Low-power thermal airspeed sensor

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Among the techniques available to measure airspeed, thermal anemometry has the virtues of simplicity and easy miniaturization. Such anemometers use the relationship between airspeed and power dissipated by a heated sensor known as King's Law. One good approximation to King's Law is:

S = A * [(P - D) / (TS − TA)]2

where:

S = air speed
A = full-scale calibration

constant

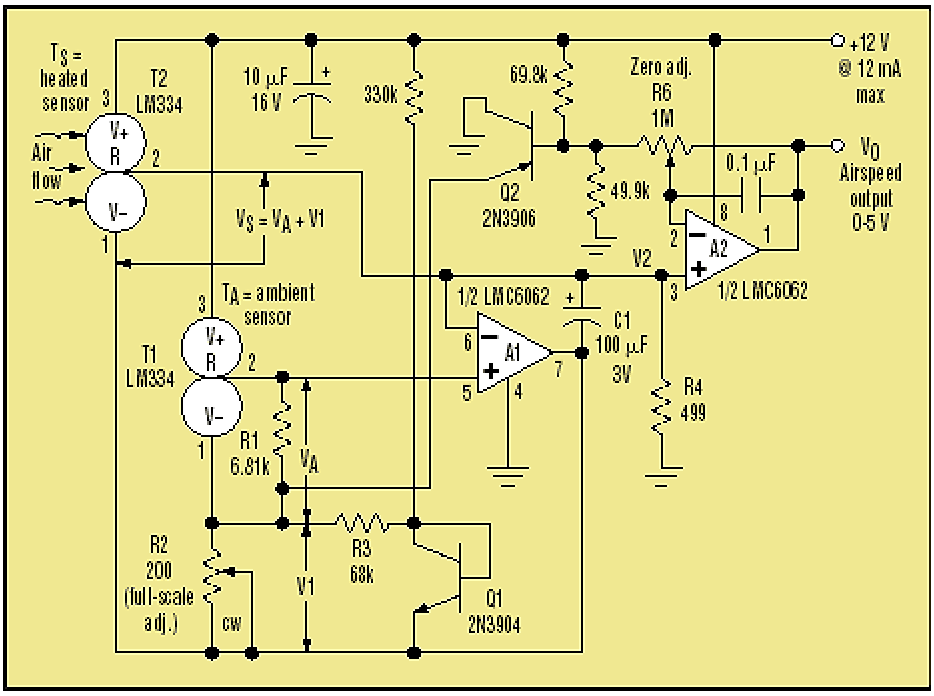
P = power dissipated by the airspeed sensor
D = "still-air" (S = 0) power dissipation
TS = temperature of the airspeed sensor
TA = ambient temperature

Two practical problems of thermal airspeed sensors are apparent from this equation. First, the accuracy of the airspeed measurement obviously depends on stability of the (TS − TA) term. This means that either the TS and TA measurements must track very closely, or the (TS − TA) differential must be made large enough to swamp the drift caused by ambient temperature excursions.

Accurate temperature measurement isn't easy, so the brute-force route usually is chosen, and the sensor is kept good and hot. The penalty of this strategy is power consumption on the order of 1 W, making portable operation problematic.

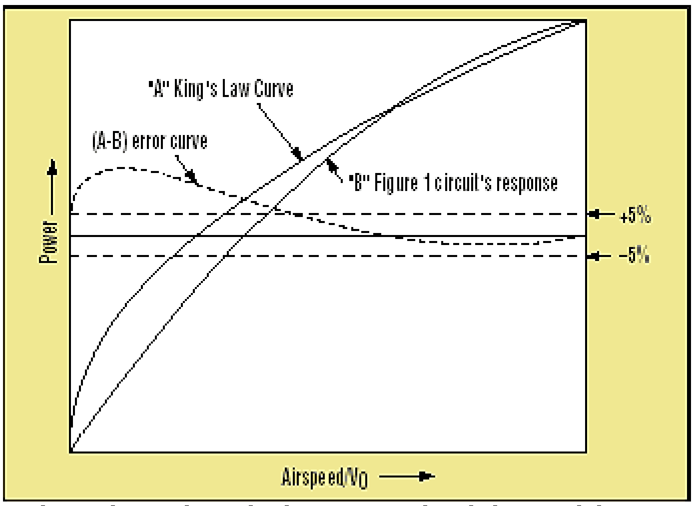
Also, the second-order exponent makes the raw sensor output nonlinear with airspeed. Therefore, thermal anemometers typically need some provision for measurement linearization.

Figure 1's circuit utilizes the venerable LM334 temperature sensor to minimize both headaches. LM334s generate a proportional-to-absolutetemperature (PTAT) voltage of ≈214µV/°Kelvin. Therefore, if a constant (VS − VA) voltage differential is maintained, a constant (TS − TA) temperature differential will result. Figure 1's arrangement of R2, R3, and Q1 provide a stable voltage difference (V1) in the range of 0 to 4 mV to be added to VA.



1. Two LM334 temperature sensors are used in this thermal airspeed sensor to minimize power consumption and provide for linearization.

Op-amp A1 adjusts V2 to maintain VS = VA + V1 and, thereby, TS = TA + V1/214 µV. This works because the power dissipation of ambient-sensor T1 is about 100 µW and is, therefore, too little to significantly heat the sensor (LM334s in TO-92 packages have a still-air dissipation constant of 5.6mW/°C). Airflow-sensor T2's dissipation, however, is much larger: P = 1.06 * (12 – V2) * V2/R4, making T2 heat up when A2's output slews positive, taking V2 with it. As V2 swings from 0 to 5 V, P goes from 0 to 74 mW. Depending on air speed, this power range is sufficient to maintain a (TS – TA) differential (as set by R2) of 4 to 13°Kelvin. V2 is buffered and zerocorrected by A2 and becomes the 0-to-5-V airspeed output signal.



2. The quadratic relationship between P and V2 helps cancel the King's Law nonlinearity, resulting in less than a 5% error over more than half of the zero to full-scale range of airspeed.

But what about measurement linearization? As illustrated in Figure 2, the inherent quadratic relationship between P and V2 does a reasonable job of canceling King's Law nonlinearity and results in less than 5% error over more than half of the zero/full-scale range of airspeeds. Anemometer zero/full-scale calibration is straightforward and interaction-free if done in the right sequence. T2 should first be exposed to air flow corresponding to the desired full-scale airspeed and R2 adjusted for VO = 5 V. T2 then is placed in calm air and R6 adjusted for VO = 0.

C1 and Q2 provide protection against feedback-loop oscillation and latchup. The 12-V supply should be well-regulated for good circuit stability. Total power consumption depends on airspeed, but never exceeds 144 mW (12 V @ 12 mA). This figure is easily six times less than the requirements of comparable performance sensors, especially anemometers that use sturdy plastic sensors instead of fragile metallic filaments. Response is fairly quick (less than 2 seconds) due to the constant-temperature operation of T2.