Today, we will:

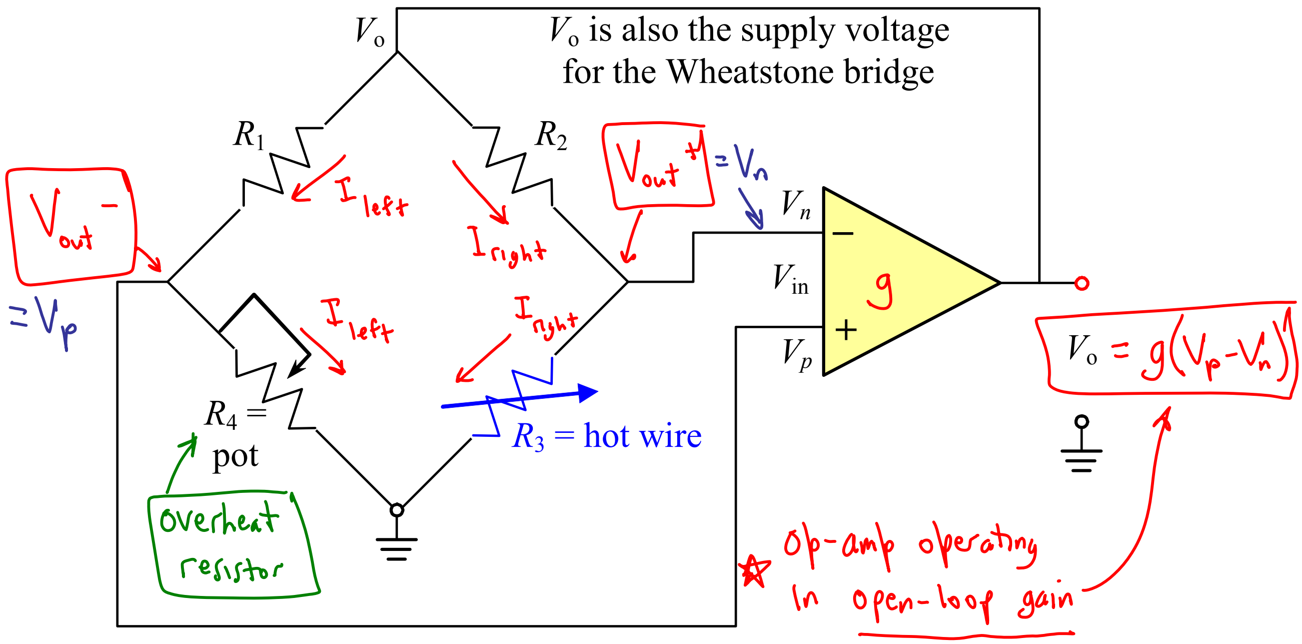
- Discuss some miscellaneous items about velocity measurement
- Do some review example problems to help you prepare for the final exam

Final Exam

- Please sit in every other seat.
- The final exam is ***comprehensive***.
- **Format:** The exam consists of two parts, a closed-book part and an open-book part, roughly equal in weight.
- **Closed portion**
  - No notes, no calculators, no sheets of papers - *nothing but a pencil*! A few equations and tables will be provided as needed.
  - This part will test your understanding of concepts and terms (Multiple choice, True/False, and short completion - *limited or no partial credit*).
  - This part will be similar to the quizzes at the Testing Center, except it will be on paper instead of on the computer.
- **Open portion**
  - You may bring: your class notes, web lecture notes, tablet PC notes from the web, tables from the web, lab manual for this course, graded lab reports, graded homeworks, a calculator, and Professor Cimbala's homework solutions.
  - At a minimum, print out and bring the **Outline and Equation sheet** and **The 12 pages of tables.** This should be all you need to do well on the final exam.
  - You may *not* bring: any books, exams or homeworks from *other* courses, anything from previous semesters of this course or its predecessors (M E 82, M E 382, or M E 345).
  - Only a basic calculator is permitted. It must be a *calculator*, not a cell phone, ipad, tablet, etc., or any device that can store notes, example problems, etc.
  - The instructor and TAs will proctor the final exam - cheating will not be tolerated.
  - No cell phone usage during the exam (turn it off).
  - This part will be *problems* similar to homework problems and class example problems - show all your work and calculations in the space provided on the exam (*there will be partial credit.*).

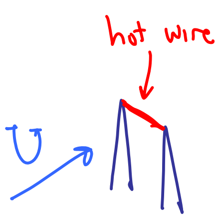
Additional Notes: Hot-Wire Anemometry Circuit

Constant temperature hot-wire anemometer circuit: [A clever Wheatstone bridge circuit!]



• Typical values: $R_1 = 1500\ \Omega$, $R_2 = 150\ \Omega$, R_4 = pot (0 to 200 Ω)

R_3 = hot wire, $R_3 \approx 10\ \Omega$, but $R_3 \downarrow$ as $T \uparrow$



(When $U \uparrow$, R_3 tries to go down since the wire wants to cool off)

• How it works:

- We adjust R_4 (the overheat resistor) so that @ $U = 0$, I_{right} is enough current to heat the hot wire to ≈ 200°C (it is a "hot wire"!)
- The bridge is slightly unbalanced, so $V_{out}^+ < V_{out}^-$
- But $V_o = g(V_p - V_n) = g(V_{out}^- - V_{out}^+)$ is thus positive
- Notice – the op-amp is wired "backwards" → [$V_{out}^+ = V_n$, $V_{out}^- = V_p$]
- So, when $U \uparrow$, $R_3 \downarrow$ & since R_3 is a ⊕ve resistor in the bridge,

V_{out} = Wheatstone bridge output = $V_{out}^+ - V_{out}^-$ goes ↓ as R_3 ↓

- But, V_{in} of the op-amp $= V_p - V_n = -V_{out}$ of the bridge

  $[V_{in} = V_p - V_n = V_{out}^- - V_{out}^+ = -V_{out}]$

- So, since $V_{out}^+ - V_{out}^-$ goes ↓ as R_3 ↓, $V_{in} = V_p - V_n$ goes ↑ as R_3 ↓

- Bottom line: As U ↑, $V_o = g(V_p - V_n)$ ↑ ☆

- The clever design here is that V_o is also the supply voltage to the Wheatstone bridge!

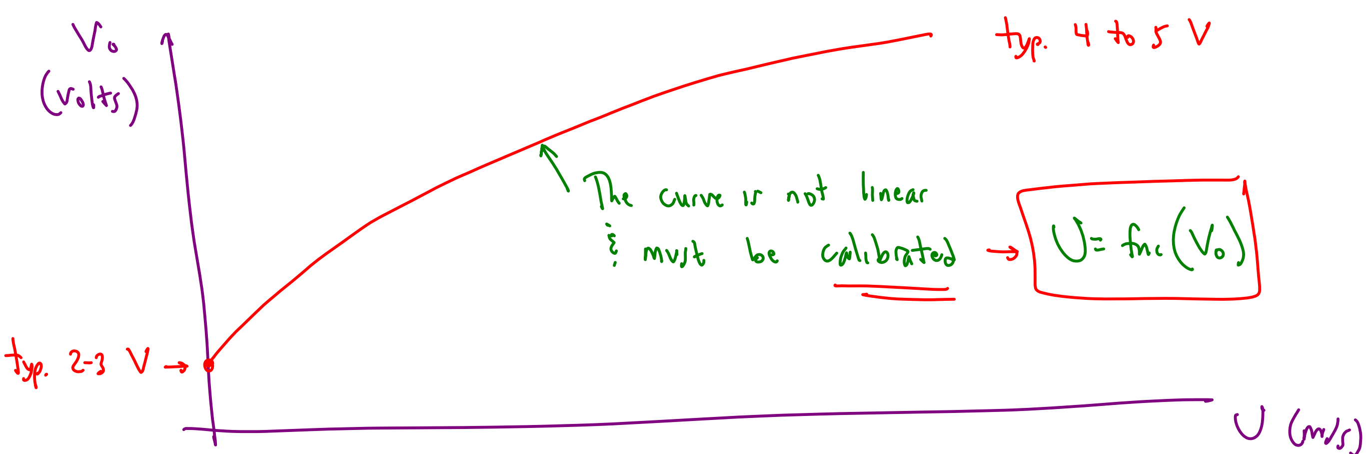
- As V_o ↑, the current through both legs goes up [I_{right} ↑, I_{left} ↑]

- Since I_{right} ↑ through the hot wire, the additional current adds more heating power to the hot wire → (it's temperature remains constant!)

[pretty clever, eh?]

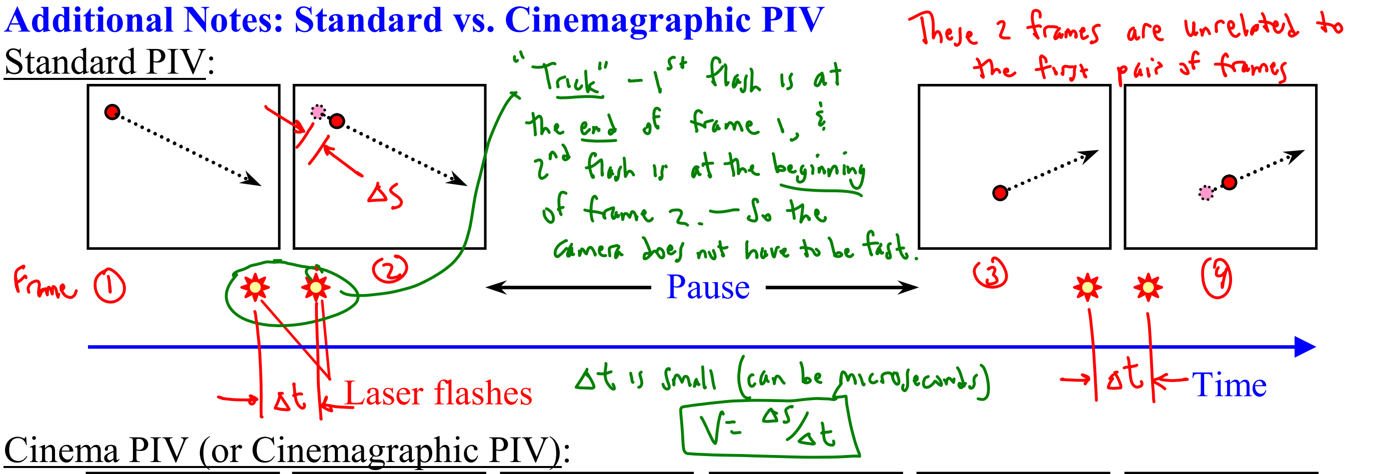
The system is stable & adjusts very rapidly since the hot wire is so small → the hot wire stays at a constant T (≈ 200°C)

Bottom Line: V_o ↑ as U ↑ ☆

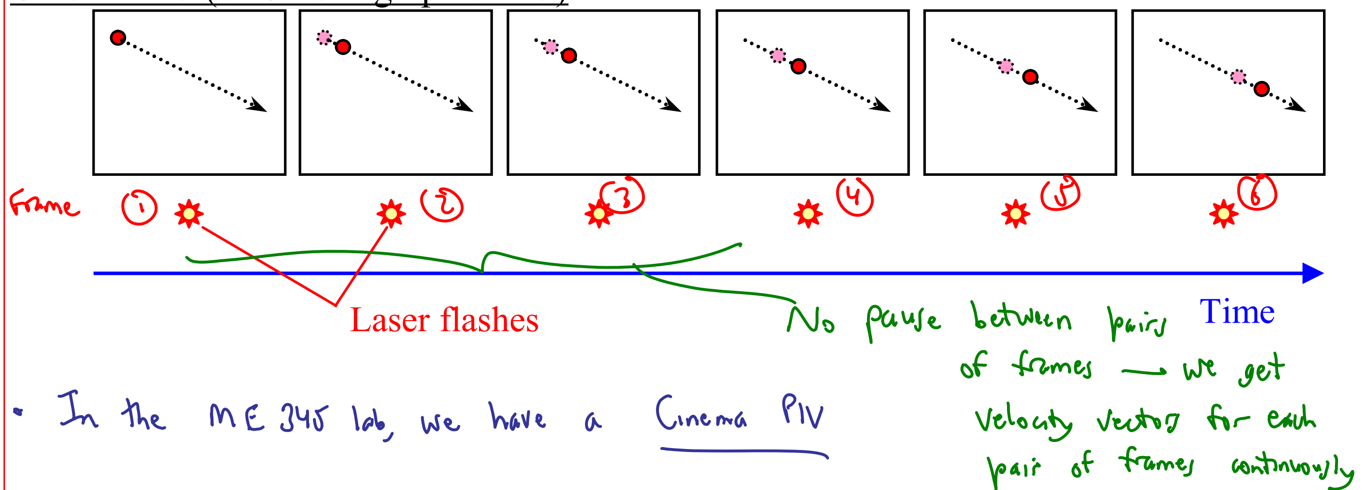


Additional Notes: Standard vs. Cinemagraphic PIV

Standard PIV:



Cinema PIV (or Cinemagraphic PIV):



- In the ME 345 lab, we have a Cinema PIV
  - Use Frames ① & ② to calculate velocity field
  - " " ② & ③ " "
  - " " ③ & ④ " ", etc.

Advantages of Cinema PIV:

- We get a continuous "movie" of the particles (no long pause between successive pairs of frames)
- Can use the frames as flow visualization
- Can use a cheaper laser – does not have to be double pulse (sync pulses with camera)

Disadvantages of Cinema PIV:

- Fill up camera memory fast – limited # frames
- Longer Δt between laser flashes → limits max. flow speed.
- Need more expensive camera w/ high frame rate and a lot of memory

Standard PIV → · expensive laser
· cheap camera

Cinema PIV → · cheap laser
· expensive camera

Example: Review for Final Exam

Given: A voltage output has a DC level of 2.0 V and two frequency components: a 30 Hz signal of amplitude 3.0 V, and some noise at 180 Hz of amplitude 0.66 V. Unaware of the noise, Jenny samples the signal at 80 Hz.

(a) To do: Sketch the frequency spectrum of this signal.

Solution:

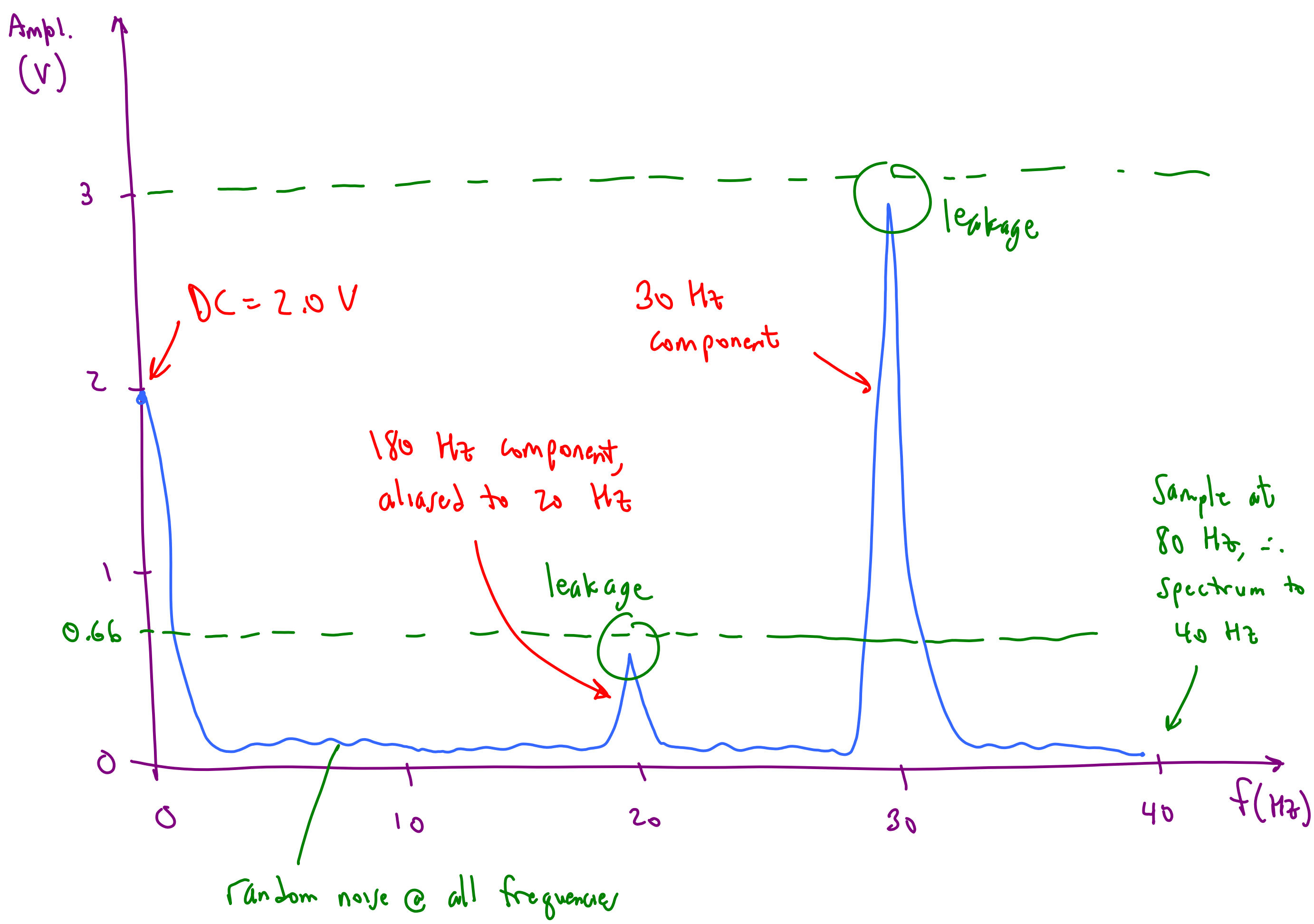
- frequency → plot from 0 to 80/2 = 0 to 40 Hz (Nyquist)
- 30 Hz component is not aliased ($2\cdot 30 = 60 < 80 = f_s$)
- 180 Hz component is aliased since $2\cdot 180 = 360 < 80 = f_s$ (Nyquist violated)

$$f_a = f_{perceived} = \left| f - f_s * NINT\left(\frac{f}{f_s}\right)\right| = \left|180 - 80 * NINT\left(\frac{180}{80}\right)\right| = \left|180 - 80*2\right| = \underline{\underline{20\ Hz}}$$

(2.25 → 2)

(the 180 Hz component will be perceived as a 20 Hz component)

SPECTRUM:



Why is there leakage? Because the sample starts & ends at different phases of the signal. ★

(b) To do: Suppose we are using Excel to do our spectral analysis. [Recall that Excel's FFT algorithm is limited to powers of 2 (..., 64, 128, 256, 512, 1024, ...).] We sample at 80 Hz for 5 seconds, but we have to throw away some of the data because of Excel's limitations. Calculate the frequency resolution in Hz (to four significant digits).

Solution:

• If no power of 2 restriction,

$$\Delta f = \frac{1}{T} = \text{frequency resolution} = \frac{1}{5\ s} \rightarrow \Delta f = \frac{1}{5}\ \text{Hz} = 0.200\ \text{Hz}$$

And, $T = \frac{N}{f_s} \rightarrow N = f_s \cdot T = \left(80\ \frac{\text{pts}}{s}\right)(5\ s) = 400\ \text{pts}$

• But, Excel is limited to powers of 2 — $N = 256$ pts actually usable by Excel's FFT

So → with $N = 256$ pts sampled at 80 Hz,

$$T = \frac{N}{f_s} = \frac{256\ \text{pts}}{80\ \text{pts}/s} = 3.2\ s$$

$$\therefore \Delta f = \frac{1}{T} = \frac{1}{3.2\ s} = \boxed{0.3125\ \text{Hz} = \Delta f}$$

Notice that the actual Δf is bigger (worse) in Excel because of its power of 2 restriction

Comment → The only way to get better (smaller) Δf is to sample for a longer time, since $\Delta f = \frac{1}{T}$

Example: Review for Final Exam

Given: Voltage is not a primary dimension, but current is.

To do: Write the dimensions of voltage in terms of primary dimensions.

Solution:

- $\dot{W}$ = power = $V \cdot I$, so $\{V\} = \left\{\frac{\dot{W}}{I}\right\}$
- $\{\dot{W}\} = \left\{\frac{\text{work}}{\text{time}}\right\} = \left\{\frac{F \cdot L}{t}\right\} = \left\{\frac{(mL/t^2)\cdot L}{t}\right\} = \left\{\frac{mL^2}{t^3}\right\} = \{\dot{W}\}$

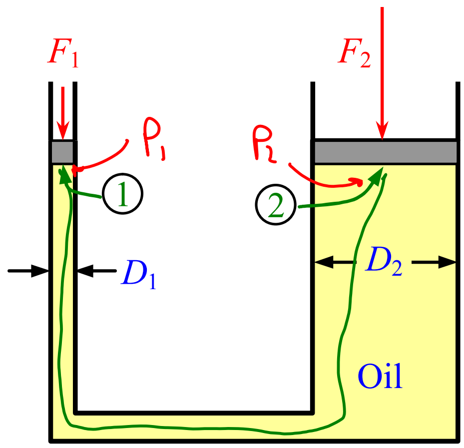
So, $\boxed{\{V\} = \left\{\frac{mL^2}{t^3 I}\right\}}$

- Additional → $\{R\} = \left\{\frac{\Delta V}{I}\right\}$ (ohm's law) → $\boxed{\{R\} = \left\{\frac{mL^2}{t^3 I^2}\right\}}$

Example: Review for Final Exam

Given: A hydraulic jack is constructed with the large piston diameter equal to 12.7 cm (5.00 inch) and the small piston diameter equal to 0.635 cm (1/4 inch).

To do: How much weight (in lbf) can a person lift with the jack if he exerts a force of 30.0 lbf on the small piston? *Give your answer to three significant digits.*



Solution:

- $P_1 = P_2$ (We can draw a line from ① to ② through the same fluid in hydrostatics, & ① & ② are at the same elevation)
- But $P_1 = \frac{F_1}{A_1} = \frac{4F_1}{\pi D_1^2}$ & $P_2 = \frac{F_2}{A_2} = \frac{4F_2}{\pi D_2^2}$

equating, $P_1 = P_2 = \frac{4F_1}{\pi D_1^2} = \frac{4F_2}{\pi D_2^2}$ → $\boxed{F_2 = F_1\left(\frac{D_2}{D_1}\right)^2}$

- Plug in numbers → $F_2 = (30 \text{ lbf})\left(\frac{5.00 \text{ in}}{1/4 \text{ in}}\right)^2 = \boxed{12{,}000 \text{ lbf}}$

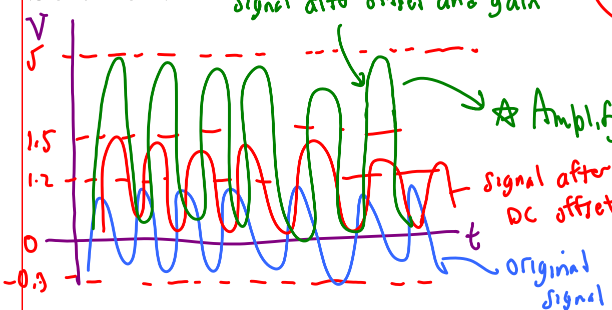
[Note the large mechanical advantage of a hydraulic jack!]

Example: Review for Final Exam

Given: A signal ranges between –0.30 V and 1.20 V. The signal is to be sampled by an A/D converter that has an input range of 0 to 5 V. For maximum resolution, the signal is to be conditioned such that it fits the full input range of the A/D converter. Obviously, a DC offset must be added to the signal, and then the modified signal must be amplified.

To do: Calculate the required DC offset and amplification (gain).

Solution:



DC offset = ⊕0.3 V (moves minimum from −0.3 to 0 Volts)

☆ Amplify from 1.5 to 5 → $G = \frac{5}{1.5} = 3.333$

DC offset by 0.3 V, Amp by 3.333...

Example: Review for Final Exam

Given: A sixth-order Butterworth low-pass filter is used to attenuate a 100-Hz noise frequency. The cutoff frequency of the filter is set to 40 Hz.

To do: By how many decibels is the 100 Hz noise attenuated?

Solution:

$$G = \frac{1}{\sqrt{1+\left(\frac{f}{f_{cut}}\right)^{2n}}} = \frac{1}{\sqrt{1+\left(\frac{100}{40}\right)^{12}}} = 0.004096 = G$$

($2n \rightarrow 12$)

$$G_{dB} = 20\log_{10} G = -47.8 \text{ dB}$$ ☆

Example: Review for Final Exam

Given: Rita is calibrating an electronic pressure transducer – using a U-tube manometer. When the true (exact) pressure is 5.000 mm of mercury (as measured by the manometer, she takes 10 readings with an electronic pressure transducer. The readings are (lowest to highest): 4.94, 4.96, 4.96, 4.96, 4.97, 4.98, 4.98, 4.99, 5.00, and 5.00 mm of mercury

The mean value of these 10 measurements is 4.974 mm of mercury.

To do: Estimate the bias error of the electronic pressure transducer in units of mm of mercury.

Solution: Bias error = mean value − true value

= 4.974 − 5.000 = −0.026 mm Hg

Additional:

Median → Avg of two middle values = (4.97 + 4.98)/2 = 4.975 → 4.98

Mode → 4.96 (most occurring)