On the Possibility of Water Detection under Asphalt Layer Using Microwave Radar System

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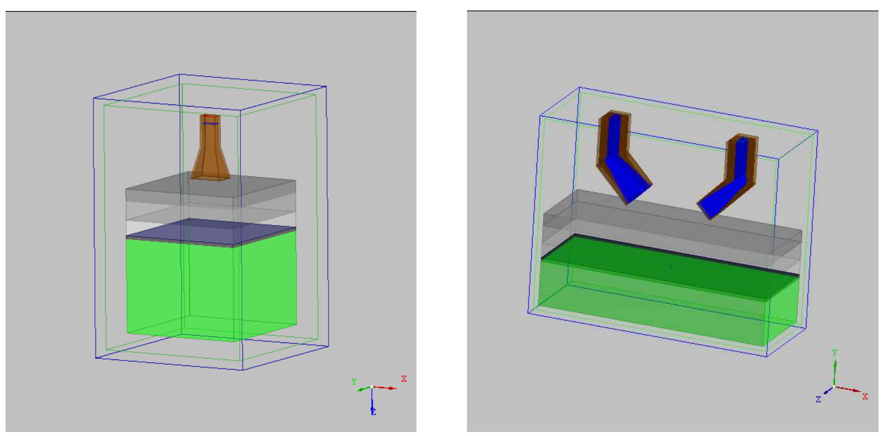
Abstract— The problem of non-destructive evaluation and testing of road quality using microwave radar system is considered. Performance of two types of radar system was studied numerically with FDTD modeling: the system with a single antenna, and the system with two horn antennas. Numerical analysis shows the general ability of microwave radar system to detect thin water layer between asphalt and concrete layers. The details of implementation of the radar system and their influence on the performance are discussed in the paper.

1. INTRODUCTION

Detection of water between asphalt and concrete layers is important part of monitoring and maintenance of road quality. Thin layer of water may cause further damage of the road, and quick discovering of this layer is important for road exploitation services. For the sake of non-destructive evaluation of the road state, different NDE/NDT technologies can be used [1]. In this paper, possibility of application of microwave radar system for detection of water layer under asphalt is explored.

2. METHOD

Two types of radar system are considered in this paper: the system with a single horn antenna (Fig. 1(a)), and the system with two horn antennas (Fig. 1(b)). The performance of the system was estimated numerically with FDTD modeling of wave diffraction on the layers of road using full-wave electromagnetic modeling software Quick Wave-3D [2].



(a) (b)

Figure 1: (a) Numerical model of single antenna and (b) multiple antennas radar systems for detection of water under asphalt layer.

The purpose of the numerical modeling was estimation of the difference in the reflected electromagnetic wave parameters in the cases of presence and absence of the thin water layer between asphalt and concrete layers of the road.

3. RESULTS

During the modeling, the parameters of the road layers were accepted as follows:

- First asphalt layer (Deckschicht): relative permittivity $\varepsilon = 4.2 - j0.06$, thickness $d = 40\,\text{mm}$;
- Second asphalt layer (Binderschicht): $\varepsilon = 4.5 - j0.06$, $d = 60\,\text{mm}$;
- Third asphalt layer (Schutzschicht): $\varepsilon = 4.9 - j0.06$, $d = 50\,\text{mm}$;

- Water layer: $\varepsilon = 77 - j12.09$, thickness is changing between 0 and 5 mm;
- Bitumen layer: $\varepsilon = 2.8 - j0.039$, $d = 10$ mm;
- Concrete layer: $\varepsilon = 4.5 - j0.06$, $d = 150\,\text{mm} \div 300\,\text{mm}$.

The results of modeling of the single antenna system are shown in Fig. 2.

Though the frequency dependence of reflection coefficient S_{11} is different for the cases of presence and absence of water layer, it seems to be difficult to apply this system for practical detection of water layers between asphalt and concrete.

The results of modeling of two-antennas system is shown in Fig. 3. The picture in Fig. 3 corresponds to TM polarization (antenna orientation). It can be seen that the absolute value of the transmission coefficient S_{21} grows gradually with increasing of water layer thickness in the frequency range from 4.8 to 5.6 GHz. This effect can be used for practical detection of water layer between asphalt and concrete and for estimation of the layer thickness.

Additional modeling shows that in case of TE polarization (with horn antennas rotated by 90 degree) this effect is not observed, and the frequency dependence of S_{21} is similar to Fig. 2.

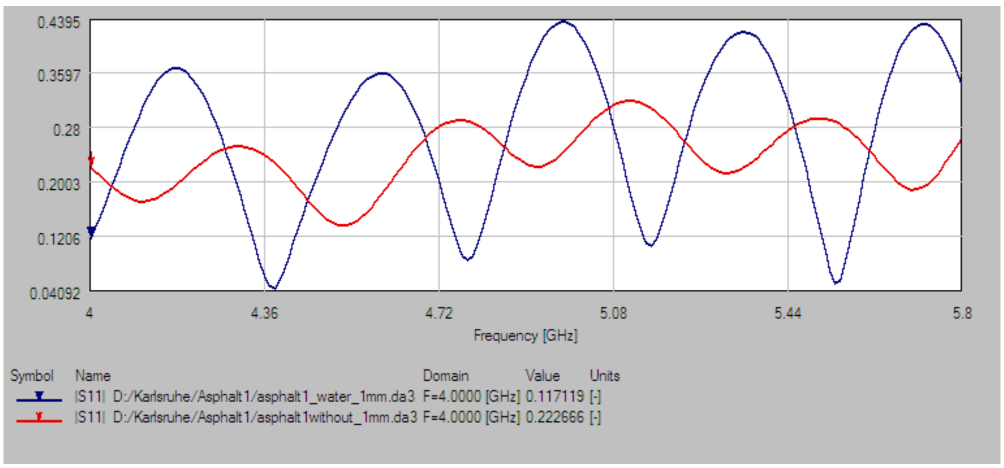


Figure 2: Reflection coefficient S_{11} of road structure with 1 mm water layer (blue line) and without water layer (red line) in the single antenna system.

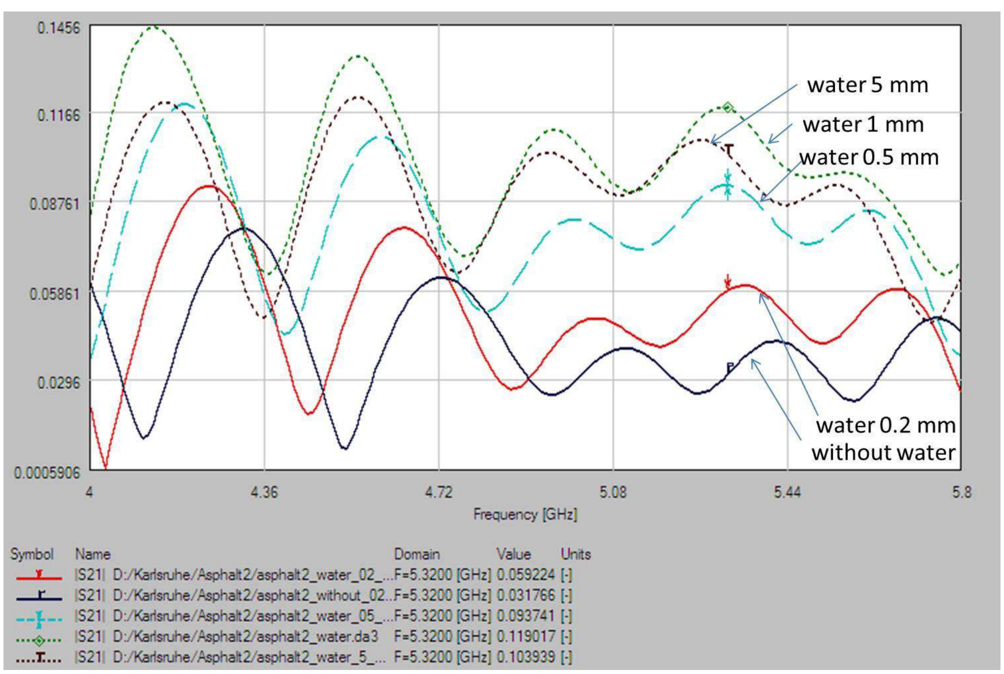


Figure 3: Transmission coefficient S_{21} of road structure in two horn antenna system (TM polarization) with water layer of different thickness.

4. CONCLUSION

Numerical analysis performed in this paper allows making the following conclusions:

- Detection of water layer under asphalt withthe use of microwave energy is possible.
- System with two horn antennas is more sensitive to the water layer in terms of transmission coefficient S_{21} than the single antenna system in terms of reflection coefficient S_{11}.
- System with TE polarization of electromagnetic wave is less sensitive to the water layer in terms of transmission coefficient S_{21}, than the system with TM polarization.
- With increasing of water layer thickness from 0 to 1 mm the difference in S_{21} parameter is increasing gradually, but after 1 mm the difference in S_{21} is small.
- Dissipated power in water layer is of the same values as in the first asphalt layer despite of smaller values in the intermediate layers; this provides potential way of elimination of water from asphalt layer by microwave heating.

REFERENCES

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2. Quick Wave-3DTM, QWED Sp. z o.o., ul. Nowowiejska 28, lok. 32, 02-010 Warsaw, Poland, http://www.qwed.com.pl/.