

ECE 209: *Circuits and Electronics Laboratory*

Notes for Lab 2 (Meters, Measurements, and Errors)

1. The digital voltmeter (DVM)

- Because voltage is defined at one point **with respect to another point**, then voltmeter must be placed at **two points** in the circuit (i.e., in “parallel” with the device under test).
- To reduce impact on circuit, voltmeter has **very high** internal resistance (i.e., an **open circuit**).
- Because voltmeter resistance is very high, if placed in series with a device, it stops all current.

2. The ammeter

- Because current is defined **at a point**, then ammeter is **inserted** in **series** to do measurement.
- To reduce impact on circuit, ammeter has **very low** internal resistance (i.e., a **short circuit**).
- Because ammeter resistance is very low, if it is placed in parallel with a device, current skips the device and usually **fries the ammeter** and possibly other parts of the circuit.

3. The digital multimeter (DMM) or digital volt-ohm meter (DVOM)

- Combines multiple measurement tools into one unit.
 - Internally, DMM is a **slow** and **high-precision** analog-to-digital converter measuring voltage.
 - Versatile: voltage, current, capacitance, inductance, resistance, temperature, frequency, etc.
 - * Convert to ammeter by measuring voltage from *measured* current \times *known* resistance.
 - * Convert to ohmmeter by measuring voltage from *known* current \times *measured* resistance.
 - * Measure temperature with a **thermocouple**.
 - * Measure capacitance by finding **rise time** of a known step across a known resistance.
 - * With an **on-board DSP**, lots of other useful measurements or conversions are possible.
- High-precision models (e.g., 6.5+ digits) can be PCI cards or larger bench-top units (e.g., function generator size) with computer interfaces. These models have advanced/extensible feature sets.
- RMS measurements are often AC coupled (i.e., DC offset/average component is stripped out).
 - So RMS measurements may be incorrect when waveform has nonzero offset.
 - Remember that $\text{RMS}^2 = \text{RMS}_{\text{AC}}^2 + \text{DC}^2$.
 - * *Calculate* true RMS by measuring DC offset (i.e., *average*) and AC RMS (i.e., RMS_{AC}).
 - * Some meters have a *special* setting that does the “AC+DC” RMS calculation for you.
- Can use **probes** or **banana connectors** (the latter is useful for *common ground* connections).
- For safety, some DMM’s have “shutters” to help prevent accidental short-circuiting by ammeter.
- Bandwidth of these devices is may involve **parasitic reactance**, but in reality *internal* filters restrict bandwidth **by design**. Typical or guaranteed bandwidth should be specified (usually on device).
 - **HP 972A** has unity gain up to 20 kHz. **HP 974A** has unity gain up to 100 kHz.
 - Should not use DMM outside of its specified bandwidth.

4. Introduce and complete the *Meters, Measurements, and Errors* lab.

- Resistor color codes: Black, Brown, ROYGBV, Gray, White correspond to **digits** 0–9
 - Far-right digit d_t has specifies *tolerance* (different colors and/or separated more).
 - $d_1-d_2-d_m-d_t$: $d_1d_2 \times 10^{d_m}$, $d_1-d_2-d_3-d_m-d_t$: $d_1d_2d_3 \times 10^{d_m}$, and so digit d_m is “# of zeros”
 - **Brown-Black-Green** = 105 = 1000000 = 1 M Ω ; **Brown-Green-Orange** = 153 = 15000 = 15 k Ω
- See procedure details on the next page.

Part 1 Measure the internal resistance of a DC voltmeter

★ V_s is is supply voltage. V_m is measured voltage across R_2 ($V_m \approx V_s/2$).

1. Connect V_s to R_1 . Connect R_1 to R_2 . Connect R_2 to 0 V (ground).
2. Temporarily **DISCONNECT** breadboard from V_s DC supply. **THEN** measure resistance across R_1 and R_2 . Record these values in your table. They should be $\sim 1\text{ M}\Omega$.
3. Set the **HP 974A** (**NOT** the **972A**) digital multimeter (DMM) to measure DC voltage. Press the **Range** button until the number in the upper-right of the screen indicates the appropriate range for your measurement (5 V for the first trial and 50 V for the second trial).
4. Use the DVM to measure V_m across R_2 . It should be $\sim V_s/2$. Record your value in the table.
5. For your lab report, plug your measured V_m , V_s , R_1 , and R_2 into the equation

$$V_m = \frac{R_2 \parallel R_v}{R_1 + R_2 \parallel R_v} \quad \text{where} \quad R_2 \parallel R_v = \left(\frac{1}{R_2} + \frac{1}{R_v} \right)^{-1} = \frac{R_2 R_v}{R_1 + R_v} \quad (1)$$

and **solve** for R_v . Compare this “calculated R_v ” to the “given R_v ” from the table. Use the percent error formula

$$\% \text{ error} = \frac{\text{Measured } R_v - \text{Given } R_v}{\text{Given } R_v} \times 100\%.$$

Note that **Equation (1)** is the V_m/V_s “transfer function” of the circuit in Figure 2(b) from your book.

★ Do these steps for **BOTH** the 4 V (5 V DVM range) and 20 V (50 V DVM range) input cases.

Part 2 Measure the internal resistance of a DC ammeter.

★ 500 Ω potentiometers (screw swings middle “wiper” pin) and screwdrivers (“probe tool”) are in cabinet.

★ Must be in ammeter mode to open and close shutter.

1. Connect V_s to R , R to Ammeter current input (open shutter), and ammeter ground to 0 V.
2. Measure current I , which should be near $(12\text{ V})/(15\text{ k}\Omega) = 0.8\text{ mA}$. If ammeter beeps or reads 0 mA, try a different ammeter (i.e., the internal fuse is blown).
3. Connect **middle** potentiometer pin to junction between R and ammeter. Connect **either one of the outside** potnetiometer pins to 0 V.
4. Adjust potentiometer screw until ammeter reads **half** of the old current (i.e., $I/2$, or around 0.4 mA).
5. **Remove** potentiometer and measure resistance between the two pins that you used (alligator clips may help). The resistance will match ammeter’s R_a (typically between 10 Ω and 15 Ω).
6. Close shutter and put ammeter back in voltage mode.

Part 3 Frequency response of AC voltmeters.

★ Make sure your table has both **HP 972A** and **HP 974A**; switch tables otherwise.

1. Use banana connectors with alligator clips to connect DMM to function generator’s cable. Set generator for HIGH Z mode. The **∞** button doubles as a **Vrms** button to make setting amplitude easy.
2. Set DMM to measure AC (RMS) voltage. Use **Range** button for 5 V (or 4 V) range. If measurement is noisy, try a different function generator. In **worst-case scenario**, turn on **Average** feature of DMM. For low frequencies, DVM RMS should match function generator RMS *almost perfectly*.
3. Record data for **BOTH** **HP 972A** (20 kHz bandwidth) and **HP 974A** (100 kHz bandwidth). Make sure to use the correct data table. See next page for instructions on how to process and display these data.

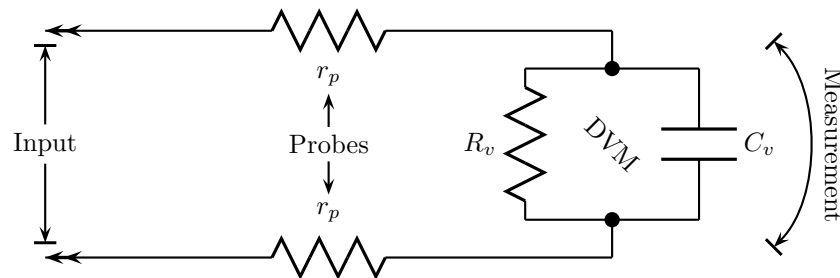
Lab report data

★ Lab book's lab 2 appendix and [course web page](#) have information about MATLAB semilogx plots.

```
f = [1 2 10 20 30 40 50 60 70 80 90 100]*1000; % Data vectors
rms = [1.998 1.99 1.789 1.414 1.109 0.894 0.743 0.633 0.549 0.485 0.434 0.392];
gain = rms/2; % Gain = rms/input (input = 2 Vrms)
gaindB = 20*log10( gain ); % Convert to decibels (dB)
semilogx( f, gaindB, '-.' ); % semilog plot (1/f (dB) looks linear)
grid on; % Turn plot grid on
xlabel( 'Frequency (Hz)' ); % X label (with units)
ylabel( 'Gain (dB)' ); % Y label (with units)
title( 'Gain magnitude for HP 972A DVM' ); % Title
```

NOTE: If the plotted response looks like a first-order step response, you can estimate its **corner frequency** f_c as the frequency where the magnitude response plot hits -3 dB.

- In theory, we can model the DVM as resistance R_v (from [Part 1](#)) in parallel with capacitance C_v .
- Under this theory, the low-pass filter is formed where the two probes, which each have resistance $r_p \approx 0.8 \Omega$, meet the DVM. So the attenuation is mostly from [dissipation](#) across $2r_p$.



- The [time constant](#) of such a filter is the product of its single capacitor C_v and the equivalent resistance from one end of the capacitor to the other when the inputs are [shorted](#).
- That is, the time constant

$$\tau \triangleq (R_v \parallel 2r_p)C_v = \frac{2R_v r_p}{R_v + 2r_p} C_v.$$

- Because $R_v \gg r_p$, then

$$R_v \parallel 2r_p \approx 2r_p \quad \text{and} \quad \tau \approx 2r_p C_v.$$

- Under this theory and assuming $R_v \gg r_p$, the corner frequency

$$f_c = \frac{1}{2\pi\tau} \approx \frac{1}{4\pi r_p C_v}$$

where the probe resistance $r_p \approx 0.08 \Omega$, and the DVM capacitance C_v is unknown.

- So you can use f_c , R_v , and our estimated r_p to estimate the DVM capacitance C_v . That is,

$$C_v \approx \frac{1}{4\pi r_p f_c} \approx \frac{1}{\pi(0.32 \Omega) f_c}.$$

- **FLAW IN MODEL:** If you estimate C_v this way, your value will be **very large** (e.g., several tens of μF — that's HUGE! A [parasitic capacitance](#) would never be that large in this application).
 - Small-signal electronics have parasitic capacitances in units of pF ($1 \mu\text{F} = 1,000,000 \text{ pF}$).
 - In reality, the DVM's equivalent circuit is more complex than a parallel R_v - C_v combination.
 - In fact, the probe resistance r_p has little to do with the bandwidth of the DVM. The bandwidth is actually set by *design* with internal analog filters.
 - Current draw of *real* DVM does not increase until *very* high frequency.