RF Band High Resolution Sounding
of
Building Structures and Works

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ABSTRACT

A subsurface radar using a multi-frequency signal has been developed. It is designated for surveying building structures and works. The characteristic feature of this device is the possibility of obtaining sounding plane radio images featuring a high resolution attaining 1 ... 2 cm. The main applications of this device includes the survey of building structures to reveal their heterogeneities and defects and the investigation of premises to detect bugging devices.

INTRODUCTION

The existing methods of the nondestructive testing of building structures have a number of deficiencies. For instance, X-ray devices require two-side access to a building, which is difficult in some cases or most commonly impossible. However, X-ray equipment has found a wide application in medicine, for baggage checking at airports, and in those technological processes where the two-side access to an object under investigation does not produce problems. Ultrasonic equipment proves to be inefficient in media containing a great number of microcracks and heterogeneities. Its field of application includes the study of continuous and relatively continuous media involving a small number of defects and allogenic inclusions. From this viewpoint, the use of the RF range appears to be most promising because reflection sounding is possible if the receipt and radiation of RF waves is performed from one side of a surface sounded. This allows for the examination of walls, ceilings, and enrichments in finished buildings. Thus, the quality control of their construction and repair is possible. The proposed method using a specially made antenna permits the survey in corners and between walls, which is barely feasible by using other techniques. A further advantage of radar sounding is a relatively long wavelength λ within the microwave band used because this wavelength does not produce reflections from insignificant natural heterogeneities such as cracks and the operational hollows of bricks and other building materials which are small as compared with λ.

Recently short impulse time domain subsurface radar systems have already found applications for sounding various building structures and coverings both for detecting hidden objects in them [1] and for defect diagnostics [2, 3, 4,]. The sounding of building structures presents certain difficulties, because the required resolution is very low and ranges from 1 cm to 5 ... 10 cm depending on the problem to be solved. These resolution requirements are related to the characteristic size of heterogeneities found in different building structures.

Especially high requirements arise when detecting various bugging devices hidden in the walls or the

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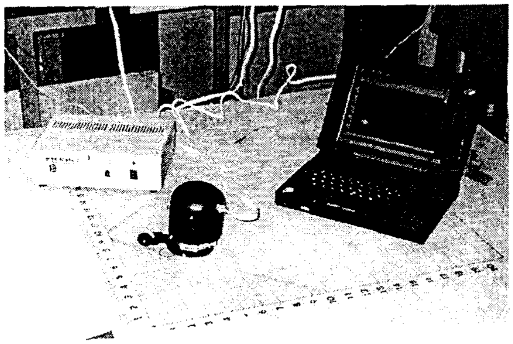


Fig. 1. General View of RASCAN Radar

enclosures and enrichments of rooms. The size of these devices is very small and their design is such that they are difficult to detect against the background of reflections from the natural heterogeneities of building structures. These heterogeneities can include steel reinforcement bars of concrete, pipes and electric cables, fastening nails and clamps, etc.

The resolution of subsurface radar has conventionally been improved by reducing the pulse duration in pulse radar or by widening the frequency band in FWCW radar. However, these measures result in more complicated and more costly equipment for this work.

The building structure sounding radar discussed in this paper operates on several fixed frequencies, and a signal is received by using two cross polarizations on each frequency. Radio images obtained have a high resolution in the sounding plane of the medium and allow for restoring the shape of objects by which assumptions can be made as to their nature and purpose.

SYSTEM

The general view of RASCAN radar developed in TsNIIRES is presented on Figure 1. This is subsurface radar using a signal whose frequency varies according to the step law.

The radar includes a transmitter radiating on 5 frequencies within the 3.6 GHz to 4.0 GHz band and two receivers operating in the same wavelength band. The transmitter power is below 10 mW. The antenna of one of these receivers has the same polarization as the transmitter antenna. The antenna of the other receiver affects cross-polarization reception. All the HF elements of the radar are mounted on an antenna unit and accommodated in a common body. The HF part of the radar is shown in the foreground of Figure 1. It is connected by a LF cable to an interface unit, which, in turn, is connected to the parallel port of the computer. The computer itself does not require modification except the installation of appropriate software. The interface unit and the computer are shown in the background of Figure 1.

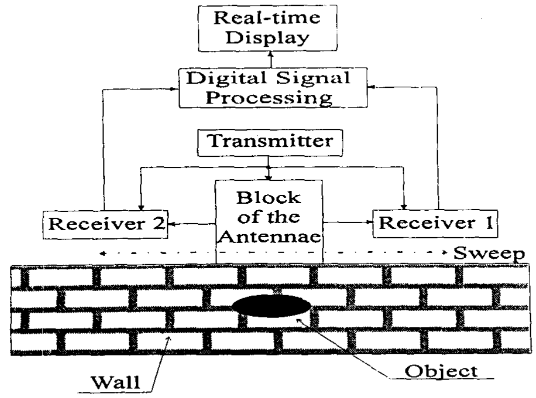


Fig. 2. Simplified Block Diagram of the Radar

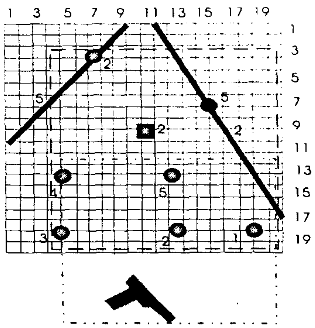
Radio images are obtained by the mechanical scanning of the antenna unit over the surface of an object under sounding. The rate of the surface scanning investigated is that which allows for taking the image of $1m^2$ of the surface over the time interval from 5 minutes to 20 minutes depending on the required space resolution. The levels of received signals are measured every 1 cm or 2 cm both along the X - axis and the Y - axis. A simplified block diagram of the radar is shown in Figure 2. Data was entered into the computer through a specially developed interface, which connected to the computer's parallel port.

When taking measurements, the oscillator was switched serially from one operating frequency to the other (f = 3.6, 3.7, 3.8, 3.9, 4.0 GHz). The frequency choice was in agreement with the requirement of changing the contrast of any object in respect to the background level at the boundaries of the frequency band. This is important for performing measurements in heterogeneous media and makes it possible to provide a sufficiently contrasted observation of an object if only for one of the frequencies and, as shown below, allows for detecting objects placed in the same line of sight but at different depths.

The electromagnetic radiation is reflected from objects possessing the dielectric permittivity contrast in respect to the medium in which they are located. By virtue of this fact, obtained images show not only metal objects but also dielectric heterogeneities, e.g., voids, which distinguish this device from metal detectors are in considerable current use. Water and the increased humidity parts of structures are also high contrast.

EXPERIMENT

To demonstrate the efficiency of RASCAN radar, the mockup wall was sounded. The mockup wall was presented by a packet consisting of seven 1 m × 1.2 m plaster boards 10.5 cm thick in the aggregate, and there were different objects placed between the wall layers. Objects to be detected included two metal wires and seven 25-mm coins. One of the coins was placed under the



● - 25-mm coins;
— - metal wires;
■ - 3 cm × 3 cm opening in the second layer;
- pistol mockup.

Fig. 3. Arrangement of Objects in the Mockup Wall

left-hand wire and the other under the right-hand wire. In addition, a 3 cm × 3 cm square opening was made in the second plaster layer and the opening depth was identical to the board thickness — 1.5 cm. The arrangement of objects within the wall mockup is given in Figure 3. The size of the shadowed surface on the diagram was 0.6 m × 0.6 m.

The figure placed at each of the objects states the ordinal number of a layer, as viewed from above, under which this object is located. For example, the object in Figure 2 is between the 2nd and 3rd layers of dry plaster. A recess was made in the 3rd and 4th layers where a pistol mockup was placed; its barrel length was 13.5 cm and its grip height was 9.7 cm. A grid was plotted on the diagram for convenience. The grid spacing is 3 cm. The experimental results for sounding the different parts of the mockup wall are given in Figures 4 and 5.

Figure 4 presents the radio image of part of the mockup enclosed by a dotted line in Figure 3. This figure shows five radio images which have been obtained by using the parallel polarizations of the radar received and transmitted signals. These images are arranged from top to bottom, as the frequency increases. Both of the wires, seven coins and the opening are observed in this picture.

A relatively high contrast of the opening can be explained by the difference between the dielectric permittivity of the air filling the void and the dielectric permittivity of the plaster board material. Let us note that the level of the contrast of objects and its sign in relation to the background varies depending on the depth of their position. This is related to the features of the design of a two-way channel wherein a signal reflected from an object is added to the signal of a transmit antenna. The coins placed both before and behind the wire are seen very well. The possibility of the observation of an object located behind another object in its shadow is related to the differences in the phases of signals reflected from objects located at different depths. By changing the frequency of a sounding signal, we can reduce the contrast of a nearby object and enhance the contrast of an object positioned at a greater depth behind the former one.

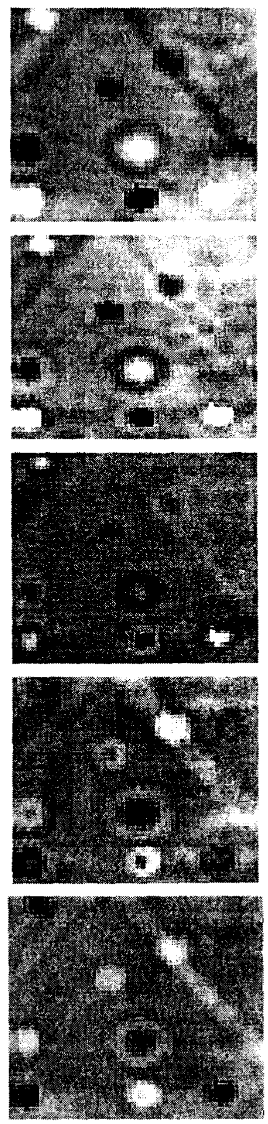


Fig. 4. Radio Images Obtained by Five Frequency Channels by Using the Parallel Polarization of Received and Transmitted Signals

Figure 5, shown on next page, presents similar radio images of objects obtained by using the cross-polarization of received and transmitted signals. This polarization results in increasing the contrast of lengthy objects (wires) and in reducing the contrast of lumped objects (coins and opening).

Figure 6 shows the radio image of the mockup enclosed by a dashed-dotted line in Figure 3. This radio image is obtained on the frequency f = 3.6 GHz. The pistol outline is seen in this picture.

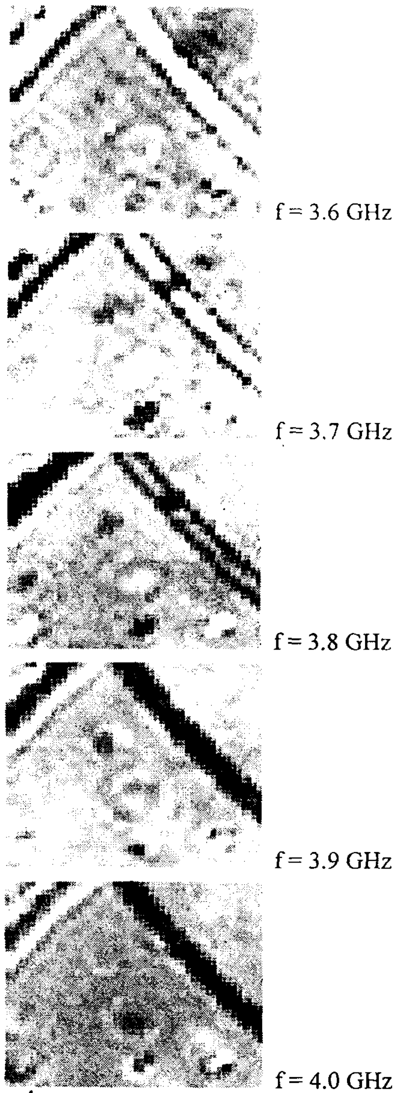


Fig. 5. Radio Images Obtained by Five Frequency Channels by Using the Cross Polarization of Received and Transmitted Signals

Other objects under investigation were the reinforced concrete and slag concrete walls of buildings. It can be seen from the radio image of a reinforced concrete wall given in Figure 7 that the reinforcing rod in the left upper part of the section under investigation is welded not to the reinforcement joint but below it.

The reinforcement was welded from 2 cm steel rods. The reinforcement mesh spacing in the wall was 0.2 m × 0.2 m and the thickness of the protective concrete coating over the reinforcement varied from 3 cm to 4 cm. Figure 8 presents the radio image of a wall made from slag concrete blocks.

The picture shows voids in these blocks in the form of light spots, and the dark lines between voids depict stiffening ribs. Wider gray lines depict joints between

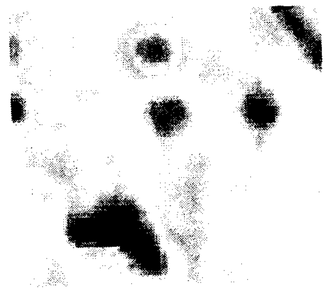


Fig. 6. Radio Images of Objects and Pistol in the Mockup Wall

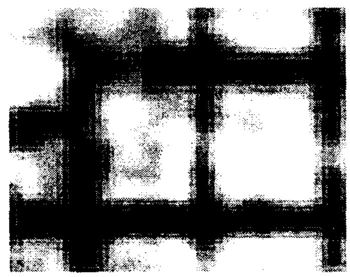


Fig. 7. Radio Image of the Reinforced Concrete Wall

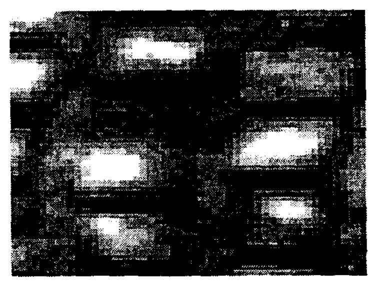


Fig. 8. Radio Image of the Slag Concrete Wall

blocks. The size of slag concrete blocks, which made up the wall, was 0.2 m × 0.5 m, and their thickness was 0.11 m.

The experiments have shown that RASCAN type radar also allows for screening structures made from other building materials, e.g., bricks and wood.

CONCLUSION

The low radiation power of the radar equal to 10 mW assures its environmental safety. For the same reason, the radar, while in operation, does not produce interferences to other devices operating in the same wavelength band. This type of subsurface radar can find applications in the following fields:

- Counterintelligence activities for detecting bugging devices;
- Operative inquiry activities of law enforcement bodies;
- Sounding of building structures for determining the position of reinforcement, voids, and other heterogeneities; and

- Sounding of critical building works (airport runways, bridges, crossings) for determining their latent flaws.

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LETTER

Editor:

"The MIKON Series: Poland Gets an 'A' "

This item, published in ***IEEE AES Systems Magazine*** (**13**, No. 10, (October 1998) 45-46), came to mind with the recent publication of a report on another European conference, "DGON/ITG International Radar Symposium'98" ***IEEE AES Systems Magazine,*** (**14**, 2, (February 1999), 17). The latter conference was larger and focused exclusively on radar. The report was centered on brief discussions of technical papers presented at the conference. These discussions indicated the important aspects of the papers. The IRS'98 report could serve as an excellent example for a report on the upcoming RADAR '99 conference in Brest, France, which should concentrate on technical papers and especially poster sessions and eliminate the photos.

Unfortunately, I found no discussion of MIKON'98 papers in that report. I personally presented papers at two MIKON conferences (October 1998 at Gdansk, before the fall of the Berlin Wall in 1989; and again at Rydzna, Poland in 1991). I am glad to report the continuation of Polish hospitality. From the caption on one of the seven photos I was delighted to learn that a Polish colleague (who immigrated to West Germany) is now back in Poland. The Preliminary MIKON'98 program indicated two of the twenty conference sessions and one poster session are devoted to radar. I hope arrangements were made for the IEEE AP and MTT Societies to carry reports in their publications addressing MIKON papers of interest.

May I suggest that the MIKON '98 report be revisited soon? I would like to see the following items expanded upon for your readers:

- A brief discussion of the nineteen radar papers at the conference;
- Did the author of the report talk to authors of poster papers; if so, can you comment on them?
- Do you recommend publication consideration of papers in ***IEEE AES Transactions*** or ***Systems magazine***?
- Did you hear any mention of another Polish conference on Modern Radar Problems? I presented a paper at the 4th conference in Zakapone, Poland, in October 1993. I hope they will have another soon.
- Was there any mention of a follow-on to the first *Polish National Cumulative Index on Radar Systems* that was published in the ***IEEE AES Transactions*** in March 1991?
- Are the *Mikon Conference Proceedings* available from the IEEE Publications Center? Has a copy of the *Proceedings* been placed in any US technical library for access by interested persons? If so, where? And what is the *Proceedings* call number?
- Has the *Proceedings* table of contents been placed on the Internet? If so, what is its URL?

I hope a copy will be provided to the IEEE AESS Radar Systems Panel Literature Indexing Committee for inclusion in the next *International Cumulative Index on Radar Systems.*

Sincerely,

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