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Preparation and Deposition of Oxides of Some Metals and Ferrite on Aluminum and Study of the Absorption In a range Electromagnetic Frequencies

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Abstract. Two-layer coatings were prepared, one layer of different metal oxides (TiO2,Fe2O3, ZnO, MgO, CuO, CdO, Ni2O3, MnO2) and the other of ferrite powder (MnFe2O4) on aluminum for each sample. The absorbance of electromagnetic waves in the frequency range (8-12.5) GHz was measured using a standing wave ratio)SWR(and the effect of exchanging the oxide layer with the ferrite powder layer upon direct exposure to ultraviolet radiation was studied. It was observed that the oxide layer (MnO2) and the oxide layer (Ni2O3) were the best among the prepared samples due to their high absorbance values close to the ferrite layer when exposed to ultraviolet radiation directly and in exchange with the ferrite layer. MnO2 oxide with ferrite gave an absorbance of (87%) in the frequency range (10.2-11.4) GHz, while (Ni2O3) oxide with ferrite gave an absorbance of (80.5%) in the frequency range (10.8-12.4) GHz, compared to the other prepared samples.

Keywords. microwave absorption, ferrite coatings, metal oxides, X-band frequencies, electromagnetic absorbers

Introduction

Numerous innovations, studies, and experimental research have addressed the effects of ferromagnetic materials on the electromagnetic spectrum, their preparation methods, and the nature of the interaction between them. It has been found that some electromagnetic wave absorbing materials have the ability to reduce the reflectivity of these waves at radar frequencies [1]. These materials may include ferromagnetic metal oxides with complex permeability, the imaginary part of which is larger than its real part. These oxides include ferrite with a cubic structure (MFe_2O_4), where (M) represents one or more divalent ions of (Nickel, Manganese, Magnesium, Copper, Cobalt, Cadmium, Zinc) (Grimes et. al., 1976)[2]. Hatakeyama and Inui prepared materials with both electrical and magnetic absorption properties, consisting of two layers: the first with a low input impedance, containing a mixture of small fibers of metals or alloys with high conductivity, in addition to ferromagnetic materials consisting of ferrite, iron, cobalt, and nickel with synthetic adhesives (resin) with a high molecular weight, in addition to the use of carbon black with ferroelectric materials such as barium titanate [3]. The second layer is of low impedance and consists of a synthetic adhesive compound with a high molecular weight (Hatakeyama and Inui, 1985). Sofia (1999) was able to prepare microwave absorbing

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coatings in the *X*-band region consisting of zinc-substituted manganese ferrite ($MnZnFe_2O_4$) and some other oxides [4]. It was observed that at a frequency of 10.5 GHz, 98% microwave absorption can be achieved if the coating is designed with a thickness of (2-3.1) mm. Peterman was able to prepare radar-absorbing coatings consisting of ferromagnetic particles of elements (iron, cobalt, carbide iron, nickel) and some other alloys of the same elements with other materials such as (Silicon, Silicon Oxide, Aluminum Oxide, and Chromium Oxide). The ferromagnetic particles were coated in a (rotating retort) device containing a gaseous compound of one of the following compounds (SiH_4, SiF_4, $SiCl_4$) that would be deposited on the particles or diffused through them (Peterman, 2002) [5].
By preparing multi-layer coatings that absorb radar waves in the frequency range (8-12.5) GHz consisting of carbon black, magnetite Fe_3O_4, and barium ferrite in addition to polyethylene, with layer thicknesses ranging between (2-3) mm, and it was possible to obtain a reduction in radar detection of (75%). Relied on previous results in the field of preparing absorbent coatings suitable for work at the beam in order to improve the specifications of these coatings, he developed absorbent coatings suitable for work at the beam [6]. The coating thickness and surface density were reduced while maintaining the attenuation level. The researcher achieved a thickness reduction of (21%) and a reduction in surface density by 11% while maintaining a good attenuation ratio. Prepare microwave absorbing coatings measured at frequencies of 10 GHz using some metal oxides and carbon with epoxy and unsaturated polyester as a binder. The highest absorption ratio (73.12%) was achieved at a thickness of (2.1) GHz ($MnFe_2O$). Studied the effect of iron and ferrite grain sizes (4) mm and their mixtures on the absorption properties of radar-absorbing surfaces within the *X* band. There is a specific range of grain sizes and specific frequencies that give a higher and more stable attenuation ratio. In the case of (9-10) GHz, the iron grain sizes were (500-106.5) μm. The size range is wider and lies between (780-200) GHz (9.5-11) GHz. In this work, the absorbance of ferrite layers and different metal oxides prepared in the form of coating layers exposed to electromagnetic frequencies at the (8-12.5) GHz band was measured, alternately for each oxide with the ferrite layer, with the aim of identifying the best absorbing layers for these frequencies [7].

Theoretical part

RAM is classified into several types based on its technical and design specifications, each with its own uses and properties. In this work, magnetic absorbers were used as coating layers, and the absorption coefficient (SWR) was calculated using standing wave measurements.
Magnetic absorber It is a magnetic layer placed directly on the metal surface. The reflection coefficient R of this absorber is given by the following relationship [8]:

$$\mathrm{R} = [Ztanh(\gamma d) - Z_0 / Ztanh(\gamma d) + Z_0] \qquad (1)$$

Where Z is the input impedance of the medium, γ is the wave propagation constant, d is the thickness of the absorbing material, Z_o is the space impedance,

$$Z_0 = Ztanh(\gamma d) \qquad (2)$$

Among the materials used in the manufacture of magnetic absorbers are various types of ferrite materials and powders of ferromagnetic oxides (2.1 mm) to provide absorption. The thickness of this absorber in the ideal case is (35) dB. In practical terms, it is considered a narrow-band absorber. This is due to the fact that the real and imaginary parts of both the permeability and permittivity of these materials change with frequency. Absorption in ferrite materials is attributed to the mechanisms of relaxation magnetization and the movement of magnetic walls [9].

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The magnetic field is applied to a ferromagnetic object, the magnetic flux density within the material increases due to its magnetization. This increase continues until the flux reaches its maximum value, after which it no longer increases. The ferromagnetic object is considered to have reached saturation. If the applied field is reduced, the magnetization of the material will begin to decrease, but it will not decrease at the same rate as its increase [10]. When the applied field reaches zero, the flux reaches a certain value called residual magnetism. The behavior of a ferromagnetic material, represented by the difference between the magnetic flux curve when the applied field increases, must be applied to bring the material's magnetization to zero, a magnetic field opposite to the first must be applied [11]. This field is called the coercive field. The larger the area of the hysteresis loop, the greater the loss of the material. It has been found that the amount of loss is proportional to the area of the hysteresis loop. Ferromagnetic materials are characterized by a structure called zones of magnetic influence. These zones are magnetized to saturation, but their magnetization direction differs from that of neighboring zones, making the net magnetization zero. When an external magnetic field is applied to this material, its magnetization will increase through the growth of fields parallel to the field direction or through the rotation of the direction of the magnetic field moments. However, the movement of the moments in these cases results in friction, which generates heat in the material and dissipates the energy of the applied field [12].
Standing waves are waves that result from the interference of two preceding waves of the same amplitude and frequency, traveling in opposite directions. The standing wave ratio can be expressed as the ratio of the maximum voltage value to the minimum voltage value within the transmission line of the waveguide. It is expressed by the following equation [13]:

$$SWR = \frac{|V_{max}|}{|V_{min}|} \qquad (3)$$

V_{min} represents the maximum reading of the meter, V_{max} represents the maximum reading of the meter, and *SWR* represents the standing wave ratio.
The minimum or lowest reading of the scale, which is calibrated at the value (1), and thus the equation becomes as follows:

$$SWR = |V_{max}| \qquad (4)$$

The value of the reflection coefficient ρ can be calculated from the relationship:

$$|\rho| = \frac{SWR - 1}{SWR + 1} \qquad (5)$$

Since there are three wave parameters:

$$\rho + T + \alpha = 1 \qquad (6)$$

Where T is the transmittance coefficient and α is the absorption coefficient. Since the transmittance coefficient T = 0 because we have a perfectly reflective surface that we want to paint (a reflective piece of aluminum), there is no transmitted wave, but rather there is a reflected wave and an absorbed wave. Thus, the absorption coefficient α can be obtained from [14]:

$$\alpha = (1 - \rho) \qquad (7)$$

The absorption percentage can be obtained using the following relationship:

$$\text{Absorption (A\%)} = \alpha * 100\% \qquad (8)$$

Practical part

a) Materials and equipment used:

1. The required quantities of ferrite powder have been prepared ($MnFe_2O_4$) and Titanium oxide TiO_2 and Iron oxide Fe_2O_3 and Zinc oxide ZnO and Magnesium oxide MgO and Copper oxide

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CuO and Cadmium oxide CdO and Nickel oxide Ni_2O_3 and Manganese oxide MnO_2. These are characterized by a high purity rate (99.9%).

2. Pieces of Aluminum sheets were prepared with dimensions (8*8) cm in order to stick the paint samples on it after completing the process of preparing the samples as a reflective metal sample to be painted.
3. A metal mold was manufactured from iron with high technical specifications. It required high precision in terms of durability, smoothness of the polished base, and smoothness of the lid. The resulting model had a smooth texture and was free of any bumps or bubbles.
4. The absorbance of all prepared samples was measured by a standing wave ratio measurement system SWR Which consists of the parts shown in the figure (1) [15].

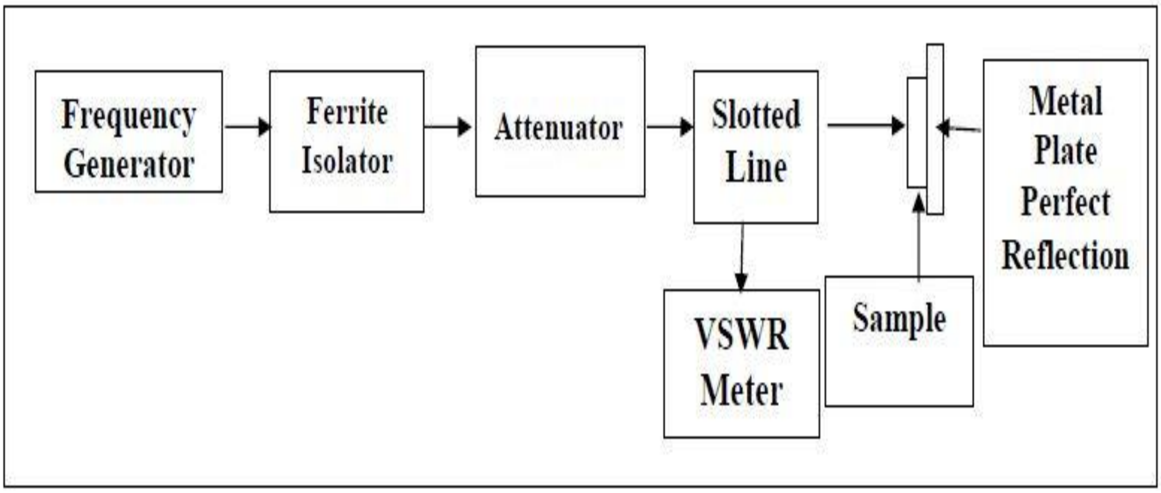

Figure (1) Schematic diagram of the standing wave ratio measurement system

b) Preparing the forms:

The paint samples were prepared in several stages. In the first stage, one sample was prepared from 1.5 gm of thermosetting agent, and 5 gm of ferrite powder. This sample was considered a comparison with the samples prepared in the second stage, with dimensions of 5* 5 cm. The thickness of this sample was measured using a micrometer at several locations, and its average was 1.14 gm. In the second stage, eight coating samples were prepared individually, each sample containing 1.5 mm oxides per gm oxide, and in weight proportions (MnO2, Ni2O3, CdO, CuO, MgO, ZnO, Fe2O3, TiO2). Each material was weighed individually, 2 gm of epoxy resin and 2 gm of the hardener. They were then thoroughly mixed with the epoxy resin and hardener, and then placed in the metal mold. After the molding process was completed, the samples were removed and their thickness was measured at several locations, and their average was taken as follows:(CuO=1.12mm ‹MgO=1.46mm ‹ZnO=1.4mm ‹Fe2O3=1.31mm ‹TiO2=1.37mm , MnO2=1.27mm ‹Ni2O3=1.28mm ‹CdO=1.29mm) with dimensions of 5* 5 cm for each model, after completing the process of preparing all models and measuring the thickness, the coating models were prepared in the form of two layers: an upper layer, named

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number (1), meaning the layer exposed to the rays, and a lower layer, named number (2), meaning the base or foundation layer, which is attached to the piece of aluminum as a metal (reflective) model to be coated and its absorbance measured.

System calibration

The reflective metal plate (calibration sample) is installed in its designated location in the system at the waveguide opening, i.e., aligned with the small aperture of the waveguide. An frequency microwave wave is then irradiated (8) GHz. The probe is then moved along the grooved waveguide while monitoring the SWR meter indicator attached to the probe. The aim is to find the maximum deviation of the indicator ($V_{max}=\infty$) on the SWR. The SWR indicator is then calibrated to the value $V_{min}=1$ on the SWR scale by controlling the device's switch.

Measurements VSWR and Absorption of Coating Models

After the paint pattern is affixed to the aluminum piece (reflector) and the system is calibrated at a reading of ($V_{min}=1$), the paint pattern is placed directly over the small opening in the waveguide. The metal plate is placed directly behind it (applied) to stabilize the pattern and allow the (8) GHz wave to fall on it. The probe is then moved along the grooved waveguide, tracking the SWR meter indicator attached to the probe to find the maximum deviation (V_{max}) of the indicator on the SWR meter inside the guide. The reading is taken directly from the SWR meter scale. The calibration process is repeated for the metal plate and for the same pattern, at (8.2,….,12.4) GHz frequencies and with a frequency interval of (0.2)GHz for each reading. The layers of the paint pattern are reversed so that layer (2) becomes layer (1), i.e., the layer exposed to the radiation, and layer (1) becomes layer (2), i.e., the base or foundation layer. The system calibration process is then repeated, measuring VSWR and absorbance for the same pattern and for all frequencies. We repeat the above paragraphs for the models prepared from the ferrite powder layer and the oxide layers (Ni_2O_3, MnO_2, CdO, CuO, MgO, ZnO, Fe_2O_3) after they are glued on the aluminum piece and individually for each model, and the measurements of the absorbance values were shown as in Figures (2, 3, 4, 5, 6, 7, 8, 9) respectively, where the VSWR values and absorbance of all the prepared models were calculated using equations (3-8).

Figure (2) shows the relationship between the absorbance A and frequency for a coating consisting of two layers of ferrite powder and Titanium Oxide, with an average thickness of (2.51) mm. It is noted from the figure that the absorbance values of the ferrite layer were greater than (80.5%) and within the frequency range (9 - 12.2) GHz were the best when exposed to direct rays compared to the Titanium Oxide layer.

Figure (3) shows the relationship between the absorbance and frequency of a coating consisting of two layers of ferrite powder and Iron Oxide, with an average thickness of (2.45) mm. It is observed that when the ferrite powder layer is the layer directly exposed to the rays, high absorbance values are observed, greater than (81.6%) within the range (10.2-12.4) GHz compared to the Iron Oxide layer.

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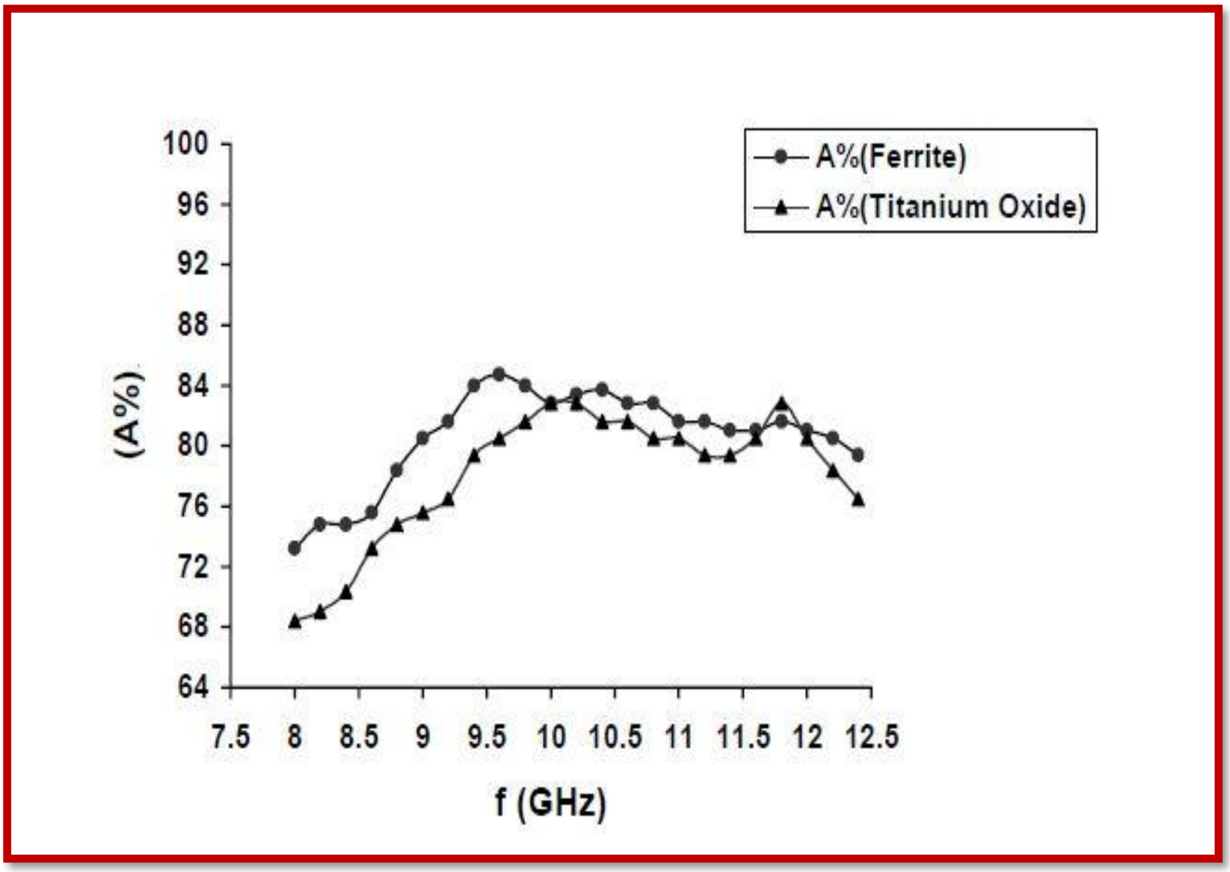

Figure 2: Relationship between absorbance and frequency for a two-layer coating (Titanium Oxide and Ferrite) at a thickness (2.51) mm.

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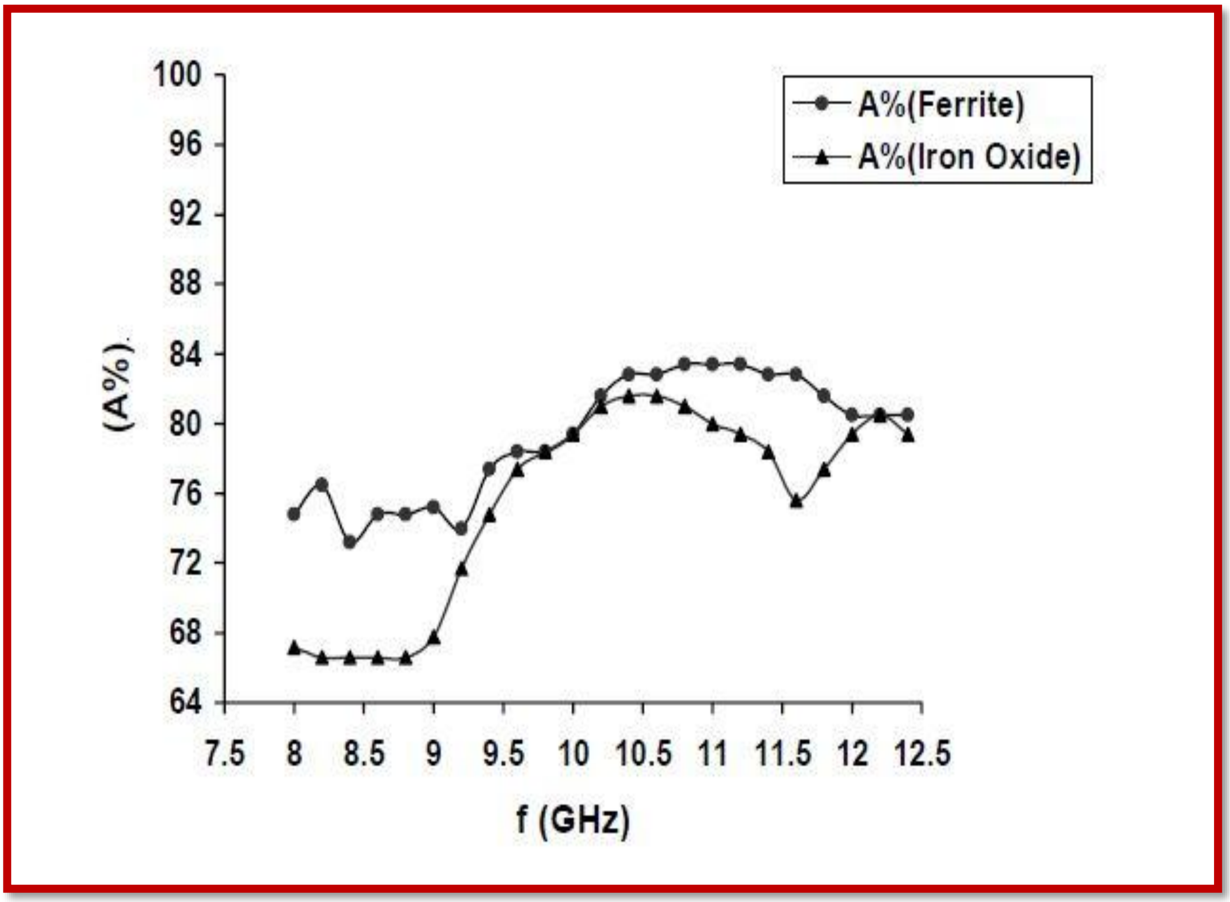

Figure 3: Relationship between absorbance and frequency for a two-layer coating (Iron Oxide and Ferrite) at a thickness (2.45) mm.

Figure (4) shows a two-layer coating of ferrite powder and Zinc Oxide with an average thickness of (2.54) mm. It is noted that the ZnO Oxide layer is better than the ferrite layer because it showed absorption values greater than 84.5% at frequencies (10.2-12.0) GHz when exposed to direct radiation.

Figure (5) shows the relationship between absorbance and frequency for a coating consisting of two layers of ferrite powder and Magnesium Oxide, with an average thickness of (2.60) mm, and high absorbance values of greater than 86% are observed in the frequency range (9.8-12.4) GHz when the ferrite layer is the layer exposed to the rays compared to the MgO Oxide layer.

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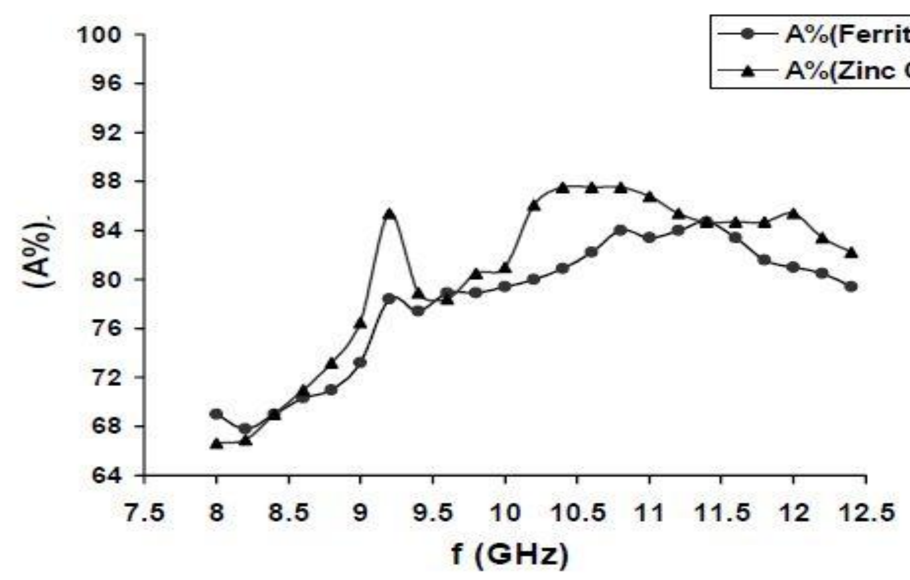

Figure 4: Relationship between absorbance and frequency for a two-layer coating (Zinc Oxide and Ferrite) at a thickness (2.54) mm.

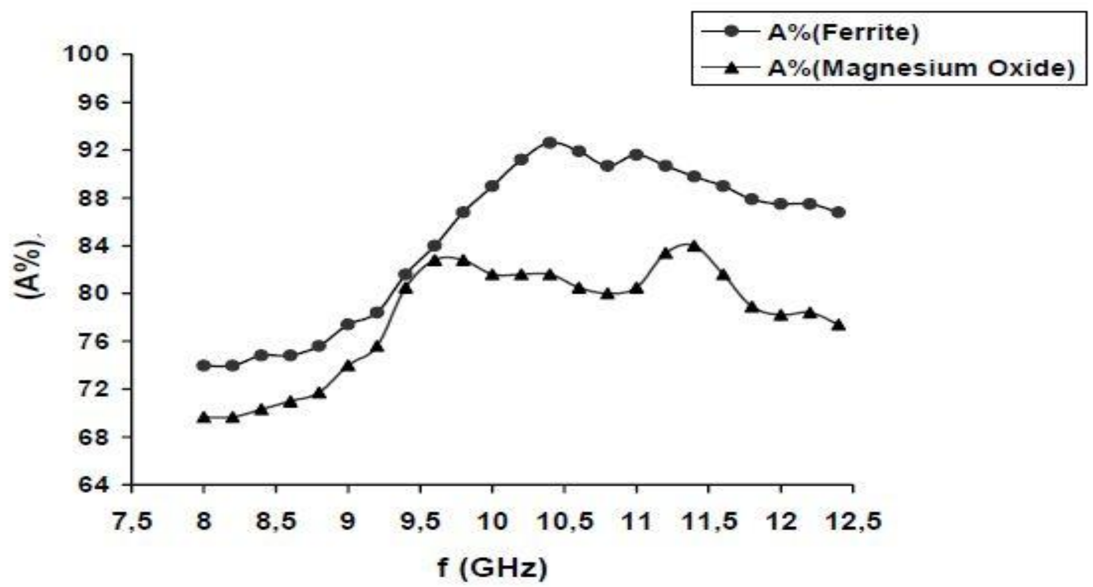

Figure 5: Relationship between absorbance and frequency for a two-layer coating (Magnesium Oxide and Ferrite) at a thickness (2.60) mm.

Figure (6) shows a coating model consisting of two layers of ferrite powder and Copper oxide, with an average thickness of (2.26) mm. It is noted that the ferrite layer works better as an

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absorbent coating when exposed to radiation than the CuO oxide layer due to the good absorption values that exceeded (83%) in the frequency range (10.2-12.2) GHz.

Figure (7) shows the relationship between the absorbance and frequency of a coating consisting of two layers of ferrite powder and cadmium oxide, with an average thickness of (2.43) mm, in which good absorbance values of greater than (83%) are observed in the frequency range (10.2-12.0) GHz when the ferrite layer is the layer exposed to direct rays compared to the CdO oxide layer.

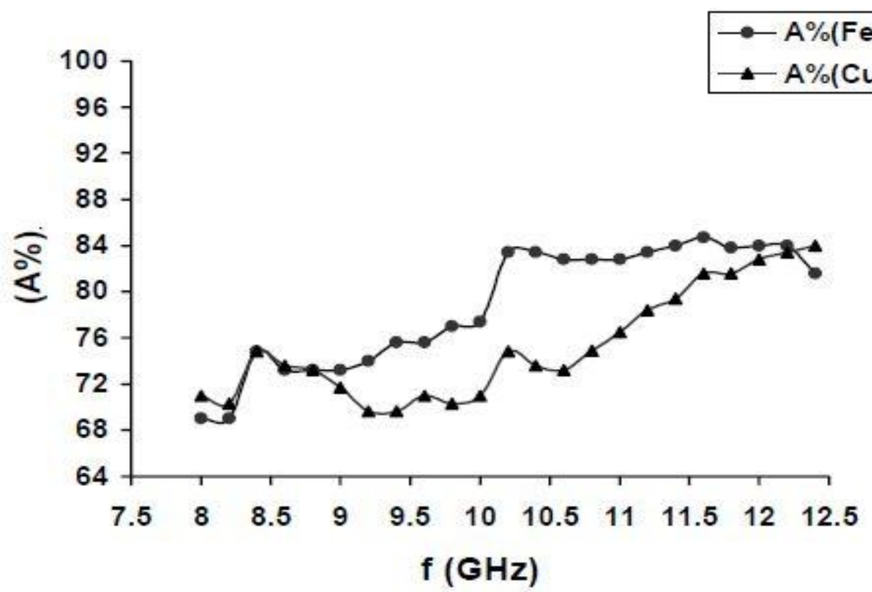

Figure 6: Relationship between absorbance and frequency for a two-layer coating (Copper Oxide and Ferrite) at a thickness (2.26) mm.

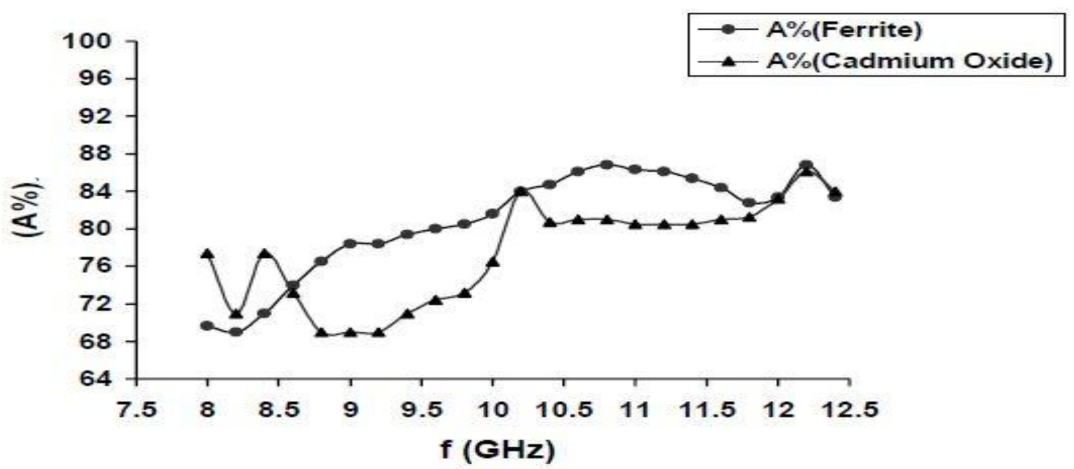

Figure 7: Relationship between absorbance and frequency for a two-layer coating (Cadmium Oxide and Ferrite) at a thickness (2.43) mm.

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Figure (8) shows that both layers of ferrite powder and MnO oxide, which have an average thickness of (2.41) mm, showed absorption values greater than (87%) for the same frequency range (10.2-11.4) GHz, and in the case of direct exposure to each of them, it can be considered the best model as an absorbent coating and in exchange for both layers when exposed to rays in the mentioned frequency range.
While in Figure (9) shows the relationship between the absorbance and frequency of a coating consisting of two layers of ferrite powder and Ni_2O_3 oxide, which has an average thickness of (2.42) mm, where it is noted that both layers showed good absorbance greater than (80.5%) and with good stability within the frequency range (10.8-12.4) GHz. In the case of direct exposure to rays for both layers, it can be considered the best model for use as an absorbent coating and in exchange when exposed to rays within the mentioned frequency range.

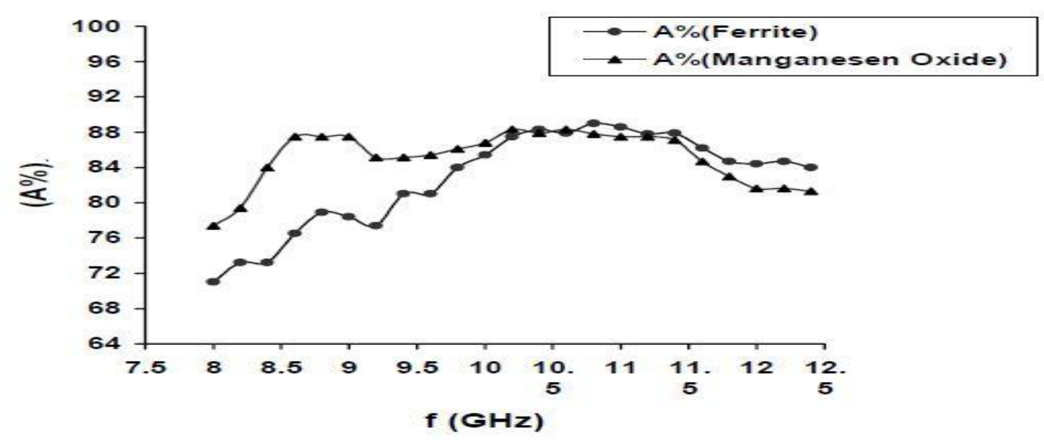

Figure 8: Relationship between absorbance and frequency for a two-layer coating (Manganese Oxide and Ferrite) at a thickness (2.41) mm.

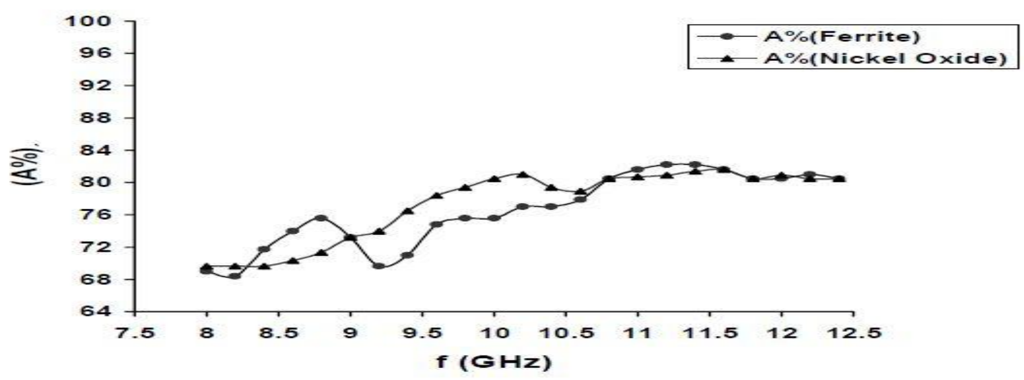

Figure 9: Relationship between absorbance and frequency for a two-layer coating (Nickel Oxide and Ferrite) at a thickness (2.42) mm.

From the above, it is noted that the absorbance in the coatings prepared in this work can be included within the magnetization mechanisms mentioned in the theoretical part. Therefore, it is noted that the reason for the ability of ferrite and its compounds to absorb microwaves is attributed to hysteresis losses, where an internal magnetic flux is generated due to the external electromagnetic field, which leads to the dissipation of a quantity of energy within the material, and thus a loss in the energy of the incident electromagnetic wave appears, and it depends on the amount of ferrite compounds in the model. As for the two oxides (Ni_2O_3, MnO_2), they are ferromagnetic oxides, and these oxides are characterized by clear magnetic properties in terms of their ability to acquire high magnetization, and they are characterized by their magnetization ability, which exceeds the rest of the materials (diamagnetic and paramagnetic) by thousands of times (X>> 1). The same is true for this type of oxides having a complex magnetic permeability (μ) and a complex permittivity (ε).

Conclusions

In this research, multi-layer electromagnetic absorbing coatings were prepared in the frequency range (8-12.5) GHz and the absorbance was measured using a VSWR measuring system with a frequency interval of (0.2) GHz for each reading. The results showed that most of the samples prepared in the form of two layers showed good absorbance values greater than (70%) and quasi-stable in the frequency range of (8.6-12) GHz at which they were measured. Also, the coating sample prepared from two layers of ferrite and titanium oxide (TiO_2), alternating between both layers, showed increasing absorbance results at frequencies (8-9.4) GHz and good and quasi-stable results at frequencies (12-9.6) GHz better than the samples prepared from a layer of ferrite and oxides (CdO, CuO, MgO, Fe_2O_3), and individually for each sample. The samples prepared from the ferrite powder layer and oxide layers (CuO, MgO, TiO_2, Fe_2O_3, CdO) individually for each sample showed good absorbance values and a near-stable range at most frequencies as a two-layer absorbent coating, but the absorbance values were better when the ferrite layer was exposed to the radiation compared to the oxide layers when exposed to the radiation. The two-layer coating sample prepared from the ferrite powder layer and the oxide layer (ZnO) showed absorbance values greater than (85%) at frequencies (10.2-12) GHz when the oxide layer was exposed to the direct radiation compared to the ferrite powder layer. The sample prepared from the ferrite powder and oxide (MnO_2) can be considered the best absorbent coating and alternately for both layers within the frequency range (10.2-11.4) GHz with absorbance values greater than (87%). Also, at frequencies (10.8-12.4) GHz, the coating model consisting of two layers of ferrite and oxide (Ni_2O_3) showed absorbance values greater than 80%, making it the best choice for acting as an alternative absorbent coating for both layers. The slight variation in thickness had no significant effect on the absorbance of all the prepared samples. This variation is a result of manually preparing the samples and the differences in the bulk density of the oxides used and their distribution within the surface area of the template. The absorbance values we obtained in this work were good and within the *X*-band range.

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