Detection of Breathing and Heartbeat Through Snow Using a Microwave Transceiver

Massimiliano Pieraccini, Guido Luzi, Devis Dei, Lapo Pieri, and Carlo Atzeni

***Abstract*—The potential of a continuous-wave microwave transceiver as a tool for detecting breathing and heartbeat of people buried in snow has been experimentally evaluated. The breathing has been clearly detected through a 1.8-m-thick snow barrier as well as through the 1.2-m-thick roof of an igloo dugout to simulate the experimental conditions of a human being trapped under an avalanche.**

***Index Terms*—Biomedical signal detection, radar, remote sensing.**

I. Introduction

NONCONTACT microwave transceivers for sensing breathing and heartbeat have been proposed since the early 1970s [1]. The current state-of-art in the field of microwave technology has made it possible to construct small and simple devices for this purpose [2], [3]. Several applications of noncontact microwave transceivers have been proposed as diagnostic tools in the biomedical field [1], as enforcement tools [4] for detecting human beings behind walls, and as rescue tools for finding survivors trapped under rubble [5].

The latter is a very challenging application for a number of reasons. Rubble can be a very attenuating medium, particularly if metallic grids are embedded. Furthermore, as rubble is a very inhomogeneous medium, local discontinuities can act as backscatterers and therefore can irradiate the operator, thus, preventing the detector from being able to distinguish between the operator's signal and that of the survivor. For these reasons, the application of microwave transceivers in detecting human beings trapped under rubble has often been disappointing.

A step of intermediate difficulty is the use of microwave transceivers for detecting the breathing and/or the heartbeat of people trapped under snow after an avalanche. In contrast to rubble, snow is a rather homogeneous medium, which can almost be transparent to microwave propagation, when it is dry.

Although some papers report the use of penetrating radar for localizing people under snow [6], [7], to the best knowledge of the authors of this letter, microwave sensing of breathing and/or the heartbeat through snow has not been reported in the scientific literature.

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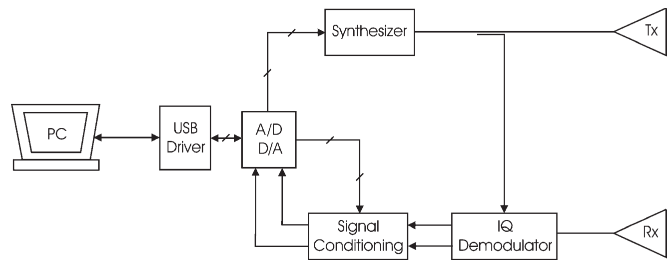

Fig. 1. Block scheme of the transceiver.

II. Transceiver

The instrument is a microwave coherent transceiver that irradiates a monochromatic wave in the field of view covered by two directional antennas (transmit and receive). The receiver detects the in-phase (I) and quadrature (Q) components of the backscattered field. This signal can be represented in the $I-Q$ plane as a generic phasor, whose amplitude and phase are sensitive to movement on the order of a fraction of wavelength.

Fig. 1 shows the block scheme of the transceiver. It is based on a standard homodyne architecture with a phase-locked loop synthesizer at 2.42 GHz.

The choice of frequency involves a tradeoff between the increased penetration depth of lower frequencies and the increased phase shift due to breathing and/or heartbeat at higher frequencies. A frequency of some gigahertz can be an effective tradeoff. In particular, we have chosen 2.42 GHz that is in the Instrumental Scientific Medical band and does not need a specific license.

The two antennas are four-element patch arrays. The half-power beamwidth is 20°. Fig. 2 shows the transceiver in operating conditions.

The radiated microwave power was 10 mW with 12-dB antenna gain, which meets the International Commission on Non-Ionizing Radiation Protection guidelines [7] even at a distance of a few centimeters from the antennas.

III. Experimental Results

The transceiver was tested in two different experimental setups: a snow barrier and an igloo.

A. Snow Barrier

An accumulation of snow was used as a 180-cm-thick snow barrier. After the test, it was sectioned as shown in Fig. 3, and samples of the four identified zones were taken. The densities

Fig. 2. Picture of the transceiver in operating conditions.

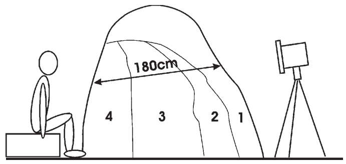

Fig. 3. Experimental setup simulating a snow barrier.

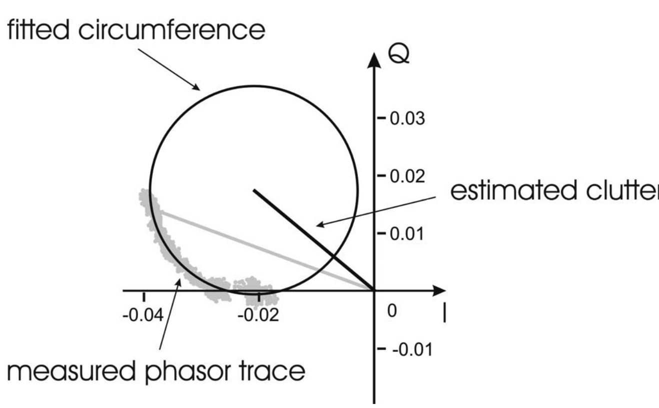

Fig. 4. Phasor of the measured signal.

of the four zones were measured by using a short pipe to sample a known volume of snow, and the following values were obtained: 80, 150, 385, and 450 kg/m^3. The first three layers were fresh and soft snow; the last one was a mix of snow, ice, and rocks.

A volunteer (one of the authors) was sitting on a chair, hidden behind the snow barrier. The volunteer was wearing winter clothes. The transceiver was positioned on a tripod on the opposite side. The measured phasor, shown in Fig. 4, lies on a circumference, whose center is located by the phasor of static clutter, whereas the rotating phasor is the signal to be detected. Since the experimental phasor describes an arc of circumference, the phasor of the static clutter can be removed by finding the center of the circumference that best fits the measured phasor trace. An effective algorithm for this operation is the

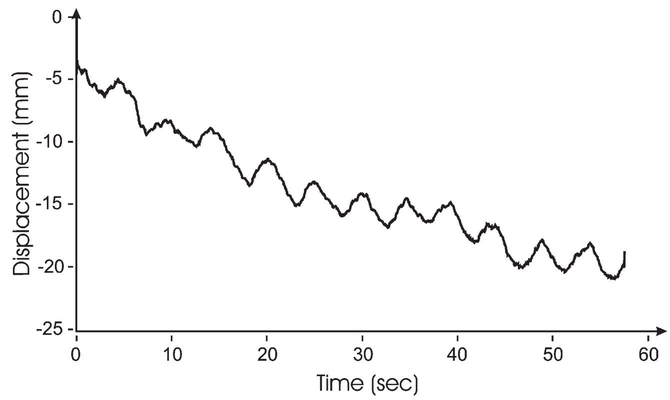

Fig. 5. Displacement versus time in the case of the experimental setup sketched in Fig. 3.

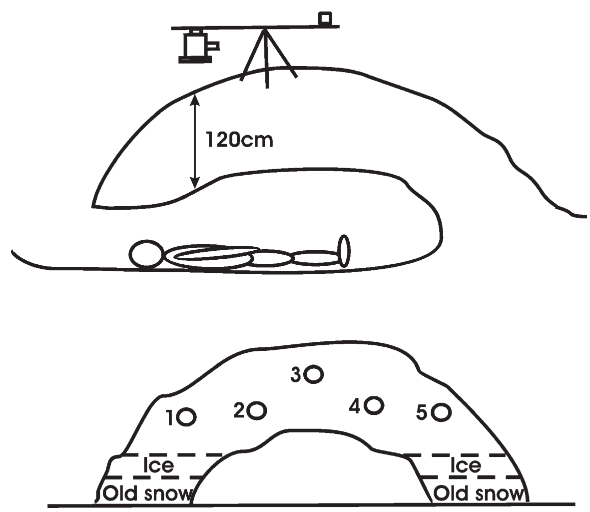

Fig. 6. Experimental setup simulating a human being trapped under an avalanche.

nonlinear minimum square Levenberg–Marquardt method [8], [9] with a parameterization proposed by Chernov–Lesort [10]. After clutter removal, the phase differences $\Delta\varphi$ were directly related to the displacements Δs of the chest of the volunteer, by the following basic equation:

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta s \tag{1}$$

where λ is the wavelength. Fig. 5 shows the measured displacement. The periodic movement of the chest due to breathing is quite evident. The detected breathing rate is 0.21 Hz.

B. Igloo

An igloo was built to simulate the condition of a human being trapped under an avalanche. The density of the snow was probed in five points as shown in Fig. 6 and the following values were obtained: 246, 254, 240, 208, and 210 kg/m^3.

The volunteer laid down and remained immobile. The thickness of the snow above the volunteer was about 120 cm. The breathing movement detected by the transceiver, shown in Fig. 7, appears very clearly. The detected breathing rate is 0.24 Hz.

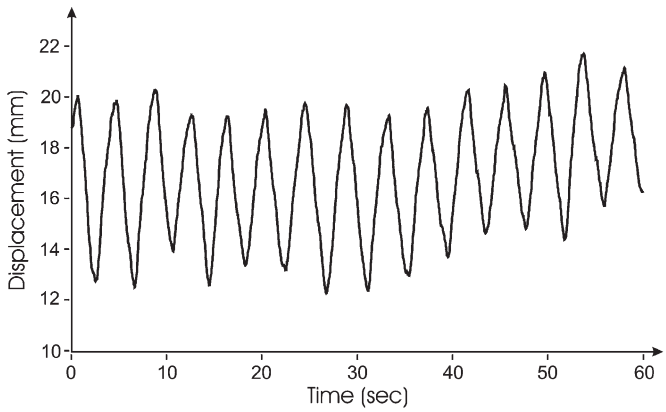

Fig. 7. Breathing detected by the transceiver in the experimental setup sketched in Fig. 6.

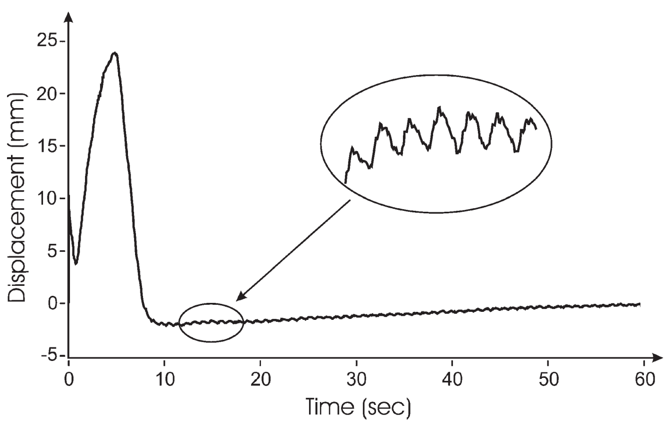

Fig. 8. Trace obtained during an apnoea showing the heartbeat signal.

To detect the heartbeat as well, the volunteer was asked to hold his breath for a few seconds (apnoea). The resulting signal, shown in Fig. 8, shows that a heartbeat can also be easily detected through a snow barrier thicker than 1 m. The detected heartbeat rate is 1.08 Hz.

IV. Conclusion

The experimental results reported in this letter demonstrate that a continuous-wave microwave transceiver is able to detect breathing and heartbeat through a snow barrier.

Nevertheless, further investigations are needed to simulate more difficult conditions. Indeed, the snow used in the described experiments was rather dry, so the positive results obtained are not particularly surprising. The capability of microwave transceivers to operate through wet snow and snow thickness of several meters should also be investigated and the effective operation depth should be evaluated. Other open questions can be investigated. For example, how the posture, the size, or the gender of the possible victim can affect the detection.

Finally, the effective operability as a rescue tool in real conditions has to be proven. The current conventional methods used to locate buried avalanche victims using wearable transceivers have proven to be highly effective, but of course they require the victim to be wearing a transceiver. The microwave method described in this letter does not require the victim to wear any electronic device, but nonetheless there are severe practical and logistical implications about the deployment of a radar in the very short time available for a successful rescue. Indeed, a transceiver based on the principle described in this communication, surely will never be able to substitute the wearable transceivers, but it can provide a useful help for scouring victims that do not wear equipment for localization.

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