39 Antenna noise and links

- In a practical application an antenna will be used to detect a specific plane-wave signal of interest, of, say, power density S_s, in the presence of a random continuum $dS(\theta,\phi,f)$ corresponding an some *effective* temperature T_a. In that case, we obtain over a finite frequency band[1] Δf containing S_s, an average received power of

$$\begin{aligned}\langle P_r\rangle &= S_s A(\theta_s,\phi_s) + \int_{\Delta f}\int dS(\theta,\phi,f)A(\theta,\phi)\\ &= S_s A(\theta_s,\phi_s) + KT_a\Delta f,\end{aligned}$$

since

$$\begin{aligned}\int_{\Delta f}\int dS(\theta,\phi,f)A(\theta,\phi) &= \int_{\Delta f}\int \frac{1}{2}L(\theta,\phi,f)A(\theta,\phi)d\Omega df\\ &= \Delta f\int \frac{KT_a}{\lambda^2}A(\theta,\phi)d\Omega = KT_a\Delta f.\end{aligned}$$

- The second term of $\langle P_r\rangle$ above is called noise power, or simply "noise", while the first term represents the signal power, or simply the "signal".

- Since we want the "signal-to-noise ratio" SNR as large as possible, we should select Δf as small as allowed, but regrettably $\Delta f = 0$ is not

[1] A suitable Δf is imposed by using an appropriate band-pass filter in cascade with the matched antenna termination.

an option in practical communication applications because of the finite bandwidth of the signal of interest (with $\Delta f = 0$ we would lose the signal together with the noise!).

The effective temperature T_a introduced above deserves some further explanation:

- Since in normal usage an antenna will not be placed in a cavity in thermal equilibrium, our usage of

$$L(\theta, \phi, f) = L(f) = \frac{2KT_a}{\lambda^2}$$

  above is just a convention that helps us to parametrize the noise power collected by a receiving antenna in terms of an equivalent temperature T_a referred to as "antenna temperature".

Antenna temperature T_a may or may not be the physical (thermodynamic) temperature of a noise source in the sky:

- When the antenna beam is fully intercepted (at some large distance) by a perfect absorber (a blackbody) of an equilibrium temperature T_b, then then the antenna temperature will be

$$T_a = T_b$$

  and measure the thermodynamic temperature of the absorbing body. In radio astronomy this fact is used to measure the surface temperatures of planets such as Venus (using a geometrical correction factor to account for the fact that the planet will not fully intercept the antenna beam).

- The universe can be regarded as a *cavity* sparsely filled with objects (galaxies, stars, planets, living things) *not* in thermal equilibrium with the cavity walls.

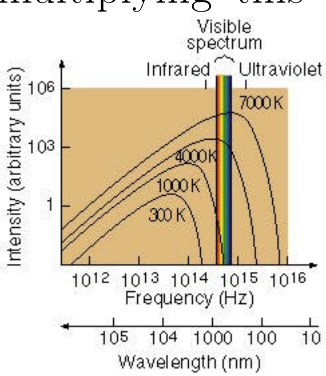
  The "walls" of the cavity — at about 13.7 billion light-years away — are known to have an equilibrium temperature of about 3 K (discovered in 1964 and taken to be the strongest evidence for Big Bang) that produces a blackbody radiance curve

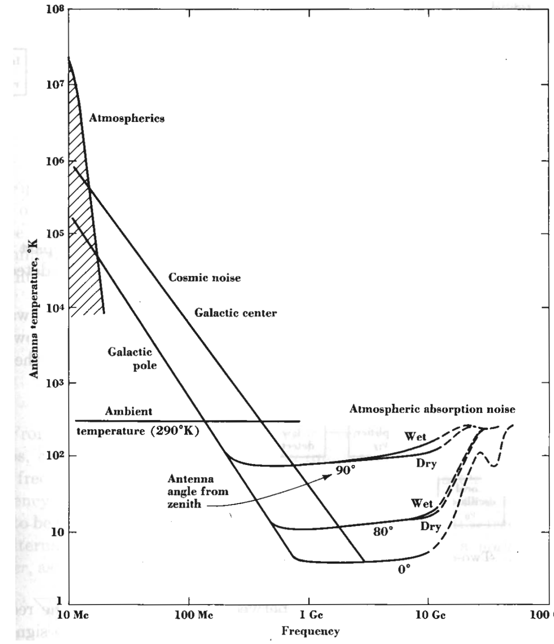
$$L_b(f) = \frac{2f^2}{c^2}\frac{hf}{e^{hf/KT_b} - 1}$$

  that peaks within the microwave frequency band.

  However, galaxies and intergalactic gases radiate by a variety of non-thermal processes (e.g., synchrotron radiation) so that the overall radiance spectrum $L(\theta, \phi, f)$ (the sum of all contributions) is non-thermal, giving rise to a frequency dependent $T_a(\theta, \phi, f)$ curve shown in the margin.

The noise power collected by an antenna can be conveniently calculated by multiplying this "equivalent" antenna temperature $T_a(\theta, \phi, f)$ with $K\Delta f$.





Antenna temperature curve from Kraus, "Radio Astronomy" (1966): Note that T_a is dominated by atmospheric noise (lightning, man-made noise) at low frequencies and by thermal emission from absorbing gases in the atmosphere past about a GHz. So-called cosmic noise from radio galaxies (including our own) dominates in VHF and UHF band.