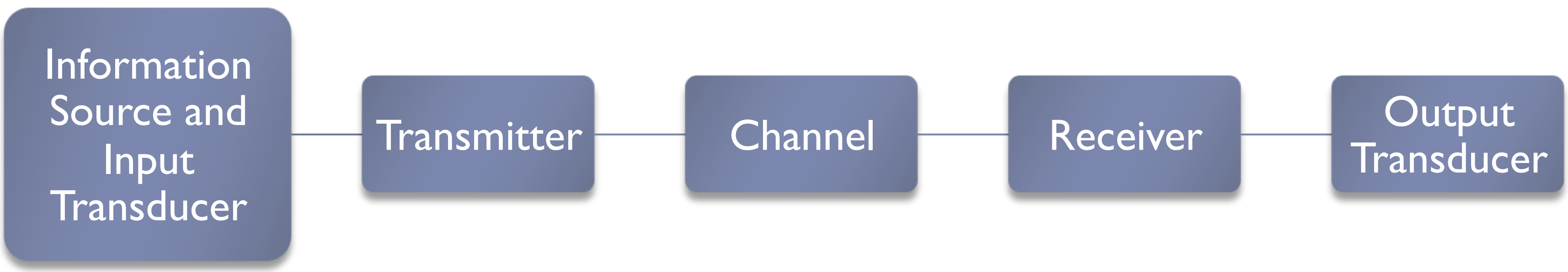
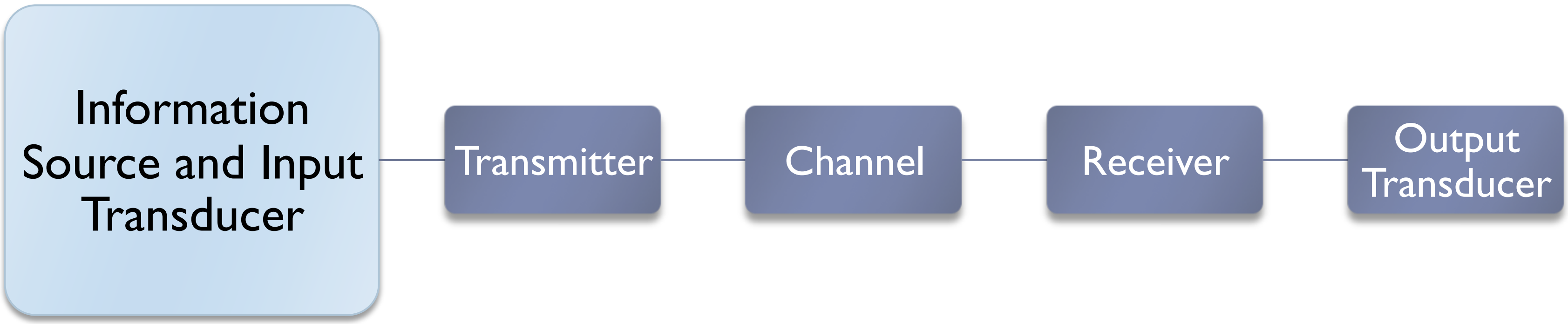
Introduction to Communication Systems

James Flynn
Sharlene Katz

Communications System Diagram



Communications System Diagram

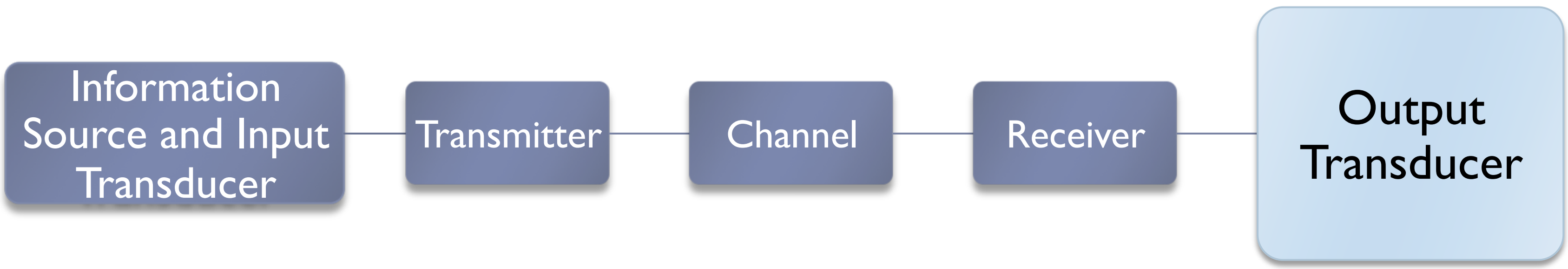


Information Source: Audio, image, text, data

Input Transducer: Converts source to electric signal

- Microphone
- Camera
- Keyboard

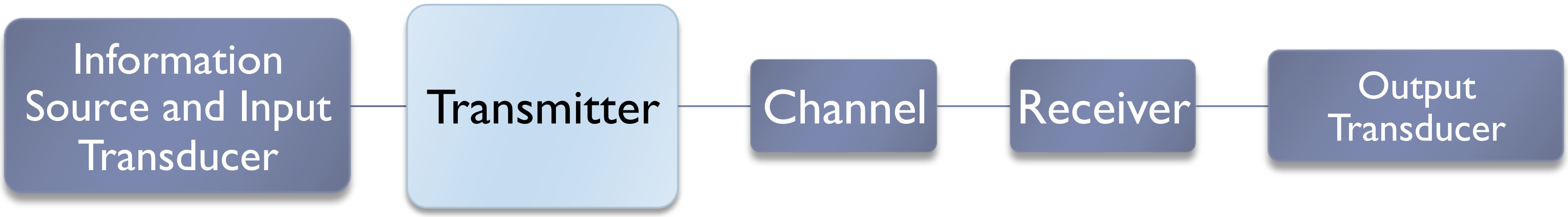
Communications System Diagram



Output Transducer: Converts electric signal to useable form

- Speaker
- Monitor

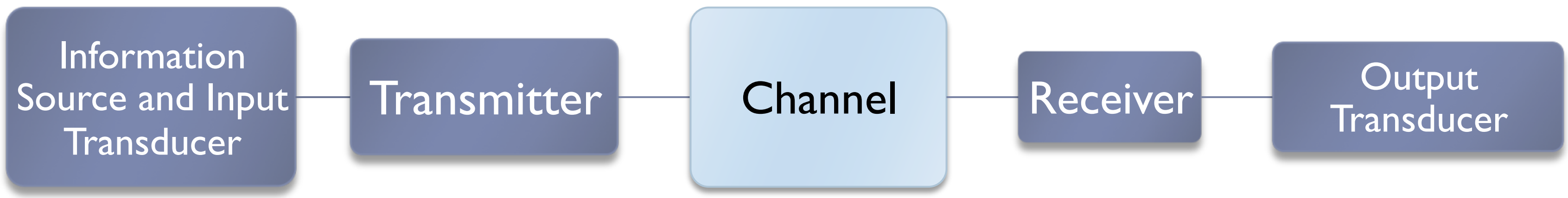
Communications System Diagram



Transmitter:

- Converts electrical signal into form suitable for channel
- Modulator
- Amplifier

Communications System Diagram



Channel: Medium used to transfer signal from transmitter to receiver. Point to point or Broadcast

- Wire lines
- Fiber optic cable
- Atmosphere
- Often adds noise / weakens & distorts signal

Communications Channels

- Wireline
  - Twisted Pair
  - Cable
  - Waveguide
  - Fiber Optics

Increasing bandwidth

- Wireless (radio): Transmission of electromagnetic waves from antenna to antenna
  - KHz to ultraviolet
  - Propagation characteristics vary with frequency

Propagation Characteristics of Radio Channels

- Ground Wave
  - Low MHz
  - Waves guided between earth and ionosphere
  - Distance of communication varies based on wavelength
  - AM Radio (1 MHz) – propagates < 100 miles in day but longer at night
  - Predictable propagation
- Sky Wave
  - Low MHz → 30 MHz
  - Signals reflect from various layers of ionosphere
  - Changes based on time, frequency, sun spots
  - Signals travel around the world
  - Less predicable propagation

Propagation Characteristics of Radio Channels (cont'd)

- Line of Sight
  - Above 30 MHz
  - Need little or no obstruction – limited by horizon
  - Noise issues
  - In GHz range – rain issues
  - Used for Satellite and local communications
  - Very predictable / stable propagation
- Other Channels
  - Acoustic channels

Table of Frequencies

- ELF : 0 – 3 kHz. Submarine communications.
- VLF : 3 – 30 kHz. Submarine communications, Time Signals, Navigation
- LF : 30 – 300 kHz. Navigation, Time Signals.
- MF: 300 kHz – 3 mHz. Maritime Voice/Data, AM Broadcasting, Aeronautical Communications.
- HF: 3 – 30 mHz. "Shortwave" Broadcasting. Amateur, Point to Point data. Maritime Voice/Data. Aeronautical Communications.
- VHF : 30 – 300 mHz. Police, Fire, Public Service mobile. Amateur. Satellite. Analog TV. FM Broadcast.

Chart of Frequencies (cont'd)

- UHF : 300 – 3,000 mHz (3 gHz) Police, Fire, Public Service communications. Satellite. Analog and HD TV. Telemetry (flight test). Radar. Microwave links (telephone/data). WiFi.
- SHF : 3 – 30 gHz Radar. Satellite. Telemetry. Microwave links
- EHF : 30 – 300 gHz Radar. Satellite. Microwave links.

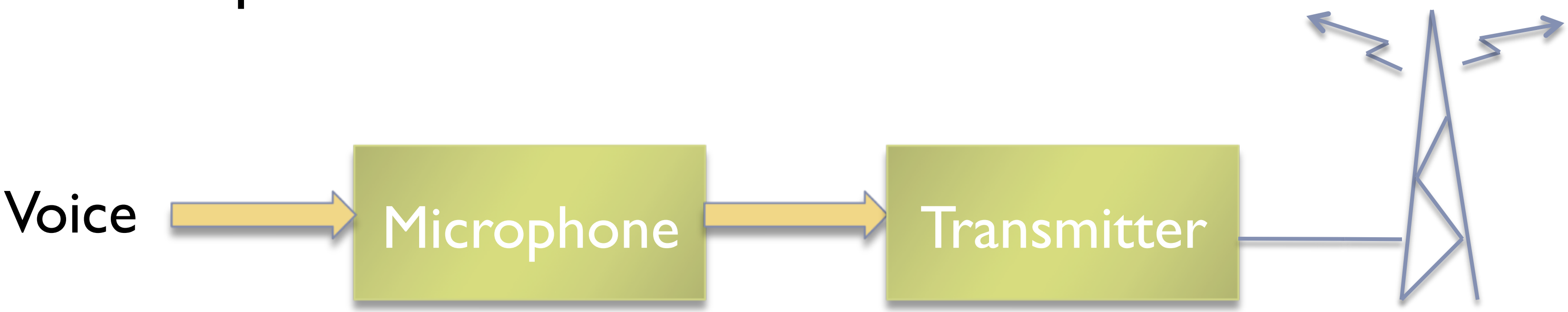
Communications System Diagram

Receiver

- Extracts an estimate of the original transducer output
- Demodulator
- Amplifier

Why do we need Modulation/Demodulation?

- Example: Radio transmission



Electric signal,
20 Hz – 20 KHz

Antenna:
Size requirement
> 1/10 wavelength

At 3 KHz: $\lambda = \frac{c}{f} = \frac{3\times10^8}{3\times10^3} = 10^5 = 100km$

$\Rightarrow .1\lambda = 10km$

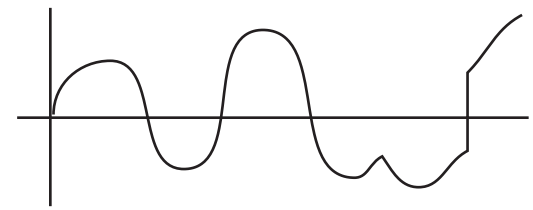
Antenna too large!
Use modulation to transfer information to a higher frequency

Why do we need Modulation/Demodulation? (cont'd)

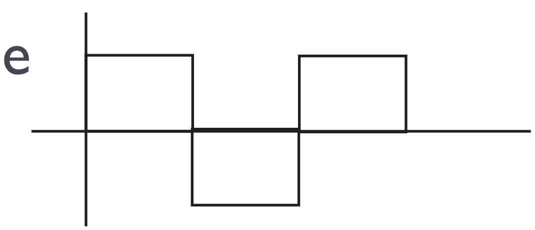
- Frequency Assignment
- Reduction of noise/interference
- Multiplexing
- Bandwidth limitations of equipment
- Frequency characteristics of antennas
- Atmospheric/cable properties

Types of Modulation

- Analog Modulation: A higher frequency signal is generated by varying some characteristic of a high frequency signal (carrier) on a continuous basis
  - AM, FM, DSB, SSB
  - An infinite number of baseband signals
  - ECE 460



- Digital Modulation: Signals are converted to binary data, encoded, and translated to higher frequency
  - FSK, PSK, QPSK, QAM
  - More complex, but reduces the effect of noise
  - Finite number of baseband signals
  - ECE 561



Performance of a Radio Link

- To determine how well a link performs, we need to know:

  -Signal to noise ratio at receiver

  -Modulation scheme

Performance of a Radio Link

In analog systems, performance is subjective.

In digital systems, performance is precisely specified as Probability of Error, P_e.

$$P_e = \frac{\text{number of errors in n bits}}{\text{n}}$$

In digital systems, P_e determined by modulation scheme and Signal to Noise Ratio, SNR.

Performance of a Radio Link

- SNR at receiver crucial in determining link performance.

$$SNR = \frac{\text{signal power at receiver}}{\text{noise power at receiver}}$$

- May be expressed in dB.

Performance of a Radio Link

- Signal Power at Receiver determined by LINK EQUATION
- Also known as the Friis Equation
- Used to compute power levels at receiver based on distance, transmitter power and antenna gain.
- Used only for free-space, line of sight links. Ground wave and ionospheric reflection are not covered.
- UHF freqencies (300-3000 mHz) are line of sight.

Performance of a Radio Link

The transmitter side:

- Assume an isotropic radiator. Radiates power equally in all directions.
- Does not exist in reality. A mathematical construct to compare other antennas to.
- Assume all of the transmitter power goes into space.

Performance of a Radio Link

Between transmitter and receiver:

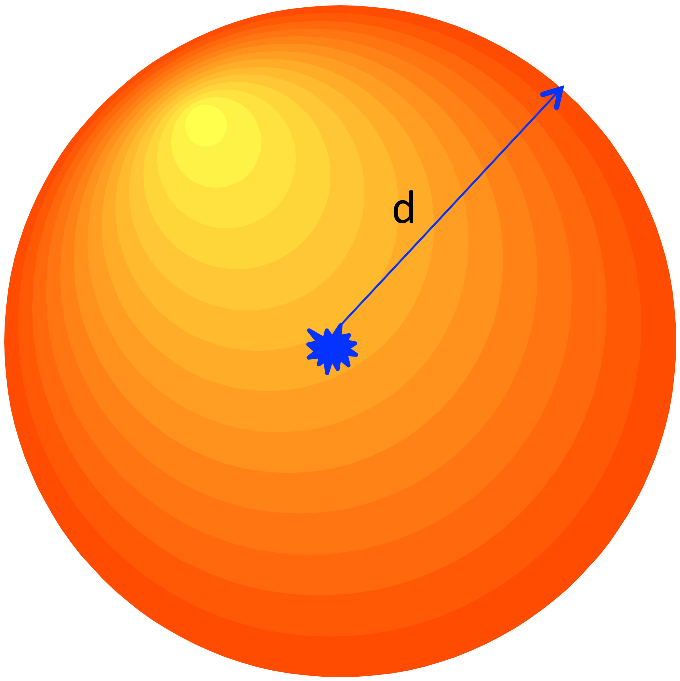
- Signal expands in all directions.
- At some distance, d, signal covers a sphere with surface area:

$$S = 4\pi d^2$$

- Power density, P_s:

$$P_S = \frac{P_t}{S} = \frac{P_t}{4\pi d^2}$$

Performance of a Radio Link



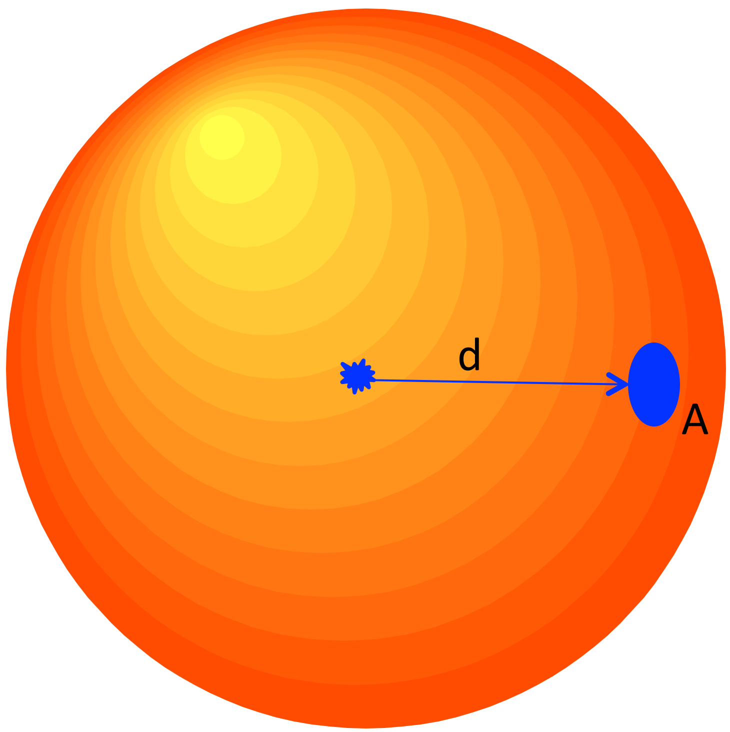
Performance of a Radio Link

At the receiver:

- Aperture : How much of the signal sphere is "captured" by the receiver antenna.
- For isotropic antenna, aperture is expressed as an area:

$$A = \frac{\lambda^2}{4\pi}$$

Performance of a Radio Link



Performance of a Radio Link

- Signal power at the receiver:

$$P_r = AP_S$$

$$= \frac{P_t \lambda^2}{(4\pi d)^2}$$

Basic Link equation with isotropic antennas.

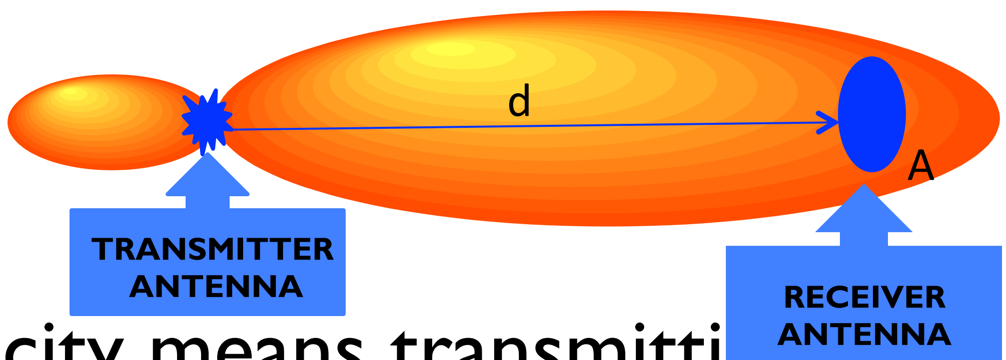
Performance of a Radio Link

Antenna Gain

- Antenna is a passive device – cannot add power and may have losses.
- Gain is power increased in one direction at the expense of it in another.

Performance of a Radio Link

- Antenna gain: same power over smaller area.
- I.e. Power density increased.



- Reciprocity means transmitting gain is also receive gain for same antenna.
- Common gains: 2 to 30 db over isotropic.

Performance of a Radio Link

- Link equation with antenna gains:

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

- Tradeoffs:
  - Higher frequency = lower receive power
  - But easier to build high gain antennas at higher frequency
  - Also lower noise at higher frequency

Performance of a Radio Link

Noise Sources:

- Terrestrial, mostly lightning. (HF)
- Extra-terrestrial, mostly the sun.(VHF through microwaves)
- Man-made. (possible at all frequencies, but usually low frequency)
- Thermal (all frequencies)
- Quantizing (only in digital signal processing)
- Circuit

Performance of a Radio Link

Thermal or Johnson noise.

Dependent on:

- Absolute Temperature, T (Kelvin)
- Bandwidth, B (Hz)

$$P_n = 4kTB$$

$$k = 1.38 \times 10^{-23} \text{ joules/°K}$$

Performance of a Radio Link

Circuit Noise

- From active devices: transistors and FETs
- Can be slightly above thermal noise power to many times thermal noise power.
- Careful design can minimize circuit noise.

Performance of a Radio Link

Quantizing noise

- Produced by A to D conversion.
- Proportional to minimum digital level.
- Also dependant on modulation scheme.

Example: signal is almost exactly between levels 1002 and 1003. Tiny change in voltage leads to full step. Effectively adding/subtracting about ½ bit level.

Performance of a Radio Link

How much SNR is enough?

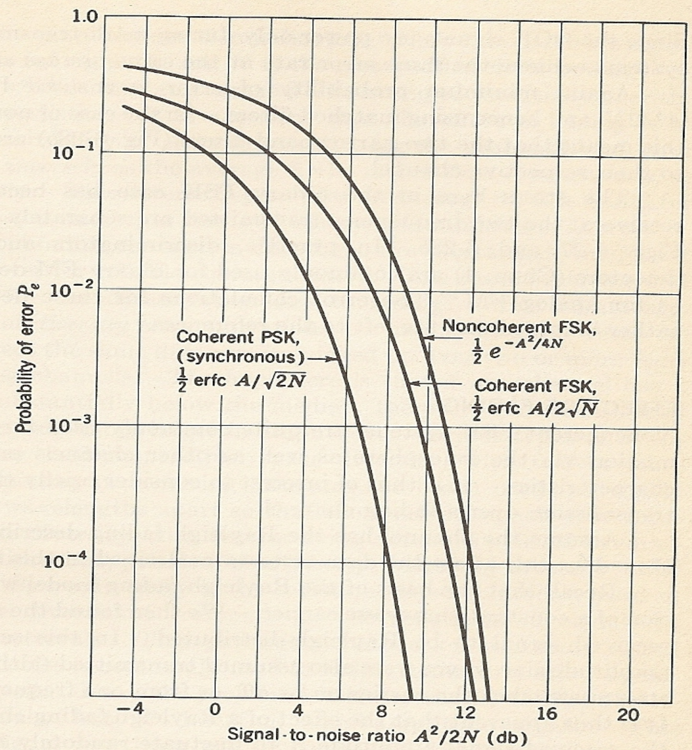


FIG. 6-33 Performance curves, binary transmission.

Performance of a Radio Link

Comparison of various simple digital systems:

$$P_{e,OOK} = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right)$$

$$P_{e,FSK} = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2}\right)$$

$$P_{e,PSK} = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right)$$

Performance of a Radio Link

Designing a System Example

- F = 400 mHz.
- P_e <= 10^{-6}
- range = 5 km max.
- Using PSK, data rate = 50 Kbaud.
- Required transmitter power = ?

Performance of a Radio Link

Noise at Receiver:

- Bandwidth = 100 kHz
- Temperature = 300 K
- Antenna gains of 1
- Assume average receiver with circuit noise = 2x thermal noise.

$$P_n = 8kTB$$

$$P_n = 3.3 \times 10^{-15} W$$

Performance of a Radio Link

Required SNR

$$10^{-6} = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right)$$

$$SNR = 90.4(19.6dB)$$

Performance of a Radio Link

Required Received Power

$$P_r = 90.4 \times 3.3 \times 10^{-15}$$
$$= 3.0 \times 10^{-13} W$$

Performance of a Radio Link

And finally back to the Link Equation:

$$3.0\times10^{-13} = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

$$P_t = 209mW$$

…not a whole lot, but more than the USRP can deliver.

Questions?