IMPEDANCE MATCHING FOR POWER GENERATION

Figure 1 (a) depicts a model of an ideal generator. This so-called "Thevenin model", consists of an ideal voltage source in series with an electrical resistance, r. The Thevenin model is commonly used to determine the power delivering capability of a battery, generator or amplifier network. The open circuit voltage, V_{OC} , is the voltage that is generated internally. This is what is measured from the device terminals A and B, in the absence of a load (the situation in Figure 1(a)). However, when a load, R, is attached, there is a voltage divider effect between the internal resistance, r, and the external load, R. The result is that the voltage that appears at the load, R, is smaller than the open circuit value, $V_{OC.}$

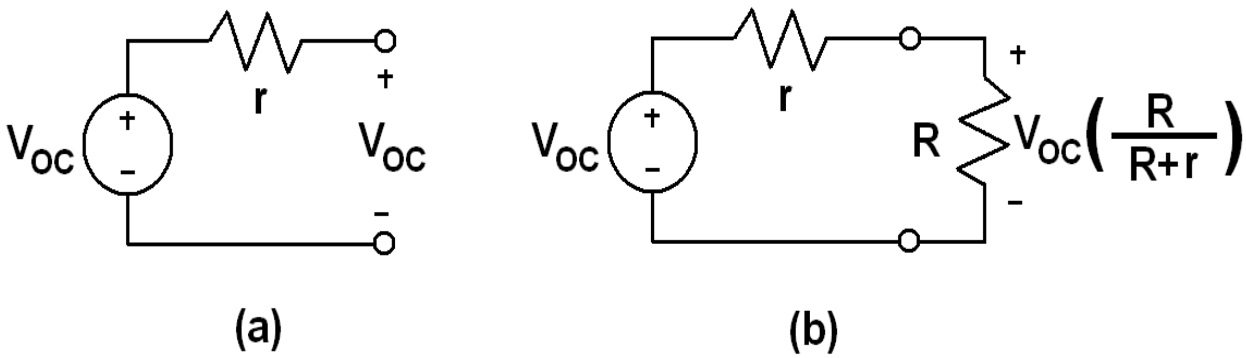

Figure 1 – A Voltage Generation Model (a) No-Load; (b) With Load R

Every thermoelectric module can be modeled with a Thevenin model. The voltage, V_{oc}, is the voltage that is measured from a module when a temperature gradient is applied across the module and there is no load attached.

When multiple thermoelements are connected together to form a thermoelectric device, the voltage that is generated is proportional to the temperature differential. For a device which has j n-type thermoelements and j p-type thermoelements that are interconnected in electrical series and thermal parallel, the open circuit (no-load) generated voltage is

$$\boldsymbol{V_{OC} = j * (S_p - S_n) * (T_h - T_c)} \quad (\mathbf{1})$$

where S_p and S_n are, respectively the Seebeck coefficients for the p-type and n-type thermoelements and we note that S_p and S_n have opposite signs. Equation (1) gives us a path for increasing the generated voltage. One way is to build the thermoelements with n-type and p-type materials having high values of S_p and S_n. Alternatively, with any given choice of thermoelectric materials, the open circuit voltage can be increased by having more series connected thermoelements, in other words, increasing j. In a given module, the type and number of thermoelements is fixed, so voltage is increased only by increasing the temperature difference $\Delta T = T_h - T_c$. A common assumption about thermoelectric materials is that their parameters, S, σ, and κ, are constant with temperature. For small values of ΔT, this is a reasonable assumption. However, S, σ and κ all have a temperature dependence and all thermoelectric materials have a “sweet spot” where they exhibit better performance, with performance degrading significantly as the temperature goes outside of that region.

From equation (1), it is clear that in an environment in which there may be wide temperature variations, the generated voltage will vary substantially. For example, in some applications it may be desirable to generate power from a 5 degree Celsius thermal differential at certain times and from a 70 degree Celsius thermal differential at other times. There is a 14:1 difference in the generated voltages in these two scenarios. Most electrical loads require a power input to occur over a relatively limited voltage range. As such, an electronic “converter” circuit is often needed to match the generated thermoelectric power to the electrical needs of the load.

From a systems standpoint, making the output voltage match the requirements of the load is not the only metric for a successful roll-out. It is important that the source be able to furnish the power requirements for an application. The key here is to make sure the source resistance, r, is sufficiently low. The power in the load, R, in Figure 1(b) is the voltage squared divided by R. So the power across the load is

$$P_R = \frac{V_{OC}^2}{R(R+r)^2} \qquad (2)$$

A well known result from circuit theory is that for a given generator, the maximum power output is obtained by matching the external load to the internal source resistance, that is, R=r, which results in a 50% efficiency. Higher efficiencies can be obtained with increasing R, but yield a reduced output power.

From equation (2), it is clear that for a given application, if there is not sufficient power delivered to the load, R, then either the open circuit voltage must be increased (ie: more temperature gradient across the thermoelectric module or have more elements in the thermoelectric module) or a module must be chosen that has a lower internal electrical resistance, r. Internal electrical resistance for a module is equal to

$$r = n \times \frac{l}{\sigma A} \qquad (3)$$

where n is the total number of thermoelectric elements (half of which are n-type and half of which are p-type), σ is the electrical conductivity of the material in each thermoelement (which we assume is the same for both p-type and n-type elements), A is the cross-sectional area of each thermoelement and *l* is the height of each thermoelement.