Radar Absorbing Material (ram) and its Effects on the Radar Detection Range

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ABSTRACT

The Radar Cross Section (RCS) has been reduced four techniques: Shaping, Radar Absorbing Material (RAM), Passive cancellation and Active cancellation. The RAM is a technology uses in camouflage application mainly in defense. The aim of this technology based on uses materials able upon absorbing the radar. The material consists of different composites consists of Polyaniline (PANI) Based on Nitrile Rubber (NBR) to produce RAMs. Permittivity of these materials is a fundamental to all other calculation. The calculation by used the cavity perturbation method in the X band (8−12 GHz), then, design four layers of the radar absorbing material backed with PEC (such a structure is typically Radar absorbing material RAS). Main goal of this design is tradeoff between low Reflection coefficients, structure thickness, the obtained results for the RC= −12.2 dB in the 12 GHz.

Keywords: Radar Cross Section (RCS), composites materials, Radar absorbing Material (RAM).

المواد الماصة لأشعة الرادار وتأثيرها على المدى الكشف الراداري

مقطع العرضي للرادار (RCS) يتقلل بالتقنياتِ الأربع: الشكل الهدف، المواد الماصة لأشعة الرادار، إلغاءَ سلبيَ ماديَ وإلغاءَ نشيطَ .المواد الماصة لأشعة الرادار(RAM) هي تقنية مستخدمة في التطبيقات التمويه في الدفاع ،تهدف هذه التقنية اساسا الى استخدام مواد قادرة على امتصاص اشعة الرادار المصطدمة بها. تتكون المواد من مركبات مختلفة تتكون من بولي انيلين (PANI) مستند على مطاط (NBR) التي تنتج المواد الماصة لأشعة الرادار . نفاذية هذه مواد تكون أساسية في كُلّ الحساباتِ الأخرى؛ ومَحْسُوبة بطريقةِ اضطراب التجويفَ للحزمة الترددية (8−12 GHz). التصميم اربع طبقات من المواد الماصة لأشعة الرادارِ دَعمتْ مَع PEC (يدعى تركيب المواد الماصة لأشعة الرادار RAS). الهدف الرئيسي من هذا التصميمِ موازنة بين اقل معامل الانعكاس و سُمك المركب والنَتائِج المكتسبة هي ان (معامل الانعكاس = −12,2 ديسيبل) في 12 GHz.

Introduction

The Radar Cross Section (RCS) is a measure of reflective behavior of a target defined as 4π times the ratio of the scattered power per soiled angle unit in an incident wave plane on the scatter from a specified direction. More precisely, it is the limit of the ratio as the distance from the scattered power is measured approaches infinity,the RCS is denoted by σ [1].

$$\sigma = 4\pi R^2 \frac{|E^{scat}|^2}{|E^{inc}|^2} \dots\dots\dots (1)$$

where E^{scat} is the scattered electric field and E^{inc} is the field incident at the target.

To reduce RCS by used the four techniques: shaping, radar absorbing material (RAM), passive cancellation and active cancellation. In this work, use RAM technique was used to reduce reflection from the target therefore use the composites materials have high dielectric constant is hard to achieve from one component to obtain on combination between the dielectric and mechanical properties.

The conducting polymer such as Polyaniline (PANI) uses as RAM because easy of synthesis, low cost and stability. The conductivity of PANI and low dielectric increases with blended with composites therefore combine with Nitrile rubber (NBR) to get high dielectric constant and improve the mechanical properties. The NBR Similar to natural rubber except for improved resistance to swelling in organic liquids and improved resistance to heat, light, and oxidative aging, Moderate cost [2]. The use of resins or rubber materials is more favorable than using sintered materials, due to flexibility and processiblity. In addition, conducting polymers are not susceptible to correction, like metallic coatings. Conducting blends of PANI with NBR due to the unique mechanical properties of the rubber. The conducting elastomer composites uses as RAM because of the light of weight, anti–correction and flexibility.

$$\varepsilon_r = \varepsilon' - j\,\varepsilon'' \dots\dots\dots\dots\dots\dots (2)$$

The complex permittivity ε_r consists of real part of permittivity (ε'_r) is a measure of how much energy from an external electric field is stored in a material. The imaginary part of permittivity (ε''_r)is called the loss factor and is a measure of how dissipative or lossy a material is to an external electric field. The imaginary part of permittivity is always greater than zero and usually smaller than real part of permittivity. The complex permittivity of theses composites calculation by means the cavity perturbation method in the X- band (8- 12 GHz). The complex permittivity is a fundamental to the calculation impedance of the composite then calculation the reflection coefficient (RC) from these composites.

Techniques to Reduce RCS

There are four techniques to reduce RCS: shaping, radar absorbing material (RAM), Passive cancellation and active cancellation.

The Shaping involve modifying the external features of the target to reduce the radar returns in a specified (usually the backscatter) direction. In the shaping technique to reduce RCS by the form target is a faceted configuration with flat surfaces to minimize normal reflection return to the radar or the form target must be smooth blended with external geometry to achieve a continuously varying curvature (e.g. Northrop B-2).

Radar absorbing materials (RAM) is to absorb the incident radar energy to minimize the energy scattered back to the radar by absorption. Radar energy is converted the energy incident into heat energy. The RAM can be reducing the radar cross section of other kinds such as ships, and other of the targets. The RAM is the three kinds of materials such as dielectric materials, magnetic materials and hybrid materials uses in the stealth technology. These materials have ability to the absorption energy incident.

Passive cancellation is the basic concept is to design the target surface so that the reflected radar signal from parts of the target cancels the reflected radar signal from another part of the target [3].

Active cancellation- also called active loading, active cancellation is even more ambitious than impedance loading. The basic concept is the target must emit radiation in the same time with incoming pulse whose amplitude and phase cancels the reflected signal. This implies that the target must be smart enough to sense these data are the angle of arrival, intensity, wave from and frequency of the received wave [4].

Composites Preparation

Polyaniline preparation

The PANI was prepared using ammonium peroxydisulfate according to the procedure described [5].

Formulation of the Preparation

The formulation of the preparation Nitrile Rubber/Polyaniline composites in Table (1), NP series represent PANI with NBR. NP merely symbols represent of the weights of PANI based on 100g of NBR. Phr represent parts of weights to the parts of rubber.

Table (1):- Formulation of the NBR/PANI

phr	NP0	NP1	NP2	NP3
NBR	100	100	100	100
PANI	0	50	100	150

Cavity Perturbation Method

The cavity perturbation method is one of the several methods to calculate complex permittivity of the composites materials at microwave frequency. The cavity perturbation method offers the advantage of relative simplicity, high sensitivity, and requires only a small quantity of the sample [6]. The resonant cavity used for the measurement of the complex permittivity is a rectangular wave-guide cavity with dimensions of 11.5 cm in length, 1.9 cm in width, and 1 cm in the height as shown in fig (1).

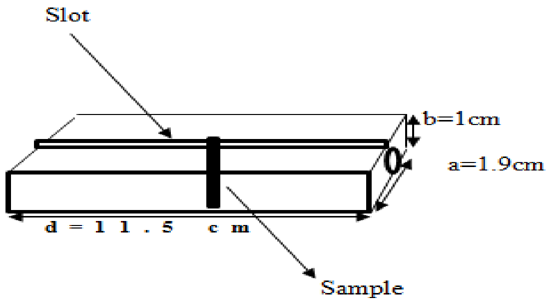

Figure 1. Design layout of the Rectangular cavity, at dimension of the X-band.

For the rectangular cavity, the Transvers Electrical modes (TE_{10N}) (N is an integer) [6] are widely used for the complex permittivity calculation. The sample placed in the position of the maximum electric field when N is odd modes usually to get the maximum electric fields [7]. The specimen position will have to be move with different TE_{10N} modes. The samples in the form of thin rectangular rods, assume the length of which equals the height of the cavity, so that both the ends of the specimen are in contact with the cavity walls, were used. The samples were inserted into the cavity through a slot and positioned at the maximum electric field. Could be excited for operation in four modes (TE_{101} to TE_{107}) and accordingly, four resonant peaks corresponding to theoretical frequencies around 8, 8.8, 10.24, 12 GHz. The real and imaginary parts of the relative complex permittivity are calculated by [7,5].

$$\varepsilon' = \left(\frac{V_C(f_C-f_S)}{2V_C f_S}\right) + 1 \ldots\ldots\ldots\ldots\ldots (3)$$

$$\varepsilon'' = \frac{V_C}{4V_S}\left(\frac{1}{Q_S} - \frac{1}{Q_C}\right) \ldots\ldots\ldots\ldots\ldots (4)$$

Where f_c and Q_c are resonant frequency and the quality factor of the empty cavity and f_s and Q_s are corresponding for the perturbed case. V_c

is the region enclosed by the cavity, and V_s is the volume of the sample, respectively.

Results and Discussion

Electrical Permittivity

In figures 2 and 3 real and imaginary part of the permittivity of the different loading of the PANI based on NBR is calculated by the cavity perturbation method at various weights of PANI are shown in Table (1). The ε' and ε" increase with increase frequencies and increase with loading of PANI are shown in the same figures. Comparison between this results of the ε' and ε" of the PANI based on Natural Rubber (NR) exits the ε' and ε" of NBR/PANI is higher than the results of the PANI based on NR [8].

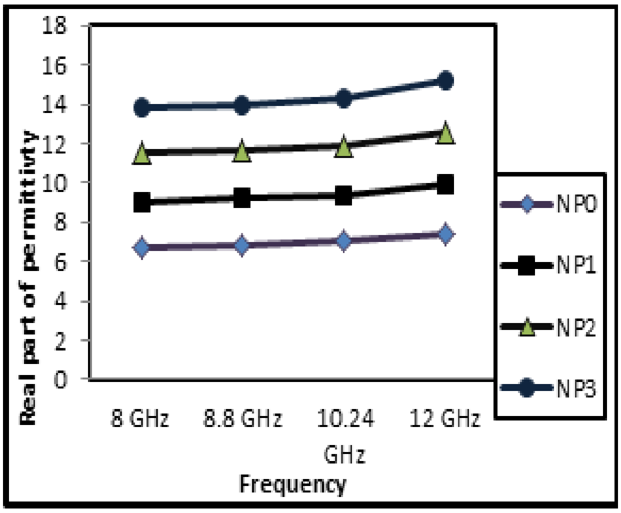

Figure 2. Real part of the NBR/PANI CPCs.

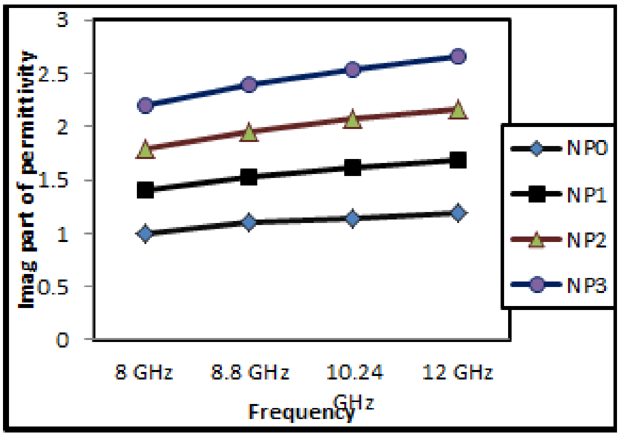

Figure 3. Imaginary part of the NBR/PANI CPCs.

Composite intrinsic wave impedance

For the transversal electromagnetic (TEM) wave propagating in a dielectric material, denoted with k index, the wave impedance η is express by the equation [9, 10].

$$\eta_k = \sqrt{\frac{\mu_k}{\varepsilon_k}} = \sqrt{\frac{\mu_\circ \mu_r}{\varepsilon_\circ \varepsilon_r}} = \sqrt{\frac{\mu_\circ}{\varepsilon_\circ}}\sqrt{\frac{\mu_r}{\varepsilon' - j\varepsilon''}} \ldots\ldots\ldots (5)$$

Where $\mu_\circ$ is the permeability of free space $(4\pi * 10^{-7}\ H/m)$ [9] and μ_r is the relative permeability of the material and equal 1 for the dielectric materials. $\varepsilon_\circ$ is the free space permittivity (8.854×10^{-12} F/Hz) and ε_r is the relative permittivity of the material. Since dielectric permittivity is a function of frequency, the microwave intrinsic impedance of the composites material depends on frequency, and its value is in general complex number. In figure (4) PANI based NBR composites intrinsic X-band microwave impedance modules are shown. It is evident that PANI based NBR show the lowest wave impedance values. The intrinsic wave impedance decreases with increases frequencies and increase the complex permittivity of the NBR/PANI composite.

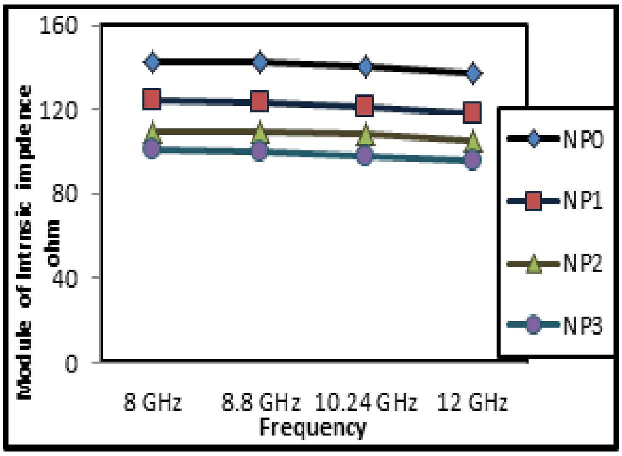

Figure 4. Microwave impedance module of for different loading of NBR/PANI in the X-band.

Numerical analysis for obtaining design solutions

Where the mathematical model to use in the subsequent, the results obtained for the real and imaginary parts of NBR/PANI CPCs and the microwave characteristic impedance will be used in order to design a multilayer system capable to minimize the reflection of an incident electromagnetic wave.

Single layer microwave absorbing structure simulation

A normal incident electromagnetic field; has been assumed, then design single layer of the NBR/PANI composites is attached on a PEC plate, as depicted in figure 5. In order to neglect border effects and the calculated Reflection Coefficient (RC) at the air-composite material layer interface by use the transmission line theory.

$$RC = 20\log_{10}\left|\frac{Z_i - Z_\circ}{Z_i + Z_\circ}\right| \ldots (6)$$

RC is the reflection coefficient (dB) at the single layer, $Z_\circ = \sqrt{\frac{\mu_\circ}{\varepsilon_\circ}} \cong 377\Omega$ is the free space impedance, and Z_i is the input impedance at the air- absorber interface. This latter can be expressed by:

$$Z_i = \eta_k \frac{Z_L \cos(\beta t) + j\eta_k \sin(\beta t)}{\eta_k \cos(\beta t) + jZ_L \sin(\beta t)} \ldots\ldots (7)$$

Where t is the thickness of the absorber layer in **m**, and the propagation number β is given by:

$$\beta = 2\pi f\sqrt{\mu_\circ \varepsilon_\circ}\,\sqrt{\mu_r\,\varepsilon_r} = \sqrt{\varepsilon' - j\varepsilon''} \ldots (8)$$

Where f is the frequency of the incident electromagnetic wave in Hz and η_k is the intrinsic wave impedances of the **xth** material have been compute using the equation (5).

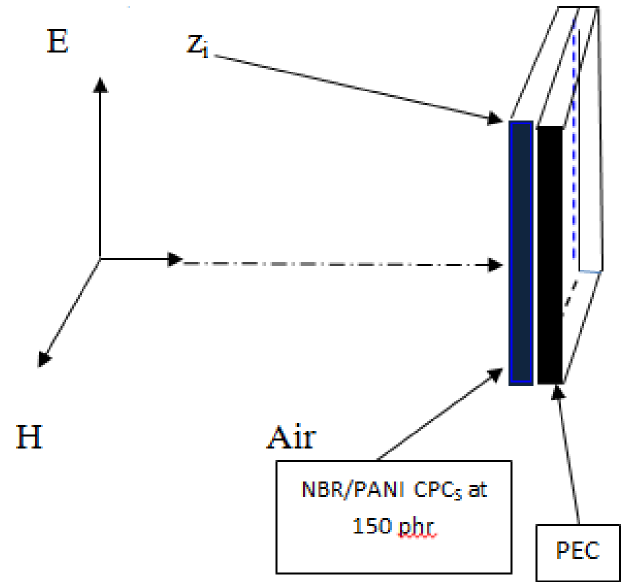

Figure 5. Microwave single layer absorber scheme.

The absorption capability of a “thin” layer is mainly due to both dielectric losses within the material and impedance matching condition. The dielectric losses are mainly function of the imaginary part of the permittivity, while the matching conditions are to be study by taking into account the microwave wavelength. From the Eq. (7) it is possible to observe that the imaginary part of Z_i vanishes for certain multiple values of the quantity βt. This route can evaluate the RC module: from figure 6 show the reflection coefficient of the NBR/PANI composite structure reaches when reflection coefficient −2.2 dB of frequency 12 GHz.

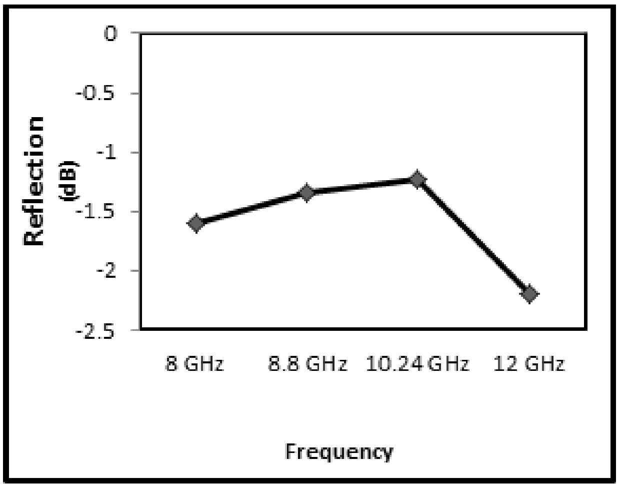

Figure 6. Module of single layer RAM structure reflection coefficient when the thickness layer =4mm.

Four Microwave Absorbing layers structure

Let us suppose a multilayer RAM structure made of four layers of composite material backed with a PEC layer, as depicted in figure 7. Using Eq. (7) iteratively, we can find the corresponding input impedance at each layer interface; by this way, we contemporary take into account of the other layers, which in turn become the new load impedances. The several input impedances are then expressed by:

$$Zi_1 = \eta_1 \frac{Z_{PEC}\cos(\beta_1 t_1)+j\eta_1 \sin(\beta_1 t_1)}{\eta_1 \cos(\beta_1 t_1)+jZ_{PEC}\sin(\beta_1 t_1)}$$

$$Zi_2 = \eta_2 \frac{Zi_1 \cos(\beta_2 t_2) + j\eta_2 \sin(\beta_2 t_2)}{\eta_2 \cos(\beta_2 t_2) + j\, zi_1 \sin(\beta_2 t_2)}$$

$$Zi_3 = \eta_3 \frac{Zi_2 \cos(\beta_3 t_3) + j\eta_3 \sin(\beta_3 t_3)}{\eta_3 \cos(\beta_3 t_3) + j\, zi_2 \sin(\beta_3 t_3)} \;\ldots.(9)$$

$$Zi_4 = \eta_4 \frac{Zi_3 \cos(\beta_4 t_4) + j\eta_4 \sin(\beta_4 t_4)}{\eta_4 \cos(\beta_4 t_4) + jzi_3 \sin(\beta_4 t_4)}$$

In addition, the resulting impedance matching condition between free space and RAM structure is RC at the four layers.

$$RC = 20\log_{10}\left|\frac{Zi_4 - Z_0}{Zi_4 + Z_0}\right| \ldots\ldots.(10)$$

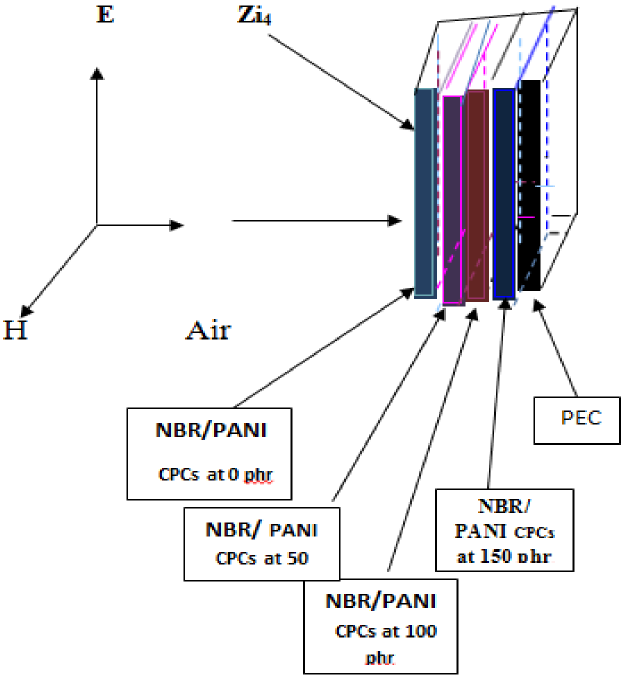

Figure 7. Four microwave absorbers layers scheme.

Let us suppose the following materials and thickness, as shown in figure 7.

-layer one: NBR/PANI 0phr 1mm.

-layer two: NBR/PANI 50phr 2mm.

-layer three: NBR/PANI 100phr 2mm.

-layer four: NBR/PANI 150phr 4mm.

The final RAM reflection coefficient is plotted in figure 8. It can be noticed that the lower RC of the NBR/PANI composites at low loading and thickness.

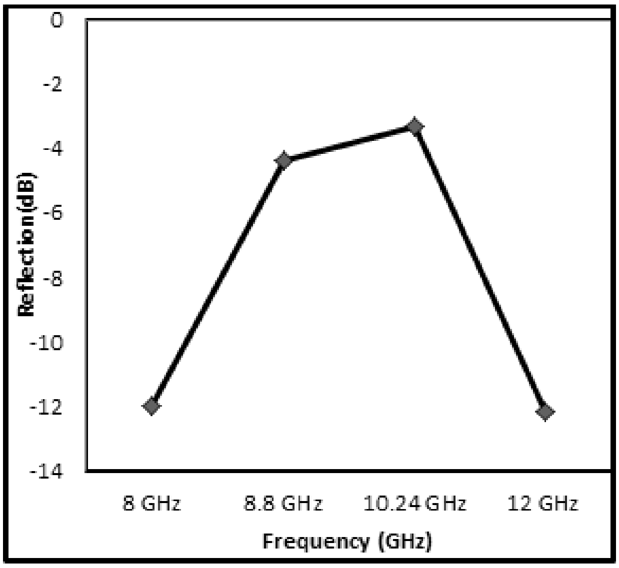

Figure 7. Module of four-layer RAM structure reflection coefficient at the X-band.

Conclusion

The uses NBR/PANI composites as radar absorbing materials (RAM) analysis in the X-band with simulation of RAM structure based on the calculated quantities. The complex permittivity of NBR/PANI computed by used the cavity perturbation method at (8-12 GHz). The results obtained the real and imaginary parts of the NBR/PANI composites increases with increased frequency and loading of PANI. At **12** GHz it is obtained (**ε'=7.4**) when 0phr then (**ε'=15.2**) at 150phr at the same frequency. The intrinsic wave impedance of NBR/PANI is calculated in the X-band and it is evident the intrinsic wave decrease with increase complex permittivity of NBR/PANI. In order to design a microwave RAM structure composed of four layers of conducting composite backed with a PEC. The absorption properties have been evaluated using the microwave reflection coefficient at the air- four layers RAM interface. The results obtained show the low **RC** (- **12.2 dB**) at the **12** GHz in the four layers is better from **RC**=- **2.2 dB** in the single layer RAM structure at the same frequency.

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