MILLIMETER WAVES SENSING BEHIND WALLS - FESEABILITY STUDY WITH FEL RADIATION*

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Abstract

Design of through-wall imaging (TWI) system needs the knowledge of constitutive parameters of different building materials. The paper describes the results of measurements of the effective attenuation constant of typical building materials such as concrete bricks, wood, tiles, sand, gypsum, etc. on mm-waves using powerful pulse FEL radiation. Since the Rayleigh criterion for surface roughness cannot be satisfied for majority of measured building materials on mm waves, the increased measured attenuation in comparison with bulky material is taken place. Additional experiments were performed to estimate a role of these effects using quasi-noise mm-wave source and wide-band mm-wave receiver.

INTRODUCTION

The through-wall imaging (TWI) systems provide unique possibility to detect and image objects behind the walls, door and other opaque medium [1, 2]. Basically, through-wall imaging (TWI) systems operate in 1.99 – 10.6 GHz or below 960 MHz [3]. The penetration capability at these frequencies is characterized by rather small attenuation caused by building material as shown in Fig.1 [4]. However, the spatial resolution of TWI systems is degraded when the operating frequency is relatively low. On the other hand, a majority of building materials demonstrate increased losses as the frequency increases. As a result, higher RF power from the source is required for quality TWI process.

The Israeli mm-wave FEL provides unique opportunity to solve the above TWI problem delivering an output power of 100-1000W at 85-105 GHz. But design of TWI system operating on mm-waves needs comprehensive study of constitutive parameters of different building materials that must be measured in real pulse operation FEL conditions. The paper describes the experimental setup assembled for measurements of the effective attenuation constant of typical building materials such as concrete bricks, wood, tiles, sand, gypsum, etc. on mm-waves using powerful FEL radiation. Since the Rayleigh criterion for surface roughness at mm-waves cannot be satisfied for majority of measured materials, the measured attenuation is different in comparison with bulky material. Additional experiments were performed to estimate a contribution of this effect into the measured attenuation. The special W-band quasi-noise sensor has been designed and assembled to carry out such experiments.

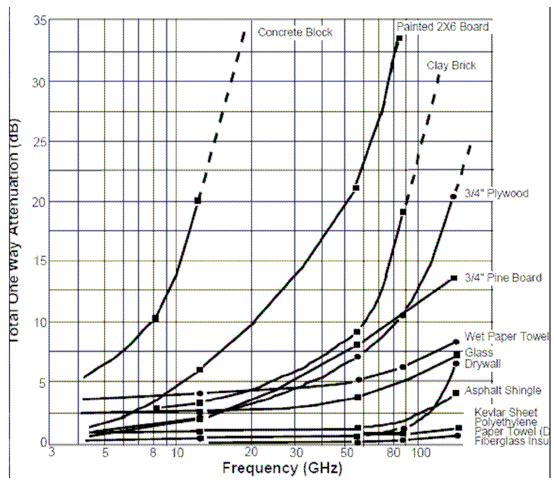

Figure 1: Illustration of penetration capabilities of different building materials as a function of frequency [4].

EXPERIMENTAL SETUP AND CALIBRATION PROCEDURE

The block-diagram of the experimental setup used for measurement of effective attenuation constant is shown in Fig.2. The pulse mm-wave FEL radiation (5-10 μs) propagating in the corrugated wave guide line excites the Tx standard rectangular horn antenna that transforms it to plane wave. This wave partially penetrates though the sample of the tested material and is captured by a similiar Rx antenna coupled with the W-band programmable attenuator and DXP-10 detector (Millitech). A similar detector is coupled with the directional couplers providing a total coupling level of -64dB. Both detected signals are independently recorded by the Tektronix digital scope.

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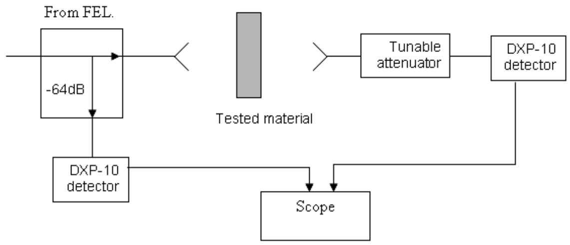

Figure 2: The block-diagram of the experimental setup.

Several detectors were preliminary compared in order to choose the two maximally identical units. A general view of the experimental setup is shown in Fig.3.

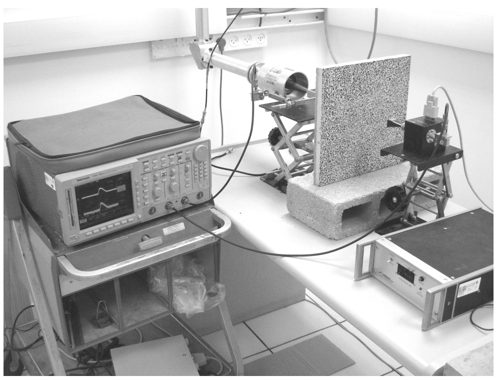

Figure 3: A general view of the experimental setup.

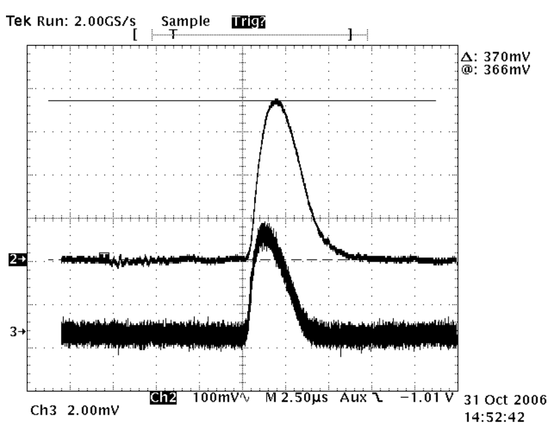

Figure 4: Examples of the detected signals recorded by the digital scope in process of calibration (channel 2 - Rx detector, channel 3 - Tx detector).

Calibration of the setup shown in Fig. 2 was done using free space conditions. Typical detected signals recorded by the digital scope in channel 2 (Rx detector) and channel 3 (Tx detector) are depicted in Fig. 4. Based on this calibration, we have found out that the RF peak power at the FEL output – 150W in the vicinity of 100GHz. When material under test is inserted between Rx and Tx antennas, the detected signal is reduced depending on material transmittance. By adjusting the variable attenuator we can restore the original amplitude of the signal in the Rx channel. The difference of the attenuator readings corresponding to the two situations gives directly the effective attenuation. The only factor that must be taken into account is the variation of the FEL's radiated power from pulse to pulse. However, suitable correction can be easily introduced into the measurements since the Tx detector in channel 3 continuously controls this parameter.

CHARACTERIZATION OF BULDING MATERILAS USING MM-WAVE PULSE RADIATION OF THE FEL

The effective attenuation of various building materials has been measured using mm-wave pulse radiation of the FEL as described in the previous section. Various materials were tested. Some selected results are presented in the Table.1 for cement plate, gypsum board and wood board.

Table 1: Measured effective attenuation of the selected building materials

Type of the material	Effective attenuation [dB]	Comments
one layer of wood board, 2cm	-19	Horizontal polarization
one layer of wood board, 2cm	-20.4	Vertical polarization
two layers of wood board, 4cm	-41.6	Both are in Vertical polarization
one layer of gypsum board, 1.2cm	- 3.5	- - -
one plate of cement tile, 2.5cm	-39.3	Vertical polarization
one plate of cement tile, 2.5cm	-39.5	Horizontal polarization

All samples of materials under test were examined in both orthogonal polarizations – horizontal and vertical. Most of building materials have a textureand demonstrate polarization sensitivity of the measured attenuation. However, the gypsum plate is quite uniform and insensitive to the polarisation of the radiated wave.

CHARACTERIZATION OF BULDING MATERILAS USING MM-WAVE QUASI-NOISE ILLUMINATION

Basically, constitutive parameters of many building materials are characterized using coherent illumination. However, TWI systems operate with UWB signals that leads to uncertainty in estimation of their real penetration capabilities. The best way to solve this problem is to measure an attenuation applying incoherent (quasi-noise) illumination. We have developed and assembled a wide band mm-wave sensor for experiments with quasi-noise signals schematically depicted in Fig. 5.

The sensor is based on heterodyne circuitry consisting of the receiving antenna connected with the W-band pin-diode modulator that provides 1 KHz pulse modulation of the received signal. Then the signal comes to W-band LNA (gain about 15 dB) and down-converted by mixer with IMPATT LO operating at 94GHz. The IF signal is amplified about 70 dB by IF LNA with 6 GHz bandwidth so that the total double-side bandwidth of the received signal is about 12 GHz. The wideband HP-423A detector, post detector's video-amp and Tektronix Digital Scope are employed for recording the signals propagating through the material under test. Full W-band FARRAN noise generator has been used as the source of incoherent illumination of the container with materials under measurements. The general view of the setup used for quasi-noise characterization of building materials is shown in Fig. 6. W-band FARRAN noise generator is placed beneath container and invisible.

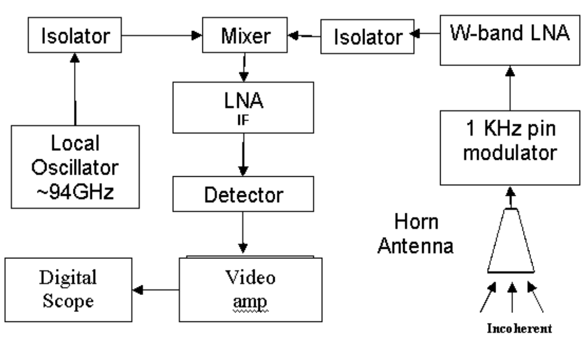

Figure 5: Schematic of the wide band mm-wave sensor.

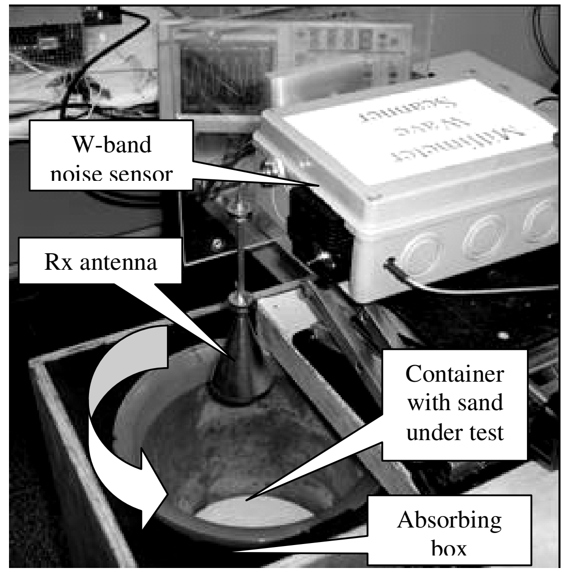

Figure 6: The general view of the setup used for quasi-noise characterization of building materials.

The setup depicted in Fig.6 was employed for measurement of an attenuation of the sand samples with different thickness. To estimate the role of depolarisation effects the container with sand was rotated and the effective attenuation has been measured for different angular orientations of the sand sample.

Typical measured attenuation as a function of sand's layer thickness is shown in Fig. 7 for the four angular position of container: ooo - 0 deg, xxx – 90 deg, ◊ ◊ ◊ - 180 deg and □□□ – 270 deg. The averaged result is plotted by the solid line.

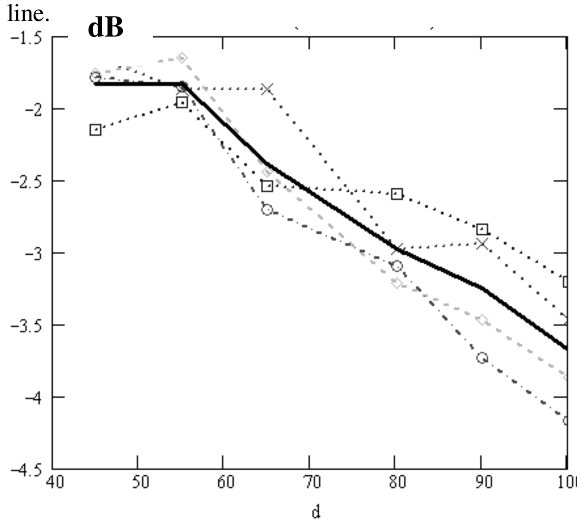

Figure 7: Measured attenuation for quasi-noise illumination in W-band as a function of sand's layer thickness for the four angular position of container: ooo - 0 deg, xxx – 90 deg, ◊ ◊ ◊ - 180 deg and □□□ – 270 deg. The solid line corresponds to the averaged result.

The same samples of sand have also been tested using coherent illuminations by means of Agilent W-band network analyzer at the frequency 100 GHz. The effective attenuation is depicted in Fig. 8 as a function of the thickness for the four angular position of the container as was done in previous experiments. We observed high variations of the measured attenuation as a function of thickness. It can not explained by properties of bulky material. The most realistic interpretation of such behaviour is interference on boundaries sand-air, surface roughness and possible depolarisation effects.

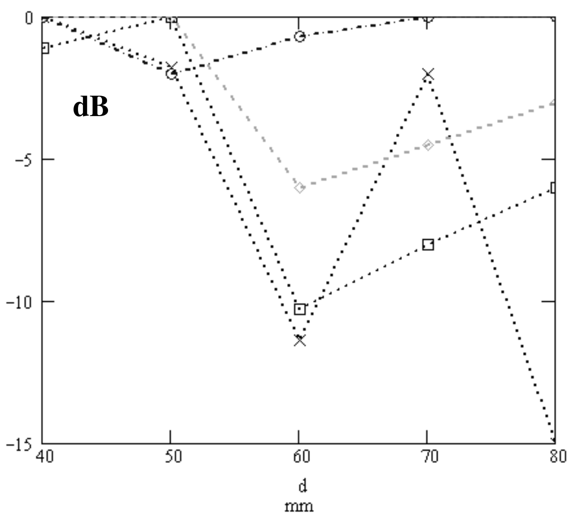

Figure 8: Measured attenuation for coherent illumination at 100 GHz as a function of sand's layer thickness for the four angular position of container: ooo - 0 deg, xxx – 90 deg, ◊ ◊ ◊ - 180 deg and □□□ – 270 deg.

CONCLUSION

The paper has presented results of measurements of effective attenuation of various building materials using powerful FEL radiation on mm-waves. Comparison of the measured losses for coherent and incoherent illuminations has revealed essential differences. The noise-like illumination suppresses interference and depolarization effects due to natural averaging in frequency domain. That can be recommended for characterization of building materials to provide more realistic data needed for design mm-wave TWI systems. The short pulse FEL generating a wide-band spectrum is a good candidate for this purpose.

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