Amplifier Noise

INEL 5207 - ECE Dept. UPRM

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Objectives

- Estimate expected amount of output noise
- Determine minimum usable signal level
- Gain insight into possible improvements

Basic Concepts

- Many types of noise
  - interference, or external, noise
  - d.c. offsets are a form of noise
  - we will study **internal or inherent noise**

- RMS value over averaging interval T:

$$X_n = \frac{1}{T}\sqrt{\int_0^T x_n^2(t)dt}$$

- X_n^2 is the *mean square value* of noise
- x represents current i or voltage e
- We will deal with multiple sources of noise
- Different noise sources are added as vectors

$$X_n = \sqrt{X_{n1}^2 + X_{n2}^2}$$

Frequency Domain

- Noise RMS: computed in the frequency domain
- The *noise power density* is normally specified

$$x_n^2(f) = \frac{dX_n^2}{df}$$

- From the power density the rms value is found

$$X_n = \sqrt{\int_{f_L}^{f_H} x_n^2(f)df}$$

- replace X with I for current, V for voltage

White & *1/f* Noise

- White: uniform spectral density

$$X_n = x_{nw}\sqrt{f_H - f_L}$$

  - white-noise power is proportional to BW

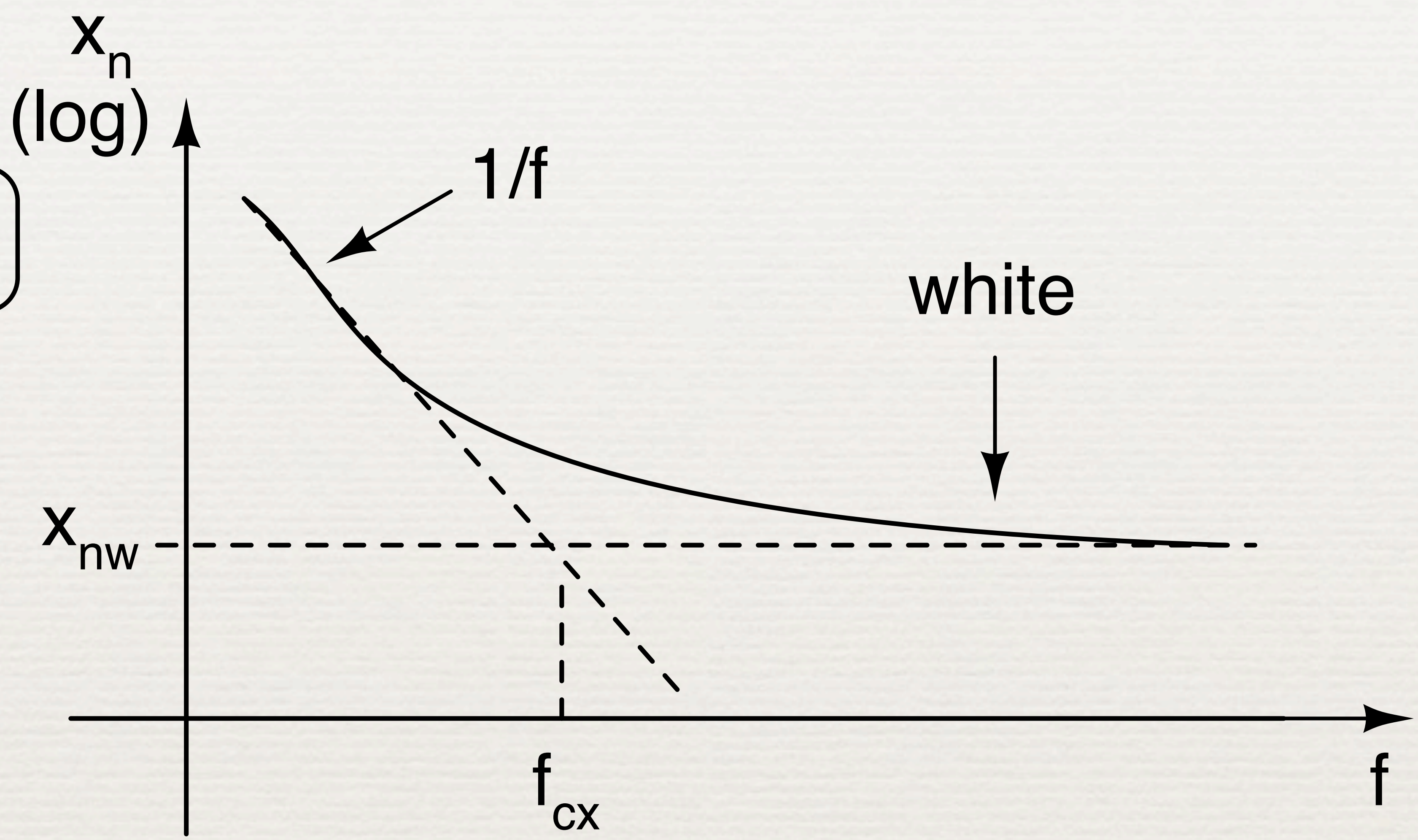
- 1/f noise: varies with reciprocal of *f*

$$x_n = {}^{K}/_{\sqrt{f}} \rightarrow X_n = K\sqrt{\ln\left({}^{f_H}/_{f_L}\right)}$$

  - *1/f* - noise power is proportional to # of decades or octaves

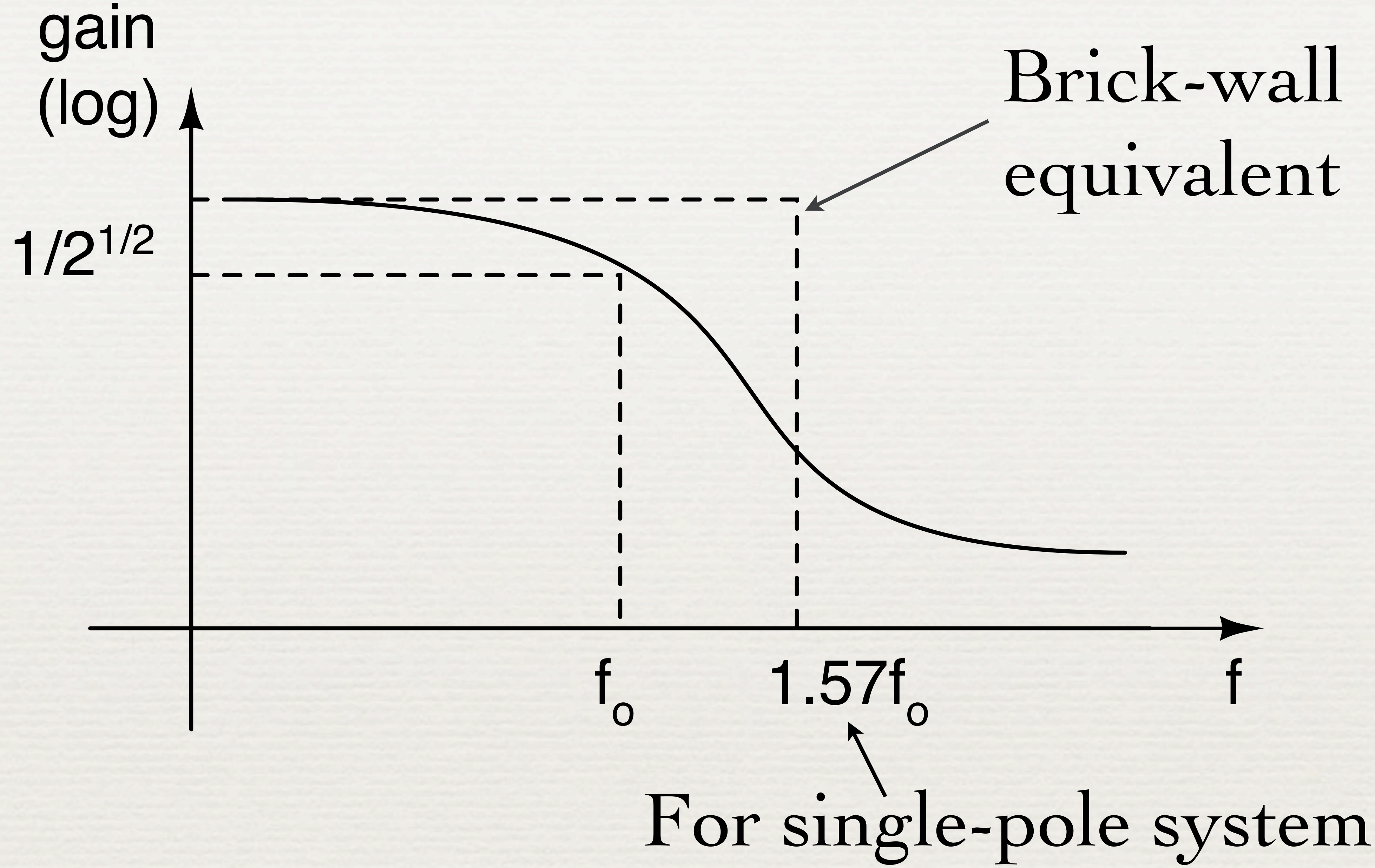
IC noise - mixture of white+1/f

x: e or i



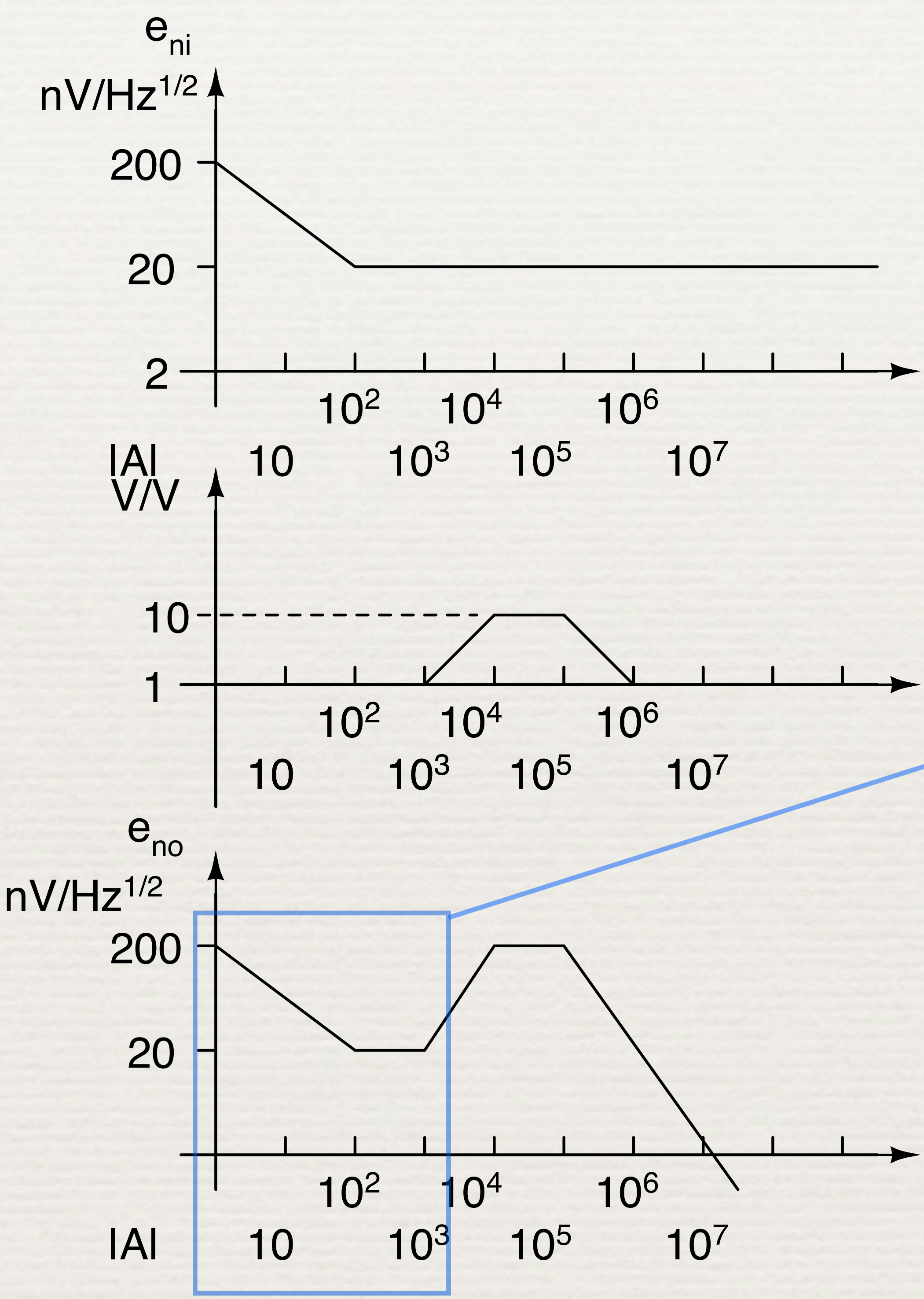
$$x_n^2 = x_{nw}^2 \left(\frac{f_{cx}}{f} + 1 \right) \rightarrow X_n = x_{nw} \sqrt{f_{cx} \ln \left({}^{f_H}/{}_{f_L} \right) + f_H - f_L}$$

- Normally noise is described by specifying e_{nw} and f_{ce} (voltage) or i_{nw} and f_{ci} (current)
- Source of noise appear in different places, and equivalent input noise sources are found
- Input sources are filtered by amplifier to produce output noise
- To simplify calculations, actual magnitude response is replaced by a *Brick-wall equivalent*



Noise-equivalent bandwidth: **1.57f$_0$** for above case

Example 7.3 Piece-wise noise integration



1 Hz to 1kHz:

$$E_n = e_{nw}\sqrt{f_{ce} ln(f_H/f_L) + f_H - f_L}$$

with

$$e_{nw} = 20nV/\sqrt{Hz}$$

$$f_{ce} = 100Hz \qquad f_L = 1Hz$$

and

$$f_H = 1kHz$$

The result is $E_{no1} = 0.822\mu V$.

From 1kHz to 10kHz,

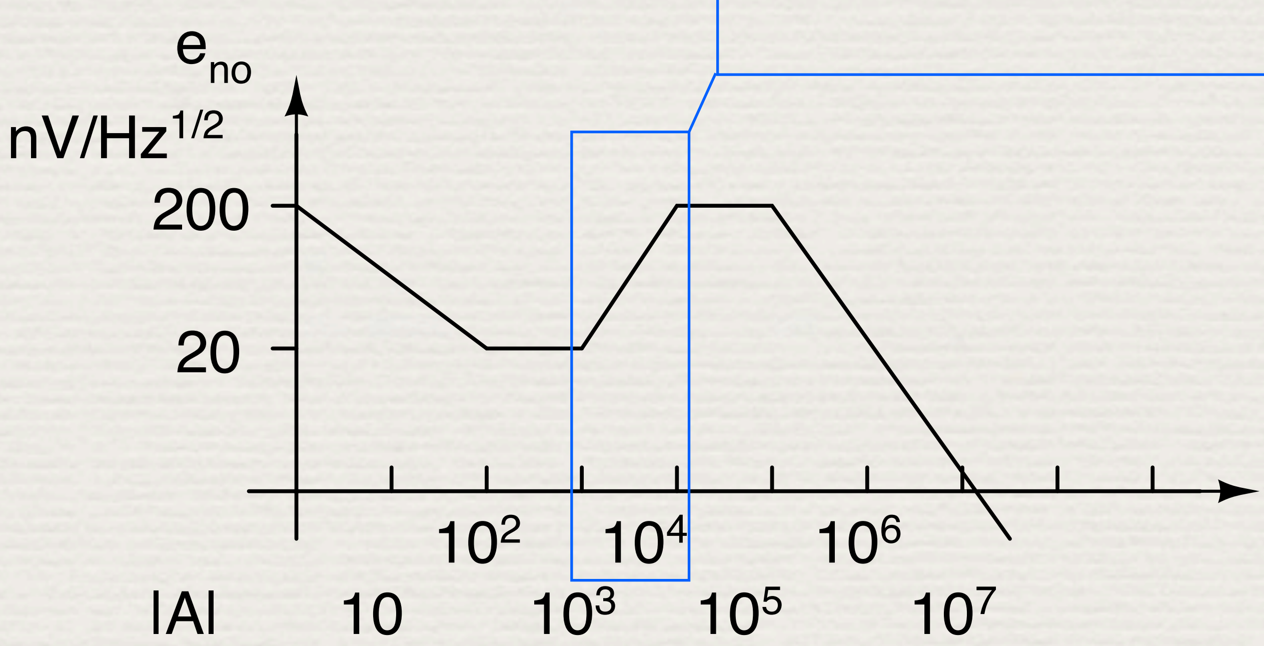
e_{no} increases with f at a rate of 1dec/dec.

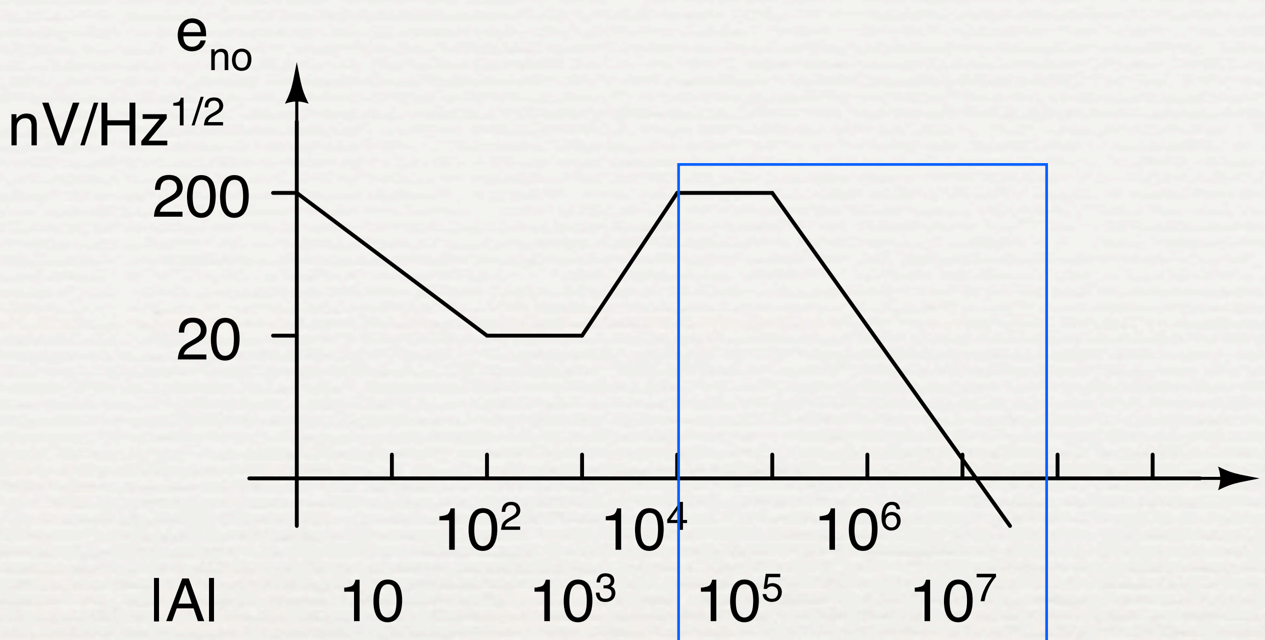
So let

$$e_{no}(f) = \left(20nV/\sqrt{Hz}\right) \times (f/10^3) = 2\times10^{-11} f$$

and

$$E_{no2} = 2\times10^{-11}\sqrt{\int_{10^3}^{10^4} f^2 df} = 11.5\mu V$$





For $f > 10^4 Hz$, we have white noise with $e_{nw} = 200 nV/\sqrt{Hz}$ going throught a low-pass filter with corner frequency $f_o = 100kHz$. Using

$$E_{no3} = e_{nw}\sqrt{1.57 f_o}$$

$$E_{no3} = (200nV/\sqrt{Hz}) \times \sqrt{1.57 \times 10^5 - 10^4} =$$

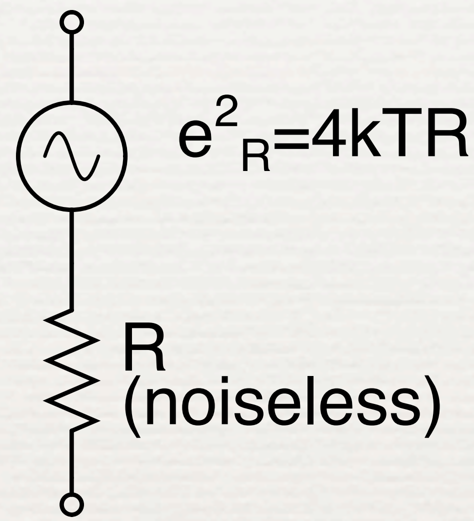
The total is the root of the sum of the square of the three components

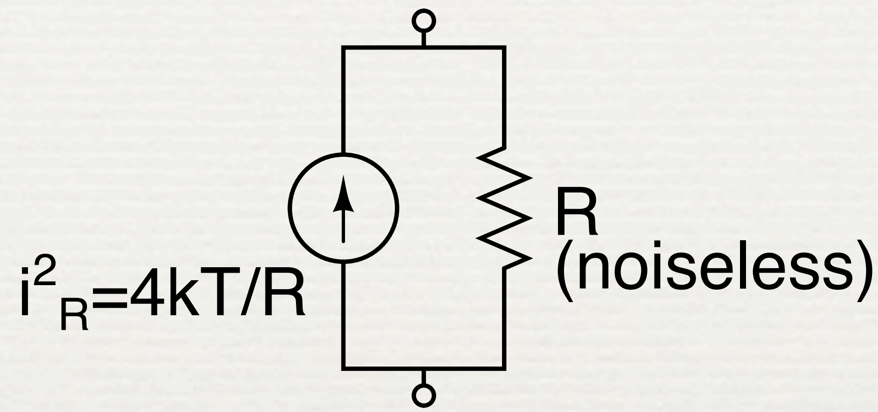
$$E_{no} = \sqrt{E_{no1}^2 + E_{no2}^2 + E_{no3}^2} = 77.5\mu V$$

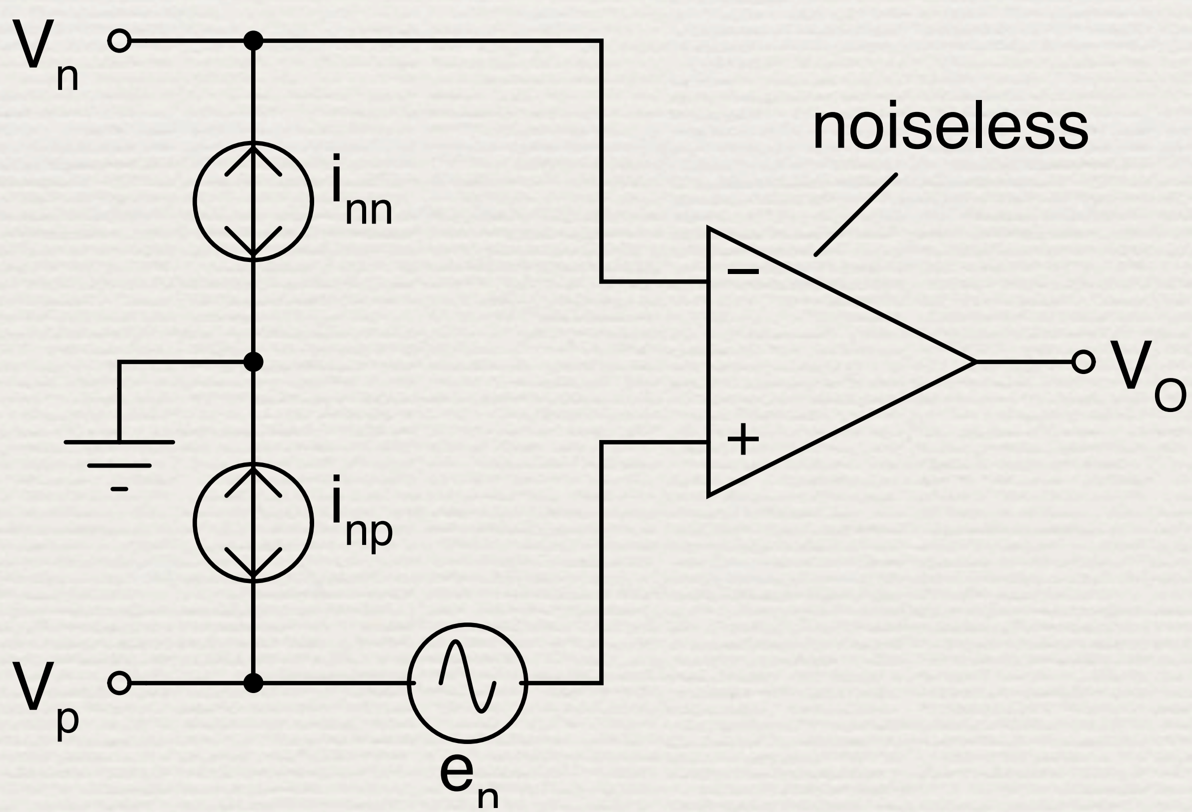
Pink-noise tangent principle

Lower a line with -0.5 dec/dec slope until it becomes tangent to the noise curve. The main contribution to the output noise will come from the portion of the noise curve that is in the vecinity of the tangent point.

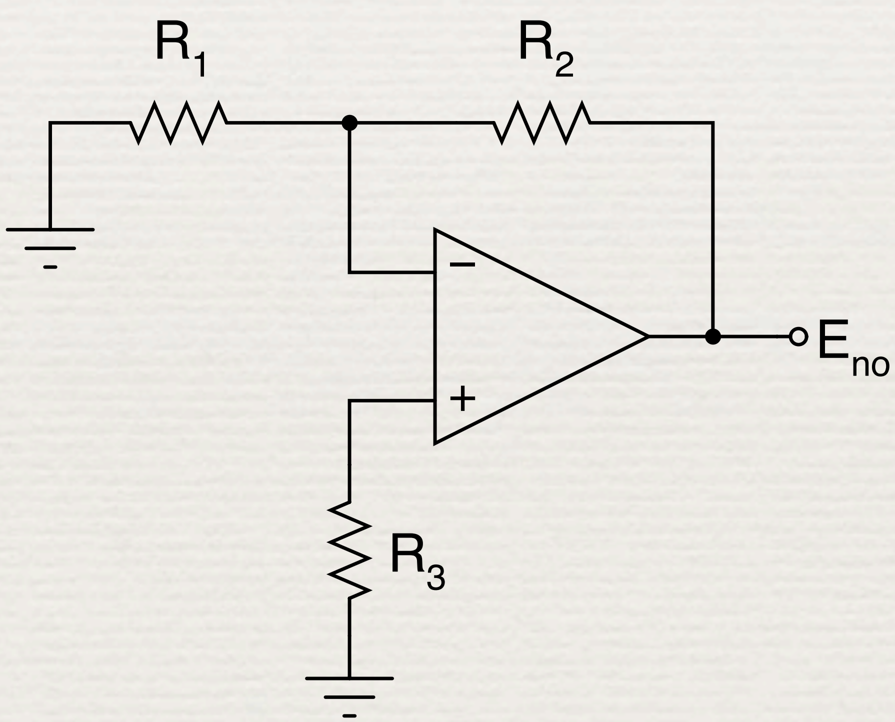
Sources of noise

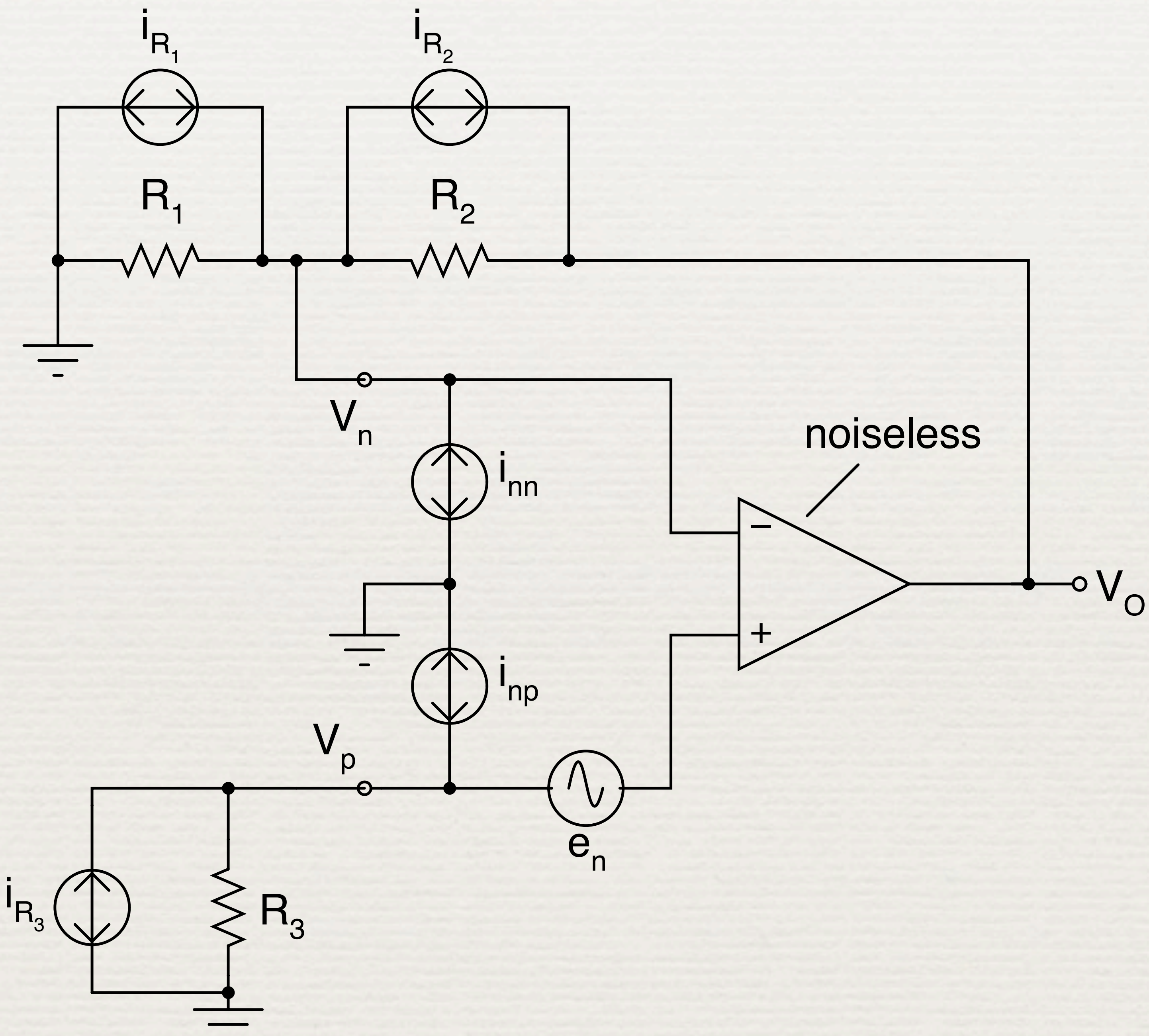






Example 7.7





Use superposition to obtain:

$$e_{ni}^2 = e_n^2 + i_{np}^2 R_3^2 + i_{R_3}^2 R_3^2 + \left(i_{nn}^2 + i_{R_1}^2 + i_{R_2}^2\right)(R_1 \parallel R_2)^2$$

Using $i_R^2 = \frac{4kT}{R}$,

$$\begin{aligned} e_{ni}^2 &= e_n^2 + i_{np}^2 R_3^2 + 4kTR_3 + \left(i_{nn}^2 + \frac{4kT}{R_1} + \frac{4kT}{R_2}\right)(R_1 \parallel R_2)^2 \\ &= e_n^2 + i_{np}^2 R_3^2 + 4kTR_3 + i_{nn}^2 (R_1 \parallel R_2)^2 + \frac{4kT}{R_1 \parallel R_2}(R_1 \parallel R_2)^2 \\ &= e_n^2 + i_{np}^2 R_3^2 + 4kTR_3 + i_{nn}^2 (R_1 \parallel R_2)^2 + 4kT(R_1 \parallel R_2) \\ &= e_n^2 + i_{np}^2 R_3^2 + i_{nn}^2 (R_1 \parallel R_2)^2 + 4kT(R_3 + R_1 || R_2) \end{aligned}$$

For $i_{np} = i_{nn} = i_n$,

$$e_{ni}^2 = e_n^2 + i_n^2 R_{s2}^2 + 4kTR_s$$

where $R_s = R_3 + R_1||R_2$, $R_{s2}^2 = R_3^2 + (R_1||R_2)^2$.

- Setting $R_3 = 0$ reduces noise.
- e_n dominates for low values of R_s: it is called the *short-circuit noise.*
- For $R_s \to \infty$, $e_{ni} \approx i_n^2 R_{s2}^2$: i_n is called the *open-circuit noise.*

Noise is amplified by:

$$A_v = \frac{1 + \frac{R_2}{R_1}}{\sqrt{1 + (f/f_A)^2}} = \frac{A_0}{\sqrt{1 + (f/f_A)^2}}$$

The total output rms noise is

$$E_{no} = A_0 \times \sqrt{E_1^2 + E_2^2 + E_3^2 + E_4^2}$$

where

$$E_1^2 = e_{nw}^2 \left(f_{ce} ln \frac{f_A}{f_L} + 1.57 f_A - f_L \right)$$

$$E_2^2 = R_3^2 i_{npw}^2 \left(f_{cip} ln \frac{f_A}{f_L} + 1.57 f_A - f_L \right)$$

$$E_3^2 = (R_1 || R_2)^2 i_{nnw}^2 \left(f_{cin} ln \frac{f_A}{f_L} + 1.57 f_A - f_L \right)$$

and

$$E_4^2 = 4kT(R_3 + R_1 || R_2)(1.57 f_A - f_L)$$

Book says: $f_L$is $1/T_{obs}$ where T_{obs} is the averaging time used to measure the output.

TI Application note says: take $f_H/f_L = NEB$.

For low-noise designs, use op amps with low e_{nw} and low corner frequencies f_{ci} and f_{cn}.

The *total rms input noise* can be obtained by dividing by the signal dc gain A_{s0}

$$E_{ni} = \frac{E_{no}}{|A_{s0}|}$$

and the signal-to-noise ratio from

$$SNR = 20log_{10}\frac{V_{i(rms)}}{E_{ni}}$$