Thermostat For High-Altitude Atmospheric Sampler Is Fault-Tolerant

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CIRCLE 521

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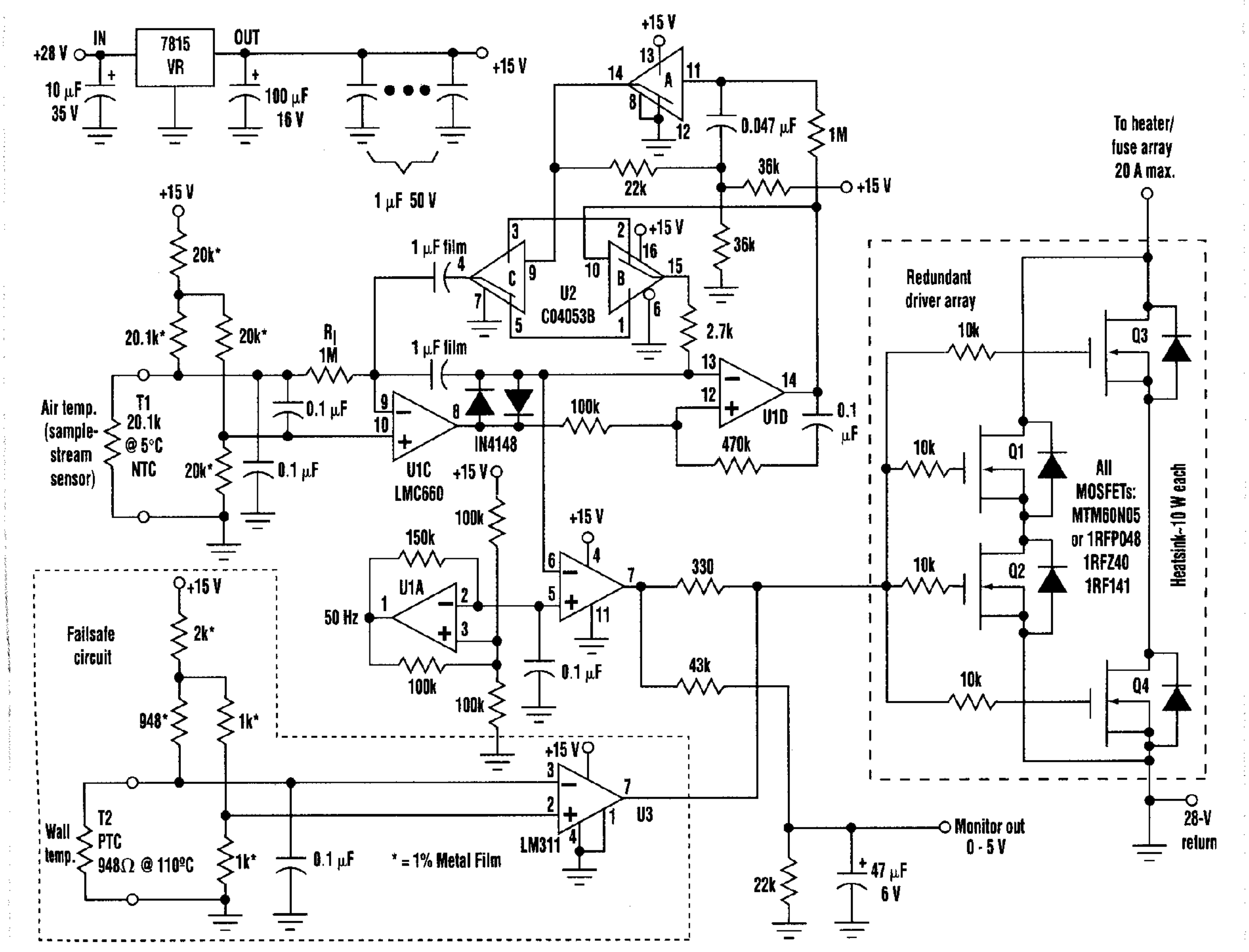
Among the many measures of good circuit design (e.g., cost, performance, and efficiency), none is more important than reliability. Usually, adequate expected reliability can be achieved by simply sticking to conservative design rules and good engineering practices. Yet in some critical applications, "any" unnecessary risk of failure may be unacceptable. At the same time, the trouble and cost of exhaustive environmental and life-cycle testing may be difficult to justify for one-of-a-kind research instruments. In these cases (like the one shown here), special design-in-depth tactics may be the most cost-effective route to adequately bulletproof system designs.

In this example, an atmospheric analysis apparatus carried aboard a NASA ER-2 high-altitude aircraft is used in ozone-layer depletion research. This device incorporates an electrically heated, constant-temperature air-sampling probe. The probe warms the incoming air stream from the stratosphere (ambient temperatures from −70°C to 5°C, ±1°C) for input to a laser spectrometer. The large delta-T (about 75°C) and high flow rate (tens of liters per second) involved in this application dictate large heater power inputs—around 400 W. Consequently, any failure of the heater control circuits would risk severe thermal probe damage. Even if permanent probe damage doesn't occur, in-flight thermostat failure would cause the loss of valuable scientific data and waste very expensive aircraft flight time.

To prevent these calamities, this design incorporates several backup provisions in the heater-control circuit-



This heater-control design incorporates several backup provisions for improved reliability, including parallel MOSFET outputs and a probe-wall overtemperature monitor.

ry. The central principle of operation of the thermostat is an analog implementation of the "Take-Back-Half" (TBH) algorithm *(see "Take-Back-Half: A Novel Integrating Temperature-Control Algorithm,"* ELECTRONIC DESIGN, *December 4, 2000; "Circuit Enables Precision Control In Radiant Heating Systems," January 8, 2001; and "Linear-RMS Phase Control Improves Thyristor-Based Thermostat," March 5, 2001).*

The temperature of the sampled air stream is sensed by T1, an NTC thermistor. The resistance of T1 will equal 20.1 kΩ when the sample-stream temperature equals the 5°C setpoint, resulting in bridge balance. At any other sample-stream temperature, the voltage at the common node of T1 and the 20.1-kΩ reference resistor will not equal the voltage at pin 10 of U1C. This imbalance will cause an error current to flow through R_T to the TBH integrator formed by U1C and the 1-µF feedback capacitor. The resulting charge accumulation will cause pin 6 of U1B to ramp down for stream temperatures below the setpoint, and up for temperatures above the setpoint.

U1B compares the integrated error voltage to the 5-V p-p, 50-Hz triangle waveform produced by U1A. This comparison produces a square wave at U1B-pin 7, with a duty cycle that increases as the integrated error signal decreases. U1B's output is applied to the MOSFET array, resulting in an average heater power that can proportionate from 0 to 400 W in response to the integrator. Thus, the average heater power will gradually increase when the stream temperature is below the setpoint, and decrease when the temperature is too high. The net result is to drive temperature deviations toward the setpoint, as any good thermostat should. Meanwhile, the TBH principle forces steady-state convergence.

To enhance reliability, four MOSFETs are used for heater power switching where one would theoretically suffice. This lets the MOSFETs be arranged in a redundant series-parallel topology that permits uninterrupted operation even with any single MOSFET open and/or any single MOSFET shorted. As further safety backup to prevent overheating damage to the probe in the event of thermostat runaway, thermal override comparator U3 monitors the probe's wall temperature. The U3 override function will take over the degraded (but still useful) control of the heater drive if a primary U1 control-loop failure should ever allow the probe wall to heat beyond 110°C.