Microwave System for the Detection of Trapped Human Beings

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ABSTRACT

When a human body is illuminated by an electromagnetic wave, the backscattered wave is modulated by the periodical body (thoracic) movements due to heartbeat and breathing of the human target. With proper processing of this backscattered wave, it is possible to extract useful information for the heart and breathing signals that modulate it. The aim of this research project is the design and development of an X-band microwave life detection system for detecting humans trapped behind rubbles or obstacles.

Keywords : microwaves, X-band, breathing signals, life detector.

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Introduction

The aim of this research project is the design and development of an X-band microwave life detector system for detecting humans trapped behind rubbles or obstacles. Greece as a country suffering from earthquakes, tries to confront this serious problem mainly by predicting the seismic phenomena.New technological innovations are widely used and predictive methods have been greatly improved. But, in the case of seismic disasters, the main task is to seek for alive persons burried in the rubble. Their immediate detection is of vital importance, since the search regions are directly defined and so the rescue time drops to a minimum value. The importance of this problem is shown also by the fact that in certain countries especially trained dogs are used for this purpose. The use of high technology worldwide for the detection and rescue of trapped persons has been very effective with extra sensitive systems for detection of clutter and temperature emitted by human bodies, but only in certain cases, e.g. when rubble is not very huge and dense or when the body temperature is capable of stimulating electronic sensors or when the human's body odors have not yet been covered.

When a human body is illuminated by an electromagnetic wave, the backscattered wave is modulated by the periodical body (thoracic) movements due to heartbeat and breathing of the human target [1],[2]. With proper processing of this backscattered wave, it is possible extract useful information for the heart and breathing signals that modulate it.

Methods

The detection system consists of three parts. The first part is the local oscillator with a Gunn diode which produces a sinusoidal signal of 10 GHz , modulated by amplitude by the dc supply (8V). The second part is a Gunnplexer [3], a waveguide (suitable for 10 GHz frequency), which consists of a silicon point contact mixer diode (1N23WG) and a circulator. These two pieces enable the Gunnplexer to detect the (weak) reflected signal, due to breathing (or heartbeat) coming from the human detected target. This is achieved with the aid of the third part, which is a pyramidoidal horn-antenna (with a gain equal to 22.5 db - theoritically calculated and practically measured in an anechoic chamber).

The block diagram of the developped device is shown in figure 1.

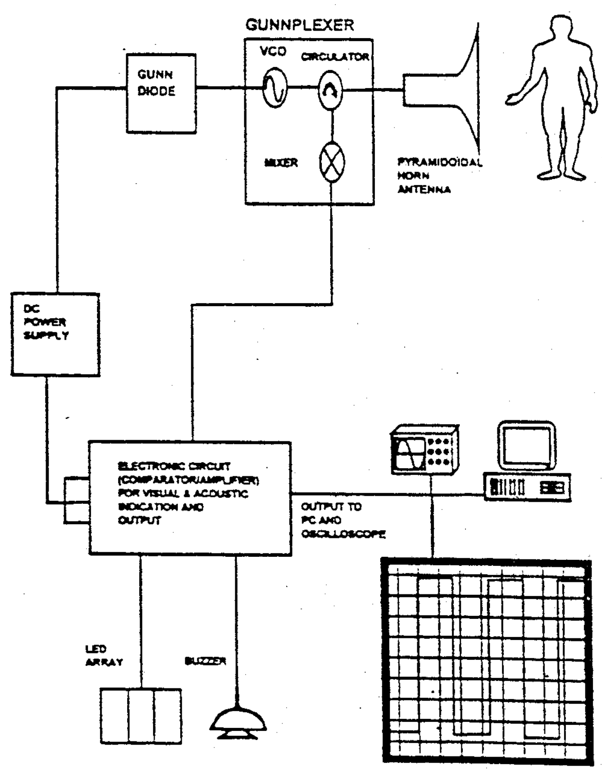

Figure 1. Block Diagram of the device.

Figure 1 illustrates the simplified circuit of the Gunnplexer using a three port circulator which is used for detecting the breathing and heart signals. The antenna is replaced by a load which offers a reflection coefficient $r_R(t)$. In general any three port network can be described by,

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \qquad (1)$$

and for the present system we have :

$$a_1 = b_G + r_G b_1 \qquad (2)$$

$$a_2 = r_R(t) b_2 \qquad (3)$$

$$a_3 = r_D b_3 \qquad (4)$$

where a_i and b_i are the incoming signal to and the outgoing signal from the ith port of the circulator, respectively. The microwave signal is connected to port 1 while the mixer diode is connected to port 3 and the antenna to port 2. When the EM wave is radiated by the antenna, it hits the different objects and the backscattered field is intercepted by the antenna and this signal works as an input to port 2. Also, it can be assumed for generality, that the mixer diode gives rise to a reflection coefficient of r_D at port 3 and the source to a reflection coefficient of r_G at port 1. Thus, equations (1)-(4) give three algebraic equations with three unknowns b_1,b_2, and b_3 which can be solved easily for known excitation b_G. However, for the present work only b_3/b_G is of interest. Further, assuming that the three port circulator is an ideal circulator, its scattering matrix may be found as:

$$[S] = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \qquad (5)$$

Hence, from equations (1)-(5), b_3/b_G is found as,

$$\frac{b_3}{b_G} = \frac{r_R(t)}{1 - r_D r_G r_R(t)} \qquad (6)$$

It can be simplified further assuming that the source and the mixer diode are matched such that $r_G = r_D = 0$.

Therefore, $$b_3/b_G = r_R(t) \qquad (7)$$

If $$r_R(t) = [\rho_R + \Delta\rho u_1(t) e^{-j\Delta\theta u_2(t)}] e^{-j\theta_R} \qquad (8)$$

where $\rho_R e^{-j\theta_R}$ is due to clutter and $\Delta\rho u_1(t) e^{-j\theta_R - j\Delta\theta u_2(t)}$ is due to the vibration of the body, then the phase, θ_3 and the square of the magnitude of b_3/b_G are found as,

$$\theta_3 = \arctan\left[\frac{-\rho_R \sin\theta_R - \Delta\rho u_1(t)\sin\{\theta_R + \Delta\theta u_2(t)\}}{\rho_R \cos\theta_R + \Delta\rho u_1(t)\cos\{\theta_R + \Delta\theta u_2(t)\}}\right] \qquad (9)$$

$$|b_3/b_G|^2 = \rho_R^2 + [\Delta\rho u_1(t)]^2 + 2\rho_R \Delta\rho u_1(t)\cos\{\Delta\theta u_2(t)\} \qquad \textbf{(10)}$$

Adjusting such as $\rho_R = 0$, or the clutter is cancelled, equations (9) and (10) reduce to

$$\theta_3 = -\theta_R - \Delta\theta u_2(t) \qquad (11)$$

$$|b_3/b_G|^2 = [\Delta\rho u_1(t)]^2 \qquad (12)$$

Thus, the functions are the following : emission of MW energy (10 mW) from the Gunn diode, which partially goes to the circulator, reception of the reflected signal (also 10 GHz MW), modulated both by amplitude and by phase by the human movement (due to breathing), mixing of this with the transmitted signal at the mixer diode and finally acquisition of the base signal of the human thorax movements.

The electronic unit of the device was constructed in order to have both a visual and an acoustic indication of the detection of the human target and consists of two parts : the supply unit and the amplifier/comparator electronic circuit. To provide the required mobility, an auto-charging, autonomous power supply was constructed in order to get the required DC voltages(±15V,-4.8V,8V). The amplifier/comparator circuit consists of three Operational Amplifiers (OPAMPs) [4]. The Gunnplexer's output is amplified and fed to the adder/comparator circuit , where a variable dc voltage is added , which provides the required null output in case of non-detection. The third part is an inverting amplifier, which amplifies the , low-level , detected signal (0.1V) and drives both the Leds and the Buzzer , providing both visual and acoustic signal whenever a breathing body is detected.

Results - Discussion

Laboratory measurements were conducted by recording the detected signal (square wave) on a digital oscilloscope as a function of distance between human body and antenna and breathing frequency. Continuous alternation between positive and negative pulses corresponds to alternate activation of a green and yellow leads.

The duration of a normal breathing detection is considered to be equal to 2 sec (30 breathings/min) and varies - in this experiment - between 1 and 4 sec (60 to 15 breathings/min respectively) and for different physical organic situation (peaceful, resting man or gasping or lying down or holding his breath etc.) [5].

The performed measurements cover all cases of detection of breathing signals, while the human subject is facing the antenna (body perpendicular to the beam) at a distance of 1m from the antenna (figure 2a), at a distance of 2m from the antenna (figure 2b), at a distance of 1.5m from the antenna (with body parralel to the beam) (figure 2c), at a distance of 1m from the antenna -with the opposite side of the body facing the antenna- (figure 2d), at a distance of 1.5m from the antenna -lying on the ground with face up- (figure 2e), at a distance of 1.2m from the antenna, with face up -standing 20-30cm, behind a wooden door (3cm thich)- (figure 2f).

Conclusion

A portable microwave detector was constructed which permits the detection of body movements due to breathing at a distance of 3 to 5 m (without any obstacle in between) and also at a distance of 2 m behind a concrete obstacle (door or wall) of medium thickness.

The efficiency of the system can be raised by increasing the transmitting power and implementing appropriate digital signal processing techniques. At the present time further research work is conducted in order to improve the system's efficiency and investigate other use of the device such as monitoring patients in hospitals.

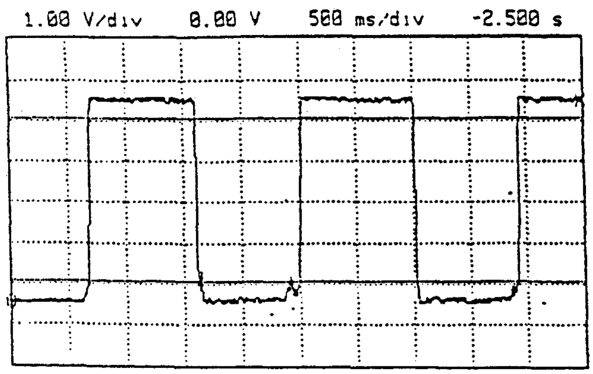

Figure 2a. *Detection of breathing signals, while the human subject is facing the antenna (body perpendicular to the beam) at a distance of 1m from the antenna*

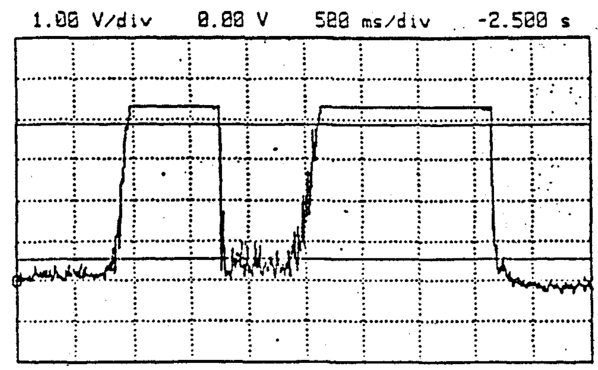

Figure 2c. *Detection of breathing signals, while the human subject is facing the antenna (body parralel to the beam) at a distance of 1.5m*

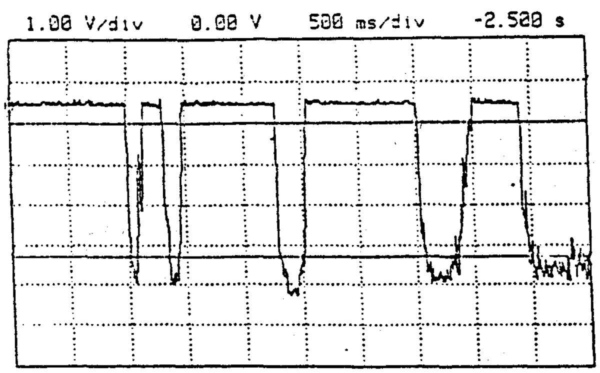

Figure 2b. *Detection of breathing signals, while the human subject is facing the antenna (body perpendicular to the beam) at a distance of 2m from the antenna*

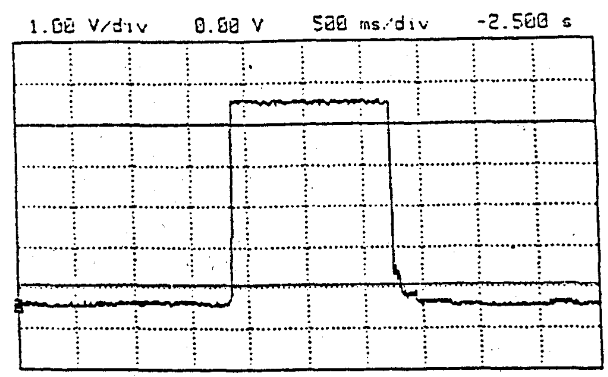

Figure 2d. *Detection of breathing signals, while the human subject is facing the antenna at a distance of 1m, with the opposite side of the body facing the antenna (the thorasic movement is less evident in this case, from the back)*

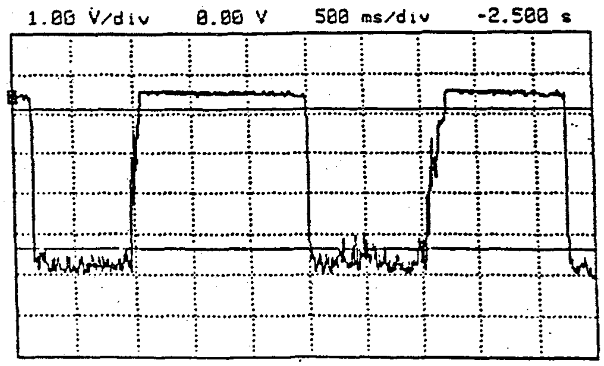

Figure 2e. Detection of breathing signals, while the human subject is facing the antenna at a distance of 1.5m from the antenna, lying on the ground with face up

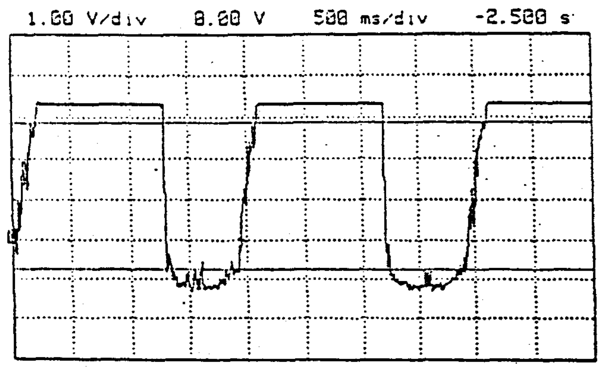

Figure 2f. Detection of breathing signals from a human subject standing 20-30cm, behind a wooden door (3cm thick) at a distance of 1.2m from the antenna, with face up

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