DARA 2017 Nairobi Unit1 Radioastronomy
Workshop on Lecture 4

1. What is the self-coherence time $\boldsymbol{\tau}_{COH}$ for a noise-like voltage of bandwidth $\Delta\nu$ = 500 MHz?

2. What is the level of rms fluctuations at the output of a total power receiving system with T_{sys} = 20K and bandwidth $\Delta\nu$ = 500 MHz for an integration time of 1 second? If these 1 second samples are averaged for 1 minute how does the rms fluctuation change?

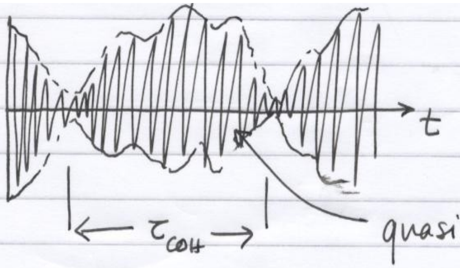
3. What is the rms power level at the input to the first amplifier for the receiver in question 2? If the equivalent power level at the output of the receiver has to be 2mW calculate the overall power gain of the receiver in dB.

4. A receiver under test in the laboratory is connected to a matched resistor that can be heated and cooled. What is the receiver noise temperature (T_{rec}) if the power output drops by 3dB when the resistor temperature is reduced from 300K to 77K?

5. If the bandwidth of a receiver is 100 MHz how long must one integrate to reach an rms noise which is 0.1% of the system noise with a basic "total power" receiver system?

6. A receiver has a local oscillator frequency of 1451 MHz and an intermediate frequency (IF) of 30 MHz. To what range of frequencies is the receiver sensitive if the final bandwidth is 10 MHz?

1.



$\Delta\nu$ bandwidth

NB if $\Delta\nu/\nu = 0.1$ (10% bandwidth) → quasi-sinusoidal for ~ 10 RF cycles

$$\Delta t = \underbrace{\tau_{COH} \simeq \frac{1}{\Delta\nu}}_{\text{depends in detail on shape of bandpass}} = \frac{1}{500\times10^{6}} = \boxed{2\times10^{-9}\ \text{sec} = 2\ \text{nanosec}}$$

[N.B. note $\Delta t\Delta\nu \simeq 1$
– basic uncertainty relation]

2. Radiometer equation $\Delta T_{rms} = T_{SYS}/\sqrt{\Delta\nu.\tau}$

$$\Delta T_{rms} = 20/\sqrt{500\times10^{6}\times1} = \boxed{8.9\times10^{-4}\ \text{K}}$$

$\boxed{0.89\ \text{milli K}}$

Average for a further 60 secs → rms reduces by $\sqrt{60}$ $\boxed{0.11\ \text{milli K}}$

(Central limit theorem in action)

3. Power $= kT\Delta\nu = 1.38\times10^{-23}\times 20\times 500\times10^{6}$

$\boxed{= 1.38\times10^{-13}\ \text{W}}$

$$\text{Gain } G = \frac{2\times10^{-3}\ (2\ \text{milliwatts})}{1.38\times10^{-13}} = 1.44\times10^{10}$$

$\boxed{= 101.6\ \text{dB}}$

4. Hot & cold load method:

$$\frac{T_{REC} + 300}{T_{REC} + 77} = Y = 2 \quad \text{(factor of 3dB)}$$

($300 = T_{HOT}$, $77 = T_{COLD}$)

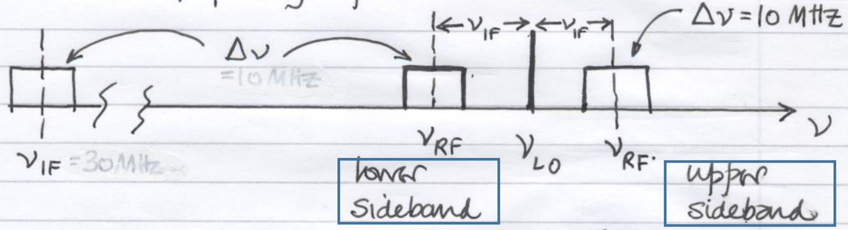
$$\Rightarrow \quad T_{REC} = \frac{T_{HOT} - Y\,T_{COLD}}{Y-1} = \frac{300 - 2\times77}{1}$$

$\boxed{T_{REC} = 146\ \text{K}}$

5. $\Delta T_{rms} = \dfrac{T_{SYS}}{\sqrt{\Delta\nu.\tau}} \rightarrow \dfrac{\Delta T_{rms}}{T} = \dfrac{1}{\sqrt{\Delta\nu.\tau}} = 10^{-3}$

$$\rightarrow \tau = 1/10^{8}.10^{-6} = 10^{-2}\ \text{sec} = 10\ \text{millisec}$$

6. Draw the frequency spectrum



Given: $\nu_{LO} = 1451$ MHz ; $\Delta\nu = 10$ MHz ; $\left\{\begin{array}{l}\nu_{IF} = 30\ \text{MHz} \\ \quad = 30\pm5\ \text{MHz}\end{array}\right\}$

Lower sideband $= \left.\begin{array}{l}1451 - 25 \\ 1451 - 35\end{array}\right\} = \boxed{1421 \pm 5\ \text{MHz}}$

Upper sideband $= 1451 \pm (30\pm5) = \boxed{1481 \pm 5\ \text{MHz}}$

Both would be mixed down to IF at 30 ± 5 MHz if the 1st amplifier covered the range 1426– 1486 MHz. Usually one sideband is rejected with a filter

1. A cable at a physical temperature of 300K has loss of 0.5 dB. A signal of peak temperature 1K is connected to the input. What is the signal temperature and what is the total noise temperature at the output of the cable?

2. A receiver has a low-noise amplifier of 5 K noise temperature and 20 dB gain, followed by a second stage amplifier of 30 K noise temperature also with 20 dB gain, followed by a mixer with 2000 K noise temperature and 0.5 dB conversion loss, and an IF amplifier of 10000 K noise temperature and 40 dB gain. Calculate the total system noise temperature .

3. The planet Uranus is observed with a 30-m diameter radio telescope operating at wavelength a wavelength λ = 3 mm. At a particular time the measured antenna temperature is 0.89K. Suppose the telescope is fitted with a receiver whose bandwidth is 10 GHz and that the overall system temperature T_{sys} is 180K. Estimate the integration time that would be required to detect Uranus with a signal-to-noise ratio of 100:1 a) for a basic radiometer; b) for a single-Dicke switched system.
(NB the planets are the standard calibration sources for observations at mm wavelengths – hence we want to detect them with a high signal-to-noise ratio.)

1. $T = 300K$

P_{IN} o—WWW—o P_{OUT}

($\equiv 1K$) Signal — attenuator loss = 0.5dB

$10\log_{10}\frac{P_{IN}}{P_{OUT}} = 0.5dB \qquad \frac{P_{IN}}{P_{OUT}} = 1.122$

$\rightarrow P_{OUT} = \underbrace{0.891}_{\text{transmission factor}} P_{IN} \rightarrow \boxed{T_{signal} = 0.891\ K}$

$(T_{IN} \times \eta) + T_{ATTEN}(1-\eta)$

$T_{OUT} = (1K \times 0.891) + 300(1 - 0.891)$

$\boxed{T_{OUT} = 33.51\ K}$

2. Cascaded stages as in notes

$T_{REC} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1G_2} + \frac{T_4}{G_1G_2G_3}$ etc

5K $G_1 = 20dB \equiv 100$

30K $G_2 = 20dB \equiv 100$

2000K $G_3 = 0.5dB = 0.89$ (as above)

10,000K $G_4 = 40dB = 10,000$

as given in question

$T_{REC} = 5 + \frac{30}{100} + \frac{2000}{100\times100} + \frac{10,000}{100\times100\times0.89}$

$\boxed{T_{REC}\ \ 6.6K}$

3. T_A uranus $= 0.89\ K$ ∴ to detect at 100:1 SNR

$\rightarrow T_{RMS} = \frac{0.89}{100} = 8.9\times10^{-3}\ K$ (8.9 milli K)

Radiometer equation $T_{RMS} = \frac{T_{SYS}}{\sqrt{\Delta\nu.\tau}} = \frac{180}{\sqrt{10^{10}.\tau}}$

$\therefore\ 8.9\times10^{-3} = \frac{180}{\sqrt{10^{10}.\tau}} \rightarrow \boxed{\tau = 0.04s}$

(10GHz)

easy to see planets with broad-band continuum receivers

Single Dicke – will take 4 x longer

NOTE THAT THE COMMENTARY CONTINUES IN ANSWER TO OTHER QUESTIONS NOT IN THE WORKSHOP – JUST IGNORE AFTER Q3

← 100m →