Time Domain Material Characterizations Using Leaky Lens Antennas

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Abstract

A novel time domain methodology to find the permittivity of materials at mm-wave frequencies is investigated. A wide-band, and non-dispersive leaky lens antenna together with an in-house fabricated wavelet generator, transmit high frequency short pulses through a dielectric slab. A non-dispersive dielectric represents an amplitude change due to the losses and the mismatch at the dielectric interface and a delay in the time domain signal that associated with the permittivity. The effects of a plexiglas dielectric slab on the time domain signal is shown and the delay in the signal is used to find the permittivity of the slab.

1. Introduction

The demand to increase the bandwidth and moving up in the frequency requires a lot of research on the materials over the different frequency bands. Material measurements are often performed using waveguides, cavities, coaxial cables, or probes at microwave frequencies and spectroscopy at THz and optical frequencies [1]. The need to have a flexible setup that can be used for different dimensions and shapes of the materials makes the free space material measurement method very popular among different existing methods. Free space measurements in time domain are mostly restricted by the bandwidth of the antennas or the phase centers vary by the frequency.

In this paper we propose a lens antenna system that consists of a leaky lens antenna [2] connected to an in-house fabricated wavelet generator at the transmitter and the receiving side is an identical lens antenna connected to a sampling oscilloscope [3, 4]. The wavelet generator produces 100 ps long pulses with the center frequency at 60 GHz. The pules are sent through the leaky lens antenna that has an almost constant phase center and does not distort the pulse shape. The transmitted signal passes through the object and it will be delayed and distorted based on the material of the object. Then the received signal is compared to the reference signal. For a non-magnetic, non-dispersive, and low loss materials the delay in the signal is sufficient to find the permittivity of the material.

2. Materials and methods

An in house fabricated wavelet generator consisting of a fast switching metal-oxide-semiconductor field-effect-transistor (MOSFET) in series with a resonant tunneling diode (RTD) is used to generate short pulses in the mm-wave frequency range [3]. The wavelet generator converts the 100 ps long baseband pulses to the center frequency $f = 60\,\text{GHz}$. Then this modulated signal is transmitted using a non-dispersive leaky lens antenna. The antenna reflection coefficient is below $-10\,\text{dB}$ over the frequency range $[15, 67]\,\text{GHz}$ and the half power beam width (HPBW) is less than 20° over the entire operating bandwidth and is about 11° at 60 GHz [4].

The transmitting and receiving antennas are separated by 50 cm and the receiving antenna is connected to the sampling head of a LeCroy WaveExpert 100H sampling oscilloscope. The received signal is averaged over 1000 pulses and time gating has also been applied to remove all other unwanted reflections and interferences that arrive after the main pulse. The material measurement is done by inserting a planar material between two antennas and comparing the received signal to the case with no object between two antennas. The delay between two signals corresponds to the permittivity of the material.

3. Results and discussion

A plexiglas sample with the dimensions of $2 \times 30 \times 30\,\text{cm}^3$ is placed at the midpoint between two antennas. Since the size of the object is much greater than the HPBW illumination, the edge effects can be ignored. A 100 ps pulse is then transmitted through the material sample in the absence and the presence of the object. The solid curve in Figure 1 shows the received signal in the absence of the object and dashed curve represents the received signal in the presence of the object. The object delays the signal by 39.4 ps.

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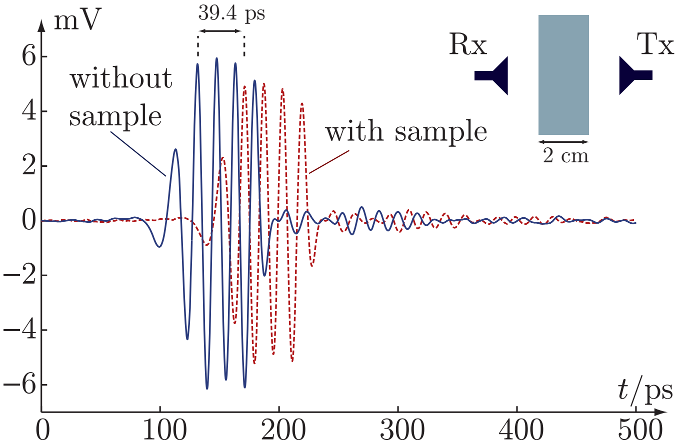

Figure 1: Pulse propagation through a 2 cm thick sample of plexiglas. The received pulse propagating in free space is shown by solid curve and the dashed curve is the received pulse in the presence of the object.

Consider an electric field received by the antenna, $\boldsymbol{E} = \hat{\boldsymbol{e}} E_0 \mathrm{e}^{-\mathrm{j}kz}$, where $\hat{\boldsymbol{e}}$ is the unit vector in the direction of the electric field, E_0 is the amplitude of the field, k is the wavenumber and z denotes the propagation distance. Here, kz/ω corresponds to the total time takes from the transmitter to the receiver, where $\omega = 2\pi f$ denotes the angular frequency. As shown in Figure 1, the presence of the material introduces a delay of $\tau = 39.4\,\mathrm{ps}$. The relative permittivity, ϵ_r, for a plexiglas slab with the thickness $d = 2\,\mathrm{cm}$ assuming that the imaginary part of the material is negligible is given by

$$\epsilon_\mathrm{r} = \left(1 + \frac{c\tau}{d}\right)^2, \tag{1}$$

where c denotes the speed of light in vacuum. The resulting permittivity using (1) is estimated to, $\epsilon_\mathrm{r} = 2.53$. It should be noted that the received signal, shown in Figure 1 is after time gating to remove the multiple scatterings inside the material as well as the extra reflections that arrive after the first signal. The loss of the material can also be estimated by determining the transmission coefficient of the slab and the ratio between the signals. This has been ignored for plexiglas since the losses in the material can be ignored.

4. Conclusions

A time domain approach to find the material properties of dielectric slabs is presented. The permittivity of a dielectric slab introduces a delay in the transmitted short pulse produced by an antenna system consisting of an RTD-MOSFET wavelet generator and a leaky lens antenna. The leaky lens antenna preserves the pulse shape and has a constant phase center which is an advantage in time domain material measurements. The measurement of a plexiglas sample shows that the permittivity for a non-dispersive and non-magnetic material can easily be found from the delay in the time domain signal.

References

1. L. F. Chen, C. K. Ong, C. P. Neo, V. V. Varadan, and V. K. Varadan. *Microwave electronics: Measurement and materials characterisation*. New York: John Wiley & Sons, 2004.

2. A. Neto. "UWB, non dispersive radiation from the planarly fed leaky lens antenna-part I: Theory and design". *IEEE Trans. Antennas Propagat.*, vol. 58(7), pp. 2238–2247, 2010.

3. M. Egard, M. Ärlelid, L. Ohlsson, B. M. Borg, E. Lind, and L.-E. Wernersson. "$In_{0.53}Ga_{0.47}As$ RTD-MOSFET millimeter-wave wavelet generator". *Electron Device Letters, IEEE*, vol. 33(7), pp. 970–972, 2012.

4. I. Vakili, L. Ohlsson, M. Gustafsson, and L.-E. Wernersson. "Wideband and non-dispersive wavelet transmission using leaky lens antenna". *Electronic Letters*, vol. 49(5), pp. 321–322, 2013.