third active balun amplifier transforms the single-ended RF input from the antenna into a differential signal, which is connected to the mixer's balanced RF port. The RF input is the signal that is reflected off the target, with its phase modulated by the target's displacement. Since the LO is a portion of the original signal, the mixer downconverts the RF signal to a baseband signal with a magnitude proportional to the displacement associated with respiration and heart activity. Isolation of about 20 dB is required between the RF output and input signals. This can be achieved either with two separate antennas, or with one antenna and a coupler or circulator.

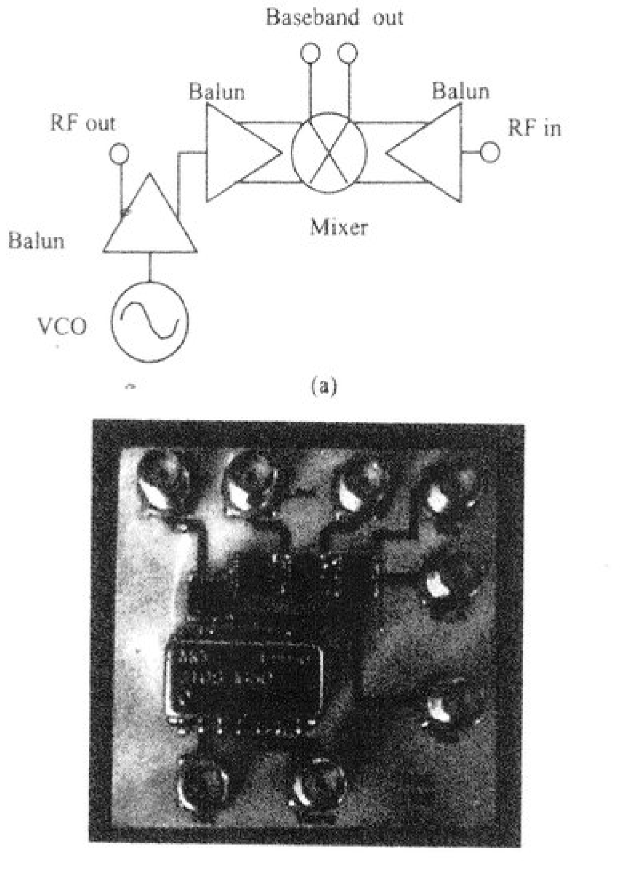

Fig. 1. Block diagram (a), and photograph (b) of Doppler radio. Custom RFICs, developed for DCS1800/PCS1900 base stations, were used for this radio.

An active balun amplifier [9] developed for DCS1800/PCS1900 base station applications was used as a power splitter in this radio. The active balun operates at frequencies up to 2 GHz. The circuit can be operated with any supply voltage between 1.5 V and 5 V, with the best output signal phase and amplitude balance and highest gain obtained with a 5 V supply. The bias current varies linearly with the supply voltage, and the power consumption varies from 13.5 mW to 325 mW. This buffer was fully integrated on a 0.25 μm silicon BiCMOS process in a 1.8 mm by 1.6 mm chip. It was packaged in an exposed pad TSSOP-16 package, which has a 3 mm by 5 mm footprint.

A fully differential CMOS resistive ring mixer [10], also developed for DCS1800/PCS1900 base station applications, was used for direct demodulation in the receiver. This is a broad-band mixer that can operate with an RF signal up to 2500 MHz and with an IF signal from DC to 300 MHz. Though the mixer achieves its best linearity performance at high LO drive, it can be operated with LO drive as low as 4 dBm and still have conversion loss less than 7 dB. The mixer requires no bias and therefore consumes no DC power. This mixer was fully integrated on a 0.25 μm silicon CMOS process in a 1.2 mm by 1.5 mm chip. It was packaged in an exposed pad TSSOP-16 package, identical to that of the active balun amplifier.

A commercially available VCO, the Mini-Circuits JTOS-1650, was used as a signal source. With the recommended supply voltage of 12 V, this VCO consumes 360 mW. By varying the control voltage from 0 V to 14 V, the frequency can be tuned from 1.09 GHz to 1.99 GHz, with an output power of 5 mW. The oscillator was in a BK377 package, with a 13 mm by 20 mm footprint. Alternatively, the size and power consumption of this radio could be reduced by using a low power, custom designed BiCMOS VCO [11], which draws 20 mA for a 36 mW total DC power consumption, in a more compact TSSOP-16 package.

The circuit board was built on a Rogers RO-4003 substrate with a dielectric constant of 3.38 and a thickness of 0.5mm. SMA connectors were used for all the inputs, outputs, and DC bias (Fig. 1(b)). The RF signals were routed to the SMA connectors via 50 Ω lines, which were 1.1 mm wide on this material. The board dimensions were 50 mm by 50 mm.

Commercially available motion sensors typically operate at higher frequency bands, such as X-band. The main benefit of working in the telecommunications bands, such as the DCS1800/PCS1900 band, is that the hardware needed to build radios at these frequencies is readily available. Also, lower frequencies offer advantages for lower cost monolithic integration, since at these frequencies it is possible to use inexpensive silicon CMOS and BiCMOS processes.