Polarimetric Submillimeterwave Reflectometry using a Real-Time Quasi-Optical System

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Abstract

First measurements of the reflectivity of different natural and artificial materials in the 600 GHz range are reported. The investigations were carried out using a heterodyne broadband dual-polarization reflectometer in quasi-optical technique.

Comparing to Fourier-transform spectrometers the described reflectometer is capable to carry out real-time measurements even outside the laboratory. Reflectivity data of several interesting materials are presented in co- and crosspolarization.

1. Introduction

A knowledge of the reflectivity of natural and artificial materials is important for the design of remote-sensing systems like radars and radiometers in order to get an impression of possible target reflectivities but also the performance of some artificial materials like absorbers or dielectrics is of extreme importance for the design of those systems.

In the submillimeterwave range most of the reflectivity measurements are carried out using Fourier-transform spectrometers (FTS) which are related to IR measurement techniques. The measurement procedure comprises the data sampling, the Fourier transformation and filtering of the data and thus only can be carried out in a laboratory. Unfortunately an improvement in the frequency resolution directly leads to increased spectrometer dimensions.

Our approach, however, is not related to the IR range but to conventional microwave remote measurement techniques like radar. The measurements can therefore in principle be carried out outside the lab. Additionally the system delivers reflectivity data in real time and its resolution is only limited by the bandwidth of the transmitter oscillator and the IF-filters.

2. The Reflectometer System

The measurement setup consists of three major parts: a transmitter source, a local oscillator system and the transmitter/receiver optics where the signal processing is carried out.

A carcinotron (backward-wave oscillator) is employed as the transmitter source. It is tuneable in frequency from 550 to 610 GHz and delivers an output power of 4.8 mW coupled out with a dual-mode horn.

The local oscillator system consists of a molecular gas laser which is optically pumped by a CO_2-Laser. The actual submillimeter wavelength depends upon the laser medium which in our case is formic acid ($HCOOH$). The output power is 1.5 mW at a wavelength of 513 μm (584.4 GHz).

Gaussian optics were used to design the transmitter/receiver optics. In contrast to most other submillimeterwave systems which consist of a fixed optical circuitry our system employs a "chessboard"-like platform /1/ on which the optical circuit is realized according to the desired measurement task. On each of the squares of our "chessboard" a quasi-optical component can be placed. In our case waveguiding is performed by lenses but also elliptical off-axis mirrors might be used.

Between two consecutive lenses we can place quasi-optical signal processing components like mirrors, wire-grid polarizers, dielectric sheets or metallic meshes and components which are composed of those elements like attenuators, diplexers and filters. The whole setup is designed frequency independent.

Fig. 1 shows the quasi-optical circuitry for our heterodyne polarimetric reflectometer. The beam of the carcinotron transmitter source is coupled into the beam waveguide via the input coupling lens ICL1. After passing the lens BWL1 the beam is deflected and is guided via BWL2 and BWL3 to the transmitter lens TL1 where the beam leaves the platform. Note that the transmitted beam is polarized perpendicular to the platform. The detector D1 allows a control of the transmitter power.

The sample S is placed in the beam waist (radius 12 mm) to provide approximately plane wave conditions. After being reflected (or scattered) from the sample a part of the power returns to the platform, passes TL1 and is then guided to the input ports of the two receiver channels depending on their polarization.

The copolarized part is guided via the dielectric beam splitter DBS1 to the Martin-Puplett-Diplexer MPD1 which consists of a vertical polarizer VP1, a diagonal polarizer DP1, a fixed rooftop mirror RM1 and a moveable rooftop mirror MRM1 which is driven by a stepper motor. Here the signal beam is combined with the LO beam.

Mixing is performed in an open structure Schottky-diode mixer SM1 which is equiped with an ultra-broadband RF choke structure /2/ thus allowing to use the whole carcinotron tuning range.

For the crosspolarized part of the reflected wave it is essentially the same: the horizontal polarizer HP1 guides the power to MPD2.

The LO beam itself is also polarized perpendicular to the platform. For the use in MPD1 the polarization of the LO beam has thus be turned by 90° in the polarization rotator PR1. To switch between the two channels the beam switch BS1 is used.

Finally the power and the frequency at the IF ports of the two Schottky-diode mixers were measured using a spectrum analyzer. We define the reflectivity R to be

$$R = \frac{P_e}{P_i} \qquad (1)$$

where P_i is the power incident on the sample and P_e is the power emerging from the sample in the direction of the incident beam. Similarly the return loss is defined as

$${}^{l}R = 10 \log \left\{ \frac{P_e}{P_i} \right\} \qquad (2)$$

The return loss was then determined with respect to a polished aluminium plate for the copolarized part and to a wire grid turned to 45° for the crosspolarized part. Diode calibration was performed with a calibrated attenuator not shown in Fig. 1. The dynamic range of the measurements was 44 dB in the copolarization and 40 dB in the crosspolarization.

3. Reflectivity Measurements

First we measured the reflectivity of different dielectric slabs because they can be used as reflectivity standards and are therefore useful to test the setup. On the other hand the return loss of a dielectric lens is an important figure for the design of quasi-optical submillimeterwave systems. The results lay well within ± 10 % of the expected values.

Nevertheless the finite thickness of the slabs causes standing wave effects which were the reason for the tolerances. As the thickness could not be determined within a few micrometers the error became too large for a precise measurement. For reflectivity measurement of dielectrics with low transmission loss it is therefore more appropriate to use prism-shaped samples, but good results were obtained with high-absorptive dielectrics. For the calibration of the reflectometer, however, we used wire grid polarizers turned to a certain angle to the transmitter polarization to result in a well-defined reflectivity in the co- and the crosspolarization.

Next we were interested in the performance of absorbers in this frequency range. As an example eccosorb was measured under room temperature and at 77 K (liquid nitrogen). This

Material	Copolarization		Crosspolarization	
	R/%	^{l}R/dB	R/%	^{l}R/dB
Teflon	6.7	-11.7		
Polyethylene	4.7	-13.2	0.1	-30
TPX	2	-16.9		
Fused Silica	4.7	-13.2		
eccosorb AN 77:				
T = 290 K	0.5	-33	0.4	-34
T = 77 K (under 20 mm LN_2)	0.16	-38	0.01	-40
T = 77 K (cooled from backside)	0.6	-32	0.5	-33
IR-Absorptive Paint on Metal	75	-1.2		
Heat-Resistive Black Paint on Metal	14	-8.5		
Oak Wood	15	-8.5		
Water	15.8	-8	3.16	-15
Sand (dry)	0.16	-28	1.6	-18
Sand (wet)	0.25	-26	1.0	-20
Sand (1 mm) on Metal	0.63	-22		
Franconian Soil	0.16	-28	1.6	-18

Table 1: Measured reflectivities of technical and natural materials at 580 GHz

could be of interest for the design of hot and cold loads in radiometer systems. We found that the reflection loss even increases with about 20 mm of liquid nitrogen over the absorber. A decrease of the reflection loss occurs when the eccosorb is cooled from its backside thus resulting in a thin ice layer on the surface. Nevertheless we found a good performance in this frequency range.

Certain samples of IR-absorptive paint on metal however which should have return losses of the order of -20 dB at 10 μm showed reflectivity values of 75 % which corresponds to a return loss of 1.2 dB.

Finally we measured some natural materials like wood, sand, soil and water. To measure the latter ones the beam emerging the transmitter lens was vertically deflected by an additional 45°-mirror. It is interesting that most of the natural materials showed return losses in the -20 dB range which is quite different from results received at millimeter wavelengths. A complete set of measured reflectivity data is presented in Tab. 1.

4. Conclusion

A new reflectometer concept for the submillimeterwave region has proven to be useful for the measurement of different materials and for future tasks in Radar engineering and environmental protection in this frequency range because of its higher bandwidth and real-time measurement capabilities.

Interesting reflectivity behaviour of different materials show the evidence to continue the work in this field.

5. References

/1/ Lesurf, J.C.G.: Millimetre-wave Optics, Devices and Systems, Adam Hilger, Bristol and New York, 1990, chap. 10

/2/ Brune, J.: An Open Structure 600 GHz Mixer with Broadband IF Output Coupling, 21st European Microwave Conference, Stuttgart, 1991, pp. 247-252

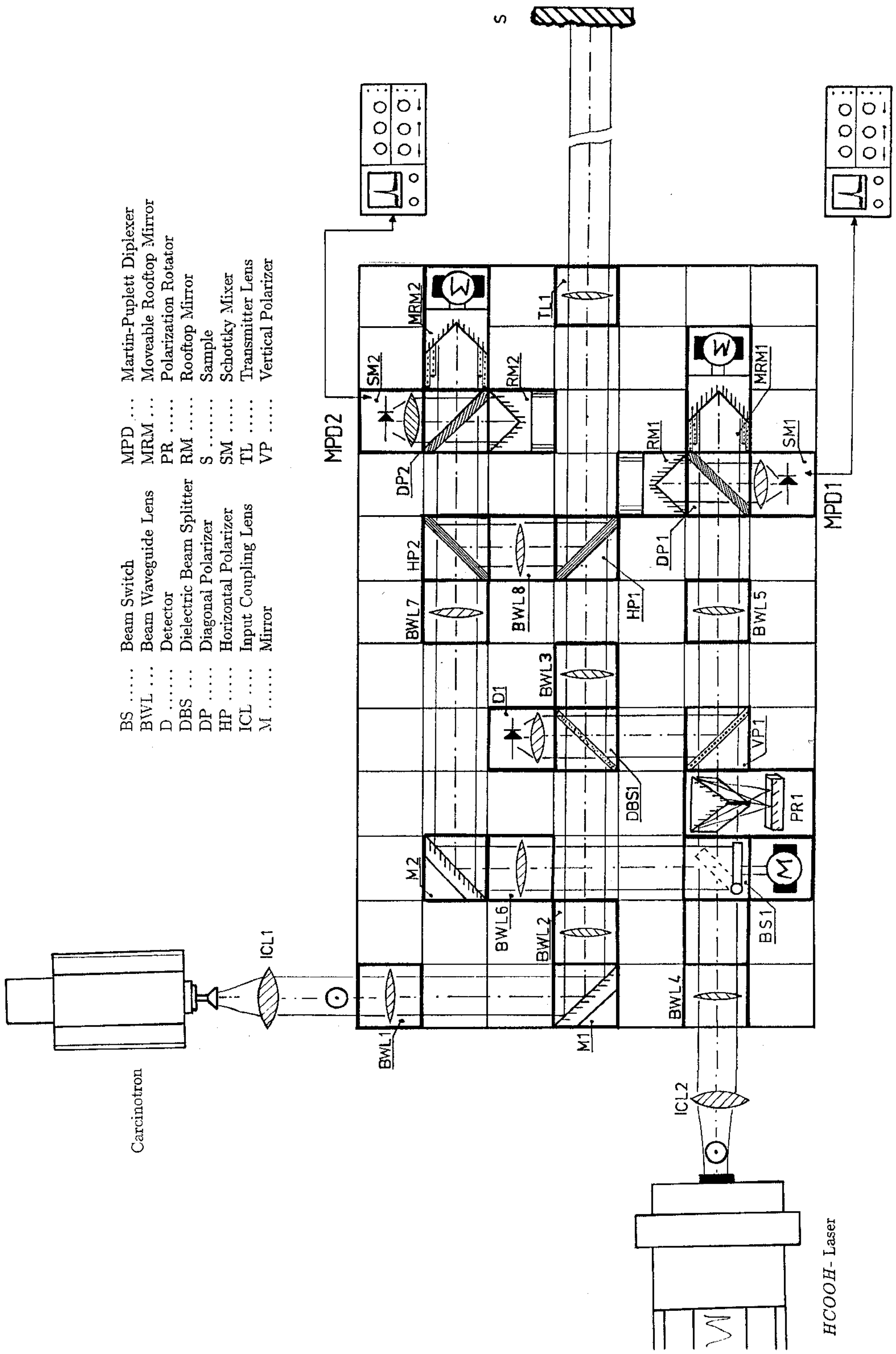

Figure 1: Principle of the polarimetric heterodyne reflectometer