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Estimation of Electrical Properties of Hidden Objects Using Microwave Signals

Steponas AŠMONTAS [1], Oleg KIPRIJANOVIČ [1] *, Boris LEVITAS [2], Jonas MATUZAS [2], Irina NAIDIONOVA [2]

[1] *Center for Physical Sciences and Technology, A. Goštauto 11, LT-01108 Vilnius, Lithuania*
[2] *Geozondas UAB, T. Ševčenkos, 16, LT-03111 Vilnius, Lithuania*

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Pulsed excitation of a horn antenna for generating large *B* wideband electromagnetic pulses was used. The antenna was excited by electrical pulses with rise time of 200 ps and pulse voltage of 15 V. The spectral properties of the electromagnetic pulses were investigated using different wide band antennas and (0 – 18) GHz passband sampling oscilloscope. It was found that the signal spectra is wide and ranges from 0.3 GHz to higher than 12 GHz. Hollow cylinders made from opaque for visible light materials were used to hide other cylinders with certain electrical properties. To reveal their presence we employ the electromagnetic pulses. Transmitted through and reflected from investigated objects pulses were received by several antennas having different frequency ranges and detected to obtain needed information. The experiments show that analyzing this information leads to conclusions about the presence of the object and its electrical properties. This methodic supposedly can be employed to disclose electrical properties of objects having complex electrical properties if broadband amplifiers and digital oscilloscopes are used.

Keywords: microwave systems, large *B* signals, wideband antennas, electrical properties, hidden objects.

1. INTRODUCTION

Last decades microwave and millimetre wave systems have been deployed for a variety of short distance applications such as through the wall imaging, non-destructive testing for structural integrity and concealed weapon detection [1 – 2]. Signal receiving in such systems is done by narrow and wideband antennas of various types. Digital oscilloscopes with pass band up to 40 GHz and corresponding software allow easy operating with different ultra-wideband signals and their bursts, containing microwave frequencies in their spectra. Both theoretical studies [3] and experimental research [4] keep uncovering new types of such super wideband signals. Some of them could be used in different investigations including those of dispersive medium and of media having strong frequency-dependent loss [5]. Some of the broad band signals have a large base *B*, where *B* is product of signal bandwidth on its duration and it is much more than 1 [6].

It should be mentioned that different microwave absorber materials are being recently designed for military or civilian applications. Increase attention during exploitation of microwave and millimeter wave systems is required in the case of their unsanctioned application [7].

In this work we attempt to use large *B* signals for experimental investigation on search of solids with expressed metallic and EM absorbing properties. Because of large spectral range we use different broadband antennas. The investigation was carried out on metallic and absorbing cylinders which were enclosed in hollow, opaque for visible light, cylinders.

2. EXPERIMENTAL

To generate electromagnetic pulses of large *B* it was used pulsed excitation of wide band horn antenna having opening 34×26 cm^2. Such horn allows experiments both at relatively short distances exploiting higher frequency antennas up to 18 GHz and at longer ones when receiving TV range radiation of frequency as low as 0.3 GHz. Schematic of experimental set up is presented in Fig. 1. The horn antenna (1) is excited by pulse generator of 200 ps rise time pulses and amplitude of 15 V (not shown). In the Fig.1 one can see receiving horn of (2 – 5.64) GHz band with aperture (12×9) cm^2 having coaxial output (4) and logoperiodic antenna operating in the range (1 – 1.7) GHz (5) to receive reflecting signal. Other antennas which were used are broadband dipole TV range antenna (0.3 – 1) GHz range and horn (8.4 – 12) GHz band with coaxial output. Hollow cylinders (2) were used to contain cylindrical objects of different electrical properties (3). In this work these objects are metallic or EM absorbers with small reflection. If it is necessary the signals are amplified by amplifier (6) and after detection (7) transmitted to the sampler of the (0 – 18) GHz passband oscilloscope.

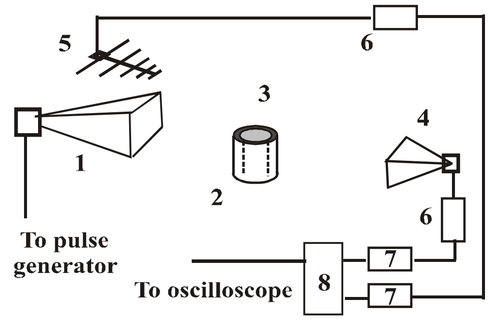

Fig. 1. Schematic diagram of experimental setup. 1 – radiating horn, 2 – cylinders made of opaque material, 3 – investigated (hidden in the cylinder) object, 4 – receiving pyramidal horn, 5 – logoperiodic antenna, 6 – amplifier, 7 – detector, 8 – oscilloscope sampler

Properties of materials which were used as hollow cylinders to hide the objects in them are presented in

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[*] Corresponding author. Tel.: +370-5-2619759; fax.: +370-5-2627123.
E-mail address: *kipriol@pfi.lt* (O. Kiprijanovič)

Fig. 2. Insertion losses of curtain material and conductive rubber, both of 1 mm thickness, were measured using method of parallel replacement in coaxial transmission line. The losses of heat-insulating material of 3 mm thickness were measured by free space horn methodic at normal fall of electromagnetic wave on piece of large area of the materials. Averaged results presented by polygonal line. In the same way reflective properties of these all materials were measured and marked by dashed lines.

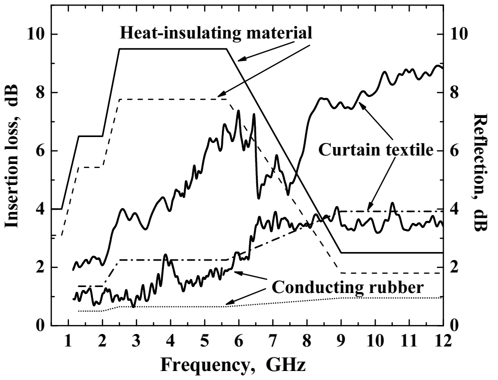

Fig. 2. Insertion loss (solid lines) and reflection (dashed lines) of EM radiation for the materials used to made hollow cylinders

The large *B* signal is very wideband and spectral density values can be at (20 – 25) dB level for harmonics above 10 GHz and up to 22 GHz. Therefore receiving antennas transform EM pulse to electric signal which correspond to each antenna operational frequency band.

Fig. 3 demonstrates wave forms of signals received by the broad TV and the logoperiodic dipole antenna. The insertion in Fig. 3 shows visualized form of whole signal which was obtained using super wideband dipole antenna.

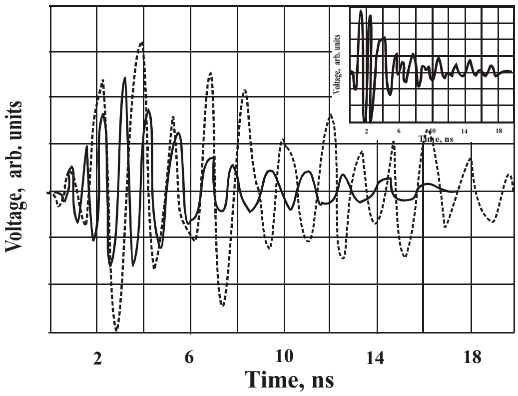

Fig. 3. Waveforms of signals received by the broadband TV range (dotted) and dipole (solid) antennas. Insertion: visualization of the whole signal using super wideband dipole antennae

Signals which were received at higher frequencies are demonstrated in Fig. 4. In it are placed two waveforms of the signals obtained from the horns with coaxial outputs. One can observe that when higher frequency antennas are used waveforms become shorter. This means that the beginning part of signal contains its high frequency components.

The hollow cylinders were made from the opaque materials and winded in two layers in case of curtain and conductive rubber and in one layer for heat insulator. Their dimensions are 9 cm height and 2.5 cm outer diameter.

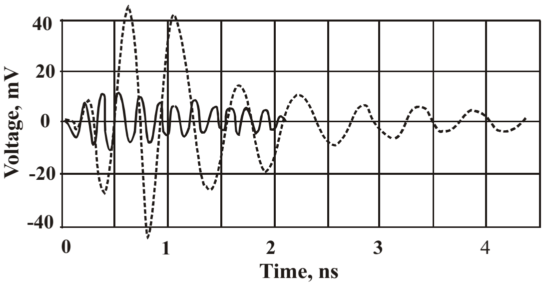

Fig. 4. Waveforms of signals received by (2 – 5.6) GHz horn (dotted) and (8.4 – 12.04) GHz horn (solid)

During the experiment cylinders were placed at the center between antennas and first we measured the decrease of amplitude of transmitted signal compared with the undistorted one when the cylinder was absent. Distances between the antennas were above meter for lower frequencies and 0.8 m for the highest. Then to measure reflection we rotated the receiving antenna by its radius from the cylinder position on the larger than 90º angle until only small leakage of the undistorted signal and of other, parasitic, reflections has remained. We then measure appearing due to the reflection from the cylinder amplitude and once again compare it to the amplitude of the undistorted signal.

3. RESULTS AND DISCUSSION

Experimental results for subranges (1 – 1.7), (2 – 5.64), (8 – 12) GHz are presented in Tables 1 and 2. The experimental cases are denoted by “one”, “two” and “three”. Because of nonlinearity of detectors, reflection and insertion data are placed in different tables. Analyzing these tables one can see two general features which can hint on the nature of the hidden object in certain cases. First, considering that reflection properties of metals are high one of the cases is expected to have higher reflection values. This is indeed observed in every reflection part of the tables and indicates that the case “two” most likely corresponds to a hidden metallic object. Both other cases will not be so easily distinguished by their reflection ability, since the reflection from absorber object can be very low.

Another common fact as seen from the tables is that both insertion loss and reflection values from the case “one” never exceed corresponding values from other two cases. This most likely indicates on that case having no object hidden at all.

Examining data of the conducting rubber cases on the Table 1 we can see that the presence of an object notably influences insertion losses. Considering also the general table features, we can conclude that the absorbing and reflecting qualities of an object hidden in this material are easily revealed in these frequency ranges.

Such revelations are not as obvious in the curtain material cases. Namely, in the (8.4 – 12) GHz subrange both insertion and reflection values are the same in the cases “one” and “three”. We must then analyze other subranges and doing so one can see that in the case “three” insertion losses are higher which indicates on appearance of the object with absorbing properties. The case “two” can then be assigned to the presence of the metallic object,

Table 1. Reduction of the detected undistorted signal amplitude induced by the cylinders

Insertion losses, %										
Antenna Range		(1 – 1.7) GHz			(2 – 5.64) GHz			(8.4 – 12) GHz		
Material	Case	One	Two	Three	One	Two	Three	One	Two	Three
Conducting rubber		1.5	2.0	5.7	4.1	10.6	8.5	6.5	8.0	10.2
Curtain material		5.4	6.1	10.0	5.8	7.2	12.8	12.1	15.8	12.4
Heat-insulating mat.		10.8	12.1	10.0	9.2	10.6	12.8	2.0	11.2	11.2

Table 2. Ratio of reflected signal amplitude to the detected undistorted signal amplitude

Insertion losses, %										
Antenna Range		1 – 1.7 GHz			(2 – 5.64) GHz			(8.4 – 12) GHz		
Material	Case	One	Two	Three	One	Two	Three	One	Two	Three
Conducting rubber		4.5	12.5	8.3	6.3	12.5	8.3	6.6	11.0	6.6
Curtain material		8.3	10.0	8.3	10.0	12.5	10.0	9.0	14.1	9.0
Heat-insulating mat.		16.7	23.3	16.7	12.5	16.7	12.5	4.4	11.1	6.5

considering the general table features.

Similarly, in the heat insulating material cases we have trouble revealing hidden object properties in the (1 – 1.7) GHz range. Here the insertion loss and reflection values are also the same in the cases “one” and “three”. This time problem is solved when analyzing data from higher frequency ranges. Once again we establish that the case “three” has higher insertion losses in another subrange which indicate on the appearance of absorbing object. Obviously case “two” is again analogically corresponds to the hidden metallic object.

Overall the analysis of data from the tables shows that despite using three different types of opaque materials, it was possible to reveal hidden in them objects with expressed metallic and absorbing properties.

It was mentioned that the large B signal which we used in this work is also received by antenna of subrange (0.3 – 1) GHz while in (12 – 18) GHz subrange there was no receiving due to lack of proper equipment. However the experimental setup cannot detect insertion or reflection in the range (0.3 – 1) GHz because the opaque cylinders dimensions are too small. In the subrange above 12 GHz spectral power density is low and the setup lacks corresponding to such range antennas, broadband amplifiers and detectors.

We would like to note that the experiment with the same setup, but in which clenched human fist was used to hide the objects instead of the opaque cylinders, also gave positive results. The presence of the objects as well as their metallic or absorbing property was successfully established in such conditions. A watch with metallic watchstrap on a hand is also distinguishable including testing in subrange (0.3 – 1) GHz. We believe that improvements of the experimental setup from technical standpoint could allow for searching objects with more complex electrical properties. These improvements include varying the antenna ranges depending on the task and usage of broadband digital oscilloscope allowing to exclude signal detection process and work directly with our broadband signal instead.

4. CONCLUSIONS

In the experiments it was used large B EM signal with bandwidth lasting from 0.3 GHz and up to 22 GHz. Three subranges depending on antenna operational frequency were used to receive and detect signal transmitted and reflected from the hidden objects. They were (1 – 1.7) GHz logoperiodic antenna, pyramidal horns of (2 – 5.64) GHz and of (8.4 – 12) GHz ranges. Employing the signal in the course of experiment we were able to reveal presence of the hidden objects within the hollow opaque cylinders and establish whether they had expressed metallic or microwave absorbing properties. When the data from some of the subranges was not sufficient to make conclusions about the properties of the hidden objects, we would rely on the data from other subranges to complement our analysis. Broad frequency range of the signal and correspondingly its different wavelengths could be useful in search of objects having varying sizes, shapes and electrical properties.

REFERENCES

1. **Jarovoy. A., Lighart, L., Matuzas, J., Levitas, B.** UWB Radar for Human Being Detection *IEEE Aerospace and Electronic Systems* 21 (3) 2006: pp.10 – 14.
2. **Jofre, L., Broquetas, A., Romeu, J., Blanch, S., Toda, A., Fabregas, X., Cardama, A.** UWB Tomographic Radar Imaging of Penetrable and Impenetrable Objects *Proceedings of the IEEE* 97 (2) 2009: pp. 451 – 464.
3. **Kravchenko, V., Lazorenko, O., Pustovoit, V., Chernogor, L. F.** A New Class of Fractal Ultra-Wideband Signals *Doklady Physics* 52 (3) 2007: pp. 129 – 133. http://dx.doi.org/10.1134/S1028335807030019
4. **Reid, A., Judd, M.** Ultra-wide Bandwidth Measurements of Partial Discharge Current Pulses in SF$_6$ *Journal* of Physics *D*: *Applied Physics* 40 2007: pp. 2948 – 2953.
5. **Armand**, **N. A.** Propagation of Broadband Signals in Dispersive Media *Radiotechnika and Electronika* 48 (9) 2003: pp. 1045 – 1057 (in Russian).
6. **Anisimovas, F., Ašmontas, S., Kiprijanovič, O., Matuzas, J.** Radiation of Large Bandwidth and Long Duration Signals by Pulsed Excitation of Monopole Antennas *In Proc. 4th Intern. Conf. Radiation Interaction with Material and Its Use in Technologies* Kaunas, Lithuania, 2012: pp. 574 – 577.
7. **Garin, B., D’yakonova, O., Kazantsev, Yu. N.** Physical Properties of Resistive Threads and Structures Based on Them in the Microwave Range *Technical Physics* 44 (1) 1999: 95 – 98.