ECE 513 - Lecture 7

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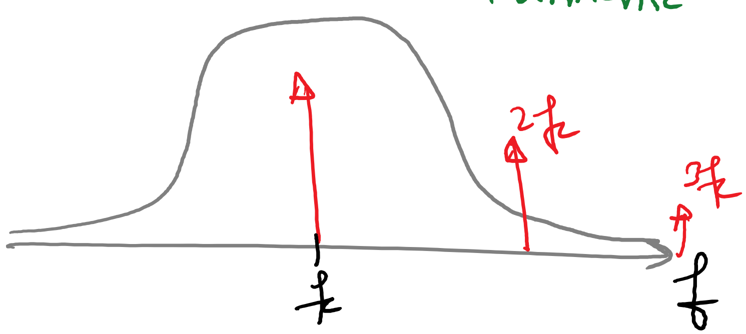
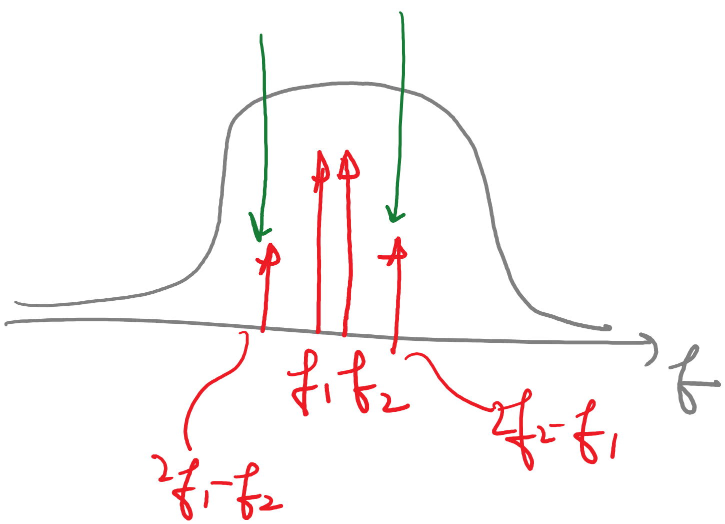
Two-tone Test :

Harmonic Test



not meaningful for narrowband circuits / systems



IM products fall within the band

↳ provide a meaningful view of the nonlinear behavior of the RF system.

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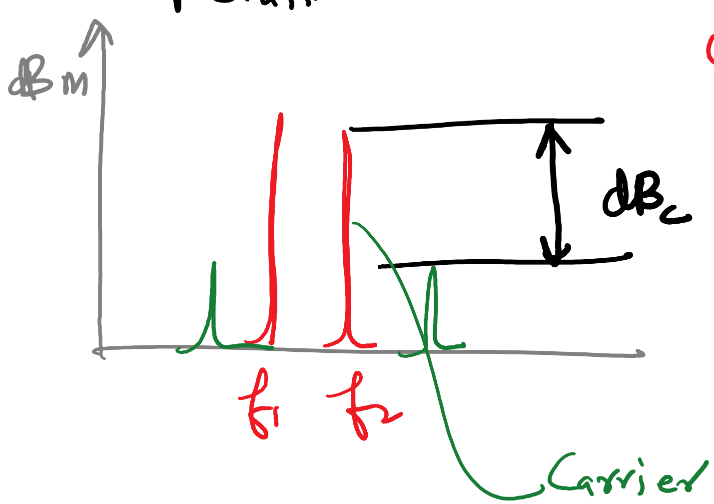
* Two pure sinusoids of equal amplitude are applied to the input
  - The amplitude of the IM products is then normalized to that of the fundamental at the output.

$$\text{Relative IM} = \underbrace{20\log_{10}\left(\frac{3}{4}\frac{\alpha_3}{\alpha_1}A^2\right)}_{dBc}$$



dB with respect to the carrier to emphasize the normalization

$A\uparrow 2\times$ (6dB) $\Rightarrow$ Relative IM $\propto A^2$ $\Rightarrow$ 12 dB

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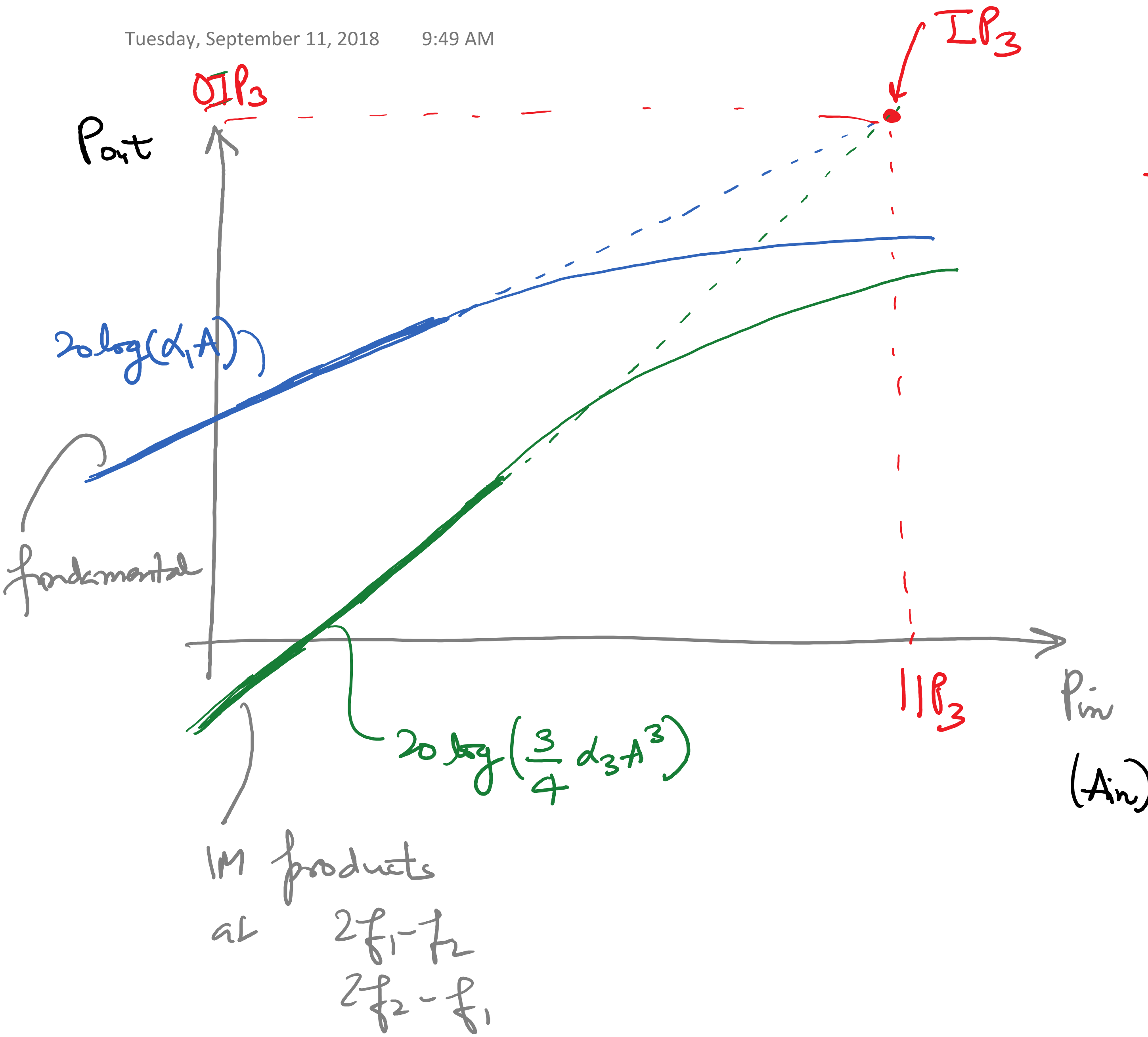
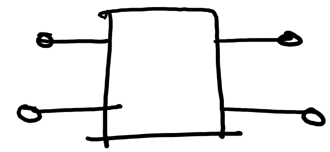
* We want a measure of IM where we don't need to know the input-level at which the two-tone test is carried out.

↳ such a measure exists and is called the third intercept point (IP_3)





IP3:

Input IP3 ⇒ IIP3

Output IP3 ⇒ OIP3

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$IIP_3 \Rightarrow 20 \log(A_{IIP_3})$

power of fundamental = power of IM_3 products

$$|\alpha_1 A_{IIP_3}| = \left|\frac{3}{4}\alpha_3 A_{IIP_3}^2\right|$$

$$\Rightarrow \boxed{A_{IIP_3} = \sqrt{\frac{4}{3}\left|\frac{\alpha_1}{\alpha_3}\right|}}$$

Also,

$$\frac{A_{IIP_3}}{A_{1dB}} = \sqrt{\frac{4}{0.435}} \simeq 9.6\,dB$$

This ratio proves helpful for simulations & measurements of 3rd order nonlinearity.

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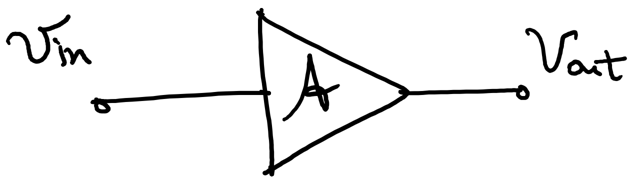
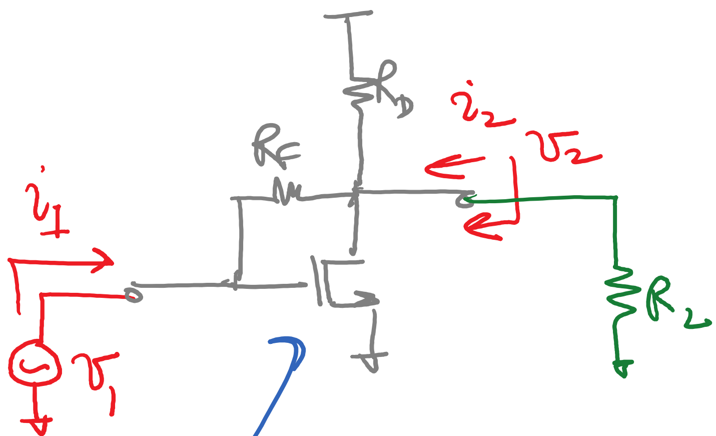
* In some systems e.g. Direct Conversion Receivers, 2^{nd}-order intermodulation products may also fall in the band of operation

↳ a Second-order intercept point (IP_2) may be defined.



$$v_{out} = A\, v_{in}$$

"Linear"

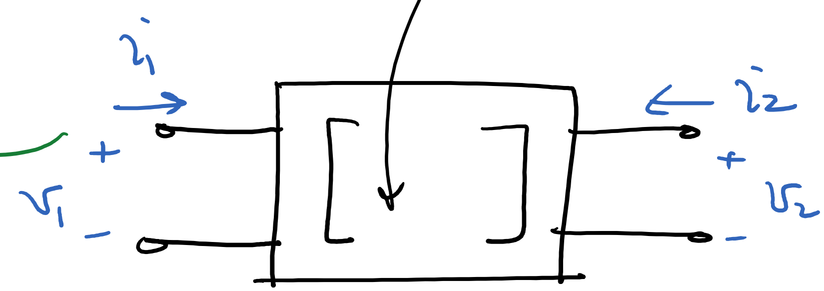


linearized

$$i_2 = \alpha_1 i_1 + \alpha_2 v_1$$

$$v_2 = \beta_1 i_1 + \beta_2 v_1$$

$$\begin{bmatrix} i_2 \\ v_2 \end{bmatrix} = \begin{bmatrix} \alpha_1 & \alpha_2 \\ \beta_1 & \beta_2 \end{bmatrix} \begin{bmatrix} i_1 \\ v_1 \end{bmatrix}$$



related to S-parameters

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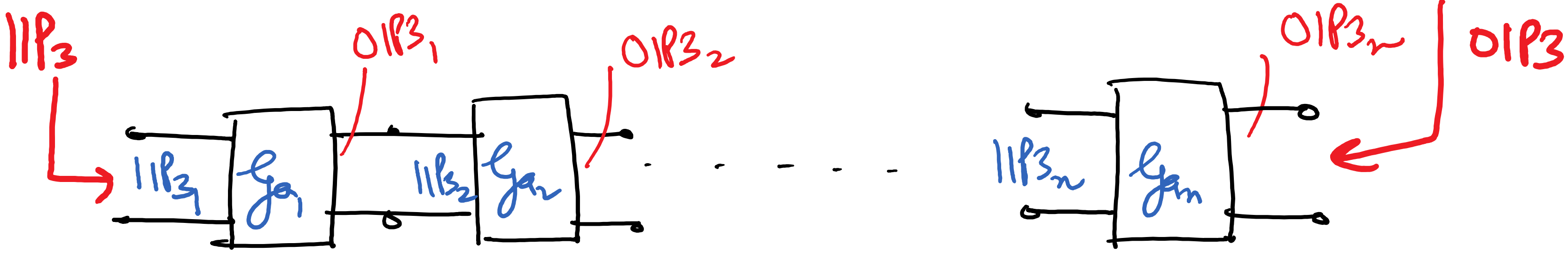
$G_{a_1} = \alpha_1^2$

$G_{a_1} \Leftarrow$ available power gain

Linearity of a chain of "two-ports"



* Conjugate match exists between each stage

$$\boxed{\frac{1}{IIP_3} = \frac{1}{IIP_{3,1}} + \frac{G_{a_1}}{IIP_{3,2}} + \frac{G_{a_1} \cdot G_{a_2}}{IIP_{3,3}} + \cdots + \frac{G_{a_1} G_{a_2} \cdots G_{a_{n-1}}}{IIP_{3,n}}}$$

NL of the first stage adds directly

NL of the 2nd stage is divided by G_{a_1}

↳ NL of the following stages is desensitized by the preceding gain.

$$\boxed{\frac{1}{OIP_3} = \frac{1}{OIP3_n} + \frac{1}{G_{a_n} \times OIP3_{n-1}} + \frac{1}{G_{a_n} \times G_{a_{n-1}} \; OIP3_{n-2}} + \cdots + \frac{1}{G_{a_2} \times \cdots \times G_{a_n} \; OIP3_1}}$$

Noise Figure :

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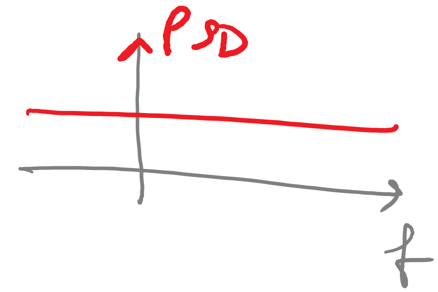
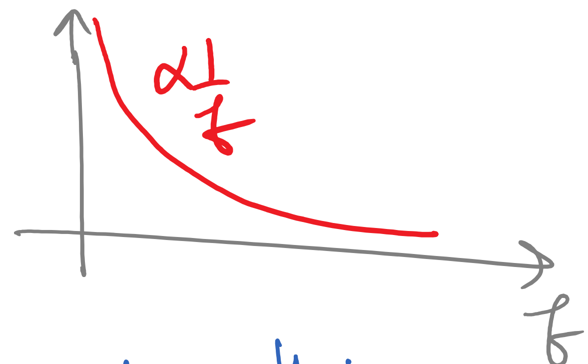
Thermal Noise → random motion of carriers $\propto T$

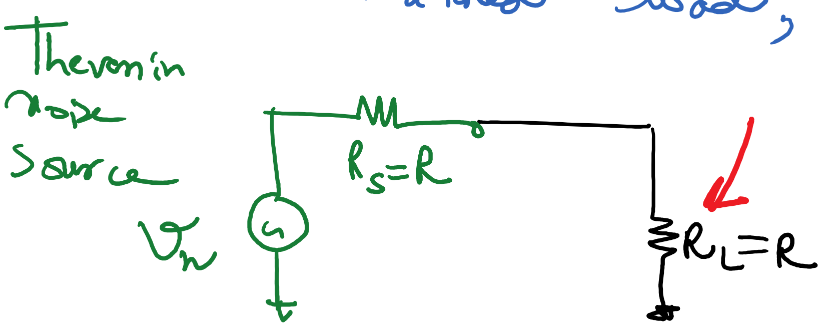
Shot Noise → diodes, BJTs

Flicker Noise → MOSFETs





Available noise power: Defined as the power that can be transferred from a noise source to a conjugately matched load, also $T > 0°K$



$$P_L = \frac{v_n}{2} \cdot \frac{v_n}{2R} = \frac{v_n^2}{4R}$$

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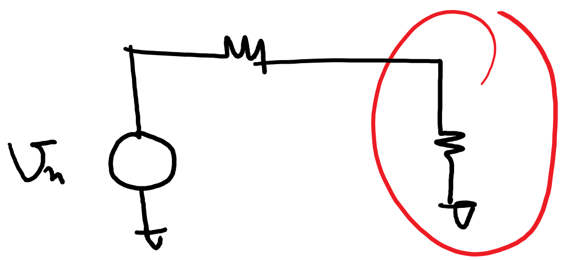

$$P_{available} = \underbrace{\frac{\overline{v_n^2}}{4R}} = \underbrace{kT\Delta f}$$

Boltzmann Constant

$\rightarrow 1.23 \times 10^{-23}$ J/K

Bandwidth of interest

mean square noise voltage $\rightarrow$ $\overline{v_n^2} = 4kTR\cdot\Delta f$

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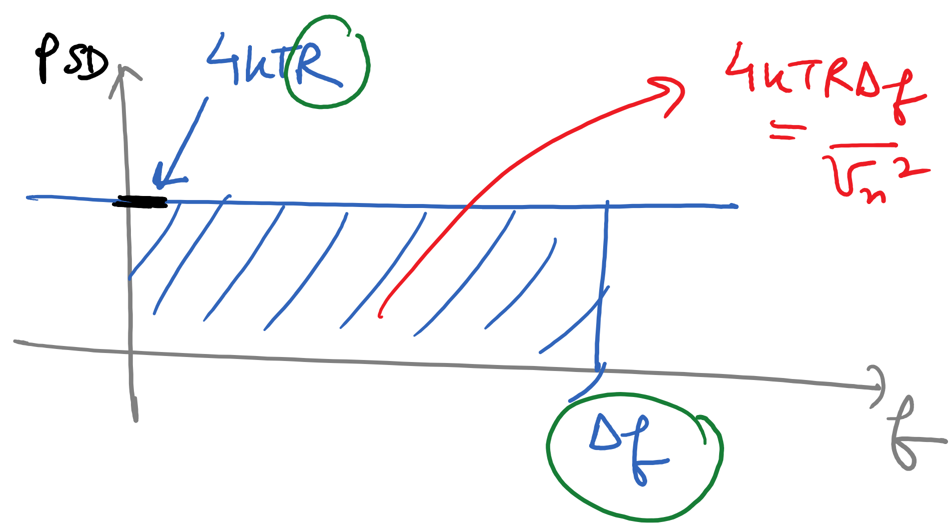
noise power



Noise figure:

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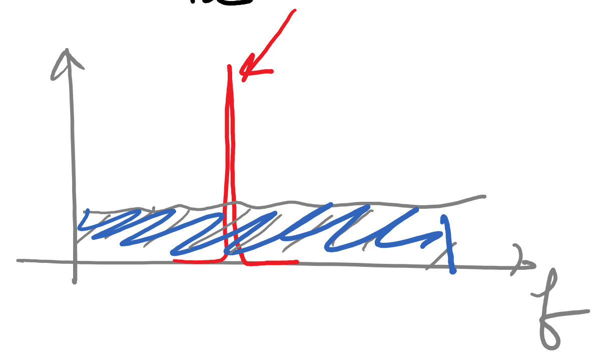
Signal to noise ratio

$$SNR = \frac{P_{signal}}{P_{noise}}$$



Noise factor:

$$F = \frac{SNR_i}{SNR_o}$$