Last Time: Working on G available for Power

\[
Ga = \frac{R_s(f)}{R_o(f)} \left| \frac{H(f) Z_i(f)}{Z_s(f) + Z_i(f)} \right|^2
\]
A Model for $H(F)$ can be got from ideal OP AMP models of circuit theory:

\[ h(t) \leftrightarrow H(F) = -\frac{Z_f(F)}{Z_i(F)} \]

Conclude: See how to use circuit theory with r.p.s. for comm. models.
Previous allows freq. dependent circuit models. Is useful.

But too complicated usually.

Freq dependence can often be modeled as "ideal" filtering functions, e.g.

That is "flat" over the band of interest.
Toward Simplest Models

- All freq. dependence is flat in band of interest.

Therefore

If in band $\Rightarrow$ Transfer functions are just gains or losses.

If out of band $\Rightarrow$ No transmission

- Also assume all circuit/block impedances are matched .... or that gains account for mismatches.
Start with Noiseless Components

- **Antenna**
  
  \[ \text{gain } G_{\text{ant}} = \frac{4\pi A_{\text{ant}}}{\lambda^2} \]

  \( A_{\text{ant}} = \text{effective area} \)

  \( \lambda = \text{wavelength at carrier freq.} \)

- **Filters**

- **Oscillator**

  \[ V_{\text{osc}} (+) = \frac{\sqrt{2} P_{\text{osc}} \cos (2\pi f_{\text{osc}} t)}{+ \text{H}} \]

- **Amp**

  gain or loss.
Basic Noisy Components

- Noise Source

\[ T_e \triangleq \text{equiv. noise temp} \quad \frac{kT_e}{2} \]

- Amplifier

\[ T_e \quad \text{Gamp, power gain} \]

Noisy amp: Amplifies input and adds noise.
Noise power in amp. output due to amp. internal noise sources is

\[ P_{\text{out, internal}} = kT e G_{\text{amp}} B \]

Power in output above equals \( P_{\text{out, internal}} \).
Standard Noise Figure

\[ \Delta \] by comparing output noise power due to internal noise sources to that due to external noise sources

Assumes external source is at standard temp \( T_0 = 290 \text{ K} \)
\[ F = \frac{P_{out}}{P_{out, \text{ external}}} = \frac{P_{out, \text{ int}} + P_{out, \text{ ext}}}{P_{out, \text{ ext}}} \]

\[ = 1 + \frac{P_{out, \text{ int}}}{P_{out, \text{ ext}}} = 1 + \frac{T_e}{T_0} \geq 1. \]

Also note

\[ T_e = T_0 (F - 1) \]

Noise Figure in dB

\[ F_{\text{dB}} = 10 \log_{10} F \]

Note: Must know to understand F.
Attenuators

\[ T = \text{physical temp} \]

\[ L \text{atten} = \frac{1}{G \text{atten}} \]

\[ T_c = (L \text{atten} - 1) T \]

\[ F = 1 + \frac{(L \text{atten} - 1) T}{T_0} \]

(This is a resistive divider model).

290K standard
Mixers

\[ G_{mixer} = \frac{1}{2} \quad T_e \text{ equiv. noise temp.} \]

mixer "looks like" noisy amp with power gain of \( \frac{1}{2} \)
Combine Basic Blocks

Noisy Bandlimited Amplifier

\[ kT_c/2 \]

Lossy Filter

\[ G_{amp} < 1 \quad T_c = T \quad \text{physical temp} \]
Receiver Antenna

Reciprocity holds: antenna props s.a. gain, pattern, impedance are same for it whether in receive or trans. mode.

But when in Rx mode sigs of int. are orders of mag. smaller than in Tx mode.

In receive mode antenna receives background noise in addition to desired sig.
\[ n_w(t) : S_{n_w}(f) = \frac{kT_{ant}}{2} \]

In a one-sided BW of B Hz this antenna with temp T_{ant} will give a noise power
\[ kT_{ant} B \]
\[ G_{ant} P_{signal} + kT_{ant} B \]
See text by Pozar have graphs of antenna temp:

\[ T_{\text{ant}} \]

\[ 290K \]

\[ f \] (GHz)

\[ 22 \] \[ 60 \]

- \[ H_2O \]
- \[ O_2 \]

antenna pointing horizontally

antenna pointing vertically

\[ \text{Penzias & Wilson: Nobel in physics} \]
Noise Fig. of Comm Systems

\[ N_{in} \xrightarrow{G_1, F_1, T_{e1}} G_2, F_2, T_{e2} \xrightarrow{N_{out}} \]

\[ F = F_1 + \frac{F_2 - 1}{G_1} \]
\[ G = G_1, G_2 \]
\[ T_e = T_{e1} + \frac{T_{e2}}{G_1} \]