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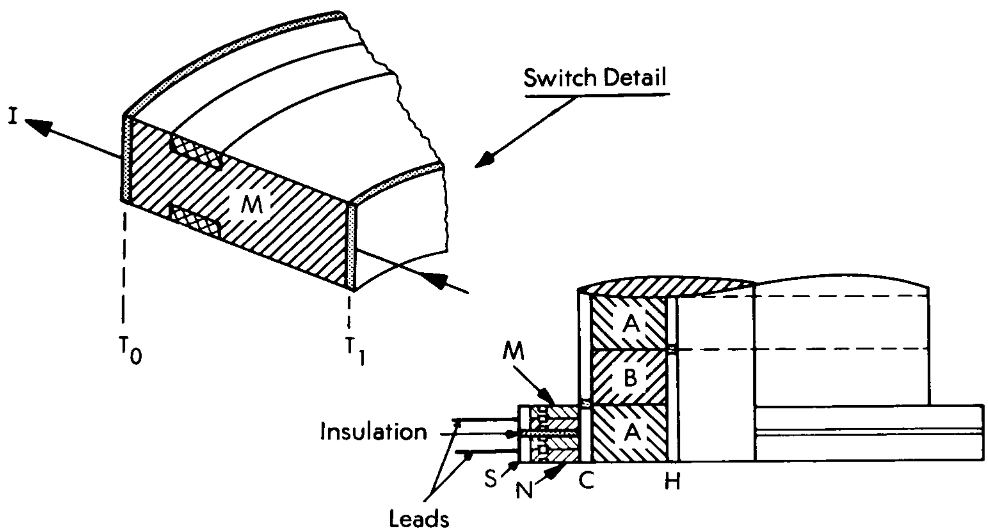
Compensation of Voltage Drops in Solid-State Switches Used with Thermoelectric Generators

The problem:

Current generated at low voltage by thermoelectric generators is ordinarily raised to higher voltages by inverters which chop the small thermoelectric DC outputs and feed the resulting alternating current to the primaries of step-up transformers. Chopping is best accomplished by solid-state switches which can be located very near to the thermoelectric junctions so as to reduce lead lengths and thus minimize power losses. Unfortunately, ordinary solid-state switches are inherently temperature sensitive and are particularly vulnerable to the high temperatures required for efficient generation of thermoelectric power and to radiation from radioactive sources.

Recent developments have made possible the fabrication of switches which operate at high temperatures and are relatively resistant to radiation; however, since all switches characteristically have an internal voltage drop of at least 0.1 volt, it is necessary to minimize the power losses resulting from the switching of large thermoelectric currents.



The solution:

Fabricate semiconductor solid-state switches from materials which have a large Seebeck coefficient and arrange to have the Seebeck potential generated in the devices with such polarity that current flow is aided.

How it's done:

A typical thermoelectric generator of tubular configuration is shown in the diagram together with a Seebeck-effect solid-state switch. A tubular heat source,

(continued overleaf)

such as a radioisotope fuel capsule, is inserted in the hollow core of the generator in contact with the inner hot-shoe H. Generator elements A and B (for simplicity, only three are shown in the diagram) may be either lead telluride or mixed germanium-silicon, suitably doped to produce the dissimilar elements. Tubular cold-shoe C is attached to a heat radiator. Switch elements M and N (only two are shown) are of a washer-like configuration and are mounted on cold-shoe C; the switch elements are in contact with a heat sink, S.

The sectional view of a switch element indicates that the construction is typical of a field-effect transistor (FET), but it may also be viewed as a bipolar transistor or SCR. The inner diameter in contact with the cold-shoe C constitutes the source electrode, and the outer diameter constitutes the drain electrode. The opposed concentric areas are the gate electrodes, and they are located near the heat sink to reduce undesirable thermal effects and to remove them as far as possible from radiation emitted by the heat source. The switch elements are fabricated from materials such as silicon, mixed silicon-germanium, and gallium arsenide or silicon carbide, suitably doped to provide a large Seebeck coefficient.

The radial flow of current I between the source and the drain takes place at a voltage drop IR, where R is the ohmic resistance; the voltage drop can be cancelled when the thermoelectric emf which is generated across the switch has a polarity which aids current flow, that is $IR = \alpha (T_1 - T_0)$, where α is the effective Seebeck coefficient of the material, T_1 is the temperature at the cold-shoe, and T_0 is the temperature at the heat sink. The ohmic resistance R can be computed from the bulk resistivity of the material, ρ, and the length of the current path (λ) and its cross-sectional area A; hence,

$$I \rho \lambda / A = \alpha (T_1 - T_0).$$

For a current density, D, of 1 ampere per cm^2, a current path of 1 cm, and a temperature difference $(T_1 - T_0)$ of 300°C, the ratio of the Seebeck coefficient to bulk resistivity is seen to be:

$$\alpha / \rho = 1/300 = 0.0033;$$

such a ratio is attainable with a semiconductor for which $\alpha = 2.97 \times 10^{-4}$ volt per degree and $\rho = 0.09$ ohm-cm.

A power supply which includes two thermoelectric power switches, a high-temperature transformer, and a high-temperature power source can be constructed in such a way that these components are in the high-temperature zone near the thermoelectric generator. The temperature-sensitive circuits which provide low-current signals to the power switches are located at a considerable distance away; thus, all parts of the voltage inverter which handle heavy currents at low voltages are interconnected by very short, heavy current leads, and the overall efficiency of the generator-inverter system can be increased by as much as 20% (10% in power-transmission line, and 10% in the switches). Moreover, since the requirements for heat and radiation shields will not be as stringent as in conventional thermoelectric power systems, reduction of system weight can also be realized.

Patent status:

This invention has been patented by NASA (U.S. Patent No. 3,648,152). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to:

NASA Patent Counsel
Mail Code 1
NASA Pasadena Office
4800 Oak Grove Drive
Pasadena, California 91103

Source: Katsumori Shimada of
Caltech/JPL
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