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Preparation of Composite Materials of Silicon Rubber Reinforced by ($CrMn_xNi_{1-x}FeO_4$) for Microwave absorption at X-band

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Abstract

In this paper, samples of silicon rubber reinforced by Ferrite compounds (CrMnxNi1-xFeO4) where x = (0.1,0.3,0.7,0.9) and (2,3)g for the added ferrite were prepared. The properties of attenuation of microwave waves within the X-band (8-12 GHz) were studied using the Vector Network Analyzer (VNA). When reinforced by 2 g of Ferrite, The maximum value of the reflective loss factor (-26.5 dB) at (11.2 GHz). The mean value of the reflection coefficient was 0.1 for x = 0.3 at the frequency (11.16-11.23 GHz). The value of the reflective loss (-25.56dB) at the frequency (10.08GHz), and the reflection coefficient reached the lowest value (0) at the frequency (8.14, 11.98 GHz) for the ratio x = 0.1. The relative permeability and relative Permittivity were also studied, where it was greater than one at most frequencies. The highest relative permeability value was 7.8 at (8.14GHz) for X = 0.1 at the addition of 3g of Ferrite. The greatest value of relative permeability reached 9.13 at (8.34GHz) for X=0.1 at addition of 2g of Ferrite.

Keywords: Silicone Rubber, microwave, ferrite.

INTRODUCTION

Microwaves are part of the electromagnetic spectrum whose wavelengths are from (1-100) cm and are located between RF and IR frequencies. Microwave waves contain many regions, Each region has specific applications of its own, such as monitoring, detection and monitoring in the long or short term. The most important is the X-band because their applications are widely used in radar systems. [1], [2] In everyday life applications, radio, satellite, radar, GPS, mobile phones and wireless networks, all operate in the microwave frequency band (18-1 GHz) and their efficiency can be strongly influenced by unwanted reflections or emissions as well as health risks associated with them. [3] The development of magnetic materials for technical applications with the development of metallurgy and the study of materials in general, has recently adopted many new applications on magnetism and magnetic materials such as wireless communication tools. [4] Ferrites play a dominant role in suppression of reflection or damping electromagnetic waves in free space. [3] This feature is made for Ferrite materials according to the two mechanism.[5]

1- **Dielectric Loss Mechanism**: The value of the imaginary part of the electrical permittivity determines the material's ability to absorb and dissipate the electromagnetic waves generated by heat inside the insulator.

2- **Magnetic Loss Mechanism**: The value of the imaginary part of the magnetic permeability determines the material's ability to absorb and dissipate the electromagnetic waves in the form of energy consumed by the material in the rotation of the domains and moving the walls in the magnetic regions.

The Ferrite materials combines these two mechanisms because they have magnetic properties in addition to the properties of insulation, and the mechanism of magnetic absorption is the main mechanism. [6], [7]

Ferrite materials are an important class of magnetic oxide materials of semi-conductive nature. They are of great technical importance due to their interesting properties. Ferrite materials are usually ferromagnetic compounds derived from iron oxides as well as other metals oxides of different proportions depending on their types. [8]–[10]

Silicone rubber has good resistance to heat for a long time. Although silicon does not exhibit high strength at room temperature, But it maintains its properties at temperatures much higher than other rubber materials, maintaining its properties within the range (-100 – 350) ℃ , This is useful in many applications such as door closures for spacecraft and furnace doors as well as unlimited age at moderate temperatures where silicone rubber is estimated to be 20 years at 120 ℃. And five years at 150 ℃. [11] The radar waves are attenuated by reducing the radar cross section, a target-specific constant used to describe the amount of reflected or scattered power from the target to the radar when the radar frequency (RF) energy is Light up the target. Electromagnetic waves are usually reflected or scattered in all directions when they fall on the target. These waves are divided into two parts, the first is composed of polarized waves such as polarization of the receiving antenna, and the other part has a different polarization with the receiver antenna and is not received by it. They are referred to as principle Polarization PP and OP orthogonal polarization, respectively. [12] In this study, rubber absorbent materials for radar waves consisting of methyl phenyl silicon rubber as a Matrix material, and spinel ferrite as a filler were prepared, they were mixed in a mechanical mixing method. Both complex permittivity, complex permeability and reflective loss were determined accurately with different compounds including various crystalline formulations of ferrites.

EXPERIMENTAL

The samples were prepared in a mixing method using the Comerio Ercole Busto Avsizo (Italian-made), It contains two rolls of diameter of one roulette (150 mm) and length (300 mm) The rubber was passed between the two rollers several times with the distance between the two rolls reduced. The materials in the rubber paste were added in the sequence shown in Table-1 with continuous mixing when adding each material. This process was carried out at laboratory temperature.

Table-1 Components of rubber paste

Material	pphr
Silicone Rubber	100
Benzoyl Peroxide	1
$CrMn_xNi_{1-x}Fe\,O_4$	2 and 3

The rubber paste is then ready to prepare a layer of silicon rubber -ferrite.

The rubber paste is placed in a mold (L = 100 mm, W = 100 mm, h = 2mm) and then pressed in a thermal hydraulic Press, under (160 ° C) and pressure (10 MPa) for 20min, this level is called Vulcanization. The rubber layers are then removed from the mold to cool, with 8 samples prepared for testing. [13] For the attenuation of microwaves within the Xband (8-12 GHz), Use the Anritsu-MS4642A (10MHz-20GHz) Vector Network Analyzer (VNA). This device measures both the scattering parameter (S11, S21, S12, and S22) for electromagnetic waves, Through which we can obtain complex permittivity and complex permeability at different frequencies within the X-band of the microwave spectrum. The parameters were determined using the (Nicolson-Ross-Weir) model.

RESULTS AND DISCUSSION

1. Reflective Loss

The results of the composite material test (silicon rubber + CrMnxNi1xFeO4) showed the reflective loss as a function of the frequency within the X-band (8-12 GHz). When adding 2 g of ferrite to rubber, the maximum reflective loss (-26.5 dB) at 11.2 GHz, as in Fig. 1

When adding 3g of ferrite, the difference is greater. Fig. 2 shows a broad absorption package for all ferrite ratios extending from the frequency (9.8-10.3) GHz. It has the greatest value for the reflective loss (-25.56dB) at the frequency (10.08GHz) for the ferrite ratio x = 0.7. There is also another reflective loss reached (-21.33 dB) at frequency (11.3 GHz).

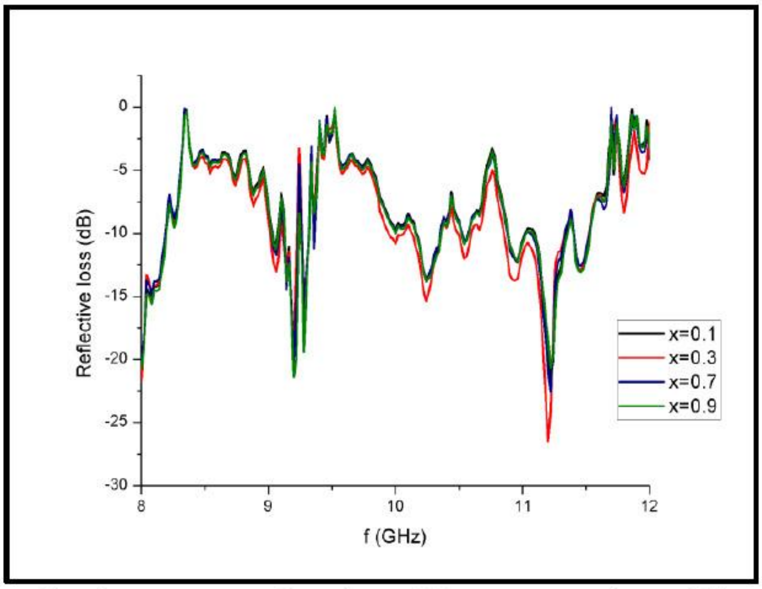

Fig.1 Reflective Loss as a function of frequency, when adding 2g of CrMnxNi1-xFeO_4 to rubber paste

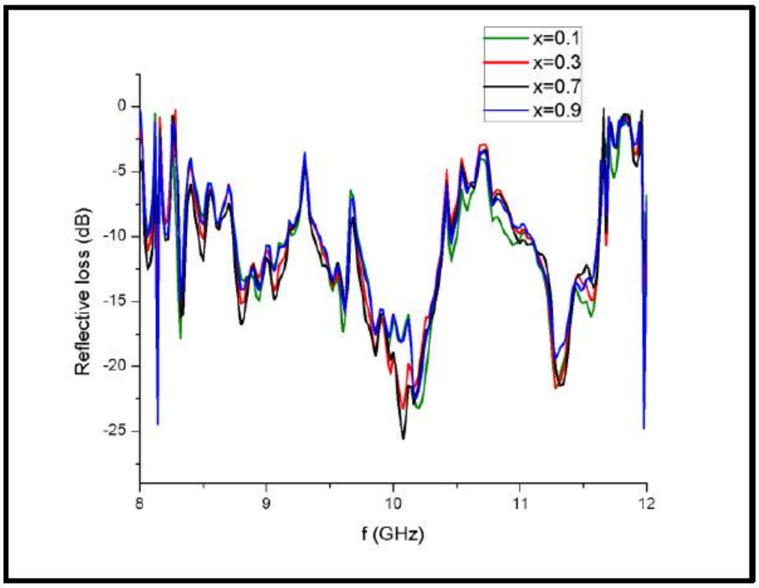

Fig.2 Reflective Loss as a function of frequency, when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

2. Reflection Coefficient

The reflection coefficient (Γ) of the prepared samples was determined as a function of the frequency. Fig.3 shows the change in the reflection coefficient of the compounds (silicon rubber + 2g of $CrMn_xNi_{1-x}FeO_4$) with frequency. The lowest value of the reflection coefficient is 0.1 at the frequency (11.16-11.23) GHz for the ferrite ratio x = 0.3, But when adding 3g of the ferrite to the rubber, as in fig.4, the reflection coefficient reached the lowest value (0) at the frequencies (8.14, 11.98 GHz) for the ratio x = 0.1 and at the frequency (8.26GHz) the reflection coefficient reached 0.04. At the 9.8-10.3 GHz band, the reflection coefficient was reduced to 0.09 for all ratios.

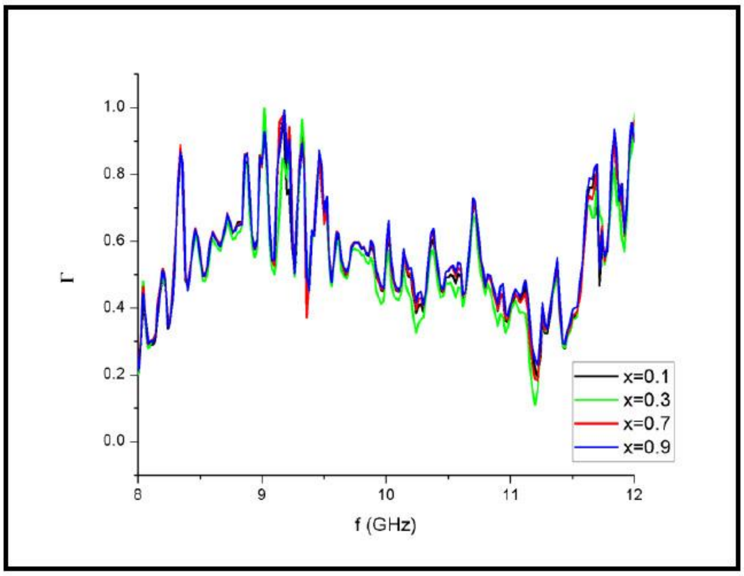

Fig.3 Reflection coefficient as a function of frequency when adding 2g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

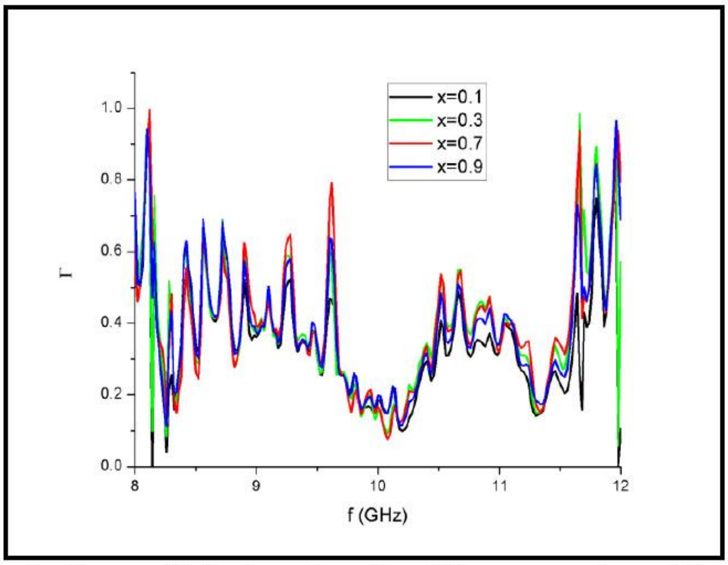

Fig.4 Reflection coefficient as a function of frequency when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

3. Complex Permittivity

The complex permittivity behavior of samples prepared as a function of frequency was studied, When adding 2g of ferrite, the value of the Dielectric Constant is 3.4 at frequency 9.38 GHz for ratio x = 0.7 and 2.8 at 8.38 GHz for x = 0.1, as in fig.5 . When adding 3g of ferrite to the rubber paste, we observe the increase of the Dielectric constant to (7.8, 5.35, 3.6, 4.34) to the ratio x = (0.1, 0.3, 0.7, 0.9), respectively, at frequency 8.14GHz, the values of the Dielectric constant reached more than 3 for all the frequencies in the region (8.26-8.39) GHz as shown in Fig.6, the reason for the change in complex permittivity values with x values is due to different ionic radii of manganese and nickel, the ionic radii of nickel is 0.69 $A°$, which is smaller than the ionic radius of manganese 0.82 $A°$, Thus resulting in deformation in the crystal structure leading to increased electrical permittivity.

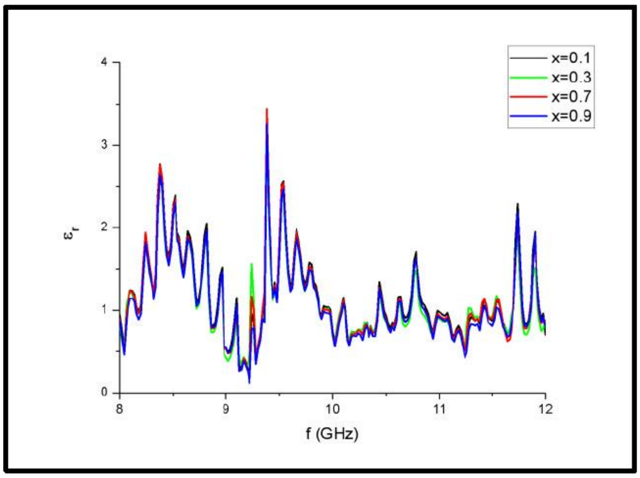

Fig.5 Dielectric Constant as a function of frequency when adding 2g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

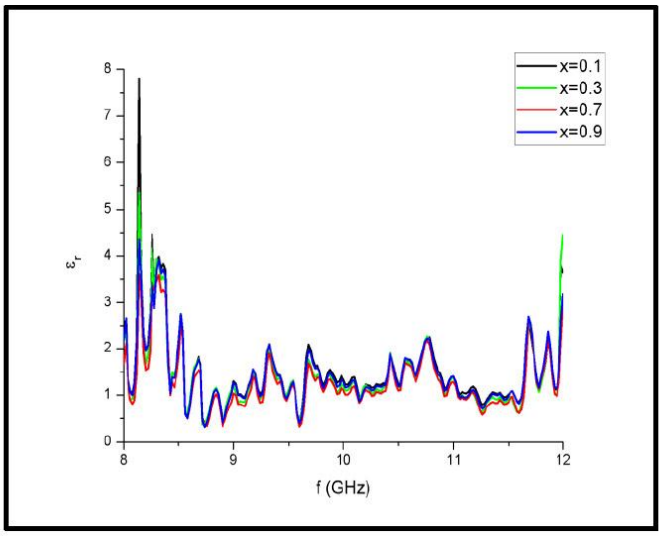

Fig.6 Dielectric Constant as a function of frequency when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

The real and imaginary part of the permittivity was also calculated as a function of frequency at the x-band within the microwaves region using the (Nicolson-Ross-Weir) method. The real part of the permittivity refers to the amount of energy from the external electric field stored in the material, and the imaginary part refers to the dispersed energy, a measure of how much the material loses to the external electric field. Fig. 7 shows the real part of the permittivity and Fig.8 showing the imaginary part of the permittivity of samples (silicon rubber + 2g ferrite). When adding 3g of the ferrite, the real part of permittivity is described in Fig. 9, and The imaginary part in Fig.10

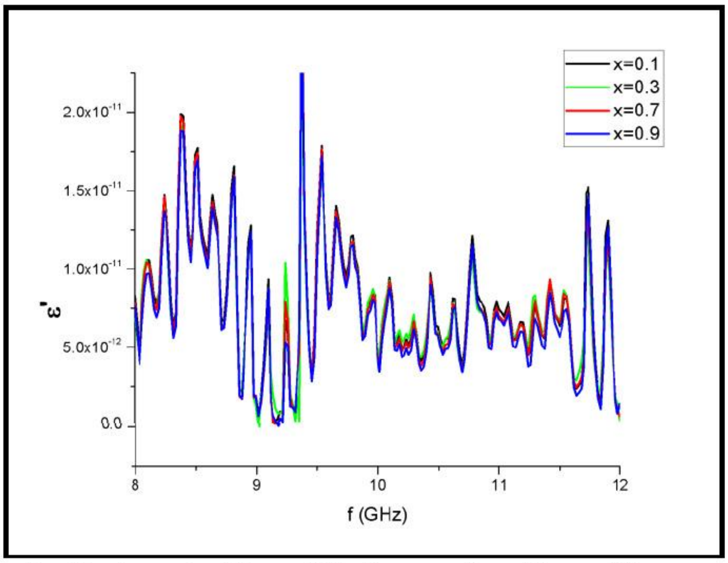

Fig.7 Real part of Permittivity as a function of frequency when adding 2g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

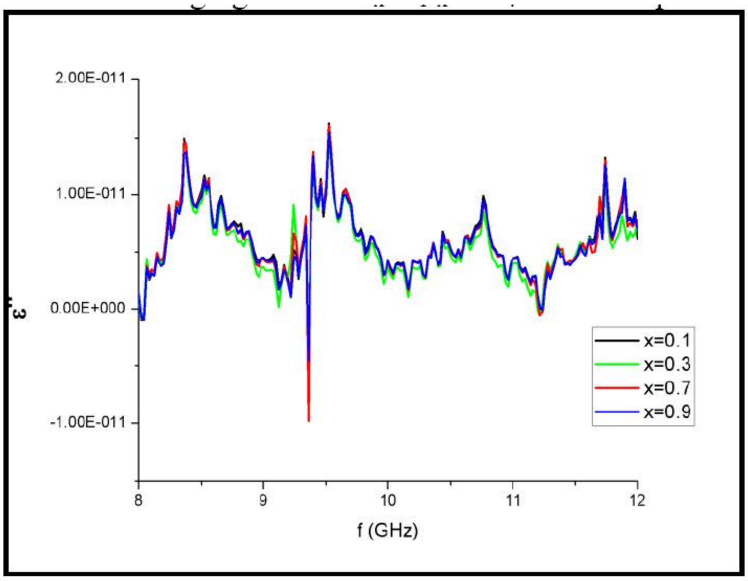

Fig.8 Imaginary part of Permittivity as a function of frequency when adding 2g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

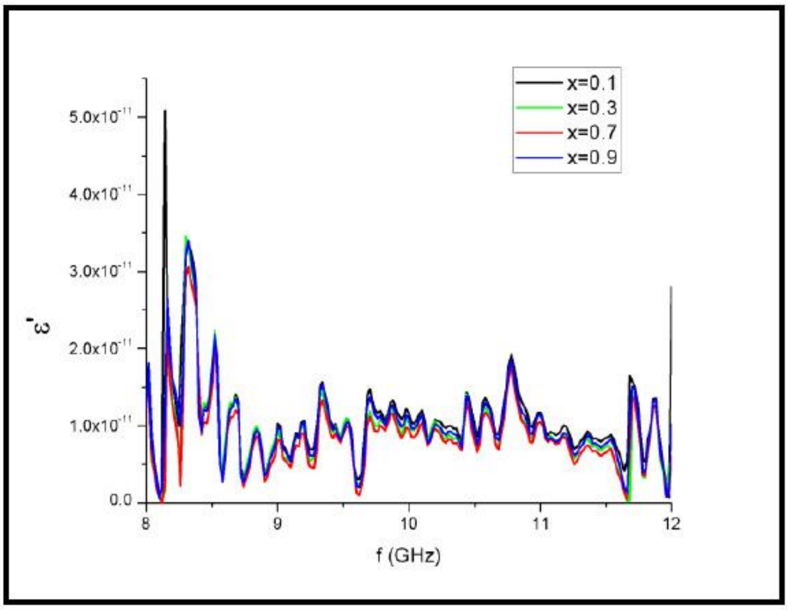

Fig.9 Real part of Permittivity as a function of frequency when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

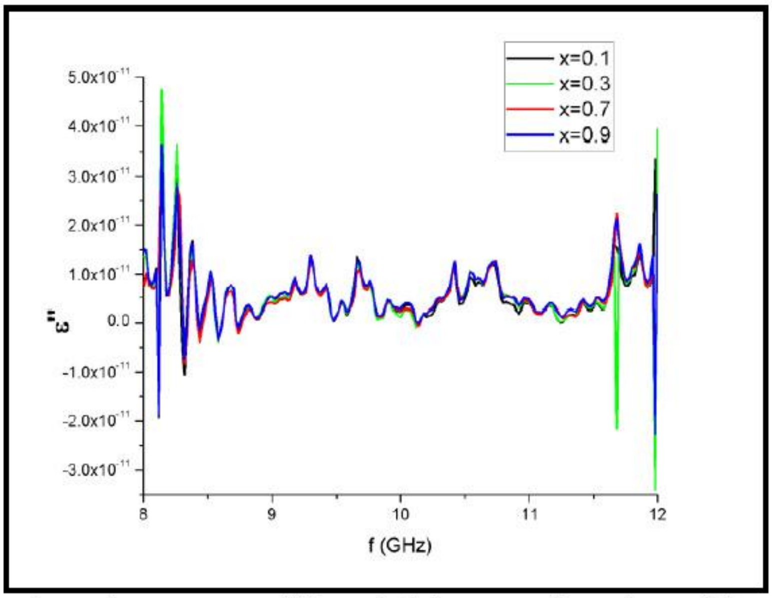

Fig.10 Imaginary part of Permittivity as a function of frequency when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

4. Complex Permeability

The complex magnetic permeability of the prepared samples was determined and the real and imaginary part of the permeability was determined at the x-band within the microwave by the S-parameters obtained from the VNA device, and by the (Nicolson-Ross-Weir) method. The real part of the permeability refers to the amount of energy from the external magnetic field stored in the material, the imaginary part refers to the dispersed energy, a measure of the loss of matter to the external magnetic field.

Figures (11, 12, and 13) show that the change of relative permeability, the real part, and the imaginary part of the permeability with the frequency in the X-band, respectively, for the samples to which 2g of the ferrite was added. It was found that the change of magnetic permeability with the added ferrite is irregular and is mainly due to the composition of the magnetic regions and the grain size and porosity of each sample where increasing the grain size reduces porosity and increases magnetic permeability.[14], [15]

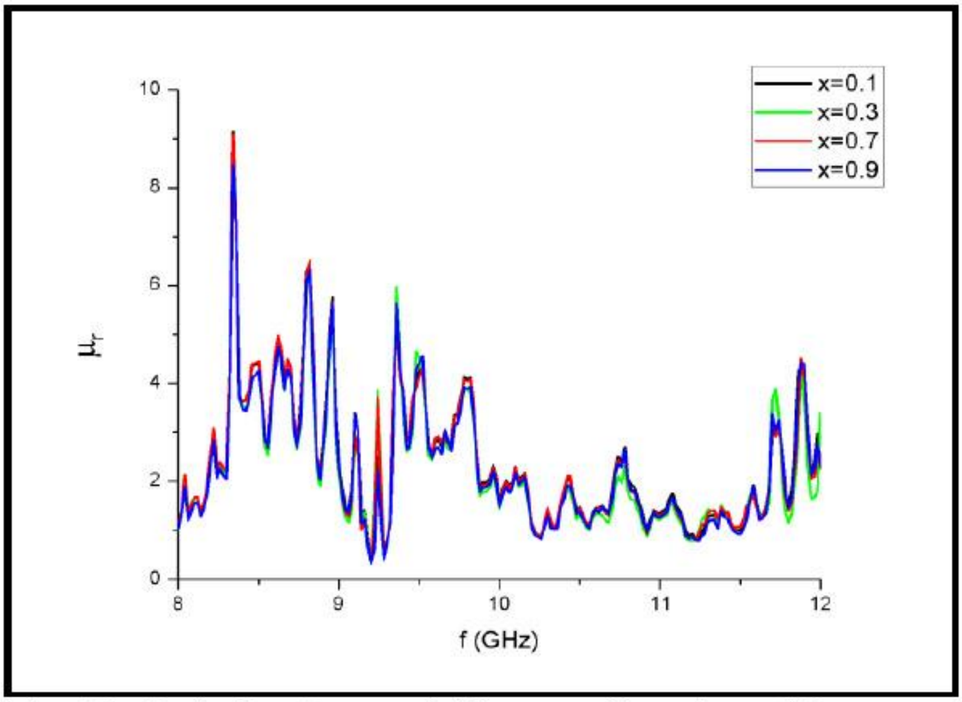

Fig.11 Relative Permeability as a function of frequency when adding 2g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

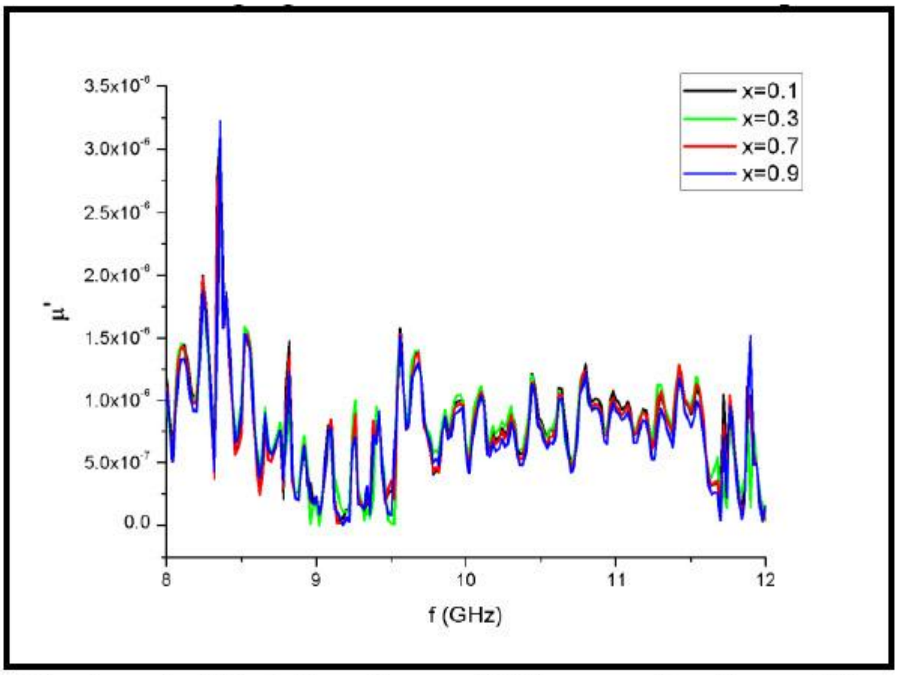

Fig.12 Real part of Relative Permeability as a function of frequency when adding 2g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

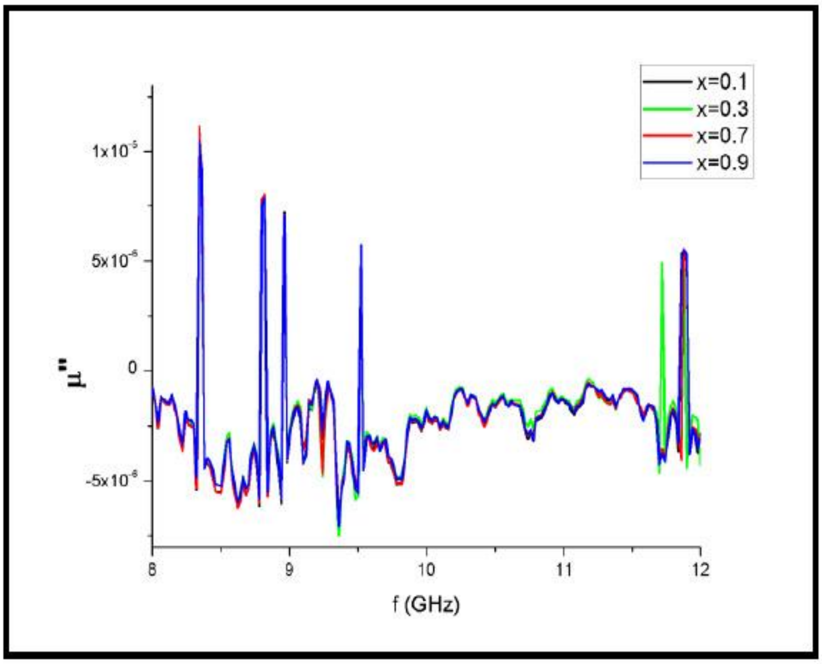

Fig.13 Imaginary part of Relative Permeability as a function of frequency when adding 2g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

Figure (14,15, and 16) explained a change the relative permeability, the real part, and the imaginary part of the permeability with the frequency in the X-band, respectively, For samples added 3g of ferrite.

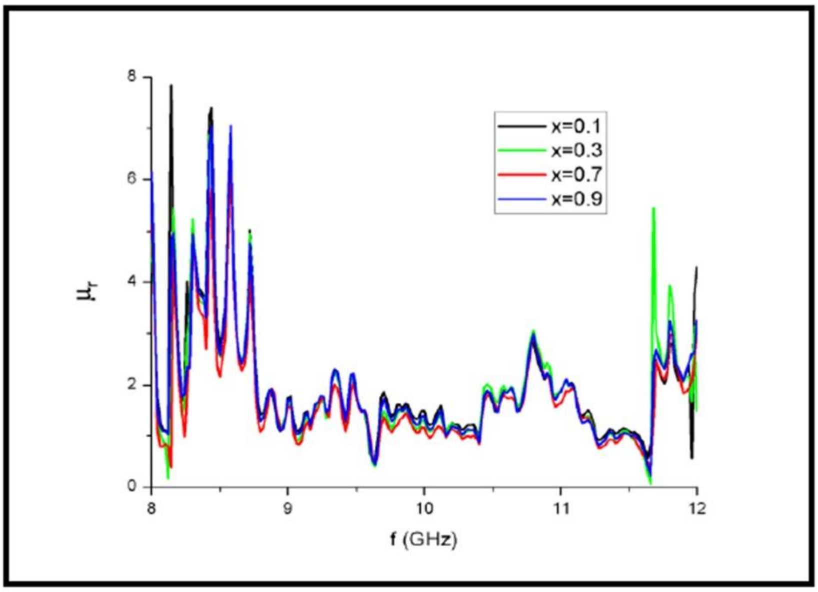

Fig.14 Relative Permeability as a function of frequency when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

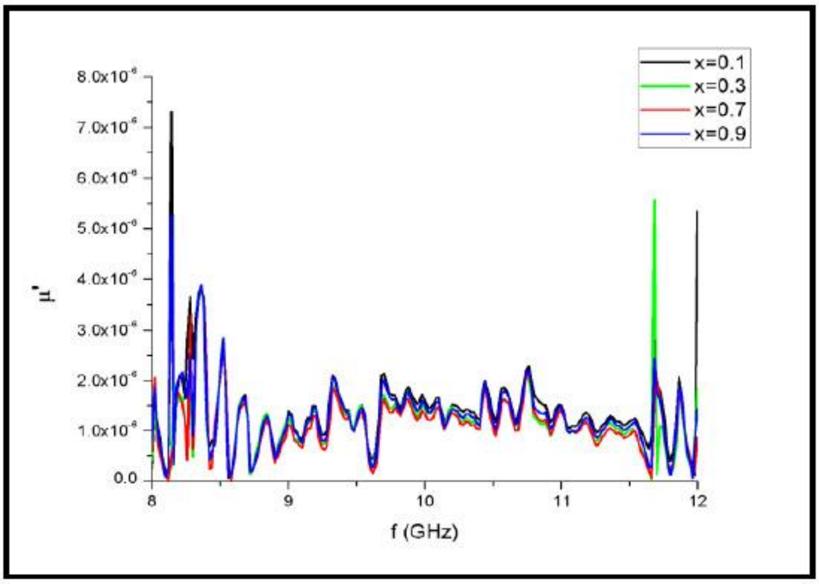

Fig.15 Real part of Relative Permeability as a function of frequency when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

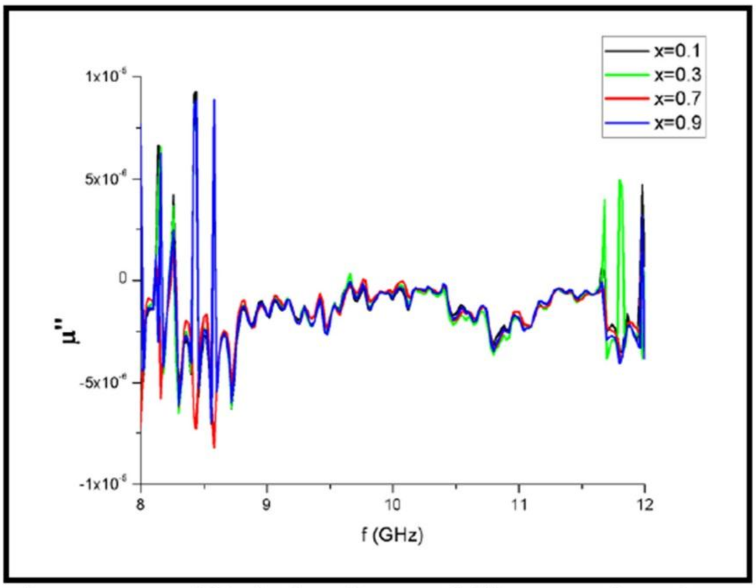

Fig.16 Imaginary part of Relative Permeability as a function of frequency when adding 3g of $CrMn_xNi_{1-x}FeO_4$ to rubber paste

CONCLUSIONS

All prepared samples had varying susceptibility to attenuation of the microwave waves within the X-band and in different ranges and with a narrow absorption band when adding 2g of the ferrite to the rubber while at the addition of 3g the absorption package was relatively exposed, due to the non-use of the multilayer ferrite system. Not to obtain a sample that absorbed all the frequency range within the X-band.

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