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# Wearable Doppler Radar with Integrated Antenna for Patient Vital Sign Monitoring

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**Abstract** — A 2.45 GHz wearable Doppler radar unit with radio data link is presented for use in portable patient monitoring and emergency response. Unlike portable Electrocardiograms (ECG) or Photoplethysmography (PPG), the near-field Doppler unit enables monitoring of the person's heart rate without the need for electrical contact or optical access to the patient's skin. The Doppler unit is designed to be embedded in a clothing garment such as a shirt or vest, or used by medical emergency personnel in an instrumented blanket or medical stretcher. Since the Doppler unit is placed directly on or behind the patient's torso, the extraneous signals due to relative motion artifacts is greatly reduced. Low-cost design is achieved by employing PWB microstrip elements for the integrated patch antenna, microwave oscillator, and tuning elements. Also, since the distance between the Doppler unit and the patient is fixed, it was possible to tune the detection phase to enable the use of a single mixer diode and eliminate the need for quadrature detection. Measured heart data from this technique shows clear waveform substructure similar to PQRST complex features found in captured ECG data.

**Index Terms** — biomedical monitoring, wireless, Doppler radar, heart rate, mobile sensors.

## I. INTRODUCTION AND MOTIVATION

In the past decade, there has been increasing interest in wireless medical devices and physiological sensors to monitor basic physiological signals, such as heart rate, blood pressure, and temperature [1]. The applications for these sensors are numerous, but several major applications include outpatient care, patient monitoring, physical therapy, elder care, sports/fitness training, and long-term monitoring of various chronic health conditions [2].

A challenging area within the field of medical instrumentation is the need to create sensors that can be used in mobile or emergency situations where standard medical equipment is not available or not practical. Examples of such scenarios include: disasters (e.g. earthquakes), military battlefield medical care, and patient monitoring in remote areas [3]-[5].

For these applications, the basic system requirements include: portability, low-power (for battery powered use), and relatively small size/weight. In addition, since many emergency situations require operation in outdoor environments, the technology used must also be rugged, carefully packaged, and able to withstand extreme environments. For applications requiring large scale

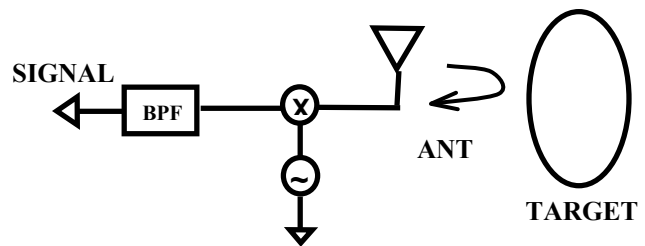


Fig. 1. Simplified block diagram for monostatic Doppler radar unit, showing oscillator, antenna, and single mixer followed by baseband band-pass filter.

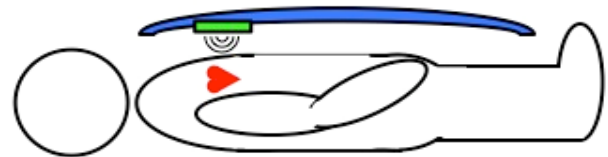


Fig. 2. Illustration of design concept showing relative position of patient's heart and Doppler sensor module. In this example, the Doppler radar unit is embedded in blanket.

deployment, an additional practical consideration is system cost.

Within this application field, the traditional approaches to heart monitoring include electrocardiograms (ECG) [6]-[7] and photoplethysmography (PPG) [8]-[9]. While these sensors can be made small and portable, they require either electrical contact to a person's skin (in the case of ECG) or optical access to certain portions of perfused skin (in the case of PPG). These limitations may be significant in emergency situations where the working environment can be quite dirty or in cases where the patient's body itself may be injured.

In this paper, we explore a relatively new alternative to mobile ECG and PPG based on Doppler radar heart monitoring, which is less invasive than ECG or PPG. In addition, we explore additional integration techniques and microstrip circuit design which enable this sensor to be integrated into clothing garments or a blanket for patient care.

## II. DESIGN CONCEPT

Doppler radar for vital sign monitoring is fairly well-known [10]-[16]. The basic concept, shown in Figure 1, involves generating a microwave beam that illuminates the heart and detects the tiny Doppler shift produced by the movement of the beating heart. Many published designs, however, make use of laboratory-grade microwave equipment and antennas which are not portable or very small. In addition, most Doppler radar systems designed for this purpose are intended for detecting a beating heart at a distance of 1 meter or more.

Our design concept is to create a Doppler radar unit that can be placed directly on top of the human body (through clothing) and used as a wearable sensor. This is illustrated in Figure 2. Although the electromagnetic interactions are quasi-near-field in nature due to the short operating distance, a reflected wave is still produced at the air-body interface and the detection circuitry can be the same as for far-field Doppler detection.

The primary advantages of this design are the following:

- 1) Non-contact – the Doppler unit can be completely sealed in a waterproof pouch or epoxy and does not require optical access to the human body. The unit can also be embedded in a shirt, worn as a pendant around the neck, or embedded in a chair or mattress. There is also no need for electrodes or wires.
- 2) Motion artifact reduction – In ECG and PPG sensors, there exist motion artifacts due to the motion of the sensors on the body. Doppler radar units also suffer from problems of relative motion between the radar unit and the human body [17]. However, in this case, if the unit is resting against the body (in a shirt, bra, blanket, chair back or bed mattress) the motion artifacts can be greatly reduced.

## III. IMPLEMENTATION

A photograph of the completed Doppler radar unit is shown in Figure 2. Each subsystem is described below.

### A. Microwave oscillator

A 2.45 GHz microwave oscillator was implemented using a single transistor (NTE65) oscillator circuit employing a microstrip resonator.

### B. Microstrip Transformer

The microwave signal was coupled to the antenna using a microstrip coupled line transformer. This served to electrically isolate the oscillator circuit and also impedance match to the antenna.

### C. Microstrip Patch Antenna

An edge-fed microstrip antenna was designed using Ansoft HFSS v11 software and designed for standard FR4 dielectric with  $\epsilon = 4.2$ . The completed antenna has a measured return loss of approx  $-18$  dBm and directional gain of approx 4 dBi. With a half-power beamwidth of approximately 60 degrees.

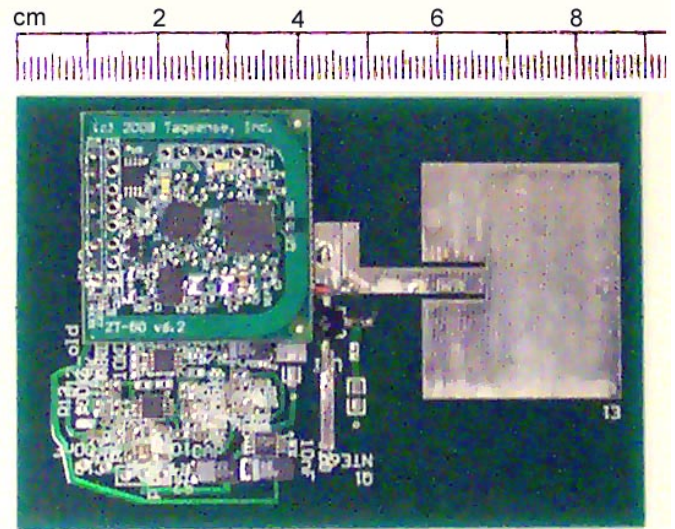


Fig. 3. Component side of Doppler radar unit showing integrated microwave circuit, patch antenna, filter, digital processing, and radio module used for wireless data transmission.

### D. Mixer

In order to minimize cost, a simple diode mixer was used (part #Avago 5082-2835). Since the distance between the antenna and the target is fixed, quadrature detection was not necessary. The phase could be tuned and optimized simply by varying the connection point of the diode along the microstrip line.

### E. Gain and Level shifting

In order to improve the AC gain and remove the DC offset due to LO leakage and amplifier offset, an instrumentation amplifier with gain = 30 dBm was used. For longer-range detection, a differential subtraction could be made using a dual radar front end [18]; however, in this case, a simple potentiometer was used to set the DC offset to be subtracted from the primary signal.

### F. Low-pass filter

The baseband filter section consisted of two 6-pole elliptic filter sections with zeros at 50 Hz and 60 Hz and a corner frequency of 100 Hz.

### G. Microcontroller

An 8-bit microcontroller (ATMEGA328P) with 10-bit ADC was used to digitize the signal and perform minimal processing.

### H. Wireless Link

A commercial 2.48 GHz radio link (TagSense ZT-Link) was used to relay the data wirelessly to nearby radio base station. The data transport protocol is based on IEEE 802.15.4 physical layer protocol compatible with low-power operations and ad-hoc wireless sensor networks.

### I. Battery

The power consumption of the Doppler unit was less than 30 mA. The radio module required an additional 30 mA when transmitting a data packet. A 6V Lithium battery was used (2CR-1/3N-cell) which is relatively small but able to source enough current for the microwave oscillator and the radio module. The total power consumption could be reduced further by only taking a measurement at periodic intervals.

The total parts cost of the Doppler radar unit was approximately US\$25, which includes the price of the printed circuit board, but does not include the cost of the radio data link (~US\$35.).

## IV. RESULTS AND DISCUSSION

For testing, human subjects were asked to lie down on the floor and the small Doppler unit was placed on their chest over their clothing. Figure 4 shows sample raw data from the Doppler unit before digitization. For validation, a commercial FDA approved PPG device (FlexComp) [19] was also used to confirm the heart rate measurements.

As shown in Figure 4 (bottom), mechanical activity of the heart (as measured by near-field Doppler) contains clear substructure analogous to the PQRST complex used in describing ECG signals. This demonstrates that the Doppler radar detection methods have promising potential for use as a non-invasive tool for diagnostic cardiology in addition to simple vital sign detection.

As compared to measurements taken at longer distances [18], the baseline variation due to breathing was greatly suppressed in the current wearable version. However, one minor surprise was that the signal from the heart at 1-2 cm

was only moderately larger than that detected by a similar system at a distance of 0.5-1 meter. We suspect the small gain and small aperture size of the antenna in the miniature Doppler unit was one factor contributing to the smaller than expected signal. In addition, the miniature Doppler unit was manufactured on FR4 substrate material which also contributes to lower antenna efficiency and lower Q-factor (and worst phase noise) for the microwave oscillator. Nevertheless, the miniature Doppler unit still produces a very usable signal with very good signal to noise.

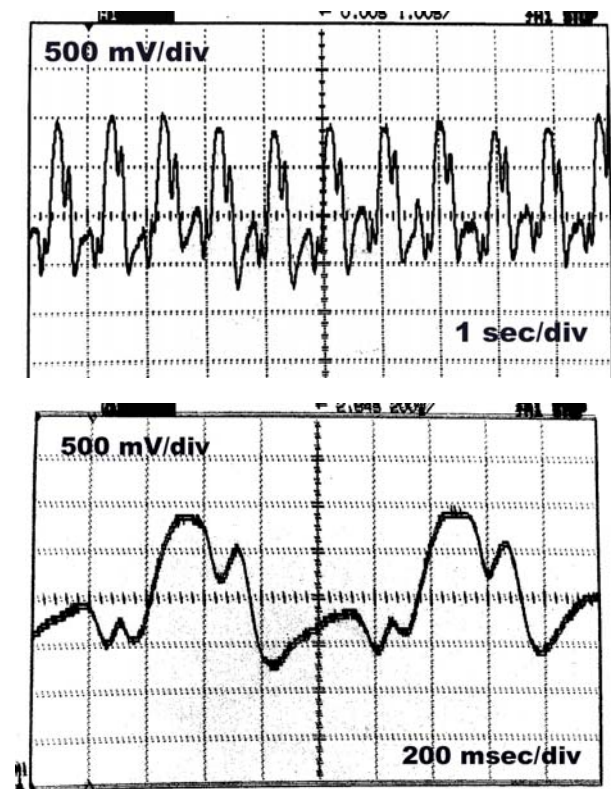


Fig. 4. Sample raw data waveform from Doppler unit before digitization (top). A closeup of the waveform reveals PQRST-like substructure (bottom).

## VI. CONCLUSIONS

We have demonstrated the feasibility and construction of a small low-cost wearable Doppler radar unit for the purpose of mobile and portable patient monitoring. While the initial goal of this project was simply to detect heart rate, the clear substructure in the measured data indicates that this sensor design may also be a potential tool for medical diagnostics and cardiology in situations where ECG measurements are not practical, not available, or too invasive.

In the short-term future, small embedded Doppler radars such as these can be of value to specialized applications in security and disaster relief. However, by embedding similar low-cost sensor technologies into clothing, blankets, beds, chairs, and everyday living spaces, it may someday be possible to realize the vision of ubiquitous computing and ubiquitous health monitoring.

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