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FACTORS AFFECTING THE PERFORMANCE OF THE RADAR ABSORBANT TEXTILE MATERIALS OF DIFFERENT TYPES AND STRUCTURES

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Abstract—In the military applications, electro-optics and electromagnetics features of the cloths made of special textile structures and certain fibers play an important role in producing textile characterized with high ability of camouflage. This means not allowing enemy to precisely determine the moving and mute targets using available radar or any other electro-optics sensors. The aim of this paper is to determine the effect of the composite fabrics structure parameters on the fabrication of a resistive sheet used in many radar applications. The objective sheet can be used as a lossy sheet in absorbing mechanism. The radar absorbing mechanism has been studied with emphasis on the single layer structure mechanism with a resistive sheet. Fabric structure of the resistive sheet was accurately chosen and coated

with lossy material. For coating, several formulas of fabrics using carbon black were tested to determine the best chemical treatment in accordance with their functional performance. Lab measurements have been done to get optimum formulas and optimum fabrics structures for high radar absorption performance.

1. INTRODUCTION

Over the past few years, there has been an emphasis on reducing the radar cross section (RCS) of military weapons using different techniques [1–6]. These techniques can now be applied to the civilian market to solve many problems. The most common and simple structure to reduce the level of the reflected power from a metallic surface is the single layer structure known as Salisbury screen [7–10] which is a sheet of porous material (resistive sheet) impregnated with graphite and spaced a quarter-wavelength of a metallic backing plate. This resistive sheet can also be used as an interference suppression with microstrip planar antennas [11, 12] when a half-wavelength spacer is used. Exploring the most suitable resistive sheet in terms of uniformity and resistivity is a particularly important issue [13, 14]. Fabric parameters, properties, structures and chemical materials have been considered to achieve our goal.

2. RADAR ABSORBING TECHNIQUES

Various techniques have been published lately for reducing the RCS of different targets [1]. Generally, there are four basic techniques for reducing the RCS of any target. These are; shaping, radar absorbing materials (RAM), passive and active cancellation. In our work, we will concentrate on RAM as a technique for reducing the RCS. The optimum RAM should be thin, light, durable, inexpensive, easy applied and have broad band frequency coverage. In fact, many absorbing materials are manufactured with lossy materials providing the loss mechanism, and the dissipation of energy takes place by the conversion of electromagnetic energy into heat. Lossy mechanism may be carbon or dielectric materials with complex indices of refraction; moreover, magnetic losses can occur as will as electric losses. Thus lossy materials may also include ferrites or carbonyl iron in additional to, or in place of, carbon. RAM may be classified as "resonant" or "broad band" depending on the structure of the used absorber materials. The simplest type of resonant absorber is known as a Salisbury screen which is a narrow frequency band technique. The bandwidth of Salisbury screen type absorber can be improved by constructing a multi-screen absorber, one behind the other and separated by a dielectric spacer. In this paper, the interest is to reduce the RCS using Salisbury screen technique as a radar absorbing materials.

3. SALISBURY SCREEN AS A RADAR ABSORBER MECHANISM

The Salisbury screen is a resonant absorber created by placing a lossy sheet on a low dielectric constant spacer in front of a metal plate forming one layer structure. Calculation of the reflected power of a normally incident plane wave from an infinite flat one-layer structure is a straight forward problem involving application of boundary conditions derived from Maxwell's equations to the general solution for the electric and magnetic fields in that layer. The basic structure, shown in Figure 2, consists of only one dielectric layer covered with a lossy sheet and stacked against a metallic backing plate with the following parameters:

Dielectric parameters of the spacer, normalized to free space, is equal to $\varepsilon_r = \mu_r = 1$

Layer intrinsic admittance Y_L, normalized to Y_0, is given by: $Y_L = \sqrt{\frac{\varepsilon_r}{\mu_r}}$

where Y_0 is the free space admittance equal to $1/377\,\Omega$

Sheet admittance Y_s, normalized to Y_0, is given by: $Y_s = G + JB$

The reflected power, in dB, of a normally incident plane wave is given by:

$$|R| = 20\log_{10}\left|\frac{P_r}{P_i}\right| \tag{1}$$

where P_i, P_r are the amplitudes of the incident and reflected propagated waves and equal to [1]:

$$\begin{aligned} P_i &= \frac{e^{-jk_0x}}{2}\left\{[2+(G+jB)]e^{jk_0x} - (G+jB)e^{-jk_0x}\right\} \\ P_r &= \frac{e^{jk_0x}}{2}\left\{-(G+jB)e^{jk_0x} - \left[2-(G+jB)e^{-jk_0x}\right]\right\} \end{aligned} \tag{2}$$

where k_0 is the free space wave number and is equal to $2\pi/\lambda$.

From Equations (1) and (2), and assuming that the lossy sheet is an infinitesimally thin resistive sheet of conductance G (i.e., $Y_s = G$), then the reflected power P_r will be zero if:

$$\left[-G^{jk_0x} - (2-G)e^{-jk_0x}\right] = 0 \tag{3}$$

This requires that the magnitudes of the two exponential in Equation (3) be equal and their phase angles be opposite. The equal amplitude requirement forces the normalized conductance G to be one, then:

$$P_r = -e^{jk_0x}\frac{e^{jk_0x} + e^{-jk_0x}}{2} = -e^{-jk_0x}\cos\frac{2\pi x}{\lambda} \tag{4}$$

So, the condition for P_r to be zero is given by:

$$x = \frac{\lambda}{4} + n\frac{\lambda}{2}, \quad n = 0, 1, 2, \ldots . \tag{5}$$

Thus for zero reflectivity, a Salisbury screen requires a 377 ohm per square sheet resistance ($G = 1$) set at a quarter wave length in front of a perfectly reflective backing. The resistive sheet can either be uniform in such as carbon weave, cloth or paper, or constructed from circuit analogue structure pattern printed with lossy wires or crosses or square metal, or pure metal plus a lossy sheet. In our research, we will concentrate on uniform resistive sheet of different structures of textile fabrics coated with carbon black with several formulas.

4. EFFECT OF TEXTILE FABRIC STRUCTURE ON ELECTROMAGNETIC WAVE PROPERTIES

The fabric structure used is highly affected by the produced fabric specification. As long as the structure of the fabric is balanced, the results obtained in both direction, (the weft and the warp direction) become more closer. Woven Fabrics with plain structure are almost homogenous because the number and the count of the used yarn are almost balanced. Hence the cover factor of the wrap and weft is balanced $k_1 = k_2$ and this brings about same percentage of appearance of the warp and the weft on both faces, and as a consequence the results obtained in both directions become closer. Warp-face twill 3/1 is obtained by raising all the wrap yarns except one in each pick, with grating the warp yarn. As a result, a group of warp inclined yarn is separated by tine inclined yarns is obtained. On the contrary, the balanced twill 2/2 structure on which the analogue obtained will have the same thickness on both the back and the face. So we found the results obtained in the second case are closer than the first one because of the balanced fabric. For the satin weave, the appearance of warp yarn and its impregnation on the surface of the fabric is more than the weft yarn. Consequently, better results are obtained in the direction of the warp than in the weft direction. The knitted fabrics (jersey, rib, derby, pointal and double face) are characterized by vertical lines on the surface of the fabrics owing to the arrangement of the needles in the dail and cylinder. Thus the fabric performance is improved in the vertical direction than on the horizontal which is the direction of the textile.

5. PARAMETERS AFFECTING RESISTIVE SHEET MANUFACTURE

Carbon black is the main pigment material used for chemical treatment of all fabric samples under test. As pigment dyes, carbon black material just sticks on the fabric surface or penetrate on the "haired surface" fibers of the fabric samples. So, on this basis, the relationship between woven fabric construction parameters and desirable resistivity could be limited on the ability of fabric surface to "hold" the carbon black, more than knitted ones, either weft or wrap knitted. This can be interpreted by the intersection density, as weave number ($M = n_i/n_r$), where the (n_i) number of intersection per inch, and (n_r) number of repeat threads (ends and fillings) per inch. The more intersections per square inch, the better holding of carbon black material on the fabric surface. Comparing radar absorbance quality for woven (plain 1/1, twill and satin) and weft knitted: Jersey, rib and double face) and warp knitted following results revealed. Plain woven fabrics show the best results of desirable resistivity. This is explained by the highest intersection density, plain were enjoys among all woven or knitted fabrics considerable number of intersection points of plain weaves allows great area of contact and sticking with carbon black as a pigment material. Twill woven fabrics show less resistivity value than plain ones. Similarly less resistivity value waves, is the trend of Satin fabric. In satin fabrics the principal reason for that is high ability of satins sateens for slippery, due to their high and softness and lustre of fabric surface. In woven structure terms, this is explained by, not only the little number or intersections or by their scattering distribution, but also, and perhaps mainly, by the hiddness of all intersection points on the effective surfaces of satins. Knitted fabrics, constructed basically from intermeshing of loop like stitches, show less ability of surface holding for any pigment materials, such as carbon black. Consequently resistivity results for all weft knitted samples "Jersey", rib, and double-face are less in comparison with woven samples. Similarly using net structure shows desirable resistivity results, in comparison with woven material samples. The following diagram Figure 1 shows the relationship between the used concentration of the carbon and the value of the resistivity obtained from plain woven fabric.

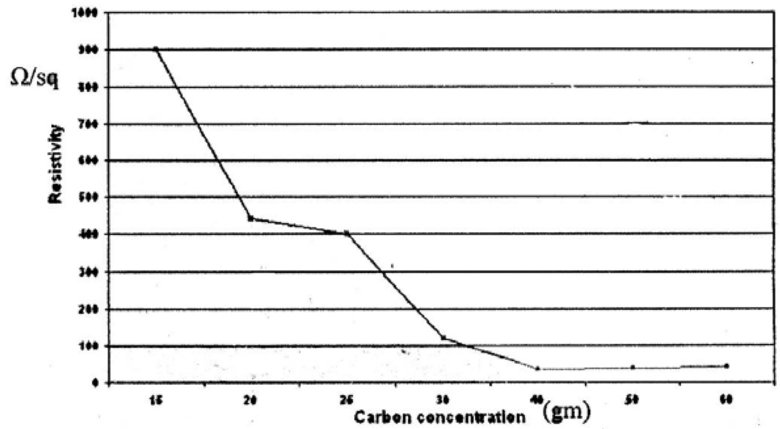

Figure 1. Effect of carbon concentration on the resistivity value obtained from plain woven fabric.

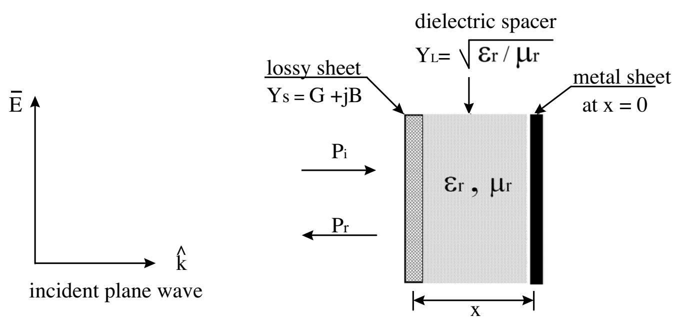

Figure 2. Configuration of Salisbury screen as single layer absorbing mechanism.

6. MEASUREMENTS OF MANUFACTURED SAMPLES

In this section, several types of the fabricated resistive sheet have been tested to find the most suitable one in terms of sheet resistivity and uniformity. A value of resistivity close to $377\,\Omega/\text{sq.}$ was required for optimum absorption of Salisbury absorbing mechanism over the greatest possible frequency band width. The resistivity of more than 40 manufactured samples has been measured to get the best structural textile fabrics. A resistivity of $400\,\Omega/\text{sq.}$ has been obtained for the sample specified with "Plain weave" structure, 100% cotton, and yarn counts. $(24/1) \times (24/1)$, fabric density per centimeter (32×30) and fabric weight ($110\,\text{gm/m}^2$). The absorption of this sample, with the configuration shown in Figure 2 at spacing $x = 4.7\,\mathrm{mm}$, has been measured using PR-17 microwave reflectometer to assist the resistive sheet absorption. The basic measurement technique is a bistatic RF return loss test much like the NRL arch [1]. The reflectometer operates in free space using transmitting and receiving antennas oriented at a bistatic angle of ±15 degree. Figure 3 shows the measured absorption of the tested sample. A minimum reflective power equal to $-15.84\,\mathrm{dB}$ at 16 GHz for a low dielectric spacer ($\varepsilon_r = \mu_r = 1$) while the performance is still respectable at frequency band 15–17 GHz.

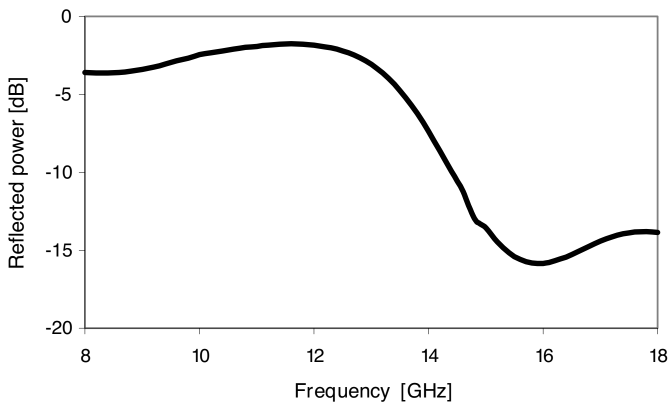

Figure 3. Measured reflected power in dB from the absorbing mechanism shown in Figure 2 at $x = 4.7\,\mathrm{mm}$.

7. CONCLUSION

Current research work is concerned with investigation of radar absorbing mechanism. Emphasis is placed on the single layer structure mechanism of a resistive sheet with different fabric structures. The latter were coated using different formulations based on carbon black. Results obtained by varying the fabric structure and those obtained by changing the ingredients of the carbon black-based formulation, brings into focus the most appropriate conditions for obtaining textiles with high ability of camouflage.

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