In this class we'll discuss various aspects of communication and radar systems. In particular we'll examine receiver and transmitter circuitry at a block level.

Expected topics to be included:

- Friis transmission equation and radar equation

- Description and characterization of classical r.f. and i.f. components including antennas, low noise amplifiers, mixers, oscillators and filters.

- Considerations of modern digital components (hardware and software aspects).
- Analog and digital modulation and demodulation techniques.
- System-level receiver design considerations.
- Power amplifiers for cellular and paging systems.
- Transmitter design considerations.
- System evaluation including effects of white noise, IF noise, phase noise, compression, intermodulation and feedthrough.
- Additional considerations in modern digital communications systems (equalization, channel coding, voice coding, etc.).
Consideration of the common multiple access schemes (FDMA, TDMA and CDMA) and their advantages and disadvantages.

Before getting into specifics of a design let's consider some basic types of radio receivers (transmitters will be covered later).

![Superregenerative Receiver Diagram]
This type of receiver was popular for low cost wireless products (such as garage door openers) until very recently.

Homodyne receivers

This type of receiver is desirable due to the simplicity. However, it tends to be poorly selective. Also, it is necessary to lock the local oscillator to the received frequency for best performance.
Superheterodyne receivers

The example shown is a single conversion superheterodyne receiver. It has nonzero IF. In general, this type of receiver may have multiple conversion stages (that is, multiple IFs). The superheterodyne receiver is by far the most popular type.
For the circuitry we've just shown we're interested in:

1) Antenna
   - What gain do we need
     (or can we achieve) ?
   - What pattern do we need ?
   - What are possible implementations
     that meet our physical
     and fiscal (p. + f.) constraints ?
   - Does the antenna satisfy
     environmental requirements ?
   - Is the antenna adequately
     efficient ?
   - What polarization/impedance
     bandwidth effects need to be
     considered ?
2) Preselect filtering

- What types of filters are available and which ones meet our P+T constraints?
- What are the specs on input/output impedance and insertion loss?
- How much cross-channel interference is there (need to include layout and tolerance effects)?
- Possible group delay and nonconstant amplitude effects?
- Does the filter satisfy environmental requirements?

For the following components physical, fiscal and environmental constraint considerations are implied.
3) Noise Noise Amplifiers

- What are the bandwidth and noise figure specs?
- What is the 1 dB compression point? What are the intercept points?
- What is the power efficiency?
- What are the matching requirements?

4) Mixer

- What are the isolation specs for RF to IF and LO to IF?
- What are the levels of the various mixing products?
- What LO drive level is required?
- What are the effects of mismatches on the various ports?

5) Local oscillator
   - What level of frequency stability is needed?
   - Is frequency tuning needed? If so, over what frequency range?
   - What are efficiencies, spurious and phase noise levels?
   - What is the output power?
   - Load pull effects?

6) IF filtering
   - Specifications are similar to those for preselect filtering.
7) IF amp
   - Specifications are similar to those for the low noise amplifier. Much less emphasis on low noise, though, and perhaps more on compression point.

8) Demodulation
   - Why type of demodulation is needed?
   
   - If it is possible to select a particular type of demodulation, which type leads to the highest spectral efficiency and best SNR or lowest BER?
   
   - What possible implementations are there?
9) Processing

- Various types of processing are possible depending on the particular techniques being used. Examples include: voice decoding, channel decoding, timeslot decoding, deinterleaving, etc. Examples for radar might include position and velocity estimates, target ID, etc.

10) Output

- Obvious types of output include speaker, LCD and hardcopy. In some cases the output may be input to another system, e.g., input to the PSTN (public switched telephone network).
For the system as a whole we are interested in various performance specs. These include:

- dynamic range
- selectivity
- noise figure or noise temperature
- cross- and co-channel interference effects.

- bit error rate (BER) or probability of detection and probability of false alarm.

- power consumption

One of the most important goals of this class is to understand (and be able to characterize) the effects of the various components on these parameters. We'll make similar considerations for transmitters.
Course expectations:  

<table>
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<tr>
<th>Assignment</th>
<th>Weight</th>
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<tbody>
<tr>
<td>Miniprojects (2-3)</td>
<td>35%</td>
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<tr>
<td>Major Project (1)</td>
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<tr>
<td>Research Paper (1)</td>
<td>10%</td>
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<tr>
<td>Exam (1)</td>
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References:


Before we get into details of receiver and transmitter analysis let's do some review.

**Friis transmission equation**

For a quick look at what our expected signal level is we can use the standard Friis transmission equation.

Recall that \( G = \frac{4\pi U_{\text{max}}}{P_{\text{in}}} \)

where \( G \) is the antenna gain, \( U_{\text{max}} \) is the maximum radiation intensity, and \( P_{\text{in}} \) is the input power to the antenna. We have another expression that relates antenna gain to the effective receiving area.
This expression is
\[ G = \frac{4\pi}{\lambda^2} A_e \quad \text{where} \]

\( A_e \) is the maximum effective area (aperture) and \( \lambda \) is the operating wavelength.

In the antenna's far field we have
\[ S = \frac{U_{\text{max}}}{R^2} \quad \text{where } S \text{ is} \]

the power density in \( \frac{W}{m^2} \),
and \( R \) is the distance from
the transmitting antenna.
So, \( S = \frac{P_{\text{in}}G}{4\pi R^2} \). To avoid
confusion between transmitting
and receiving antenna we use $G_t$ instead of $G$. Also, we use $P_t$ instead of $P_{in}$ to emphasize the transmitted power. Hence,

$$S = \frac{P_t G_t}{4\pi R^2}$$

The power delivered to the receiver load (assuming a matched condition at the receiver) is

$$P_r = S A_{e_r}$$

where $A_{e_r}$ is the maximum effective area (aperture) of the receive antenna.
Combining these results we have the Friis transmission equation, i.e.,

\[ P_r = \frac{P_t G_t A_{er}}{4\pi R^2} \]

Notice that this equation assumes propagation through freespace. In reality most propagation problems involve ground effects, diffraction, scattering and absorption, and multiple path effects. For now we'll account for these effects by including a loss parameter \( L \) in the equation, i.e.,

\[ P_r = \frac{P_t G_t A_{er}}{4\pi R^2 L} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2 L} \]
Example:

\[ P_t = 10 \text{w} \]

\[ G_t = 10 \text{dB} \]

\[ G_r = 0 \text{dB} \]

\[ R = 10 \text{km} \]

\[ \lambda = 3.53 \text{m} \quad (f = 850 \text{ MHz}) \]

So, \[ P_r = \frac{(10)(10)(1)(3.53)^2}{16\pi^2 (10^4)^2 (1)} = 0.79 \text{ mw} \]

This assumes free space since free space is assumed in this case.

L may actually be 100, 1000 or more in many cases.

Consider a radar example:

In this case the parameter \( \sigma \) (radar cross section) takes into account effective area,
gain and absorption loss
effects of the target. In
addition the problem involves
two-way propagation so that
the radar equation becomes

$$P_r = \frac{P_t G_t}{4\pi R_t^2} \frac{\sigma}{4\pi R_r^2}$$

In most cases a backscattering
measurement is done, and
the receive and transmit
antennas are often the
same so that

$$P_r = \frac{P_t G_t^2 \lambda^2 \sigma}{(4\pi R_t^2)^2 (4\pi)}$$

Notice that the units for
$\sigma$ is $m^2$. 
Radar example:

\[ P_t = 100 \text{ W} \]
\[ G_t = 30 \text{ dB} \]
\[ G_r = 30 \text{ dB} \]
\[ R = 10 \text{ km} \]
\[ \lambda = 0.03 \text{ m } (f = 10 \text{ GHz}) \]
\[ \sigma = 3 \text{ m}^2 \]
\[ P_r = \frac{(100)(1000)^2(0.03)^2(3)}{(4\pi)^3(10^4)^4} = 13.6 \times 10^{-15} \text{ W} \]

Notice the tremendous difference in received powers.

It is to work with decibels for these types of problems.

For the communication example:

\[ P_r (\text{dBm}) = P_t (\text{dBm}) + G_{t\text{dB}} + G_{r\text{dB}} + 20 \log(\lambda) - 10 \log(16\pi^2) - 20 \log R \]
Or,

\[ P_r(\text{dBm}) = 40 + 10 + 0 - 9.04 \]
\[ - 21.98 - 80 = -61 \text{dBm or .79 nW} \]

For the radar example,

\[ P_r(\text{dBm}) = P_t(\text{dBm}) + 2G_t(\text{dB}) \]
\[ + 20 \log(\lambda) + 10 \log(S) \]
\[ - 10 \log(64\pi^3) - 40 \log R \]

\[ = 50 + 60 - 30.5 + 4.77 \]
\[ - 32.98 - 160 = -108.7 \text{dBm} \]

or \[ 13.5 \times 10^{-15} \text{W} \]