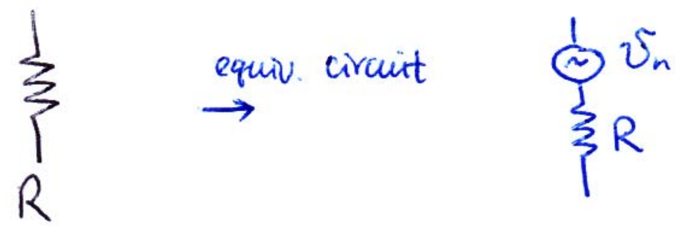
PHYS 3360/AEP 3630

Lecture 40

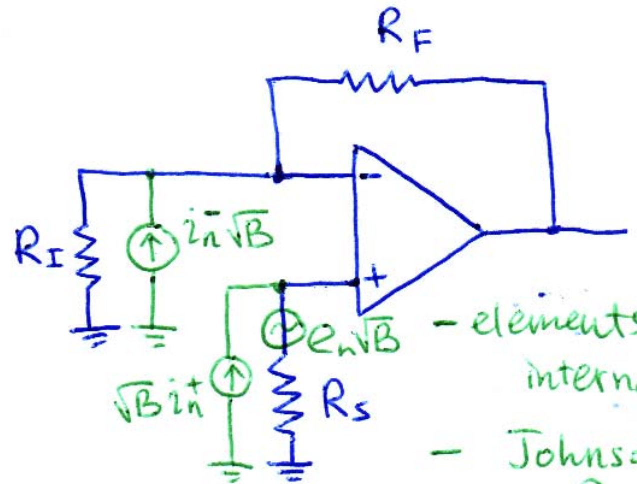
1) Horowitz, Hill Ch 7, 15 – great resource on noise
2) start with ways to minimize intrinsic noise (prev. lecture)

Noise in op-amps

Recall Johnson noise



$$(v_n)_{rms} = \sqrt{4 k_B T R B}$$



general configuration

Q: volt. source ?
A: omit, superposition; interested only in noise

– elements in green: internal to op-amp

– Johnson volt. noise R_I, R_s, R_F not shown

Noise terms:

– 3 resistors (thermal)

– 2 input current noise sources; see spec. sheets specified as $A/\sqrt{Hz}$ (i_n^- or i_n^+)

– 1 input voltage noise source; specified as $V/\sqrt{Hz}$ (e_n)

uncorrelated; total $= \sqrt{term1^2 + term2^2 + \ldots}$

$$R_I: \quad v_{out}\Big|_{R_I} = \sqrt{4 k_B T R_I B}\left(\frac{R_F}{R_I}\right) \leftarrow \text{inverting gain}$$

R_F : $v_{out}|_{R_F} = \sqrt{4k_BTR_FB}$

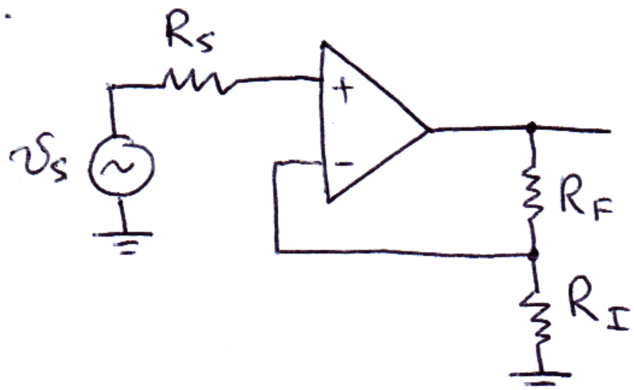
R_s : $v_{out}|_{R_s} = \sqrt{4k_BTR_sB}\left(1+\frac{R_F}{R_I}\right)$ ↵ non-inverting gain

e_n : $v_{out}|_{e_n} = e_n\sqrt{B}\left(1+\frac{R_F}{R_I}\right)$

i_n^- : $v_{out}|_{i_n^-} = i_n^-\sqrt{B}\,R_F$ ↵ ask the class to show

i_n^+ : $v_{out}|_{i_n^+} = i_n^+\sqrt{B}\,R_s\left(1+\frac{R_F}{R_I}\right)$

Ex.



E.g. LF356

$e_n \sim 12\,nV/\sqrt{Hz}$ (above f_{corner} ~100Hz)

$i_n^\pm \sim 0.01\,pA/\sqrt{Hz}$

$R_I \simeq 1k\Omega$

$R_F = 100k\Omega$

$R_s \simeq 5k\Omega$

$B \sim 20kHz$, $T \sim 300K$

$v_{out}|_{R_I} = 57.6\ \mu V_{rms}$ ⟹ $v_{out,n} = 223\,\mu V_{rms}$

$v_{out}|_{R_F} = 5.8\ \mu V_{rms}$

$v_{out}|_{R_s} = 130\,\mu V_{rms}$

$v_{out}|_{e_n} = 171\,\mu V_{rms}$

$v_{out}|_{i_n^+} < 1\,\mu V_{rms}$

Q: Will TDS1002 scope be able to measure this?

A: (1MΩ), 60 MHz BW ⟹ 2mV/div (20MHz)

$(v_n)_{rms} \sim 570\,\mu V_{rms}$ (only if physical resistor)

128 avg → $570/\sqrt{128}$ → $50\,\mu V_{rms}$

Yes.

II Interference (often more important than intrinsic)

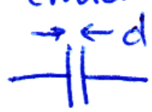
- noise due to sources external to the circuit (or cross-talk)
- can be ~ eliminated

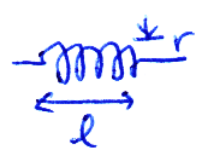
Sources

- any device with spark gap
  - car ignition
  - elect. motors
  - relays
  - fluorescent lights
  - lightning
- power lines / transformers (60Hz)
- radio, TV, wireless
- solar flares
- vibrations

Coupling mechanisms

① Mechanical (microphonics)

- $C \sim \frac{A}{d}$ 

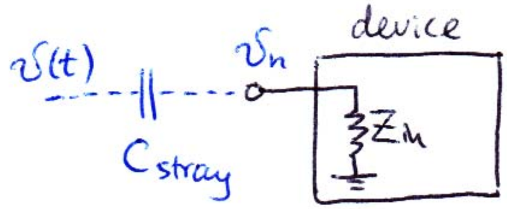
, d changes ⇒ C changes
- $L \sim \frac{r^2 (N^2)}{\ell}$ 

r, ℓ —"— ⇒ L —"—
- piezoelectric effect
- flexing coax → impedance change, intermittent contact in braid

② Capacitive coupling

- any two conductors connected by E-field lines have capacitance b/w them

- stray C couples volt. fluctuations from other / ext. parts of circuit
- e.g. $C_{stray} \sim 10\text{-}100 \frac{pF}{m}$ for a wire run around the lab, couples to ~10–100 V due to power lines, fluorescent lights, ...



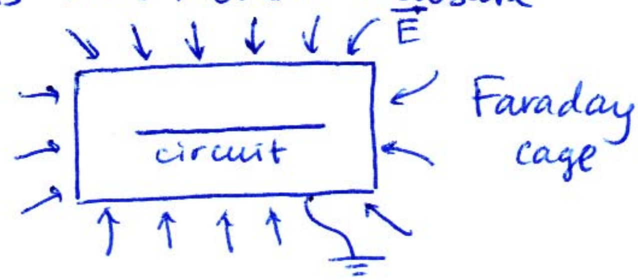
$$v_n \sim v(t) \frac{Z_{in}}{Z_{in} + \frac{1}{j\omega C_s}}$$

E.g. let $R_{in} \sim 1 M\Omega$, $C_s \sim 20 pF$, $v \sim 120 VAC$

$|Z_{cs}| \sim 133 M\Omega$, $\Rightarrow v_n \sim 0.9 VAC$

To reduce

- shield all leads & components with metallic enclosure at fixed potential



- use coax or triax (doubly shielded)
- move high level signal parts from high-Z inputs
- run wires close to conducting ground plates to reduce fringing E-fields