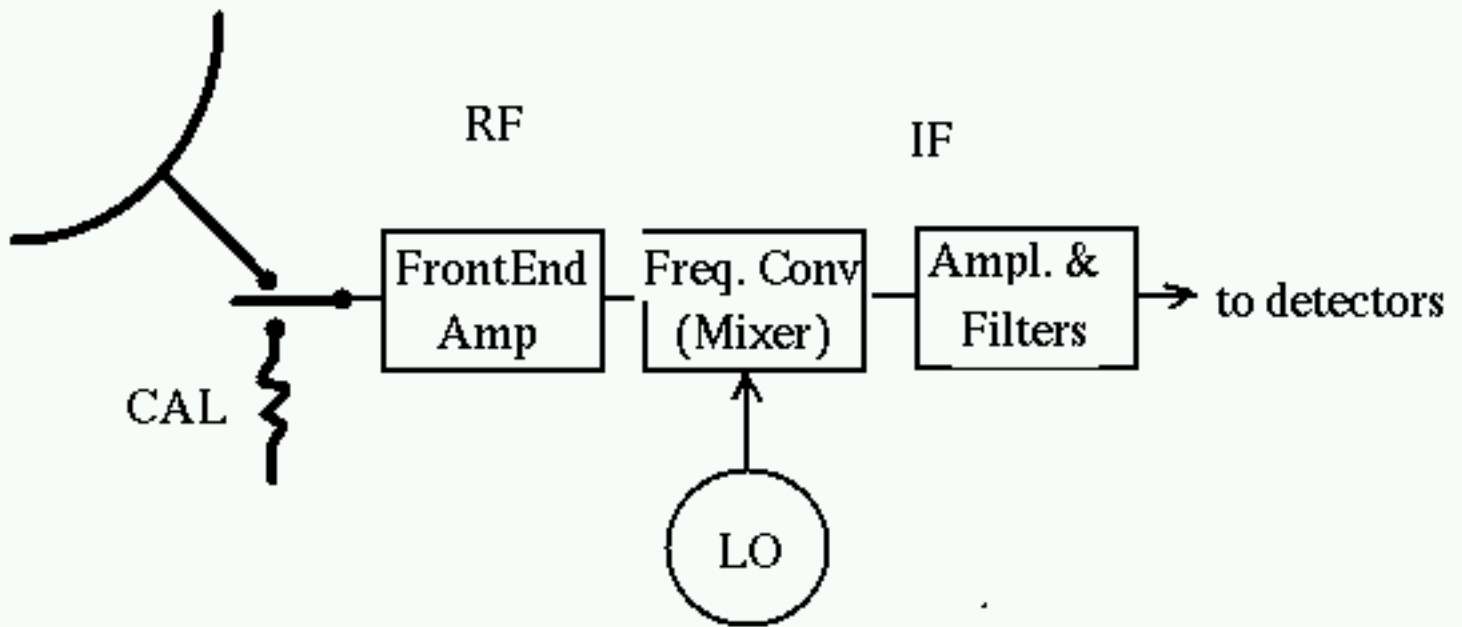


Lecture 2: Noise in Receivers

Receiver System:



- Horn and CAL Load
- FrontEnd (Low Noise) Amplifier
- Frequency Converter (Mixer)
- IF Amplifier and Filters
- Detectors

Fundamental Noise Limit

- Gaussian statistics: $\sigma(N) = \sqrt{N}$
- $N = \tau/\Delta t = \tau \times \Delta\nu$ independent samples
- Uncertainty (or “thermal noise”) in a single sample T_{sys} :

$$\frac{\Delta T}{T_{sys}} = \frac{1}{\sqrt{N}} = \frac{1}{\sqrt{\Delta\nu\tau}}$$

(see RW p62-63 for full derivation)

Example: $T_{sys} = 150$ K, $\nu = 100$ GHz,
 $\Delta\nu = 1$ MHz, $\tau = 1$ minute

$$\Delta T = \frac{150}{\sqrt{10^6 \times 60}} = 0.02 \text{ K}$$

Receiver Stability

- signal measured by the detector:

$$W = k(T_A + T_{sys})G\Delta\nu$$

- gain variation leads to:

$$W + \Delta W = k(T_A + T_{sys})(G + \Delta G)\Delta\nu$$

- variation in T_{sys} leads to:

$$W + \Delta W = k(T_A + T_{sys} + \Delta T)G\Delta\nu$$

then, $T_{sys}\Delta G = \Delta T G$

$$\frac{\Delta T}{T_{sys}} = \frac{\Delta G}{G}$$

Combined in quadrature with thermal noise,

$$\frac{\Delta T}{T_{sys}} = \sqrt{\frac{1}{\Delta\nu\tau} + \left(\frac{\Delta G}{G}\right)^2}$$

Dicke Switching

A receiver is switched between antenna (T_A) and a calibration load R (T_R):

- signal measured on the antenna:

$$W_A = k(T_A + T_{sys})G\Delta\nu$$

- signal measured on the load:

$$W_R = k(T_R + T_{sys})G\Delta\nu$$

- differencing the two signals:

$$W_A - W_R = k(T_A - T_R)G\Delta\nu$$

$$k(T_A - T_R)(G + \Delta G)\Delta\nu = k(T_A + \Delta T - T_R)G\Delta\nu$$

$$\frac{\Delta T}{T_{sys}} = \left(\frac{\Delta G}{G}\right)\left(\frac{T_A - T_R}{T_{sys}}\right)$$

If $(T_A - T_R) \ll T_{sys}$, then the gain variation can be removed!
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Receiver Calibration

In principle, one can derive T_{sys} from W_A by setting $T_A = 0$ if G is known. In practice, T_{sys} is derived by using two different loads with known temperature:

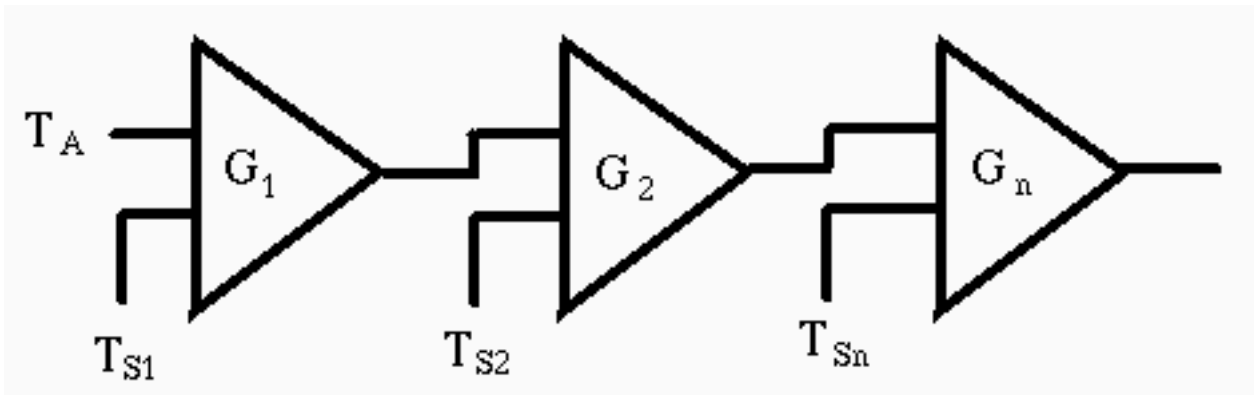
- signal measured with T_1 :
$$W_1 = k(T_1 + T_{sys})G\Delta\nu$$
- signal measured with T_2 :
$$W_2 = k(T_2 + T_{sys})G\Delta\nu$$
- “Y factor”: $Y \equiv \frac{W_1}{W_2} = \frac{T_1 + T_{sys}}{T_2 + T_{sys}}$

$$T_{sys} = \frac{T_1 - T_2 Y}{Y - 1}$$

Example: $T_1 = 300$ K (ambient load),
 $T_2 = 3$ K (sky)

Cascading of Amplifiers

To amplify power by 80-140 db (10^8-14)



$$G = \prod G_i$$

- $P_0 = kT_A$
- $P_1 = (P_0 + kT_{S1})G_1 = k(T_A + T_{S1})G_1$
- $P_2 = (P_1 + kT_{S2})G_2 = k([T_A + T_{S1}]G_1 + T_{S2})G_2$
- $P_n = (P_{n-1} + kT_{S_n})G_n$

Cascading of Amplifiers (cont.)

To rewrite as $P_n = k(T_A + T_S)G$,

$$T_S = T_{S1} + \frac{1}{G_1}T_{S2} + \frac{1}{G_1G_2}T_{S3} + \dots \\ + \frac{1}{G_1G_2\dots G_{n-1}}T_{Sn}$$

To minimize T_S , keep T_{S1} as small as possible for all $G_i > 1$.

Low Noise Front-End Amplifiers:

- maser amplifiers ($\frac{n_2}{n_1} = \frac{g_1}{g_2}e^{-\Delta E/kt}$)
- parametric amplifiers (oscillating capacitance)
- transistor amplifiers (FET, HEMT)