High accuracy measurement line in microwave range for polymer samples weak doped with BaTiO$_3$

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Abstract. The nowadays tendencies regarding the process of making microprocessors presume architectures that, in the nearby future, it would be possible, to work on a frequency located between the range 5-10 GHz. In this context, it is imperious to know the behaving of the plastic materials that build the microchip in the microwave frequency range, as well as the behaving of the polymeric capsule of the electrical capacitors from the electric circuits. The aim of this contribution is to demonstrate throughout high-level experimental analysis how the main electric parameters of plastic materials, which build the microchip capsule and the one of electric capacitors, depend on the frequencies on which they work from the microwave range.

1. Introduction

An electromagnetic wave comprises dynamic variations in time and space of electrical and magnetic field intensities. Since no matter is being transported, only energy, an electro-magnetic wave is also able to propagate in a vacuum. This takes place at the speed of light. If the wave passes through some other medium it slows down. Propagation can be characterized by the vector of electromagnetic energy density (Pointing vector) [1].

A transmission line can be represented by the circuit diagram shown below (Figure 1). The line is fed with the harmonic voltage $U_0 e^{j\omega t}$. The source has the internal resistance $Z_i$. The transmission line of the length $l$ is loaded at one end with the load impedance $Z_L$.

![Figure 1. The transmission line model.](image)

The standing wave is generated by the incoming wave reflecting off the load impedance. The reflected power that is not absorbed by the load is consider a loss of available transmission power. This loss can be depicted by the power-reflection coefficient $\rho$ which corresponds to the percentage of the reflected powered divided by the incident power:

$$|\rho| = 100 \% \frac{E_r}{E_i}^2$$

(1)
The reflected power has to be absorbed in the remaining waveguide elements and can lead to thermal overloads when primary power levels being applied are high. For that reason good matching to load in terms of the characteristic impedance of the line and the associated low $\rho$ is all the more important. Since we are also investigating general reflection conditions in our measurement assembly, we may possibly have to deal with returning waves that are of the same power magnitude as those generated by the microwave generator, i.e. the Gunn diode. For that reason an isolator (one-way waveguide) is connected between the oscillator and the slotted measuring line. The isolator provides for good transmission power (in the arrow's direction), meaning very little wave attenuation in one direction, while providing very high attenuation in the other. As such the reflected or returning wave is subjected to severe attenuation by the isolator (Figure 2) and consequently is unable to affect the oscillator.

**Figure 2.** The isolator SO4100-4B.

2. The experimental measurement line

The experimental analysis bench is composed by two categories:

A. The calibration of the measurement line
   - The measurement line in example A (Figure 3) is composed by Gunn oscillator, isolator, directional coupler and
   - for first branch: variable attenuator, waveguide coax junction box, waveguide short, Low Noise Converter (LNC), SMA cable, the "X-Band Measurement Interface" experiment card and Unitrain-I Interface (USB cable to the computer).
   - for the second branch: isolator, rotary coupling, 2 x E-plane bend 90° angles, slotted line, coaxial measuring probe for slotted guide, waveguide terminator, N socket/SMA plug adapter, LNC, SMA cable, the "X-Band Measurement Interface" experiment card and Unitrain-I Interface (USB cable to the other computer).

All the measurement line components work at frequency adjustment range: 8.5 to 9.6 GHz.

The Gunn oscillator (operating voltage: 8 to 10 V DC, Power: $+17$ dBm 50mW) is an X-band oscillator with mechanical frequency adjustment is used to generate high-frequency electro-magnetic waves. Frequency adjustment is performed using a micrometer screw.

The isolator (insertion loss: < 1 dB, decoupling: > 20dB) is a non-reciprocal waveguide element and is primarily used for decoupling the oscillator from waves coming back from the waveguide assembly further down the line.

Directional couplers (SWR of the main arm <1.2, SWR of ancillary arm <1.5, nominal coupling: 20 or 30dB +/- 1dB, power loss: < 0.2 dB) are used to divide power and it consists of two waveguides, a main arm and an ancillary arm positioned one on top of the other side- and lengthwise. The ancillary arm is terminated at one end with the characteristic impedance and is not accessible there. A portion of the energy is coupled as a function of the direction into the ancillary arm by means of a series of holes between the waveguides. The directional coupler can be disassembled by opening the fast-action couplers. The connecting iris can be interchanged to permit different couplings.
The variable attenuator (attenuation: > 20 dB, Max. power consumption: 1 W) is a waveguide element with mechanical adjustment allowing for attenuation of electromagnetic energy by converting it into heat. A micrometer screw adjusts the attenuation.

The waveguide coax junction box (SWR: < 1.25, Connection: N-socket) is a waveguide component for a properly matched junction between a waveguide and coaxial line.

The coaxial measuring probe for slotted guide is designed to detect the electrical field within the waveguide.

The LNC receiver (input sensitivity > -75 dBm, volume range ≥ 50 dB, 16 dB gain) operates just like a receiver for satellite television reception. The basic circuit is that of a superheterodyne receiver with low-noise input stage, microwave mixer, IF amplifier and rectifier.

The rotary waveguide coupling (rotation range: 360° without end stop, division of degrees: both sides 180°, SWR: < 1.15, Power loss: < 0.5 dB) consists of two waveguide coaxial transitions which are mounted on top of each other on a rotating axis. The alignment remains independent of the selected rotation angle. The rotation angle is indicated by means of a scaled dial face.

A slotted line measuring system (slider range: 70mm, residual ripple SWR <1.05, frequency range: 8.5 to 9.6 GHz) consists of a waveguide that has a slot along the horizontal plane and a slide carriage with a cylindrical scale measuring scale positioned above it. The measuring slider accommodates an electric field probe with an amplitude detector which is inserted through the slot in the waveguide. The position of the sliding measurement carriage may be adjusted along the slot and fixed using knurled screws. Slotted line units are designed for obtaining graphical records of measured values.

The waveguide terminator (SWR <1.05, Directivity: 20 dB aperture) is a load matched to the characteristic impedance associated with the waveguide and is designed to completely absorb electromagnetic waves propagating within the waveguide.

Throughout the calibration of the measurement line, it is meant that the form and amplitude of the microwave field before using the coaxial measuring probe for slotted guide, are the same for the measurement line sampled and for the one for which we do not have a sample. The adjustment of microwave's field amplitude in the sector with polymer sample is done with a variable attenuator. In this configuration of the measurement line, the differences of amplitude of the microwave field throughout the two segments are smaller than 0.5%.

B. The measurement line
The measurements of the electromagnetic microwave field, simultaneously, in the measurement line with the polymer sample and last but not least in the line without polymer sample. The measurement
line (Figure 4) in example B is composed by the calibration of the measurement line without waveguide coax junction box but with a slotted line with sample and the waveguide terminator.

![Figure 4. The measurement line.](image)

The sample of the polymer (Figure 5) has a specific shape and size, being provided with a longitudinal slot.

![Figure 5. The polymer sample.](image)

The electrical signals coming from the two LNC are processed separately from the "X-Band Measurement Interface" units and the results are sent to separate computers.

3. Experimental Results

The numeric values of the main electric parameters, as well as the graphic structures obtained as a result of the automatic process of experimental dates, are the result of the exclusive using of virtual measurement instruments.

The analysis [2] that has been done in the measurement line with the help of the polymer sample, having the same chemical structure as the material from which the microprocessors capsule is built, have followed two aspects:

- the knowledge of the structural distribution of the longitudinal component of the microwave electromagnetic field within the sample, at a frequency of 8.5 GHz, 9 GHz and 9.5 GHz [3].
- the attenuation of the longitudinal electrical component's amplitude of the electromagnetic microwave field into an established point from the sample when the frequency of electromagnetic field varies between 8.5 -9.5 GHz.

For the first category of measurements, resulted from the experimental dates, we can see:

- the polymer sample has modified the wavelength of the electromagnetic waves.
- the characteristic impedance of the communication line has also been modified.
- a decrease of the electrical microwave component's amplitude on the propagation direction in examination has been identified.

The sample of the polymer (Figure 5) has a specific shape and size, being provided with a longitudinal slot.
For the second category of measurements, the experimental dates have revealed:

- a slow attenuation of the electrical component of the microwave field in the area 8.5 - 9.08 GHz.
- a significant attenuation of the electrical component's value of the microwave field on the frequency 9.13 GHz, followed by an increasing around 82% from the electric component on a frequency of 9.10 GHz when the rating has reached 9.18 GHz (Figure 7).
- a slow attenuation of the electrical component's value between the area 9.18 - 9.5 GHz.

The model [4] of the waveguide segment with a slotted line measuring system is shown in Figure 6.

![Figure 6. Rectangular waveguide loaded with dielectric sample.](image)

![Figure 7. The attenuation variation at x=2.55mm in sample.](image)

The structure of the microwave field in the drawn polymer can see in Figure 8. The frequency of the microwave field which took a measurement was 9 GHz.

![Figure 8. The electrical component variation at 9 GHz.](image)
4. Conclusions
In this paper, a new method is presented to determine the complex permittivity and complex permeability of a dielectric material at X-band frequencies using two-port rectangular waveguide [5]. The S-parameters was measured using the UniTrain-I Interface and UniTrain-I Experimenter and calculated using theory of transmissions lines by L@Bsoft, the method developed in this article makes it possible to determine the electrical most important parameters of dielectric material. By matching the calculated value with the measured value of the S-parameters of an X-band rectangular waveguide, loaded by polymer material samples [6]. The absorption of energy of the polymer sample, on the frequency 9.13 GHz, can presume an additional heating of the microchip capsule when the working frequency touch this value, fact that can contribute to major modifications in the functioning of the microprocessor.

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