# Engineering Note 43

## Two ways of looking into things

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# Two ways of looking into things

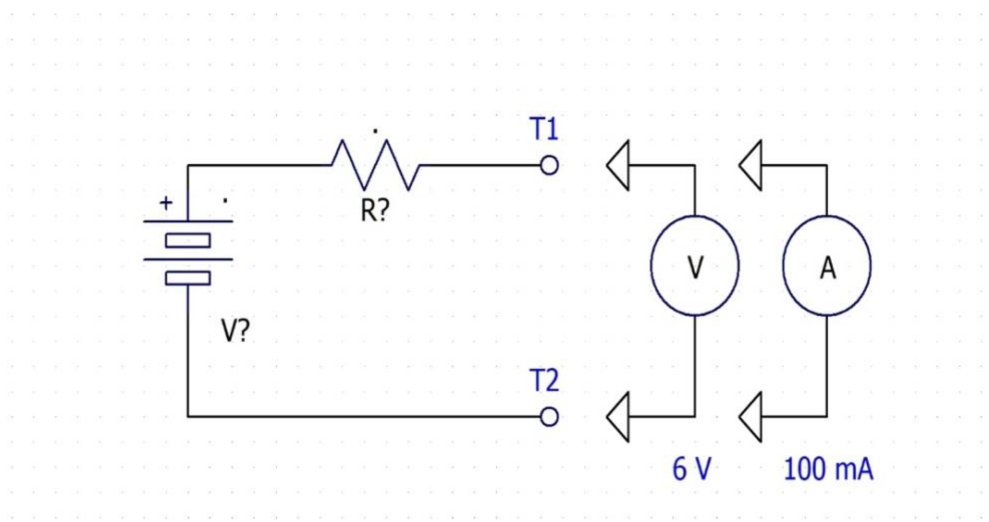
Consider a cell - electrical, not biological or prison.

It has three, sometimes four parts, a metal cathode, the negative terminal, an electrolyte, a chemical that can split into positively-charged and negatively-charged fragments while releasing energy, and an anode, usually a metal different from the cathode metal, which is the positive terminal. Some types have a fourth layer between the electrolyte and the anode, called a depolarizer, a chemical that absorbs unwanted gas. Without going more deeply into the chemistry, when a conducting circuit is connected between anode and cathode, electrons from the electrolyte are driven to the cathode and flow round the circuit to the anode. Because electrons have a negative charge, that flow is a conventional electric current flowing the other way, from anode to cathode.

All three parts have electrical resistance, although it's made as low as possible to prevent wasting energy. We can add the three (or even four) resistances together to make a single resistor, called the 'internal resistance', in series with an ideal source of voltage, having no resistance, created from the chemical energy in the electrolyte. This is an 'equivalent circuit' of the cell. It's a bit simplified, because the resistances change as the cell discharges (or is charged, if it's rechargeable).

Now suppose we are given a mysterious box, with two terminals, and invited to find out what is inside it. We connect an ideal voltmeter (that draws no current) and measure, say, 6 V. Now instead, we connect an ideal ammeter (that has no resistance) and find that the current is 10 mA. Following the reasoning in the first two paragraphs, we can say that whatever is actually inside the box, when we 'look into' the terminals, it behaves to the outside world as an ideal 6 V source in series with a 600 Ω resistor. This shown in Figure 1.

**Figure 1 - Mysterious box with meters applied**



We have just discovered Thévenin’s theorem, but don’t let that put you off.

The point is that we can use that process for **any** ‘mysterious box’, and it works for sine-wave AC as well as DC, if we also measure the phase angle between the voltage and current, and the frequency (an oscilloscope will measure both of those). If the current lags the voltage, there is an inductor in series with the resistor, and if it leads the voltage, there is a capacitor in series. Measurements at more than one frequency can tell us more, but there is always either a capacitor or an inductor, or both, in series with a resistor.

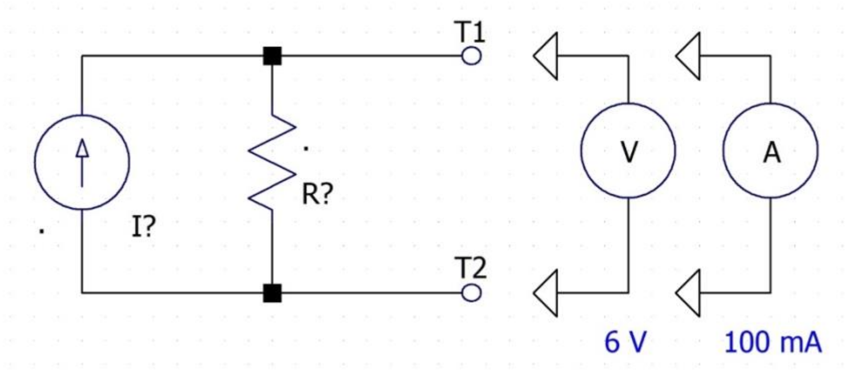
The cell need not be in the box; it could just as well be connected through another pair of terminals, making a ‘four-terminal network’.  Many pieces of equipment are four-terminal networks, such as an audio amplifier. For an amplifier, we need an external sine-wave source, of course, and we can’t connect a zero-resistance ammeter to the output, because that would either activate the short-circuit protection or cause smoke to be emitted. What we do in that case is to measure the voltage at the output terminals with no load resistance connected, and measure it again with a known-value load resistance connected. With those two voltages and the resistor value, we can easily calculate the value of the internal resistance (can’t you? It’s just Ohm’s Law).

Let’s throw away the cell and replace it by something rather less familiar, a professional electret microphone capsule, not one of the little aluminium-clad ‘pills’, which include a FET pre-amplifier. We only need to consider the diaphragm and backplate. The diaphragm is processed during manufacture with a high-voltage source that induces a permanent electric charge on the surface that is not metallized. (This is the electrical equivalent of the more familiar permanent magnet.) We expose it to a sinusoidal sound wave from a loudspeaker. When a sound wave vibrates the diaphragm, the electric charge varies in distance from the backplate, and this produces a voltage between the film and the backplate.

But something is odd: if we connect a microammeter and a resistor in series across the device, we find that the current doesn’t vary when we vary the series resistance (up to hundreds of megohms, anyway). This is logical; there is near-infinite resistance between the film and the backplate, so adding more resistance doesn’t reduce the current. The device is a ‘current source’.

Now we have the idea of a ‘current source’, we can go back to our original ‘mysterious box’ and look at the measurement results again. Figure 2 shows what we have.

**Figure 2 - The mysterious box seen as a current source and a resistor.**




We can see that, when we look into the terminals, it can be represented by a 10 mA current source (having infinite internal resistance) with a 600 Ω resistor **in parallel**. Just like before, this applies to **any** ‘mysterious box and, as in the former case, to sinusoidal AC as well as DC. If the current leads or lags the voltage, the capacitor or inductor appears in parallel with the resistor. It’s called ‘Norton’s theorem’, but never mind that, the point is that it works in practice and can be very useful in analysing how a circuit works.