Transistor linearly digitizes airflow

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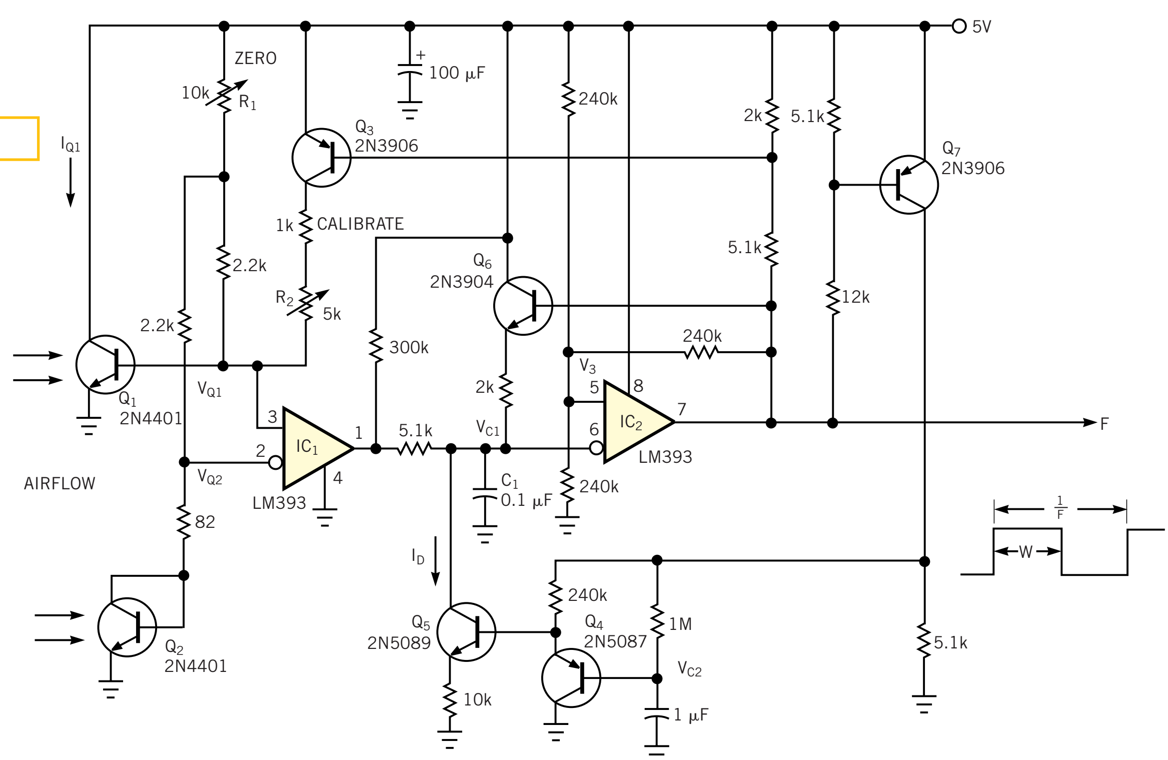
A sensitive and reliable way to measure airflow is to take advantage of the predictable relationship between heat dissipation and air speed. The principle of thermal anemometry relies on King's Law, which dictates that the power required to maintain a fixed differential between the surface of a heated sensor and the ambient air temperature increases as the square root of air speed. The popular hot-wire anemometer exploits this principle, but it suffers from the disadvantage of using a specialized and fragile metallic filament, the hot wire, as the airflow sensor. The circuit in **Figure 1** avoids this disadvantage by using a pair of robust and inexpensive transistors instead of a flimsy wire for airspeed sensing. The Q_1/Q_2 front end of the circuit borrows from an earlier Design Idea (**Reference 1**). Just as in the 1996 circuit, the circuit in **Figure 1** works by continuously maintaining the condition $V_{Q1}=V_{Q2}$. To perform this task, the circuit must keep Q_1 approximately 50°C hotter than Q_2.

V_{BE} balance requires this temperature difference, because Q_1's collector current, I_{Q1}, is 100 times greater than that of Q_2, I_{Q2}. If Q_1 and Q_2 were at the same temperature, this ratio would result in V_{Q1}'s being greater than V_{Q2} by approximately 100 mV. Proper control of I_{Q1} establishes differential heating that makes Q_1 hotter than Q_2. The method thus exploits the approximate −2-mV/°C temperature coefficient of V_{BE} to force V_Q balance. The resulting average, I_{Q1}, proportional to the average power dissipated in Q_1, is the heat-input measurement that forms the basis for the thermal air-speed measurement. Calibration of the sensor begins with adjustment of the R_1 zero-adjust trim. You adjust R_1 such that, at zero airflow, $V_{Q1}=V_{Q2}$ with no help from Q_3. Then, when moving air hits the transistors and increases the heat-loss rate, V_{Q1} increases and causes comparator IC_1 to release the reset on C_1. C_1 then charges until IC_2 turns on, generating a drive pulse to Q_1 through Q_3.

The resulting squirt of collector current generates a pulse of heating in Q_1, driving the transistor's temperature and V_{BE} back toward balance. Proper adjustment of R_2 calibrates the magnitude of the I_{Q1}-induced heating pulses to establish an accurate correspondence between pulse rate and air speed. Now, consider measurement linearization. The square-root relationship of King's Law makes the relationship between heat loss and air speed nonlinear. You must iron the kinks out of the air-speed-calibration curve. You might achieve linearization in software, of course. However, depending on

Figure 1



Using a simple transistor as sensor, this circuit yields a digitized, linear measurement of air speed.

the flexibility of the data system the anemometer works with, a software correction is sometimes inconvenient. Another earlier Design Idea (**Reference 2**) presented an analog solution to linearization. But if you want the advantages of a digital, pulse-mode output—that is, noise-free transmission over long cable runs—you need a different fix.

The circuit in **Figure 1** provides both linearity and a digital output. The average heat the pulses deposit in Q_1 is $H=5V\times I\times F\times W$, where I is the amplitude of the Q_1 current pulses (adjusted with R_2), F is the output frequency, and W is the pulse width. W is inversely proportional to I_D, the discharge current that ramps down V_{C1} and controls the on-time of IC_2. Q_4 and Q_7 average the output duty cycle to generate a control voltage for Q_5 and thus make W a function of F. In fact, the feedback loop this arrangement establishes implicitly makes $W=K/(W\times F)$, where K is a calibration constant determined by the component values. Therefore, $W^2=K/F$, and $H=5\times I\times F/\sqrt{K/F}$. This expression yields $F=(H/5I)^2/K$, making F the desired function of H^2 and thus linearizing the relationship between frequency and air speed.

References

1. Woodward, Steve, "Self-heated transistor digitizes airflow," *EDN*, March 14, 1996, pg 86.

2. Woodward, Steve, "Transistor and FVCs make linear anemometer," *EDN*, Sept 26, 1996, pg 72.

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