Introduction -- THE BIG PICUTURE
(without: detailed #s, math or circuits)

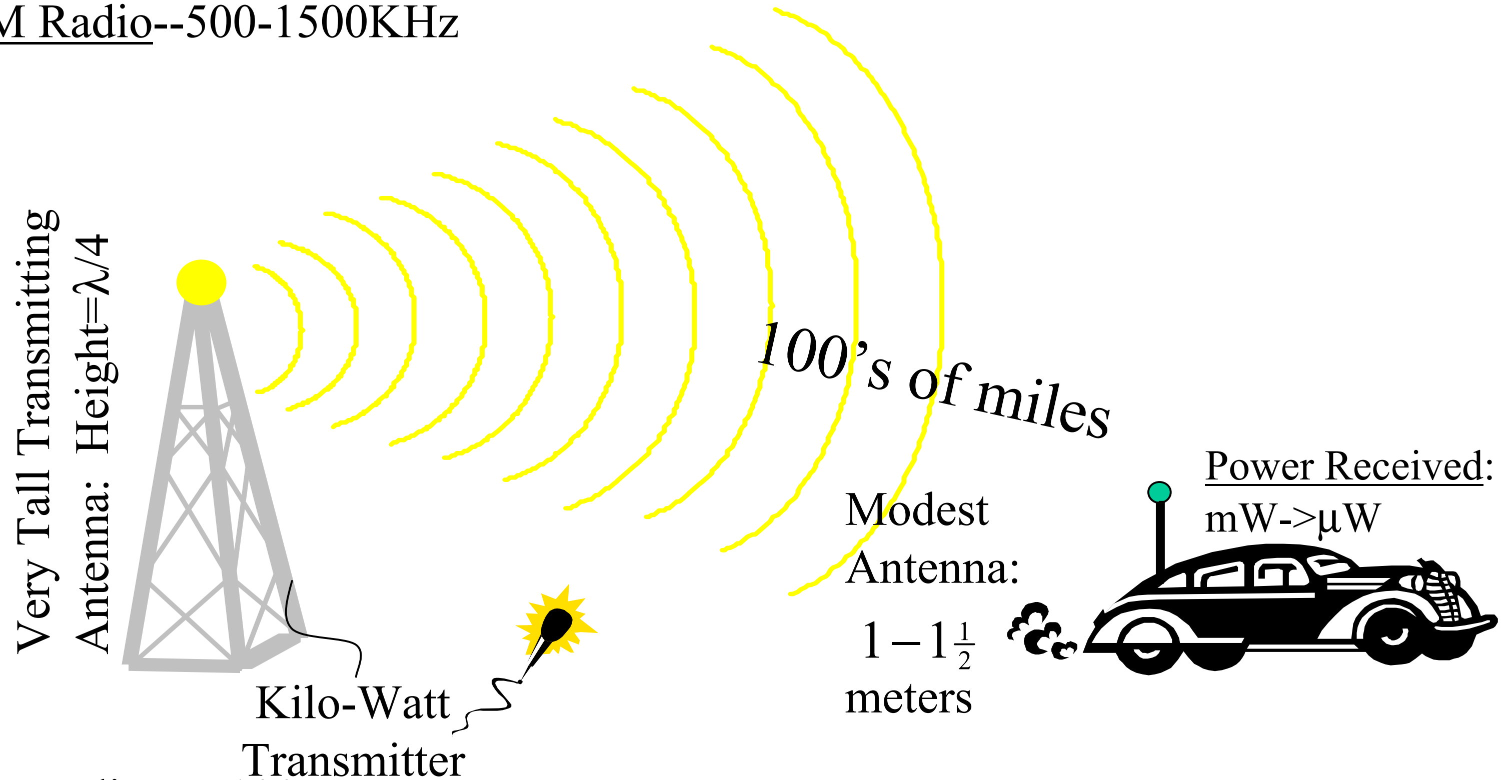
Communications: Moving information; modulating and demodulating (i.e. the word "modem"); coding and decoding (i.e. the word "Codec")

Bandwidth (B or BW): How much information -- digital speaks both in Mbits/sec and MHertz (actually, Gbits and GHz are here to stay); analog tends to focus on Freq. (Hz)

FCC: Fed. Communications Commission -- regulates freq., BW, power and generally use (and misuse) of "The Ether" (we'll be talking about wireless so that means propagaton in free space ε_0)

Examples

AM Radio--500-1500KHz

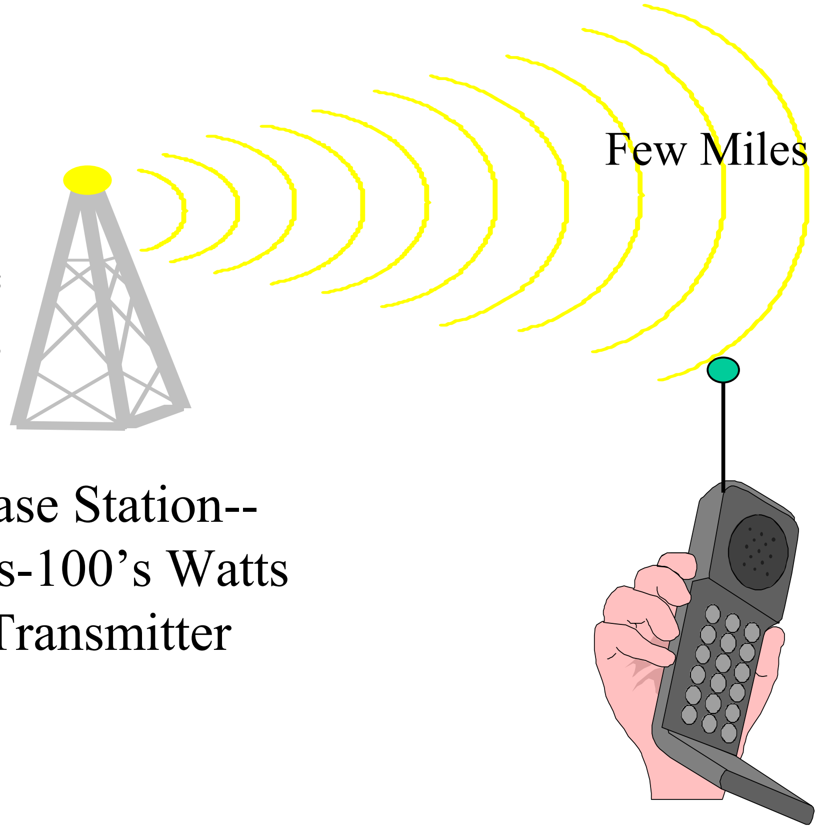


FM Radio -- ~100MHz

Transmission side, quite similar except antenna doesn't have to be as "tall" (we'll discuss soon)

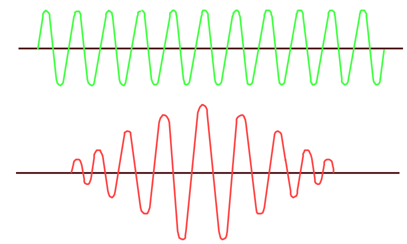
Receiver side, same antenna (duh!) but actually it is "good match" of length for FM. Received power about the same.

Cell Phones--few GigaHz (I.e. 1.xx-2.yy GHz)



Base Station--
10’s-100’s Watts
Transmitter

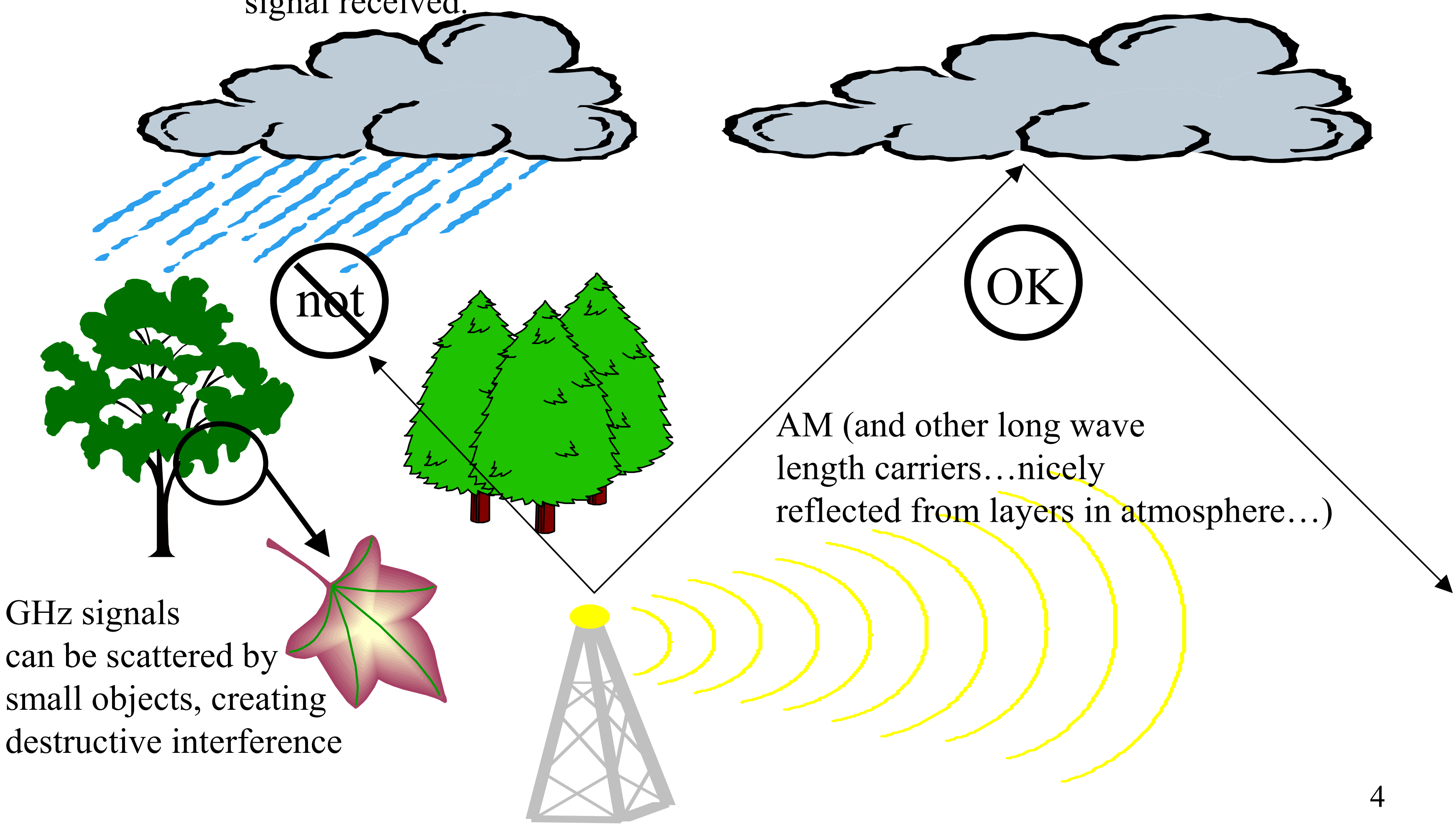
Received Power,
also small…
mW -> µW
BUT!!



…you may
have **other**
transmitters
near by…
(we’ll need to
consider various
kinds of
“**interference**”)

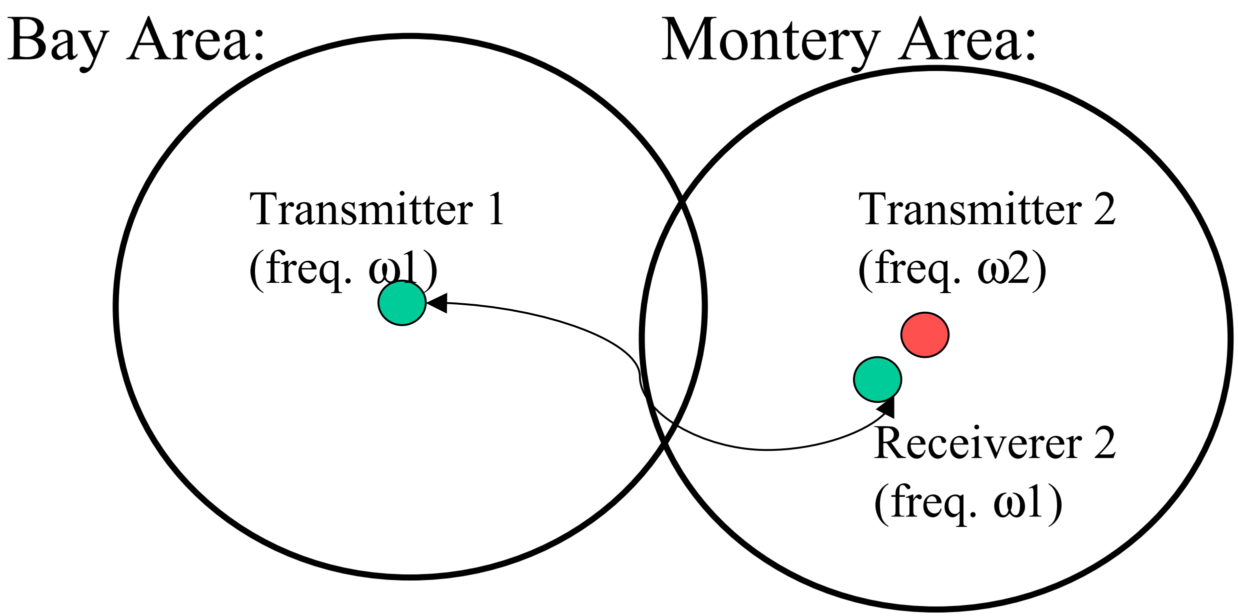
A bit about Propagation Reflection and Attenuation of Wireless signals. Next we'll get into the #s of actual wavelengths at different frequencies but basic laws of physics (aha, there was a reason for Physics 43)--

- Surfaces/objects larger than λ tend to reflect
- Surfaces/objects on the order of λ scatter (diffuse) and hence will attenuate signal received.



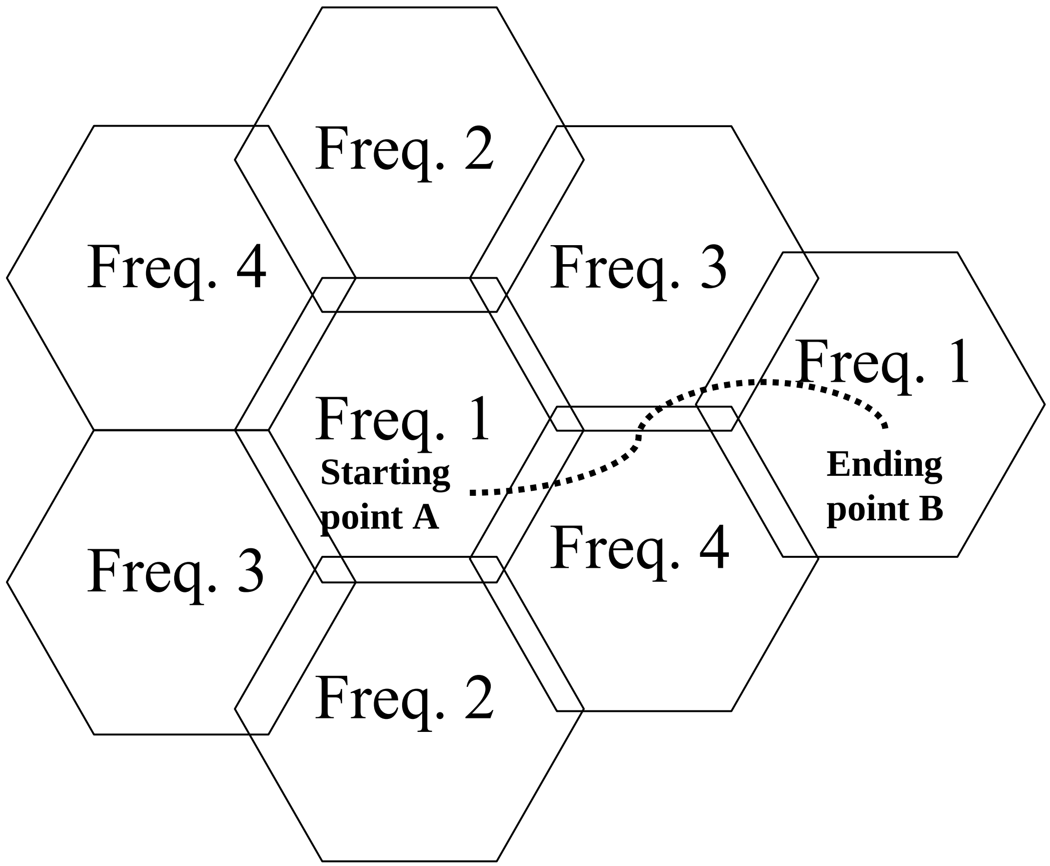
Oh yea, and about "Broadcasting" (a farming term for sowing seeds) vs. "cells" in a cell phone system.

AM & FM (Broadcasting) -- the more power the better, but the FCC regulates. When you run out of "range", get another frequency band from FCC and add "translator" (we'll discuss!)



"Translator": moves modulated signal to a different carrier freqency… (with same info.) Also called "heterodyning"

Cell Phones -- power (and range) is controlled. Basically they are organized and controlled so that you "tile" an area (i.e. Mosaic tile like on MemChu) with non -- overlapping frequencies (sorta like the translator -- example).

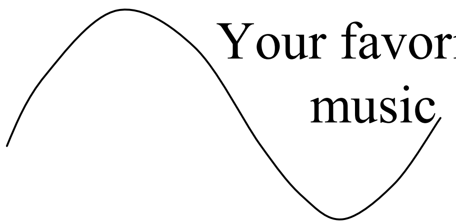


As the cell phone moves from starting point A to ending point B, there will be “frequency hand-offs” f1->f4->f3->f1.

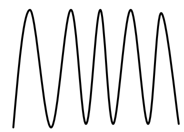
Modulation: the process of taking information and "attaching" it to the carrier frequency (or multiple frequencies)

Demodulation: the process of retrieving the information from the modulated signal

Examples:

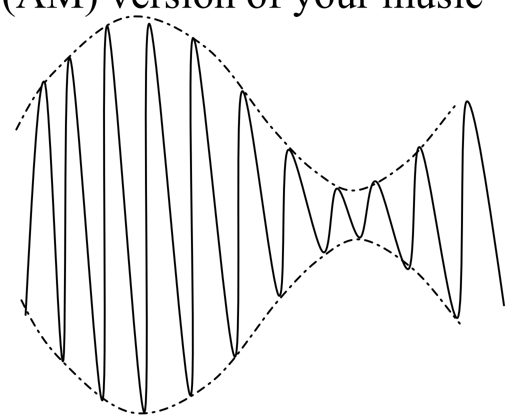


Your favorite music



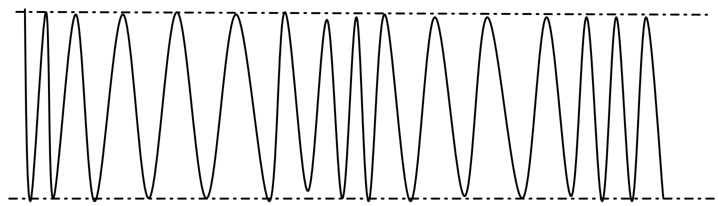
Your station's carrier frequency

The Amplitude Modulated (AM) version of your music



That is, your music changes the amplitude of the carrier signal. Obviously $f_{carrier} >> f_{music}$

The Frequency Modulated (FM) version of your music



That is, the carrier frequency is shifted (very slightly up and down) by your music's frequency.

Again $f_{carrier} >> f_{music}$

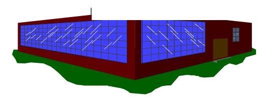
And now, THE GAME PLAN for this quarter (and beyond if you love it)

- Learn just enough theory, just in time so…
- You can build and test real circuits to do modulation/demodulation of both AM & FM (analog) signals and then!
- We will put all the pieces together and build an almost minimal radio (walkie-talkie) system and do the following….
- Field testing:

The TREASURE HUNT!

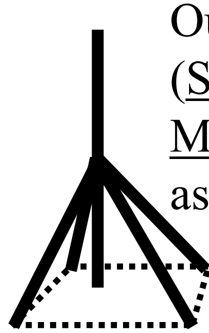
Where can you go..on-campus and even off-campus and still receive the exciting words from K-SPAM?

Allen CIS,
Clark Bio-X
Med School...
(shopping center?)



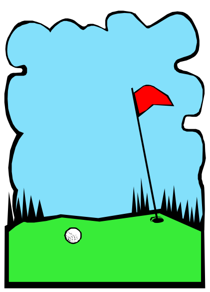
The Barn

Rodin Sculpture garden



Our "SPAMing" Transmitter (Stanford Projects in Angle Modulation…as many dBm as we can get!)

The Golf Course



PRIZES and Pizza Party
Follows the final Demo Event!

MemChu

To help with the theory, Prof. Andrea Goldsmith is teaching EE104 this quarter and plans to help us out with notes and her own preview of the BIG PICTURE.

The textbook (Solid State Radio Engineering) by Krauss et al is old (vintage 1980) but is excellent in terms of all the essentials. As Krauss notes, the book was targeted for Full Year (i.e. 3 Quarters) but what the heck! (your Stanford's BEST, and we can do it!)

Read Chapter 1 (a bit more detail there than these notes)

And now, the preview of Ch. 2 & 3 plus plans and introductions to Lab #1

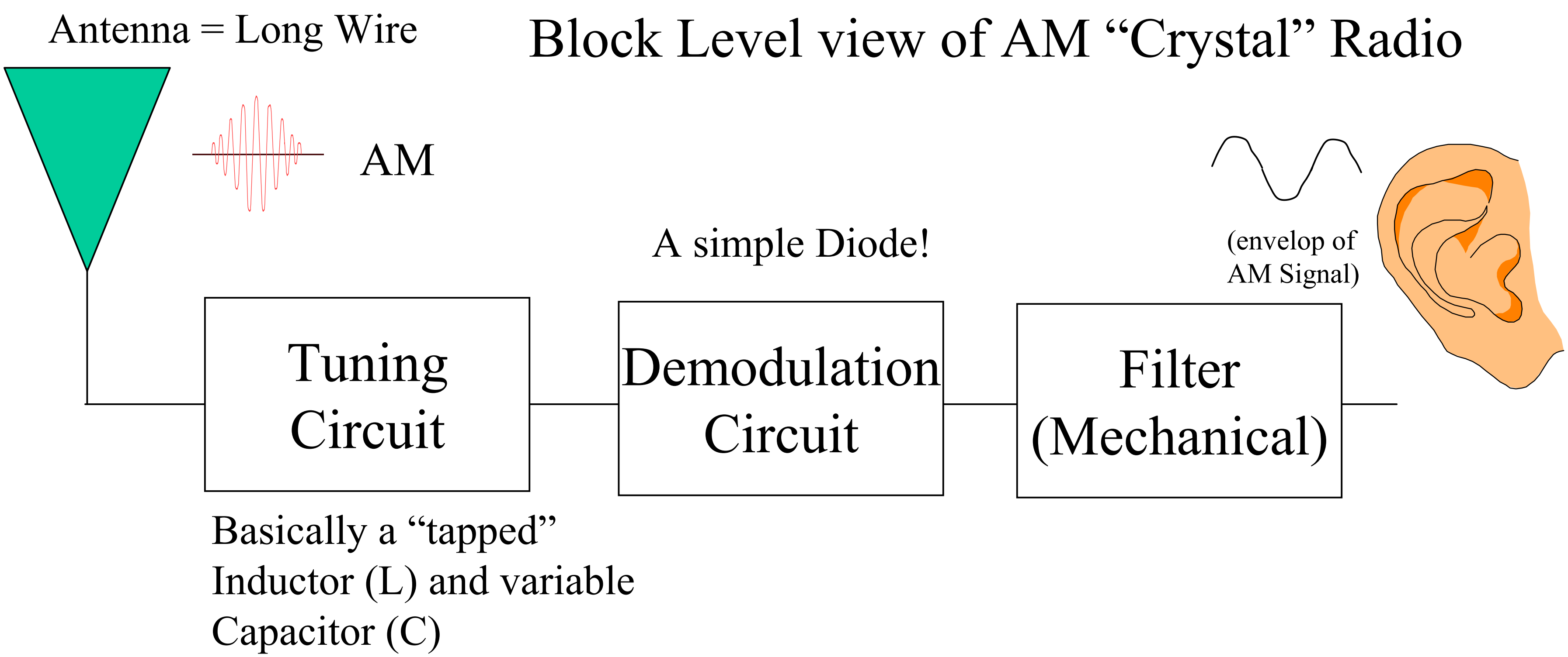
Oh yea, about Labs*! (and Lab Notebooks*)

The "pre labs"* are illustrative and essential information. BUT, the difference between EE133 and the prereq. (EE122 REQUIRED!) is that you need to get organized, plan your work and work to become independent. That is, we want you to do more design and become good at experimentation and discovery (on your own)

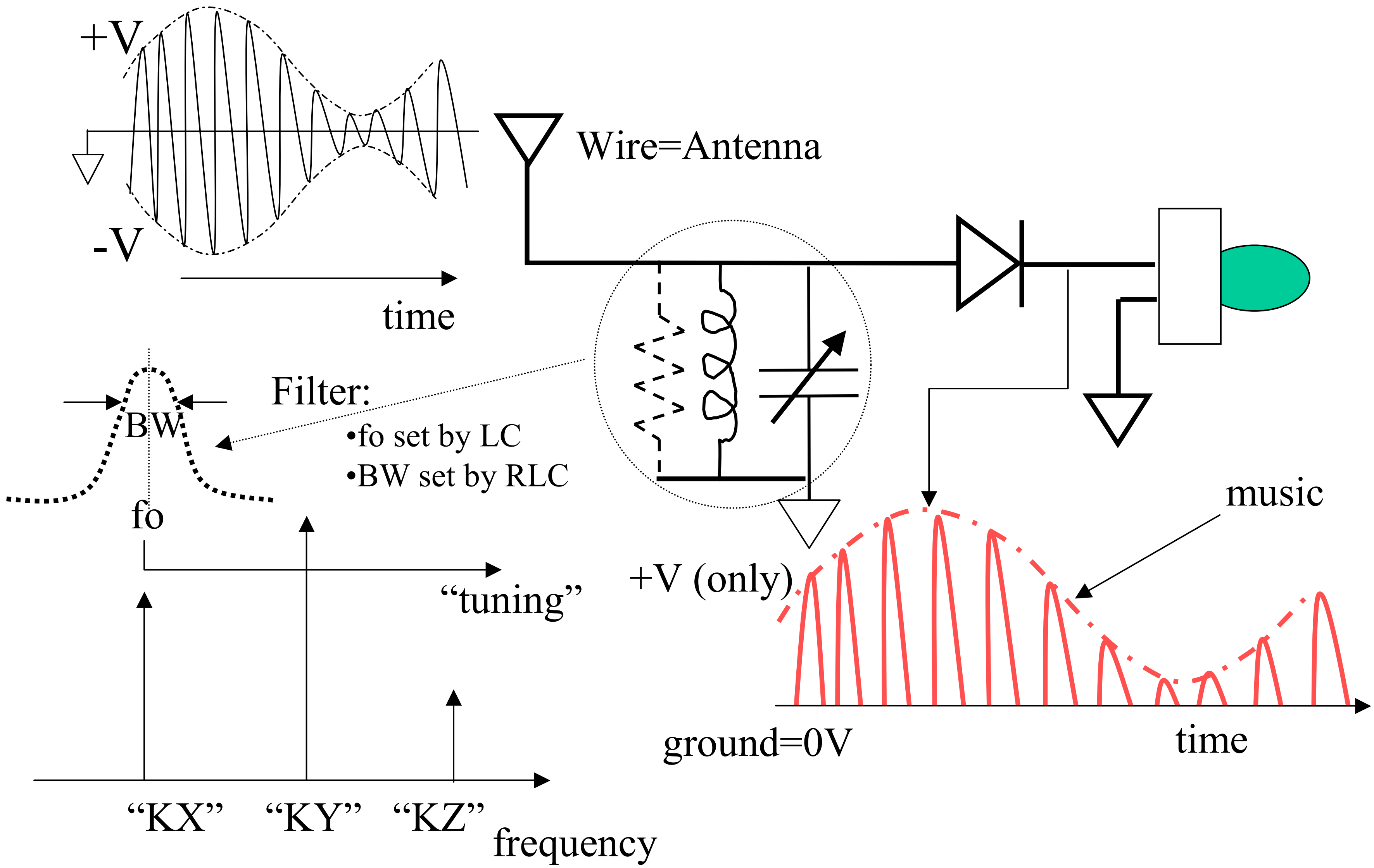
* see formal and more detailed discussion in specific lab handouts

Noise, Bandwidth and Tuning

Let's start with our common experience, we all have radios, and go to the most simple and basic form of an AM radio. The crystal radio (less than $10 at Radio Shack) is the minimum radio -- no batteries, no transistors, one diode (the "crystal") and passive components.



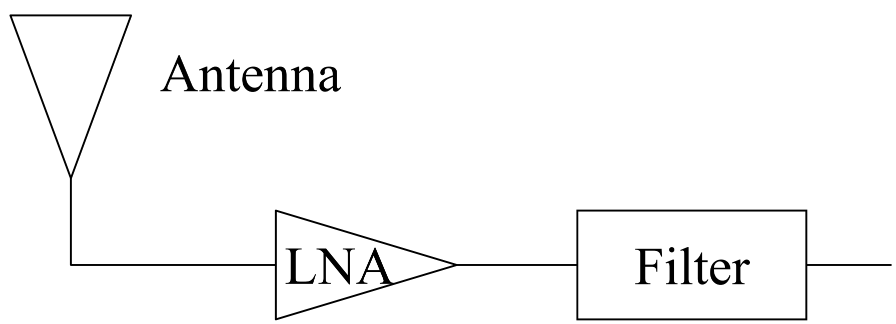
Signal Flow in Crystal Radio



Further details about Tuning will be given shortly. The demodulation (namely a "peak detector" is given in separate hand out)

Moving beyond the minimal radio to a "front end" (receiver) more like that which we'll build and test:

Closer look at practical radio front-end



NOISE

Chapter 2 is concise and quite readable. But, it gets you into transistor models and overall system issues a bit quicker than is needed (yet, anyway).

Perfect L's and C's NO NOISE!

R's are the problem…either R's that we use in circuits or R's that are part of wire, contacts etc. in L's and C's.

To get low noise, use small resistors (at least on voltage gain path). But, antenna (and free space for that matter) has characteristic impedance. (i.e. see §2-2 on p. 14-15 in Krauss). And, hopefully as you might remember from E40, to get maximum power transfer from input source, you'll want to and need to match impedances between antenna and amplifier. That is,

R_{in} (LNA)$\neq 0$ $\therefore$ Noise due to Amp. must be considered.

Let's consider just one resistor … p. 11 (Krauss) and Example 2-1.1

consider noise voltage for a resistor R at temperature T (°k) and for a Bandwidth "B"

Boltzmann constant

↓

$$V_n^2 = 4kTR \cdot B$$

To reduce noise, smaller R (but still needs to "match") and smaller B (bandwidth). B is an interesting quantity.

Type 1: The minimum B would be "information bandwidth" (that is, over what range of frequencies have information been transmitted…we'll talk more about this!

Type 2: A maximum B might be all frequencies that you might want to receive (for example both AM and FM signals 500KHz → 100^{+}MHz)

Example 2-1.1 actually is using a liberal B of Type 1. B=1MHz

$$V_n^2 = 16\times 10^{-10}(\text{Volts})^2$$

$$RMS \Rightarrow \left(V_n^2\right)^{1/2} = 40\mu V$$

Also, this is for a 100KΩ resistor…not the best we can do.

Bottom -- Lines (for this week anyway):

R & B both affect noise performance

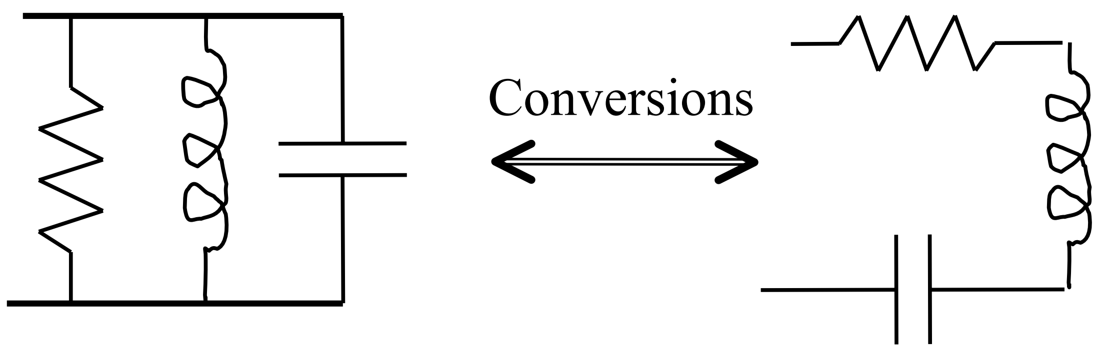
*exercise for you audio lovers…go read the spec. on your FM receiver about front end sensitivity.

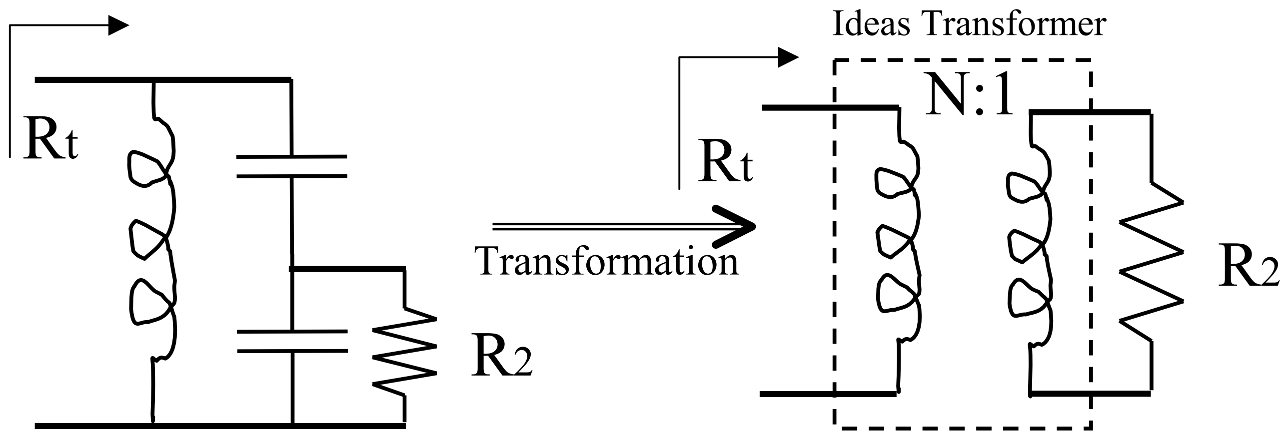
OK, it's clear from TWO perspectives that Bandwidth matters: a) per this handout about tuning KX vs. KY or KZ and b) the noise depends critically on B (as well as R) based on previous page and "Bottom--Lines"

BANDSWIDTH, TUNING (i.e. RESONANT CIRCUITS)

Chapter 3 is key and essential reading. We will use both series and parallel resonant circuits. Also, the conversions (i.e. Appendix 3-1 and associated Tables) are extremely important and you will learn them well and love them during Pre-Lab and Lab #1. Finally, the notion of transformed impedances is a wonderful and powerful design tool. For example, if you need motivation look at §5-5 (Chapter 5) where every possible aspect of Ch. 3 is used. Also, that oscillators (such as the Colpitts) will also become a dear old friend very soon.

Bottom -- Lines:

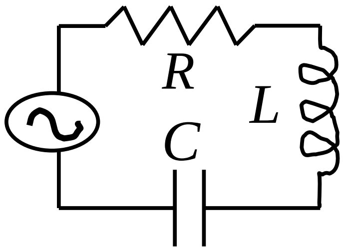


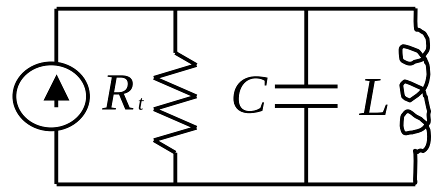


Your goals in reading and digesting Ch 3 are closely connected to these schematic pictures of tuned circuits (and their associated bandwidth)

HIGHLIGHTS of CH.3 KRAUSS

Resonant Circuits (summary and highlights Krauss Ch 3)





(Formula # in Krauss)

↓

(K3-6)

$$Z(j\omega) = R\left[1 + jQ\left(\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}\right)\right]$$

(K3-9)

$$Y(j\omega) = \frac{1}{R_t}\left[1 + jQ_t\left(\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}\right)\right]$$

(K3-2)

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

(K3-5)

$$Q = \frac{\omega_o L}{R}$$

(K3-8)

$$Q_t = R_t \omega_o C$$

$$B_{3\,dB} = f_2 - f_1$$

(K3-7)

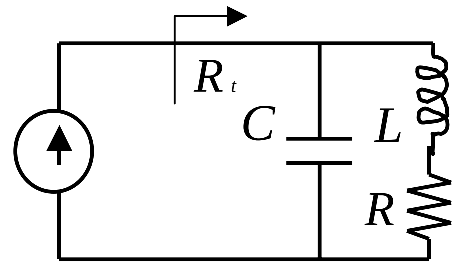
$$Q = \frac{f_o}{f_2 - f_1} = \frac{f_o}{B}$$

(K3-12)

$$B = \frac{f_o}{Q_t} = \frac{1}{2\pi R_t C}$$

(K3-13)

$$Y(j\omega) = \frac{R}{R^2 + (\omega L)^2} + j\left[\omega C - \frac{\omega L}{R^2 + (\omega L)^2}\right]$$



(K3-14) new resonance

$$\omega_o = \left(\frac{1}{LC} - \frac{R^2}{L^2}\right)^{1/2}$$

(K3-15) at resonance

$$Z(j\omega_o) = R_t = \frac{L}{RC}$$

(K3-16)

$$Q_t = \frac{\omega_o L}{R}$$

(K3-17)

$$R_t = R(Q_t^2 + 1)$$

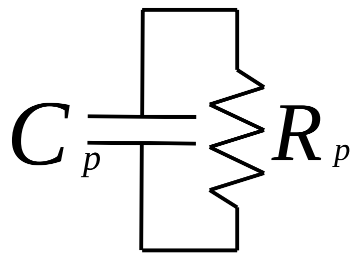
↑

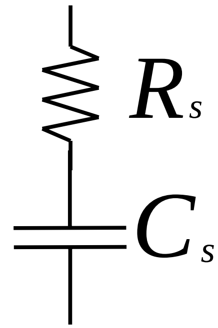
key "design" equation

This property can be useful in connection with collector of transistor (and its shunt resistance)… Also, as we'll see next, we can extend the concept to design for impedance-transformed circuits.

Invaluable Design tools! (Krauss Tables 3-5.1, 3-5.2)

Parallel -- Series Conversions (K--Table 3-5.1)





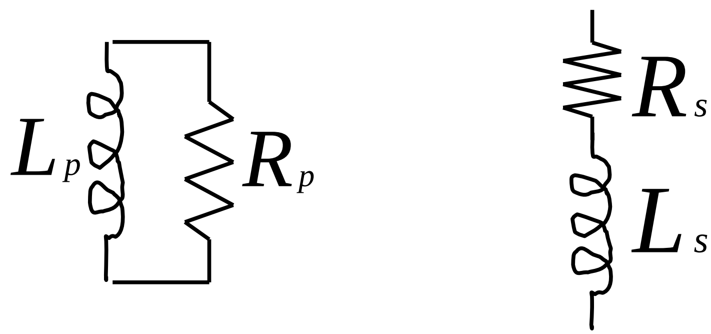
$$X_p \equiv \frac{1}{\omega C_p} \qquad X_s \equiv \frac{1}{\omega C_s}$$

$$Q_p \equiv \frac{R_p}{X_p} \qquad Q_s \equiv \frac{X_s}{R_s}$$

$(\text{series} \rightarrow \text{parallel})$ $(\text{parallel} \rightarrow \text{series})$

$$R_{pe} = R_s\left(1+Q_s^2\right) \qquad R_{se} = \frac{R_p}{1+Q_p^2}$$

$$C_{pe} = C_s\left(\frac{Q_s^2}{1+Q_s^2}\right) \qquad C_{se} = C_p\left(\frac{Q_p^2+1}{Q_p^2}\right)$$



$$X_p \equiv \omega L_p \qquad\qquad X_s \equiv \omega L_s$$

$$Q_p \equiv \frac{R_p}{X_p} \qquad\qquad Q_s \equiv \frac{X_s}{R_s}$$

$$(\text{series} \rightarrow \text{parallel}) \qquad\qquad (\text{parallel} \rightarrow \text{series})$$

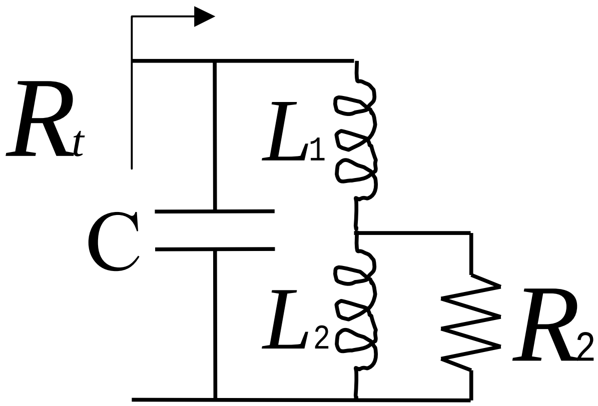
$$R_{pe} = R_s\left(1 + Q_s^2\right) \qquad\qquad R_{se} = \frac{R_p}{1 + Q_p^2}$$

$$L_{pe} = L_s\left(\frac{Q_s^2 + 1}{Q_s^2}\right) \qquad\qquad L_{se} = L_p\left(\frac{Q_p^2}{1 + Q_p^2}\right)$$

These conversions (and simplified forms when Q≥10) are used <u>extensively</u> when dealing with realistic circuit configurations… (see the next examples for tapped inductance).

Now, let's get down to business about Lab #1

Design Formulation* (Tapped Inductance)

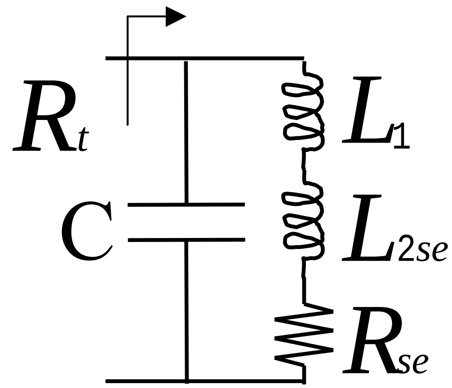


$$(Q_p \geq 10)$$

$$Q_p = \frac{Q_t}{N}$$

$$L_2 = \frac{L}{N}$$

$$L_1 = (N-1)L_2$$



$$(Q_p \leq 10)$$

$$Q_p = \left(\frac{Q_t^2+1}{N^2} - 1\right)^{1/2}$$

$$L_2 = \frac{R_2}{\omega_o Q_p}; L_1 = L - L_{2se}$$

$$L_{2se} = \frac{L_2 Q_p^2}{(Q_p^2+1)}$$

(assume)

$$Q_t \approx \frac{f_o}{B} \geq 10$$

(then)

$$C \approx \frac{1}{2\pi B R_t}$$

$$L \approx \frac{1}{\omega_o^2 C}$$

$$N = \left(\frac{R_t}{R_2}\right)^{\frac{1}{2}}$$

Example: f_o=15MHz; B=0.1MHz; R_t=10kΩ; R_2=50Ω

$$Q_t = \frac{15MHz}{0.1MHz} = 150 \quad N = \left(\frac{10K\Omega}{.050K\Omega}\right)^{1/2} = 14.1$$

$$Q_p = \frac{150}{14.1} = 10.6 \quad (ala \quad LHS \quad eqn.)$$

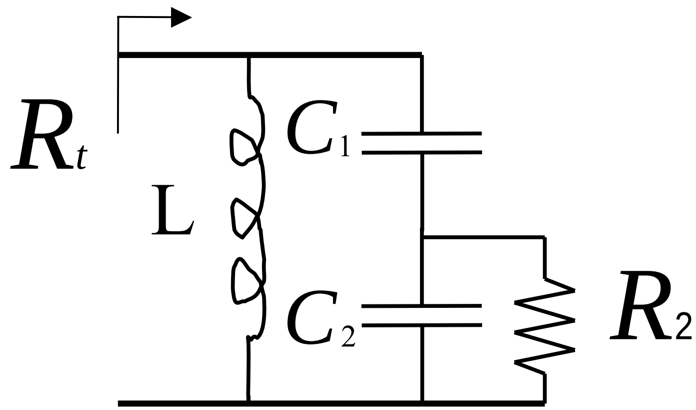
$$C = \frac{1}{(2\pi \cdot 0.1MHz \cdot 10K\Omega)} = 159\,pF$$

$$L = \frac{1}{\left((2\pi 15MHz)^2 159\,pF\right)} = 0.71\mu H \left\langle \begin{array}{l} L_2 = \dfrac{L}{14.1} = 0.05\mu H \\ L_1 = 13.1 L_2 = 0.66\mu H \end{array} \right.$$

*These equations are derived using both the resonant circuit equations from previous page and parallel-series conversions as per Tables found in Krauss et al (Sol. St. Radio Eng. '80 J. Wiley p. 76-81)

By analogy there is the Tapped - Capacitance version. This may also be used in creating (or analyzing) a Colpitts oscillator (see next page)

Tapped Capacitance (Design Formulations* cont'd)



$$Q_t \approx \frac{f_o}{B} \geq 10$$

$$C \approx \frac{1}{2\pi B R_t}$$

$$L \approx \frac{1}{\omega_o^2 C}$$

$$N = \left(\frac{R_t}{R_2}\right)^{\frac{1}{2}}$$

$(Q_p \geq 10)$

$$Q_p = \frac{Q_t}{N}$$

$$C_2 = NC$$

$$C_1 = \frac{C_2}{N-1}$$

$(Q_p \leq 10)$

$$Q_p = \left(\frac{Q_t^2 + 1}{N^2} - 1\right)^{1/2}$$

$$C_2 = \frac{Q_p}{\omega_o R_2}; C_1 = \frac{C_{se} C}{C_{se} - C}$$

$$C_{se} = \frac{C_2 \left(Q_p^2 + 1\right)}{Q_p^2}$$

Overall Summary:

- Basic Definitions and first-order series/parallel RLC circuits
- Parasitic R (as part of L) and slightly more complex formulae
- Conversions -- key to complex problems!
- Examples:
    - Tapped L ala Crystal Radio
    - Tapped C future Colpitts Osc.