GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 9/19/80

Project Title: Measurements of Reflective and Absorption Properties of Selected Resonant Dipoles at Millimeter Wavelengths (MMW's)

Project No: A-2744

Project Director: Dr. R.L. Moore

Sponsor: MERADCOM, Ft. Belvoir, VA


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Assigned to: ETL/EE (School/Laboratory)

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SPONSORED PROJECT TERMINATION

Date: 11/3/80

Project Title: Measurements of Reflective and Absorption Properties of Selected Resonant Dipoles at Millimeter Wavelengths (MMW's)

Project No: A-2744

Project Director: Dr. R.L. Moore

Sponsor: MERADCOM, Ft. Belvoir, VA.

Effective Termination Date: 10/31/80

Clearance of Accounting Charges: 10/31/80

Grant/Contract Closeout Actions Remaining:

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- Final Fiscal Report
- Final Report of Inventions
- Govt. Property Inventory & Related Certificate
- Classified Material Certificate
- Other _______________________

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FINAL ENGINEERING REPORT
PROJECT A-2744

REFLECTION AND TRANSMISSION MEASUREMENTS OF CAMOUFLAGE SAMPLES

MERADCOM, Camouflage Branch
Purchase Order No. DAAK70-80-P-4890

Attn: Dr. J. W. Bond

By
R. L. Moore

3 October 1980

Electromagnetic Effectiveness Division
Electronics Technology Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia  30332
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A. Introduction

During the time period 7-11 July 1980 samples of camouflage cloth were made and tested at 98.6 GHz for their power reflection and transmission properties. The camouflage samples were constructed by coating 12-inch by 12-inch polyester sheeting material with 1 mm (8 and 12μm diameter) and 3mm (4μm diameter) lengths of stainless steel fiber. Additional samples were coated with 1mm and 3mm (37μm diameter) F-911 conductive (carbonized) Nylon 6 fiber. These fibers were deposited by sifting them through a No. 70 standard sieve (Tyler equivalent 65 mesh), and allowing them to fall at random on the cloth surface. The conductive fibers were bonded to their cloth support with Krylon acrylic adhesive. As indicated previously, no effort was made to control the relative orientation of the fibers on their cloth substrates. Of 25 samples made, 19 samples were picked based on a visual investigation of the uniformity of the conductive fibers on the cloth surfaces.

The number density, \( \rho \), of the conductive fibers on each sample was determined by a visual count using an optical microscope set at a magnification of 50X. Thus the unit area which was inspected was circular and 12.7mm\(^2\) or \( \approx 1.5 \lambda_o^2 \) at 98.6 GHz. An average number density, \( \rho \), and number density standard deviation, \( \sigma \), were determined by counting fibers in 20 unit areas per sample.

Figure 1 shows a conceptual diagram of the equipment configuration used to measure power transmission, \( T \), and reflection coefficients, \( R \), of each camouflage sample. Each sample was positioned on a flat styrofoam support, whose surface was placed perpendicular to the transmitting and receiving horn antenna apertures, and approximately 4 inches from the transmitting antenna. The position of each sample was varied slightly about this 4-inch distance in an attempt to account for any near-field
Figure 1. Conceptual diagram of the experimental configuration.
or VSWR effects. The variations resulting from position changes were observed to be about ± 2 dB for the two samples having fiber concentrations greater than 100 fibers per \( \lambda_0^2 \) where \( \lambda_0 \) is measured at 98.6 GHz. For all other samples, variations were less than ± 1 dB. The data shown in Table 1 are the average measured reflection coefficients, \( R \), referenced to the return of a flat silvered plate placed 4 inches from the transmitting horn. The average transmission coefficients, \( T \), are referenced to a clear-sight measurement.

B. Experimental Results

Table 1 shows the data for two separate experiments to measure a two horn transmission and reflection coefficients performed at 98.6 GHz on 19 camouflage samples. In addition, results are shown for five woven camouflage cloth samples made by Riegel Textile. These contained the indicated concentration by weight of steel fiber. Separate measurements performed for Riegel Textile indicate that 20 dB of attenuation at X-band can be achieved using these Riegel samples.

Data for 1 mm steel fibers, which are \( \sim 0.35 \lambda_0 \) in length, indicates that reflection and transmission properties can be reasonably well controlled and nearly 10 dB attenuation can be obtained. Reflection measurements would indicate that the major portion of this attenuation is due to backscatter, however, definite conclusions cannot be made unless swept frequency measurements and measurements at other than normal incidence are made. Comparing the data for 8\( \mu \)m and 12\( \mu \)m diameter steel fibers indicates that 12\( \mu \)m or thicker fibers are desirable. However, microscopic investigation of camouflage samples coated with 8\( \mu \)m diameter fibers indicate that these fibers curled on passing through the sifting screen. This curling could explain the relatively low attenuation observed using the 8\( \mu \)m diameter fibers. The maximum attenuation that was observed occurred with sample 10. Microscopic investigations of this sample showed that conductive elements were arranged in very dense multi-layers and therefore an absolute density level could not be measured.
### Table I
POWER TRANSMISSION AND REFLECTION DATA AT 98.6 GHz

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Fiber</th>
<th>Diameter (µm)</th>
<th>Length (mm)</th>
<th>Number Density (N/λ²)</th>
<th>Reflection (dB)</th>
<th>Transmission (dB)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Experiment #2</td>
<td>Experiment #2</td>
</tr>
<tr>
<td>1</td>
<td>Steel</td>
<td>4</td>
<td>3</td>
<td>8.9</td>
<td>-13.0</td>
<td>-1.8, -2.0</td>
</tr>
<tr>
<td>2</td>
<td>Steel</td>
<td>4</td>
<td>3</td>
<td>3.6</td>
<td>-13.0</td>
<td>-2.1, -2.0</td>
</tr>
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<td>3</td>
<td>Steel</td>
<td>4</td>
<td>3</td>
<td>&gt;&gt;100</td>
<td>-9.0</td>
<td>-10.0, -11.0</td>
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<tr>
<td>4</td>
<td>Steel</td>
<td>12</td>
<td>1</td>
<td>3.8</td>
<td>-13.0</td>
<td>-1.0, -0.6</td>
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<td>5</td>
<td>Steel</td>
<td>12</td>
<td>1</td>
<td>20.5</td>
<td>-9.0</td>
<td>-3.6, -3.5</td>
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<td>6</td>
<td>Steel</td>
<td>12</td>
<td>1</td>
<td>27.2</td>
<td>-10.0</td>
<td>-4.8, -8.0</td>
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<td>7</td>
<td>Steel</td>
<td>12</td>
<td>1</td>
<td>36.2</td>
<td>-7.0</td>
<td>-6.5, -7.0</td>
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<td>8</td>
<td>Steel</td>
<td>12</td>
<td>1</td>
<td>55.0</td>
<td>-8.2</td>
<td>-8.2, -7.0</td>
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<tr>
<td>9</td>
<td>Steel</td>
<td>12</td>
<td>1</td>
<td>&gt;&gt;100</td>
<td>-9.2, -8.5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Steel</td>
<td>12</td>
<td>1</td>
<td>&gt;&gt;100</td>
<td>-5.0</td>
<td>-11.4, -14.0</td>
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<td>Steel</td>
<td>8</td>
<td>1</td>
<td>&gt;&gt;1</td>
<td>-12.5</td>
<td>-.4, -.5</td>
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<tr>
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<td>66.7</td>
<td>-11.5</td>
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<tr>
<td>14</td>
<td>Carbonized Nylon</td>
<td>37</td>
<td>3</td>
<td>1.0</td>
<td>-12.5</td>
<td>-0.7, -0.6</td>
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<tr>
<td>15</td>
<td>Carbonized Nylon</td>
<td>37</td>
<td>3</td>
<td>4.0</td>
<td>-13.0</td>
<td>-0.5, -0.4</td>
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<tr>
<td>16</td>
<td>Carbonized Nylon</td>
<td>37</td>
<td>3</td>
<td>10.0</td>
<td>-12.5</td>
<td>-0.5, -0.6</td>
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<tr>
<td>17</td>
<td>Carbonized Nylon</td>
<td>37</td>
<td>1</td>
<td>1.3</td>
<td>-12.5</td>
<td>-.6, -.6</td>
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<td>18</td>
<td>Carbonized Nylon</td>
<td>37</td>
<td>1</td>
<td>3.2</td>
<td>-12.3</td>
<td>-.5, -.4</td>
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<td>19</td>
<td>Carbonized Nylon</td>
<td>37</td>
<td>1</td>
<td>8.1</td>
<td>-12.0</td>
<td>-.6, -.4</td>
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<tr>
<td>20</td>
<td>Riegel 2.0%</td>
<td>1</td>
<td>8.1</td>
<td>-12.7</td>
<td>-3.3, -3.2</td>
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<tr>
<td>21</td>
<td>Riegel 4.4%</td>
<td>1</td>
<td>8.1</td>
<td>-4.6</td>
<td>-3.3, -3.4</td>
<td></td>
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<tr>
<td>22</td>
<td>Riegel 5.5%</td>
<td>1</td>
<td>8.1</td>
<td>-5.5</td>
<td>-3.4, -3.2</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Riegel 6.4%</td>
<td>1</td>
<td>8.1</td>
<td>-5.0</td>
<td>-3.5, -3.6</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Riegel 7.6%</td>
<td>1</td>
<td>8.1</td>
<td>-5.5</td>
<td>-6.2, -5.0</td>
<td></td>
</tr>
</tbody>
</table>
A major question to be addressed in this measurement work was whether it is necessary to use conductive fibers, \( \leq \lambda_0/2 \) in length, to achieve maximum attenuation. The present data would indicate that fibers near one wavelength long could also be used. It should be noted that this is based on comparing only three measurements. It proved difficult to control the 3mm fiber densities since a wide range of sifting screen sizes was not available. Only samples with relatively low or very high number densities could be made in the time available. Comparison of attenuation data for 1mm and 3mm steel fibers at the same number density indicates that either length fiber is equally effective. A precise explanation of these results will be addressed during additional research efforts. Comparison of the 3mm and 1mm steel fiber reflection data indicates that the backscattered power for 3mm samples is always lower. This is expected since \( \lambda \) length wire elements have a low backscatter cross section. This measurement admits the possibility of using \( \lambda \) length elements to obtain appreciable attenuation while maintaining low backscatter power.

Samples made using carbonized nylon fibers proved to be nearly transparent. This is explained by their high resistivity, \( \approx 10 \) ohm-cm. Therefore, despite Badische claims, this fiber is not like pure graphite. A search of textile journals indicates that graphite fiber can be obtained from Hercules Corporation, and samples of this fiber can be obtained for additional research efforts.

C. Conclusions and Recommendations

These power transmission and reflection measurements show that camouflage samples can be constructed to control the magnitude of transmitted and reflected power by varying the number density of randomly oriented fibers deposited on textile substrates. At 98.6 GHz, 10 db or greater of attenuation can be achieved with short \( \approx 0.35 \lambda_0 \) or \( \lambda_0 \) length conductive elements. By using \( \lambda_0 \) length elements, a substantial decrease in backscattered power can be achieved, and this behavior may prove useful in camouflage applications.
A preliminary 10 GHz measurement of attenuation has been performed on 1mm and 3mm samples (numbers 3 and 10) which showed 10 dB or better attenuation at 98.6 GHz. Attenuation at 10 GHz was found to be $\geq 3$ dB for each of these two samples. In comparison, woven textile camouflage materials give a higher attenuation over X-band.

Further measurements are recommended using steel fiber near 1.4mm in length. These measurements should resolve the question of higher attenuation using $\lambda_c/2$ wire elements. In addition, graphite fiber should be evaluated as a conductive fiber candidate. Graphite fiber will be obtained from Hercules Corporation and steel fiber from Bekaert Steel Wire Corporation.

Two-way transmission measurements will be performed by the MERADCOM staff using the MERADCOM Macroscope. The measurements will be performed on candidate-Georgia Tech made camouflage samples.