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Accurate Nine-Decade Temperature-Compensated Logarithmic Amplifier

The problem:

To develop a circuit, capable of monitoring ion-chamber currents over spans of 8 or 9 decades (10^{-12} to 10^{-13} A), for use in nuclear-reactor instrumentation. Logarithmic devices are common in this application because they permit presentation of the entire dynamic range of the reactor without range-switching.

A single transistor can provide an excellent logarithmic characteristic. Its circuit provides a fixed output-signal level of 60 V per decade of current and requires that the collector-base voltage of the logarithmic transistor be held to less than 1 mV for input currents less than 10^{-10} A. At 10^{-12} to 10^{-10} A the electrometer tube or the insulated-gate field-effect transistor (MOS-FET) is often used as the input stage for the amplifier; in either case, the input stability is poorer than the 1 mV required by the transistor logarithmic element.

The solution:

A transistor-driven temperature-stable amplifier with logarithmic operating characteristics. The temperature-stabilization is provided by a silicon resistor connected across the amplifier network; this causes a temperature-dependent compensatory voltage-change across the resistor, equal in amplitude and opposite in polarity to the voltage produced by the transistor.

How it's done:

The disadvantage created by the electrometer tube and MOS-FET can be avoided if a string of two-terminal logarithmic devices are connected as the feedback element; the following advantages are realized:

1. The base and collector are always at the same potential, and 1-to-5% linearity, in the voltage per decade constant, is obtained for 9 decades of input current.
2. By use of ten transistors the voltage per decade constant is 0.6 V—much greater than the instability of the input stage.
3. No selection is required, because of the uniform characteristics of the transistors.

The circuit is temperature-compensated. The transistors have a temperature coefficient (TC) of approximately –2.8 mV/°C; therefore a string of ten transistors has a temperature coefficient of –28 mV/°C. The silicon resistor has a resistance-temperature coefficient of +0.7%/°C. By selection of a certain value of constant current (greater by at least an order of magnitude than the greatest signal current) to pass through a given silicon resistor, a temperature-dependent voltage-change across the resistor, equal and opposite to that of the transistor, is generated.

If a 4-mA current is passed through a 1,000-ohm silicon resistor, 4 V is developed at 25°C. The voltage-temperature coefficient, +28 mV/°C, compensates for the TC of the transistors. The logarithmic response has been used from 10^{-12} to 10^{-3} A.

Notes:

1. This circuit would be useful in industrial applications in which electronic instrumentation is used to monitor processing of materials under ultrahigh vacuum; thus it may interest designers or manufacturers of vacuum instrumentation.

(continued overleaf)

2. Inquiries concerning this innovation may be directed to:

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Patent status:

Inquiries concerning rights for commercial use of this innovation may be made to:

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