December 1972 B72-10507

NASA TECH BRIEF
*NASA Pasadena Office*

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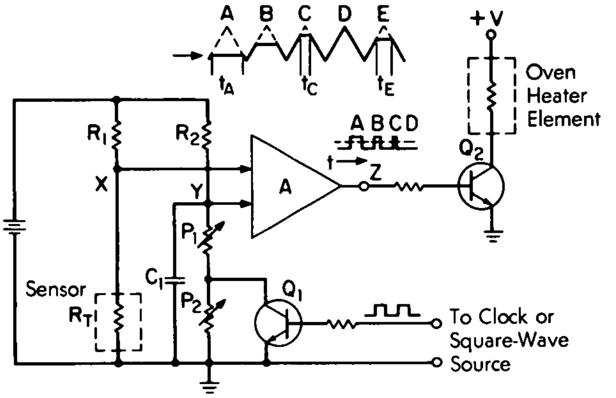
# Pulse-Width-Modulated Device for Precision Temperature Control

Conventional temperature controllers supply power to heating elements in an on-off mode; as a result, the temperature of the system under control oscillates above and below a nominal temperature, and the difference between the two extremes is used as a measure of the degree of refinement of the controller. Power is turned off at one extreme of the temperature oscillation and on at the other extreme; thus, there is a "dead band" because the controller is essentially inoperative between the two temperature extremes. An alternative statement is that the controller sampling rate is very low and occurs only during the brief intervals when the temperature is nearly at or beyond either extreme.

In order to obtain a closer temperature control, that is, to reduce the difference between temperature oscillations about the control point, expensive complex devices are often incorporated in controllers so that the power delivered to heating elements is in proportion to the difference between the selected temperature and the actual temperature of the system under control; since dead bands are eliminated and the controller is active at all times, it is evident that the controller sampling rate has been increased.

The controller shown in the diagram provides an inexpensive means of reducing the difference between temperature excursions. The temperature sensor, $R_T$, is any standard temperature-sensitive resistor element of a type which is highly stable and reproducible; as a result, temperature settings can be duplicated at any time. The temperature-sensing circuitry is a conventional DC bridge consisting of $R_1$, $R_2$, $R_T$, and $P_1 + P_2$; power is supplied by a battery or a highly regulated supply, and ordinarily, $R_1 = R_2$.



The effective resistance of the combination of $P_1$ and $P_2$ is governed by the conduction state of $Q_1$; the clock or square-wave source supplies a symmetrical signal which compels $Q_1$ to perform as a switch, that is, all on or all off for equal intervals. Consequently, $P_2$ is alternately shorted or allowed to remain in the network at a rate determined by the clock or square-wave source, and the effective resistance of the combination of $P_1$, $P_2$, and $Q_1$ over a relatively long interval of time can be made to vary between $P_1$ and $P_1 + P_2$ as a function of the switching rate of $Q_1$. Accordingly, at a given switching rate, $P_1$ and $P_2$ can be selected so that the effective resistance of the combination of $P_1$, $P_2$, and $Q_1$ equals $R_T$, the resistance of the temperature sensor at the selected control temperature; when the control temperature is achieved, the

(continued overleaf)

bridge is balanced and there is no DC potential difference between points X and Y. The operational amplifier shown in the diagram controls power delivered to the oven heater element via $Q_2$; when no potential difference exists across points X and Y, $Q_2$ is biased off by the operational amplifier and no power is supplied to the heater.

The value of capacitor $C_1$ is selected for the particular clock-rate to produce a sawtooth voltage at point Y. The combination of DC voltage produced by bridge unbalance at points X and Y and the sawtooth resulting from insertion of $C_1$ give rise to pulse width modulation (PWM) at point Z. Referring to the characteristic sawtooth patterns shown in the diagram, at pattern A the bridge is unbalanced because the sensor temperature is too low and the heater "on" time is indicated as $t_A$; at pattern C, the sensor temperature is much closer to the control temperature and the heater "on" time is shorter ($t_C$). Sawtooth pattern D indicates that the resistance of the temperature sensor is identical to the set point; no power is supplied to the heater, but natural cooling will drop the temperature a small amount to yield pattern E. The heater "on" time, $t_E$, is very close to the power input required to compensate for heat losses from the controlled system and, ideally, the system should idle at this point with only infinitesimal power level adjustments made at the rate of sampling equal to the clock frequency.

The conduction state of $Q_1$ can be controlled by programming its switching frequency; thus, the effective resistance of the combination of $P_1$ and $P_2$ ($P_2$ can be omitted) can be controlled by a digital computer to give a precise rate of temperature change without overshoot for a properly designed system. For example, an oven can be brought up to a presoak temperature as fast as possible, held at presoak temperature for a given time, then heated at (e.g.) one degree per minute to a new temperature and held there for a time, and then brought back to presoak temperature in exactly the same length of time it took to achieve the higher temperature, and finally turned off.

## Notes:

1. The final temperature in an experimental oven was held to ±0.001°C with a thermistor sensor.
2. Requests for further information may be directed to:

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Reference: TSP72-10507

## Patent status:

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(NPO-11407)