Applications of Noise Spectroscopy in the Analysis of Periodic Material Structures

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Abstract— The authors discuss the application of broadband noise signal in the research of periodic structures and present the basic testing related to the described problem. The aim is to find a metrological method utilizable for the investigation of metamaterials in the frequency range between 100 MHz and 10 GHz; this paper therefore characterizes the design of a suitable measuring technique based on noise spectroscopy and introduces the first tests conducted on a periodic structure (metamaterial). In this context, the applied equipment is also shown to complement the underlying analysis.

1. INTRODUCTION

In the comprehensive investigation of material structures for the micro-wave application (tensor and composite character), the properties of materials are studied by means of the classic single-frequency methods, which bring about certain difficulties in the research process [1]. In boundary changes with a size close to the wave-length there can occur wrong information concerning the examined objects [2, 3]. One of the possible ways of suppressing the negative sources of signals consists in the use of wide-band signals such as white noise, and this approach can be further reinforced by analysing the problem of absorption in the examined material. The indicated methods require a source of noise, a receiving and a transmitting antenna, and A/D conversion featuring a large bandwidth; for our purposes, the bandwidth ranged between 50 MHz and 10 GHz. Until recently, it had not been possible to design an A/D converter of the described speed or materialise devices with the above-mentioned bandwidth. Currently, high-end oscilloscopes are available with a sampling frequency of hundreds of Gsa/s.

2. NOISE SOURCE

For UWB systems, several methods enabling the generation of short pulses with large bandwidth have been developed to date, see reference [4]. However, these singly-iterative processes are not applicable for noise spectroscopy; in this respect, there is the need of a continuous noise signal source (ideally one producing white noise) with the given bandwidth.

The type of source referred to is currently being supplied by certain manufacturers operating in the given field. Importantly, for the noise spectroscopy application, we require a comparatively large output power of up to 0 dB/mW; the assumed bandwidth characteristics range up to 10 GHz. Nevertheless, at this point it is appropriate to mention the fundamental problem of finding active devices capable of performing signal amplification at such high frequencies. As a matter of fact, our requirements are thus limited by the current status of technology used in the production of commercially available devices; the highest-ranking solution for the bandwidth of up to 10 GHz can be found only up to the maximum of 0 dB/mW.

Our response to the above-discussed problem consisted in an attempt to produce a noise generator in laboratory conditions because, in principle, this type of generator can be considered as sufficient for testing and basic measurement. In view of the price and availability of noise diodes, we decided to apply thermal noise on electrical resistance as the basic noise source. The specific connection is shown in Fig. 1. The first transistor is in the CC configuration (stage), where we require mainly a high input impedance of the amplifier. The input thermal noise is given by the amplifier's input circuit element parameters. Even though the generator could operate even without a resistor at the transistor input, the unconnected input would cause a substantial deterioration of the connection stability. The second and third transistors form a cascade voltage amplifier in the CE configuration (stage); the output impedance of the third amplifier is 50 Ω.

Figure 1 shows the tested noise generator, whose output power is 0 dBm in the frequency range between 100 kHz and 10 GHz.

Figure 1: The noise generator and power amplifier.

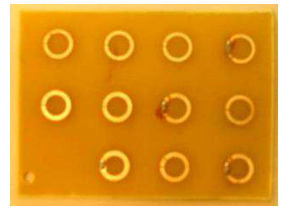
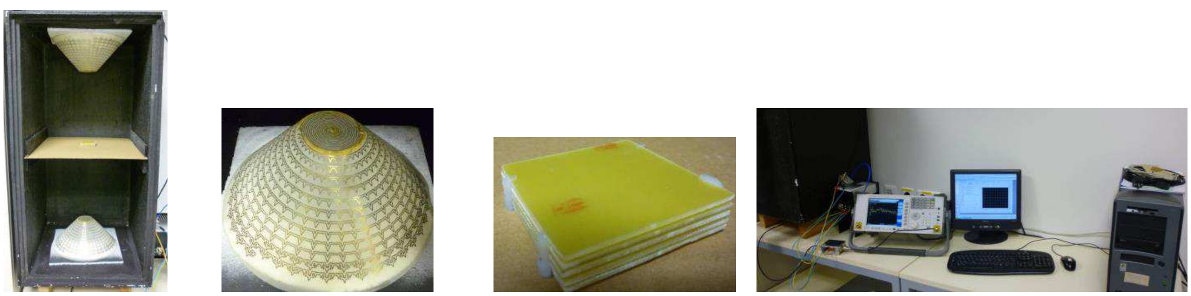


Figure 2: The first tested tuned periodic structure to verify noise spectroscopy measurement.

3. METHOD

The noise spectroscopy laboratory and the measuring instruments are shown in Fig. 3. In order to find the desired environment, we carried out several experiments in various shielded and anechoic chambers (Fig. 7). After the use of an ideal white noise (Fig. 4), a number of wideband antennas (Fig. 7), and an anechoic chamber, it became obvious that a closed, unshielded room without significant anechoic effect, Fig. 3, is fully satisfactory for the needs of noise spectroscopy. The research technique using UWB signal was tested as follows: The case to hold the examined sample (Figs. 2 and 3(c)) contained two suitably set and fixed UWB antennas, Fig. 3(b)). The first of these antennas was supplied from the noise generator and power amplifier (Fig. 1, Fig. 5), while the second one sensed the signal from both the noise generator and the adjacent electromagnetic sources; the signal spectrum was recorded iteratively. The initial stage involved repeated transmission and sensing of both the signal provided by the noise generator and the external signals. The repetition



(a) (b) (c) (d)

Figure 3: The measuring equipment and instruments: (a) antenna chamber; (b) antenna; (c) layered sample; (d) noise spectroscopy evaluation laboratory.

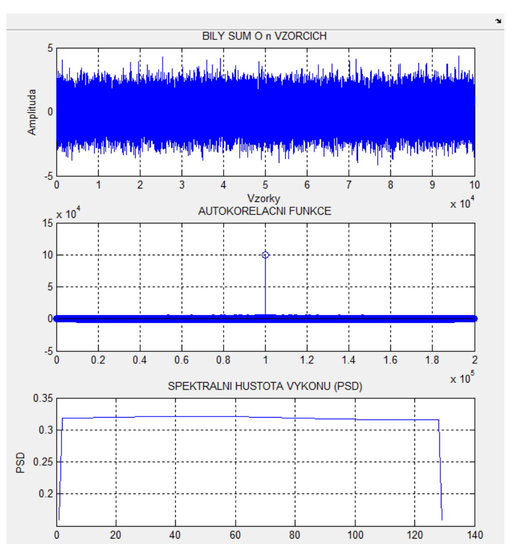


Figure 4: The spectrum of N white noise signal acquisitions.

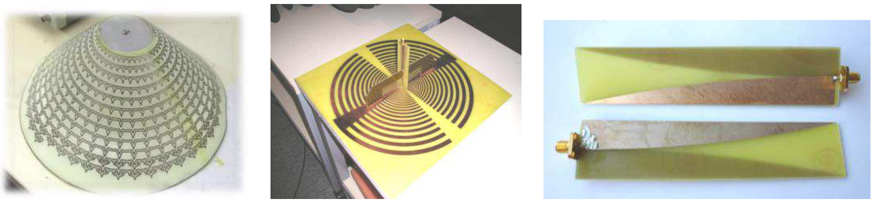


Figure 5: The tested wideband antennas.

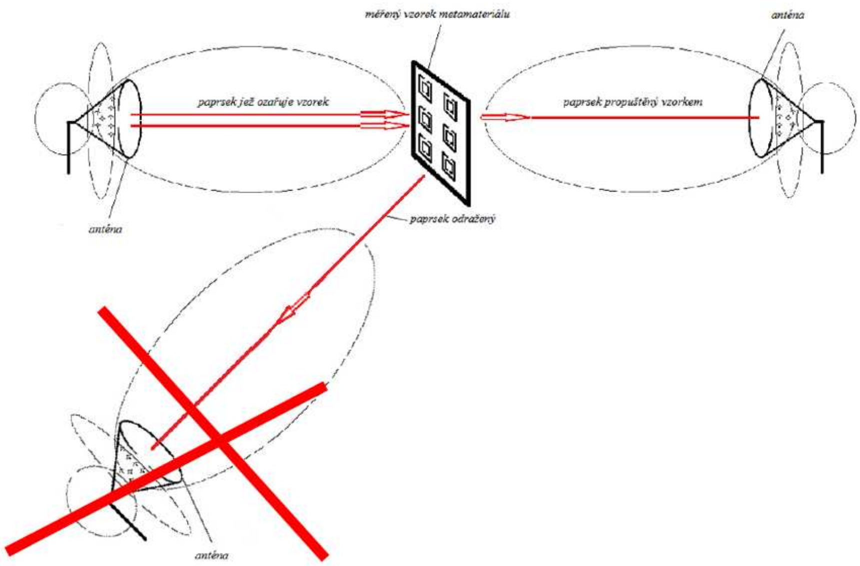


Figure 6: The irradiation of the measured sample, and signal sensing.

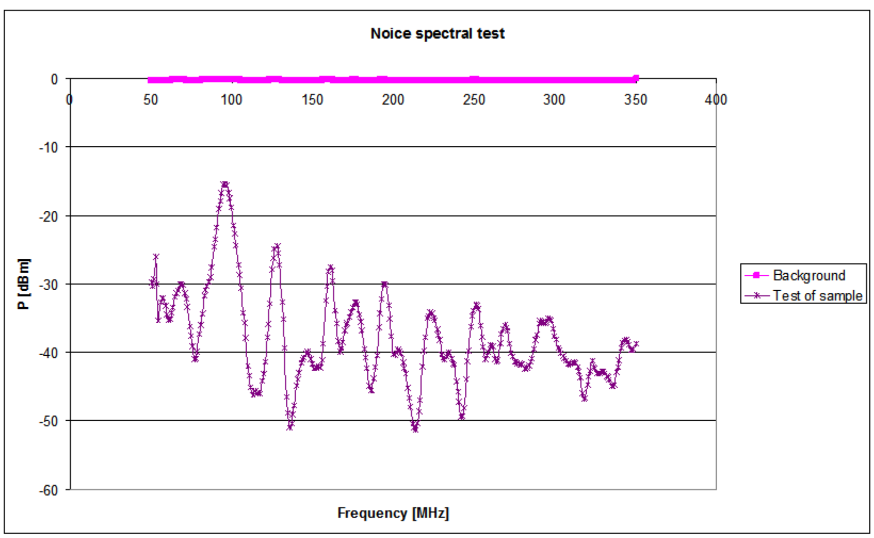


Figure 7: The waveform and spectrum of the noise generator output for the measured sample, f = 50–350 MHz.

was carried out for each sampled frequency, and the incident power spectrum was summed. Thus, we obtained the frequency dependence of the transmitted energy distribution. Generally, if the transmitter/receiver set is not located in a room with a defined spectral absorbance, we can expect uniform energy distribution within the whole frequency range. This record is, at its end, transformed to the frequency dependence of the specific power. In the described manner, we acquired the characteristics of the spectrum measurement background. At this point, the examined sample was placed in the support case; the sample for such application can be layered or periodic, and it is expected to provide the assumed frequency characteristic (Figs. 2 and 3(c)). Subsequently, repeated measurement was performed observing the above-outlined procedure. In the case of a markedly frequency-dependent background, the obtained characteristic can be corrected. Fig. 7 show the frequency dependencies of the measurement setup and the multi-layer material.

4. CONCLUSION

The research paper provides an elementary overview and description of the laboratory equipment for the realization of noise spectroscopy measurement and the related experiments. Noise spectroscopy within the frequency band of between 10 MHz and 10 GHz is realizable using the currently available technologies.

The initial noise spectroscopy testing was carried out in a shielded Faraday room converted to an anechoic chamber, and the later research was confined to the laboratory shown in Fig. 3. The noise source comprised a generator (NC1108A) and an amplifier (NC1128A). The set of tested wideband antennas included conical fractal, Vivaldi, spiral, conical, and periodic dipole devices. The conical fractal antenna proved especially useful for the given purpose.

The problem of the sensitivity and accuracy of the measurement method was solved via repeated measurement and application of the stochastic model principles.

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