HANDS-ON LAB INSTRUCTION SHEET – MODULE 3

CAPACITORS, TIME CONSTANTS AND TRANSISTOR GAIN

NOTES:

1) To conserve the life of the Multimeter's 9 volt battery, be sure to turn the meter off if not in use for over 5 minutes. Always double check the unit is off when finishing your work, or leaving the classroom.
2) All work is to be done individually and submitted before you leave
3) If you did not finish Hands-on Module 1 or Module 2, be sure to finish it NOW! *before starting Module 3. If you don't finish by the end of the class, consult instructor.*
4) Always keep the Instruction sheets*.*
5) *Enter your Kit # in the upper right corners of ALL RESULTS sheets.*

BILL OF MATERIALS

Radio Shack Electronic Learning Lab Console , AC Adapter (*9 volts at 150 mA*), Digital Multimeter, Wire Stripper, Miscellaneous Connecting leads and wires (Standard for all labs)
(1) Red or Green LED
(1) 2N5551 NPN Silicon Transistor
(1) 100Kohm, ½ Watt Resistor *with color code:* ***brown black yellow gold*** (*100KΩ at 5%*)
(1) 1000 Ohm, ½ Watt Resistor *with color code:* ***brown black red gold*** (*1KΩ at 5%*)
(1) 100µF Electrolytic Capacitor

CAPACITORS

Capacitors, as discussed in class, are constructed of two plates separated by an insulator that have been shown to hold a charge on their plates. The larger the capacitance, the larger the charge that can be stored, to the point that, as we will see in today's lab, a 100 microfarad (***100µF***) electrolytic capacitor can be viewed as a temporary voltage source!

CHARGING A CAPACITOR

1. We will wire the circuit of **Figure 3** using a **100,000 ohm (100KΩ) resistor** and a **100 µF capacitor** (*note that the shorter lead - or the one on the side of the white stripe - is MINUS*) using the unregulated voltage (available at the top left 5 connection points and controlled by the Console Power switch) as the voltage **V**.

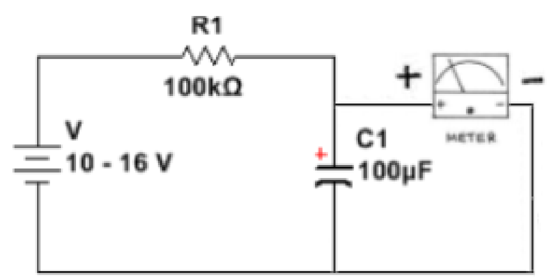


Fig 3.1. Capacitor Charging Circuit

1.1 To make connections and disconnections simpler, we will use the double-pole/double-throw **DPDT Switch** (*springs #43 – #45)* and **SPST** push button **S1** *(springs 46 and 47)* to connect parts of this circuit and enable us to easily short out the capacitor. Using Figure 3.4 as a guide, connect a **RED** wire from the unregulated voltage **V** (e.g., the top left voltage connection at '**5**') to **Spring #43** and connect a **YELLOW** wire from **Spring #44** to Breadboard connection **T11**. Insert a **100KΩ** resistor [**brown-black-yellow-gold**] between connections **T13** and **T18**. Use a **YELLOW** wire to connect between **T20** and **Spring #46**. Connect a **BLACK** wire between **Spring #45** and **Spring #47** and another **BLACK** wire from **Spring #47** to **ground**. Connect the **100µF** capacitor between **Spring #46** and **Spring #47 (minus** lead**)**. Now connect the Multimeter's **RED** (**+**) lead to **Spring #46** and the **BLACK** (**-**) lead to **Spring #47**. Set the meter to the **20V** range and place the **DPDT** Switch in the **UP** position.

The "time constant" ***Tau*** for this circuit is calculated as τ = ***RC = 10 seconds***
(100E3 ohms) x (**100E-6 farads) =** (***100,000) x (0.000100) = 10 s***

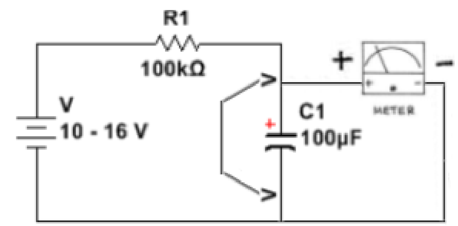


Fig 3.2. Short the Capacitor

1.2 Turn Console Power **ON**. You should see the voltage increasing slowly. Press the **S1** push button to **short the capacitor for a few seconds** such that the $V_{initial}$ 'starting voltage' will be zero**. Release the short at *t = 0***. As best you can, record the voltages at 10 and 50 seconds and average three values of voltage across the capacitor for each time measurement.

3.1.a) Voltage across capacitor $V_{C@\tau}$ after **one Tau = 10 seconds** $V_{C@\tau}$ = _____ volts

3.1.b) Voltage across capacitor $V_{C@5\tau}$ after **five Tau = 50 seconds** $V_{C@5\tau}$ = _____ volts

3.1.c) Record the unregulated voltage **V** after at least two minutes **V** = _____ volts

Measured Versus Theoretical Values:

The theoretical capacitor voltage *after one*τ should be ≈ ***63%*** of supply voltage **V**.
3.1.d) Calculate your *actual One Tau voltage % at 10 seconds*:

$V_{C@\tau}$ **/ V x 100% = Result** $@\tau$ _______ %

The theoretical capacitor voltage *after five*τ should be ≈ ***99%*** of the supply voltage **V**.
3.1.e) Calculate your *actual Five Tau voltage % at 50 seconds*;

$V_{C@5\tau}$ **/ V x 100% = Result** $@5\tau$ ________ %

We expect the experimentally measured values to be less than the theoretical values of 63% and 99% respectively due to meter resistance, component value tolerances and leakage current in the electrolytic capacitor.

DISCHARGING A CAPACITOR

2. Using the current circuit, charge the capacitor to exactly **10.0 volts** and then disconnect it from the circuit by removing the **RED** wire between **Spring #44** and **T11**. Leave the meter and all other components and wires connected. Watch the capacitor voltage on the meter as it drops, very slowly, due to the meter's *one megohm* internal resistance. It could take 10 minutes to go to zero volts. Instead, we will wait until the voltage across the capacitor is **3.7 volts**. This is the value for Tau for the circuit from which we *could* calculate the meter's actual internal equivalent resistance. *If you do not reach 3.7 volts after about 2 minutes of discharging there is an error.* This RC circuit is shown as Figure 3.3.

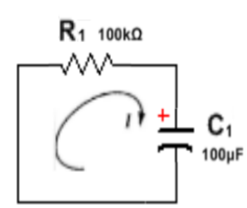


Figure 3.3. Discharging Capacitors

3.2.a) How long does it take to discharge to 3.7 volts ***without R1***?___ seconds
2.1) Reconnect the **RED** wire from **T11** to **Spring #44** and once again charge the capacitor to exactly **10.0 volts**. This time push the **DPDT** Switch **DOWN** (see Figure 3.5) for exactly **10.0 seconds**, *as best you can*, and read the voltage on the meter (you might also try this with the **BLACK** Meter lead disconnected to reduce the error of the parallel *1M* Meter resistance which results in an R_{actual} ≈ ***90KΩ***).

3.2.b) What is your measured value of $V_{c@\tau}$ after one **Tau**? _________ volts

Repeat this experiment to find the ***5 Tau*** voltage: **DPDT UP**, charge capacitor to **10.0** volts, **DPDT DOWN**, allow ***5 Tau or 50 seconds of discharge into the 100K resistor with meter connected***. Disconnect the resistor and measure the capacitor voltage. We expect an answer near the final value of zero volts.

3.2.c) What voltage did you find for $V_{c@5\tau}$ after five **Tau**? ________________ volts

This is Instructor check point 2B.

After the check of your work you may remove the wires from the above circuit.
Note: *There are many reasons for errors in this experiment.*
Do not be discouraged if you did not come close.
The important thing is to be aware of how capacitors can be used to introduce delays.

CONSOLE WIRING DIAGRAM – CHARGING THE CAPACITOR

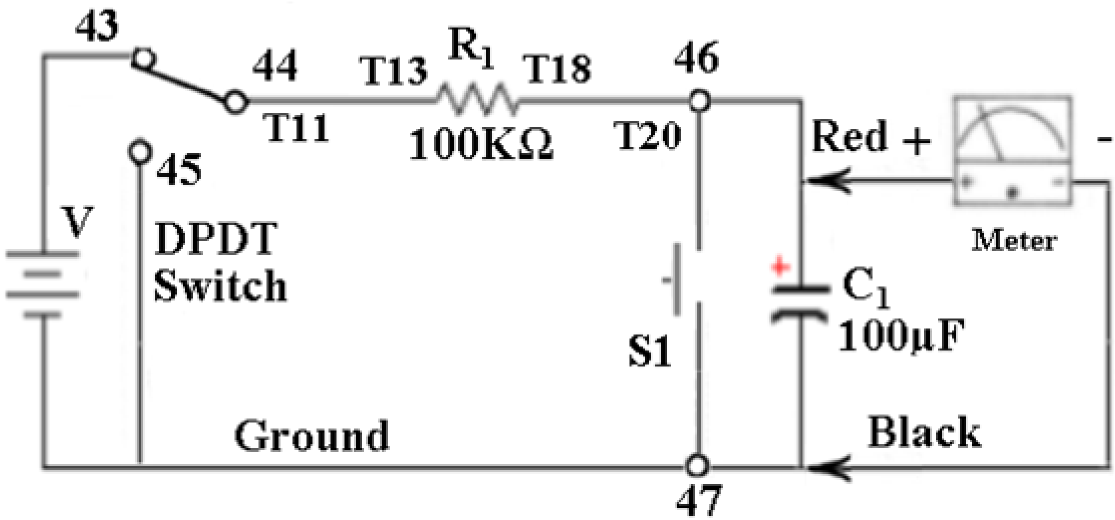


Figure 3.4. Possible Console Breadboard Layout of Capacitor Charging Schematic

CONSOLE WIRING DIAGRAM – DISCHARGING THE CAPACITOR

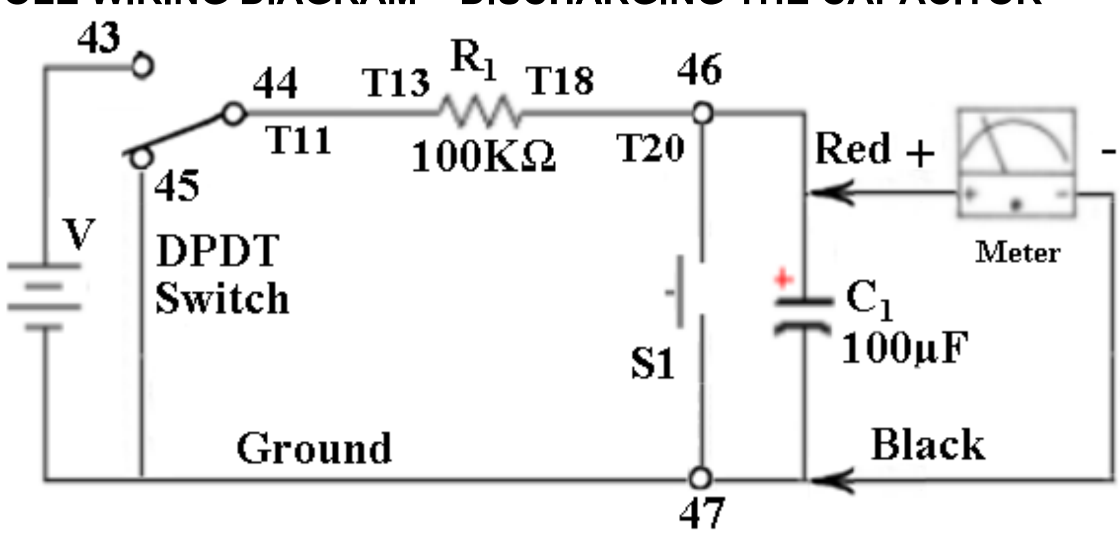


Figure 3.5. Possible Console Breadboard Layout of Capacitor Discharging Schematic

USING SPECIFIC BREADBOARD PINS

Please note that the Console Breadboard has pins across the top which also connect in groups of 5 across with the first five being internally connected to the 9VDC AC Adapter. In next week's lab we will create a voltage regulator for this unregulated power supply which we will connect to the other 25 connections at the top of the Breadboard. All 30 connections across the bottom are used as a common ground as they are ALL interconnected.

All other connection holes are uniquely identified by their Row (**A – T**) from top to bottom and their Column (**1-30**) from left to right (see Figure 3.6 below). The left topmost pin (not counting the power 1-5 sets of strips) would therefore be **A1**, the rightmost topmost pin being pin **A30**. Similarly, above the ground strip, the left bottom pin would be **T1** and **T30** at bottom right.

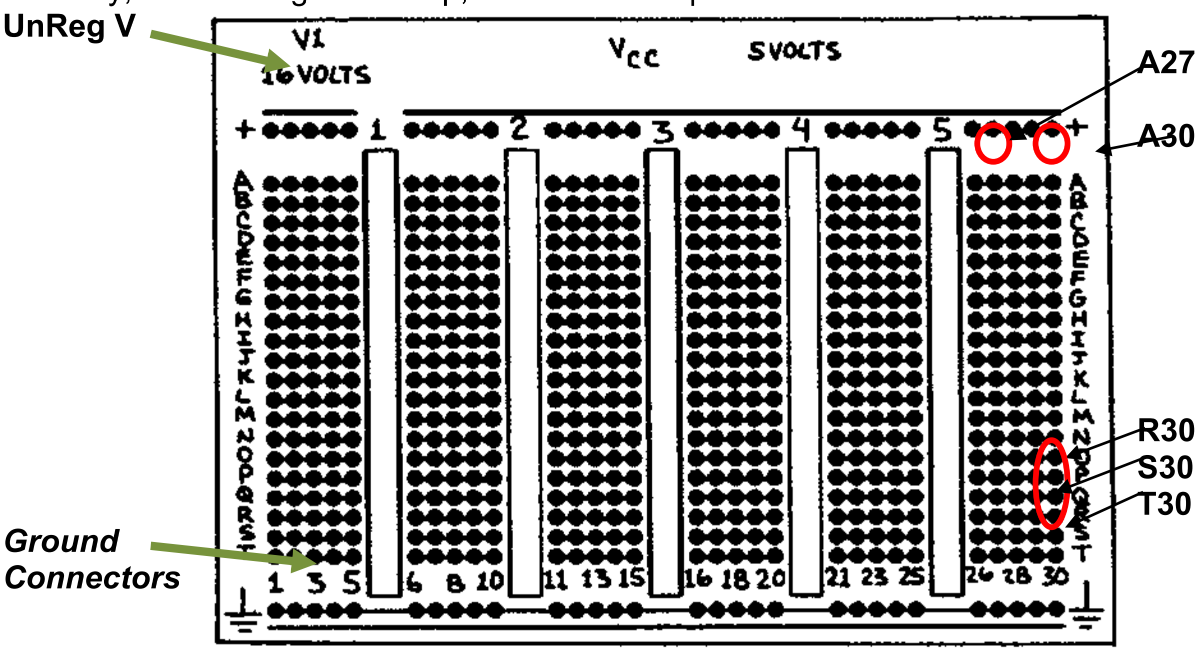


Fig 3.6. Radio Shack Electronic Learning Lab Breadboard

MEASURING THE CURRENT GAIN OF A TRANSISTOR

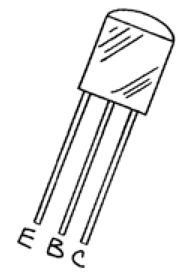
3) As we saw earlier, a potentiometer - commonly called a "pot" - is a circular resistor with an internal slider and a knob you can rotate to move the slider from one end of the resistor to the other. We'll use the **10K pot** on the console (at the lower left).

Connect the bottom of the pot (**Spring #39**) to one of the ground pins at the bottom row of pins on the Breadboard with a black wire, and the top of the **10Kohm** pot (**Spring #37**) to the unregulated positive supply voltage **V** with a **red** wire connected to the top left voltage connection at '**5**'.
Connect your multimeter *as a voltmeter* with the **red** to lead to the **10Kohm** pot slider **Spring #38**, and **black** to **Spring #39**). *In the future we will not specify every connector spring # or breadboard point but it is helpful during your initial work…*
3.3.a) Turn the Power Switch **ON** and use the **10Kohm** pot knob to adjust the voltage from **0** to full supply voltage.

Did this work? (___ YES ___NO)

If this doesn't work ask for help NOW.

3.1) Find the type **2N5551** transistor on the pink foam in your parts kit. This is a semiconductor manufactured in a **small black plastic (TO-92) case** – see figures below right. It has three (3) inline wire leads internally connected to the transistor's Emitter (E), Base (B) and Collector (C).



3.2) The circuit we are going to set up is somewhat similar to the one on page 54 of the Electronic Workbook 1 in the middle of the page, but there are enough differences so that we will use a **different placement** of parts. Refer to Figure 3.7.

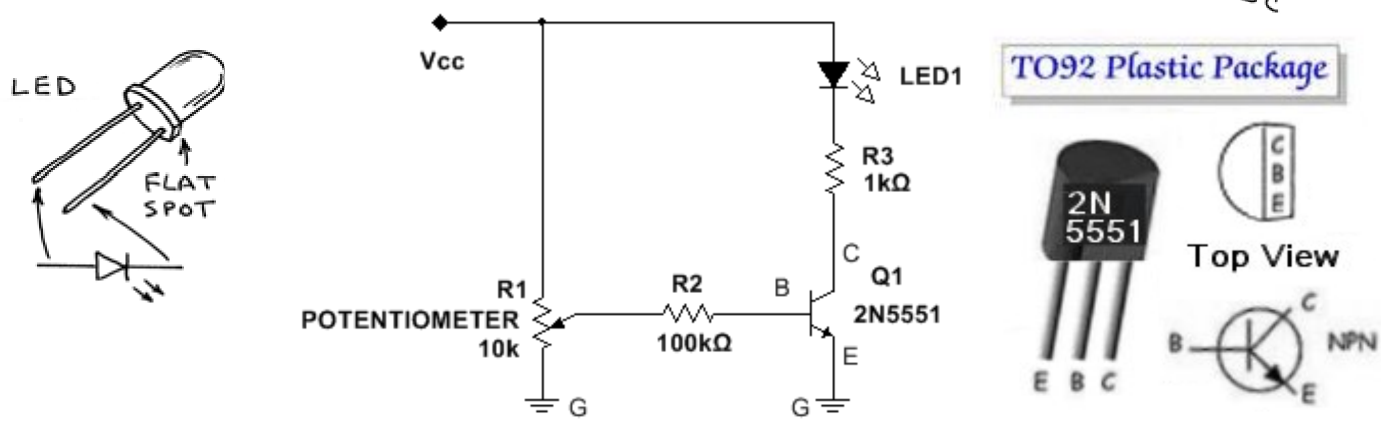


Figure 3.7. Current Gain Measurement Circuit

THEORY and CIRCUIT CONSTRUCTION

The current gain h_{FE} of a transistor can be measured by dividing the current flowing in the device's collector lead (I_C) by the current flowing in the device's base lead (I_B) The overall formula for current gain is thus:

$$h_{FE} = I_C / I_B$$

*(**Figure 3.7 shows two fixed resistors, 1Kohm and 100Kohm, in addition to the 10Kohm pot. Note that** $I_B = V_{R2}/100K$ **the current through the 100Kohm resistor - between the pot slider** (center spring of pot), **and the base B** (center pin) **of the 2N5551 transistor**.)*

3.3) Turn the input power (**Vcc**) **OFF** (Console Power Switch **down**). Insert the transistor (***flat side facing right***) into the breadboard holes **R30**, **S30** and **T30**. This means that the **2N5551**'s **Collector**, *in pin **R30***, is available for direct interconnections at **R26**, **R27**, **R28**, and **R29**. Likewise connections can be made to the **Base** at **S26**, **S27**, **S28**, and **S29**, and connections to the **Emitter** can be made at **T26**, **T27**, **T28**, and **T29**.

3.4) Connect the **2N5551** transistor's **Base (S30)** to a **100Kohm** resistor. Use a **YELLOW** wire to connect the **100Kohm** resistor to the slider on the **10Kohm pot**. You already connected the **10Kohm pot** between the **RED**, **Vcc**, wire and ground.
NOTE: Figure 3.8 on Page 7 shows a possible layout of this circuit.

3.3) Connect the **Emitter (T30)** to **ground** with a **black** wire from **T29**.

3.4) Now connect the **Collector (R30)** to the voltage supply through a **1Kohm** resistor and an *individual* (not mounted) **red LED**. The **red LED** should be inserted into **A30** and **C30** with the **shorter wire** (*cathode=negative terminal, FLAT side*) into **C30**. The **1Kohm** resistor goes from **C29** to **R29** at the transistor's collector (using a **yellow** wire if needed).

3.5) Turn the unregulated input power (**Vcc**) **ON** (Power Switch **up**).
3.3.b) Using the **10Kohm** pot knob adjust the voltage available to the **100K** resistor in the transistor's base circuit. It should be possible to vary the brightness of the LED in the collector circuit. Did this work ? (____ YES ____ NO)

Instructor check point 3B

Demonstrate this circuit *to your instructor.*

TAKING THE MEASUREMENTS

4) Connect your multimeter as a voltmeter across R_3 the **1Kohm** collector resistor and adjust the **10Kohm pot** to get V_{R3} to approximately equal ***5.0 volts across*** R_3 ***the 1Kohm resistor***. (As usual a reading with a minus sign means you have the leads backwards.)

Note that this adjustment gives you approximately ***5 mA of collector current****.*

3.4a) Measure the **voltage** V_{R2} **across** R_2 (the **100Kohm** resistor connected to the base).

The voltage V_{R2} is: ___________volts (measured).

3.4b) *Measure* V_{BE} *– the voltage from point B (base) to point E (emitter) – note as the emitter is at ground,* The voltage V_{BE} is: ___________volts (measured).

3.4c) Calculate the base current using Ohm's Law: I_B = ____________ **mA**

*(Calculate using Ohms Law [**I = V/R**] - Remember that **volts / Kohms** = **mA**)*

3.4d) Knowing the collector and base currents, calculate the current gain $h_{FE} = (I_C / I_B)$

h_{FE} = _______ (a number without units)

Fill in Table 3.1 with the appropriate values for the transistor with a 5 ma collector current.

Instructor check point 3C.

Show above to instructor as soon as you have it.

3.4e) Change the **10Kohms** pot position to set V_{R3} to be **2.0 volts** across R_3. Measure the voltage across R_2,, and then measure V_{BE} and fill in the second line of Table 3.1.
3.4f) Change the **10Kohms** pot position to set V_{R3} to be **1.0 volts** across R_3. Measure the voltage across R_2,, and then measure V_{BE} and fill in the third line of Table 3.1.
Then calculate the remaining I_B values, in **mA**.

I_C	V_{R2}	I_B (mA) = V_{R2} / 100K	V_{BE}	h_{FE}
5 mA				
2 mA				
1 mA				

Table 3.1. Current Gain Measurements

5) You should have found that h_{FE} is reasonably constant, *i.e., the collector current is roughly proportional to base current.* On the other hand, a slight change in base-emitter voltage should make a large change in collector current. *The base-emitter voltage is the forward biased voltage drop across the base-emitter junction. This value should be on the order of 0.6 volts – the same value you found for silicon diodes in previous experiments.*

Keep this Instruction Sheet for your records

Parts of this circuit are used in Lab Module 4 – Do Not Remove!

CONSOLE WIRING DIAGRAM – TRANSISTOR GAIN MEASUREMENTS

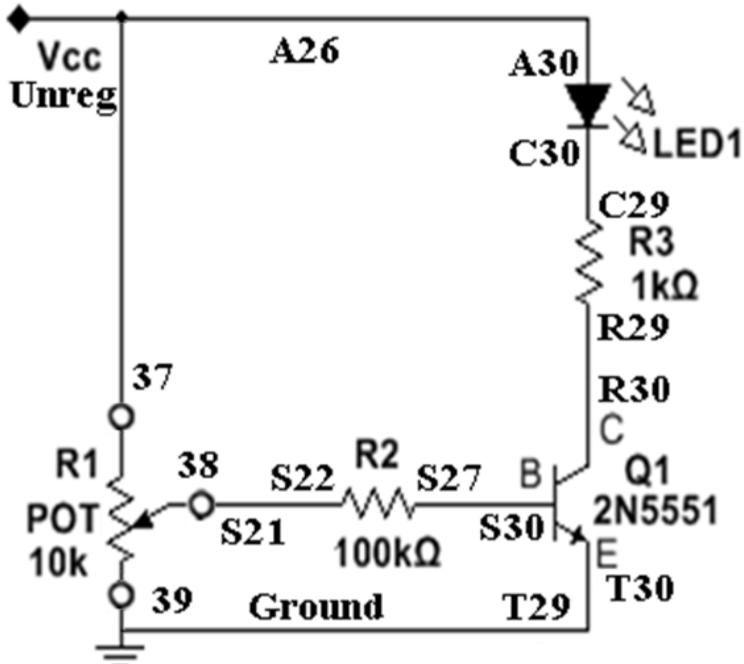


Figure 3.8. Possible Console Breadboard Layout for Figure 3.7

The circuit above illustrates one possible configuration for the Current Gain Measurement Circuit of Figure 3.7.

METHOD FOR SIMPLIFYING VOLTAGE MEASUREMENTS

You will note that in this module you are being asked to measure $\mathbf{V_{R3}}$ across the collector resistor, $\mathbf{V_{R2}}$ across the resistor in the base circuit and $\mathbf{V_{BE}}$ the base-emitter junction voltage for three different collector current values (*5 mA, 2mA, and 1mA*) and use these to calculate the base current $\mathbf{I_B}$ and then the $\mathbf{h_{FE}}$ of a **2N5551** Silicon NPN Transistor.

The first step has you setting the voltage $\mathbf{V_{R3}}$ across the **1KΩ** collector resistor. Resistor $\mathbf{R_3}$ (per the diagram above) is connected between **C29** and **R29** and is 'flat' on top of the Breadboard. Place the Multimeter **RED** lead on the resistor lead connected to **C29** and the **BLACK** lead on the resistor lead connected to **R29** to make this measurement.

Next measure $\mathbf{V_{R2}}$ across the **100KΩ** base resistor between **S22** and **S27** - note that it is 'high' above the Breadboard. Attach the Multimeter's leads to this resistor's leads (ignore the polarity) and merely record the voltage on the Table.

Note that the resistor lead in **S27** is already at the base of the transistor. To measure the base-emitter voltage $\mathbf{V_{BE}}$ leave one Multimeter lead at **S27** and place the other lead at ground for this measurement. After all measurements are made the base current is calculated using Ohm's Law dividing $\mathbf{V_{R2}}$ / **100KΩ** = $\mathbf{I_B}$ and the transistor gain by dividing the currents $\mathbf{I_C}$ / $\mathbf{I_B}$ = $\mathbf{h_{FE}}$ and including those values in the Table.