

Circle 520

Build Your Own Optical Heart-Rate Sensor

W. STEPHEN WOODWARD

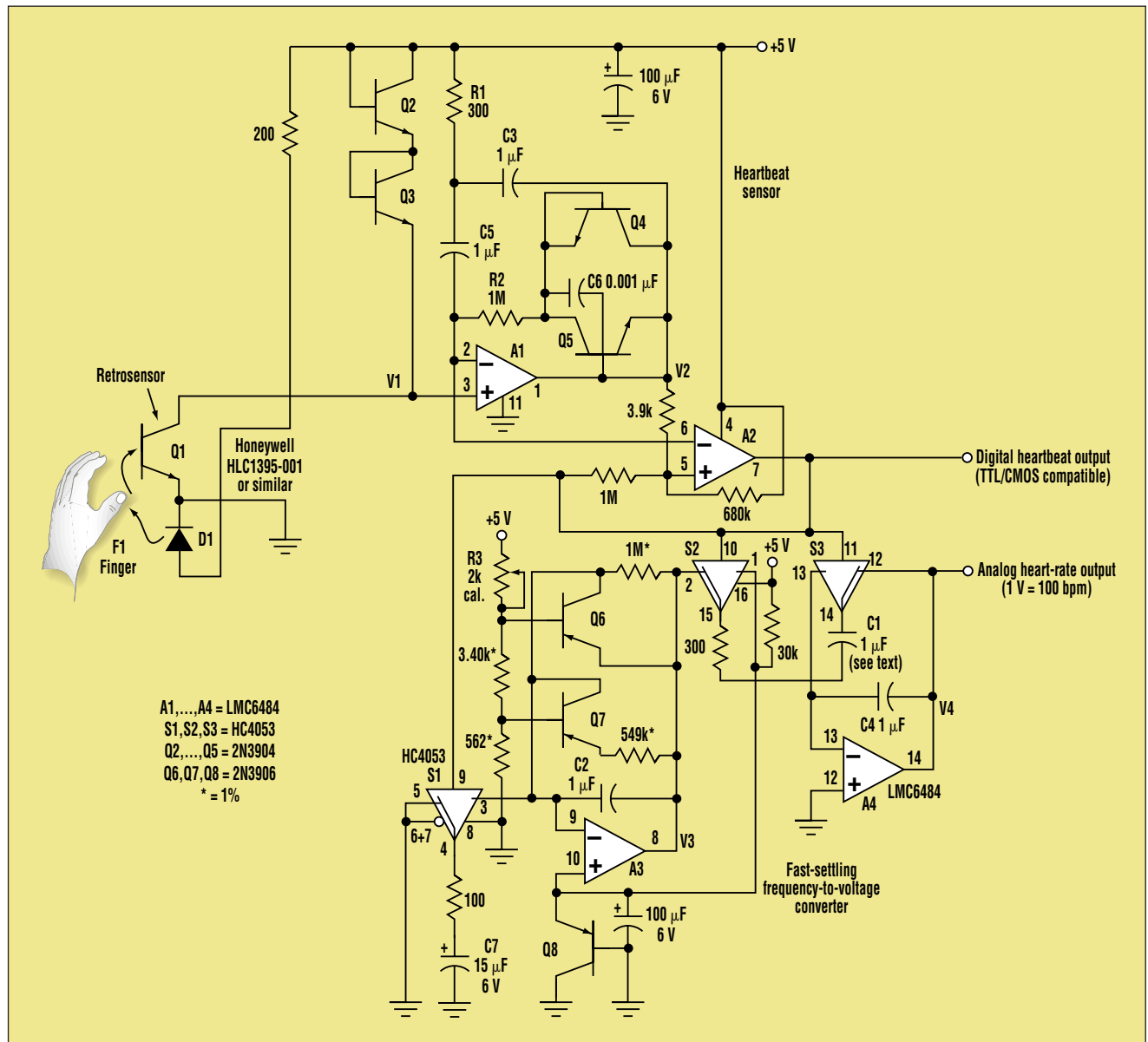
Venable Hall, CB3290, University of North Carolina, Chapel Hill, NC 27599-3290; e-mail: woodward@net.chem.unc.edu.

Plenty of noninvasive methods exist for electronically sensing the human heartbeat. The job can be done acoustically (stethoscope or Doppler), mechanically (sphygmo-

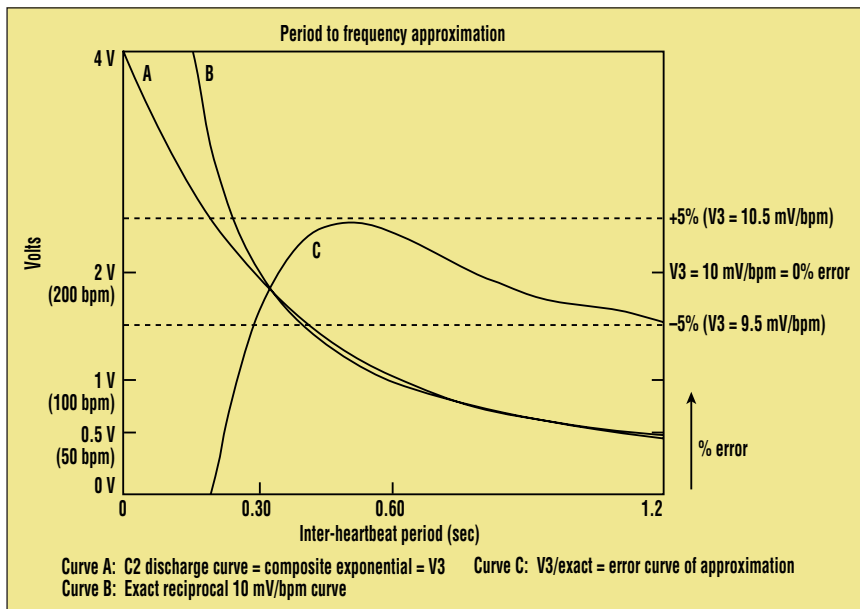
manometer), electrically (EKG), and optically. One handy optical technique presented here exploits the fact that tiny subcutaneous blood vessels (capillaries) in any patch of

skin (fingertip, ear lobe, etc.) furnished with a good blood supply, alternately expand and contract in time with the heartbeat. An ordinary infrared LED/phototransistor pair can sense this rhythmic change as small but detectable variations in skin contrast (Fig. 1, upper half).

When gently held against the skin (too much pressure will flatten the surface capillaries and suppress the pulsation effect), some of the radiation from D1 reflects back into Q1. Q1's photocurrent produces an ac signal across Q2 and Q3 of $\approx 500\text{-}\mu\text{V}$ p-p for every 1% change in skin reflectance. This logarithmic relation-



1. The upper half of this optical heart-rate sensor contains an infrared LED /phototransistor that senses rhythmic change as small variations in skin contrast. The lower half constitutes a "zero-ripple" frequency-to-voltage converter that's optimized for human pulse-rate measurement.



2. C2's discharge is nonlinear. R6, R7, and Q7 synthesize a composite exponential curve V3 that approximates the reciprocal relationship between pulse period and pulse rate.

ship is constant over many orders of magnitude of photocurrent. Consequently, reliable circuit operation is possible despite wide variations in skin contrast and light level. A1 and the surrounding discrete components comprise a high-gain adaptive filter that rejects ambient optical and electrical noise (mostly 60-Hz pickup) and presents a cleaned-up signal to comparator A2 so that it can extract a digital pulse-rate signal.

A2's TTL/CMOS-compatible output is suitable for direct input to a digital period-measurement circuit, and for such applications, that's all that's needed. But for some simple heart-rate display situations, an analog representation of pulse rate is convenient. So the lower half of Figure 1 illustrates an unusual, "zero-ripple," frequency-to-voltage converter (FVC) uniquely optimized for human pulse-rate measurement.

Most FVCs are characterized by an unavoidable trade-off between response time and output ripple. Usually, in order to have an acceptable output ripple of the order of a few percent, the settling time of the converter must be at least ten periods of the lowest expected input frequency. Normal human hearts usually beat at rates within the 4:1 range of 50 to 200 beats per minute (bpm) ≈ 0.83 Hz to ≈ 3.3 Hz. A conventional frequency-to-voltage converter (FVC) would therefore

need an unpleasantly long (>10 second) output settling time. Some converters avoid this limitation but tend to be complex (ELECTRONIC DESIGN, Feb. 21, 1994, p. 115).

The relatively simple "instant-settling" FVC in Figure 1 employs a period-to-rate approximation trick that works well in this application. To understand the idea, consider S1, which is arranged to alternately switch C7 between ground and A3's summing point. When a rising edge from A2 at S1 pin 9 connects C7 to A3 and C2, the

resulting transfer of charge into C2 causes A3's output to slew positive until clamped by Q6. Adjusting R3 trims the clamp voltage and thereby sets full-scale calibration for the circuit.

C2 immediately begins to discharge back toward zero, but it doesn't do so linearly. Instead, R6, R7, and Q7 synthesize a composite exponential curve V3 (Fig. 2) that, from 285 (210 bpm) to 1250 ms (48 bpm), is a good approximation (within 5%) of the reciprocal relationship between pulse period and pulse rate. Thus, each time the digital signal from A2 returns high, V3 will equal the reciprocal of the time elapsed since the previous transition and, therefore, the actual instantaneous heart rate. S2, S3, and C1 then transfer V3 to sample/hold A4 for continuous output as V4 = 10 mV/bpm. If C1 = C4, only one charge transfer is needed for instant convergence.

However, normal hearts have significant beat-to-beat aperiodicity that sometimes causes V3 to jump around quite a bit. If desired, choose C1 < C4 to provide a degree of signal averaging and thus smooth this effect out. Q8 provides V_{be} and temperature compensation for the Q6 and Q7 breakpoint voltages. Thus, these transistors should be thermally coupled for good tracking. Notice that with an appropriate change of time constants, this circuit also has general potential as an optical tachometer for other difficult low-contrast applications.