(a) Shot Noise:

$$i_n = \sqrt{2 q I_D \Delta f}$$

This noise occures due to quantum nature of Electron Flow through a Potential Barrier. Carriers exhibit average rate (DC value) of crossing, but indivisual carriers cross barrier as random events

In above equation I_D is the forward current in the device, and Δf is measurement bandwidth.

Clearly Shot noise $\propto \sqrt{I_D}$, but it is $\neq f(\text{Temp})$

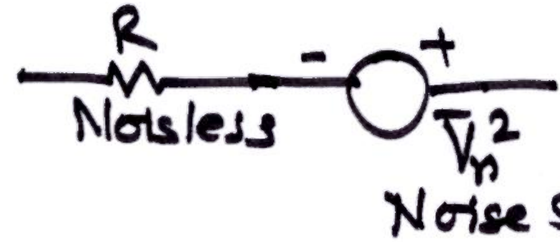
In MOSFET, Subthreshold Currents exhibits Shot Noise.

(b) Johnson Noise (Thermal Noise):

Random carrier motion (Drift, Diffusion) gives rms Noise power as

$$S_n(f) = \int_{f_1}^{f_2} kT\, df = kT\,\Delta f$$

$\therefore S_n(f) \propto T \Rightarrow$ Thermal Noise

A resistor can be modeled as 

spectral density

$$S_v(f) = kT\,\Delta f = \frac{\bar{V}_n^2}{R}$$

or $\bar{V}_n^2 = kTR\,\Delta f$

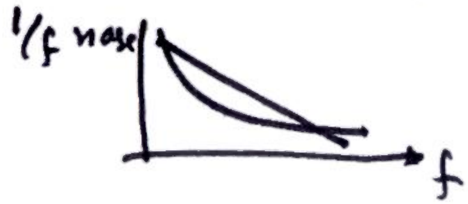
If V_n is expressed in rms value & $\Delta f = 1\,Hz$ then $\bar{V}_n^2 = 4kTR$

As $\overline{i_n}^2 = \frac{\overline{V_n}^2}{R^2}$ current noise source

$\therefore \quad \overline{i_n}^2 = \frac{4kT}{R} = 4kT.G \quad (G = \frac{1}{R})$

(c) 1/f Noise (Flicker Noise)

Due to number fluctuations occuring due to Defects, Contaminants and <u>Interface States</u>, one observe 1/f noise. Johnson invented it in 1923 is Vacuum Tubes. Exact nature is not very much known, but a low frequencies, The noise shows inverse proportion to frequency (1/f behavior), and hence called 1/f Noise



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(d) G-R Noise :

Generation - Recombination of Carriers in semiconductors (Devices) results in statistical variation of number density. This leads to Noise, also known as Random Telegraph Noise (RTN)

(e) Popcorn noise : Also Known as Burst Noise, show $1/f^2$ dependance

A typical origin of such noise is seen in channel current of a MOSFET.

Discrete modulation of Channel Current by capture and Emission of Carriers in the Channel leads to Popcorn Noise

Two Types of Noise can be

[A] "Man Made Noise"

- Signal coupling
- Substrate Coupling
- Finite Power Supply Rejection

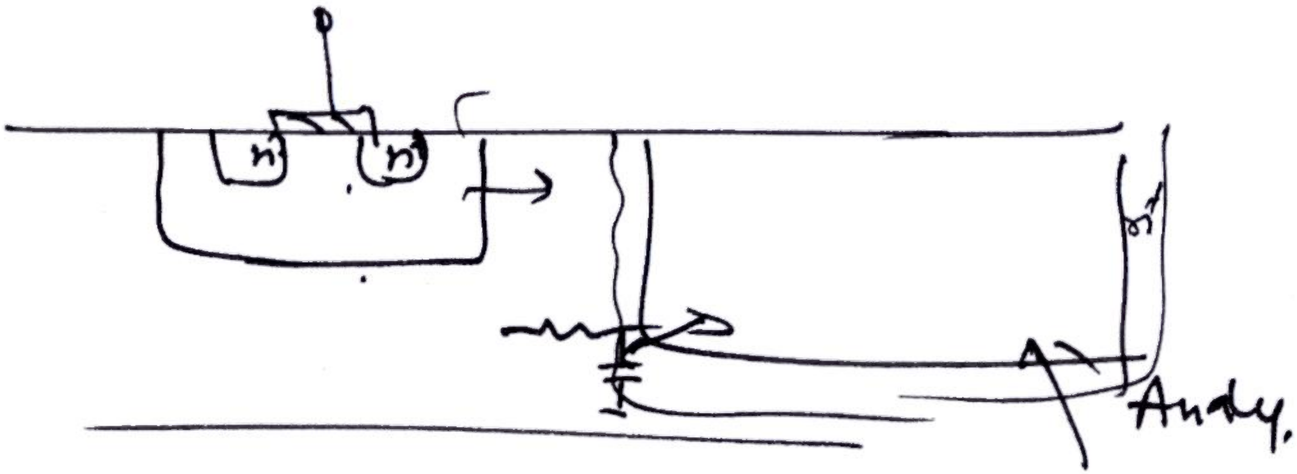
Possible methods of Eliminations

(i) Fully Differential Circuits

(ii) Proper Layout of the Circuit

[B] "Electronic Noise due to Devices"

Noise due to Components



$$\theta = \frac{\Delta T}{\Delta P}$$

Effects of Electronic Noise on Circuits

ⓐ Minimum Detectable / Processed Signal is Limited

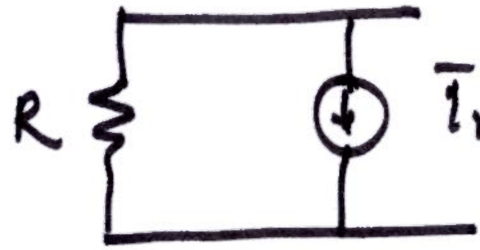
ⓑ Noise Directly shows Trade-Off with Power Dissipation and Speed

— Low Noise requirement dictates the use of Large Capacitors and or large g_m ⇒ Both leads to High Power Dissipation

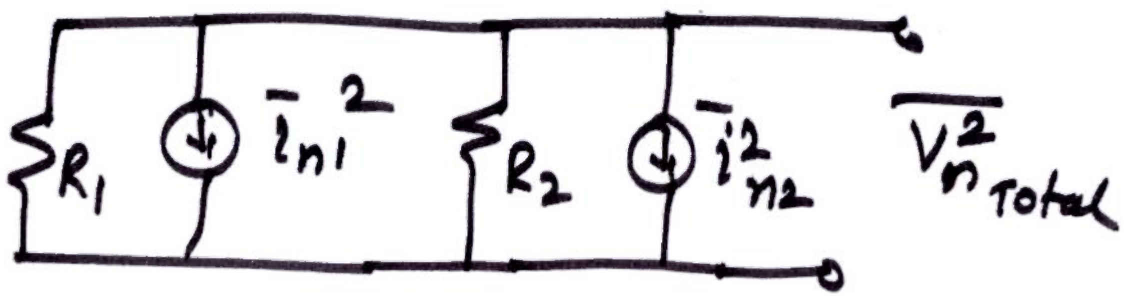
ⓒ With Scaledown technology, Power Supply voltage also decreases, thus Reducing SNR.

Hence Design of Low Power (Low Voltage), precision circuit has Strong dependance on Electronic Noise

Thermal Noise due to Resistor



$$\overline{i_n^2} = \frac{4kT}{R} \; A^2/Hz$$



$$\overline{i^2_{n\,Total}} = \overline{i^2_{n1}} + \overline{i^2_{n2}}$$

$$= 4kT\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = 4kT\,(R_1+R_2)/R_1R_2$$

$$\overline{V^2_{n\,Total}} = \overline{i^2_{n\,Total}} \cdot (R_1 \| R_2)^2 = \overline{i^2_{n\,Total}}\left(\frac{R_1 R_2}{R_1+R_2}\right)^2$$

$$\therefore \overline{V^2_{n\,Total}} = \frac{4kT(R_1+R_2)}{R_1R_2} \cdot \frac{(R_1R_2)^2}{(R_1+R_2)^2}$$

$$\overline{V^2_{n\,Total}} = 4kT\,(R_1 \parallel R_2)$$

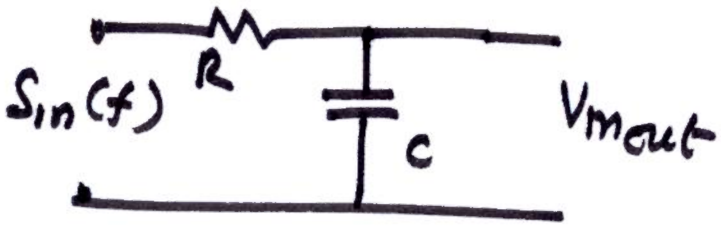
Properties of Thermal Noise

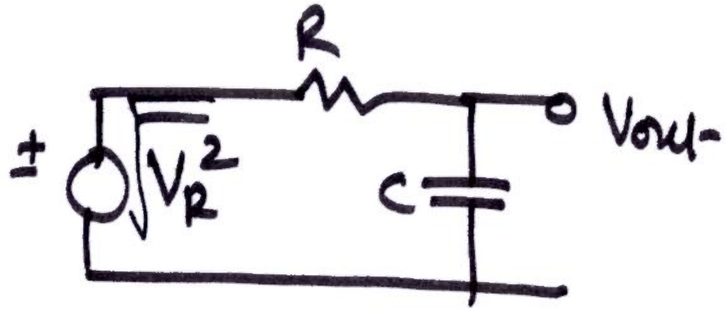
i Every Conductor is source of Thermal Noise

ii This Noise is not dependent on DC current.

iii Instantanious value is Indeterministic

iv Thermal Noise has Average Power.





$$\frac{V_{out}}{V_R} = \frac{1}{1 + RCs} = \text{Transfer } F^n$$

or $$S_{out}(f) = S_R(f) \left| \frac{V_{out}}{V_R}(j\omega) \right|^2$$

$$= 4kTR \frac{1}{4\pi^2 R^2 C^2 f^2 + 1}$$

$$\therefore P_n(out) = \int_0^\infty S_{out}(f)\, df$$

$$\therefore P_{n\,out} = \int_{0}^{+\infty} \frac{4kTR}{1+4\pi^2R^2C^2f^2}\,df$$

$$= \int_0^\infty \frac{4kTR\,df}{1+(2\pi RCf)^2}$$

$$x = 2\pi RCf$$

$$\text{or } dx = 2\pi RC\,df \qquad \text{or } df = \frac{dx}{2\pi RC}$$

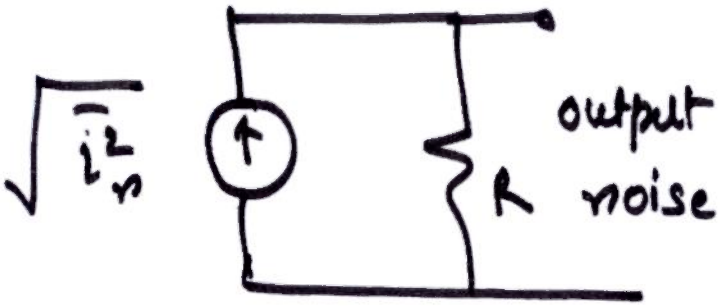
$$\therefore 4kTR\,df = \frac{4kTR\,dx}{2\pi RC}$$

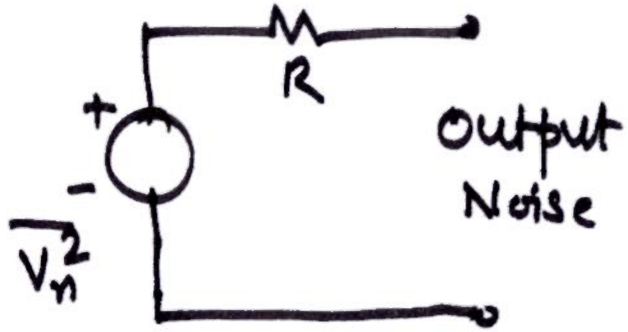
$$= \frac{2kT}{C}\cdot\frac{1}{\pi}\,dx$$

$$\therefore P_{n\,out} = \int_0^\infty \frac{2kT}{C}\cdot\frac{1}{\pi}\,\frac{dx}{1+x^2} = \frac{2kT}{C}\cdot\frac{\pi}{2\pi} = \frac{kT}{C}\ (V^2)$$

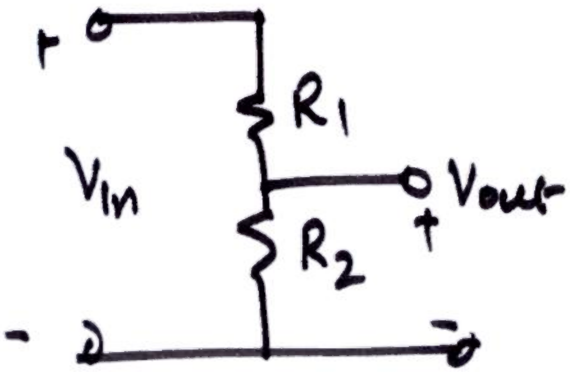
$$\neq f(R)$$

$$\overline{v_n^2} = 4kT \cdot R = \overline{i_n^2} \cdot R^2$$

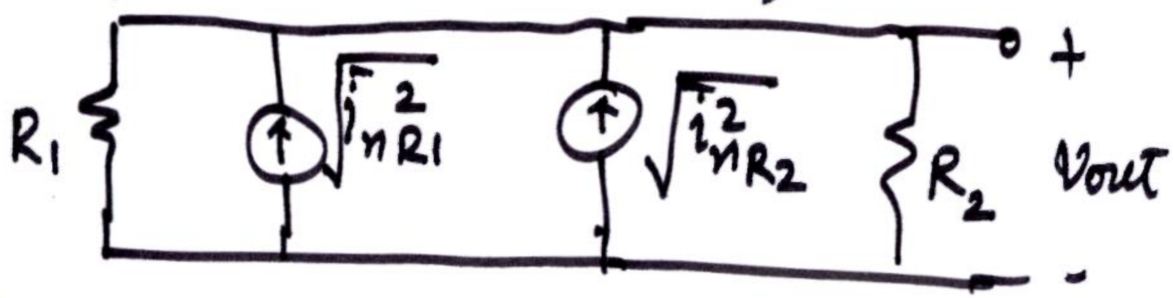




Noise Voltage of Potential Divider



Noise Eq. Ckt will be as shown (for the output node)



Evaluate noise RMS voltage at output from Bandwidth of DC to 1 kHz

We have :

$$\sqrt{\overline{i^2_{nR_1}}} = \sqrt{\frac{4kT}{R_1}} \quad A/\sqrt{Hz}$$

$$\sqrt{\overline{i^2_{nR_2}}} = \sqrt{\frac{4kT}{R_2}} \quad A/\sqrt{Hz}$$

$$\sqrt{\overline{V^2_{nR1}}} = \sqrt{\overline{i^2_{nR1}}} \cdot \frac{R_1R_2}{R_1+R_2} \quad V/\sqrt{Hz}$$

$$\sqrt{\overline{V^2_{nR_2}}} = \sqrt{\overline{i^2_{nR_2}}} \cdot \frac{R_1R_2}{R_1+R_2} \quad V/\sqrt{Hz}$$

Total RMS squared Output noise voltage over a Bandwidth f_0 is given by

$$\overline{V^2_{on}} = \int_{f_L}^{f_H} \left(\overline{V^2_{nR1}} + \overline{V^2_{nR2}} \right) df$$

Then $\sqrt{\overline{V^2_{on}}} \Rightarrow$ Voltage $/\sqrt{Hz}$

Here $f_L = 0 \quad f_H = f_0$

We may at times want to know effective Input noise for the divider. We have

$$\sqrt{\overline{V^2_{in}}} \cdot \frac{R_2}{R_1 + R_2} = \sqrt{\overline{V^2_{outn}}}$$

Problem $R_1 = 5K \quad R_2 = 0.5K$

$$\sqrt{\overline{i^2_{nR1}}} = \sqrt{\frac{4kT}{R_1}} = \frac{1.28\times 10^{-10}}{\sqrt{R_1}} = \frac{1.28\times 10^{-10}}{2.236}$$

$$= \frac{5.72}{31.622}\ nA/\sqrt{Hz} = 0.18\times 10^{-9}\ A/\sqrt{Hz}$$

$$\sqrt{\overline{i^2_{nR2}}} = \sqrt{\frac{4kT}{R_2}} = \frac{1.28\times 10^{-10}}{22.36} = 0.057\ nA/\sqrt{Hz}$$

$$\frac{R_1 R_2}{R_1+R_2} = \frac{2.5\times 10^{6}}{5.5\times 10^{3}} = 455$$

$$\therefore \sqrt{\overline{V^2_{nR1}}} = 0.18\times 10^{-9}\times 455 = 206.8\ nV/\sqrt{Hz}$$

$$\sqrt{\overline{V^2_{nR_2}}} = 0.057\times 10^{-9}\times 455 = 25.33\ nV/\sqrt{Hz}$$

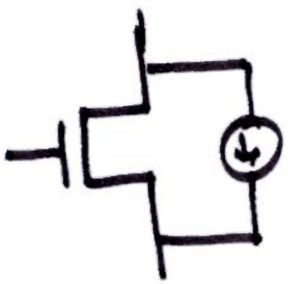
$$\overline{V_{on}^2} = \int_0^{10^3} (4.748) \times 10^{-14} \, df$$

$$= 47.48 \times 10^{-12} \quad V^2/Hz$$

$$\overline{V_{on}} = 6.9 \times$$ [redacted] $\mu V/\sqrt{Hz}$

MOSFET Noise Model

MOSFET behaves as voltage dependent Resistors and hence show Thermal Noise as noise source.

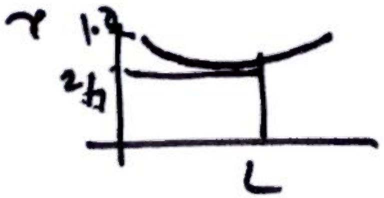


$$\overline{i_n^2} = 4kT\gamma g_m \Delta f$$

g_m = g_m in Sat. Mode

Δf = 1 Hz normally

γ = Noise Coefficient



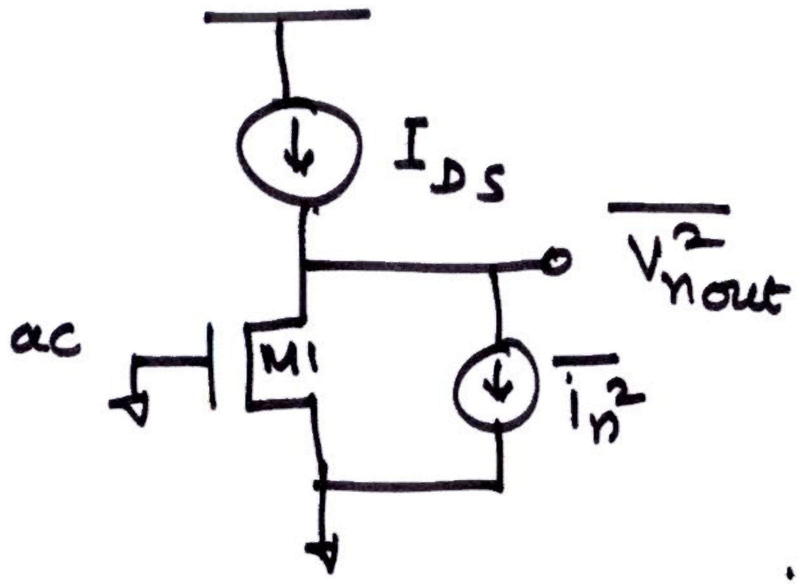
For long channel device $\gamma = 2/3$

For longer channel $\gamma \rightarrow$ Enhances

In Short channel case, hot carrier effects dominates and we see γ increasing towards 2→5 or so

In reality $\gamma = 1$ for Sch. case

A simple CS Amplifier noise can be now evaluated.



If Rout is output resistance of M1 (r_{o1}) & Current Source has $R_{out} \to \infty$ then Noise current $\sqrt{\overline{i_n^2}}$ flows through r_{o1} output resistance

$$\therefore \overline{V^2_{nout}} = \overline{i_n^2} \cdot r_{o1}^2$$

$$= 4kT\left(\frac{2}{3} g_m\right) r_{o1}^2$$

$$\text{or } \sqrt{\overline{V^2_{nout}}} = \sqrt{\frac{8}{3} kT g_m} \cdot r_{o1} \quad V/\sqrt{Hz}$$

$\therefore$ Low Noise $\Rightarrow$ low g_m. (Lower Gains)

Design Specifications :

1. DC Gain   2a. Bandwidth

2(b) Gain Bandwidth Product GBW

3. Input Common-Mode Range ICMR

4. Slew Rate

5. Output Load Capacitance

6. Output Voltage Swing ($V_{outmax} - V_{outmin}$)

7. Power Dissipation P_D

8. Common Mode Rejection Ratio CMRR