

# Introduction & Overview

Welcome to EE 133!

*Analog Communications Design Laboratory*

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- Course Information (including Handouts etc.):  
<http://www.stanford.edu/class/ee133/>
- Staff:
  - TAs--Justin Hwang, Jianbo Wang and Tom Lee (not to be confused with Prof. Tom Lee)
  - Advisors--Greig Scott (MRI group), Dave Leeson (and other "friends of SPAM")
  - Support--Keith Gaul, Miho Nishi (332 CISX)

This page gives only the most basic information about EE133...

For the more complete and up to date information, please go to the web site (although it probably won't be completely updated until sometime next week)

The purpose of the first lecture is to give a quick, broad-brush, overview of where we will be headed over the quarter.

Basically, the target is to get you up to speed--both from a first-order theory perspective and more importantly HANDS-ON experience--with radio frequency (RF) analog communications circuits.

Those good old days of RADIO (are still here:)



## What's fishing got to do with EE133?

- (nothing really but...) Both are experimental and experience helps (and fly poles make good antennae in the MHz range)
- Lab class--lectures are driven by "need to know"
- Course Description (HO#1) tells a bit of the story about what you'll learn (but actually there's much more...:)
- So, let's get started:
  - o System-Level View
  - o Information and Spectrum
  - o Filtering
  - o Amplification



Bob's hike across back country of Yosemite--August, 2001

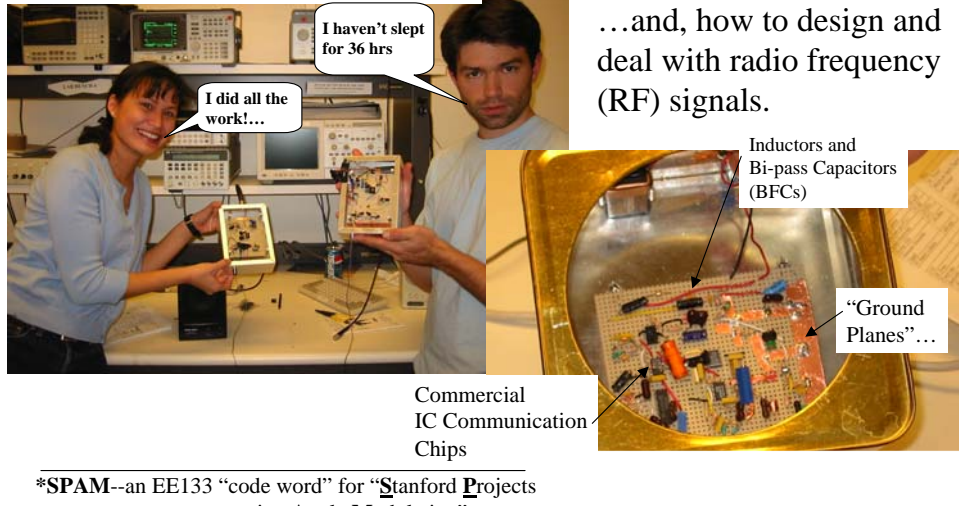
Warning--I have a rather weird sense of the world and am often prone to tell rather random stories. Sorry, there are just too many fun and funny stories to tell.

Anyway, today's lecture will first "preview" the lab project (give you a sense that other students have really survived the experience) and walk through a very quick outline of system-level issues.

Namely, we'll talk about Spectrum, how to get some (and the "dark side" of the FCC not wanting you to get too much), and very briefly "who lives where" in the Spectrum...at least a few applications that hopefully you can relate to.

## Where are we headed?

### Integrated “Spamming\*” Systems



Here are TWO SURVIVORS :)

They don't look that unhappy...

These are Transmit and Receive modules for our SPAM radio Walkie-Talkie systems.

Why SPAM? (Dutton random humor)--Stanford Projects in Angle Modulation. Angle Modulation (as we will discuss in another week or so) is the general terminology that covers both Frequency Modulation (FM) and Phase Modulation (PM).

Look inside the box...you'll see a board stuffed with cool RF components:

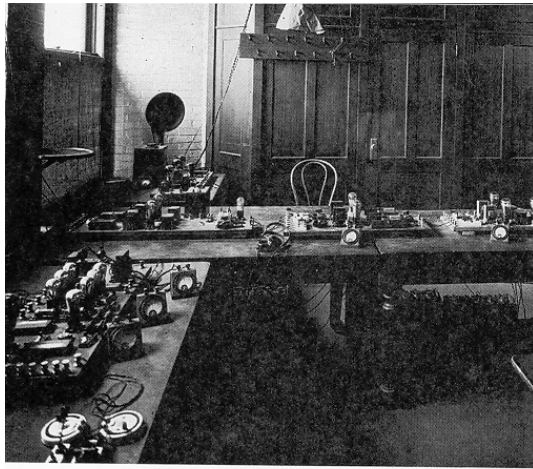
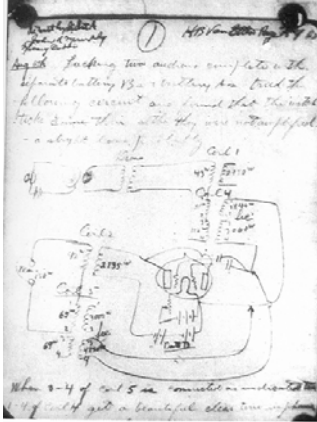
Inductors--you will come to know and love them!

Ground Planes--you'll wish you could have them magically inserted to help you (but alas, you get to do paper dolls with copper)

And ICs!--these are definitely VERY COOL and usually make life much easier (unless they blow out and you have to re-solder another one :)

## A Word about Lab & Notebooks

Lab Notebook from DeForest  
(key in Major Patent Battle)



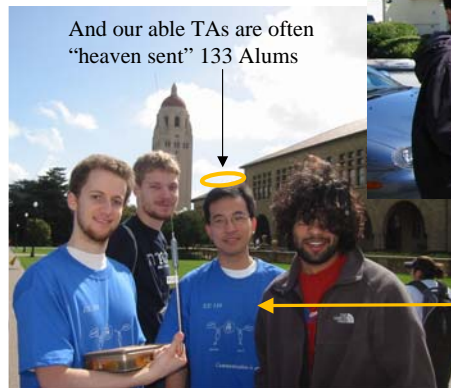
Armstrong's laboratory at Columbia.

You need to get and keep a hard-bound lab notebook. This is stuff that is absolutely KEY for defining and protecting IP. When you go for a job interview after graduation and you show them your EE133 Notebook (and IF you've done a careful, diligent job), you might find it to be a major asset (=“job experience”)

The DeForest story is amazing. He and his arch rival John Armstrong (inventor of FM and Hetero-dyning) had a pitched battle over IP. Unfortunately, this “B-” lab book was used as “evidence” even though DeForest couldn't actually explain his “invention”

## SPAMMING in the Quad (transmit antenna atop Packard Bldg...go as far as you can)

These happy Spammers made it past California Avenue!



And our able TAs are often "heaven sent" 133 Alums

...and, T-Shirts to memorialize your joyful experience are often created

And, then there's DEMO DAY...date to be announced soon!

This is the REALLY FUN part of the course and end-game for EE133. Basically, we hook-up your transmitters to a very nice antenna on top of Packard Building and SPAM-the-World.

Namely, we transmit some random stuff (music etc.) and see how far you can go with your receivers and still get signal that we agree is what WE are sending (vs. sometimes received signals from other sources)

In past years we have had receivers that, running off 9V batteries and portable antenna (or, as shown above with the aid of a local sign post :), have worked at a range of more than one MILE and past California Ave.

## System-Level View

- Wireless transmission of information, including both the coding and decoding at Radio Frequencies (RF)
- Applications: a) well-known AM & FM radio (“broad casting”, 500-1800KHz & 80-108MHz respectively), b) “walkie-talkie” radio (two-way, 10’s MHz), c) cordless phones (700MHz), d) cell phones (1-2GHz), e) Wireless “LAN” (10GHz)...
- We’ll talk in detail about a) & b); we’ll also consider some of the issues at higher frequencies, including different coding/transmission technologies

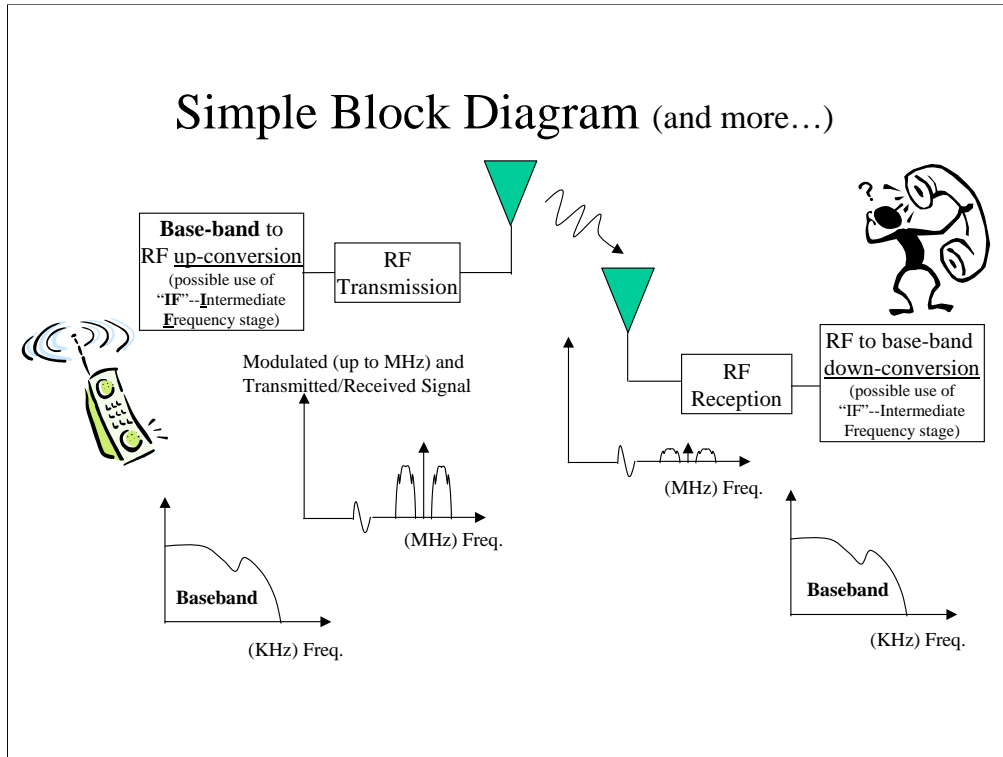
When talking about coding and decoding, we can consider both analog and digital formats. For 133 we’ll stick to analog. The digital is a cool “add on” but doesn’t change the basics of working in the frequency domain.

There is one interesting aspect of digital however. The speed of processors and (DSP) is moving up in frequencies to the point where using several frequencies (I.e. an “intermediate frequency” or IF section) is not necessary...more later

The applications listed are only an obvious set of examples and by no means exhaustive. A KEY point here is that the frequency spectrum from KHz to GHz is filled with lots of interesting uses.

(I didn’t even put TV in there :)

The issues at higher frequencies and using different coding/transmission techniques will be discussed only at the end of the quarter. They are listed here to “round out” your view of how the techniques we’ll be doing in lab can be “super charged” and scaled to commercial levels.



This block diagram is only trying to point out a few basic points:

- We talk about “Baseband” as the frequency spectra where your information (I.e. voice, music, “data”..) resides
- Modulation (as we’ll see mathematically very soon) “moves” that baseband information up in frequency to the “radio frequencies” where it can propagate as electro-magnetic waves
- There may be more than one stage of “up conversion” modulation--(possible use of IF)--also referred to heterodyning
- The modulated signal will typically (unless we do special stuff) generate “Sidebands” (mirror images of each other) about the “carrier” frequency (the “up arrow” between them)
- On the receiving side the signal has been attenuated; basically it will fall off in energy away from the transmitting antenna
- The receiver does the “inverse” of up conversion; the signal is demodulated (down converted). There are also details of filtering needed so that...
- Finally, we recover the original Baseband signal

## Information and Spectrum

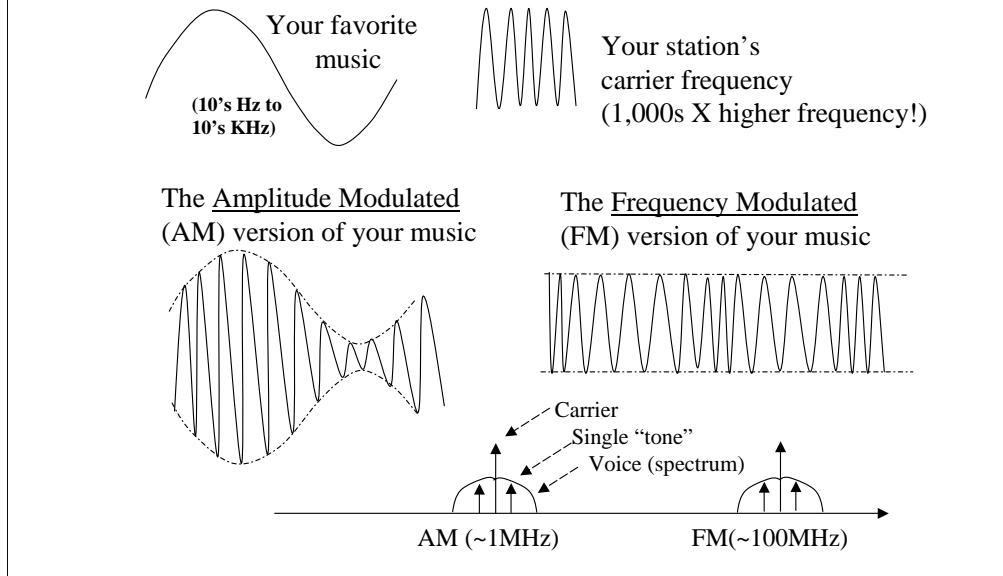
- Range of frequencies where electro-magnetic waves can propagate; limitations imposed by:
  - Nature and Environment (diffusion/scattering--related to wavelength:  $f \cdot \lambda = c(\text{velocity})$  )
  - Regulatory Agencies (I.e. FCC)
- Information needs to be coded onto carrier frequencies (and later decoded off them)--the information doesn't propagate very far without E&M waves
- Bandwidth (about carrier frequency) depends on coding method--can be as "narrow" as audio or could be much broader as in the cases of : "wide band" FM, data links or "spread spectrum" transmission techniques (discussed much later)

There are a few more details we will discuss in class about numerical examples to go along with the basic equation. The speed of light in free space is  $3 \times 10^{10}$  cm/sec. Using frequencies ranging from AM (1.5MHz) to Cell Phone (1.5GHz) we find that the wavelength ( $\lambda$ ) ranges from 200meters (two football fields length) to 20 centimeters (about 8 inches).

The coding/decoding part of the discussion was in the last slide. The basic point is that electro-magnetic waves need to be launched and received. There's a broad range of frequencies we can use; the size of the antenna and "bandwidth" of our circuit elements determine which range we use. For our SPAMming project (Stanford Projects using Angle Modulation), we choose the "unlicensed" band used by the CB (Citizen Band) folks. We have convenient antennae (I.e. lots of them) and the 25MHz frequency range is not too demanding on the amplifiers, transistors, multipliers etc.

In class we will talk briefly about "narrow band" versus "wide band" modulation/demodulation. Generally speaking, the wider the bandwidth, the less influence of specific interfering signals ("noise"). But, for noise in general...it is proportional to bandwidth (BW)

## What does coded information look like? (in frequency and time domains...)



Let's take a couple of specific examples--AM and "narrow band" FM:

The above simple figure shows a "signal" such as your voice (humming a single note) and a MUCH higher frequency corresponding to either AM ~ (1-2MHz) or FM (~100MHz) "carrier" frequency.

As their simple names imply, we imagine that AM looks like a modulated envelop (I will probably tell the rather pathetic K-10 analogy to Indian "chanting" versus Tarzan in the jungle). The FM modulated signal changes frequency, proportionally to modulating signal...(more to come about details)

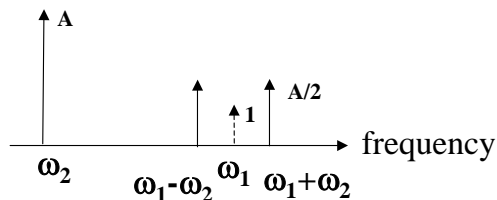
The frequency domain version of both AM and FM (narrow band) look virtually identical (rather amazing) except for the fact that they are separated by 100X in frequency--they BOTH have side bands (Or a shaped spectra) on either side of the carrier.

## How do we code (and decode) information?

- **Multiplication** (a non-linear operation) of sinusoidal signals creates signals at different frequencies...remember Law of Sine and Cosine?
- Let's take a simple example--Amplitude Modulation:

$$\begin{aligned}V(t) &= [A \cdot \text{Cos}(\omega_2 t)] \otimes \text{Cos}(\omega_1 t) \\ &= \frac{A}{2} [\text{Cos}(\{\omega_1 + \omega_2\}t) + \text{Cos}(\{\omega_1 - \omega_2\}t)]\end{aligned}$$

- Results in frequency domain look as follows:



OK, let's take the AM example and do a bit of math to make sure we all understand: a) how to get the sidebands and b) remember our high school trig. identities.

AM mathematically looks exactly as shown...the AMPLITUDE of the carrier (carrier is at  $\omega_1$  in this example) is modulated at the frequency  $\omega_2$

Now, back to those glorious days in high school when you memorized these IDENTITIES...

Very neatly, two NEW frequency components appear at the sum and difference of the carrier and modulating frequencies. In this case, there is no carrier left. In reality, we have some portion of the carrier that does get transmitted.

There are two reasons for having  $\omega_1$  present:

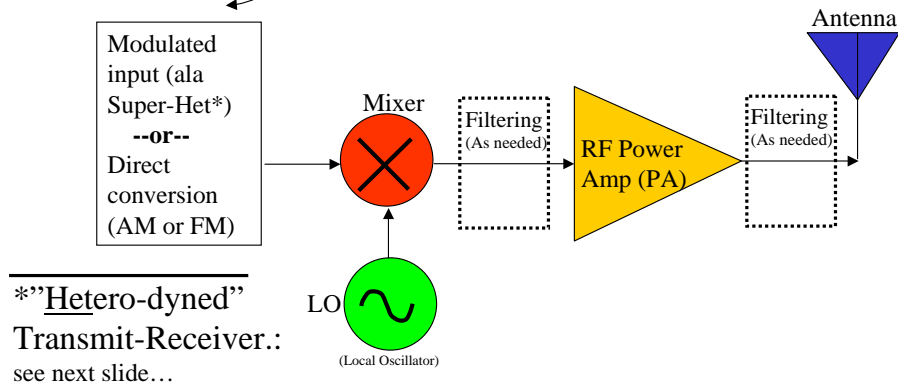
- 1) The system is not perfect (as you will see in lab as well), hence some of the signal sneaks through without being perfectly multiplied and
- 2) We actually will NEED to have the carrier frequency available so we can then demodulate to get the information back



## Transmitter Side Issues...

There are LOTS of choices and combinations here:

- Baseband-up-to-10's MHz can be done with DSP!
- AM is really easy (it's below 2MHz anyway)
- FM is also easy...BUT, frequency stability is not (so easy)
- Impedance matching and filtering at RF poses challenges as well...



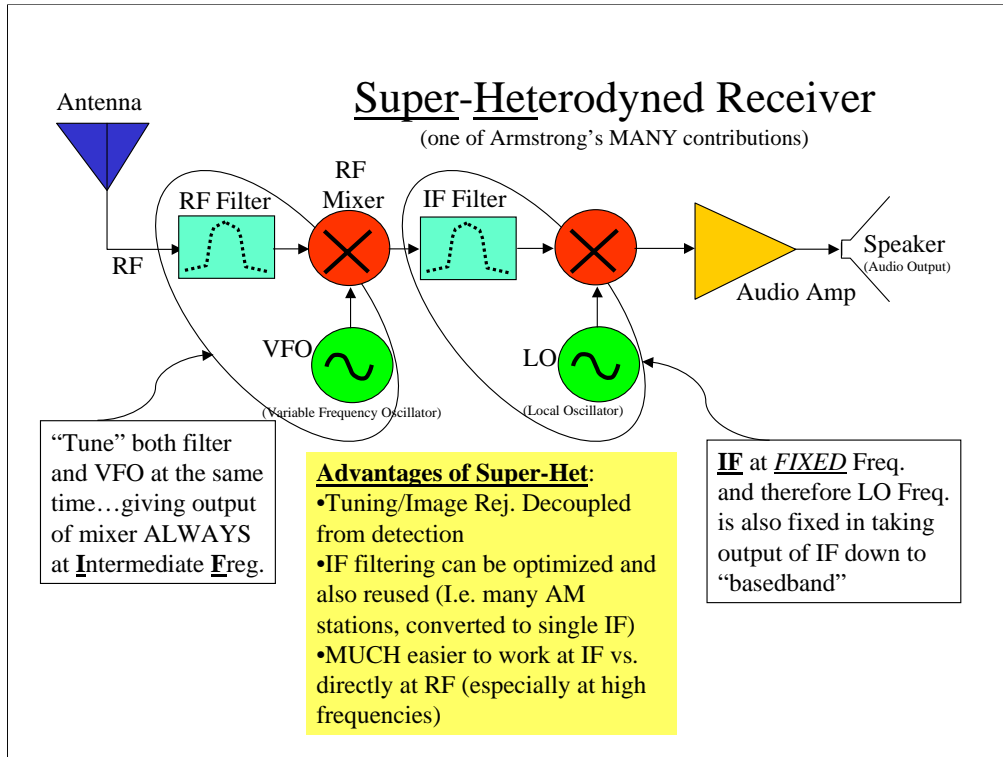
The last slide (about receiver) introduced a couple of new “twists” on how multiplication gives rise to need for filtering (I.e. to avoid unwanted product terms that become “aliased” into the same place where “our spectrum” is) AND

That we may use multiplication several times or with different local oscillator (LO) frequencies to move the signals around in the frequency domain.

This slide is pretty much a “generic” transmitter (either AM or FM) with the option left open about moving the modulated signal up in frequency twice--referred to as “super hetero-dyning” (a term that I believe Armstrong coined. Armstrong is OUR HERO in terms of inventing most of the COOL stuff like FM etc.)

The rest of this slide simply says:

- 1) Take the AM, FM or whatever...
- 2) Use a “mixer”=Multiplier to move it up in frequency
- 3) Filter it, amplify (for POWER) and
- 4) Radiate it into the ether--riding on E&M waves



One more pass on the Receiver side, this time giving a quick preview of how your commercial radio receivers work...

As you will certainly see (by doing in Lab #5), down conversion to a nicely controlled and well-defined intermediate frequency (IF) is very useful.

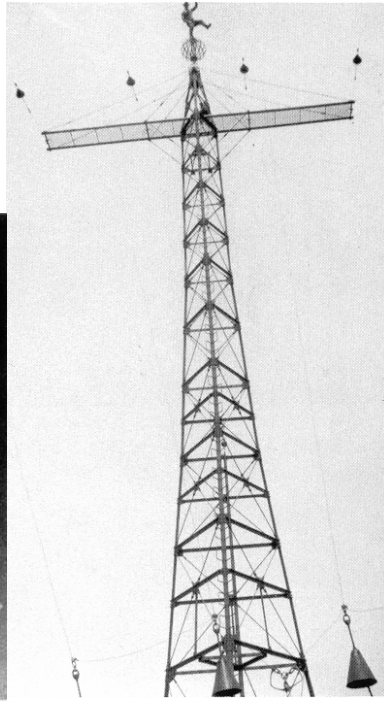
In commercial radio this is at 455KHz (and for your projects it will be a bit lower). It is at a FIXED frequency for ALL stations.

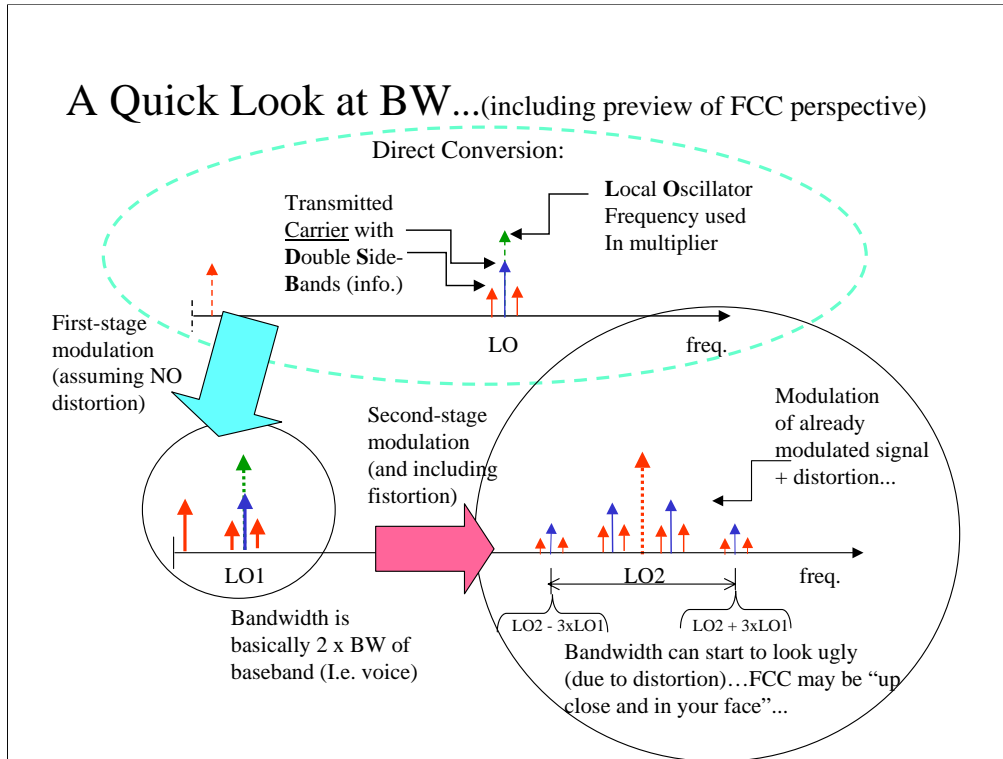
That means that the stage before the IF needs to have it's local oscillator (LO) “tuned” (using a Variable Frequency Oscillator=VFO) such that the resulting spectrum (I.e. the difference term from the law of the cosines) ends up exactly at the IF.

Then, when the spectrum (your station's signal) modulated about the IF is multiplied times the IF/LO, the signal is NOW at baseband.

The above slides and discussion are definitely a “fast forward” on things we will spend the rest of the quarter working on. This discussion is purely motivational in terms of block diagrams of transmitters and receivers....

Armstrong,  
Antennae &  
Wireless





The top figure is a very simple story (in theory) that is the wished for future--Direct Conversion. Basically, simply to move the information (double side bands) directly up to the carrier frequency and, by means of the LO (exactly at that carrier frequency) to again down convert the spectrum to baseband.

The lower figure shows that exact same figure PLUS the second stage modulation (hetero-dyning) to a second (and obviously higher) frequency.

The new piece of information here is the fact that various blocks, for example amplifiers, may not be linear and the process of distortion creates additional signals. Basically, the multiplier is happy to send them up in frequency and the overall bandwidth (BW) of the system can get large and ugly.

The Federal Communications Commission (FCC or "big brother") doesn't really like to see this ugliness. If we are in commercial radio band this may be putting your signals into some else's licensed band (a serious NO-NO...you get "shut down" for not obeying the rules)

Bottom-line: We will spend time as we go along learning more about spectra, bandwidth and linearity issues