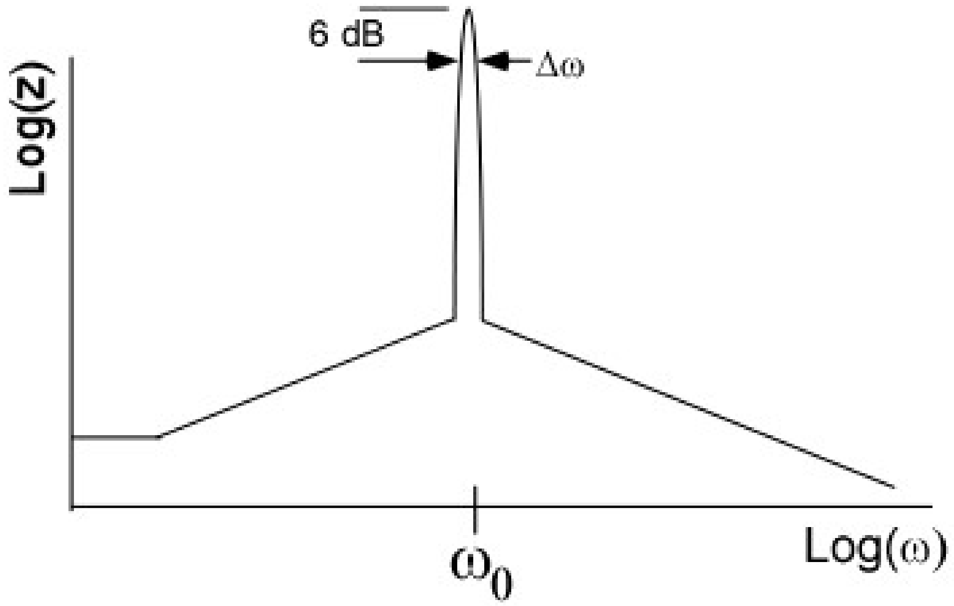
Magnetically coupled coils, aka "Transformer"

$$v_2 = \frac{N_2}{N_1} v_1$$

$$z_1 = \frac{N_1^2}{N_2^2} z_2$$

Step 4: Selectivity

- The RLC tuned circuit has a “bandwidth” defined as the width of the maximum peak at its half-max point.



Q can be defined several ways. In terms of bandwidth it follows

$$Q = \frac{\omega}{\Delta\omega}$$

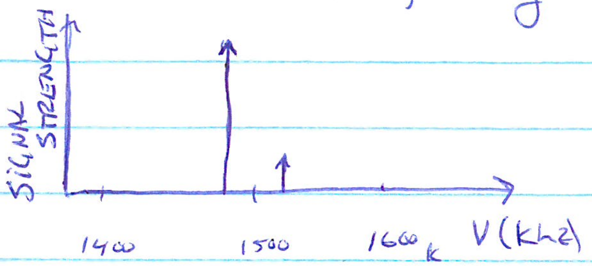
A decent RLC circuit will reach Q=50. At 1510 KHz, that means the bandwidth is

$$\Delta\nu = \frac{1510kHz}{100} \approx 15kHz$$

AM stations can be located as close as 20 kHz from each other. Strong stations can overwhelm neighbors.

Example

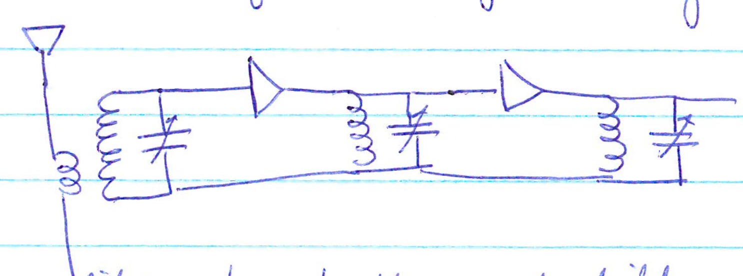
Consider 2 radio signals that are separated by 20 KHz, and where one signal is 10 times stronger than the other, say at 1490 KHz and 1510 KHz



To listen to the weak station, the filter must reduce the strong signal by over a factor of 10

For the case described in Step 4 ($\Delta\nu = 15$ KHz), the strong signal would only be attenuated to 30% of its original value (I used a "universal Q-curve" to extract that value) so it would still dominate the weak signal.

Solution: more filters! You could gang them like this.



The amplifier stage buffers each filter so they are not loaded. Each filter would reduce the strong signal proportionally, and eventually the weak signal would prevail

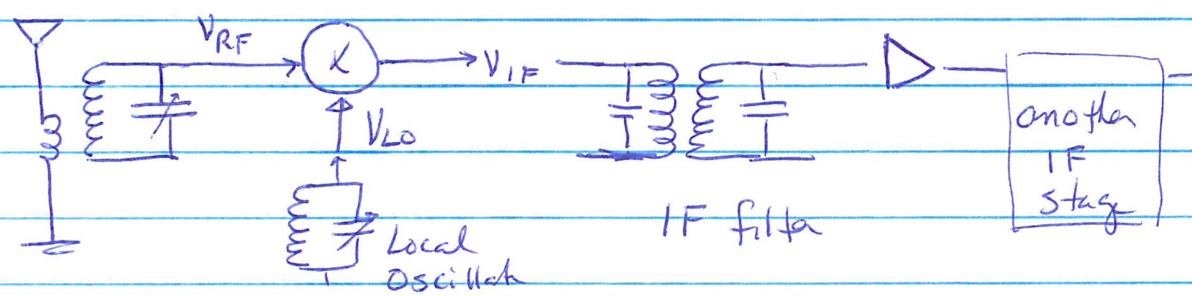
But... this requires a lot a well-tuned filters. There is a better way.

Heterodyne

Modern radios use heterodyne detection. The incoming signal is mixed with a "local oscillator" that operates at a different frequency. The mix creates a difference frequency, called the Intermediate Frequency

$$\nu_{RADIO} - \nu_{LO} = \nu_{IF}$$

The advantage of this is that the IF filters can be made with very high Q, and excellent rejection of unwanted signals



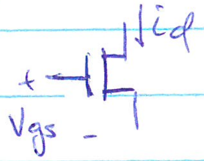
The IF filter can be made with quartz crystals, so they have very high Q. But crystals cannot be tuned, so the radio frequency must be reduced to IF, and that is what the mixer does.

Mixer

To create a "difference frequency", a <u>non linear</u> circuit is required.

A linear circuit would only create a superposition of the two frequencies.

A good example of a nonlinear circuit is the MOSFET



$i_D = K(V_{gs} - V_T)^2$ V_T is a constant

Ignoring the constant V_T, consider what happens when 2 signals are sent to the mosfet

$V_1 = A\cos\omega_{RF}t + B\cos\omega_{LO}t$

$V^2 = A^2\cos^2\omega_{RF}t + B^2\cos^2\omega_{LO}t + 2AB\cos\omega_{RF}t\cos\omega_{LO}t$

Recall $\cos^2\omega t = \frac{1}{2} + \frac{1}{2}\cos 2\omega t$

$\cos x \cos y = \frac{1}{2}\cos(x-y) + \frac{1}{2}\cos(x+y)$

The signal after the MOSFET has several frequencies, at $\nu = 0$, $\nu = 2\nu_{RF}$, $\nu = 2\nu_{LO}$, $\nu = \nu_{RF} - \nu_{LO}$, $\nu = \nu_{RF} + \nu_{LO}$

The IF filter easily blocks all the term at $\nu = \nu_{RF} - \nu_{LO}$

A second advantage of heterodyne is that the IF signal strength is a product of the weak RF signal with a strong LO.

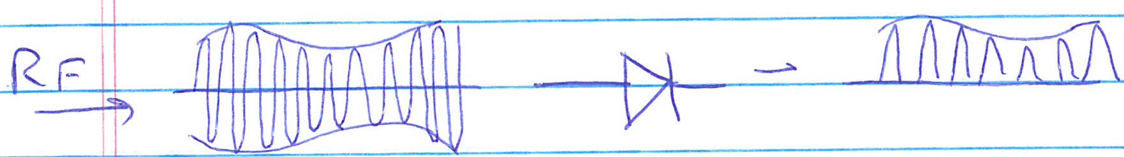
$$\frac{AB}{2}\cos(\omega_{RF} - \omega_{LO})t$$

The radio signal might only be 1 mV, but the LO can be made to have an amplitude of several 1000 mV, so the mixed signal at the IF is boosted. This is effectively gain.

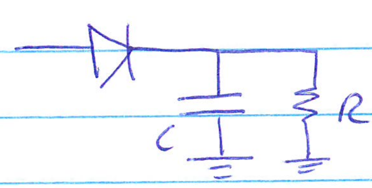
Detection

Finally you need to recover the original signal from the IF signal.

For AM, a diode is used



The IF signal is rectified by a diode, creating a series of half waves at 455 KHz. The envelope of the pulses show the encoded signal.



A simple "integrator" filters out the IF, and results in a low frequency signal proportional to the envelope

The RC time constant is chosen such that $\frac{1}{RC}$ corresponds to the highest frequency of the encoded signal.