THE WHEATSTONE BRIDGE:

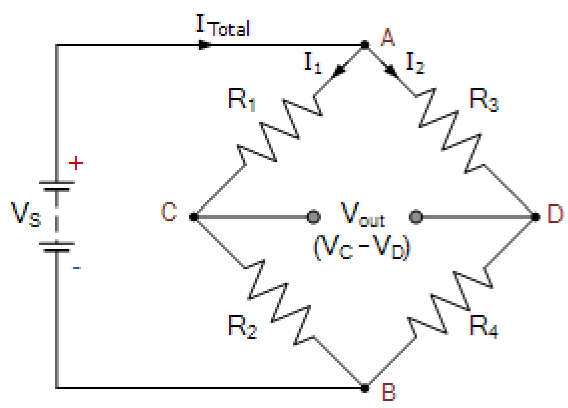
The **Wheatstone Bridge** was originally developed by Charles Wheatstone to measure unknown resistance values and as a means of calibrating measuring instruments, voltmeters, ammeters, etc, by the use of a long resistive slide wire.

Although today digital multimeters provide the simplest way to measure a resistance. The *Wheatstone Bridge* can still be used to measure very low values of resistances down in the milli-Ohms range.

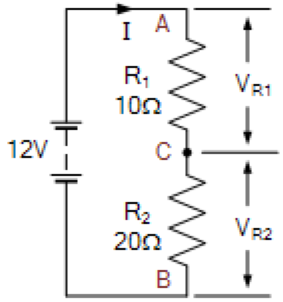
The Wheatstone bridge (or resistance bridge) circuit can be used in a number of applications and today, with modern operational amplifiers we can use the *Wheatstone Bridge Circuit* to interface various transducers and sensors to these amplifier circuits.

The Wheatstone Bridge circuit is nothing more than two simple series-parallel arrangements of resistances connected between a voltage supply terminal and ground producing zero voltage difference between the two parallel branches when balanced. A Wheatstone bridge circuit has two input terminals and two output terminals consisting of four resistors configured in a diamond-like arrangement as shown. This is typical of how the Wheatstone bridge is drawn.

The Wheatstone Bridge



When balanced, the Wheatstone bridge can be analysed simply as two series strings in parallel. In our tutorial about **Resistors in Series**, we saw that each resistor within the series chain produces an **IR** drop, or voltage drop across itself as a consequence of the current flowing through it as defined by Ohms Law. Consider the series circuit below.



As the two resistors are in series, the same current (i) flows through both of them. Therefore the current flowing through these two resistors in series is given as: V/R_T.

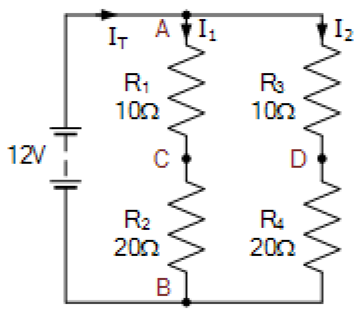
$$I = V \div R = 12V \div (10\Omega + 20\Omega) = 0.4A$$

The voltage at point C, which is also the voltage drop across the lower resistor, R_2 is calculated as:

$$V_{R2} = I \times R_2 = 0.4A \times 20\Omega = 8 \text{ volts}$$

Then we can see that the source voltage V_S is divided among the two series resistors in direct proportion to their resistances as $V_{R1} = 4V$ and $V_{R2} = 8V$. This is the principle of voltage division, producing what is commonly called a potential divider circuit or voltage divider network.

Now if we add another series resistor circuit using the same resistor values in parallel with the first we would have the following circuit.

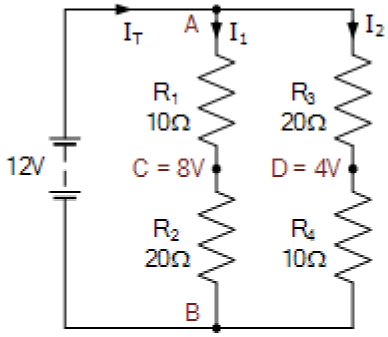


As the second series circuit has the same resistive values of the first, the voltage at point D, which is also the voltage drop across resistor, R_4 will be the same at 8 volts, with respect to zero (battery negative), as the voltage is common and the two resistive networks are the same.

But something else equally as important is that the voltage difference between point C and point D will be zero volts as both points are at the same value of 8 volts as: C = D = 8 volts, then the voltage difference is: 0 volts

When this happens, both sides of the parallel bridge network are said to be **balanced** because the voltage at point C is the same value as the voltage at point D with their difference being zero.

Now let's consider what would happen if we reversed the position of the two resistors, R_3 and R_4 in the second parallel branch with respect to R_1 and R_2.



With resistors, R_3 and R_4 reversed, the same current flows through the series combination and the voltage at point D, which is also the voltage drop across resistor, R_4 will be:

$$V_{R4} = 0.4A \times 10\Omega = 4 \text{ volts}$$

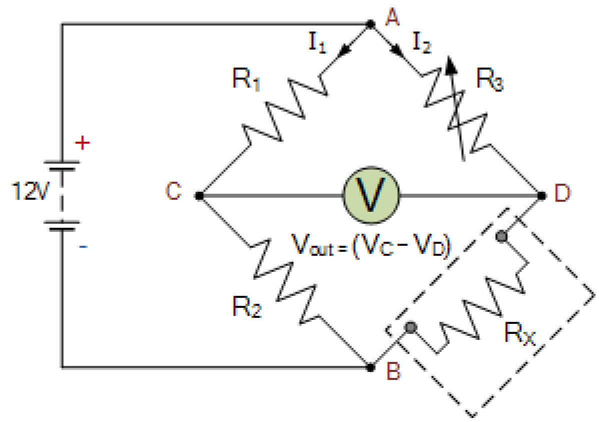
Now with V_{R4} having 4 volts dropped across it, the voltage difference between points C and D will be 4 volts as: C = 8 volts and D = 4 volts. Then the difference this time is: 8 – 4 = 4 volts

The result of swapping the two resistors is that both sides or "arms" of the parallel network are different as they produce different voltage drops. When this happens the parallel network is said to be **unbalanced** as the voltage at point C is at a different value to the voltage at point D.

Then we can see that the resistance ratio of these two parallel arms, ACB and ADB, results in a voltage difference between **0 volts** (balanced) and the maximum supply voltage (unbalanced), and this is the basic principal of the **Wheatstone Bridge Circuit**.

So we can see that a Wheatstone bridge circuit can be used to compare an unknown resistance R_x with others of a known value, for example, R_1 and R_2, have fixed values, and R_3 could be variable. If we connected a voltmeter, ammeter or classically a galvanometer between points C and D, and then varied resistor, R_3 until the meters read zero, would result in the two arms being balanced and the value of R_x, (substituting R_4) known as shown.

Wheatstone Bridge Circuit



By replacing R_4 above with a resistance of known or unknown value in the sensing arm of the Wheatstone bridge corresponding to R_X and adjusting the opposing resistor, R_3 to "balance" the bridge network, will result in a zero voltage output. Then we can see that balance occurs when:

$$\frac{R_1}{R_2} = \frac{R_3}{R_X} = 1\ (\text{Balanced})$$

The Wheatstone Bridge equation required to give the value of the unknown resistance, R_X at balance is given as:

$$V_{OUT} = \left(V_C - V_D\right) = \left(V_{R2} - V_{R4}\right) = 0$$

$$R_C = \frac{R_2}{R_1 + R_2} \quad \text{and} \quad R_D = \frac{R_4}{R_3 + R_4}$$

$$\text{At Balance}: R_C = R_D \quad \text{So,} \quad \frac{R_2}{R_1 + R_2} = \frac{R_4}{R_3 + R_4}$$

$$\therefore\ R_2\left(R_3 + R_4\right) = R_4\left(R_1 + R_2\right)$$

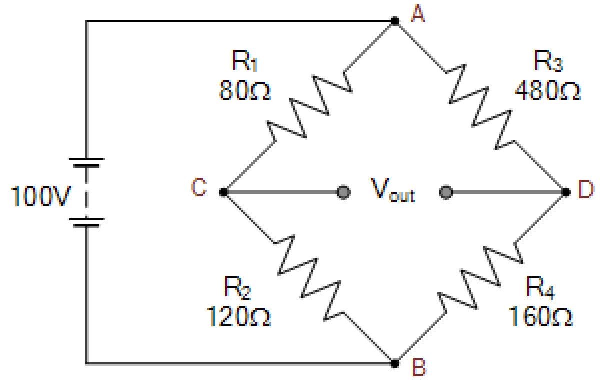
$$R_2R_3 + \cancel{R_2R_4} = R_1R_4 + \cancel{R_2R_4}$$

$$\therefore\ R_4 = \frac{R_2R_3}{R_1} = R_X$$

Where resistors, R_1 and R_2 are known or preset values.

Wheatstone Bridge Example No1

The following unbalanced Wheatstone Bridge is constructed. Calculate the output voltage across points C and D and the value of resistor R_4 required to balance the bridge circuit.



For the first series arm, ACB

$$V_C = \frac{R_2}{(R_1 + R_2)} \times V_S$$

$$V_C = \frac{120\Omega}{80\Omega + 120\Omega} \times 100 = 60\text{volts}$$

For the second series arm, ADB

$$V_D = \frac{R_4}{(R_3 + R_4)} \times V_S$$

$$V_D = \frac{160\Omega}{480\Omega + 160\Omega} \times 100 = 25\text{volts}$$

The voltage across points C-D is given as:

$$V_{OUT} = V_C - V_D$$

$$\therefore V_{OUT} = 60 - 25 = 35\text{volts}$$

The value of resistor, R_4 required to balance the bridge is given as:

$$R_4 = \frac{R_2 R_3}{R_1} = \frac{120\Omega \times 480\Omega}{80\Omega} = 720\Omega$$

We have seen above that the **Wheatstone Bridge** has two input terminals (A-B) and two output terminals (C-D). When the bridge is balanced, the voltage across the output terminals is 0 volts. When the bridge is unbalanced, however, the output voltage may be either positive or negative depending upon the direction of unbalance.