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THE ROLE OF DEPOLARIZATION EFFECTS IN MOISTURE MEASUREMENTS OF GRANULAR MATERIALS

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Abstract: The paper presents experimental study of depolarization effects taken place in granular materials illuminated by both coherent and incoherent (noise like) sources in 75-110 GHz. The measurements have been performed in free space using receiving and transmitting linear polarised horn antennas. Wide band mm-wave sensor with total 12 GHz bandwidth has been developed to be used for incoherent experiments. The transmittance through granular materials with size of particles 2-3 mm have been measured for co-polarised and cross-polarized orientations of horn antennas. Strong depolarization effects in both orientations of antennas have been found out at some frequencies. However, illumination by incoherent signal has effectively suppressed depolarisation effects. So, such a noise source is strongly recommended for estimating moisture content when the dimensions of particle are compared with a wavelength. Examples of determination of moisture contents using mm-wave incoherent source are reported.

Key words: granular materials, scattering coherent-incoherent polarization, moisture content, mm-waves measurements.

1. INTRODUCTION

Moisture measurement of granular materials is of interest for many industrial and scientific purposes. Their dielectric properties depend on many parameters including density, frequency, temperature, shape of granules etc. Investigation of a behavior of complex permittivity when these factors are varied is becoming important for better understanding of an interaction of electromagnetic waves with granular materials and optimum design of proper moisture meters.

There are many publications estimating the role of these factors basically when dimensions of particles are much less of a wavelength [1-4]. But few of them have considered the role of depolarization effects [5, 6] that are becoming very important for characterization materials when dimensions of particle are compared with a wavelength. Most important feature of numerous microwave methods operating in frequency domain is an application of coherent sources. When granular materials are considered the scattering and depolarization effects may also cause strong interference signal variations that can prevent the experimenter to measure true attenuation of the wave propagating throughout the testing cell. One of the ways to solve the problem is to employ incoherent like a noise source of illumination. [7].

Since we are going to compare forward scattering for coherent and incoherent illuminations, the two experimental setups have been assembled both using a free space technique. Agilent-8757D Network Analyser was employed for coherent forward scattering experiments. To perform incoherent experiments we have developed wide band noise sensor operating in the W-band. Granular polymer materials under study have been placed into the foam polystyrene container transparent for mm-waves in both experimental setups that permitted to compare the role of depolarisation effects more accurately. The two shapes of granules were studied: spheroids of the diameter d = 3/32" (Nylon, Teflon), and d = 1/8" (Polypropylene).

Granules distributions within container are similar to investigated in [8] and shown in Fig.1. The diameter of container D = 27mm and single layer configurations have been investigated in all experiments described in the paper.

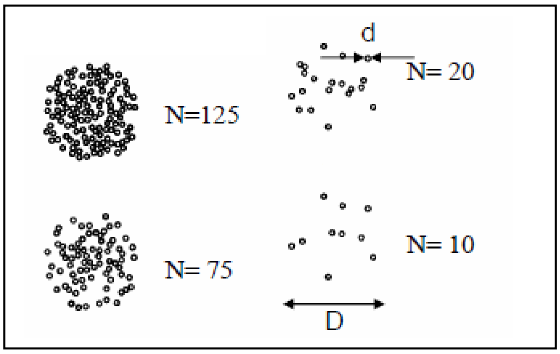

Figure 1 – Examples granules distribution within the container

2. COHERENT FORWARD SCATTERING EXPERIMENTS

The RF part of experimental setup used for measuring forward scattering losses in granular materials illuminated by coherent signal is shown in Fig.2. The foam polystyrene

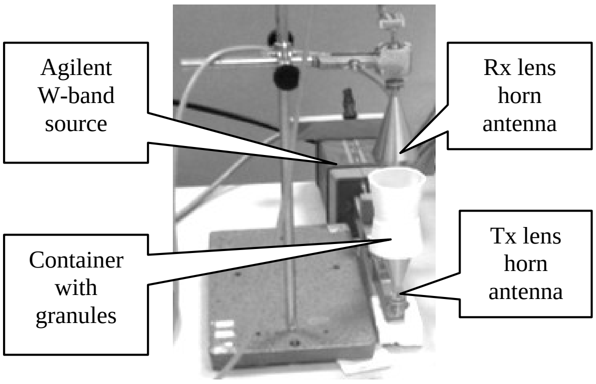

Figure 2 – RF part of the experimental setup used for coherent experiments with granular materials

container being transparent for mm-waves is filled with polymer granules placed between transmitting (Tx) and receiving (Rx) identical horn-lens antennas. They have the gain about 30 dB and the beamwidth about 5 deg. on the 3 dB level. Agilent W-band source connected with Agilent-8757D Network Analyser was employed for measuring coherent forward scattering loss.

Examples of measured forward scattering losses for spheroid shaped granules are shown in Fig.3: Nylon (A), Teflon (B) and Polypropylene (C). The measurements were done for co-polarized alignment of R_x and T_x antennas and different number N of particles in the container, N = 20, 60 and 100.

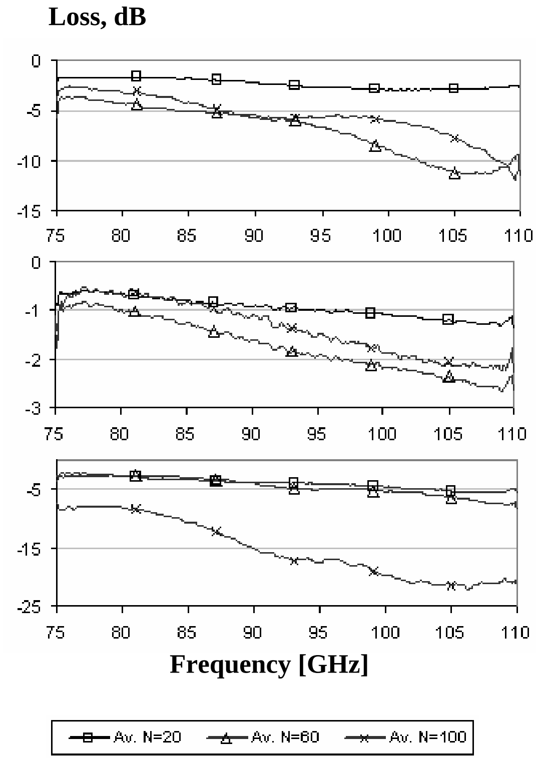

Figure 3 – Measured coherent forward scattering losses for different spheroid granules (A - Nylon, B - Teflon, C – Polypropylene) after averaging in co-polarized antennas alignment with number of particles N = 20, 60, 100

There is observed a valuable increase of the losses as frequency increased that can not be explained by bulky material behavior in frequency domain. For example, Polypropylene granules (N=100) has demonstrated strong variation of co-polarized loss more than 10 dB in the range 75-110 GHz. Similar experiments have been carried out for cross-polarized alignment of Rx and T_x antennas. As an example, measured forward scattering cross-polarized losses are depicted in Fig.4 for Polypropylene granules. There is observed decreasing cross-polarized loss for N=20.

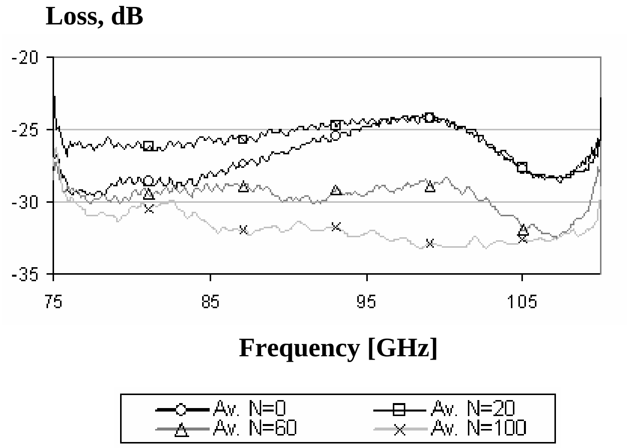

Figure 4 – Measured coherent forward scattering losses for different spheroid granules Polypropylene after averaging in cross-polarized antennas alignment and number particles N = 20, 60, 100

In general, forward scattering power component $P_{forward}$ consists of the two parts: co-polarized power $P_{co\text{-}pol}$ and cross-polarized power $P_{cross\text{-}pol}$ resulting in $P_{forward} = P_{co\text{-}pol} + P_{cross\text{-}pol}$. The observed behavior clearly indicates existing depolarization effects depending on the ensemble structure – different N number.

3. INCOHERENT FORWARD SCATTERING EXPERIMENTS

3.1. Wide band mm-wave sensor

To carry out incoherent forward scattering experiments the wide band mm-wave sensor has been developed. Its schematic is shown in Fig.5. Receiving antenna (R_x) is connected with the W-band LNA (gain about 15 dB), then the signal is down-converted by mixer with IMPATT LO (94 GHz). The IF signal is amplified by wideband amplifier (gain about 70 dB) with the bandwidth about 6 GHz so that the total double-side bandwidth is 12 GHz. Wideband HP-423A detector and Tektronix Digital Scope are employed for recording forward scattering signals.

W-band FARRAN noise source has been used for incoherent illumination of the container with material under test. Figure 6 shows the signal at the detector output recorded by the scope when the noise source is pulse modulated. The Δ_{up} and Δ_{down} correspond to the “cold” and “hot” states of the noise source.

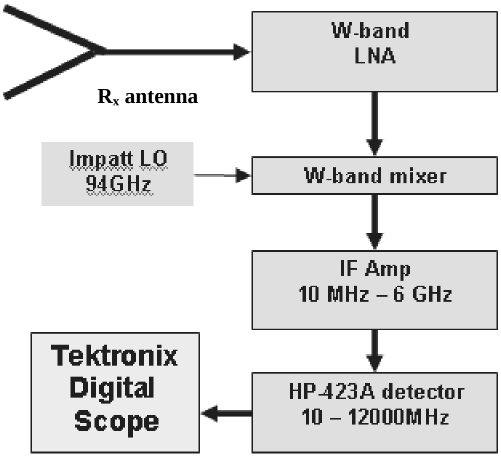

Figure 5 – Schematic of W-band sensor used for incoherent experiments

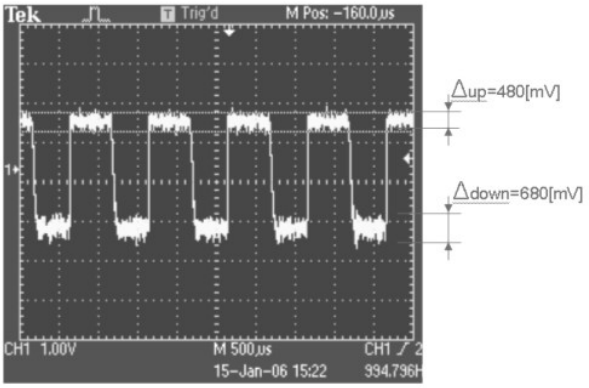

Figure 6 – Recorded detector's output for pulse modulated noise source in the "cold" and "hot" states of the noise source.

3.2. Incoherent forward scattering results

The experimental setup used for incoherent forward scattering experiments was the same schematic as depicted in Fig. 2 but the Agilent W-band source is replaced by FARRAN W-band noise source and the above mentioned wide band mm-wave sensor was used to measure transmitting signal. To observe the forward scattering signal in frequency domain we have connected Anritsu Spectrum Analyser at the IF amplifier output of the sensor. Some typical results recorded for spheroid granules (Polypropylene) illuminated by incoherent radiation are shown in Fig.7.

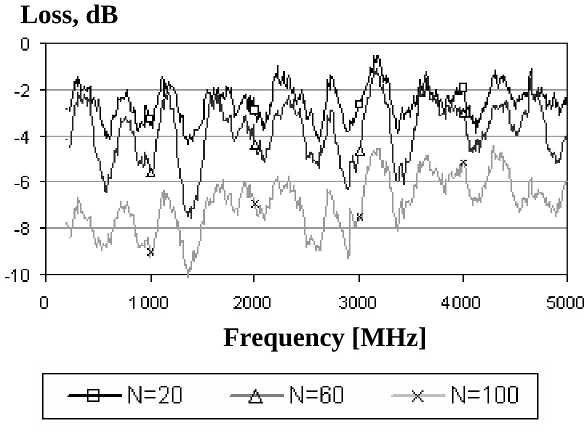

Figure 7 – Recorded forward scattering signals in IF frequency domain for Polypropylene granules illuminated by incoherent source

Comparison with the coherent experiments of the same material reveals considerable reduction of forward scattering losses when incoherent source has been applied. Since depolarization effects are frequency sensitive, the application of incoherent source leads to their averaging in frequency domain resulting the efficient suppressing of factors causing depolarization.

4. APPLICATION OF INCOHERENT RADIATION FOR MOISTURE CONTENT DETERMINATION

Most widely used microwave moisture meters are based on strong correlation between insertion loss and water content in a bulky materials under test. When size of particles of granular material is compared with wavelength depolarization effects may cause additional increasing forward scattering loss which may drastically increase the error in moisture content determination.

In order to illustrate the role of this phenomenon we have compared the forward scattering losses in wet sand with known moisture content. The samples have been placed in the container illuminated both coherent and incoherent signals. The results of such measurements in W-band are shown in Fig. 8. Due to natural imperfections within sand samples the depolarization leads to additional increasing loss for coherent radiation compared with incoherent one. Discrepancy in measured loss is about 5-10 dB that is in principle unacceptable for accurate moisture determination.

5. CONCLUSION

The paper has demonstrated the role of depolarizing effects in granular materials when their particle dimensions are comparable with wavelength. Comparison of measured forward scattering losses for coherent and incoherent (noise like) illuminations has revealed essential difference. The noise like illumination suppresses depolarization effects due to averaging in frequency domain. So that the measured losses of granular materials are more close reflects bulky materials properties. As a result, incoherent sources are recommended to be employed for moisture determination in the situations considered.

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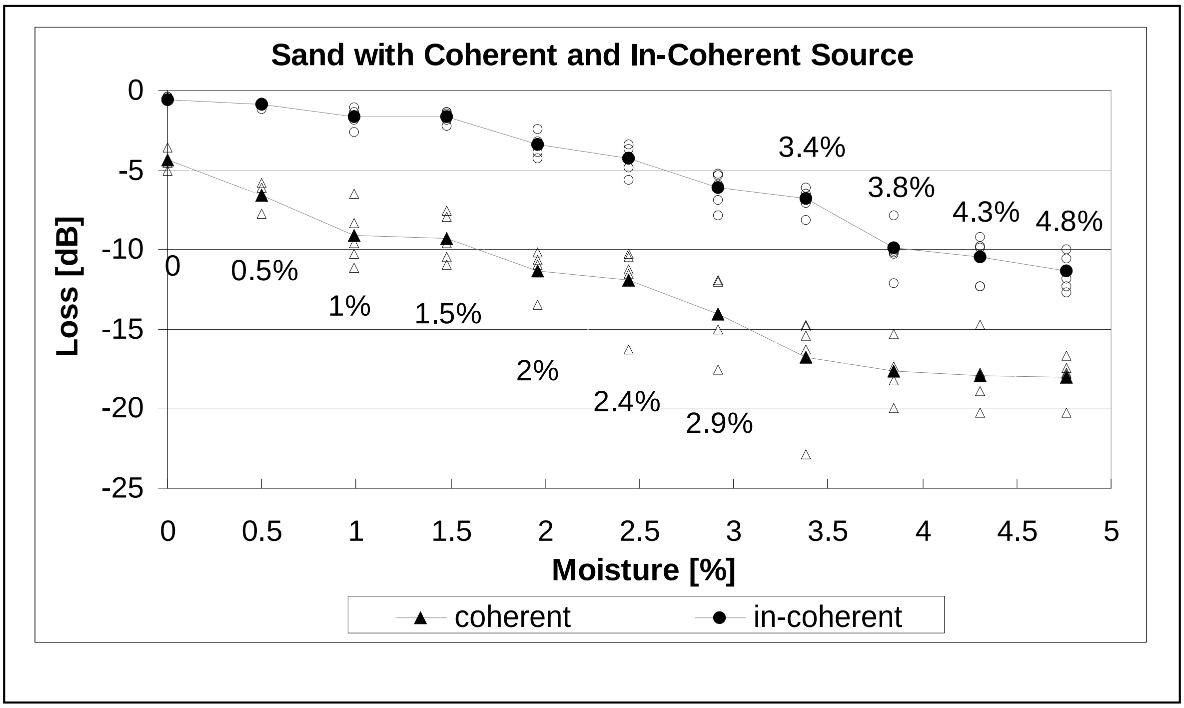

Figure 8– Measured forward scattering loss as a function of moisture content for coherent and incoherent illuminations of the wet sand samples

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