An X-Band Microwave Life-Detection System

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Abstract—**An X-band microwave life-detection system has been developed for detecting the heartbeat and breathing of human subjects lying on the ground at a distance of about 30 m or located behind a cinder block wall. The basic principle of the system is to illuminate the subject with a low-intensity microwave beam, and then from the backscattered microwave signal, extract the heart and breathing signals that modulate it. The circuit description of the system and some experimental results are presented. Potential applications of the system are noted.**

I. Introduction

There are needs for remotely observing the physiological status of wounded subjects lying on the ground at a distance or for detecting the vital signs of human subjects located behind barriers. This can be done with microwave radiation as follows. We illuminate the subject with a low-intensity microwave beam. The small amplitude body vibrations due to heartbeat and breathing of the human subject will modulate the backscattered wave, producing a signal from which information of the heart and breathing rates can be extracted using phase detection in the microwave receiving system.

This technique has been used by several workers [1]–[3] for similar purposes. However, those experiments were limited to short distances, less than 1 m. In this paper, we report the circuit description and performance of an X-band microwave life-detection system that can be used to detect the heartbeat and breathing of human subjects lying on the ground at a distance of 30 m or farther or sitting behind a cinder block wall over 3 m away.

This system may be useful for locating persons trapped behind rubble or barriers or it may find medical applications such as the remote monitoring of the breathing and heartbeat of a patient in a clinic.

II. Theoretical Background

In order to study the behavior of the backscattered field from a human body illuminated by plane electromagnetic waves, we simplify the problem by modeling the body as a sphere of complex permittivity. The solution of this simplified problem is well known [4]. Using the coordinate system shown in Fig. 1, the expression for the backscattered electric field may be constructed as

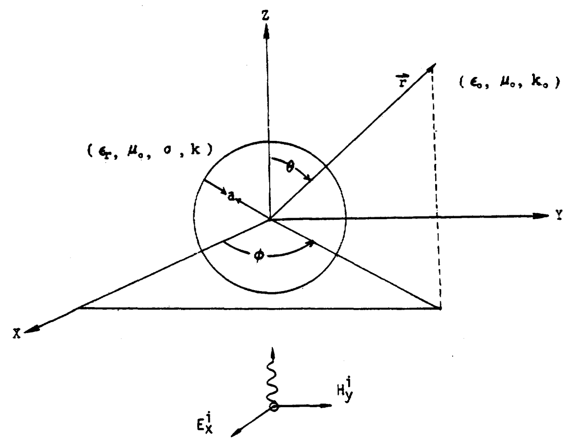

Fig. 1. Coordinate system for the spherical model.

$$\vec{E}_{BS} = \hat{x}\frac{-E_0}{2k_0 r}\sum_{n=1}^{\infty} j^n(2n+1) \cdot [-d_n \hat{H}_n^{(2)}(k_0 r) + j e_n \hat{H}_n^{(2)\prime}(k_0 r)] \tag{1}$$

where

$$d_n = \frac{\sqrt{\epsilon_r}\,\hat{J}_n'(ka)\,\hat{J}_n(k_0 a) - \hat{J}_n'(k_0 a)\,\hat{J}_n(ka)}{\hat{H}_n^{(2)\prime}(k_0 a)\,\hat{J}_n(ka) - \sqrt{\epsilon_r}\,\hat{J}_n'(ka)\,\hat{H}_n^{(2)}(k_0 a)} \tag{2}$$

$$e_n = \frac{\hat{J}_n(k_0 a)\,\hat{J}_n'(ka) - \sqrt{\epsilon_r}\,\hat{J}_n'(k_0 a)\,\hat{J}_n(ka)}{\sqrt{\epsilon_r}\,\hat{H}_n^{(2)\prime}(k_0 a)\,\hat{J}_n(ka) - \hat{H}_n^{(2)}(k_0 a)\,\hat{J}_n'(ka)} \tag{3}$$

$$\hat{J}_n(x) = \sqrt{\frac{\pi x}{2}}\,J_{n+1/2}(x) \tag{4}$$

$$\hat{H}_n^{(2)}(x) = \sqrt{\frac{\pi x}{2}}\,H_{n+1/2}^{(2)}(x). \tag{5}$$

ϵ_r is the complex permittivity of the sphere, a is its radius, k and k_0 represent wavenumbers inside and outside the sphere, respectively, and usual notations for Bessel functions and their derivatives are employed. E_0 is the amplitude of the incident plane wave and $\hat{x}$ represents the unit vector along the x axis.

The phase and the square of the magnitude of the back-

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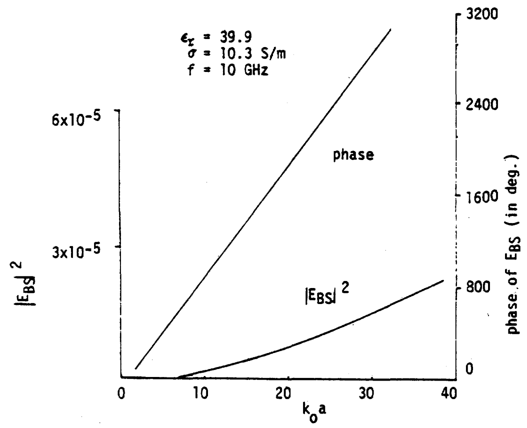

Fig. 2. Phase and magnitude squared of the backscattered field E_{BS} from a sphere as a function of $k_0 a$ at 10 GHz at a distance of 30.48 m.

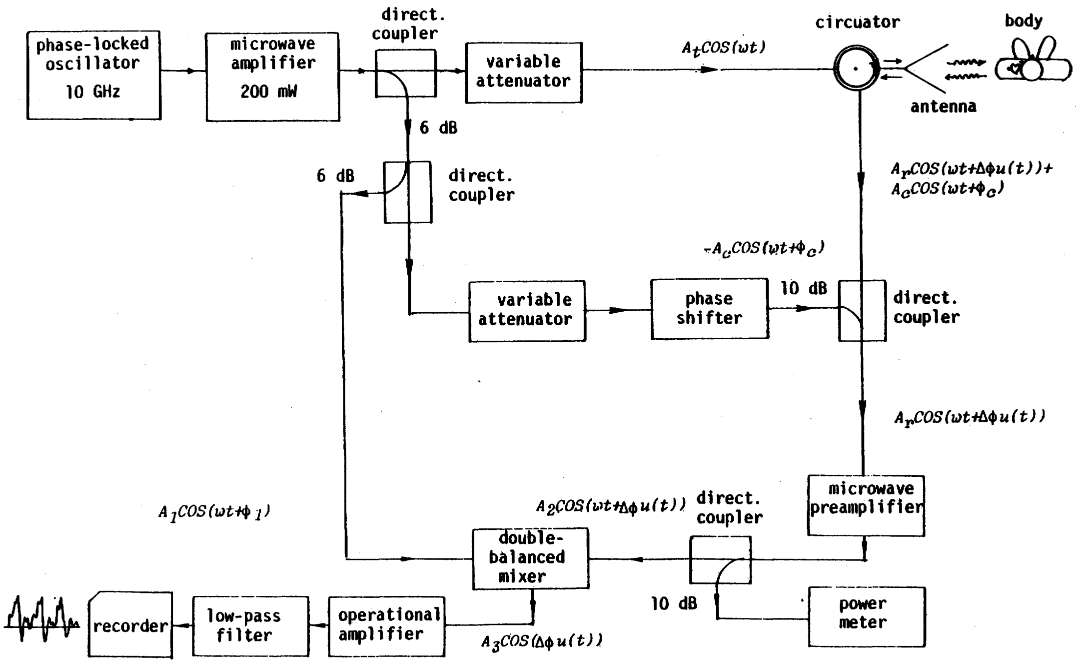

Fig. 3. Circuit diagram of the distance life-detection system.

scattered electric field $\vec{E}_{BS}$ from a sphere of relative permittivity 39.9 and conductivity 10.3 s/m are depicted in Fig. 2 as functions of the radius multiplied by the wavenumber k_0 of the medium. The frequency of the microwave radiation is assumed to be 10 GHz, and the sphere is situated 30.48 m (100 ft) from the transceiver. Breathing and heartbeat produce small vibrations of the spherical surface due to changes in its radius. From Fig. 2, we conclude that these vibrations will produce a linear change in the phase and a relatively smaller linear change in the amplitude squared of the backscattered field. Similar results were obtained when the body was modeled as an infinitely long cylinder [5] of complex permittivity, illuminated by a TM-polarized plane electromagnetic wave.

These simplified models show that there will be, in general, amplitude as well as phase modulation of the incident wave as it is backscattered by the body. However, since the phase variation is more linear and it is easier to detect the phase variation from the viewpoint of the signal/noise ratio, we used the phase modulation of the backscattered wave to find the vibrations of the body surface caused by the heartbeat and breathing.

III. Description of the System

The schematic diagram of the X-band life-detection system is shown in Fig. 3. A phase-locked oscillator at 10 GHz produces a stable output of about 20 mW. This output is amplified by a low-noise microwave amplifier to a power level of about 200 mW. The output of the amplifier is fed through a 6 dB directional coupler, a variable attenuator, a circulator, and then to a horn antenna. The 6 dB directional coupler branches out $\frac{1}{4}$ of the amplifier output to provide a reference signal for clutter cancellation and another reference signal for the mixer. The variable attenuator controls the power level of the microwave signal to be radiated by the antenna. Usually, the radiated power is kept at a level of about 10–20 mW. The horn antenna radiates a microwave beam of about 15° beamwidth aimed at the human subjects lying on the ground. The signal received by the antenna consists of a large clutter and a weak return signal scattered from the body. The large clutter signal is cancelled by a reference signal, the amplitude and phase of which are adjusted by a variable attenuator and a phase shifter, in a 10 dB directional coupler. After this clutter cancellation, the output of the 10 dB directional coupler contains mainly the weak scattered signal from the body. This body-scattered signal is a 10 GHz CW microwave signal modulated by the breathing and the heartbeat. This signal is then amplified by a low-noise microwave preamplifier (30 dB) and then mixed with another reference signal in a double-balanced mixer. Between the microwave preamplifier and the double-balanced mixer, a 10 dB directional coupler is inserted to take out a small portion of the amplifier signal for monitoring its intensity. This monitoring is mainly for checking how well the clutter is cancelled. The mixing of the amplified, body-scattered signal and a reference signal (7–10 mW) in the double-balanced mixer produces low-frequency signals resulting from motion due to breathing and heart motion within the body. This output from the mixer is amplified by an operational amplifier and then passed through a low-pass filter (4 Hz cutoff) before reaching a recorder.

IV. Measured Heart and Breathing Signals

Recordings of the heart and breathing signals of several persons were taken under different conditions. However, only a few of them are presented here for illustration [5], [6]. Fig. 4 shows the measured heart and breathing signals of a human subject lying on the ground at a distance of 30 m with a 4.5 mW, 10 GHz microwave beam aimed at him. The top graph in Fig. 4 shows the breathing signal superimposed upon the heart signal when the human subject was lying on the ground in a face-up position with the body perpendicular to the microwave beam. The middle graph in Fig. 4 shows only the heart signal when the subject was holding his breath. The bottom graph in Fig. 4 shows the background noise. The results of Fig. 4 indicate satisfactory performance of the system in detecting the heart and breathing signals of human subjects lying on the ground at a distance of 30 m or farther. However, the system performance will deteriorate if a large time-varying clutter created by moving trees and bushes is present.

We have also studied the effect of clothing on the system performance by repeating the experiment with different clothing on the subject, e.g., up to four layers of very thick jackets. The effect of the clothing over the sensitivity of the system was found to be insignificant. Furthermore, the polarization effect of the microwave signal on the system performance was also investigated. When circular, linear–vertical, and linear–horizontal polarization were employed, the system sensitivity was found to be of the same order in all three cases.

Fig. 5 shows the measured heart and breathing signals

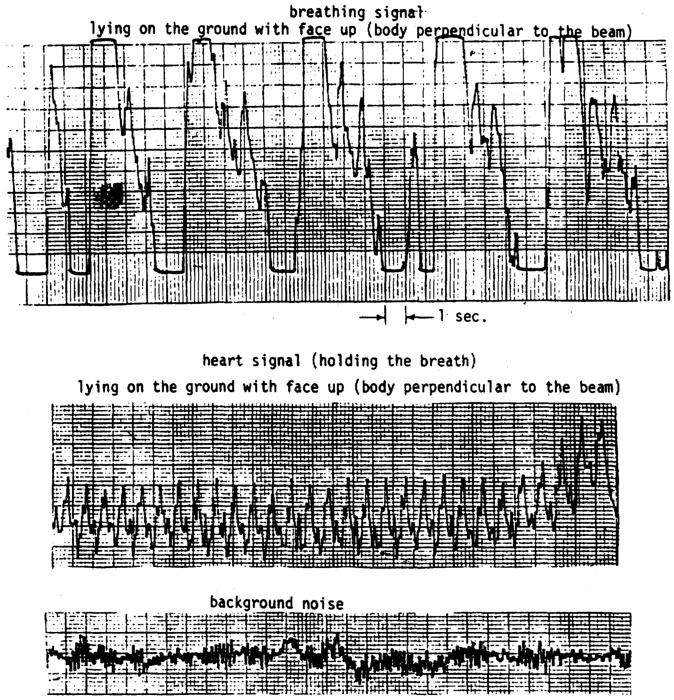

Fig. 4. Heart and breathing signals of a human subject lying on the ground at a distance of 30 m measured with a 4.5 mW, 10 GHz microwave beam.

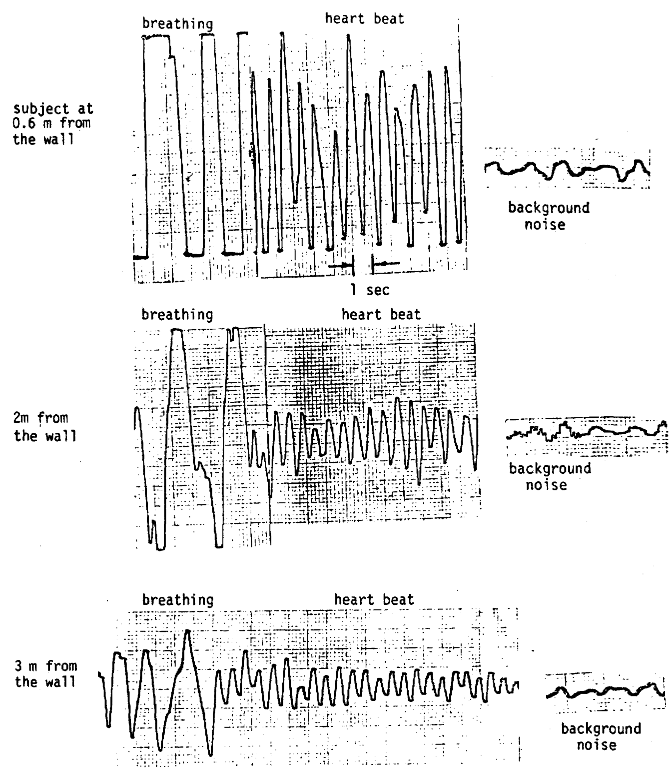

Fig. 5. Measured breathing and heart signals from a human subject sitting behind a cinder block wall (15.24 cm thick) at various distances. The antenna of the life-detection system was located on the other side of the wall and it radiated a power of about 20 mW at 10 GHz.

of a human subject sitting behind a dry 15.24 cm (6 in) cinder block wall at a distance of 0.6, 2, or 3 m. The antenna was placed close to the other side of the wall and energized to radiate 20 mW at 10 GHz. It is observed

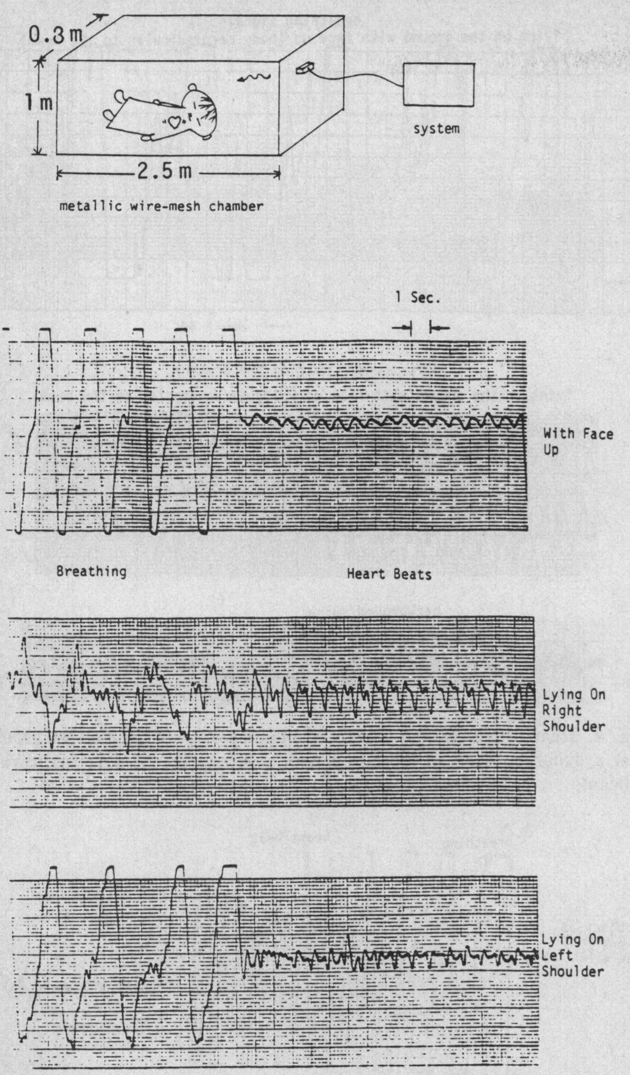

Fig. 6. Breathing and heartbeats recorded for a person lying inside a metallic wire-mesh chamber with dimensions 2.5 × 1 × 0.8 m. The body was parallel to the radiation beam, with the head away from the antenna. Transmitted power was about 100 μW.

from Fig. 5 that the heart and breathing signals were clearly detected at all three distances. The background noise in each case is also shown in the figure. The results of Fig. 5 indicate that the microwave beam can penetrate the wall and a satisfactory detection of the heart and breathing signals of human subjects behind the wall is possible. We have repeated the experiment by moving both the system and the human subject away from the wall. It was found that the system could perform satisfactorily even when the human subject was 5 m away from the wall while the antenna on the other side was about 3 m from the wall. If the antenna was moved further from the wall, system performance was affected by movement of the system operator.

This life-detection system can be easily modified to produce a device for monitoring the breathing and heartbeat of a patient in a clinic. To conduct such an experiment, a metallic wire-mesh chamber with the dimensions of 2.5 × 1 × 0.8 m was constructed as shown in Fig. 6. The antenna of the system was replaced by an open-ended waveguide which was mounted on a wall of the chamber. A microwave signal of 100 μW at 10 GHz was radiated into the chamber through the waveguide. A human subject was lying inside the chamber in various positions, face up, or lying on his right or left shoulder. The measured heart and breathing signals of the subject lying in these three positions are shown in Fig. 6. It is observed that a clear detection of the heart and breathing signals can be achieved. It is noted that since the microwave field is confined inside a metallic chamber and the environmental noise is minimal, only very low power microwave radiation is needed for this purpose.

The experimental results of Fig. 6 may suggest potential applications of the system, such as detection of human subjects hiding inside a vehicle without searching the interior of the vehicle.

V. Discussion

In this paper, we have described the circuit and performance of an *X*-band microwave life-detection system that can be used to detect the heartbeat and breathing of human subjects lying on the ground at a distance of 30 m or farther or sitting behind a cinder block wall at a distance of about 3 m. The system can also be used for noninvasive, remote monitoring of the breathing and heartbeat of a patient in a clinic. Other potential applications for the system are also noted.

The performance of the system can be severely hampered if a large time-varying clutter, as that which would be created by moving trees and bushes or other moving objects, is present. To solve this problem, a high-gain antenna for providing a sharp microwave beam and an appropriate signal processing scheme such as adaptive noise cancellation scheme should be implemented.

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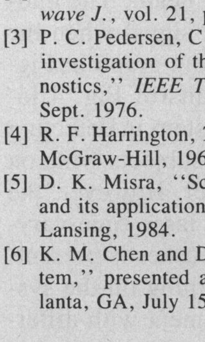

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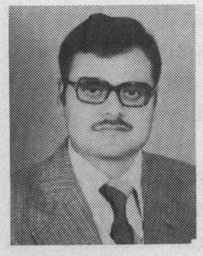

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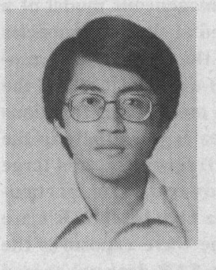

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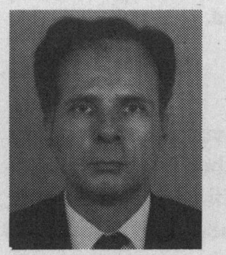

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