NOISE

- Noise in electrical terms may be defined as any unwanted introduction of energy tending to interfere with the proper reception and reproduction of transmitted signals.
- Noise is mainly of concern in receiving system, where it sets a lower limit on the size of signal that can be usefully received. Even when precautions are taken to eliminate noise from faulty connections or that arising from external sources, it is found that certain fundamental sources of noise are present within electronic equipment that limit the receivers sensitivity.

Classification of noise

NOISE

NOISE WHOSE SOURCES ARE EXTERNAL TO THE RECEIVER	**NOISE CREATED WITHIN THE RECEIVER ITSELF**

EXTERNAL NOISE

- Noise created outside the receiver
- External noise can be further classified as:
  1. Atmospheric
  2. Extraterrestrial
  3. Industrial

ATMOSPHERIC NOISE

- Atmospheric noise or static is generally caused by lightning discharges in thunderstorms and other natural electrical disturbances occurring in the atmosphere.

- Since these processes are random in nature, it is spread over most of the RF spectrum normally used for broadcasting.

- Atmospheric Noise consists of spurious radio signals with components distributed over a wide range of frequencies. It is propagated over the earth in the same way as ordinary radio waves of same frequencies, so that at any point on the ground, static will be received from all thunderstorms, local and distant.

- Atmospheric Noise becomes less at frequencies above 30 MHz Because of two factors:-

1. Higher frequencies are limited to line of sight propagation i.e. less than 80 km or so.
2. Nature of mechanism generating this noise is such that very little of it is created in VHF range and above.

EXTRATERRESTRIAL NOISE

COSMIC NOISE **SOLAR**

NOISE

Solar Noise

- Under normal conditions there is a constant noise radiation from sun, simply because it is a large body at a very high temperature (over 6000°C on the surface, it therefore radiates over a very broad frequency spectrum which includes frequencies we use for communication.

- Due to constant changing nature of the sun, it undergoes cycles of peak activity from which electrical disturbances erupt, such as corona flares and sunspots. This additional noise produced from a limited portion of the sun, may be of higher magnitude than noise received during periods of quite sun.

Cosmic Noise

- Sources of cosmic noise are distant stars (as they have high

- temperatures), they radiate RF noise in a similar manner as our Sun, and their lack in nearness is nearly compensated by their significant number.

- The noise received is called Black Body noise and is distributed fairly uniformly over the entire sky.

INDUSTRIAL NOISE

- This noise ranges between 1 to 600 MHz (in urban, suburban and other industrial areas) and is most prominent.

- Sources of such Noise : Automobiles and aircraft ignition, electric motors, switching equipment, leakage from high voltage lines and a multitude of other heavy electrical machines.

- **The Noise is produced by the arc discharge present in all these operations. (this noise is most intense industrial and densely populated areas)**

INTERNAL NOISE

- Noise created by any of the active or passive devices found in receivers.

- Such noise is generally random, impossible to treat on individual voltage basis, but easy to observe and describe statistically. Because the noise is randomly distributed over the entire radio spectrum therefore it is proportional to bandwidth over which it is measured.

- Internal noise can be further classified as:
  1. Thermal Noise
  2. Shot Noise
  3. Low frequency or flicker Noise

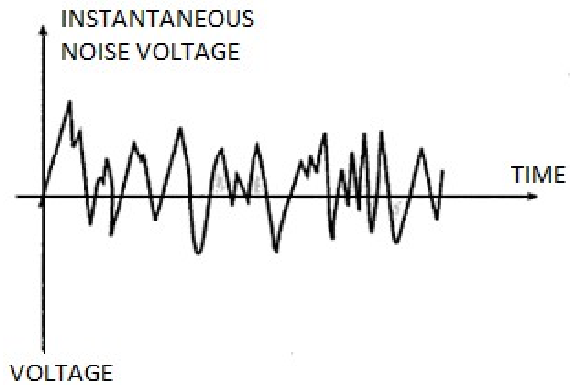
4. Burst Noise
5. Partition Noise

Thermal Noise

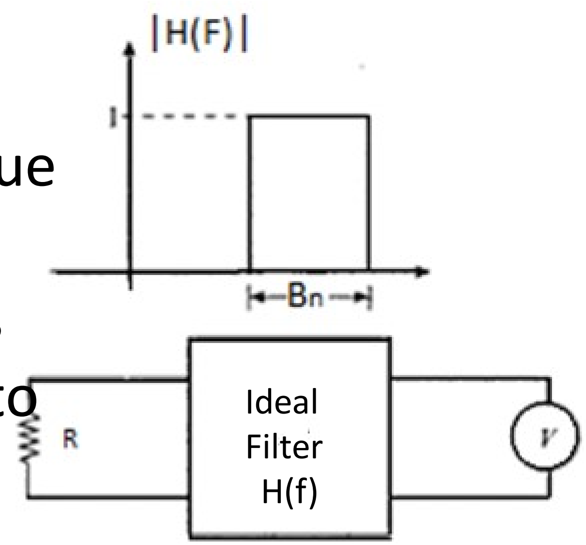
- The noise generated in a resistance or a resistive component is random and is referred to as thermal, agitation, white or Johnson noise.

- CAUSE :
  - The free electrons within an electrical conductor possess kinetic energy as a result of heat exchange between the conductor and its surroundings.
  - Due to this kinetic energy the electrons are in motion, this motion is randomized through collisions with imperfections in the structure of the conductor. This process occurs in all real conductors and gives rise to conductors resistance.
  - As a result, the electron density throughout the conductor varies

randomly, giving rise to randomly varying voltage across the ends of conductor. Such voltage can be observed as flickering on a very sensitive voltmeter.



- The average or mean noise voltage across the conductor is zero, but the root-mean-square value is finite and can be measured.
- The mean square value of the noise voltage is proportional to the resistance of the conductor, to its absolute temperature, to the frequency bandwidth of the device measuring the noise.
- The mean-square voltage measured on the meter is found to be



MEASUREMENT OF THERMAL NOISE

$$E_n^2 = 4RkTB_n \qquad (1)$$

Where E_n = root-mean-square noise voltage, volts

R = resistance of the conductor, ohms

T = conductor temperature, kelvins

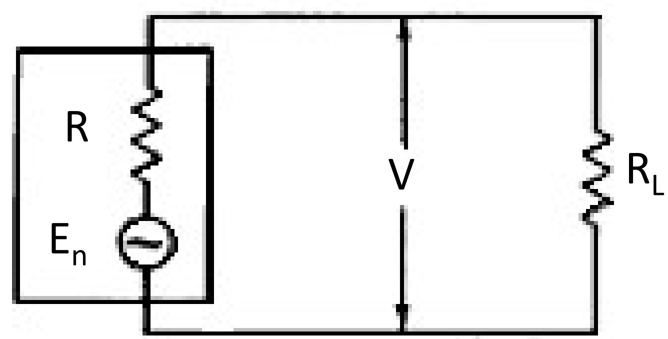
B_n = noise bandwidth, hertz

k = Boltzmann's constant (1.38×10^{-23} J/K)

And the rms noise voltage is given by :

$$E_n = \sqrt{(4RkTB_n)}$$

NOTE: Thermal Noise is not a free source of energy. To abstract the noise power, the resistance **R** is to be connected to a resistive load, and in thermal equilibrium the load will supply as much energy to **R** as it receives.



➢ In analogy with any electrical source, the available average power is defined as the maximum average power the source can deliver. Consider a generator of EMF E_n volts and internal resistance R .

➢ Assuming that R_L is noiseless and receiving the maximum noise power generated by R; under these conditions of maximum power transfer, R_L must be equal to R. Then

$$P_n = V^2/R_L = V^2/R = (E_n/2)^2/R = E_n^2/4R$$

Using Equation 1,

$$P_n = kTB_n$$

❖ Example:

Calculate the thermal noise power available from any resistor at room temperature (290 K) for a bandwidth of 1MHz. Calculate also the corresponding noise voltage, given that R = 50 Ω

Solution: For a 1MHz bandwidth, the noise power is

$$P_n = 1.38 \times 10^{-23} \times 290 \times 10^{6}$$

$$= 4 \times 10^{-15}\ W$$

$$E_n^2 = 4 \times 50 \times 1.38 \times 10^{-23} \times 290$$

$$= 8 \times 10^{-13}$$

$$= 0.895\ \mu V$$

- The thermal noise properties of a resister R may be represented be the equivalent voltage generator .

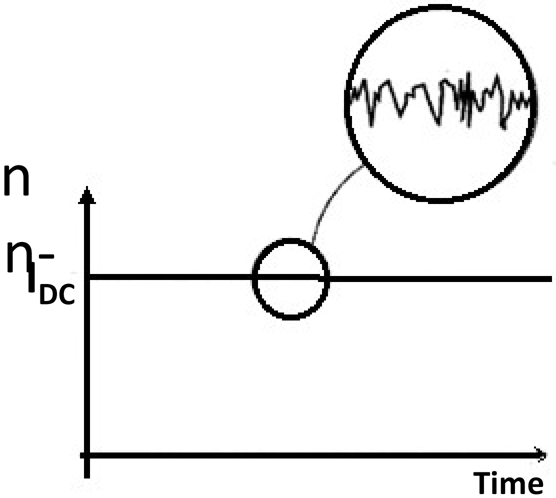
- Shot Noise

➢ Shot noise is random fluctuation (in electron emission from cathodes in vacuum tubes) that accompanies any direct current crossing potential barrier. The effect occurs because the carriers (electrons and holes in semiconductors) do not cross the barrier simultaneously but rather with random distribution in the timing of each carrier, which gives rise to random component of current superimpose on the steady current.

- In case of bipolar junction transistors , the bias current crossing the forward biased emitter base junction carries the shot noise.
- When amplified, this noise sounds as though a shower of lead shots were falling on a metal sheet. Hence the name shot noise.

- Although it is always present, shot noise is not normally observed during measurement of direct current because it is small compared to the DC value; however it does contribute significantly to the noise in amplifier circuits.

- The mean square noise component is proportion to the DC flowing, and for most devices the mean-Square, shot-noise is given by:



$$I_n^2 = 2I_{dc}\, q_e\, B_n \text{ ampere}^2$$

Where I_{dc} is the direct current in ampere's, q_e is the magnitude of electronic charge in columbs and B_n is the equivalent noise bandwidth in hertz.

❖ Example:

Calculate the shot noise component of the current present on the direct current of 1mA flowing across a semiconductor junction, given that the effective noise bandwidth is 1 MHz.

- SOLUTION

$$I_n^2 = 2 \times 10^{-3} \times 1.6 \times 10^{-19} \times 10^6$$

$$= 3.2 \times 10^{-16}\ A^2$$

$$= 18\ nA$$

- Example:

A noise generator using diode is required to produce 15 micro volts noise voltage in a receiver which has an input impedance of 75 Ω (purely resistive). The receiver has a noise power bandwidth of 200kHz. Calculate the current through the diode?

-

Low Frequency or Flicker Noise (or 1/f noise)

- This noise is observed below frequencies of few kilohertz and its spectral density increases with decrease in frequency. For this reason it is sometimes referred to as 1/f noise.

- The cause of flicker noise are not well understood and is recognizable by its frequency dependence. Flicker noise becomes significant at frequency lower than about 100 Hz. Flicker noise can be reduced significantly by using wire-wound or metallic film resistors rather than the more common carbon composition type.

- **Source:** In vacuum tubes it arises from slow changes in the oxide structure of oxide-coated cathodes and from the migration of impurity ions through the oxide. In semiconductors because of fluctuations in the carrier densities.

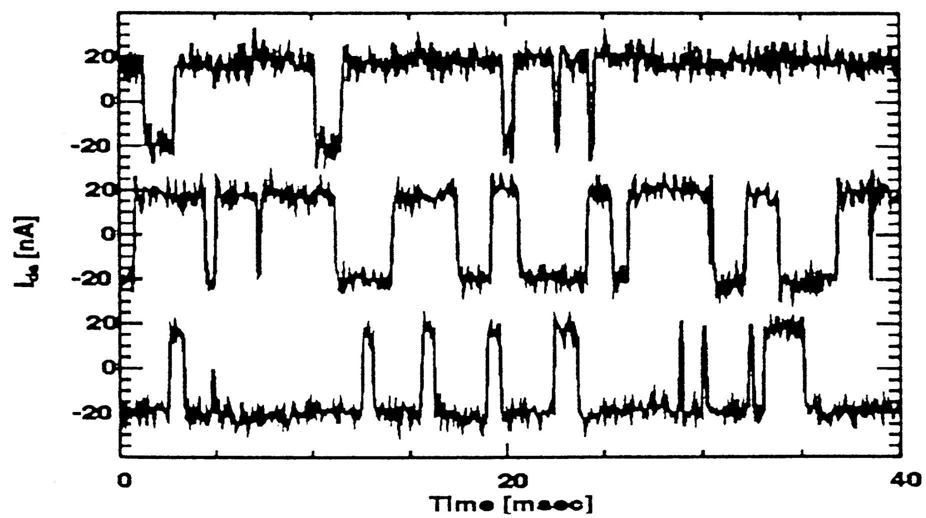
In semiconductors, flicker noise arises from fluctuations in the carrier densities (holes and electrons), which in turn give rise to fluctuations in the conductivity of the material. i.e . the noise voltage will be developed whenever direct current flows through the semiconductor, and the mean square voltage will be proportional to the square of the direct current.

Burst Noise (Popcorn Noise)

- **Source:** Bipolar Transistors
- It consists of sudden step-like transitions between two or more discrete voltage or current levels, as high as several hundred microvolts, at random and unpredictable times. Each shift in offset voltage or

- current often lasts from several milliseconds to seconds, and sounds like popcorn popping if hooked up to an audio speaker.

- The most commonly invoked cause is the random trapping and release of charge carriers at thin film interfaces or at defect sites in bulk semiconductor crystal. In cases where these charges have a significant impact on transistor performance (such as under an MOS gate or in a bipolar base region), the output signal can be substantial. These defects can be caused by manufacturing processes, such as heavy ion-implantation, or by unintentional side-effects such as surface contamination.



Typical popcorn noise, showing discrete levels of channel current modulation due to the trapping and release of a single carrier, for three different bias conditions

Partition Noise

- Partition noise occurs whenever current has to divide between two or more electrodes and results from the random fluctuations in the division.

- It is therefore expected that a diode would be less noisy than a transistor if the third electrode draws current. It is for this reason that the input stage of microwave receivers is often a diode circuit.

- In case of common base transistor amplifier , as the emitter current is divided into base and collector current , the partition noise effect arises due to **random fluctuation in the division of current between the collector and the base.**

Signal to noise ratio

- In communication it is the signal to noise ratio rather than absolute value of noise.

- It is defined as a power ratio $S/N = P_s/P_n = V^2{}_s/V^2{}_n$

- signal to noise ratio in dB = 10 log (P_s/P_n) = 20 log(V_s/V_n)

NOISE FACTOR

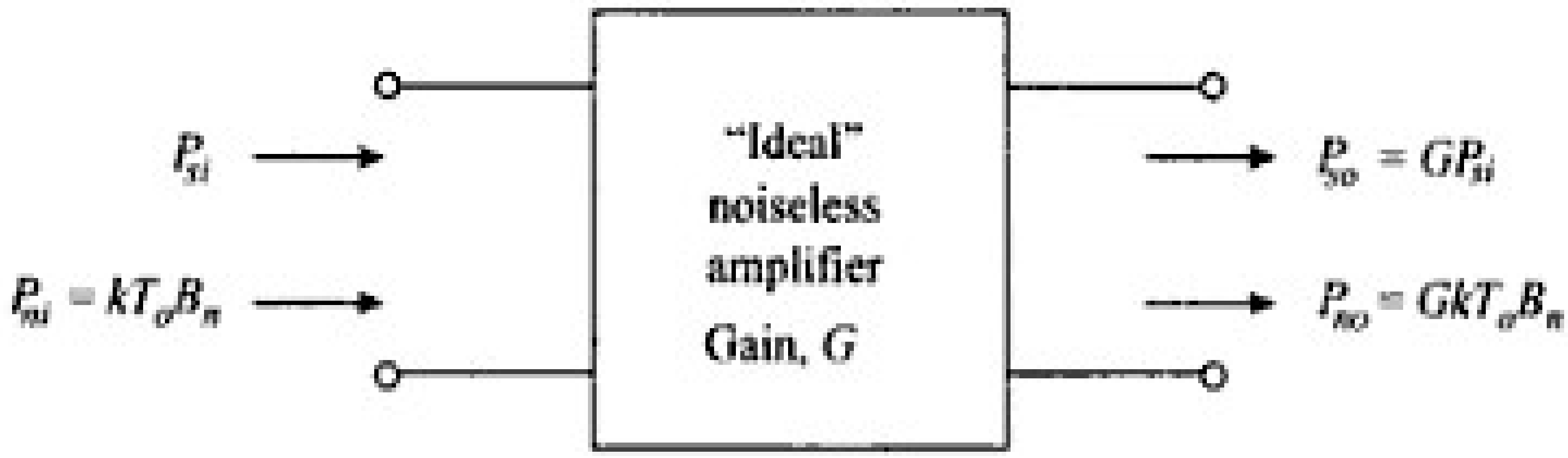
- Noise factor is the ratio of available S/N ratio at the input to the available S/N ratio at the output .

- Consider a signal source at room temperature T_o = 290K providing an input to an amplifier . The available noise power from this would be

$$P_{ni} = kT_oB_n \ .$$

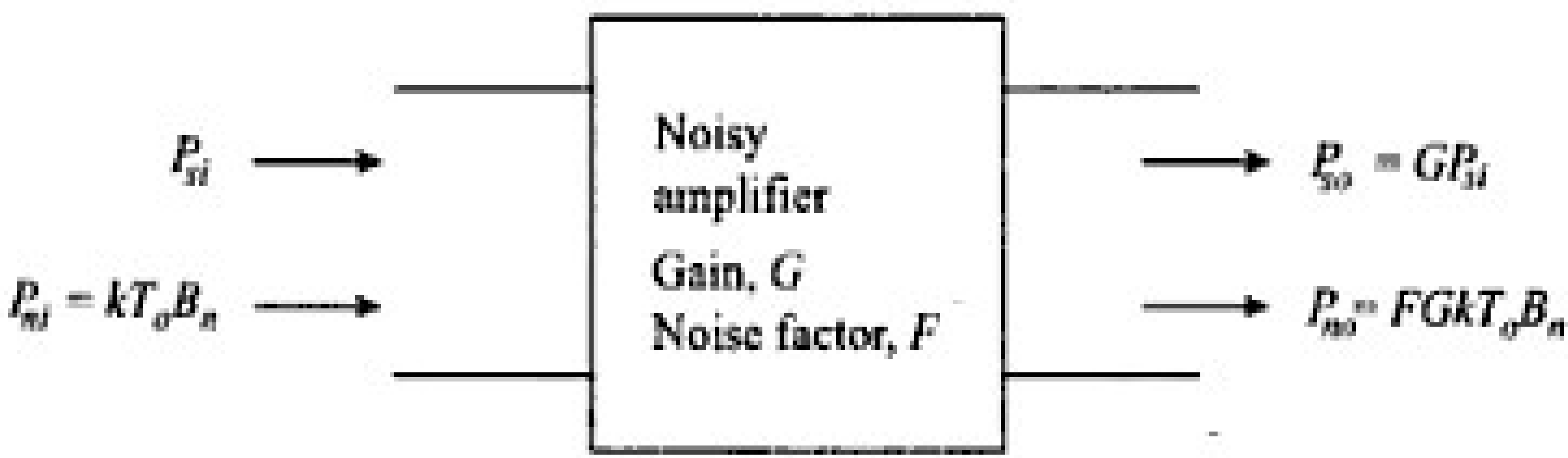
where , k = boltzmann constant = $1.38X10^{-23}$ J/K

B_n = equivalent noise bandwidth in Hz



P_{si}
$P_{ni} = kT_oB_n$
"Ideal" noiseless amplifier
Gain, G
$P_{so} = GP_{si}$
$P_{no} = GkT_oB_n$

(a)



P_{si}
$P_{ni} = kT_oB_n$
Noisy amplifier
Gain, G
Noise factor, F
$P_{so} = GP_{si}$
$P_{no} = FGkT_oB_n$

- Let the available signal power be P_{si} , then available signal to noise ratio from the source is

$$(S/N)_{ni} = P_{si} /kT_o B_n$$

- The source connected to the amplifier represents available signal to noise ratio.
- If amplifier has the available power gain denoted by G , the available output signal power $P_{so} = GP_{si}$ and if the amplifier was entirely noiseless , the available noise power would be $P_{no} = GkT_o B_n$.

However , it is known that all real amplifiers contribute noise and the available output signal to noise ratio will be less than that at the input.

NOISE FIGURE:

- The noise factor F us defined as

F = (available S/N power ratio at the input) / (available S/N power ratio at the output)

$$F = (P_{si} / kT_o B_n) \times (P_{no} / GP_{si})$$

$$\mathbf{F = P_{no} / GkT_o B_n}$$

- It follows from this that the available output noise power is given by

$$\mathbf{P_{no} = FGkT_o B_n}$$

F can be interpreted as the factor by which the amplifier increases the output noise , for ,if amplifier were noiseles the output noise would be $GkT_o B_n$.

The available output power depends on the actual input power delivered to the amplifier .

➢ Noise factor is a measured quantity and will be specified for given amplifier or network. It is usually specified in decibels , when it is referred to as the NOISE FIGURE. Thus

noise figure = (F) dB = 10logF

❖ Example

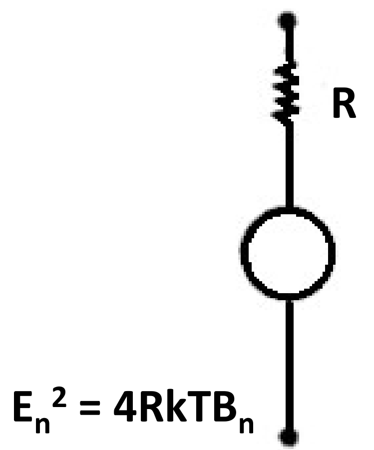
The noise figure of an amplifier is 7dB. Calculate the output signal to noise ratio when the input signal to noise ratio is 35 dB.

- Sol . From the definition of noise factor ,

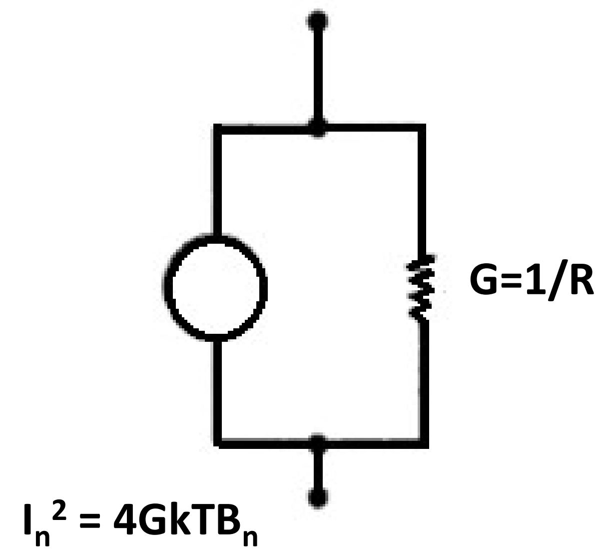
$$(S/N)_o = (S/N)_{in} – (F)\ dB$$
$$= (35 – 7)\ dB$$
$$= \mathbf{28\ db}$$

➢Equivalent current generator is found using the Norton's Theorem. Using conductance G = (1/R), the rms noise current is given by :

$I_n^2 = 4GkTB_n$



a) Equivalent Voltage Source



a) Equivalent Current Source

Resisters in Series

- let R_{ser} represent the total resistance of the series chain, where $R_{ser} = R_1 + R_2 + R_3 + ...$; then the noise voltage of equivalent series resistance is

$$E_n^2 = 4R_{ser}\, kTB_n$$
$$= 4(R_1 + R_2 + R_3 + ...)kTB_n$$
$$= E_{n1}^2 + E_{n2}^2 + E_{n3}^2 + ...$$

Hence the noise voltage of the series chain is given by:

$$E_n = \sqrt{(E_{n1}^2 + E_{n2}^2 + E_{n3}^2 + ...)}$$

Resisters in Parallel

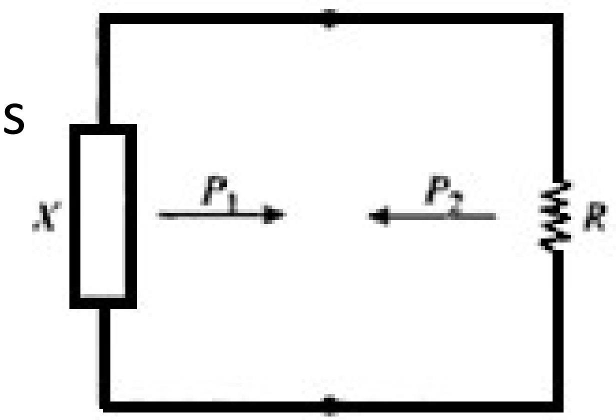
- With resistors in parallel it is best to work in terms of conductance.
- Let G_{par} represent the parallel combination where G_{par} = $G_1 + G_2 + G_3 +$ …; then

$$
\begin{aligned}
I_n^2 &= 4G_{par}\,kTB_n \\
&= 4(G_1 + G_2 + G_3 + \ldots)kTB_n \\
&= I_{n1}^2 + I_{n2}^2 + I_{n3}^3 + \ldots.
\end{aligned}
$$

Example

Two resistors of 20 and 50k Ω are room temperature (290K). For a bandwidth of 100kHz, calculate the thermal noise voltage generated by (a) each resistor, (b) the two resistors in series, and (c) the two resistors in parallel.

REACTANCE



- Reactances do not generate thermal noise. This follows from the fact that reactances cannot Dissipate power.
- Consider an inductive or capacitive reactance connected in parallel with a resistor R.
- In thermal equilibrium, equal amounts of power must be exchanged; that is, $P_1 = P_2$. But since the reactance cannot dissipate power, the power P_2 must be zero, and hence P_1 must also be zero.

Avalanche Noise

- Avalanche breakdown takes place in a reverse biased PN junction.
- In the process of avalanche breakdown, the holes and electrons in the depletion region gain sufficient energy from the reverse biased field to ionize atoms by collisions.
- This produces more holes and electrons which further ionize more atoms to produce more holes and electrons. This chain process ultimate leads to avalanching.
- The electrons atoms collision taking place in this process give rise to large noise spikes in the avalanche current.
- This unwanted voltage spikes can be avoided by using zener diodes.

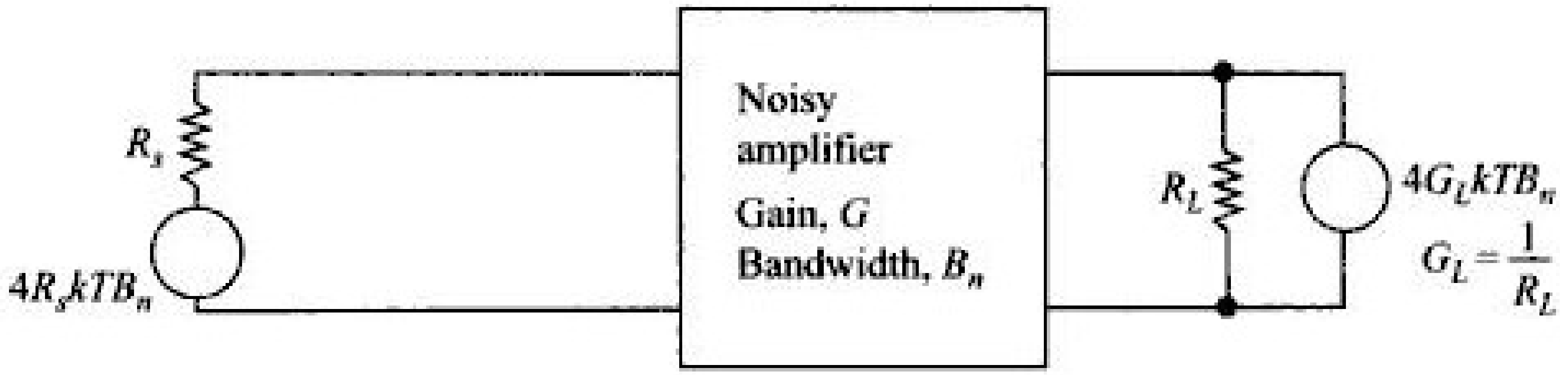
Bipolar Transistor Noise

- The noise Source present in a BJT are Thermal noise, shot noise, partition noise, flicker noise and burst noise.
- The shot noise and partition noise are produced by the bias currents in BJT. Whereas the base current produces the flicker and burst noise.

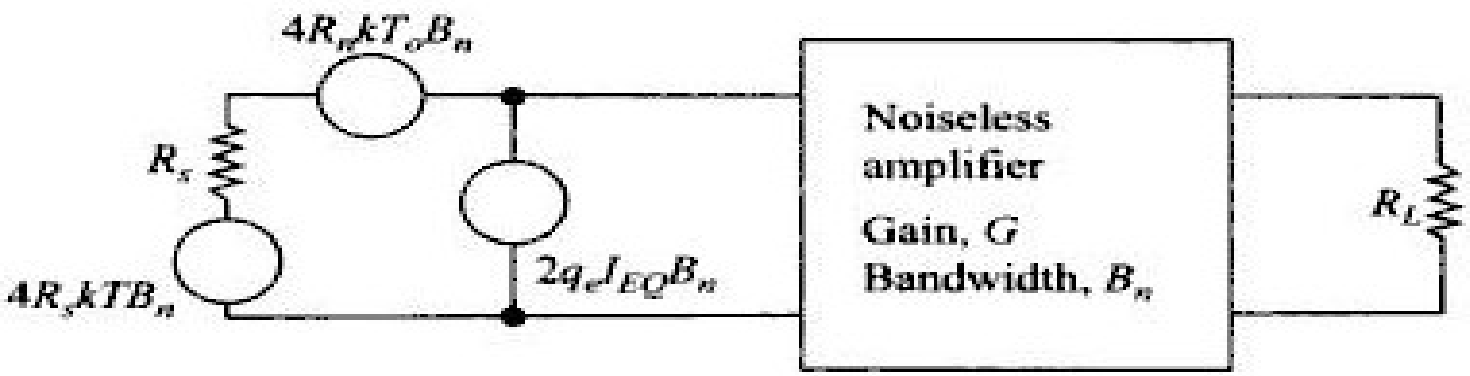
Field Effect Transistor Noise:

- In the JFET and MOSFET the most important source of noise is the thermal noise. It is generated by the physical resistance of the drain-source channel. Also produce a small flicker noise.
- The gate leakage current creates the shot noise in FET.

Equivalent and Input Noise Generators and Comparison of BJTs and FETs



(a) Noisy amplifier



(b) the equivalent input noise generators.

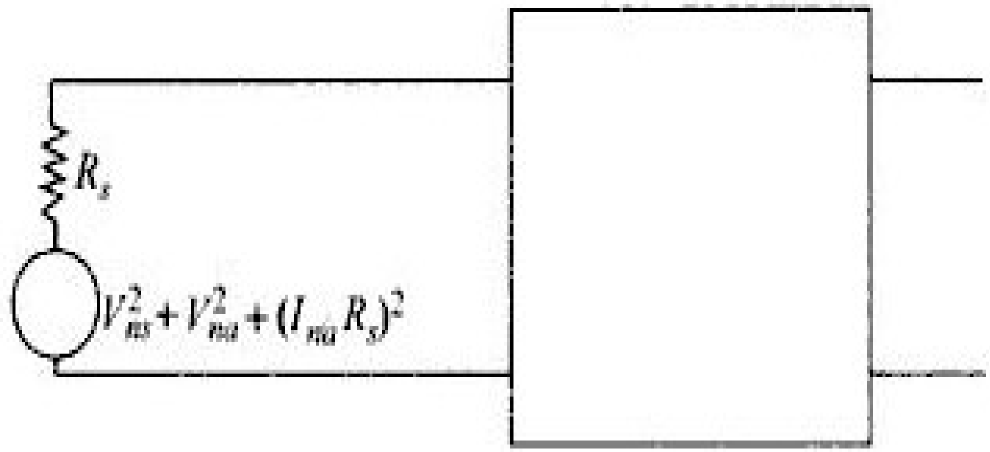
$$V_{na} = \sqrt{4R_nkT_oB_n} \text{ and } I_{na} = \sqrt{2q_eI_{EQ}B_n}$$

What is new here is the *fictitious* resistance R_n ohms, known as the *equivalent input noise resistance* of the amplifier, and I_{EQ} amperes, the *equivalent input shot noise current.*

$$V_{ns}^2 = 4R_s k T_o B_n$$

$$V_{na}^2 = 4R_n k T_o B_n$$

$$I_{na}^2 = 2q_e I_{EQ} B_n$$



The Noise generated by Load R_L is generally very small compared to the other sources and is assumed negligible, so this is dropped from the equivalent circuit.

Thus the equivalent noise voltage at the input to the amplifier is

$$V_n = \sqrt{V_{ns}^2 + V_{na}^2 + (I_{na} R_s)^2}$$

Comparison of BJT and FET Amplifiers

- R_n of BJT amplifiers is smaller than that of FET amplifiers
- I_{EQ} of BJT amplifiers is higher than that of FET amplifiers.
- If the value of signal source resistance R_s is low, then the shot noise voltage I_{na} R_s would be small enough and we can neglect it. Then the BJT will produce lower noise than FET due to smaller value of R_n.
- If the value of R_s is large than the noise voltage. I_{na} R_s also will be large and hence can not be neglected. Then due to smaller value of I_{EQ} , the FET amplifiers will produce lower noise than BJT amplifiers.

S/N Ratio of a Tandem Connection

- Repeater /amplifier insert to make up for the loss in analog telephone cable

  If power loss of a line section is L then repeater amplifier power gain G is chosen so LG=1,long line divided into identical section

  If input signal power=P_s to first section as signal passes along the link power output at

- each repeater is Ps since LG=1 for each link but noise power are additive and the total noise at the output of m^{th} link is $P_n=P_{n1}+P_{n2}+\ldots\ldots+P_{nm}$

- If each links are identical and contribute P_n then total noise power is $P_{nm}=MP_n$ then output signal to noise ratio is

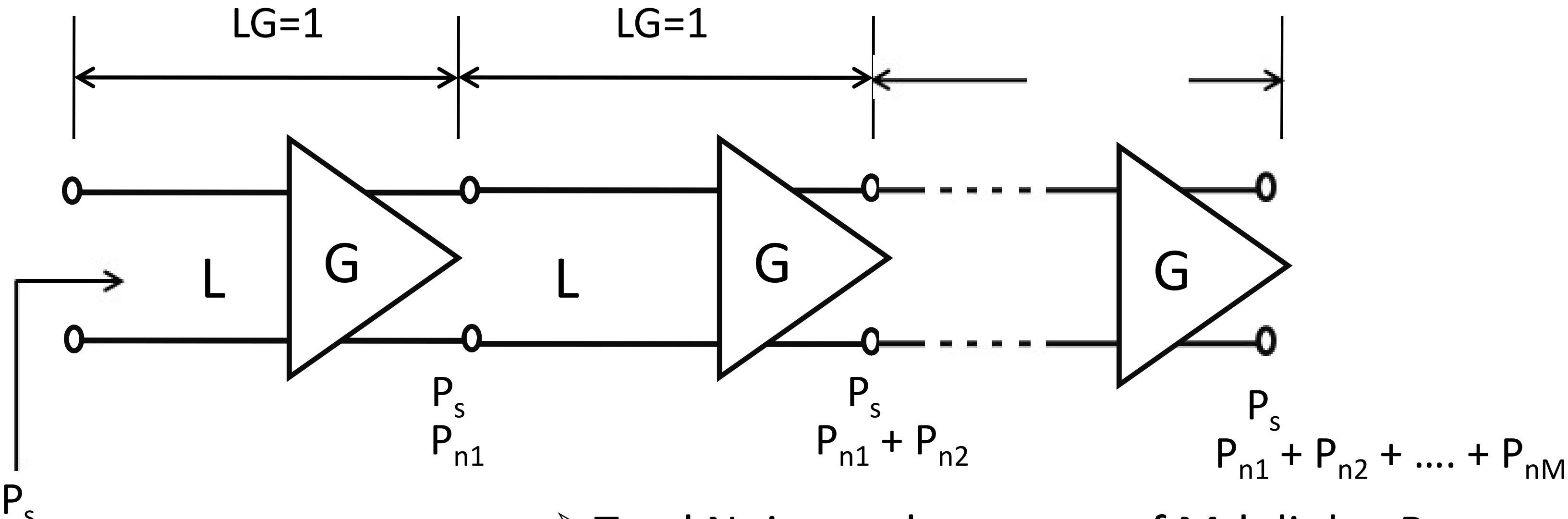
$$(S/N)_o dB = 10\log P_s/MP_n=(S/N)_1 dB-(M)dB$$

  where, $(M)dB = 10 \log M$

- Where $(S/N)_1$ is ratio for one link and M is no of links expressed as power ratio in decibels.

S/N Ratio of a Tandem Connection

Different sections of a Telephone Cable in analog telephone system.



Different Parameters:

L = Power Loss of a line section
G = Amplifier gain
P_s = Input signal Power
P_{n1} = Noise due to 1st repeater
P_{nM} = Noise due to Mth repeater
$(S/N)_1$ = Signal to noise ratio of any one link
(M)dB = No of Links expressed as power ratio in decibels

- Total Noise at the output of Mth link = $P_{n1} + P_{n2} + ... + P_{nM}$

  If the links are identical such that each link contributes P_n , the total noise power becomes

- $$P_{nM} = MP_n$$

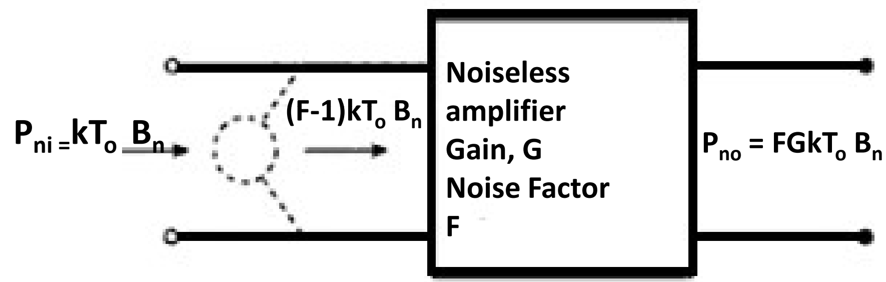
- Output signal to noise ratio :-

$$(S/N)_o = 10\log (P_s / MP_n)$$
$$= (S/N)_1 \text{ dB} – (M) \text{ dB}$$

Amplifier Input Noise in terms of F

➢Amplifier noise is generated in many components throughout the amplifier , but it proves convenient to imagine it to originate from some equivalent power source at the input of the amplifier . Then the total available input noise is

$$P_{ni} = P_{no} / G$$
$$= FkT_o B_n$$



The source contributes an available power $kT_o\ B_n$ and hence the amplifier must contribute P_{na} , where

$$P_{na} = FkT_o\, B_n - kT_o\, B_n$$

$$= \mathbf{(F - 1)kT_o\, B_n}$$

Example :

An amplifier has a noise figure of 13dB. Calculate equivalent amplifier input noise for a bandwidth of 1 MHz.

Sol. 13 dB is a power ratio of approximately 20 : 1. hence

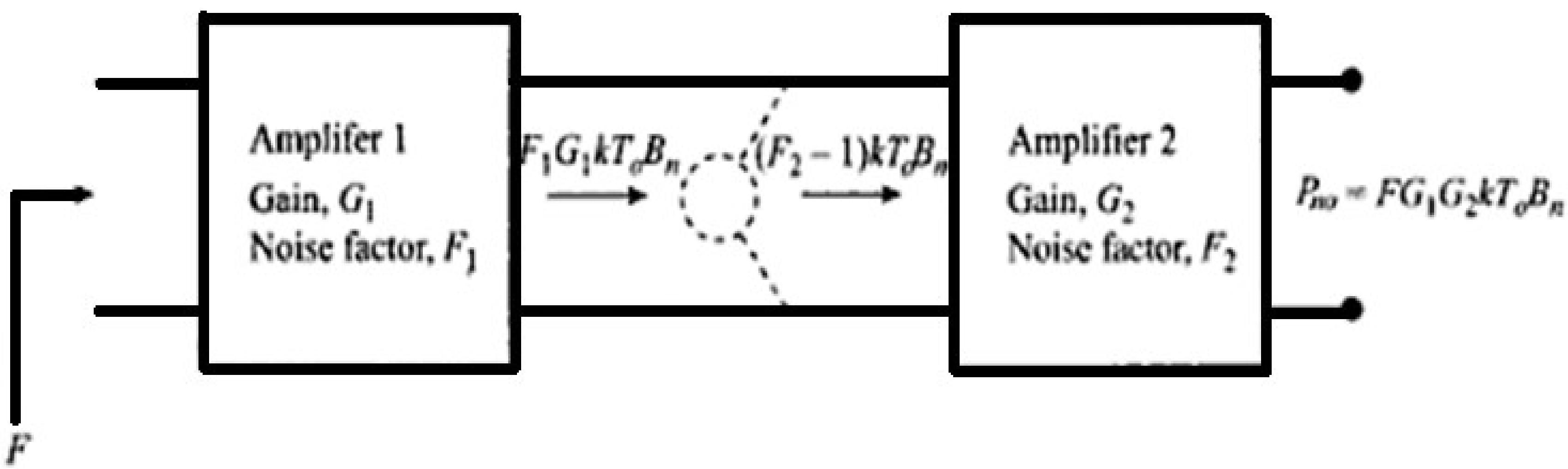
$$P_{na} = (20 - 1) X\ 4\ X\ 10^{-21}\ X\ 10^{6}$$

$$= \mathbf{1.44pW.}$$

Noise figure must be converted to a power ratio F to be used in the calculation.

Noise factor of amplifiers in cascade

➢Consider first two amplifiers in cascade . The problem is to determine the overall noise factor **F** in terms of individual noise factors and available power gains. The available noise power at the output of the amplifier 1 isP_{no1} = F_1 G_1 kT_o B_n and this available to amplifier.



e 4.15.1 Noise factor of two amplifiers in cascade.

- Amplifier 2 has noise $(F_2 - 1)kT_o B_n$ of its own at its input, hence total available noise power at the input of amplifier 2 is

$$P_{ni2} = F_1 G_1 kT_o B_n + (F_2 - 1)kT_o B_n$$

- Now since the noise of amplifier 2 is represented by its equivalent input source , the amplifier itself can be regarded as being noiseless and of available power gain G_2 , so the available noise output of amplifier 2 is

$$P_{no2} = G_2 P_{ni2}$$

$$= G_2 (F_1 G_1 kT_o B_n + (F_2 - 1)kT_o B_n) \qquad (1)$$

- The overall available power of the two amplifiers in cascade is

$G = G_1 G_2$ and let overall noise factor be **F ;** then output noise power can also be expressed as

$$P_{no} = FGkT_oB_n \qquad (2)$$

equating the two equations for output noise (1) and (2)

- $$F_1 G_1 G_2 kT_o B_n + (F_2 - 1) G_2 kT_o B_n = FGkT_oB_n$$
- $$F_1 G_1 G_2 + (F_2 - 1) G_2 = FG$$
- $$F = F_1 G_1 G_2 / G + (F_2 - 1) G_2 / G$$

  where $G = G_1 G_2$

- $$\mathbf{F = F_1 + (F_2 - 1) / G_1}$$

- This equation shows the importance of high gain , low noise amplifier as the first stage of a cascaded system. By making G_1 large, the noise contribution of the second stage can be made negligible, and F_1 must also be small so that the noise contribution of the first amplifier is low.
- The argument is easily extended for additional amplifiers to give

$$\mathbf{F = F_1 + (F_2 - 1)/G_1 + (F_3 - 1)/\ G_1\ G_2 + \ldots}$$

This is known as **FRIIS'S FORMULA.**

- There are two particular situations where a low noise , front end amplifier is employed to reduce the noise. One of these is in satellite receiving systems.

- The other is in radio receivers used to pick up weak signals such as short wave receivers.

- In most receivers , a stage known as the *mixer stage* is employed to change the frequency of the incoming signal , and it is known that the mixer stages have notoriously high noise factors. By inserting an RF amplifier ahead of the mixer , the effect of the mixer noise can be reduced to negligible levels. This is illustrated in following example.

❖Example

A mixer stage has a noise figure of 20dB and this is preceded by an amplifier that has a noise figure of 9 dB and an available power gain of 15dB. Calculate overall noise figure referred to the input .

Sol. It is necessary to convert all decibel values to the equivalent power ratios :

F_2 = 20dB = 100:1 power ratio

F_1 = 9dB = 7.94:1 power ratio

G_1 =15dB = 31.62:1 power ratio

$F = F_1 + (F_2 – 1)/ G_1$

$= 7.94 + (100-1)/31.62$

= **11.07**

This is overall noise factor. The overall noise figure is

(F)dB= 10 log 11.07

= **10.44dB**

NOISE TEMPERATURE

- The concept of noise temperature is based on available noise power equation

$$P_n = kT_a B_n$$

Here the subscript has been included to indicate the noise temperature is associated only with available noise power.

- In general, T_a will not be same as that physical temperature of the noise source.
- As an example, an antenna pointed at deep space will pick up a small amount of cosmic noise.

The equivalent noise temperature of antenna that represents this noise power may be a few tens of kelvins, well below the physical ambient temperature of the antenna.

If the antenna is directly pointed at the sun , the received noise power increases enormously and the corresponding equivalent noise temperature is well above the ambient temperature.

- When the concept is applied to an amplifier, it relates to equivalent noise of the amplifier referred to the input. If the amplifier noise referred to the input is denoted by P_{na} , the equivalent noise temperature of the amplifier referred to the input is

$$T_e = P_{na} / kB_n \quad \rightarrow (3)$$

We know equivalent input power for an amplifier is given in terms of its noise factor by

$$P_{na} = (F-1)kT_o B_n$$

$$P_{na} / k B_n = (F-1)T_o$$

putting this in equation (3)

we get equivalent noise temperature of the amplifier as $\mathbf{T_e = (F-1)T_o}$

This shows the proportionality between T_e and F.

➢In practice it is found that noise temperature is the better measure for low noise devices , such as low noise amplifiers used in satellite receiving systems while noise factor is a better measure for the main receiving system.

Equivalent Noise Temperature For Cascade System:

➢Friss's formula can be expressed in terms of equivalent noise temperatures. Denoting by T_e the overall noise of the cascaded system referred to the input , and by T_{e1} , T_{e2} , and so on , the noise temperatures of the individual stages , the in Friss's formula is easily rearranged to give

$$T_e = T_{e1} + T_{e2} / G_1 + T_{e3} / G_1 G_2 + \ldots\ldots.$$

Proof by using Friss's Formula

By Friis's formula $\mathbf{F = F_1 + (F_2 -1)/G_1 + (F_3 -1)/ G_1 G_2 + \ldots}$

Substract "1" from both the sides to get,

$$\mathbf{F -1= (F_1 -1)+ (F_2 -1)/G_1 + (F_3 -1)/ G_1 G_2 + \ldots}$$

Since $\mathbf{T_e = (F\text{-}1)T_o}$, $\mathbf{(F\text{-}1) = T_e /T_o}$

$$\mathbf{T_e /T_o = (T_{e1} /T_o)+ (T_{e2} /T_o G_1)+ (T_{e2} /T_o G_1 G_2)+ \ldots}$$

$$\mathbf{T_e = T_{e1} + T_{e2} /G_1 + T_{e3} / G_1 G_2 + \ldots}$$

Q. A receiver has a noise figure of 12dB and it is fed by a low noise amplifier that has gain of 50dB and a noise temperature of 90 K. calculate the noise temperature of the receiver and the overall noise temperature of the receiving system.

SOL. 12dB represents a power ratio of 15.85 : 1. Hence

T_{em} = (15.85-1) X 290 = 4306 K (by formula **$T_e = (F-1)T_o$**)

The 50dB gain represents a power ratio of 10^5 : 1 . Hence

T_e = 90 + 4306/ 10^5 **(by formula $T_e = T_{e1} + T_{e2} / G_1$**)

= **90 K**

This example shows the relatively high noise temperature of the receiver , which clearly cannot be its physical temperature. It also shows how the low noise amplifier controls the noise temperature of the overall receiving system.

Measurement of Noise Temperature and Noise Factor

- Noise temperature (and noise factor) can be measured in number of ways, the method selected depending largely on the range of values expected.
- For normal receiving systems, an avalanche diode noise source is commonly employed. We discuss this method
- Excess Noise Ratio (dB) = 10 log $\{(T_h - T_c)/ T_c\}$

  where, $T_c = T_o = 290K$, T_h = hot temperature
- The ENR for the source is normally printed on the diode enclosure and is specified by the manufacturer for a range of frequencies. Knowing the ENR and T_c the hot temperature T_h can be found.

- Now let the diode source be matched to the input of the amplifier under test, and let the equivalent input noise temperature of the amplifier be denoted by T_e (unknown).
- The amplifier output noise is measured for two conditions: First, one with the diode in the avalanche mode, denoted by P_h .

$$P_h = Gk(T_h + T_e)B_n$$

- Another one with the reverse bias switched off, denoted by P_c

$$P_c = GK(T_c + T_e)B_n$$

$$Y = \frac{P_h}{P_c} = \frac{T_h + T_e}{T_c + T_e}$$

Solving these equation for T_e

$$T_e = \frac{T_h - YT_c}{Y - 1}$$

Measurement fo Noise Factor

- From the value of noise temperature, we can find the value of the noise factor
- We know that $T_e = (F-1)T_o$
- Substituting the the expression of T_e we get

$$F = \frac{T_e}{T_o} + 1$$

By substituting the value of T_e , we get

$$F = \frac{T_h - YT_c}{T_o(Y-1)} + 1 = \frac{T_h - YT_c + T_o(Y-1)}{T_o(Y-1)}$$

From ENR

$$ENR = \frac{T_h - T_c}{T_c}$$

$$T_h = T_c(ENR + 1)$$

- Substituting in to the expression for F we get, where ($T_c = T_0$)

$$F = \frac{ENR}{(Y-1)}$$

- Example: In the measurement of noise temperature, avalanche diode source diode source is used, the ENR being 14 dB. The measured Y factor is 9dB. Calculate the equivalent noise temperature of the amplifier under test.

Noise Factor of a Lossy Network

- When a signal source is matched through a lossy network, (example connecting cable), signal power at the output is reduced due to insertion loss of the network.
- Noise out put is kT_oB_n remains unchanged , because noise power is independent of source resistance.
- In effect, the network attenuates the source noise, but the same time adds noise of its own. The S/N ratio is therefore reduced by the amount that the output power is attenuated.
- Power insertion loss ratio denote as L, signal power at the output is 1/L times the input signal power, then noise factor is

  $F = (S/N)/(S/LN) = L$

- So overall Noise factor for a lossy network with available power gain is 1/L by Friss's formula is

$$F = F_{nw} + (F_a - 1)/ G_{nw} = L + (F_a - 1).L$$

When input source is connected with lossy network to the amplifier

F_{nw} = Noise factor of lossy network

F_a = Noise factor of amplifier

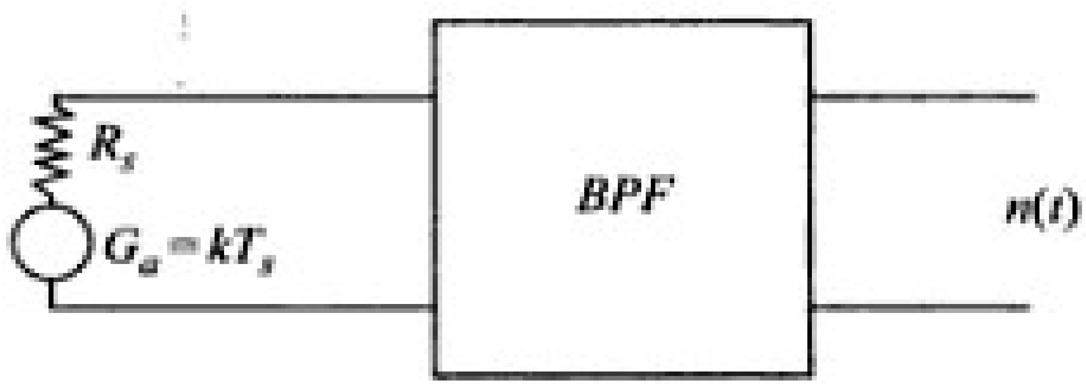
- Alternatively, if the amplifier is placed ahead of the network, the overall noise factor is

$$F = F_a + (F_{nw} - 1)/ G_a = F_a + (L - 1)/ G_a$$

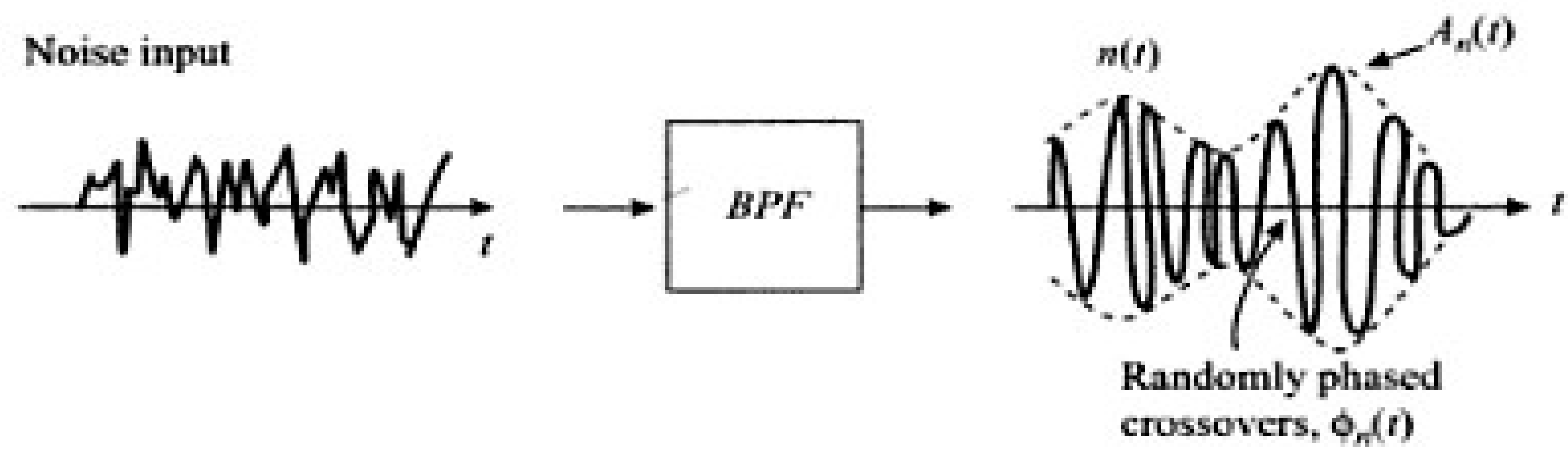
In this case, provided the amplifier has high gain, the overall noise factor of the system is essentially that of the amplifier alone.

Narrow Bandpass Noise

- **Narrow Bandpass System:** System in which the center frequency is much higher than the bandwidth



where R_s is Internal Resistance, system noise is referred to the input as a thermal noise source at noise temperature T_s .



- The available power spectral density of the thermal noise at the input is kT_s
- Filter bandwidth determines the available noise power as kT_sB_N
- The output waveform has the form of a modulated wave and can be expressed mathematically as $n(t) = A_n \cos(\omega_c t + \varphi_n(t))$.
- Where A_n is randomly varying voltage envelope and $\varphi_n(t)$ is random phase angle.

$$n(t) = A_n\left[\cos(\omega_c t)\cos\left(\varphi_n(t)\right) - \sin(\omega_c t)\sin\left(\varphi_n(t)\right)\right]$$
$$= n_I(t)\cos(\omega_c t) - n_Q(t)\sin(\omega_c t)$$

Where $n_I(t) = A_n \cos\left(\varphi_n(t)\right)$ is random noise voltage termed the in-phase component because it multiplies by a cosine term and $n_Q(t) = A_n \sin\left(\varphi_n(t)\right)$ is random noise voltage termed the quadrature component because it multiplies by a sine term.

- Power spectral density of $n(t)$` is $G_a(f) = kT_s$
- Power spectral densities for $n_I(t)$ and $n_Q(t)$ are $G_I(f) = G_Q(f) = 2kT_s$