

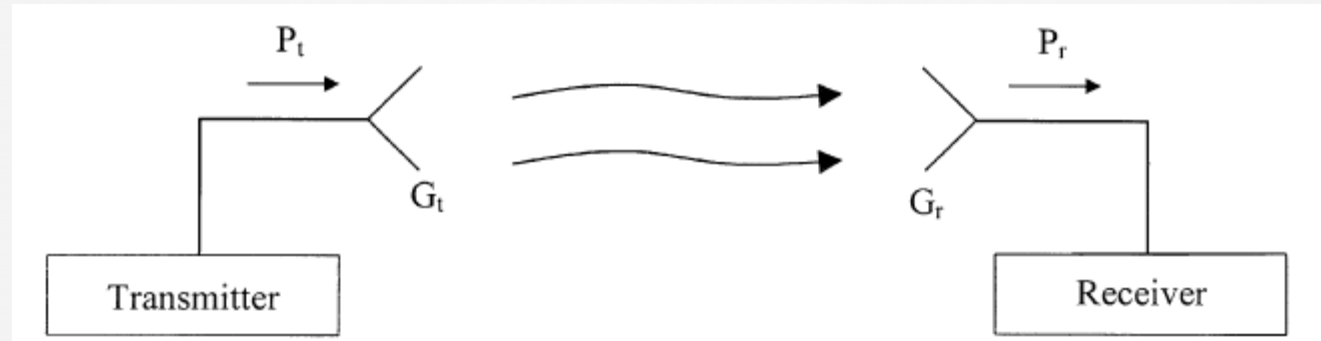


# Friss Equation and Noise

Communication Systems  
Lecture 4

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# Friis Transmission Equation



# Friis Transmission Equation

The power density at the receiving antenna for an isotropic transmitting antenna is given as

$$S_I = \frac{P_T}{4\pi R^2} \text{ W/m}^2$$

For Directivity Antenna

$$S_I = \frac{P_T G_T}{4\pi R^2} \text{ W/m}^2$$

The received power is equal to the power density multiplied by the effective area of the receiving antenna

$$P_r = \frac{P_T G_T A_{er}}{4\pi R^2}$$

The Effective Area

$$G_r = \frac{4\pi}{\lambda_0^2} A_{er} \quad \text{or} \quad A_{er} = \frac{G_r \lambda_0^2}{4\pi}$$

# Friis Transmission Equation

Power at the receiver

$$P_r = P_t \frac{G_t G_r \lambda_0^2}{(4\pi R)^2}$$

The received power is proportional to the gain of either antenna and inversely proportional to  $R^2$

If  $P_r = S_{i,\min}$ , the minimum signal required for the system, the maximum range given by

$$R_{\max} = \left[ \frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 S_{i,\min}} \right]^{1/2}$$

# Friis Transmission Equation

By including the effects of various losses due to misalignment, polarization mismatch, impedance mismatch, and atmospheric loss, one can add a factor  $L_{\text{sys}}$  that combines all losses.

$$R_{\text{max}} = \left[ \frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 S_{i,\text{min}} L_{\text{sys}}} \right]^{1/2}$$

# Natural Sources of Noise

The receiver encounters two types of noise.

- The noise picked up by the antenna
- Noise generated by the receiver

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The receiver encounters two types of noise.

- The noise picked up by the antenna
  - sky noise, earth noise, atmospheric (or static) noise, galactic noise, and man-made noise.
- Noise generated by the receiver
  - Thermal noise, Shot Noise, Flicker

# Sky noise

- **Thermal Radiation** from the atmosphere in its field of view. Unless the atmosphere is very opaque it will also collect some noise from astronomical sources in the field of view.
- The total noise power reaching the receiver can be represented in terms of the noise temperature contributions from the atmosphere and the astronomical 'sky'.

# Sky noise

- Sky noise is normally expressed in terms of the noise temperature ( $T_A$ ) of the antenna.
- For an antenna pointing to the earth or to the horizon  $T_A \sim 290$  K.
- For an antenna pointing to the sky, its noise temperature could be a few kelvin.
- The noise power is given by

$$N = kT_A B$$

where  $B$  is the bandwidth and  $k$  is Boltzmann's constant,

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

# Static or Atmospheric Noise

- Static or atmospheric noise is due to a flash of lightning somewhere in the world.
- The lightning generates an impulse noise that has the greatest magnitude at 10 kHz and is negligible at frequencies greater than 20 MHz.

# Galactic noise

- Galactic noise is produced by radiation from distant stars. It has a maximum value at about 20 MHz and is negligible above 500 MHz.

# Man Made Noise

Example, when **electric current is switched on or off**, voltage spikes will be generated. These transient spikes occur in electronic or mechanical switches, vehicle ignition systems, light switches, motors, and so on.

- **Electromagnetic radiation** from communication systems, broadcast systems, radar, and power lines is everywhere, and the undesired signals can be picked up by a receiver.
- The **interference** is always present and could be severe in urban areas.

# Noise Generated at the Receiver

- The receiver itself adds further noise to the signal from its amplifier, filter, mixer, and detector stages.
- The quality of the output signal from the receiver for its intended purpose is expressed in terms of its signal-to-noise ratio (SNR):

$$\text{SNR} = \frac{\text{wanted signal power}}{\text{unwanted noise power}}$$

# Thermal, Johnson, or Nyquist Noise

- This noise is caused by the random fluctuations produced by the **thermal agitation of the bound charges**. The rms value of the thermal resistance noise voltage of  $V_n$  over a frequency range  $B$  is given by:

$$V_n^2 = 4kTBR$$

where  $k$  = Boltzman constant =  $1.38 \times 10^{-23}$  J/K

$T$  = resistor absolute temperature, K

$B$  = bandwidth, Hz

$R$  = resistance,  $\Omega$

# Shot Noise

- The fluctuations in the number of electrons emitted from the source constitute the shot noise. Shot noise occurs in tubes or solid-state devices.

# Flicker

- A large number of physical phenomena, such as mobility fluctuations, electromagnetic radiation, and quantum noise, exhibit a noise power that varies inversely with frequency.
- The Flicker noise is important from 1 Hz to 1 MHz. Beyond 1 MHz, the thermal noise is more noticeable.

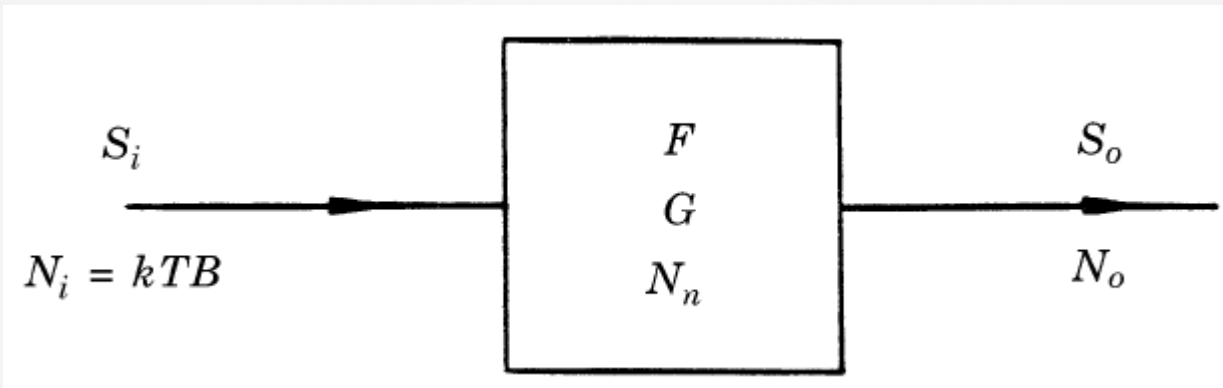
# Receiver Noise Figure and Equivalent Noise Temperature

- Noise figure is **a figure of merit** quantitatively specifying how noisy a component or system is.
- The noise figure of a system depends on a number of factors such as **losses in the circuit, the solid-state devices, bias applied, and amplification**.

$$F = \frac{\text{SNR at input}}{\text{SNR at output}} = \frac{S_i/N_i}{S_o/N_o}$$

- The noise figure is simply the noise factor converted in decibel notation.

# Receiver Noise Factor



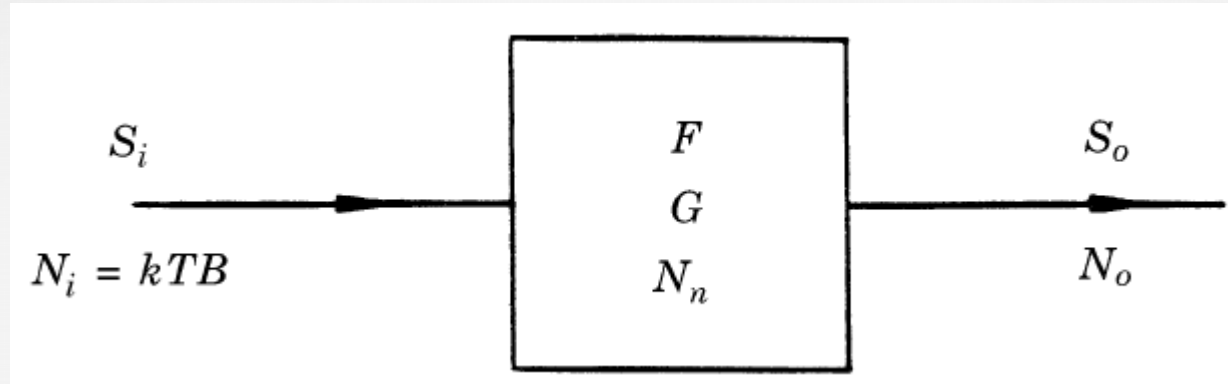
$$S_o = GS_i$$

$$N_n = N_o - GN_i \quad (\text{W})$$

$$F = \frac{S_i/N_i}{GS_i/N_o} = \frac{N_o}{GN_i}$$

$$N_o = FGN_i \quad (\text{W})$$

# Receiver Noise Figure



For a cascade system

$$N_i = kT_0B \quad (\text{W})$$

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots + \frac{F_n - 1}{G_1 G_2 \dots G_{n-1}}$$

$$F = \frac{N_o}{GkT_0B}$$

The gain and noise figure in the first stage are critical in achieving a low overall noise figure.

It is very desirable to have a low noise figure and high gain in the first stage.

For a passive component with loss  $L$  in ratio, we will have  $G = 1/L$  and  $F = L$

# Reference

- Sanjeeva Gupta, “Microwave Engineering”