AE_Lecture 9_Noise Sources & Noise Figure.*

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Abstract

AE_Lecture 9 describes the internal and external sources of noise, defines Noise Figure and states the Friss Formula which gives the overall Noise Figure in multistage Amplifier.

AE_Lecture no-9
Noise sources and theoretical formulation of noise parameters.
Internal Noise Sources

- Resistors
- Vacuum Tubes
- BJT & Other Solid State Devices

External Noise Sources

- Atmospheric
- Man Made
- Extraterrestrial sources
- Multiple Transmission Paths
- Random Changes in attenuation within the transmission medium.

1. ATMOSPHERIC NOISES

Due to electric discharge in thunder clouds spurious radio waves are produced.

In time domain, electric discharge is a SPIKE (or a Dirac Delta Function). In frequency domain we have uniformly distributed RF waves in MW region 540kHz to1.6 MHz. Below 100MHz field strength of the radiations from the electric discharges are significant in Medium Wave Range of RF and not in Short Wave Range. This is why during thunder storms maximum static is produced in MW Range of radio reception.

1. MAN MADE SOURCES

1. High voltage powerline corona discharge.
2. Commutator-generated noise in DC electric motors..

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3. Switching gear noise.
4. EM Interference by high intensity radio transmitters in neighbourhood.
5. **EXTRATERRESTRIAL NOISE SOURCES**

i. Periodic increase in Solar Activities(The period is 11 years) in the form of increased sun-spots and furious sun-flares lead to major disruptions in power transmissions and communication systems. The surface of the Sun is a roiling mass of plasma- charged high-energy particles- some of which escape from the surface and travel through the space as the solar wind. During a sun storm solar wind carries billion-tonne glob of plasma, a fireball known as coronal mass ejection(CME). If the CME hits the Earth, it changes the configuration of Earth's Magnetic field leading to severe Electro-Magnetic Induction in the long lines of Power Grids. This will cause increased dc currents leading to saturation of the magnetic core of the transformers. The saturation of magnetic cores will limit the opposing e.m.f. leading to runaway currents in the secondary coil. This leads to rapid heating, melting of the transformer. One such event in March 1989 in Quebec, Canada, left 6 million people without electricity for 9 hours.
ii. Global Radio Broadcast at short wave RF gets seriously affected due to disruptions of ionosphere surrounding the Earth.
iii. QUASERS-Quasi-Stellar Radio Sources are important Radio Noise Sources in frequency range from MHz to GHz.
iv. Pulsars RF interference- Pulsars are Neutron Stars which are rapidly spinning and which have the magnetic field axis inclined to geo-graphical polar axis of spin. Due to this inclination, there is synchrotron radiation covering the entire span of spectrum. It emits radio waves, optical waves, X-Rays and Gamma Rays. This is emitted from the polar ends of the magnetic axis. Hence a beam of EM radiation are sweeping the entire space around the spinning Neutron Star at the same rate as that at which it is spinning. If our Earth falls in its line of sight, it receives periodic burst of EM radiations hence they are called pulsars. This is generally very weak hence does not cause much disturbance on Earth.
v. **MULTIPLE TRANSMISSION PATHS-**This occurs due to reflection off buildings, earth, airplanes & ships or from refraction from stratification in the transmission medium.

1. Diffused Noise Source-received signals are numerous reflected components.
2. Specular Noise Source-Received signals are one or two reflected strong rays.
3. **RANDOM CHANGES IN ATTENNUATION IN THE ATMOSPHERE -**this leads to fading.

INTERNAL NOISE SOURCES

Thermal Noise :- Random Motion of electrons in the conductor leading to fluctuations in the conducting semi free electron density(n) in the metallic lattice. This leads to fluctuating dipole leading to thermal voltages. This directly depends on the absolute temperature of the conductor.

Shot Noise:- Statistical fluctuations in the thermionic emissions from the cathode or the fluctuations in the forward current in the forward biased pn junction diode.

Partition Noise:- Statistical fluctuations in the current division or current merger in Vacuum tubes of in solid state devices.

Flicker Noise:-The number of free electrons or holes present in the channel decide the conductivity of the channel in FET devices. But due to interface states at the Gate Oxide in MOS the channel conductivity fluctuates due to random capture of majority carriers from the channel. This noise is inversely proportional to frequency. Hence it is also known as [

$$\frac{1}{f}]$$

Figure 1

noise.
Thermal Noise in Resistors(R)

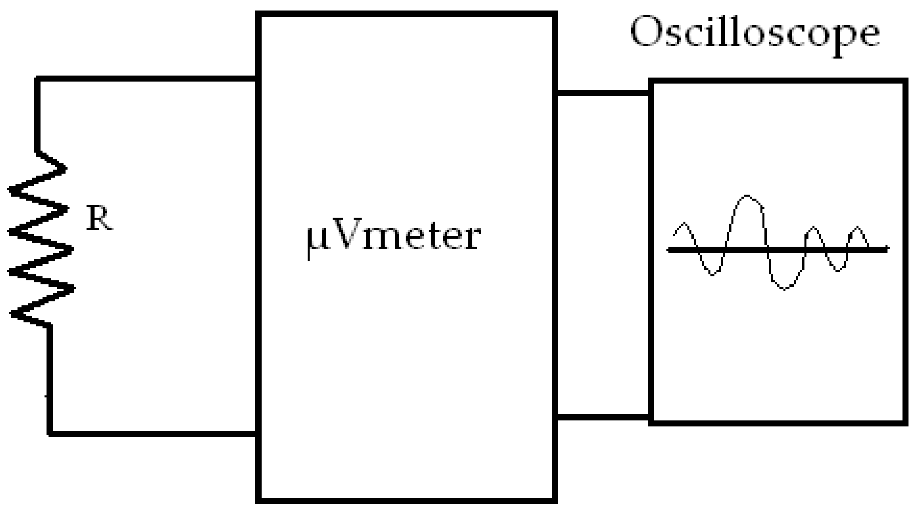

Figure 1. Thermal noise can be detected across the terminals of resistance by a sensitive ac voltmeter or by a sensitive oscilloscope.

Figure 2

Random motion of electrons due to thermal energy(

$$\frac{1}{2}kT \text{ is the thermal energy asosciated with electron for every degree of freedom}$$

Figure 3

)leads to fluctuating dipole in the metallic lattice. This leads to random voltage fluctuation at the terminals.

This random voltage

$$\propto T\,(in\ kelvin)$$

Figure 4

Mean Square Noise Power Spectral density=

$$kT\ (Joules) = kT\left(\frac{W}{Hz}\right) = S_N$$

Figure 5

In double sided representation

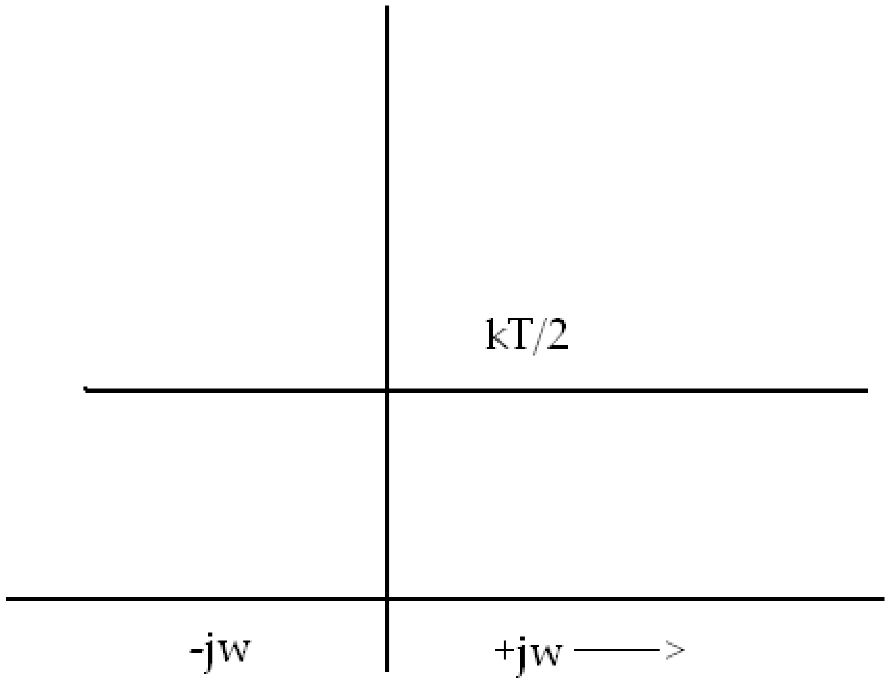

Figure 2.DoubleSided Noise Power Specrum.

Figure 6

Figure 2. Noise Power Spectral Density Distribution w.r.t. frequency in a double sided spectrum.

We have almost uniform Noise Power Spectral Density over the entire frequency spectrum. Therefore Thermal noise(Johnson Noise) is also known as White Noise. Just as WHITE LIGHT has all the seven colours in equal magnitude, in the same way WHITE NOISE has equal spectral components over the entire frequency spectrum.

The actual Noise Power measured will depend on the Bandwidth B Hz.

Therefore Mean Square Noise Power in a resistance over B Hz.

$$P_n = S_N B$$

Figure 7

watts;

$$P_n = kTB\ Watts$$

Figure 8

At 300K,

$$S_N = kT = 4.412 \times 10^{-21} J$$

Figure 9

=

$$4.412 \times 10^{-21} W/Hz$$

Figure 10

Let BW=1MHz

$$\therefore P_n = kTB = 4.412 \times 10^{-15} W$$
$$= Total\ Power\ assosciated\ with\ Thermal\ Noise$$

Figure 11

= Available Noise Power.

This is the noise actually present in the resistance but the amount of noise available for the load is to be calculated now.

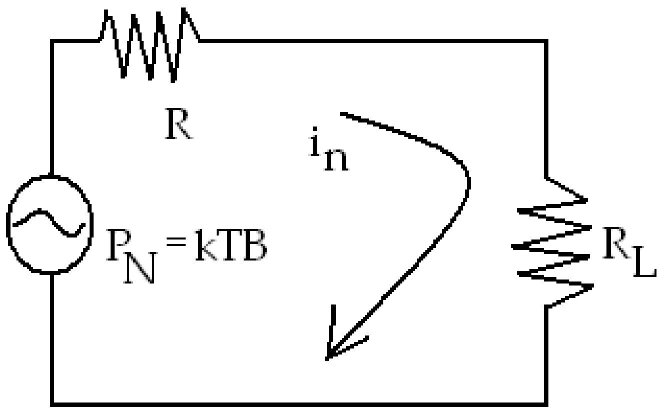

Figure 3. Actual noise power delivered to a Load Resistance.

Figure 12

Figure 3. Equivalent circuit of a noisy resistance connected to a load. The figure shows the available power at the load. The noisy Resistor has been represented as a power source of P N watts delivering noise power to the load and with an internal resistance R having no noise.

$$(i_n)_{RMS} = \frac{v_n}{R + R_L}$$

If R=R_L, then

$$(i_n)_{RMS} = \frac{v_n}{2R}$$

Maximum power transferred to R_L =Available noise power from the resistan to the load

$$= i_n^2 R_L = i_n^2 R = P_{AN}$$

$$\therefore P_{AN} = \frac{v_n^2}{4R^2} \times R = \frac{v_n^2}{4R}$$

Figure 13

$$\therefore v_n^2 = 4RP_{AN} = 4RkTB$$

Mean Square Noise Voltage= $\langle v_n^2 \rangle = 4RkTB$

RMS Value of Noise Voltage=$\sqrt{\langle v_n^2 \rangle} = \sqrt{4RkTB}$

Figure 14

If R=1k, B=1MHz, T=300K

$$\sqrt{\left(\overline{v_{an}^{2}}\right)} = rms\ V_{an} = 4\mu V$$

$$v_{an} = RMS\ value\ of\ Available\ Noise\ Voltage = 4\mu V$$

Figure 15

The signals received at the antenna of a receiver is of comparable amount and hence the intelligent signal can easily be swamped by the thermal noise at the front end of a communication receiver. In deep space communication the problem is further compounded due to the fact that received signal from PIONEER or VOYAGER from the very edge of heliosphere is one or two orders of magnitude fainter than 4μV.

CALCULATION OF EFFECTIVE NOISE TEMPERATURE and DEFINITION of NOISE FIGURE.

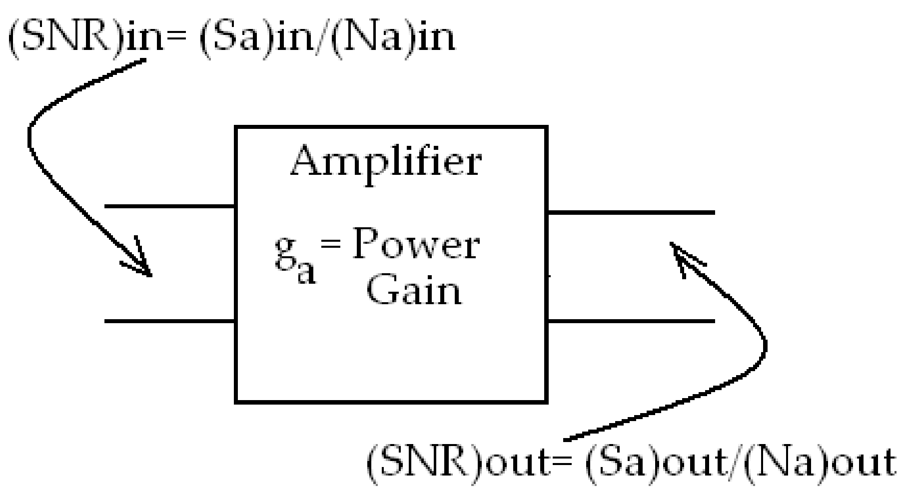

Figure 4. Block Diagram of an Amplifier with internal noise. This internal noise deteriorates the Signal to Noise Ratio in the process of Amplification.

Figure 16

Figure 4. A two port network with SNR at the input and output.

SNR=Signal to Noise Ratio=$\frac{Mean\ Square\ Signal\ Voltage}{Mean\ Square\ Noise\ Voltage} = \frac{<V_s^2>}{<V_n^2>}$

$$(S_a)_{out} = g_a (S_a)_{in}$$

$$(N_a)_{out} = g_a (N_a)_{in}$$

So, ratio $\left(\frac{S_a}{N_a}\right)_{out} = (SNR)_{out} = \left(\frac{S_a}{N_a}\right)_{in} = (SNR)_{in}$

Figure 17

But actually it is not so because there is some internally generated noise in the amplifier. Thus

$$(N_a)_{out} \neq g_a (N_a)_{in}$$

It is actually:

$$(N_a)_{out} = g_a (N_a)_{in} + N_{int}$$

Thus:

$$(SNR)_{out} = \frac{g_a (S_a)_{in}}{g_a (N_a)_{in} + N_{int}}$$

$$(SNR)_{out} = \frac{\frac{g_a (S_a)_{in}}{g_a (N_a)_{in}}}{1 + \frac{N_{int}}{g_a (N_a)_{in}}} = \frac{(SNR)_{in}}{1 + \frac{N_{int}}{g_a (N_a)_{in}}}$$

Figure 18

Therefore:

$$\text{Noise Figure}=\frac{(SNR)_{in}}{(SNR)_{out}} = 1 + \frac{N_{int}}{g_a (N_a)_{in}}$$

Figure 19

An Ideal Noise Figure for an amplifier should be 0dB but it is never 0dB in actual practice. In actual practice the noise figure can be 0.1dB/ 0.2dB/0.5dB/1 dB or more.

EFFECTIVE NOISE TEMPERATURE

At the input:

$$(N_a)_{in} = kT_iB$$

There is a thermal noise generator of equivalent temperature=T_i

This is the noise picked up by the antenna .

The noise power at the o/p:

$$(N_a)_{out} = g_a k T_i B + \Delta N$$

Here $\Delta N = Internal\ Noise\ Power$

Figure 20

Therefore:

$$(N_a)_{out} = g_a kB\left(T_i + \frac{\Delta N}{g_a kB}\right)$$

Figure 21

Thus:

$$(N_a)_{out} = g_a kB(T_i + T_e)$$

Where: $T_e = Effective\ Noise\ \ Temperature\ of\ \Delta N\ = \frac{\Delta N}{g_a kB}$

$$(SNR)_{in} = \left(\frac{S_a}{N_a}\right)_{in} = \frac{(S_a)_{in}}{kT_i B}$$

$$(SNR)_{out} = \frac{g_a (S_a)_{in}}{g_a kB(T_i + T_e)}$$

$$Noise\ Figure = \frac{(SNR)_{in}}{(SNR)_{out}} = \left(1 + \frac{T_e}{T_i}\right)$$

Figure 22

While the signal is passing through an amplifier the signal to noise ratio deterioration is defined by

$$\frac{T_e}{T_i}$$

Figure 23

. If by cryogenic cooling effective noise temperature of the front end amplifier is minimized to zero then we achieve the ideal N.F. of 1 or 0dB.

IN COMMUNAICATION RECEIVER SYSTEMS

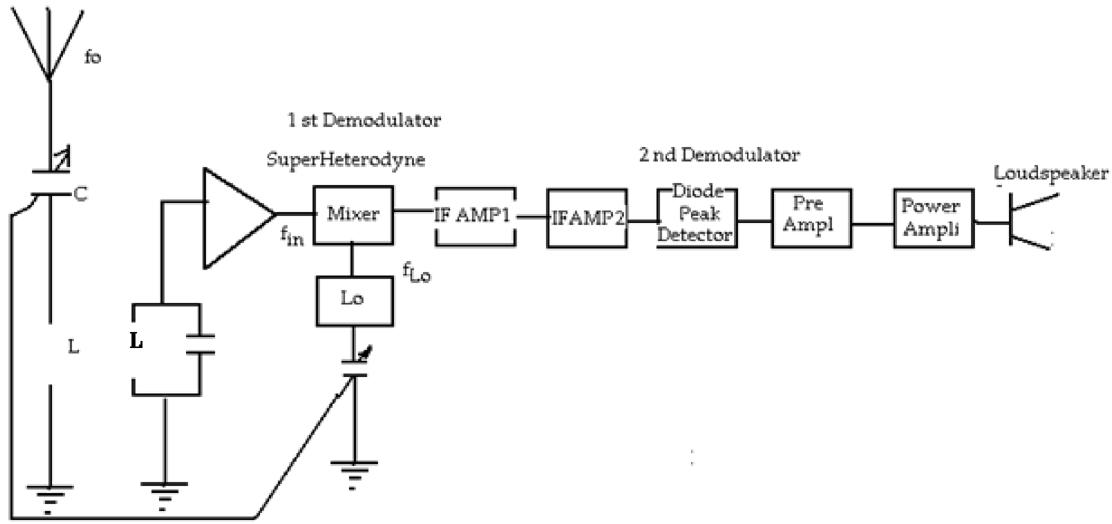

Figure 5. Block Diagram of Superhetrodyne Receiver.

Figure 24

Figure 5. A Communication Receiver in RF range. Different stages of the receiver are shown. In the first stage we have series resonance circuit tuned to a given station or tuned to a given communication frequency. At resonance frequency maximum electromagnetic induction takes place and maximum current is introduced in the primary coil of RF Transformer. The first stage is a RF tuned amplifier. After amplification, picked up radio frequency is downward frequency translated to intermediate frequency (IF). IF is 455kHz in AM Radio Receivers or 10.7MHz in TV or FM Radio. IF signal is amplified and then second detection or demodulation takes place. In the second detection it is again downward frequency translated to base band signals. This base band signal is voltage amplified by pre-amplifier and power amplified by Complementary Symmetry Amplifier. The power amplified is fed to the Speaker or Video Monitor.

The first downward frequencytranslation is known as 1^{st} detection or 1^{st} demodulation. This is also known as superhetrodyne mixing of tuned frequency f_0 and f_{Lo} and $f_{Lo} - f_0$ = Intermediate Frequency (I.F.).

FRISS FORMULA will have to be utilized to calculate the overall noise figure.

FRISS FORMULA

What is the overall noise figure of 2 cascaded stages ?

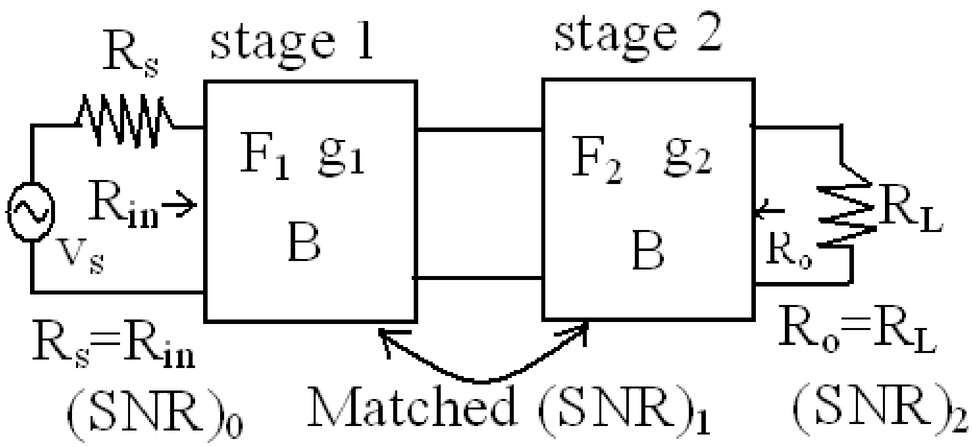

Figure 6. Calculation of overall noise figure in multistage amplifier.

Figure 25

Figure 6: Two Stage Cascaded Amplifier
We have a matched network for maximum power transfer.
Overall Noise Figure

$$F = F_1 + \frac{(F_2 - 1)}{g_1}$$

For n Stage cascade system:

$$F = F_1 + \frac{(F_2 - 1)}{g_1} + \frac{(F_3 - 1)}{g_1 g_2} + - - - - - + \frac{(F_n - 1)}{g_1 g_2 - - - g_{n-1}}$$

Figure 26

This formula implies that the overall Noise Figure is dominated by the noise figure of the first stage.

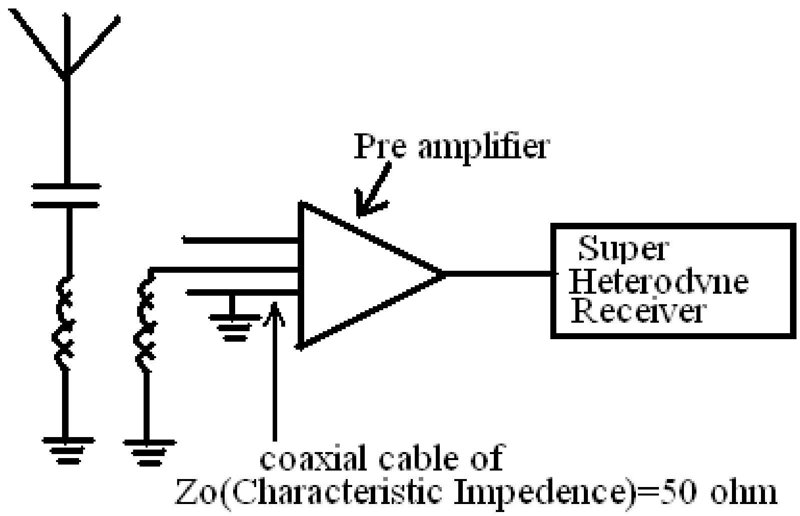

Figure 7(a) A Typical Antenna Stage With A Preamplifier

Figure 27

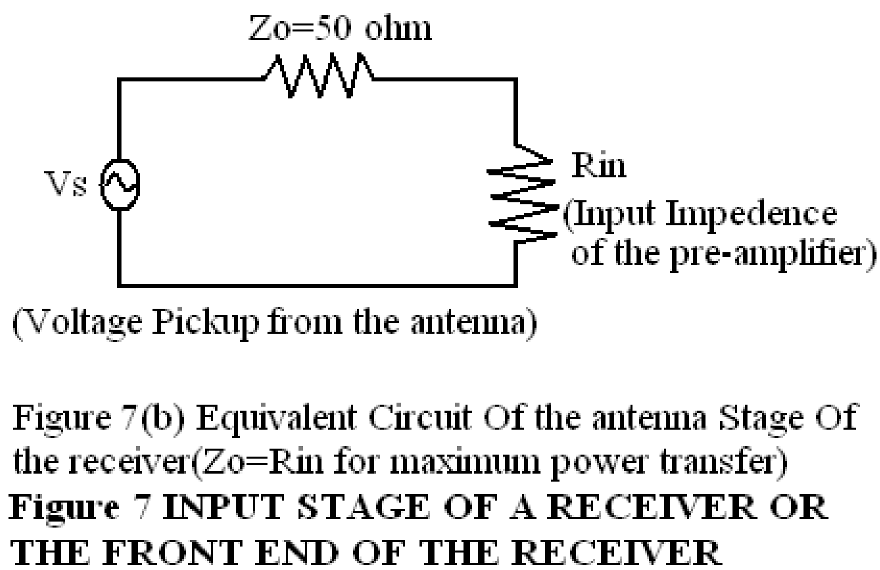

Figure 28

Front end amplifier is referred to as Low Noise Amplifier.

With a good front-end having cryogenic cooling, we achieve a good amplification with no deterioration in SNR as we proceed along the cascade chain.

Table 1. Typical Noise Figure

Amplifier	NF(abs)	NF(dB)	T_e (K)	Gain(dB)	f_{op}(GHz)
Parametric Amplifier(uncooled)	1.45	1.61	130	10-20	9
Parametric Amplifier(77K)	1.17	0.69	50	10-20	3&6
Parametric Amplifier(4K)	1.03	0.13	9	10-20	4
Travelling Wave Tube(TWT)	1.59	2.00	170	20-30	2.66
	1.86	2.7	250		3
	2.69	4.3	490		9
Tunel Diode Amplifier-Ge	2.38	3.77	400	20-40	?
Tunnel Diode Amplifier-GaAs	1.69	2.28	200	20-40	?
Low Noise Heterodyne Receiver	2.38	3.77	400	20-40	500kHz-30MHz
IC BJT IF Amplifier for TV	5.01	7	1163	50	10.7MHz
GaAs MESFET Amplifier	?	?	?	?	?

Table 1

(1)Mumford & Scheibe,Noise Performance Factors in Communication Systems,Horizon House-Microwace,Inc,Dedham,Mas
36,39

(2)Linear Integrated Circuits Data Book,Motorola Inc.,(1974).

References:

1.Ziemer & Tranter,Principles of Communications-System,Modulation and Noise,Wiley India,5th Edition,2002.

2. Shanmugam,Digital and Analog Communication Systems, Wiley-India,Reprint 2007.

APPENDIX-1. Derivation Of The FRISS FORMULA (Refer to figure 6)

Noise at the output of the second stage is:

$$N_{a2} = g_2 N_{a1} + \Delta N_2 \_\_\_\_\_\_\_\_ (1)$$

Similarly the output of the first stage is:

$$N_{a1} = g_1 N_{a0} + \Delta N_1 \_\_\_\_\_\_\_\_ (2)$$

Available Noise power Input at the First stage is:

$$N_{a0} = kT_o B \_\_\_\_\_\_\_\_ (3)$$

Figure 29

Substituting (3) into (2), we get,

$N_{a1} = g_1 k T_o B + \Delta N_1$____(4)

Substituting (4)in (1),we get,

$$N_{a2} = g_2(g_1 k T_o B + \Delta N_1) + \Delta N_2$$

Further Simplifying it,

$N_{a2} = g_2 g_1 k B(T_o + \Delta N_1 / g_1 k B) + \Delta N_2$______(5)

But $\Delta N_1 / g_1 k B = T_{e1} = Effective\ Temperature\ of\ the\ stage\ 1$__(6)

And$\Delta N_2 / g_2 k B = T_{e2} = Effective\ Temperature\ of\ the\ stage\ 2$___(7)

Also, $F_1 = 1 + T_{e1}/T_o$ and $F_2 = 1 + T_{e2}/T_o$_______(8)

Figure 30

From Eq(8), we have $T_{e2} = (F_2 - 1)T_o$_______(9)

From Eq(9)and(7),

$\Delta N_2 = T_{e2} g_2 k B = (F_2 - 1) T_o g_2 k B$_____(10)

Using relations(6) ,(8) and(10),

Eq(5) can be re-written as:

$$N_{a2} = g_2 g_1 k B(T_o + \Delta N_1 / g_1 k B) + \Delta N_2$$

Figure 31

$$N_{a2} = g_2 g_1 kB(T_o + T_{e1}) + (F_2 - 1)T_o g_2 kB$$

Simplifying:

$N_{a2} = g_2 g_1 kBT_o F_1 + (F_2 - 1) g_2 kBT_o$_______(11)

But, $N_{a2} = kBT_o g_2 g_1 F$ ______(12)

[this is arrived at by induction logic recognizing the $N_{a1}=g_1kBF_1T_0$]

Where F is the overall noise figure.

Hence dividing(11)by (12), we get,

$F = F_1 + \frac{F_2 - 1}{g_1}$ _______(13)

Figure 32

For 3 stages: $F = F_1 + \frac{F_2 - 1}{g_1} + \frac{(F_3 - 1)}{g_1 g_2}$________(14)

For n stages:

$\boldsymbol{F = F_1 + \frac{(F_2 - 1)}{g_1} - - + \frac{(F_n - 1)}{g_1 g_2 - - - g_{n-1}}}$_____***(15) FRISS FORMULA.***

Figure 33