EEE6420

SATELLITE & OPTICAL COMMUNICATIONS

Prof Richard Langley

r.j.langley@sheffield.ac.uk

Outline Syllabus
Part 1 Satellite Communications

Communication basics

- System components
- Noise

Satellite Systems:

- Satellite system introduction
- Antennas
- Satellite orbits
- Satellite communications
- Astra satellite for TV broadcasting

Recommended Books

Benoit, H. “Satellite Television” - Arnold

Gomez, J .M. Satellite Broadcast Systems Engineering - Artech House

Livingston, D.C. The Physics of Microwave propagation - Prentice Hall

Doble, J Introduction to Radio Propagation for Fixed and Mobile Communications - Artech House

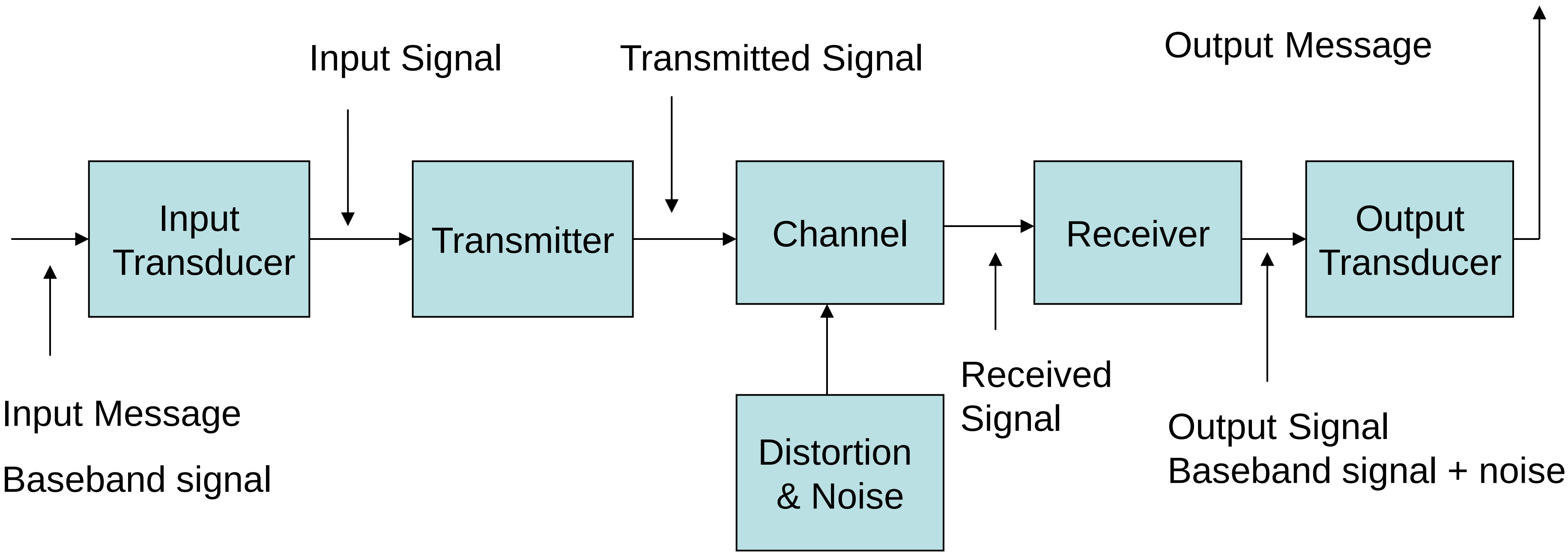
Pritchard, W.L. & Sciulli, J .A. Satellite Communication Systems Engineering - Prentice Hall

Pratt, T. & Bostian C.W., Satellite Communications - Wiley

Wood, J. Satellite Communications - Newnes

Communication BASICS

Basic Communication System

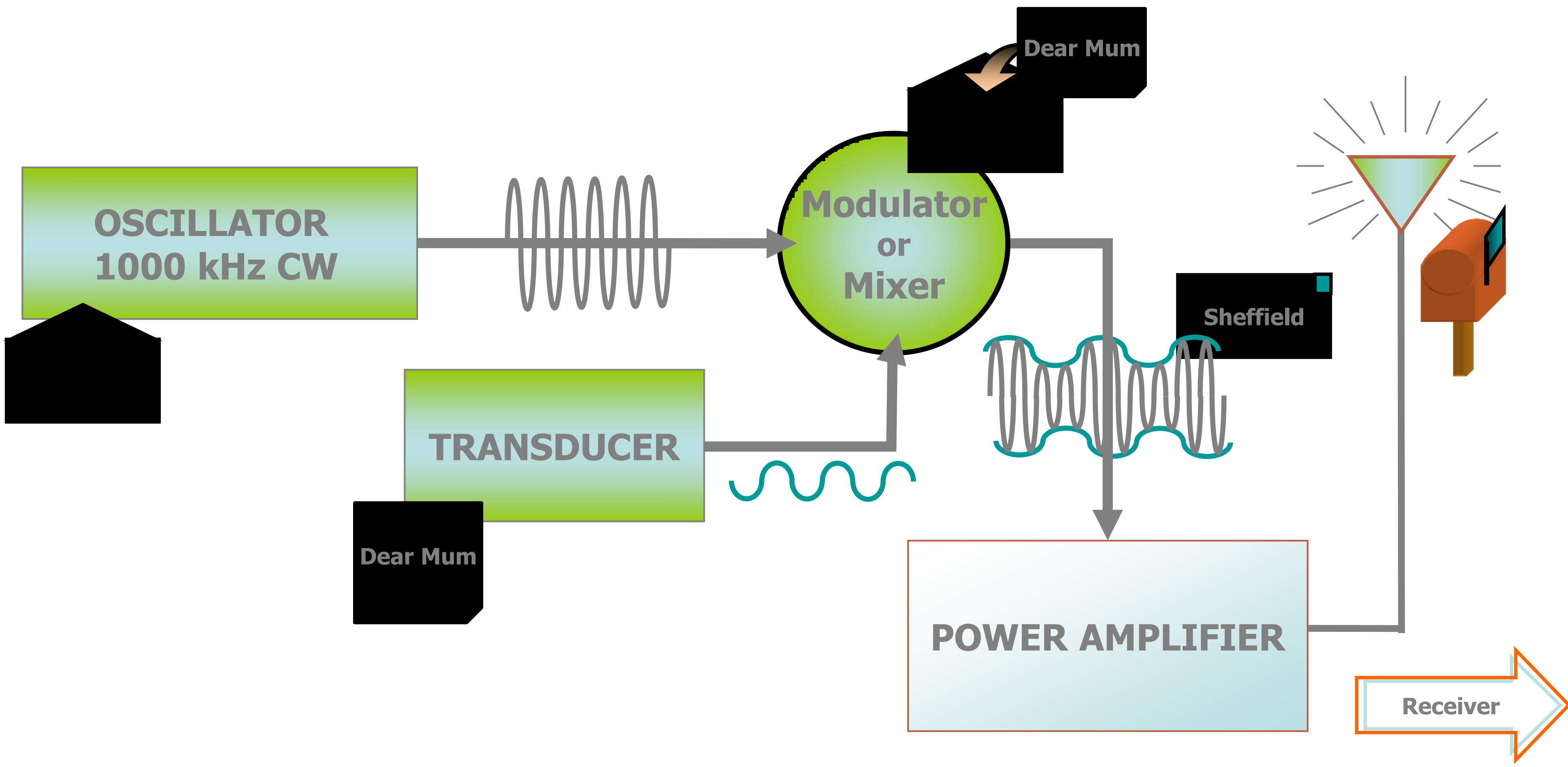


Satcom systems use frequencies above 1GHz (λ<30cm) and the transmitter and receiver spacing is >>λ.

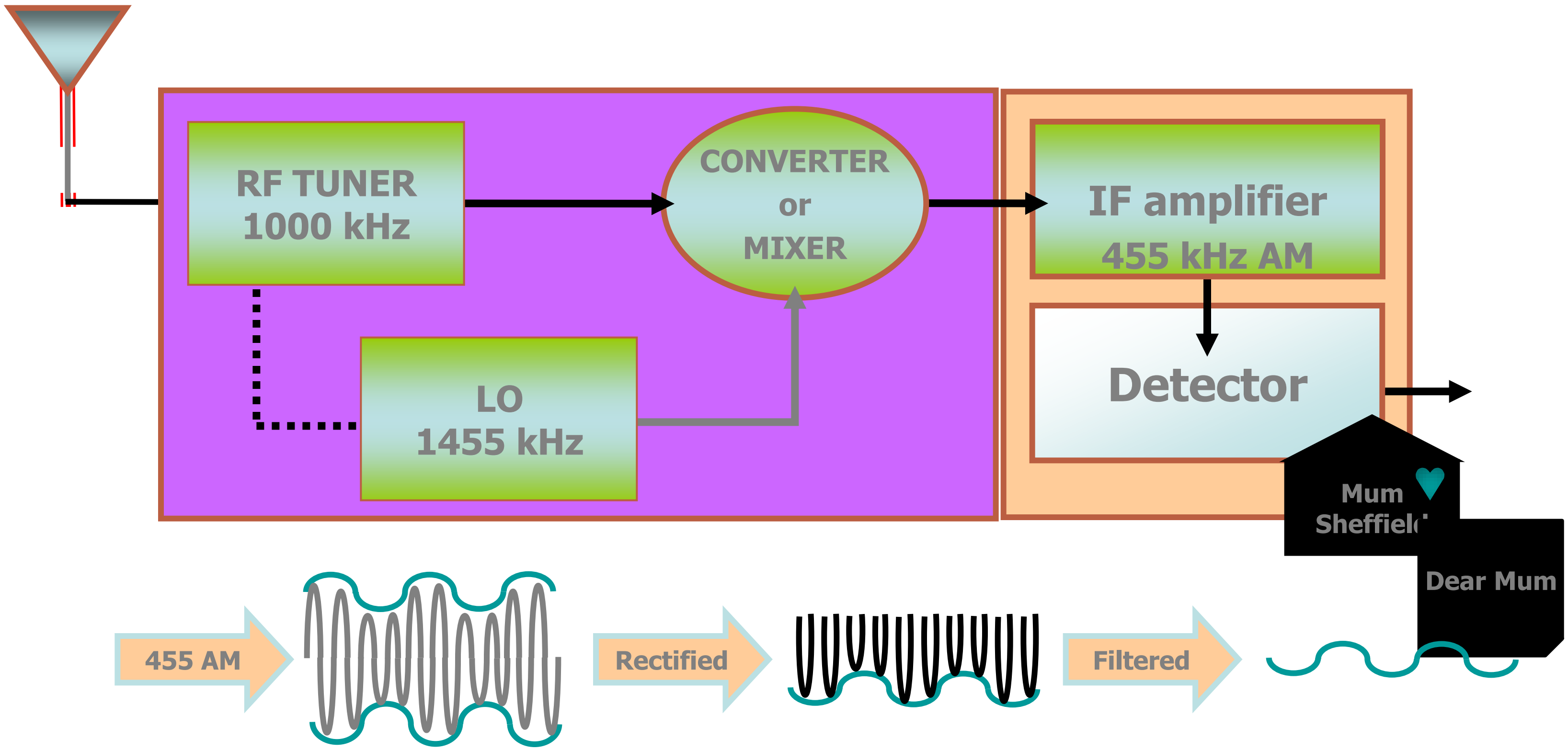
Hence only consider **<u>plane wave</u>** propagation.

Signal strength at receiver estimated from Friis formula.

COMMUNICATION TRANSMITTER



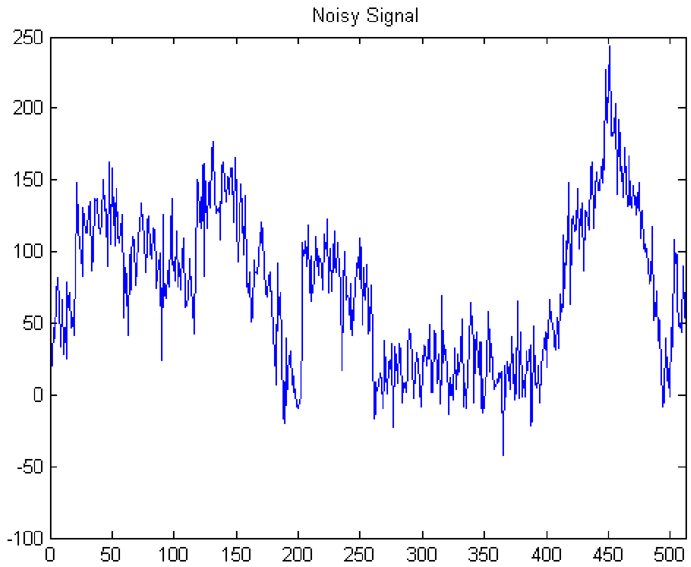
COMMUNICATION RECEIVER



Rectifies the modulated signal, then filters out the 455 KHz Leaving only the audio frequency or intelligence of 50 Hz – 20 KHz Which is sent to the AF amplifiers.

NOISE

Fundamental challenge in communication system design is that of receiving a signal that is strong enough to detect i.e. has an acceptable signal to noise ratio.



Noise Power

Noise power is expressed in Watts or Watts/Hz but it is more convenient in system design to relate it to a fictitious noise temperature T through the formula

$$P = kTB \quad \text{Watts}$$

where k = Boltzman's constant = 1.38×10^{-23} Watts/Hz/K

T = absolute temperature in degrees Kelvin

B = bandwidth in Hz

The effective noise temperature does not correspond to the physical noise temperature of the noisy component in the system but is merely a theoretical concept.

NOISE FACTOR AND NOISE FIGURE

For a linear 2 port device (amplifier) the noise factor F is defined by

$$F = \frac{C_{in} / N_{in}}{C_{out} / N_{out}} = \frac{\text{output noise power}}{\text{input noise power}}$$

where C = carrier power, N = noise power

Input noise power is equivalent to that produced by a resistor matched to the input terminal impedance of the 2 port at a standard temperature $T_0 = 290K$.

Hence F is a measure of the noise produced by a real component as compared with that from a perfect noise free component which has F = 1.

Now G = amplifier gain = C_{out}/C_{in}

$$F = \frac{N_{out}}{kT_0BG} = \frac{kT_0BG + \Delta N}{kT_0BG}$$

kT_0BG = noise power with a termination at T_0 = 290K

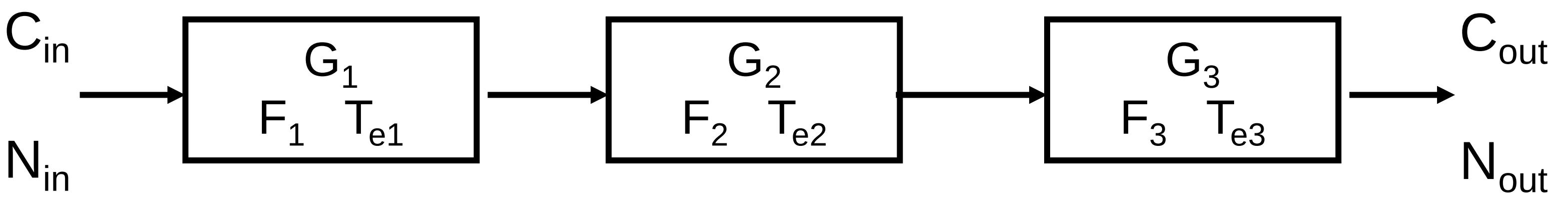
Excess noise generated by 2 port itself $\Delta N = kT_eBG$

Where T_e = temperature of fictitious resistor at input of noise free 2 port which would generate as much noise as the real noisy 2 port

Hence noise factor is given by $F = \frac{T_0 + T_e}{T_0} = 1 + \frac{T_e}{T_0}$

and **noise figure = 10 $\log_{10}$ F dB**

NOISE FACTOR OF AMPLIFIERS IN CASCADE



Noise generated by each amplifier stage multiplied by gain of next stage and succeeding stages.

3 stage ampifier:

$C_{out} = C_{in}G_1G_2G_3$

$N_{in} = k\,T_0\,B, \quad T_0 = 290K$

$N_{out} = k\,T_0\,B\,G_1\,G_2\,G_3 + k\,T_{e1}\,B\,G_1\,G_2\,G_3 + k\,T_{e2}\,B\,G_2\,G_3 + k\,T_{e3}\,B\,G_3$

Now $F_n = 1 + T_{en} / T_0$

Then $N_{out} = N_{in} G_1 G_2 G_3 + N_{in} (F_1 - 1) G_1 G_2 G_3 + N_{in} (F_2 - 1) G_2 G_3 + N_{in} (F_3 - 1) G_3$

$F = (C_{in}/N_{in})/(C_{out}/N_{out}) =$

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots\dots\dots \frac{F_n - 1}{G_1 G_2 .. G_{n-1}}$$

Hence it is an advantage to have a first amplifier stage with a low noise factor F_1 and a high gain G_1

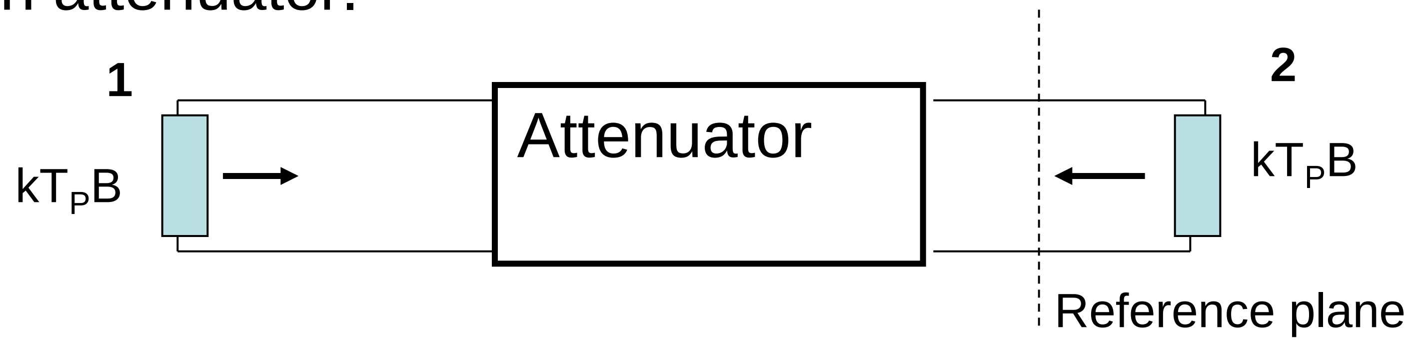
The effective noise temperature is

$$T = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \dots\dots + \frac{T_n}{G_1 G_2 ... G_{n-1}}$$

EXERCISE – show this relationship using $F_n = 1 + T_{en} / T_0$

NOISE TEMPERATURE OF LOSSY NETWORK

In practice the receiver will be connected to the antenna via a lossy transmission line or waveguide. This will act as an attenuator.



Attenuator is at a physical temperature T_P and is terminated in matched loads.

The attenuator loss factor L is defined as:

$$L = \frac{\text{powerin}}{\text{powerout}} = \frac{P_{in}}{P_{out}}$$

The fractional power absorbed by the attenuator is

$$\frac{P_{in} - P_{out}}{P_{in}} = 1 - \frac{1}{L} = 1 - t$$

Also fractional power flowing through the reference plane from LHS = power flowing from RHS

$$tkT_P B + P_n = kT_P B$$

where t=1/L and P_n =noise power generated by attenuator

Hence $P_n = kT_P B(1 - t) = kT_P B(1 - 1/L)$

*Attenuator noise temp referred to output is $T_{eout} = (1 - 1/L)T_P$

Now $$L = \frac{power.in}{power.out} = \frac{kT_{e.in}B}{kT_{e.out}B} = \frac{T_{e.in}}{T_{e.out}}$$

Hence $T_{e.out} = \dfrac{T_{e.in}}{L}$ $\quad T_{e.in} = LT_{e.out}$ & $T_{e.in} = (F-1)T_0$

Hence noise factor for a lossy network is substituting for T_{eout}

$$F = 1 + T_{e.in}/T_0 = 1 + (L-1)T_P/T_0$$

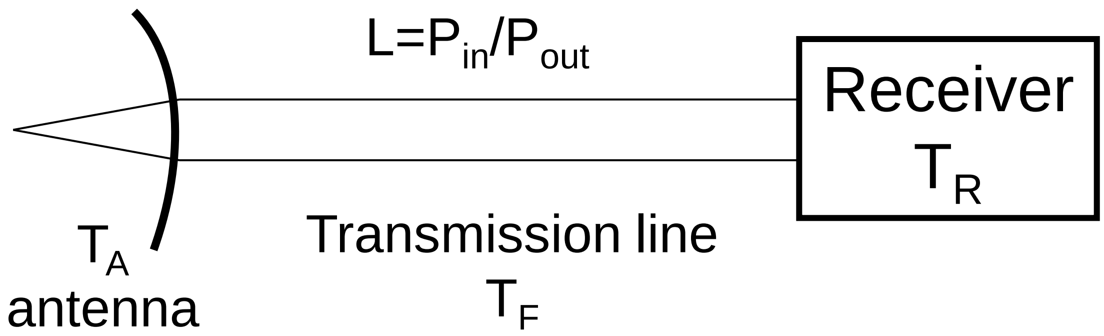
Now if $T_P = T_0$, F=L (this is usually the case)

i.e. the noise factor is numerically equal to the loss factor

e.g. In terms of noise figure, if a lossy network has an attenuation of 5 dB, its noise figure is also 5 dB.

NB For calculations use ratio NOT dB

RECEIVING SYSTEM NOISE TEMPERATURE



Total system noise temperature T_S has 3 components

T_A = noise power received by antenna from external sources and itself
T_F = noise generated due to losses in transmission line
T_R = noise power generated in receiver

*Attenuator noise power referred to output is

$$T_{eout} = T_F = (1 - 1/L)T_P$$

Now $T_P = T_0$ and noise temperature **at receiver** is

$$T'_S = \frac{T_A}{L} + (1 - \frac{1}{L})T_0 + T_R$$

If we now refer the noise plane to the **antenna** then

$$T_S = LT'_S$$

$$T_S = T_A + (L - 1)T_0 + LT_R$$

Remember $L = P_{in}/P_{out}$

So lowest T_S when $L = 1$ (no loss) and then $T_S = T_A + T_R$

At low frequencies $T_A >> T_R$ and receiver noise performance is of less importance.

At microwave carrier frequencies T_A is small and therefore T_R must be as small as possible for a high performance receiver system.

For a domestic satellite television receiver at 11 GHz, noise figure is ~0.6 dB = 100K.

Sky noise vs elevation angle

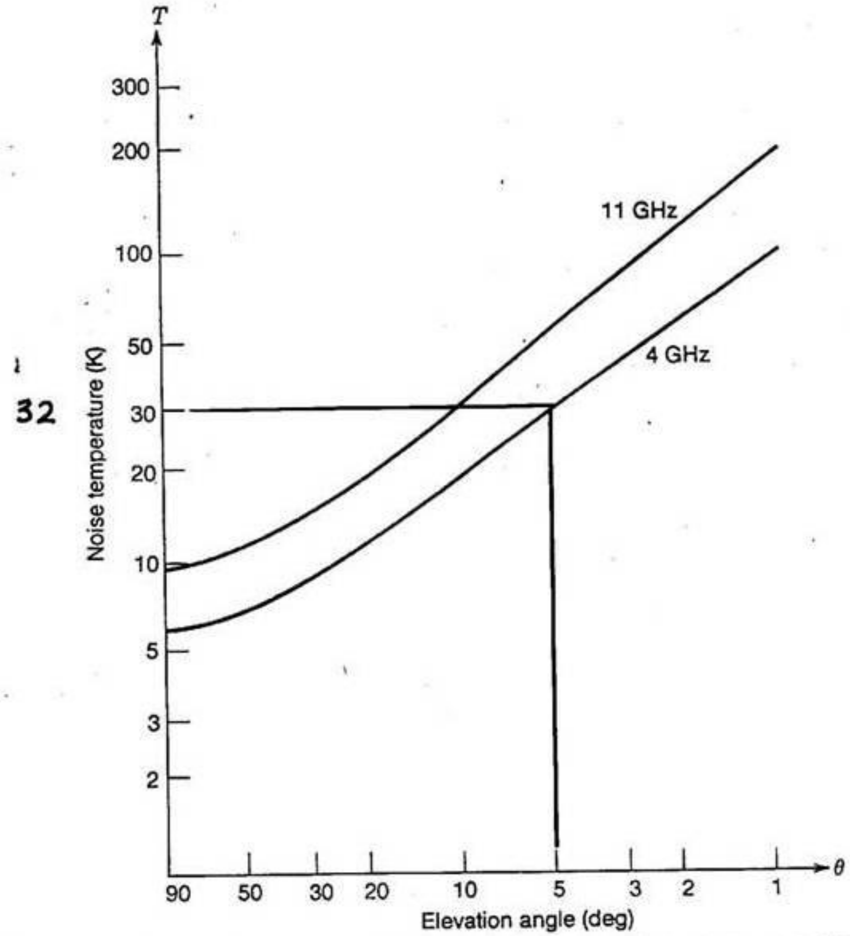


Figure 9.15 Sky noise temperature as a function of elevation angle at 4 GHz and 11 GHz. Clear-air conditions.

Example: A radio receiver operating at 1 GHz has a noise figure of 2 dB.

(a) If it is directly connected to an antenna/amplifier with a gain of 6dB and noise temperature of 100 K, estimate the overall system noise figure.

(b) If the antenna is now connected to the receiver via a 5 m length of coaxial cable with an attenuation of 1 dB, estimate the new system noise figure.

Noise factor $$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots\ldots\ldots \frac{F_n - 1}{G_1 G_2 .. G_{n-1}}$$

And F related to T by $$F = 1 + \frac{T_e}{T_0}$$, T_0 = 290

Example

A simple superhet receiver was used to receive signals from a satellite based transmitter operating at 3.8 GHz. The measured carrier-to-noise ratio was 5 dB. This was increased to 17 dB by inserting a GaAs FET amplifier between the receiver and the receiving antenna. If the amplifier has a power gain of 20 dB, and a noise figure of 1 dB, estimate the noise figure of the receiver alone.

Solution

For receiver alone

$C_o / N_o = C_i/(N_i F)$ $\quad\quad\quad\quad$ $F = (T_o + T_R)/T_o$

$N_i = kT_oB = k290B$ $\quad\quad$ and $N_i F = kT_oB\,(T_o + T_R)/T_o = kB(T_o + T_R)$