Noise in Communication Systems

What is noise?

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- In electrical terms, it is an unwanted signal, which interfere with the desired signal.

Example:

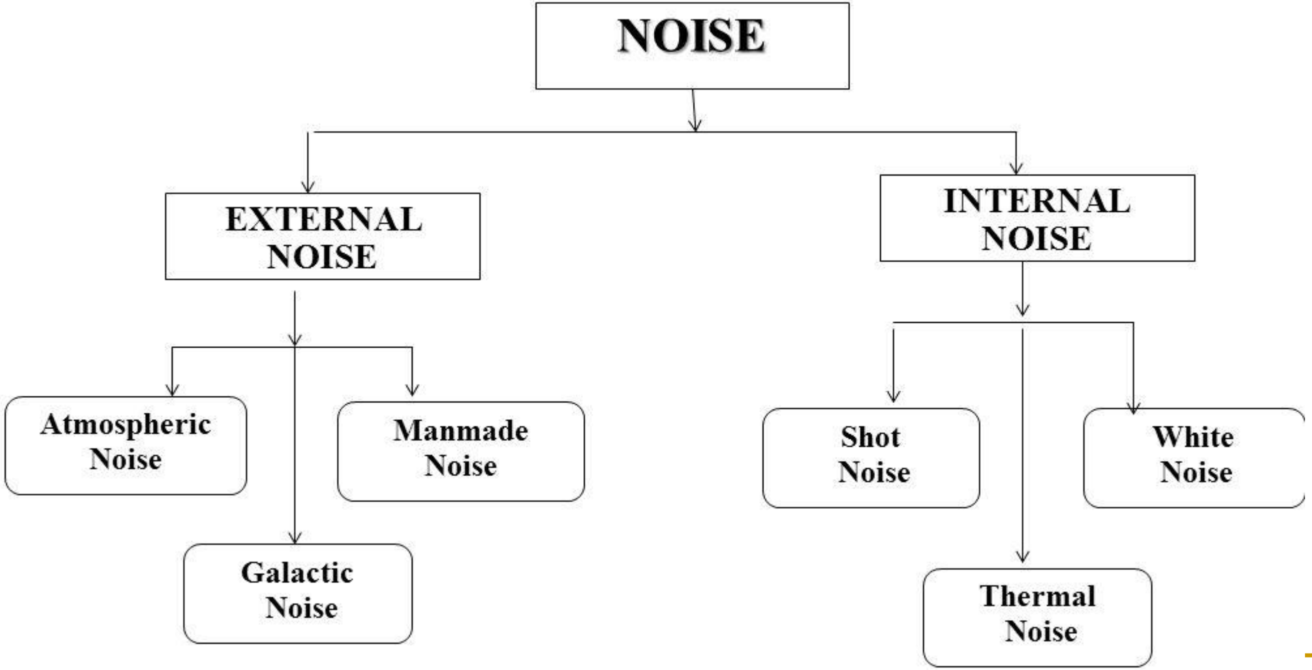
- In radio receiver: ‘Hiss’ sound from speaker
- In TV: ‘Snow’ or ‘confetti’(colored snow) display on the picture.

Drawback of Noise

- For a given transmitted power ,it limit the range of systems
- It affects the Sensitivity of receivers
- Sometimes Force reduction in bandwidth of the system

NOISE

Noise can be defined as an unwanted signals that tends to disturb the transmission and processing of signals in communication system



Sources of Noise

- External Noise : Noise created outside the receiver
- Internal Noise : Noise created inside the receiver

Source of External Noise:

- Atmospheric Noise
- Extraterrestrial Noise
  - Solar Noise
  - Cosmic Noise
- Industrial Noise

Source of Internal Noise:

- Thermal Agitation Noise or Johnson Noise
- Shot Noise
- Transit Time Noise

Atmospheric Noise or Static noise

caused by lighting discharges in thunderstorms,

the electrical impulses are random in nature and spread over most of the RF spectrum used in broadcasting.

Atmospheric Noise consists of false radio signals and distributed over wide range of frequencies.

It is propagated over the earth and at any point on the ground atmospheric noise will be received from the thunderstorms.

This Noise will interfere more with radio receiver then the television. Atmospheric noise is less severe above about 30 MHz.

Extraterrestrial Noise or Space Noise

- caused by radiation of RF noise by sun and distant stars.

- Sun is a large body at a very high temperature over 6000 ^{0}C on the surface) and Radiates over a very broad frequency spectrum which includes the frequencies we Use for communication.

- Distant stars are also suns and have high temperatures, they radiate RF noise in the same manner as our sun .

- The noise received is called thermal (or black-body) noise and is distributed uniformly over the entire sky.

Industrial Noise

This noise is effective in industrial and densely populated area

Source of industrial noise are

1.Automobile and aircraft ignition

2.Leakage from high voltage lines

3.Heavy electric machines

4.Fluorescent light ,etc

This noise is observable at frequencies in the range from 1MHz to 600 MHz

Internal Noise

- Created by the active or passive devices present in the receiver
- Distributed randomly over the entire radio spectrum
- Impossible to treat instantaneous voltage basis ,in place of that it is easily describe statistically.

Source of Internal Noise

1.Thermal,agitation,white or Johnson noise

2. Shot Noise

3.Transit-Time Noise

Sources of Electrical Noise

- **Thermal Noise**
- **Shot Noise**
- **Flicker Noise**
- **Interference**

Thermal Agitation or White or Johnson noise

- Randomly distributed over the bandwidth
- Generated in resistance or the resistive component
- Generated due to the random motion of atoms and electrons inside the components
- The noise generated by a resistor, for example, is proportional to its absolute temperature as well as the bandwidth over which the noise is to be measured

Johnson noise

$$P_n \propto T\Delta f$$

$$P_n = kT\Delta f$$

where k = Boltzmann's constant J/K (joules per Kelvin)
T = absolute temperature in Kelvin, K = 273 + ^{o}C

Δf = frequency bandwidth of system

P_n = maximum noise power output

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Here K = Boltzmann constant = $1.38X10^{-23}$J/k

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Ans $0.0828X10^{-12}$ Watts

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We know that thermal noise power is given by

$$N = 10 \log (k) + 10 \log (T) + 10 \log (B) \text{ dBW}$$

$$N = 10 \log (1.38 \times 10^{-23}) + 10 \log (294) + 10 \log (10 \times 10^{6}) \text{ dBW}$$

$$N = -228.6 + 24.7 + 70 = -133.9 \text{ dBW}$$

Calculate the thermal noise power density at room temperature, usually specified as T = 17°C or 290 K.

Solution The noise is generally assumed to be independent of frequency.

We know that thermal noise power density is given by

$$N_0 = kT \text{ watts/Hz of bandwidth}$$

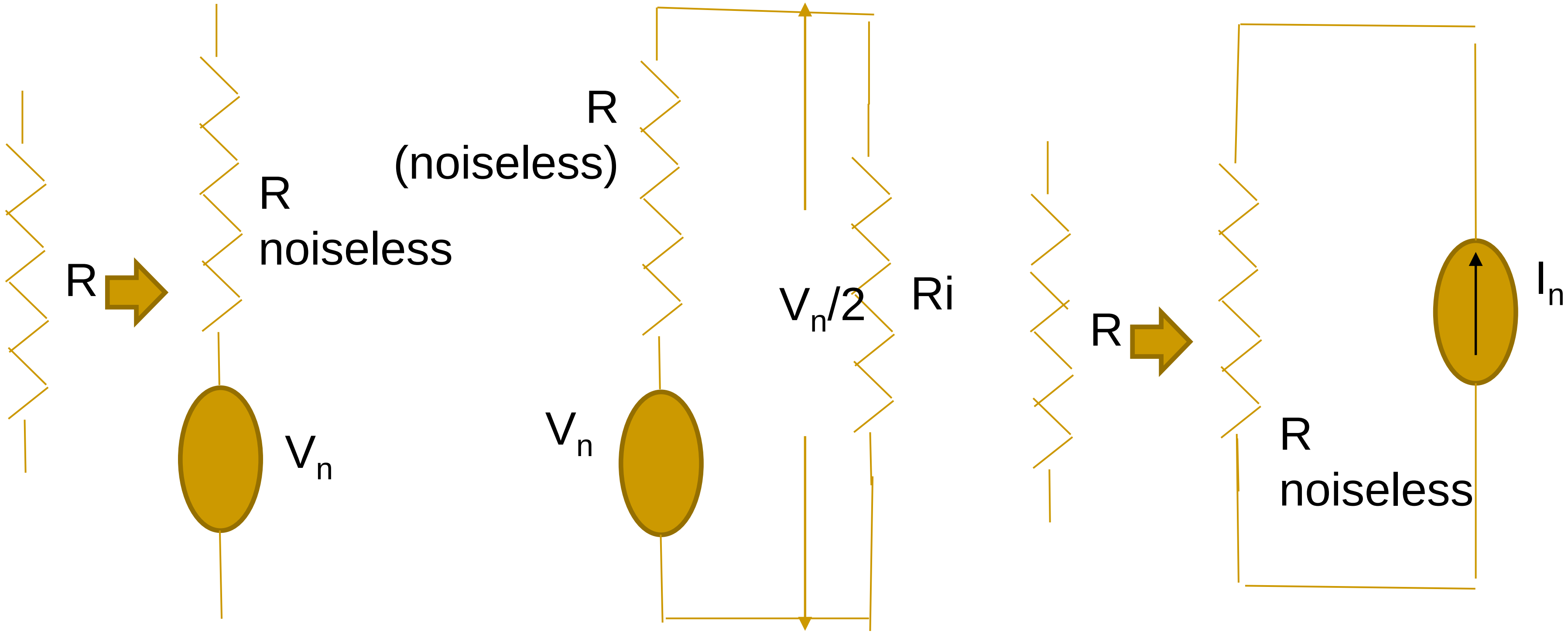
where k is Boltzmann's constant ($= 1.38 \times 10^{-23}$ J/K), and T is the absolute temperature in K.

$$\therefore \quad N_0 = (1.38 \times 10^{-23}) \times 290 = 4 \times 10^{-21} \text{ W/Hz}$$

Expressing it in dBW/Hz, we have

$$N_0 = 10 \log (4 \times 10^{-21}) = -204 \text{ dBW/Hz}$$

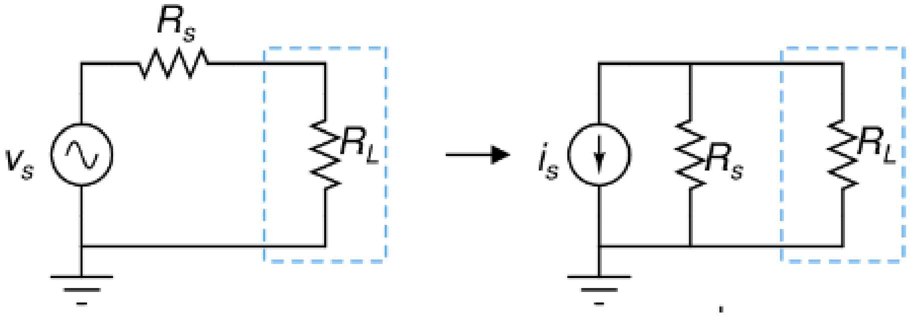
Noise Voltage across resistor R



If the load is noiseless and is receiving the maximum noise power generated by our noisy resistor then the following is true:

$$P_n = kT\Delta f$$

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



$$V_n = \sqrt{4kT\Delta f R}$$

NOISE VOLTAGE

$$V_N = \sqrt{4kTBR}$$

where:

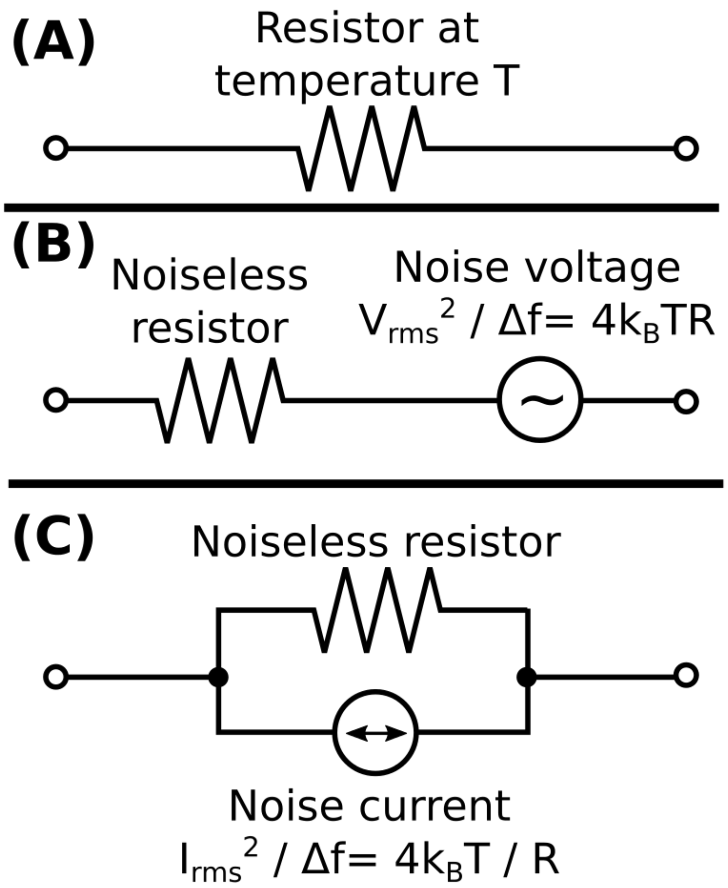
V_N =RMS noise voltage, (V)

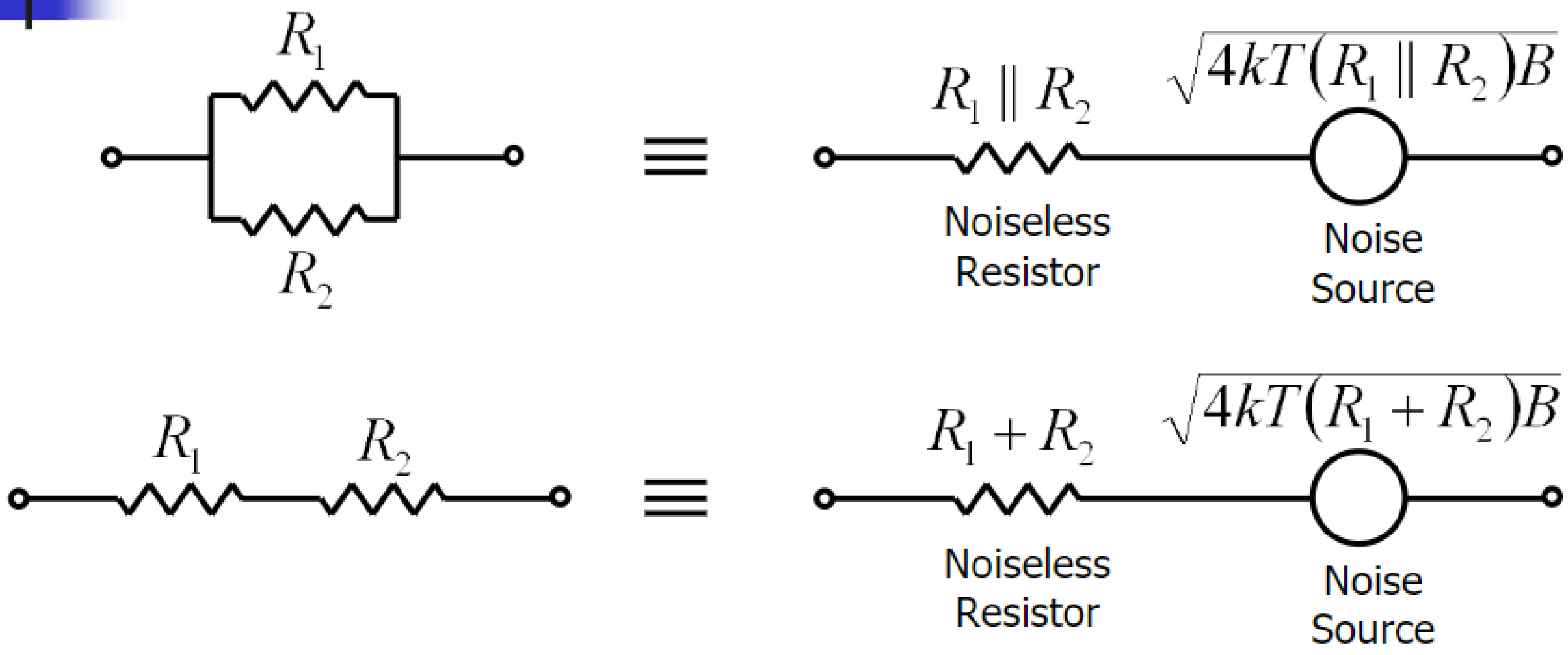
R =equivalent noise resistance, (Ω)

T =temperature of the conductor, (K)

B =bandwidth of the noise spectrum, (Hz)

Noise Voltage across resistor R





NB. When adding noise sources, the result is the root of the sum of squares.

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$K = 1.38 \times 10^{-23} J/^0K$, $T = 27^oC = 300^oK$, $B = (20-18)$ MHz $= 2 \times 10^6 Hz$, $R = 10 \times 10^3 \Omega$

$$V_n = \sqrt{(4KT\,\delta f\,R)}$$
$$= \sqrt{(4 \times 1.38 \times 10^{-23} \times 300 \times 2 \times 10^6 \times 10 \times 10^3)}$$
$$= \sqrt{(331.2 \times 10^{-12})}$$
$$= 18.2 \times 10^{-6}\ V$$
$$= 18.2\ \mu V$$

Question : The noise produced by a resistor is to be amplified by a noiseless amplifier having a voltage gain of 75 and a bandwidth of 100 kHz. A sensitive meter at the output reads 240 mV rms. Assuming operation at 37°C, calculate the resistor’s resistance. If the bandwidth were cut to 25 kHz, determine the expected output meter reading.

Shot Noise

Also known as quantum noise or Schottky noise.

$$I_{noise,rms} = \sqrt{2\,q\,I_{dc}\,B}$$

q is the electron charge = 1.602 x 10^{-19} C

I_{dc} is the dc current flowing across the measurement interface

B is again the measurement bandwidth in Hz

Signal to Noise Ratio

Signal to noise Ratio

Signal-to-Noise Ratio (SNR) is the ratio of the signal power to noise power. The higher the value of SNR, the greater will be the quality of the received output.

Signal to noise Ratio

Signal-to-Noise Ratio at different points can be calculated using the following formulas.

$$\textbf{Input SNR} = (\mathrm{SNR})_\mathrm{I} = \frac{\text{Average power of modulating signal}}{\text{Average power of noise at input}}$$

$$\textbf{Output SNR} = (\mathrm{SNR})_\mathrm{O} = \frac{\text{Average power of demodulated signal}}{\text{Average power of noise at output}}$$

$$\textbf{Channel SNR} = (\mathrm{SNR})_\mathrm{C} = \frac{\text{Average power of modulated signal}}{\text{Average power of noise in message bandwidth}}$$

Figure of Merit

The ratio of output SNR and input SNR can be termed as **Figure of Merit**. It is denoted by **F**. It describes the performance of a device.

$$\mathbf{F} = \frac{(\mathbf{SNR})_\mathbf{O}}{(\mathbf{SNR})_\mathbf{I}}$$

Figure of merit of a receiver is

$$\mathbf{F} = \frac{(\mathbf{SNR})_\mathbf{O}}{(\mathbf{SNR})_\mathbf{c}}$$

It is so because for a receiver, the channel is the input.

Noise Modelling

Additive White Gaussian noise (AWGN) is a basic noise model used in communication system.

- Additive because it is added to any noise/signal
- White refers to the idea that it has uniform power across the frequency band for the information system.
- Gaussian because it has a normal distribution in the time domain with an average time domain value of zero (Gaussian process).

SNR & Figure of Merit – AM, FM

Assumptions

- Additive White Gaussian Noise
- N_0 is the average noise power per unit bandwidth
- The signal available for demodulation is given by

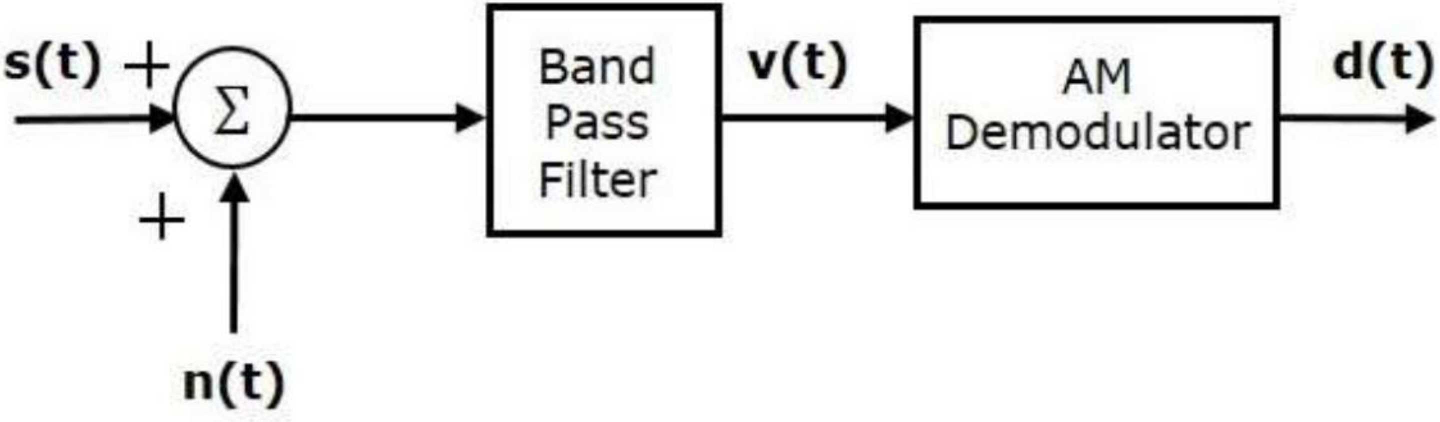
$$x(t) = s(t) + n(t)$$

Where s(t) is signal and n(t) is narrowband noise

$$n(t) = n_I(t)\cos(2\pi f_c t) - n_Q(t)\sin(2\pi f_c t)$$

SNR & Figure of Merit - AM (DSCFC)

Consider the following receiver model of AM system to analyze noise.



Amplitude Modulated (AM) wave is

$$\boldsymbol{s(t) = A_c[1 + k_a \mathrm{m}(t)] \cos(2\pi f_c t)}$$

$$\boldsymbol{=> s(t) = A_c \cos(2\pi f_c t) + A_c k_a \mathrm{m}(t) \cos(2\pi f_c t)}$$

Average power of AM wave is

$$\boldsymbol{P_s = \frac{A_c{}^2}{2} + \frac{A_c{}^2 k_a{}^2 P}{2}}$$

$$\boldsymbol{=> P_s = \frac{A_c{}^2(1 + k_a{}^2 P)}{2}}$$

P is the power of the message signal $= \boldsymbol{Am^2/2}$

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Average power of AM wave is

$$P_s = \frac{{A_c}^2}{2} + \frac{{A_c}^2 {k_a}^2 P}{2}$$

$$=> P_s = \frac{{A_c}^2 (1 + {k_a}^2 P)}{2}$$

Average power of noise in the message bandwidth is

$$P_{nc} = WN_O$$

Substitute, these values in **channel SNR** formula.

$$(SNR)_{C,AM} = \frac{\textbf{Average power of AM wave}}{\textbf{Average power of noise in message bandwidth}}$$

$$=> (SNR)_{C,AM} = \frac{A_c{}^2(1 + k_a{}^2 P)}{2WN_O}$$

W is the message bandwidth

Hence, the input of AM demodulator is

$$v(t) = s(t) + n(t)$$

$$=> v(t) = A_c[1 + k_a m(t)]cos(2\pi f_c t) + [n_I(t)cos(2\pi f_c t) - n_Q(t)sin(2\pi f_c t)]$$

$$=> v(t) = [A_c + A_c k_a m(t) + n_I(t)]cos(2\pi f_c t) - n_Q(t)sin(2\pi f_c t)$$

Note: n(t) is narrowband noise n(t) = $n_I(t)cos(2\pi fct) - n_Q(t)sin(2\pi fct)$

$n_I(t)$ and $n_Q(t)$ are in phase and quadrature phase components of noise.

$$v(t) = [A_c + A_c k_a m(t) + n_I(t)]\cos(2\pi f_c t) - n_Q(t)\sin(2\pi f_c t)$$

The output of AM demodulator is nothing but the envelope of the above signal

$$d(t) = \sqrt{[A_c + A_c k_a m(t) + n_I(t)]^2 + \left(n_Q(t)\right)^2}$$

$$\Rightarrow d(t) \approx A_c + A_c k_a m(t) + n_I(t)$$

$$d(t) = \sqrt{[A_c + A_c k_a m(t) + n_I(t)]^2 + \left(n_Q(t)\right)^2}$$

$$=> d(t) \approx A_c + A_c k_a m(t) + n_I(t)$$

Average power of the demodulated signal is

$$P_m = \frac{{A_c}^2 {k_a}^2 P}{2}$$

Average power of noise at the output is

$$P_{no} = WN_O$$

Substitute, these values in **output SNR** formula.

$$(SNR)_{O,AM} = \frac{\textbf{Average power of demodulated signal}}{\textbf{Average power of noise at output}}$$

$$=> (SNR)_{O,AM} = \frac{{A_c}^2 {k_a}^2 P}{2WN_O}$$

Substitute, the values in **Figure of merit** of AM receiver formula

$$F = \frac{(SNR)_{O,AM}}{(SNR)_{c,AM}}$$

$$=> F = \left(\frac{{A_c}^2{k_a}^2P}{2WN_O}\right) \Big/ \left(\frac{{A_c}^2(1+{k_a}^2P)}{2WN_O}\right)$$

$$=> F = \frac{K_a^2 P}{1 + K_a^2 P}$$

Therefore, the Figure of merit of AM receiver is less than one.

Two resistors, 5 kohm and 20 kohm, are at 27°C. Calculate the thermal noise power and voltage for a 10 kHz bandwidth

for each resistor

for their series combination

for their parallel combination