Automatic Clutter-Canceler for Microwave Life-Detection Systems

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Abstract—**A microprocessor-controlled automatic clutter-cancellation subsystem, consisting of a programmable microwave attenuator and a programmable microwave phase-shifter controlled by a microprocessor-based control unit, has been developed for a microwave life-detection system (L-band 2 GHz or X-band 10 GHz) which can remotely sense breathing and heartbeat movements of living subjects. This automatic clutter-cancellation subsystem has drastically improved a very slow process of manual clutter-cancellation adjustment in our previous microwave system. This is very important for some potential applications including location of earthquake or avalanche-trapped victims through rubble. A series of experiments have been conducted to demonstrate the applicability of this microwave life-detection system for rescue purposes. The automatic clutter-canceler may also have a potential application in some CW radar systems.**

I. Introduction

RECENTLY a microwave life-detection system (L-band 2 GHz or X-band 10 GHz) has been developed [1]–[2] to remotely detect the breathing and heartbeat signals of human subjects lying on the ground at a 100-ft distance, or located behind a barrier wall. The basic principle of the system is to illuminate the human subject with a low-intensity microwave beam so that the small amplitude body-vibrations due to the breathing and heartbeat of the human subject will modulate the backscattered microwave signal. The breathing and heartbeat signals can be extracted from this backscattered signal by phase-detection in the microwave receiving system.

A potential application of this system is to locate living human subjects buried in rubble after an earthquake or avalanche by remotely detecting breath and heartbeat movements through the barrier (Fig. 1). In order to maintain a high sensitivity for this application, the clutter wave reflected from the rubble or the surface of the ground has to be cancelled as thoroughly as possible before it reaches and saturates the receiving microwave amplifier. In our previous system, the clutter cancellation was performed by a very slow manual-adjustment process. This is not practical for a real-world emergency rescue operation which demands a fast process. In this paper, we present a newly developed automatic clutter-cancellation subsystem using a microprocessor-based control unit designed to control a programmable microwave attenuator and a programmable microwave phase-shifter for performing the real-time automatic clutter-cancellation. The basic principle of this subsystem is to use the microprocessor-based control unit to scan the attenuator and phase-shifter to minimize the input signal to the microwave amplifier and hence cancel the clutter component.

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RESCUE

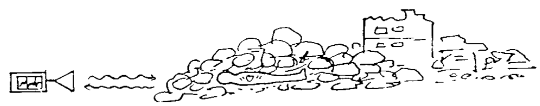

Fig. 1. Rescue application of the microwave life-detection system.

A series of experiments has been conducted to measure the breathing and heart signals of a human subject through a layered pile of bricks simulating rubble. It was found that the performance of the X-band (10 GHz) system became marginal when the brick structure exceeded about 1.5 ft in thickness (about 5 layers of bricks), while for the L-band (2 GHz) system it was possible to penetrate a pile of dry rubble of up to about 3 ft in thickness (about 10 layers of bricks). This suggests that a lower frequency will be more capable of detecting vital signals of living subjects through a very thick barrier.

II. Theoretic Background and Microwave System Principles

The behavior of the backscattered field from the vibrations of the body surface caused by the heartbeat and respiration when illuminated by an EM plane wave has been studied by assuming the body has the geometry of a sphere or cylinder [1]–[3]. In general, the backscattered wave from the body has both amplitude and phase modulation. Since the phase variation is more linear and more easily detected from the viewpoint of signal/noise (S/N) ratio, the phase demodulation scheme has been adopted.

The system schematics and the circuit diagram of the new system are depicted in Fig. 2. A phase-locked generator at 2 GHz (or 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, and a circulator to a

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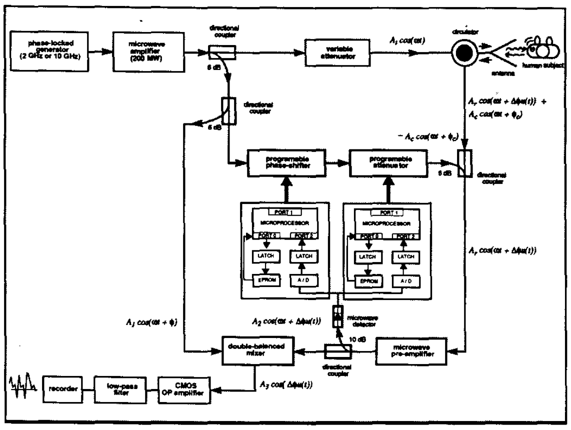

Fig. 2. Block diagram of the microprocessor-controlled microwave life-detection system.

horn antenna. The directional coupler output provides reference signals for clutter cancellation and mixer operation. The variable attenuator controls the power level to be radiated by the antenna. The radiated power is usually kept at a level of about 10–20 mW. The antenna radiates a 15° beam, which is aimed at the human subject. The signal received by the antenna consists of a large amount of clutter reflected from the background environment and a weak return signal scattered from the body. To be able to detect the weak signal modulated by the body movement, the background clutter needs to be canceled. This is accomplished by an automatic clutter-cancellation subsystem which digitally controls the phase shifter and the attenuator. The output of the 6-dB directional coupler then mainly contains the weak signal scattered from the body, and caused by the breathing and the heartbeat. It is then amplified by a low-noise microwave preamplifier (30 dB) and then mixed with the reference signal in a double-balance mixer. Between the preamplifier and the mixer, a 10-dB directional coupler provides an input to the microprocessor unit which controls the phase-shifter and attenuator. The mixer output provides the low-frequency breathing and heartbeat signals from the body. The mixer output is amplified by an operational amplifier and then passes through a low-pass filter (4-Hz cut-off) before being applied to a recorder.

III. Microprocessor-Based Control Unit for Automatic Clutter-Cancellation [4]

The schematic diagram of the microprocessor-based control unit for automatic clutter-cancellation is shown in Fig. 3. There are two identical sets of microprocessor circuits in the control unit for manipulating the programmable attenuator and phase-shifter, respectively. The circuit description of the microprocessor circuits follows.

1) A **microprocessor** is the central processor in each set.

2) **Port 0** of the microprocessor is connected to a **Latch** and an **EPROM** where the program is stored. When the microprocessor sends memory addresses from **Port 0** to the **EPROM** through the **Latch**, the **Latch** keeps address information until the **EPROM** sends memory data to the microprocessor.

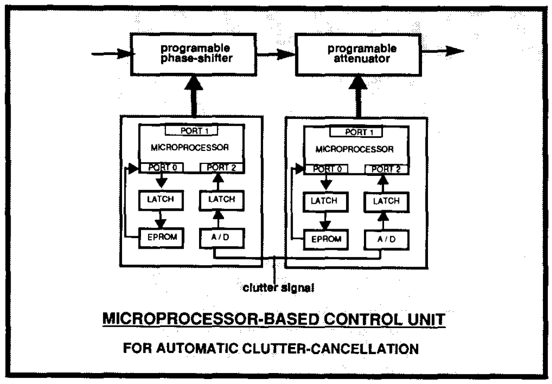

Fig. 3. Circuit diagram of the microprocessor-based control unit for automatic clutter-cancellation.

3) **Port 1** of the microprocessor is connected to the **programmable microwave phase-shifter** (or the **microwave attenuator**) in the microwave system. Through **Port 1** the microprocessor controls the phase-shifter (or the attenuator) to cancel the clutter signal automatically.

4) **Port 2** of the microprocessor and the output bus of an **A/D converter** are connected to a **Latch**. The clutter signal is sampled by the A/D converter. The **Latch** keeps the output data of the sampled clutter-signal from the A/D converter until the data are fetched to **Port 2** of the microprocessor.

The program stored in the EPROM is executed in the microprocessor to search for the optimal settings of the programmable attenuator and phase-shifter to completely cancel the clutter. The algorithm of the program scans the entire ranges of the attenuator and the phase-shifter. And then the program determines the optimal settings by detecting the minimum clutter signals sent to the microprocessor control unit. The program executing time is less than a millisecond.

IV. Experimental Setup and Measurement Results

A series of experiments were conducted with the setup depicted in Fig. 4 [5]. Various layers of New Orlean's homestead bricks were laid on a wooden frame which formed a cavity for a human subject to lie down inside. This setup simulated a human subject trapped under a thick layer of rubble. Microwave absorbers were used to line the side of this brick structure to prevent microwave scattering through the pile. The antenna was placed on the top of the structure aiming at the human subject. Fig. 5 shows the breathing and heart signals of the human subject lying face-up or face-down under four layers (13 1/2″) of dry bricks, measured by the 10-GHz system. In each recorded graph, the breathing signal, the heartbeat

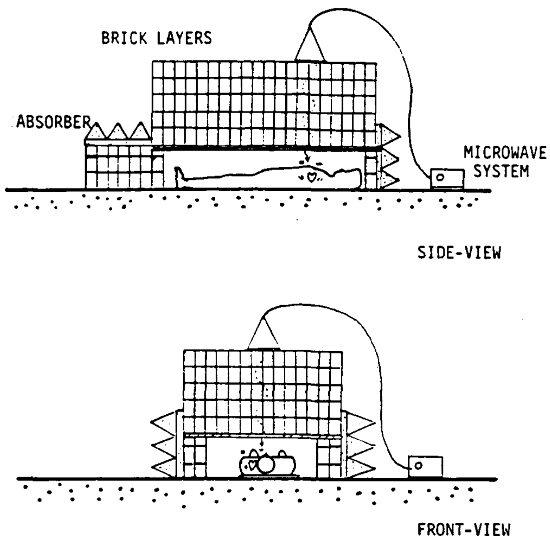

Fig. 4. Experimental step for the measurement of heart and breathing signals of a human subject under layers of bricks using the microwave life-detection system.

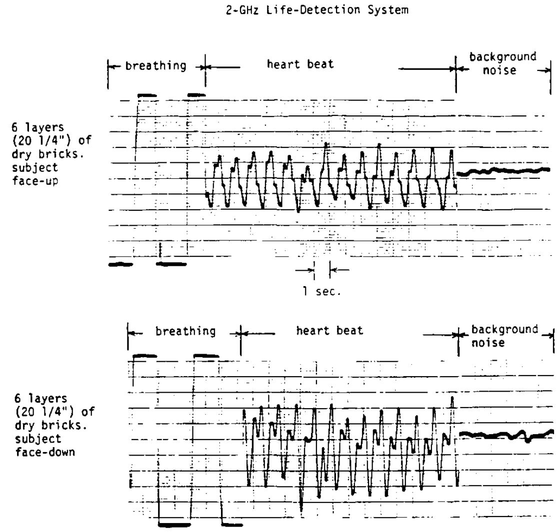

Fig. 6. Heart and breathing signals of a human subject, lying with face-up or face-down position under six layers of bricks, measured by the 2-GHz microwave life-detection system.

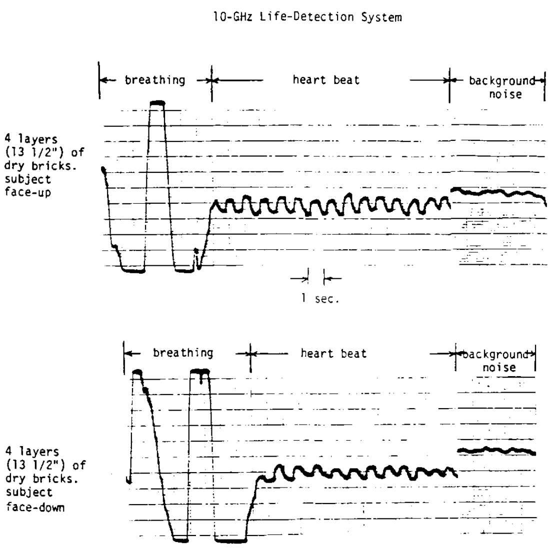

Fig. 5. Heart and breathing signals of a human subject, lying with face-up or face-down position under four layers of bricks, measured by the 10-GHz microwave life-detection system.

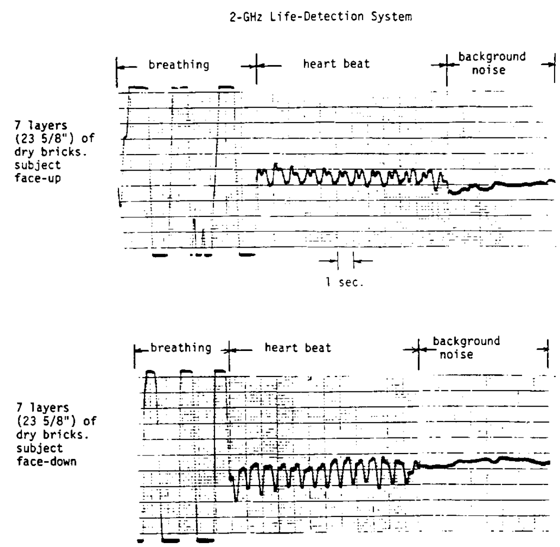

Fig. 7. Heart and breathing signals of a human subject, lying with face-up or face-down position under seven layers of bricks, measured by the 2-GHz microwave life-detection system.

signal (the subject holding his breath), and the background noise were included. Both the heartbeat and breathing signals were clearly detected for each position. When the thickness of this brick structure exceeded five layers (16 7/8″) of bricks, the performance of the 10-GHz life-detection system became marginal. Figs. 6 and 7 show the performance of the 2-GHz measured heartbeat and breathing signals of a human subject under six layers (20 1/4″) and seven layers (23 5/8″) of dry bricks, respectively. In each of these figures, the heartbeat and breathing signals are both clearly recorded. By increasing the operational amplifier gain of the system, it was found that it is easy to penetrate a pile of dry rubble of up to about 3-ft thickness with the 2-GHz system.

To test the effect of moisture on the performance of our life-detection systems, one layer of wet bricks was used to construct the brick wall. When we used wet bricks soaked in water for several hours, the performance of both systems was affected insignificantly. However, a significant effect was observed when we used very wet bricks

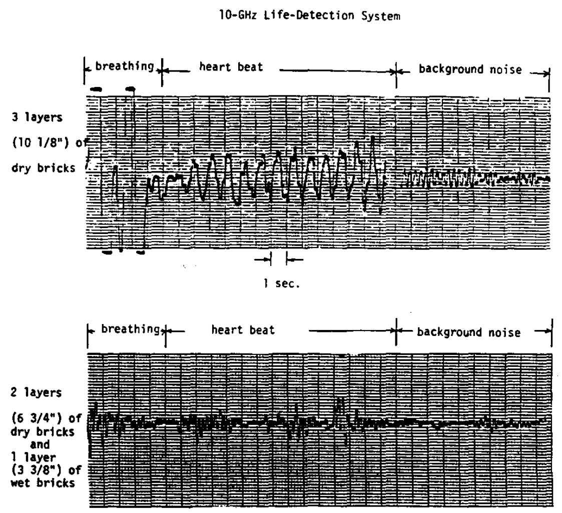

Fig. 8. Heart and breathing signals of a human subject measured through walls of dry and wet bricks with the 10-GHz microwave life-detection system. One layer of wet bricks severely hampered the penetration of the microwave beam.

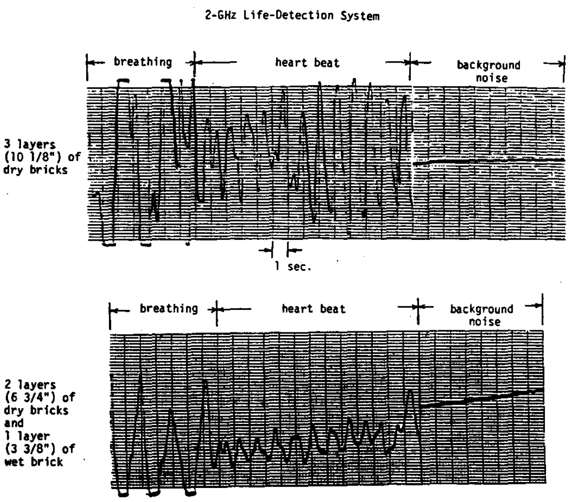

Fig. 9. Heart and breathing signals of a human subject measured through walls of dry and wet bricks with the 2-GHz microwave life-detection system. One layer of wet bricks had a considerable but not severely hampering effect on the penetration of the microwave beam.

which were soaked in water for 3 days. Figs. 8 and 9 show the breathing and heartbeat signals of a human subject measured through three layers of dry bricks and two layers of dry bricks with a layer of very wet bricks, using the 10-GHz and 2-GHz systems, respectively. It is observed that with one layer of very wet brick, the penetration of the 10-GHz microwave beam was severely hampered, but we are still able to clearly detect the heartbeat and breathing signals using the 2-GHz system, although the magnitudes of the measured signals were reduced. Therefore, it is reasonable to conclude that for the purpose of detecting vital signs of human subjects through thick layers of wet rubble, the life-detection system should be designed to operate at low frequencies, such as lower than 1-GHz.

V. Conclusion

We have developed a microprocessor-controlled automatic clutter-cancellation subsystem and a microwave life-detection system to remotely detect the breathing and heartbeat signals of living subjects through rubble or some other barrier. The operation of the system is much more flexible and faster than our previous system due to its microprocessor-controlled automatic clutter-cancelling function. The 2-GHz system performs well for remotely detecting human breathing and heartbeat siganls through a pile of rubble of up to about 3 ft thick. The penetration distance can be futher increased by using lower frequency systems (below 1-GHz). In addition to the application of this system for locating earthquake or avalanche victims, it may also have potential applications in CW radar systems, such as Underground CW Radar, in which surface-clutter cancellation is a vital function to expand the dynamic range of operation [6].

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