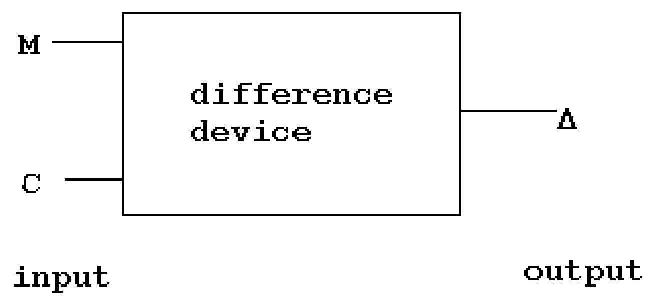
# Physics 214 INTRODUCTION TO LABORATORY ELECTRONICS Lecture 4

**Topics:** Wheatstone bridge, practice with Kirchoff's Laws, Thévenin's Theorem

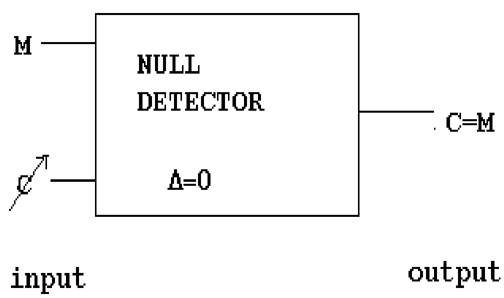
**USEFUL SOFTWARE TOOL:**
Electronics Workbench. available on PCs @front of the Elliott 139 terminal room

## Measurements using DIFFERENCES and NULL measurements

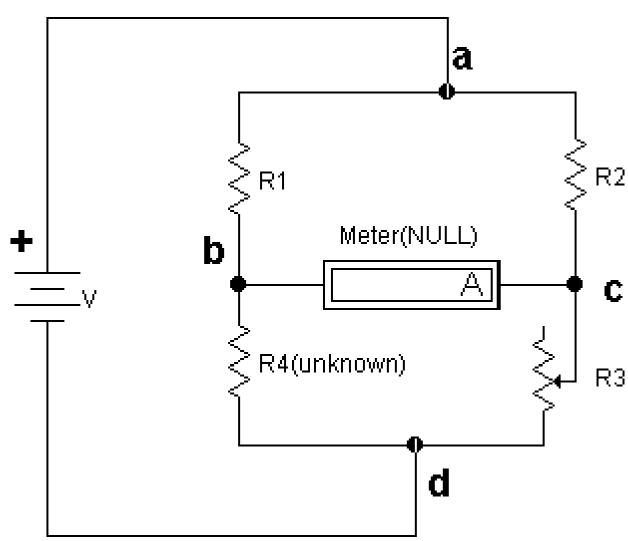
To make precise and accurate measurements often it is necessary to measure the difference between a unknown value of a quantity (eg voltage, current, resistance, etc) and a known or calibrated value. If $\Delta$ is the measured difference, and C is the calibration value, then the unknown value to be measured is just calculated as: $M = \Delta + C$




Another approach is to measure $\Delta$ and adjust C until $\Delta$=0. This is achieved with a NULL DETECTOR.




**Wheatstone Bridge** is an example of a NULL detector used for measuring resistance.




The Meter is a 'NULL detector' (voltmeter or ammeter)
R1 and R2 are fixed and known resistances
R4 is unknown and to be measured
R3 is a variable resistor whose value is known.

R3 is varied until the Meter reads 0
'At Balance': $R1/R4 = R2/R3$
or $R4 = R1 \times R3/R2$

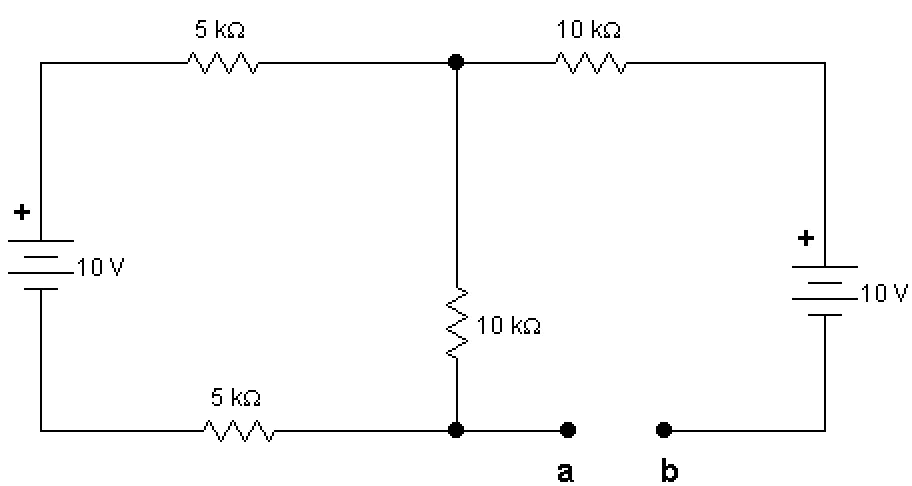
**Example of Use:**
R4 could represent a 'thermistor', this is a device whose resistance varies with temperature as $R_T = Ae^{B/T}$ . Measuring the resistance gives the temperature if the termistor calibration constants, A and B, are known: $T = \dfrac{B}{\ln(R_T / A)}$.

The termistor is an example of a *transducer*. Converts temperature into resistance. We measure the resistance (using eg a Wheatstone Bridge) then calculate a temperature using the measured resistance and calibration constants. In the lab you'll do this. In fact, you'll calibrate the termistor by measuring the resistance at fixed temperatures determined from a calibrating termometer. The calibration curve is obtained by measuring the slope and intercept of $\ln R_T = \ln A + B\left(\dfrac{1}{T}\right)$.

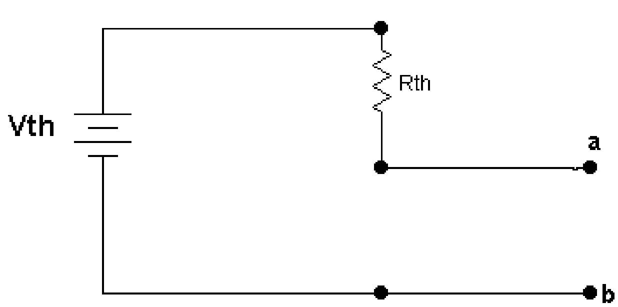
**ANALYSIS of Wheatstone's Bridge using Thévenin's Theorem**
Thévenin's Theorem is a very powerful tool for simplifying complicated circuits into a very simple one:

> **Thévenin's Theorem**
> **A network of resistances, current sources and voltage sources can be replaced by a single equivalent voltage source, $V_{TH}$, in series with a single equivalent resistance, $R_{TH}$.**

**For Example:** we want to know the voltage drop across a and b in the following.
Thévenin's Theorem says we can replace this:



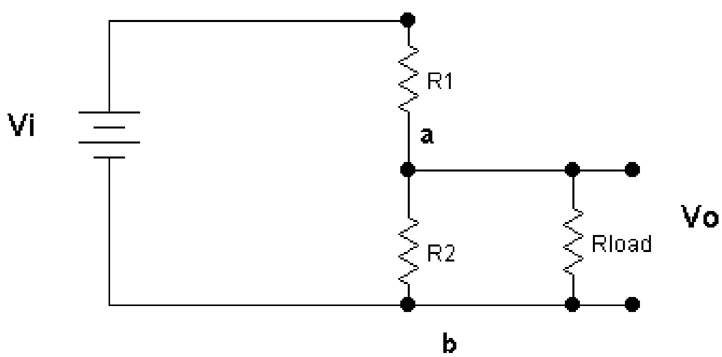

by this:




MUCH SIMPLER, EH?

1. The voltage drop across the element to be studied is labelled Vth and the element is removed from the circuit. Then calculate Vth (eg, using Kirchoff's rules) with the element out.
2. Simply replace all voltage sources with "plain old wires", then calculate Rth.
3. Place the element which you removed in 1. back into the circuit in series with Vth and Rth.
4. you're done.

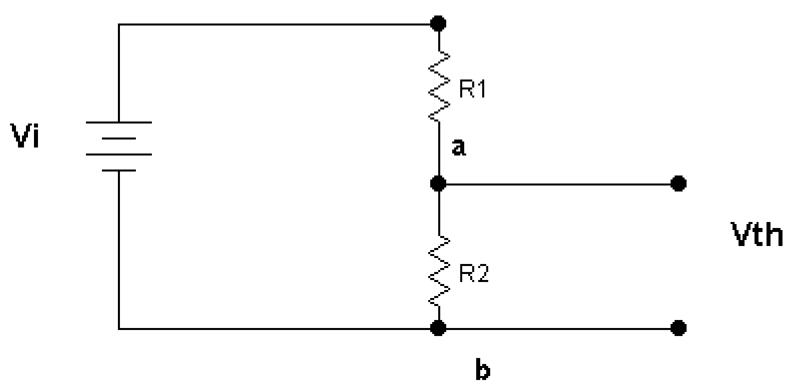
**Example 1:**
The voltage divider is used to setup a voltage R2/(R1+R2) Vi. Then a load is put on the output




The 'load' on a two-terminal output of a circuit is the follow-on stage of the circuit that draws current. There is an equivalent resistance associated with the load, denoted as $R_{LOAD}$, through which the load current flows. For example, when powering a radio with a battery, the circuitry of the radio is considered the 'load' on the battery.

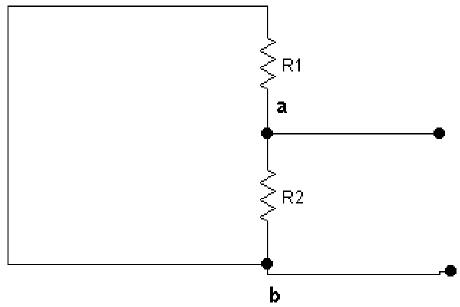
of the divider, Rload. We want to know the voltage across Rload .

**1. Remove Rload, since that is what we want to study. The voltage Vab is now Vth.**



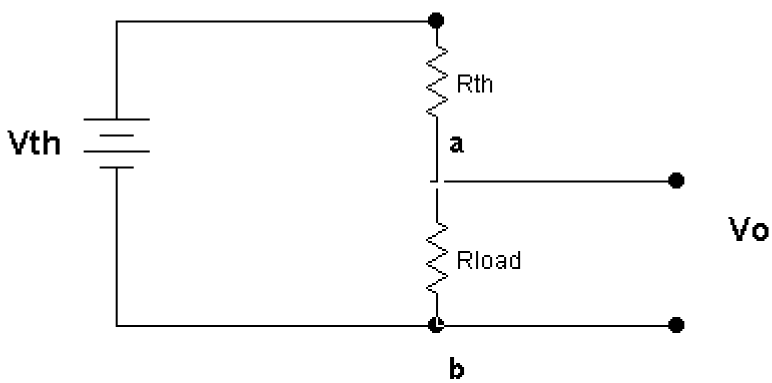

Now calculate Vth = Vi R2/(R1+R2)

**2. Now short out Vi and calculate Rth:**




Rth = R1 R2 /(R1+R2)

**3. Put the Rload into the Thevenin circuit.**

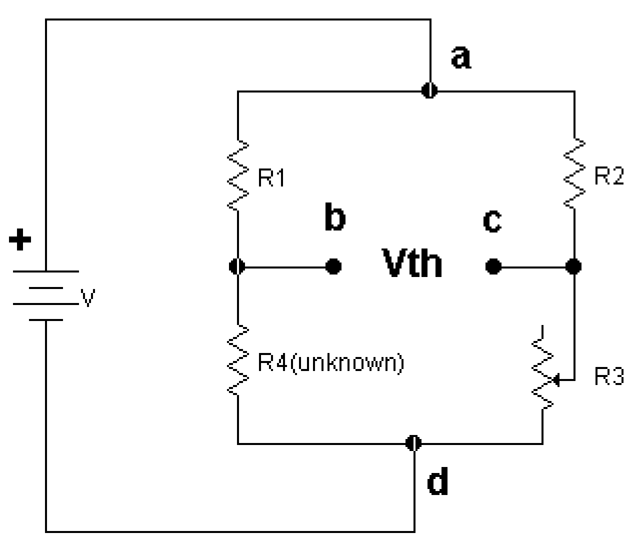


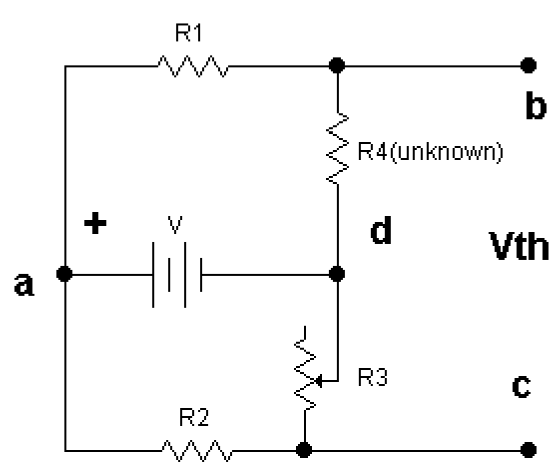

So now we can determine that Vo = Vth Rload/(Rload +Rth)

**EXAMPLE 2:**

Wheatstone's Bridge analysis

The meter is the element of interest and has some resistance Rm. At balance, the voltage across the two terminals is zero. We'll start the analysis by letting that be Vth:



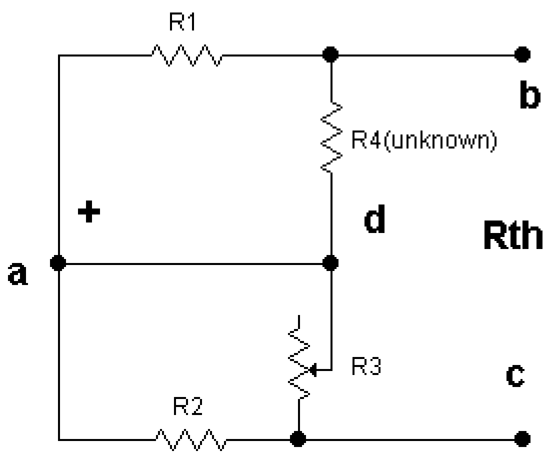
$$Vth = Vbc = V \times \left( \frac{R4}{R1 + R4} - \frac{R3}{R2 + R3} \right)$$

AT BALANCE:

$$Vth = Vbc = 0$$

$$\frac{R1}{R4} = \frac{R2}{R3}$$

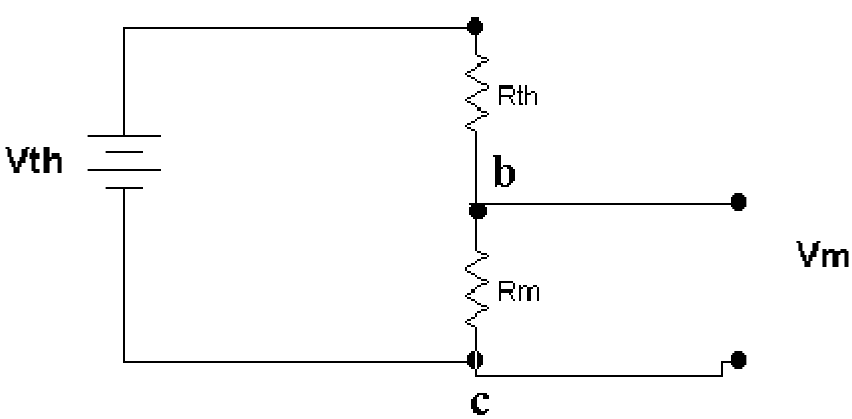
**Now find Rth:**




$$Rth = \frac{R1 \times R4}{R1 + R4} + \frac{R2 \times R3}{R2 + R3}$$

OFF BALANCE:

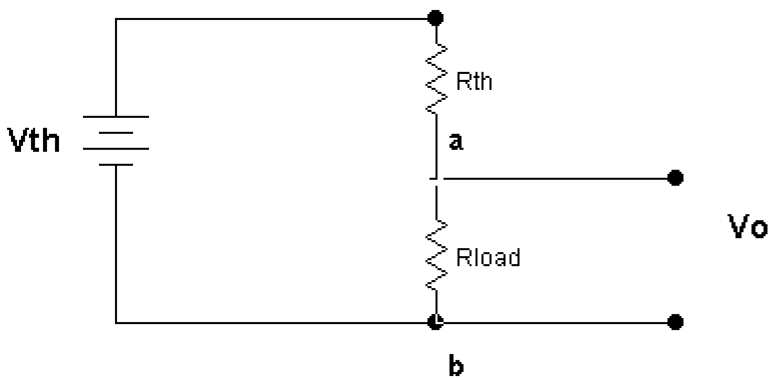
$$Vm = Vth \frac{Rm}{Rm + Rth}$$



**Maximum Power Transfer to a Load**

Power delivered to a load is, of course the current squared times the load resistance. The question arises: what is the value of a load resistance when the power delivered to it is a maximum? This is important when a source cannot deliver much power, for example when receiving a weak radio transmission. In that case, one wants as much power delivered to the load as possible.

Considered the circuit:




The power delivered to $R_{LOAD}$ is $I^2R_{LOAD}$ and $I=V_{th}/(R_{th}+R_{LOAD})$ so the power transferred to $R_{LOAD}$ is:
$P_{LOAD} = V_{th}^2 R_{LOAD} /(R_{th}+R_{LOAD})^2$.

This is a maximum when $dP_{LOAD} / d R_{LOAD} = 0$.

$dP_{LOAD} / d R_{LOAD} = V_{th}^2 ( (R_{th}+R_{LOAD})^2 - 2 R_{LOAD}(R_{th}+R_{LOAD}) ) /(R_{th}+R_{LOAD})^4 = 0.$

so $(R_{th}+R_{LOAD})^2 - 2 R_{LOAD}(R_{th}+R_{LOAD}) = 0$
$\rightarrow (R_{th}+R_{LOAD}) - 2 R_{LOAD} = 0$
$\rightarrow R_{LOAD} = R_{th}$

This means the maximum power you can transfer to a load occurs when $R_{LOAD} = R_{th}$
and the maximum power is $V_{th}^2 R_{LOAD} /(2R_{LOAD})^2 = V_{th}^2 /(4R_{LOAD})$.