High Accuracy Investigation of Microwave Absorption in Polymer Electrical Components on Motherboard of Computers

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Abstract. Electronic operating at high frequencies can have problems with emission of high frequency noise. Once put inside an enclosure, the energy will add in phase at certain frequencies to cause resonances which will hinder the performance of the device. These absorbers are based upon open celled foam impregnated with a carbon coating. It is quite possible that in the near future, microprocessors would be to work on a frequency located in 5 to 10 GHz. In these circumstances it is useful to know how and how much of the electromagnetic field emitted by a microprocessor, it is absorbed by the circuit elements in the immediate vicinity of the microprocessor. The aim of this contribution is to demonstrate throughout high-level experimental analysis how the main electric parameters of polymer materials, which build the printed circuits and the one of electric capacitors and resistors, depend on the frequencies on which they work from the microwave range.

1. Introduction
In computers, various circuits are already operating at frequencies above 3 GHz, so we can say that these electronic circuits become microwave generating sources. They are absorbed by a very large number of materials, and once microwaves penetrate, electromagnetic energy is converted into heat. The effect generated primarily depends on its physical properties so that a material that has large dielectric losses inside it will heat up more than one with low dielectric losses [1]. When the high frequency waves are absorbed, they form so-called "hot spots". The phenomenon of maximum absorption occurs in the surfaces and volume of the metallic materials. This property of metallic materials represents a barrier to the propagation of the microwave field. Since most of the electronic components in the circuits that make up the structure of a computer are in polymeric capsules, it is necessary to know the level of microwave absorption in this type of materials [2]. In both cases, the absorption of the microwave field in metallic materials as well as the absorption into dielectric materials, the effect is the same, ie local heating. Excessive heating of electronic components due to microwave absorption can cause an accelerated aging of the structures from which the electronic components are made or abnormal functioning. In this article we studied the level of absorption of the microwave field in the metallic materials that constitute the electrolytic capacitor, in the polymeric materials that constitute the capsule of other electronic components, as well as in the insulating material which constitutes the base of the electric circuits. Following a thorough study and a large
number of measurement variants, we built a measuring stand characterized by a very high accuracy of the measurements.

2. The measurement method of microwave absorption in polymer electrical components

The measurement method is of differential type and the measuring material is positioned in the space between two Horn antennas. A horn antenna facilitates the transition of $\text{TE}_{10}$ waves emerging from the waveguide into free space. We chose the differential measure method to be able to eliminate the measurement errors caused by the voltage fluctuations of the source feeding the Gunn diode oscillator. 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 we have to reckon with reactions affecting the oscillations generated by the Gunn oscillator. 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. Typical values of this kind of field displacement isolator for the X-band from 8.5 GHz up to 9.6 GHz amount to a minimum of 30 dB reverse attenuation and maximum 0.5 dB for forward attenuation. As such the reflected or returning wave is subjected to severe attenuation by the isolator and consequently is unable to affect the oscillator. In order, to not disturb the normal operation of the oscillator that generates the microwave field by returning the reflected wave, the measuring line is provided with an isolator which attenuates with 54 dB the eventual wave reflected by the sample positioned between the Horn antennas. The isolator is a special high-frequency ferrite component, in which the propagation of the wave is influenced. The magnetic materials used here are ferrite with high electrical resistivity. High resistance is a necessity to keep attenuation losses as low as possible. A ferrite plate is used at the waveguide edge where the magnetic field vector circulates. This is located in the static magnetic field $B$ of a permanent magnet. The direction of this magnetic field is parallel to the electric field lines of the $\text{TE}_{10}$-mode, i.e. perpendicular to the waveguide's wide side. The magnetic moments in the ferrite carry out a precession motion around the direction of the permanent magnetic field with the frequency $f = \frac{\gamma B}{\mu}$, Here $f$ means frequency, $\gamma$ is the Landé factor, $\mu$ is Bohr's magneton, $B$ is the magnetic field strength and $h$ Planck's constant (of action). The ferrite plate can absorb circularly polarised electromagnetic waves of the frequency specified by the equation above. However, the absorption only appears for one rotation direction, the one predetermined by the direction of the static magnetic field.

![Figure 1. The isolator SO4100-4B (Frequency range: 8.5 to 9.6 GHz).](image)

The condition imposed and monitored in the measurement activity is that, irrespective of the frequency of the oscillator generating the microwave field, the intensity of the microwave field in the space in which the sample to be placed, is to be the same. For this purpose, the measuring line is
constructed with a two-branch bifurcation. The microwave field produced by the Gunn diode is divided by a waveguide section that has the property of roughly dividing the incident wave. The role of each of the two branches after bifurcation, is:

- One of the branches guides the microwave field to a separate detector connected to a virtual measuring device.
- The second branch guides the microwave field to the Horn antenna system.

The microwave field interacting with the sample is taken over by the second Horn antenna in the system and directed by a rectangular guide segment toward a detector device. The electrical voltage at the output of the detector device is taken over by an LNC connected via the SMA cable with a X-Band Measurement Interface. This device provides for an operating frequency range between 8.3 - 9.9 GHz in the X-band range.

3. The experimental analysis of polymer materials

The experimental analysis bench is composed by four categories:

- Main branch having the structure composed of: Gunn oscillator, ferrite isolator and cross directional coupler SO4100-4R (Input Direct Line);
- The first branch that has the structure of the following components: R100/N adapter (waveguide-coax transition) SO4100-4H, LNC "Low Noise Converter", SMA cable and X-Band Measurement Interface;
- The second branch (emissive branch) that has the structure of the following components: Variable attenuator SO4100-4D, Slotted line, N socket/SMA plug adapter, Coaxial measuring probe for slotted guide, LNC, dual BNC/DIN cable, SMA cable, X-Band Measurement Interface, waveguide adapter and Horn antenna;
- The third branch (the receiving branch) that has the structure of the following components: Horn antenna, two waveguide adapters, coaxial adapter, power sensor, dual BNC/DIN cable and power meter.

3.1. Description and role of the main components

Gunn oscillator: An X-band oscillator with mechanical frequency adjustment is used to generate high-frequency electromagnetic waves. Frequency adjustment is performed using a micrometer screw. Operating voltage: 8 to 10 V DC, power: + 17 dBm (50mW), frequency range: 8.5 to 9.6 GHz, connection: BNC socket.

**Directional coupler SO4100-4R:** Cross couplers serve to separately measure the wave travelling in forward and reverse propagation in a transmission line. This can be carried out simultaneously for the receiving direction. The cross coupler consists of a main arm and a side arm situated at a right angle above this, in which, as indicated in the figure below, a portion of the power travelling in the main arm is decoupled. The decoupling is normally carried out using apertures or holes in the waveguide wall shared by the two arms, as specified in the image below (cross-shaped holes).

![Figure 2. Directional coupler SO4100-4R (Frequency range: 8.5 to 9.6 GHz).](image)

LNC receiver: 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 X-band LNC in conjunction with an internal oscillator of 10 GHz and mixer generates receives the X-band signal to be measured with a frequency around 9 GHz and generates a proportional signal with an intermediate frequency (IF) in the range of 1 GHz. This IF signal is supplied by the LNC to the receiver card of the UniTrain-I Experimenter via an SMA cable and there it is further processed and rectified. The LNC is also supplied with operating voltage via the SMA cable. Input sensitivity > -75 dBm, volume range ≥ 50 dB, 16 dB gain.

Variable attenuator: are designed to absorb a certain portion of the incoming microwave power and conduct the rest. The attenuation strength of a variable attenuator can be affected both by its length as well as by the position of resistive material inside the waveguide. Here in the middle of the waveguide's width, i.e. the location where the strength of the electric field is maximum, an absorbing plate is immersed penetrating into the interior of the waveguide.

Figure 3. Variable attenuator (Frequency range: 8.5 to 9.6 GHz).

X-Band Measurement Interface: The "X-Band Measurement Interface" experiment card is designed as the measurement and control interface for all waveguide experiments. The card is equipped with an integrated short-circuit protected power supply for the Gunn diode. Operating voltage +5V± 0.1V, adjustable DC operating voltage for Gunn diode 0...10 V, logarithmic receiver with dynamic response up to 50dB, 16-bit data, bandwidth 500 MHz, sensitivity -70 dBm, frequency measurement 8.3 ... 9.9 GHz.

3.2. Generating and propagating the microwave field in the measuring stand
The microwave field generated by the oscillator Gunn will pass through the insulator with negligible attenuation. When passing through the directional coupler (Cross coupler), the microwave field will be divided into two approximately equal intensity beams. The first microwave beam will cross the adapter (waveguide-coax transition) and will be taken over by the LNC and transmitted via the SMA cable to X-Band Measurement Interface. The second microwave beam will cross the variable attenuator, it will come and go the slotted line and it will reach the first Horn antenna in the antenna system where the test sample is placed. The micrometric screw of the variable attenuator will be adjusted for each microwave frequency so that the levels of the electrical signals taken over by the probes and transmitted through the two LNCs are the same. In this way, we have the certainty that for each frequency of the microwave field generated by the Gunn oscillator, the intensity of the microwave field that will interact with the measurement sample placed between the Horn antennas, will have the same value [3]. Under these conditions, the microwave field attenuation measurements
after its interaction with the sample to be measured will be accurate, having the same incident reference value of the incident beam [4]. The emissive side of the measuring stand is shown in figure 4. The elements that make up the measuring cell (the Horn antenna system and the detector element) are shown in figure 5. The whole measuring stand, consisting of the main branch, the first branch, the second branch, as well as the branch of the measurement and measurement of the attenuation after passing the microwave beam through the measurement sample, is shown in figure 6. Positioning of the sample to be measured inside the Horn antenna system is done by means of dielectric wires made of materials that do not absorb the energy of the microwave field from the incident beam.
4. Experimental Results

Measured probes were two different types of non-polarized ceramic capacitors and two electrical resistors, which were taken from an electrical circuit in the close proximity of a PC computer's microprocessor. The values of the measured electrical quantities are shown in table 1 to table 4.

Table 1. Measured parameter values (sample no.1).

| No. | Frequency (GHz) | Level (dBm) | Attenuation correction (mm) | Component Type | Power level (mW) |
|-----|----------------|-------------|----------------------------|----------------|------------------|
| 1   | 9.00           | -22.5       | 0.00                       | Capacitor (C1) | 0.293            |
| 2   | 9.05           | -22.5       | 0.03                       | Capacitor (C1) | 0.290            |
| 3   | 9.10           | -22.5       | 0.00                       | Capacitor (C1) | 0.293            |
| 4   | 9.15           | -22.5       | 0.00                       | Capacitor (C1) | 0.292            |
| 5   | 9.20           | -22.5       | 0.07                       | Capacitor (C1) | 0.290            |
| 6   | 9.25           | -22.5       | 0.00                       | Capacitor (C1) | 0.293            |
| 7   | 9.30           | -22.5       | 0.01                       | Capacitor (C1) | 0.275            |
| 8   | 9.35           | -22.5       | 0.00                       | Capacitor (C1) | 0.283            |
| 9   | 9.40           | -22.5       | 0.00                       | Capacitor (C1) | 0.286            |
| 10  | 9.45           | -22.5       | 0.04                       | Capacitor (C1) | 0.290            |

Table 2. Measured parameter values (sample no.2).

| No. | Frequency (GHz) | Level (dBm) | Attenuation correction (mm) | Component Type | Power level (mW) |
|-----|----------------|-------------|----------------------------|----------------|------------------|
| 1   | 9.00           | -22.5       | 0.01                       | Capacitor (C2) | 0.290            |
| 2   | 9.05           | -22.5       | 0.03                       | Capacitor (C2) | 0.290            |
| 3   | 9.10           | -22.5       | 0.00                       | Capacitor (C2) | 0.285            |
| 4   | 9.15           | -22.5       | 0.00                       | Capacitor (C2) | 0.286            |
| 5   | 9.20           | -22.5       | 0.03                       | Capacitor (C2) | 0.283            |
| 6   | 9.25           | -22.5       | 0.01                       | Capacitor (C2) | 0.277            |
| 7   | 9.30           | -22.5       | 0.01                       | Capacitor (C2) | 0.269            |
| 8   | 9.35           | -22.5       | 0.00                       | Capacitor (C2) | 0.273            |
| 9   | 9.40           | -22.5       | 0.05                       | Capacitor (C2) | 0.276            |
| 10  | 9.45           | -22.5       | 0.04                       | Capacitor (C2) | 0.284            |
Table 3. Measured parameter values (sample no.3).

| No. | Frequency (GHz) | Level (dBm) | Attenuation correction (mm) | Component Type | Power level (mW) |
|-----|----------------|-------------|-----------------------------|----------------|-----------------|
| 1   | 9.00           | -22.5       | 0.00                        | Resistor (R1)  | 0.293           |
| 2   | 9.05           | -22.5       | 0.00                        | Resistor (R1)  | 0.296           |
| 3   | 9.10           | -22.5       | 0.03                        | Resistor (R1)  | 0.295           |
| 4   | 9.15           | -22.5       | 0.03                        | Resistor (R1)  | 0.296           |
| 5   | 9.20           | -22.5       | 0.01                        | Resistor (R1)  | 0.295           |
| 6   | 9.25           | -22.5       | 0.05                        | Resistor (R1)  | 0.297           |
| 7   | 9.30           | -22.5       | 0.00                        | Resistor (R1)  | 0.299           |
| 8   | 9.35           | -22.5       | 0.00                        | Resistor (R1)  | 0.299           |
| 9   | 9.40           | -22.5       | 0.06                        | Resistor (R1)  | 0.301           |
| 10  | 9.45           | -22.5       | 0.07                        | Resistor (R1)  | 0.301           |

Table 4. Measured parameter values (sample no.4).

| No. | Frequency (GHz) | Level (dBm) | Attenuation correction (mm) | Component Type | Power level (mW) |
|-----|----------------|-------------|-----------------------------|----------------|-----------------|
| 1   | 9.00           | -22.5       | 0.03                        | Resistor (R2)  | 0.283           |
| 2   | 9.05           | -22.5       | 0.01                        | Resistor (R2)  | 0.286           |
| 3   | 9.10           | -22.5       | 0.00                        | Resistor (R2)  | 0.288           |
| 4   | 9.15           | -22.5       | 0.02                        | Resistor (R2)  | 0.288           |
| 5   | 9.20           | -22.5       | 0.04                        | Resistor (R2)  | 0.293           |
| 6   | 9.25           | -22.5       | 0.00                        | Resistor (R2)  | 0.297           |
| 7   | 9.30           | -22.5       | 0.02                        | Resistor (R2)  | 0.299           |
| 8   | 9.35           | -22.5       | 0.00                        | Resistor (R2)  | 0.303           |
| 9   | 9.40           | -22.5       | 0.01                        | Resistor (R2)  | 0.302           |
| 10  | 9.45           | -22.5       | 0.00                        | Resistor (R2)  | 0.303           |

5. Conclusions
From the analysis of the experimental data obtained at the power measurements absorbed by the studied samples, the following conclusions can be drawn:

- In the case of electric capacitors, a microwave field absorption is observed near the frequency of 9.30 GHz;
- In the case of electric resistors, there is a progressive decrease in the absorption of the microwave field when it increases the frequency of the electromagnetic field with which the probe interacts in the space between the two Horn antennas;

The situation encountered in the behavior of electric capacitors, we can say that the dielectric assembly inside the capsule as well as the capsule itself shows an increased absorption near the frequency of 9.30 GHz. Since the measurement time was short and due to the fact that the introduction of a temperature sensor into the interaction space of the sample with the microwave field would significantly disturb the measured values, it was avoided to measure temperature variations [5]. In a more detailed analysis, we will analyse the interaction of the microwave field separately for the dielectric in the capsule, and then an analysis of the microwave field interaction only for the electric capacitor capsule. This future study will help determine which of the two components has a major interaction with the microwave field [6]. A primary conclusion is that these types of electrical capacitors would not have been recommended to be found in the electronic circuits of the PC type if they would operate at frequencies close to the reference value of 9.30 GHz.
In case of the study of the microwave field absorption phenomenon in the volume of electric resistors, it can be said that this phenomenon is possible to meet at frequencies lower than 9.00 GHz. In the near future, we are planning to study the behaviour of resistors in microwave fields whose frequency ranges from 7.50 to 9.00 GHz.

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