APECE-302: Radio & Television Engineering

Applied Physics, Electronics & Communication Engineering

LEC PPT # 02
Introduction to Noise

University of Dhaka | APECE DU

Course Teacher: S.M. Riazul Islam, PhD

Date: 2013 Year, 05 Month, 16Day

Contents

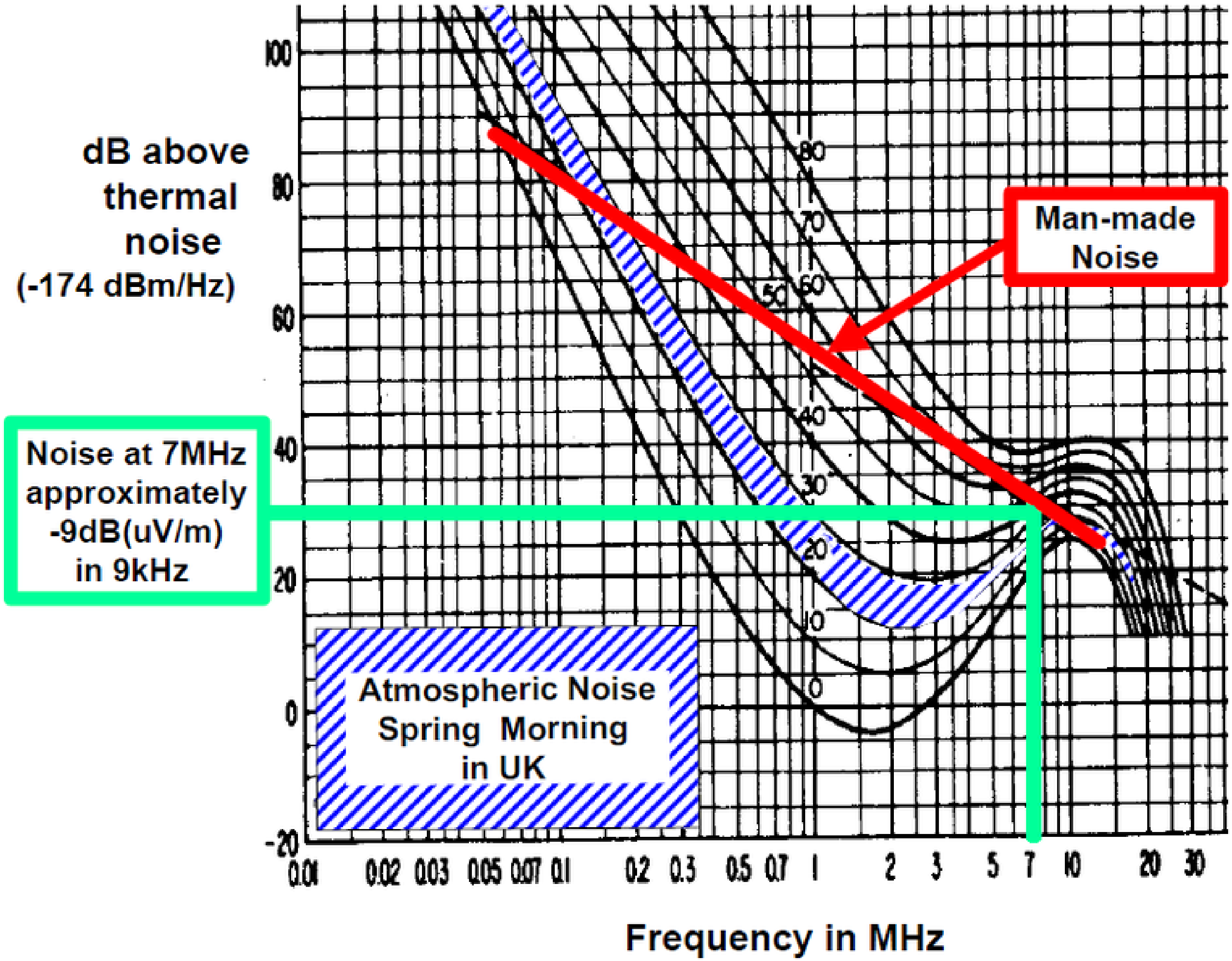
Noise and its classification

- Noise: Unwanted Signal

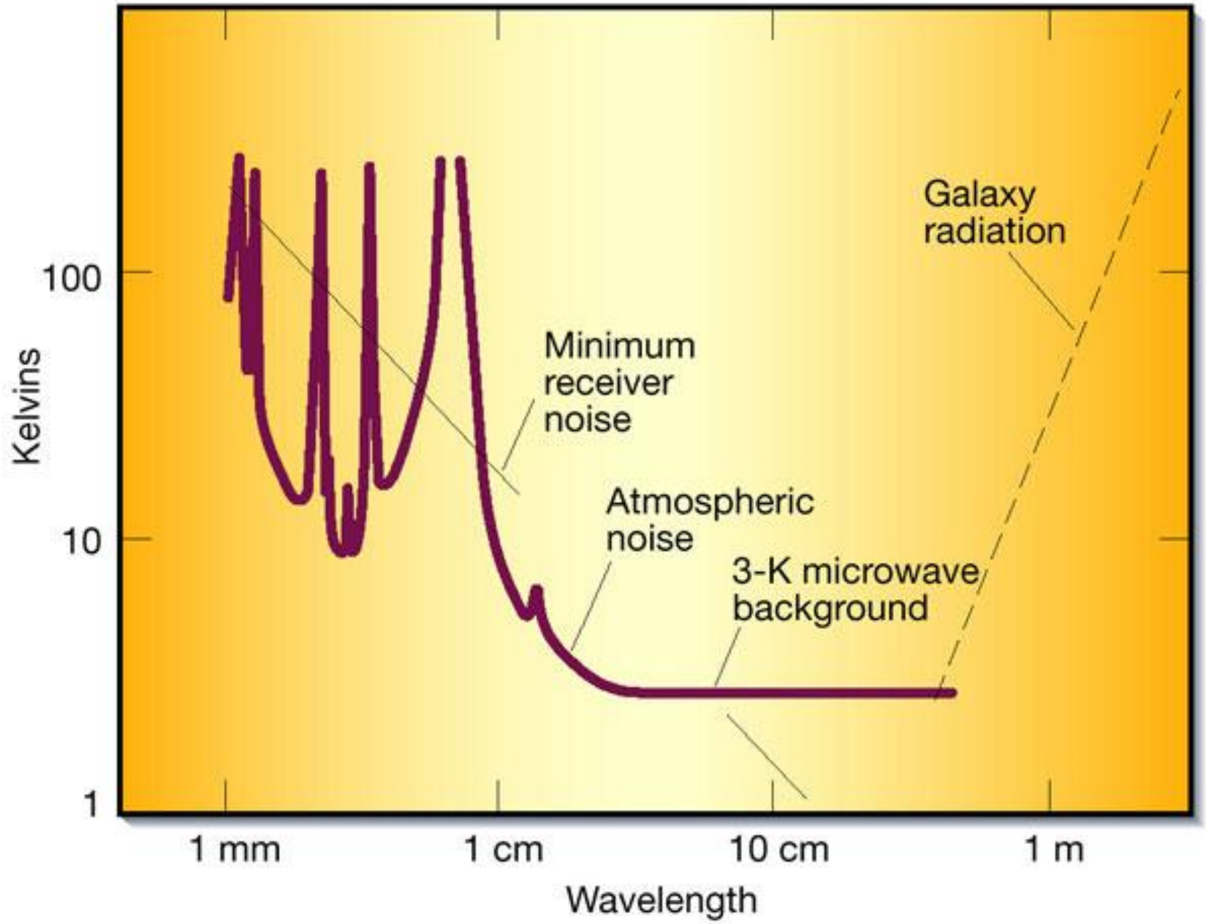
- External
  - Atmospheric/static
  - Extraterrestrial
  - Man-made

- Internal
  - Thermal
  - Shot
  - Transit time
  - Misc (Flicker, Transistor thermal, partition)

Noise and its classification



Noise and its classification



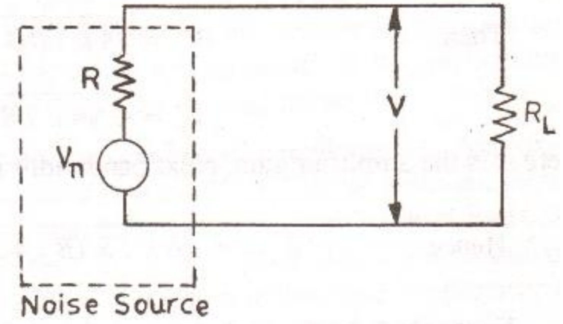
Thermal noise

Noise Power:

$$P_n = \bar{k}\,TB$$

$\bar{k}$ is the Boltzmann constant (1.38×10^{-23} Joule/deg. K)
T is the absolute temperature, K = 273° + deg. C
B is the bandwidth in hertz.

Resistor as a noise generator



$$P_n = \frac{V^2}{R_L} = \frac{V^2}{R} = \frac{(V_n/2)^2}{R} = \frac{V_n^2}{4R}$$

$$V_n^2 = 4R\,P_n = 4R\,\bar{k}\,TB$$

$$V_n = \sqrt{4R\,\bar{k}\,TB}$$

Thermal noise

[redacted] *A resistor of value 20 kΩ is connected at the input of an amplifier operating over the frequency range 10 to 11 MHz. Compute the rms noise voltage at the input of the amplifier if the ambient temperature is 24°C.*

$$V_n = \sqrt{4\bar{k}TRB} = \sqrt{4 \times 1.38 \times 10^{-23} \times (273+24) \times 20 \times 10^3 \times (11-10)\, 10^6 \text{ volt}} = 18.1\ \mu\text{V}.$$

[redacted] *The noise output of a resistor is amplified by a noiseless amplifier having gain of 40 and bandwidth of 40 KHz. A meter connected to the output of the amplifier reads 4 mV rms (a). If the resistor is operated at 27°C, what is its resistance ? (b) If the bandwidth of the amplifier is reduced to 10 KHz, its gain remaining constant, what will the meter read now ?*

Thermal noise

Solution. (*a*) $V_n = \sqrt{4\bar{k}TRB}$

Hence $R = \dfrac{Vn^2}{4\bar{k}TB}$

The rms noise voltage generated in the resistor $= \frac{4\,mV}{40} = 100\,\mu V$

Hence $$R = \frac{(100 \times 10^{-6})^2}{4 \times 1.38 \times 10^{-23} \times (273 + 27)\, 40 \times 10^3}\,\Omega$$

$$= 15.1 \times 10^6\,\Omega$$

(*b*) Initially $B = 40$ kHz

Then $V_n = \sqrt{4\bar{k}TRB}$

$V_o = A\sqrt{4\bar{k}TRB}$

where A is the amplifier gain. Next bandwidth is reduced to 10 kHz, *i.e.* $B' = B/4$.

Hence $$V_o = A\sqrt{4\bar{k}TR\,(B/4)} = \frac{1}{2}A\sqrt{4\bar{k}TRB} = \frac{1}{2} \times 4\text{ mV} = 2\text{ mV}.$$

Shot noise

For a diode, rms shot noise current:

$$I_n = \sqrt{2\,q\,I_p\,B}$$

where	q	is the magnitude of the charge of an electron (1.6×10^{-19} Coulomb)
	I_p	is the direct diode current, Amp.
and	B	is the bandwidth of the system, hertz.

Adding thermal noise and shot noise component??

Overcome by taking R_eq

Addition of noise due to several sources

Several thermal noise sources in series:

$$V_{n_1} = \sqrt{4\bar{k}TBR_1}$$

$$V_{n_2} = \sqrt{4\bar{k}TBR_2}$$

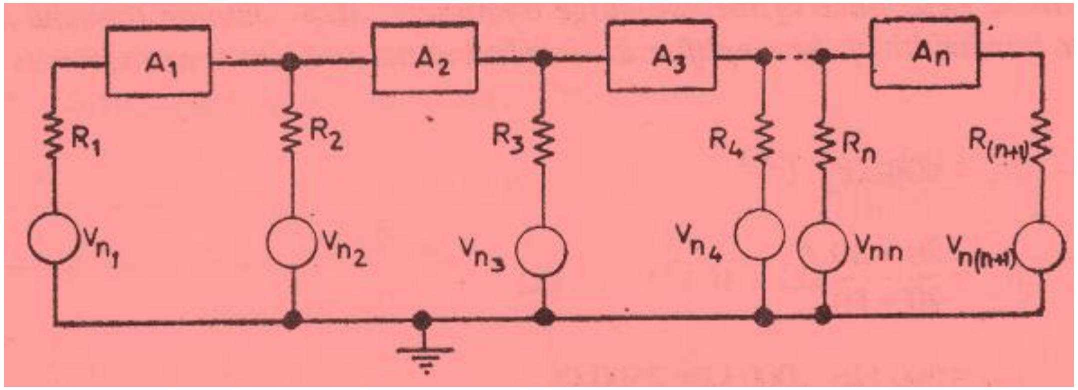
$$V_{nr} = \sqrt{V_{n1}^2 + V_{n_2}^2 + V_{n_3}^2 + \ldots\ldots} = \sqrt{4\bar{k}TB(R_1 + R_2 + R_3 + \ldots\ldots)}$$

$$= \sqrt{4\bar{k}TBR}$$

$$R = R_1 + R_2 + R_3 + \ldots\ldots$$

Addition of noise in cascaded amplifiers

Equivalent I/P noise voltage:



$$V_{n_3} = \sqrt{4\bar{k}TBR_3}$$

$$V_{n3}' = \frac{V_{n_3}}{A_2} = \frac{\sqrt{4\bar{k}TBR_3}}{A_2} = \sqrt{4\bar{k}TBR_3'}$$

$$R_3' = \frac{R_3}{A_2^2}$$

$$R_{2t} = R_2 + R_3' = R_2 + \frac{R_3}{A_2^2}$$

$$R_2' = \frac{R_{2t}}{A_1^2} = \frac{R_2 + R_3/A_2^2}{A_1^2} = \frac{R_2}{A_1^2} + \frac{R_3}{A_1^2 A_2^2}$$

$$R_{eq} = R_1 + R_2' = R_1 + \frac{R_2}{A_1^2} + \frac{R_3}{A_1^2 A_2^2}$$

Addition of noise in cascaded amplifiers

[redacted] *The first stage of a two stage amplifier has output resistance of 20 kΩ, voltage gain of 10, input resistance of 500 Ω and equivalent noise resistance 2000 Ω. The second stage has output resistance of 400 kΩ, voltage gain of 20, input resistance of 80 kΩ and equivalent noise resistance of 10 kΩ. Compute the equivalent input noise resistance of the two stage amplifier. Also compute the equivalent input noise voltage given that the bandwidth of the amplifier is 10 kHz and the ambient temperature is 300 K.*

$$R_3 = 400\text{k}\Omega$$

$$R_2 = \frac{20 \times 80}{20 + 80}\text{k}\Omega + 10\text{ k}\Omega = 26\text{ k}\Omega$$

$$R_1 = 500\ \Omega + 2000\ \Omega = 2500\ \Omega.$$

$$R_{eq} = R_1 + \frac{R_2}{A_1^2} + \frac{R_3}{A_1^2 A_1^2}$$

$$= 2500 + \frac{26,000}{(10)^2} = \frac{400,000}{(10 \times 20)^2}\text{ ohms} = 2670\ \Omega$$

$$V_{neq} = \sqrt{4\bar{k}TBR_{eq}} = \sqrt{4 \times 1.38 \times 10^{-23} \times 300 \times 10^4 \times 2670}\text{ volt}$$

$$= 0.677\ \mu\text{V}.$$

Signal to Noise Ratio (SNR)

- Purpose?
  - Comparing two system's performances
  - To know the relative signal strength at the same point

$$\frac{S}{N} = \frac{P_s}{P_n} = \frac{V_s^2/R}{V_n^2/R} = \left(\frac{V_s}{V_n}\right)^2$$

Noise Figure:

$$F = \frac{S/N \text{ at the input}}{S/N \text{ at the output}}$$

Greater than unity

>>> Noise Figure & Noise Temperature>>> Next Lecture>>>

Noise Figure and Calculation

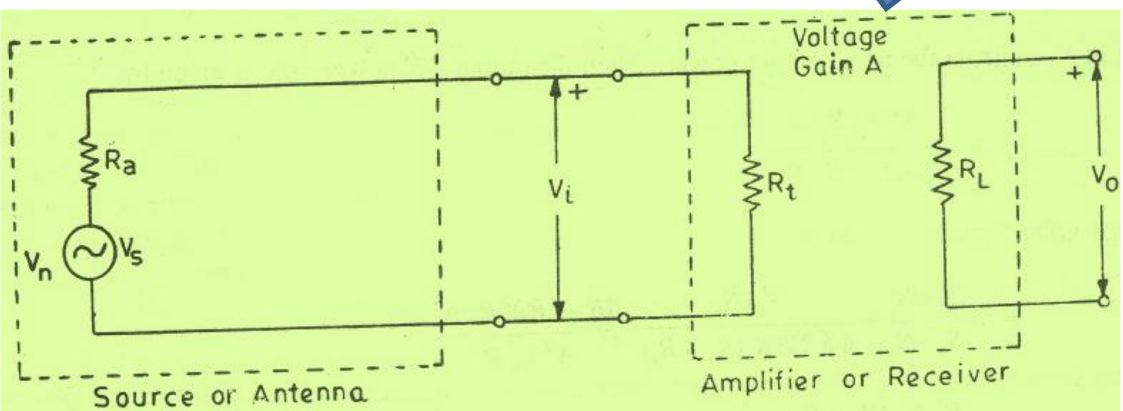
- Noise Figure

Noise Figure:

$$F = \frac{S/N \text{ at the input}}{S/N \text{ at the output}}$$

- Calculation of Noise Figure

(i) Determine the input signal power S_i
(ii) Determine the input noise power N_i
(iii) Calculate the input signal-to-noise power ratio S_i/N_i
(iv) Determine the output signal power S_o
(v) Determine the output noise power N_o
(vi) Calculate the output signal-to-noise power ratio S_o/N_o
(vii) From steps (iii) and (vi) calculate the noise figure F.



$$V_{si} = \frac{V_s R_t}{R_a + R_t}$$

$$S_i = \frac{V_{si}^2}{R_t} = \left(\frac{V_s . R_t}{R_a + R_t}\right)^2 \frac{1}{R_t} = \frac{V_s^2 R_t}{(R_a + R_t)^2}$$

Calculation of Noise Figure

Input noise voltage is given by, $V_{ni}^2 = 4\bar{k}TB\dfrac{R_a R_t}{R_a + R_t}$

Hence input noise power is, $N_i = \dfrac{V_{ni}^2}{R_t} = \dfrac{4\bar{k}TBR_a}{R_a + R_t}$

The input signal-to-noise power ratio is given by,

$$\frac{S_i}{N_i} = \frac{V_s^2 R_t}{(R_a + R_t)^2} \cdot \frac{(R_a + R_t)}{4\bar{k}TBR_a} = \frac{V_s^2 R_t}{4\bar{k}TBR_a(R_a + R_t)}$$

The output signal power is given by,

$$S_o = \frac{V_{so}^2}{R_L} = \frac{(A\,V_{si})^2}{R_L} = \left(\frac{A\,V_s R_t}{R_a + R_t}\right)^2 \cdot \frac{1}{R_L}$$

$$= \frac{A^2 V_s^2 R_t^2}{(R_a + R_t)^2 R_L}$$

Calculation of Noise Figure

$$\frac{S_o}{N_o} = \frac{A^2 V_s^2 R_t^2}{(R_a + R_t)^2 R_L N_o}$$

Hence the noise figures is given by,

$$F = \frac{S_i / N_i}{S_o / N_o} = \frac{V_s^2 R_t}{4 \bar{k} TBR_a (R_a + R_t)} \cdot \frac{(R_a + R_t)^2 R_L N_o}{A^2 V_s^2 R_t^2}$$

$$= \frac{R_L N_o (R_a + R_t)}{4 \bar{k} TBA^2 R_a T_t}$$

Noise Figure in terms of Noise Resistance

Equivalent noise resistance

$$R_{eq} = R_1 + R_2' = R_1 + \frac{R_2}{A_1^2} + \frac{R_3}{A_1^2 A_2^2}$$

I/P resistance of the first stage

Eq. noise resistance of the first stage

Noise resistance of the subsequent stages referred to the I/P of the first stage

$$R_{eq}' = R_{eq} - R_t \;\Rightarrow\; R = R_{eq}' + \frac{R_a R_t}{R_a + R_t} \;\Rightarrow\; V_{ni} = \sqrt{4kTBR}$$

Noise Figure in terms of Noise Resistance

Substitute N_0

$$N_o = \frac{V_{no}^2}{R_L} = \frac{(A\,V_{ni})^2}{R_L} = \frac{A^2 4 \bar{k} TBR}{R_L}$$

$$F = \frac{R_L(R_a + R_t)}{4\bar{k}TBA^2 R_a R_t} \cdot \frac{A^2 4\bar{k}TBR}{R_L}$$

$$= R\frac{R_a + R_t}{R_a R_t} = \left(R_{eq}' + \frac{R_a R_t}{R_a + R_t}\right) \cdot \frac{R_a + R_t}{R_a R_t} = 1 + R_{eq}' \frac{R_a + R_t}{R_a . R_t}$$

$R_t >> R_a$

$$F = 1 + \frac{R_{eq}'}{R_a}$$

Noise Temperature

- Noise Figure is a good indicator of noise performance
  - However, UHF, microwave low noise antenna, Rx or devices!
  - Noise temp << addition of noise power from several sources

$$P_t = \bar{k}\, T_t B$$

$$P_t = P_1 + P_2 = \bar{k}\, BT_1 + \bar{k}\, BT_2$$

$$\bar{k}\, BT_t = \bar{k}\, B(T_1 + T_2)$$

$$T_t = T_1 + T_2$$

Greater variation than F

where P_1 and P_2 are the two individual noise powers which may respectively be the noise powers received by the antenna and the power generated by the antenna.

T_1 and T_2 are the individual noise temperatures corresponding to P_1 and P_2 respectively and T_t is the *total* noise temperature.

Noise Temperature

- We introduce equivalent noise temperature, $\mathbf{T_{eq}}$, like Eq. noise resistance

$$F = 1 + \frac{R_{eq}'}{R_a} = 1 + \frac{\bar{k}\, T_{eq}\, BR_{eq}'}{\bar{k}\, T_o\, BR_a} = 1 + \frac{T_{eq}}{T_a}$$

where

$R_{eq}' = R_a$ as assumed in the definition of T_{eq},

$T = 27°C = 300° K$

T_{eq} = equivalent noise temperature of the receiver or amplifier under consideration.

$$T_o F = T_o + T_{eq}$$

Hence

$$T_{eq} = T_o (F - 1)$$

Noise Temperature

A receiver having equivalent noise resistance of 2500 Ω and input resistance of 500 Ω is connected to an antenna of resistance 50 Ω. Compute the noise figure (in dBs) and equivalent noise temperature for the receiver.

Solution.

$$F = 1 + \frac{R_{eq}'}{R_a}$$

$$R_{eq}' = R_{eq} - R_t = 2500 - 500 = 2000\ \Omega$$

Hence

$$F = 1 + \frac{2000}{50} = 41$$

$$F \text{ in dB} = 10 \log_{10} 41 = 16.12 \text{ dB}$$

$$T_{eq} = T_o (F - 1) = 300\,(41 - 1) = 1200°\text{K}.$$

Q & A