A Compact Low-Cost Add-On Module for Doppler Radar Sensing of Vital Signs Using a Wireless Communications Terminal

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***Abstract* — A simple add-on module that allows the detection of human respiration and heart activity using an unmodified wireless telecommunications terminal is presented here. The module combines an antenna and mixing element to receive direct and back-scattered transmissions from the wireless terminal, and through Doppler radar principles produces an output signal proportional to the motion of the user's heart and chest. This signal can be used to monitor heart and respiration rates, and can potentially be relayed by the wireless terminal to a remote health monitoring facility via the existing telecommunications infrastructure. Module functionality is demonstrated here using a 2.4 GHz cordless telephone.**

I. INTRODUCTION

As healthcare systems adapt to accommodate the now predominant and still growing needs of patients suffering from chronic illness [1], new technologies are being sought to facilitate outpatient health monitoring. A wide range of appliances have been developed which allow patients and healthcare personnel to measure various patient vital signs in the patients home and relay them to a physician or monitoring facility via a telecommunications link [2,3]. While this approach shows great promise, issues including availability, affordability, and patient interaction remain determining factors in its wide spread acceptance and use. A system that adequately deals with these issues would not only simplify matters for those seeking medical assistance, but could make possible more widespread usage for early problem detection and general wellness monitoring of those considered healthy.

Research indicates that a limited scope of human vital signs monitoring may be possible using only the existing telecommunications infrastructure [4]. A telecommunications terminal with an RF transceiver and network connection can potentially provide both a means for the detection of heart and respiration activity and a channel for remote facility monitoring. By using Doppler radar techniques to analyze the transmissions from these devices as they backscatter from the body of the user, the motion of the user's heart, lungs, and chest can be detected and used to determine heart and respiration rates and patterns. Although laboratory demonstrations of the use of Doppler radar for cardiovascular and respiratory measurements were first reported in the late 1970's and early 1980's [5-7], the current proliferation of suitable inexpensive radio based appliances now gives this technique great potential for widespread monitoring applications. Additionally, these telecommunications terminals have the capacity to transmit voice or other data to most any remote facility in a standardized manner, and should be able to accommodate the transmission of the simple low frequency data required for human vital signs.

An inexpensive add-on module for Doppler radar sensing of human respiration and heart activity with a telecommunications terminal is presented here. The compact module consists of an antenna-diode combination that was originally developed as part of a low-cost electronic price label [8]. Functionality of the module is demonstrated using an ordinary 2.4 GHz cordless telephone.

II. CONCEPT

While the necessary elements for Doppler radar sensing are present in many telecommunications terminals, some degree of hardware or software modification would be required for the terminals to actually perform this function [4]. Although modified terminals or dedicated remote-sensing radios could still benefit greatly just from leveraging existing design and production technologies [9], the additional necessary steps present a barrier for the introduction of this new form of health monitoring. Alternatively, the technique described here shows that it is possible to combine an unmodified telecommunications terminal with an inexpensive supplemental module that can perform the Doppler radar function using the terminal's normal RF transmission, and potentially transmit the data using the terminal's existing network connection.

By the Doppler effect, a radio wave reflected at a moving surface undergoes a frequency shift proportional to the surface velocity. If the surface has periodic motion, like that of the heart and chest, this can also be seen as a phase shift proportional to the surface displacement [9]. If the displacement is small compared to the wavelength, a circuit that couples both the transmitted and reflected

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signals to a mixing element can produce an output signal with a low frequency component that is directly proportional to the object displacement.

A circuit of this type can be realized using a resonant antenna combined with a non-linear device in a technique similar to that used in high frequency quasi-optical radiometers [10]. As illustrated in Fig. 1, when the module is placed in proximity with the transmitting terminal, the antenna couples both the transmitted LO signal ($f(\omega t)$) and the body-reflected phase modulated RF signal ($f'(\omega t+\phi(t))$) to the non-linear device. The device mixes the signals to produce the desired phase demodulated output. In this case the output is a low-frequency (less than 100 Hz) amplitude modulated signal that could potentially be routed with some degree of conditioning $g(\phi(t))$, to the terminal for transmission via the normal voice or data channel. The entire supplemental module could be similar in cost and complexity to a wireless phone hands-free headset.

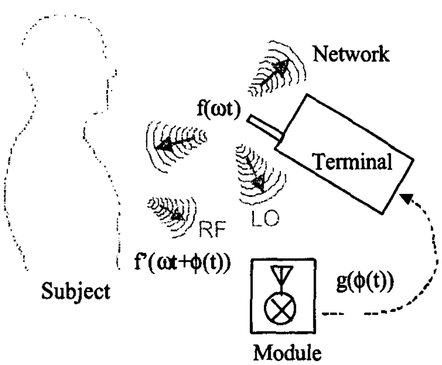

Fig. 1. Vital sign remote monitoring system. A simple module receives both direct (LO) and body-scattered (RF) signals to produce a Doppler radar signal proportional to the motion of the subject's chest and heart.

III. Experiment

A supplemental module created using circuitry from a previously developed low-cost RF electronic price label transponder [8] was used to demonstrate this principle. The label, shown in Fig. 2(a), contained an inverted-F type antenna combined with a Schottky diode. The entire label was approximately four inches wide, one inch tall, one-half inch deep, and cost less than one dollar. The antenna and diode occupied about one inch of the label width. The terminals for the antenna-diode combination were isolated from the rest of the price label circuitry (Fig. 2 (b)) and routed through a chain of Stanford Research System SR560 Low Noise Amplifiers to a Tektronix TDS3012 digitizing oscilloscope. The module was placed a few centimeters away from a radiating Antenna Specialists ASPT2976 omni-directional antenna (8 dBi) connected to an HP 83640B 2.4 GHz, 0 dBm source, facing a human subject seated about a one-half meter away. All measurements were made in an anechoic chamber.

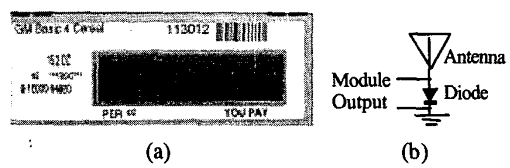

Fig. 2. Electronic price label (a) and portion of label circuitry used as the Doppler radar receiver (b) [8]. The price label is approximately 4 in. wide x 1 in. tall x ½ in. deep, and the antenna diode combination occupies only one inch of the width.

The module output amplified by a factor of 1000 is shown in Fig 3. The top trace is the basic signal, subjected to 12 dB/octave high-pass filtering at 0.03Hz to remove DC offset, and 12 dB/octave low-pass filtering at 3 Hz to avoid aliasing error. Both the respiration and heart activity for the subject can be seen qualitatively in this trace, the former having larger amplitude and a frequency less than one Hertz, and the latter superimposed with a frequency greater than one Hertz. The heart signal was further isolated with an additional 12 dB/octave high-pass filter at 1 Hz, with an additional gain of 2, as shown in the middle trace. The lower trace shows the response from a UFI-1010 pressure-pulse sensor on the subject's finger, for comparison. A correspondence between the radar derived heart rate and that of the reference is clearly visible at about 84 beats/minute. Respiration rate from the signals is about 13 breaths/minute.

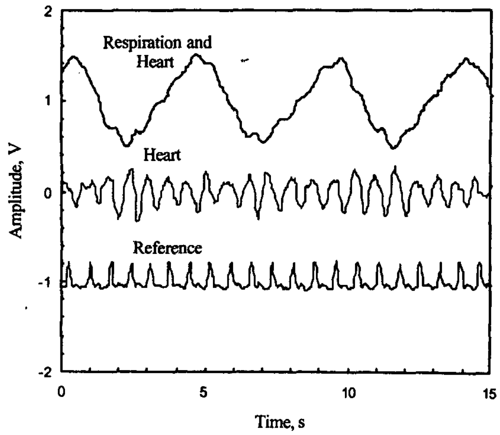

Fig. 3. Measured module response using a 2.4 GHz signal generator. The upper trace varies slowly with respiration motion (~ 0.2 Hz) with some heart related response is evident. The high-pass filtered middle trace clearly varies with heart activity, at the same rate as the lower reference-pulse trace (~ 1.4 Hz)

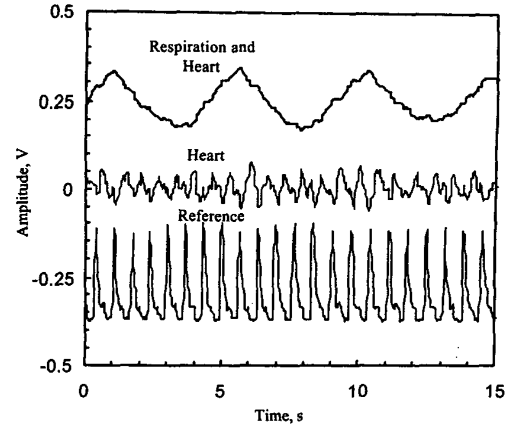

Fig. 4. Measured module response using a 2.4 GHz cordless telephone handset. The upper trace clearly shows respiration related motion (~ 0.2 Hz), and the fundamental frequency of the high-pass filtered middle trace varies at the same rate as the lower reference-pulse trace (~ 1.5 Hz), indicating heart activity.

A similar measurement was made using an unmodified Casio 2.4 GHz analog cordless telephone handset as the radar source. The measured output of the module amplified by a factor of 10,000 is shown in Fig. 4. The output is substantially weaker in this case, but the heart and respiration rates are still clearly visible, and correspond accurately to the reference measurement. Reliable automated extraction of such rate data from similar signals has been demonstrated using DSP techniques. Analog filters can be replaced with digital filters, to better separate the heart and respiration signals and auto-correlation techniques can be used to identify and track rates [11].

IV. Discussion

The experiments described here involve commonly encountered communications signals and appliances along with only simple and basic radio techniques, yet they indicate potential for a powerful means for widespread health monitoring. The type and quality of heart and respiration data obtained in these experiments are adequate for determining basic rate information, and possibly suitable for some form of signature diagnostics. Heart rate variability alone has recently been recognized as a powerful diagnostic and prognostic tool for a variety of health conditions [12, 13], and a correspondence between respiration patterns and emotional and mental state has been recognized for many years [14, 15].

While this experiment demonstrates that a potentially useful set of human vital signs can be determined through the analysis of common backscattered radio waves, there are various additional issues that must be resolved to realize a practical monitoring system. First, different wireless communications terminals have their own unique operating characteristics with regard to transmit power level, base station interplay, voice/data channel constraints, and likely operational position and environment. While generally functional, the cordless telephone system used here would require that the user be seated or lying in the vicinity of the handset (or base unit), or carrying the handset. Other terminals, such as a wireless mobile telephone could potentially provide greater mobility. There also remains the issue of isolating the subject to be monitored from the environment. This includes not only the undesired detection of extraneous reflections, or clutter, but also the detection of the subject's own motion not associated with the vital signs of interest. To some extent such problems can be resolved through digital signal processing techniques, but the process remains a challenge [11].

V. Conclusion

A means for remotely monitoring heart and respiration activity of human subjects using common telecommunications signals and terminals has been demonstrated. A simple module consisting of an antenna-diode combination was used to receive direct and back-scattered transmissions from a cordless telephone handset, and produce a Doppler radar signal proportional to the motion of the user's heart and chest. Realized as an inexpensive accessory that plugs into the telephone headset jack, the compact module could potentially be used to send heart and respiration data to a remote health monitoring facility through the existing telecommunications infrastructure.

ACKNOWLEDGEMENT

The authors wish to acknowledge J. Housel, C. Tran, T. Sizer, II, and L. Manzione of Lucent Technologies, Murray Hill, NJ, and J. Lin of the University of Illinois, Chicago for their assistance. The work described was supported in full by Lucent Technologies.

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