Radio Telescope Fundamentals II

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Single Dish Observing School
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$$\sigma_S = \frac{T_{sys}}{G\sqrt{n_p t \Delta f}}$$

Terms and Concepts

S, σ_S	Flux Density , Standard Deviation of Flux Density
T_{sys}	System Temperature
G	Gain
n_p	Number of Polarization
t	Time
Δf	Bandwidth

Text books on Radio Astronomy

- Essential Radio Astronomy
- https://science.nrao.edu/opportunities/courses/era

Essential Radio Astronomy

James J. Condon, Scott M. Ransom

Princeton University Press, Apr 5, 2016 - Science - 376 pages

Essential Radio Astronomy is the only textbook on the subject specifically designed for a one-semester introductory course for advanced undergraduates or graduate students in

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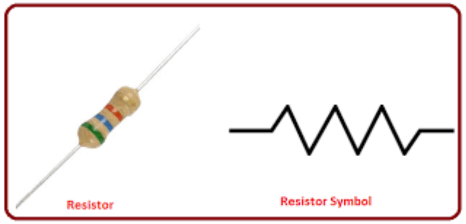
Tools of Radio Astronomy

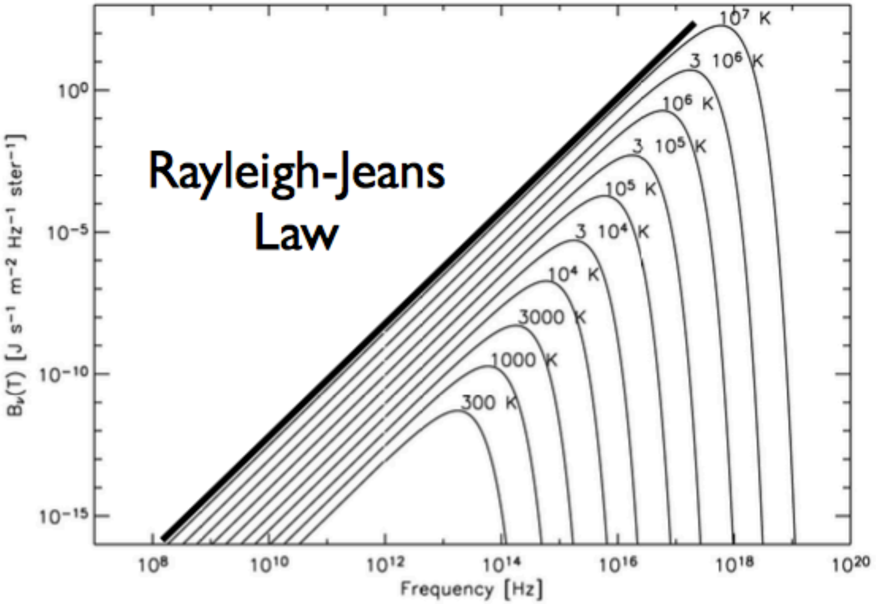
Authors: **Wilson**, Thomas, **Rohlfs**, Kristen, **Huettemeister**, Susanne

Presents the 6th edition of a leading textbook on radio astronomy to include state-of-the-art descriptions of instrumentation and new observations

Warm Resistor:



- Warm resistors are useful in radio astronomy as standards for calibrating antennas and receivers, so the noise power per unit bandwidth received by a radio telescope is often described in terms of the Rayleigh–Jeans antenna temperature.



- Where:
  - P is power
  - k_b is Boltzmann's constant
  - T is temperature
  - Δf is bandwidth
  - Multiply by ½ for single pol.

$$P = k_b T \Delta f$$

S

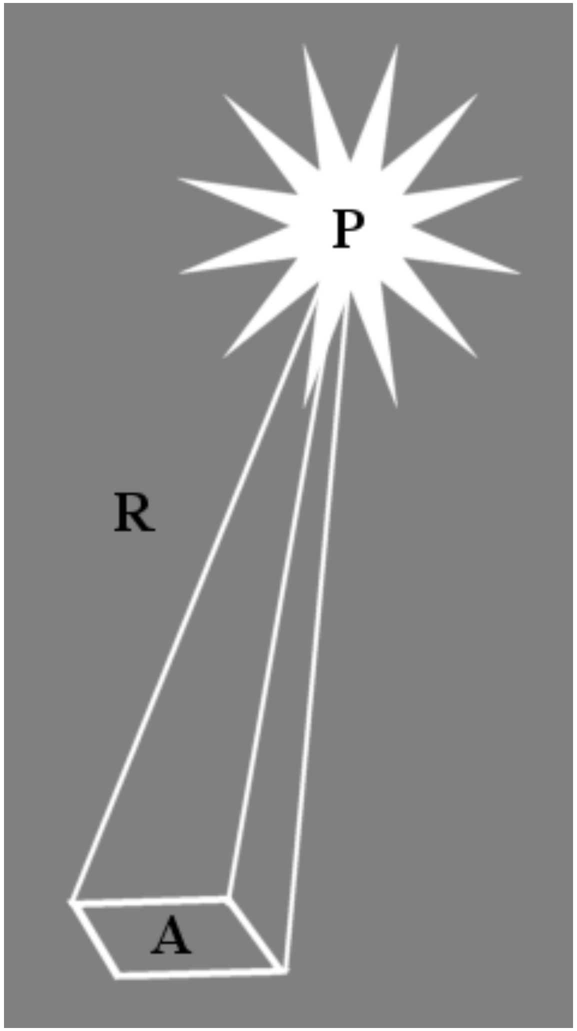
Intrinsic Power (P) (Watts)
Distance (R) (meters)
Aperture Area (A) (sq.m.)

Flux = Power/Area
Flux Density (S) = Power/Area/bandwidth
Bandwidth (Δf)

A "Jansky" is a unit of flux density

$$10^{-26} Watts / m^2 / Hz$$

$$P = AS\Delta f$$



Antenna Temperature:

- The antenna temperature of a receiving antenna is defined as the temperature of an ideal resistor that would generate the same Rayleigh–Jeans noise power per unit bandwidth as appears at the antenna output.

- Antenna temperature is not a physical temperature.

- Collecting area is replaced with effective area A_e. Where η is the telescope efficiency.

$$P = k_b T \Delta f / 2$$

$$P = A S \Delta f$$

$$T_A = \frac{S A_e}{2 k_B} = SG$$

$$A_e = \eta A$$

T_{sys}

Physical temperature vs antenna temperature

For an extended object with source solid angle Ω_s,
And physical temperature T_s, then

for $\Omega_s < \Omega_A$ $T_A = \frac{\Omega_s}{\Omega_A} T_s$

for $\Omega_s > \Omega_A$ $T_A = T_s$

In general : $$T_A = \frac{1}{\Omega_A} \iint_{source} P_n(\theta,\phi) T_s(\theta,\phi) d\Omega$$

T_{sys}

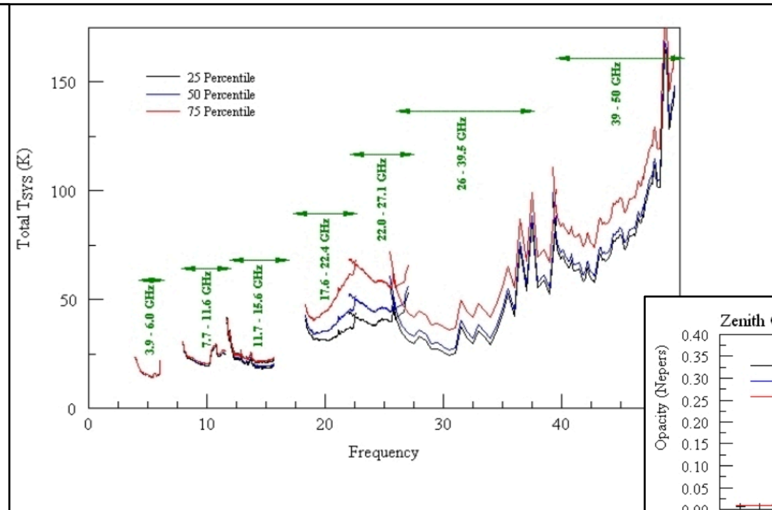
System Temperature

= total noise power detected, a result of many contributions

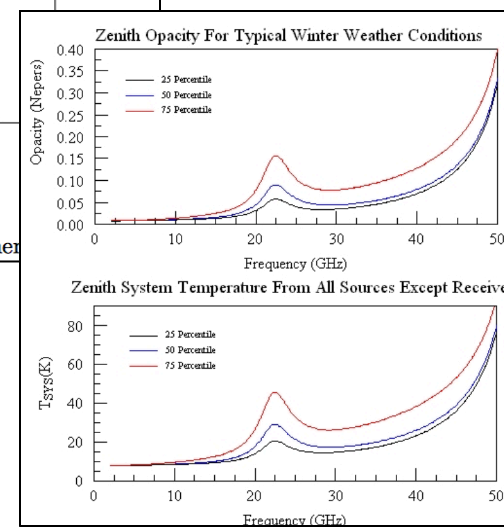
$$T_{sys} = T_{ant} + T_{rcvr} + T_{atm}(1 - e^{-\tau a}) + T_{spill} + T_{CMB} + \cdots$$

Table 2.2: Properties of the Prime Focus and Gregorian Focus Receivers.

	Name	ν Range (GHz)	Polarization	Beams	Polns/ Beam	T_{rec} (K)	T_{sys} (K)
		— Prime Focus Receivers —					
PF1	Rcvr_342	0.290-0.395	Lin/Circ	1	2	12	46
PF1	Rcvr_450	0.385-0.520	Lin/Circ	1	2	22	43
PF1	Rcvr_600	0.510-0.690	Lin/Circ	1	2	12	22
PF1	Rcvr_800	0.680-0.920	Lin/Circ	1	2	21	29
PF2	Rcvr_1070	0.910-1.230	Lin/Circ	1	2	10	17
		— Gregorian Focus Receivers —					
L-band	Rcvr1_2	1.15-1.73	Lin/Circ	1	2	6	20
S-band	Rcvr2_3	1.73-2.60	Lin/Circ	1	2	8-12	22
C-band	Rcvr4_6	3.95-8.0	Lin/Circ	1	2	5	18
X-band	Rcvr8_10	8.00-10.1	Circ	1	2	13	27
Ku-band	Rcvr12_18	12.0-15.4	Circ	2	2	14	30
KFPA	RcvrArray18_26	18.0-26.5	Circ	7	2	15-25	30-45
Ka-band	Rcvr26_40 (MM-F1)	26.0-31.0	Lin	2	1	20	35
Ka-band	Rcvr26_40 (MM-F2)	30.5-37.0	Lin	2	1	20	30
Ka-band	Rcvr26_40 (MM-F3)	36.0-39.5	Lin	2	1	20	45
Q-band	Rcvr40_52	38.2-49.8	Circ	2	2	40-70	67-134
W-band	Rcvr68_92 (FL1)	67-74	Lin/Circ	2	2	50	160
W-band	Rcvr68_92 (FL2)	73-80	Lin/Circ	2	2	50	120
W-band	Rcvr68_92 (FL3)	79-86	Lin/Circ	2	2	50	100
W-band	Rcvr68_92 (FL4)	85-92	Lin/Circ	2	2	60	110



ure 16.3: The zenith system temperatures for typical weather



T_{sys}

System Temperature

= total noise power detected, a result of many contributions

$$T_{sys} = T_{ant} + T_{rcvr} + T_{atm}(1 - e^{-\tau a}) + T_{spill} + T_{CMB} + \cdots$$

$$\sigma_{T_{sys}} = \frac{T_{sys}}{\sqrt{n_p t \Delta f}}$$

Receiver Gain Instability

$$P = gT_{sys}\left(k\Delta f\right)$$

What happens:

$$\Delta P = \Delta g T_{sys}\left(k\Delta f\right)$$

Indistinguishable from:

$$\Delta P = g\Delta T_{sys}\left(k\Delta f\right)$$

$$\Delta T_{sys} = T_{sys}\left(\frac{\Delta g}{g}\right)$$

$$\sigma_{T_{sys}} = T_{sys}\left[\frac{1}{t\Delta f} + \left(\frac{\Delta g}{g}\right)^2\right]^{\frac{1}{2}}$$

Pink or1/f Noise

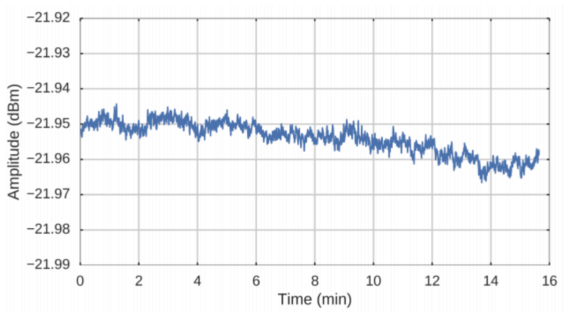


Figure 1. Measured receiver output power for 15 min. The signal has been low-pass filtered with a cut-off frequency of approximately 2 Hz in order to emphasise the gain fluctuations. The trace here is therefore dominated by pink noise.

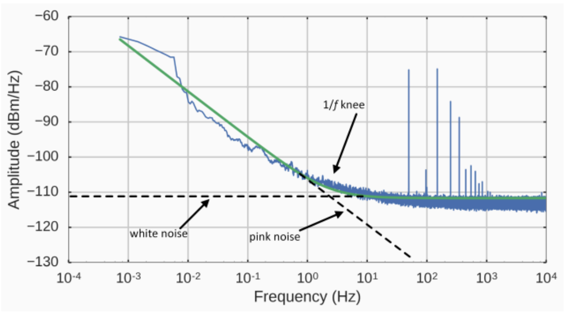
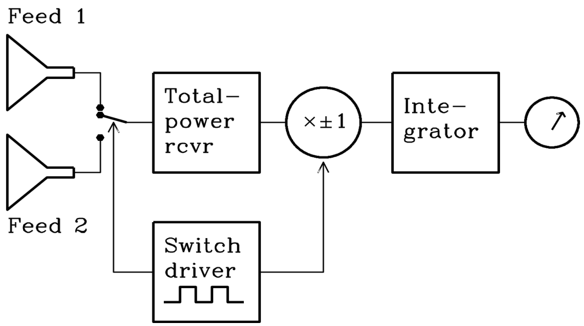


Figure 2. Noise power spectrum of the non-filtered output signal presented in Figure 1. The spectra have been logarithmically smoothed using a moving average filter. Note the additional narrow-band signals at 50 Hz and its harmonics due to mains-frequency pickup.

- Integrations longer than $\tau \approx 1/(2\pi f_k)$ will likely increase the receiver output fluctuations.
- Depending on the stability and bandwidth of the radiometer, ~1Hz<fk<~1kHz.

Pink or1/f Noise



$$T_1 - T_2 << T_1$$

$$\left(\frac{\Delta g}{g}\right)^2 = \frac{2}{\Delta\nu\tau} * \frac{T_1^2 + T_2^2}{T_1 - T_2}$$

$$\sigma_{T_{sys}} = T_{sys}\left[\frac{1}{t\Delta f} + \left(\frac{\Delta g}{g}\right)^2\right]^{\frac{1}{2}}$$

- Dicke Switching
  - Fluctuations in atmospheric emission and in receiver gain are effectively suppressed for frequencies below the switching rate, which is typically in the range 10 to 1000 Hz.
- Main draw back is that only ½ the time is being spent on source and that the noise doubles.
- Note: In last eq. t= tau/2

Flux Density Noise Level

$$S = \frac{2kT_{sys}}{A_e} = \frac{T_{sys}}{G} = S.E.F.D.$$

$$G = \frac{A_e}{2k}$$

$$\boxed{\sigma_S = \frac{T_{sys}}{G\sqrt{n_p t \Delta f}}}$$

Propagation of Uncertainty

$$S = \frac{T}{G}$$

$$\sigma_S^2 = \left(\frac{T}{G}\right)^2 \left[\left(\frac{\sigma_t}{T}\right)^2 + \left(\frac{\sigma_G}{G}\right)^2\right]$$

$$\left(\frac{\sigma_t}{T}\right)^2 = \frac{1}{n_p t \Delta f}$$

$$\frac{\sigma_G}{G} \propto \frac{1}{f}$$

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