International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

# Data Analysis of Polyethylene Base RAM for Small Vehicle's low Signature's Applications

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**Abstract –** The signature of radar target is an important aspect in military war. The demands for low signature targets have been increased to achieve the 'critical mission successes' in defence. Worldwide scientists and engineers are incessant working on it. This paper presents the data analysis of radar absorbing material (RAM) suitable for attaining of low signature applications for small air vehicles such as sUAV, µUAV, drones, hexcopter, spy birds etc. In this paper, the polyethylene (PE) and their composites characteristics and data analysis are presented, for applications in small air vehicles to attain the lower value of their target signatures. This is achieved in terms of EM measurement parameters of RAM material such as reflection loss, transmission loss, absorption loss, shielding effectiveness (SE), radar cross section (RCS) etc. The obtained values of reflection loss are – 29.49 dB, - 36.91 dB and – 23.94 dB; then, the transmission loss are – 133.18 dB, - 128.70 dB and – 0.19 dB for PE, polyethylene terephthalate (PET) and PET + conductive paint (PETCP) respectively for materials by waveguide measurement (WGM) method. The SE range are – 0.009 dB to – 0.19 dB, - 0.005 dB to - 0.29 dB, and - 0.022 dB to – 1.91 dB in WGM; then, - 9.44E-07 dB to – 1.13E-06 dB, - 9.57E-07 dB to – 1.01 E-06 dB and – 9. 31 E-07 dB to – 1.08E-06 dB in OATS experiments for PE, PET and PETCP respectively for the materials are obtained. The lowest value of RCS in OATS method are 1.63E-08 $m^2$, 6.46E-08 $m^2$ and 5.63E-08 $m^2$ for PE, PET and PETCP respectively for material are obtained. The contact angle & material thickness ($t$) are 78.50 & 0.08 mm; 66.18 & 0.09 mm and 93.45 & 0.12 mm for PE, PET and PETCP respectively, are proposed in this paper. There is good agreement between the material controlling parameters design and the tabular analysis presented in this paper. This materials are used as RAM in small aircrafts, sUAV, µUAV, drones, hexcopter, spy birds, ships etc, to attain their low signature value, low RCS, stealth and shielding applications in X – band of 8 to 12 GHz frequency range.

**Keywords – EM wave and shielding, Small Vehicle's low Signature's, PE base RAM material, WGM & OATS methods, RCS.**

## 1. Introduction

Radar determines the maximum range at which a particular radar can detect a target. It indicates the physical behaviour dependences of EM (electromagnetic) wave propagation up to the receiving of the echo signals. The echo signals are received from the radar target. The target signature is the signal, which is produced by the interference of the transmitted radar pulse and the target pulse. With the help of target signature the radar detects the target. In this case the 'target' is detected due to the 'higher' value of their 'signature' on radar, which we don't want. Therefore, in this paper, the authors of this manuscript have presented the 'target' having 'lower' value of their 'signature' on radar, is presented. In todays electronic warfare (EW) [1] in the battle field circumference, hiding of target is a major requirements. Eventhough, the target is present in the radar range, it would not be detected by the radar or detected with low signature level. In this case, the radar cross section (RCS) of the target is low, due to this the target is hide from the radar detection. It is very difficult to bring the RCS value as low as to hide the target from the radar detection. In the globe, researchers and scientists are trying to bring target signature (RCS) value low, possibly to 'non detection level' of target. There are many ways, methods, techniques, analysis, algorithms used to reduce the signature (RCS) of target. Designing of a novel specialised radar absorbing material (RAM) for low target signature is presented in this paper. By the use of a spcialised design and fabrication processes, the controlling parameters of the RAM are obtained for low target signature [2]. The EM parameters and their measurement methods are thoroughly explained in this paper. The detailed data analysis of these parameters are presented in this paper for X – band of 8 to 12 GHz frequency range. A polyethylene and their composites are designed, fabricated and measured as a RAM for low signature target applications. This RAM is used for small vehicles such as small aircrafts, sUAV (small unmanned aerial vehicles), µUAV (micro unmanned aerial vehicles), drones, hexcopter, spy birds, ships etc, for its low target signature applications [2] [3]. The materials are Polyethylene (PE), Polyethylene terephthalate (PET) and PET + Conductive Paint (PETCP) are used as RAM for low target signature applications. The contact angle / thickness of these RAM materials are 78.50 / 0.08 mm, 66.18 degree / 0.09 mm for PET, 93.45 degree / 0.12 mm for PE, PET and PETCP are used. The detailed data analysis in terms of EM measurement parameters of RAM such as reflection loss, transmission loss, absorption loss, shielding effectiveness (SE), radar cross section (RCS) are presented in this paper. In this study the Polyethylene [4] are used as base material to design its composite RAM materials. In this paper, the literature review mentioned are related to the work presented by the authors of this manuscript. The N. V. Venkatarayalu et al [5], presented the Effect of Resistivity of indium titanium oxide (ITO) thin film when used in transparent checker board surfaces for rcs reduction applications in the X - band. Based on the reflection coefficients, the theoretical reduction in RCS can be computed and presnetd at [5]. The computed RCS reduction level is – 58.02 dB and – 64.28 dB at 8.7 GHz and 11.8 GHz respectively are presented [5]. Rosério Valente et al [6] presnetd the electrically conductive polymer composites at frequencies up to 3.0 GHz for calculating of EMI Shielding Effectiveness in terms of S - parameters. The obtained range of SEtot, insertion loss (IL) and VSWR are – 1 to – 0.2 dB, 0.3 to 0.9 dB and 1 to 1.3 dB respectively at 0.1 to 3 GHz frequency range are presented [6]. Sathyamurthy Anuradha et al [7] presented the discrimination of stealth target with and without coating of RAM material based on natural resonances. This resonance based technique provides a real-time, accurate and aspect independent solution for stealth target discrimination. Perfectly Electrically Conducting (PEC) target is coated uniformly with sintered nickel- zinc - ferrite, a magnetic Radar Absorbing Material (RAM) with complex dielectric and magnetic properties. The resonant range Radar Cross Section (RCS) of the aircraft for different coating thicknesses is computed using the Method of Moments (MoM). The resonances contained in the RCS are extracted using the vector fitting method, and the dominant resonances representing the target are determined by applying the power criteria. aircraft of electrical size 1.5 λ and 7 λ are studied [7]. Priyambada Sahoo et al [8] presented the microwave absorbing material MAM for stealth applications in advanced airborne platforms. In this paper, the entire range of material used as MAM has been provided such as carbon, carbon based fiber, Graphene, Conducting polymer, Porous carbon, Magnetic metals, Magnetic metal alloys, Spinel ferrites and related composites, Hexaferrite, MXene, Carbide, Oxide, Titanium dioxide, Zinc oxide, Phosphides, Sulfide, High-entropy materials etc. The reflection loss presented is in the range of -13 to 44 dB, for different material thickness i.e. in the range of 1.4 to 7 mm [8]. Weihua Gu1 et el [9] described shaddock peel - based carbon aerogel for thermal insulation and microwave absorption applications. The microstructures of the samples were achieved by field emission scanning electron microscopy (FESEM). At frequency range of 2 – 18 GHz, electromagnetic parameters of complex permeability and permittivity were recorded. The prominent peaks at1350 and 1580 $cm^{-1}$ correspond to D - band and G - band, which are related to disordered carbon and $sp^2$ bonded carbon respectively are presented [9]. Jan Kruzelak et al [10] presented polymers and polymer composites used as efficient materials for EMI shielding. Jan described the intrinsic conductive polymers, polymers filled with

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

the different types of inorganic and organic fillers, as well as multifunctional polymer architectures are provided with respect to their conductive, dielectric, magnetic and shielding characteristics, which are able to shield harmful electromagnetic radiation [10]. P. R. Thote et al [11] described the different types of cutting edge materials for RAM and its general performance. Thote, discussed the Ferrite-based paints for lower frequencies as a RAM material for aerospace in RCS reduction, shipboard, aperture antenna absorber coating (RCS antenna) applications [11]. Haotian Zeng et al [12] presented the fast coating analysis and modeling method Higher – Order Method of Moments (HOMOM) and Locally Coating Method (LCM) etc, for aircraft RCS reduction application. The RCS is analysed with and without coating of material.The range 5 to – 35 dB at $\theta = 95^0$ , - 2 to – 50 dB at $\theta = 90^0$ and -1 to – 21 dB at $\theta = 0^0$of RCS is presented [12]. I. Nicolaescu et al [13], discussed the RAM used for target camouflage, to reduce the scattered signal by different metallic parts of military equipment and facilities. The multi layred RAM material is used. At 1 to 20 GHz frequency range, the reflection coefficient range is from 0.01 to 0.05 dB and 0.06 to 0.08 dB is for five and six layers material structure respectively are achieved from lossy dielectric and magnetic materials [13] Andrea Delfini et al [14] presented the ceramic – based materials for multifunctional applications in space environment. The carbon - based composites for aerospace research and space missions and widespread variety of multifunctional applications are also presented. The resulted reflection coefficient is – 1 to – 7 dB for graphite and – 0.1 to – 35 dB for multi-wall carbon nanotubes (MWCNT) in 8 to 12 GHz frequency range are presented [14]. Tarek M. Sallam et al [15], presents the nonmagnetic, homogeneous, and non-dispersive RAM material reflectivity (R) with two different thicknesses in terms of EMI and SE at 0 to 40 GHz frequency range. The reflectivity (R) is in between – 2 to – 25 dB in terms of relative real permittivity range between 0 to 20 at 0 to 40 GHz frequency range is presented. The analysed *SE* range is 0 to 420 dB is presented in this paper [15]. In this literature review there are many materials and their EM characterization are presented with different thicknesses. The minimum thickness ($t$) of those material are high, which is greater than 1.2 mm (i.e. $t >> 1.2$ mm); but the material with minimum thickness ($t$) = 0.08 mm are presented in this paper. Secondly, the authors of this manuscript are used the two characterization and measurement methods i.e. wave guide measurements (WGM) method and open area measurements method (OATS), which was not presented in literature review. Comparative studies of the results of these methods are also presented in this paper, which was not in literature review. The tabular analysis of the results are presented in this paper.

## 2. Experimental Result Analysis

The experimental results are performed by using two methods, such as wave guide measurement (WGM) method and open area test site (OATS) method. With those two methods, the RAM shield materials are characterized for small vehicle's low signature's applications, interms of reflection coefficient (*S11*) , transmission coefficient (*S21*), shielding effectiveness for absorption ($SE_{ab}$), shielding effectiveness for reflection ($SE_{refle}$), total shielding effectiveness ($SE_{tot}$) and radar cross section ($\sigma$). The three RAM material films such as PE, PET and PETCP are used for measurement purposes. In WGM method, initially the vector network analyser (VNA) is calibrated in X – band frequency with respect to the RF cables, connectors, waveguides etc before to start the experiment. The RAM materials are kept in between the two wavguides for measurement of reflection coefficient and transmission coefficient in WGM method. The tabular analysis of RAM material for PE is investigated in terms of *S11, S21, |X11|^2, |X21|^2, 1-|X11|^2, SE(Reflen), SE(Absn)* and *SE(Total)* in X – band frequency for WGM method, is shown in table 1. Where, *S11* and *S21* are the linear values (linear magnitude) of reflection coefficient and transmission coefficient respectively. The *X11* and *X21* are the linear constant values obtained from reflection coefficient (*S11*) and transmission coefficient (*S21*) respectively. In table 1, for PE, the minimum linear magnitude values are 0.052 dB at 8.5 GHz and 0.983 dB at 9.5 GHz for linear reflection coefficient (*S11*) and linear transmission coefficient (*S21*) respectively are measured.

Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

Table 1 Shows PE material linear values of S11 and S21 alongwith calculated all type of SE's in WGM method.

<table>
<tr><th>F(GHz)</th><th>S11(MAG)</th><th>S21(MAG)</th><th>|X11|^2</th><th>|X21|^2</th><th>(1-|X11|^2)</th><th>SE(Refln)</th><th>SE(Absn)</th><th>SE(Total)</th></tr>
<tr><td>8</td><td>0.058</td><td>0.99</td><td>0.0032</td><td>0.976</td><td>0.997</td><td>-0.014</td><td>-0.0921</td><td>-0.106</td></tr>
<tr><td>8.5</td><td>0.052</td><td>0.988</td><td>0.0026</td><td>0.977</td><td>0.997</td><td>-0.011</td><td>-0.089</td><td>-0.104</td></tr>
<tr><td>9</td><td>0.073</td><td>0.989</td><td>0.0052</td><td>0.978</td><td>0.994</td><td>-0.022</td><td>-0.072</td><td>-0.095</td></tr>
<tr><td>9.5</td><td>0.056</td><td>0.983</td><td>0.0031</td><td>0.967</td><td>0.997</td><td>-0.013</td><td>-0.13</td><td>-0.144</td></tr>
<tr><td>10</td><td>0.081</td><td>0.984</td><td>0.0066</td><td>0.973</td><td>0.993</td><td>-0.029</td><td>-0.089</td><td>-0.118</td></tr>
<tr><td>10.5</td><td>0.082</td><td>0.993</td><td>0.0067</td><td>0.987</td><td>0.993</td><td>-0.029</td><td>-0.029</td><td>-0.058</td></tr>
<tr><td>11</td><td>0.064</td><td>1.007</td><td>0.0040</td><td>1.014</td><td>0.996</td><td>-0.017</td><td>0.082</td><td>0.064</td></tr>
<tr><td>11.5</td><td>0.067</td><td>1.014</td><td>0.0044</td><td>1.029</td><td>0.996</td><td>-0.019</td><td>0.145</td><td>0.126</td></tr>
<tr><td>12</td><td>0.091</td><td>1.006</td><td>0.0081</td><td>1.013</td><td>0.992</td><td>-0.035</td><td>0.093</td><td>0.057</td></tr>
</table>

The maximum linear values – 0.011 dB at 8.5 GHz, 0.145 dB at 11.5 GHz and 0.126 dB at 11.5 GHz for *SE(Refln)*, *SE(Absn)* and *SE (Total)* respectively are obtained, is shown in table 2. These values are calculated and obtained from equation (1), (2) and (3) mentioned in next section 'materials and methods'. The table 2, shows tabular analysis of second RAM material PET, interms of *S11* (linear magnitude of reflection coefficient), *S21* (linear magnitude of transmission coefficient), *|X11|^2*, *|X21|^2*, *1 - |X11|^2*, *SE(Reflen)*, *SE(Absn)* and *SE(Total)* in 8 to 12 GHz frequency range.

Table 2 Shows PET material linear values of S11 and S21 alongwith calculated all type of SE's in WGM method.

<table>
<tr><th>F(GHz)</th><th>S11(MAG)</th><th>S21(MAG)</th><th>|X11|^2</th><th>|X21|^2</th><th>(1 - |X11|^2)</th><th>SE(Refln)</th><th>SE(Absn)</th><th>SE(Total)</th></tr>
<tr><td>8.0</td><td>0.074</td><td>0.984</td><td>0.005</td><td>0.970</td><td>0.994</td><td>-0.024</td><td>-0.107</td><td>-0.132</td></tr>
<tr><td>8.5</td><td>0.094</td><td>0.983</td><td>0.009</td><td>0.966</td><td>0.991</td><td>-0.038</td><td>-0.108</td><td>-0.146</td></tr>
<tr><td>9.0</td><td>0.110</td><td>0.99</td><td>0.012</td><td>0.960</td><td>0.987</td><td>-0.053</td><td>-0.123</td><td>-0.177</td></tr>
<tr><td>9.5</td><td>0.091</td><td>0.973</td><td>0.008</td><td>0.947</td><td>0.991</td><td>-0.036</td><td>-0.198</td><td>-0.234</td></tr>
<tr><td>10.0</td><td>0.121</td><td>0.986</td><td>0.014</td><td>0.973</td><td>0.985</td><td>-0.064</td><td>-0.050</td><td>-0.115</td></tr>
<tr><td>10.5</td><td>0.121</td><td>0.989</td><td>0.014</td><td>0.979</td><td>0.985</td><td>-0.064</td><td>-0.027</td><td>-0.091</td></tr>
<tr><td>11.0</td><td>0.113</td><td>1.005</td><td>0.012</td><td>1.010</td><td>0.987</td><td>-0.056</td><td>0.102</td><td>0.046</td></tr>
<tr><td>11.5</td><td>0.120</td><td>1.009</td><td>0.014</td><td>1.018</td><td>0.985</td><td>-0.063</td><td>0.143</td><td>0.089</td></tr>
<tr><td>12.0</td><td>0.134</td><td>1.003</td><td>0.018</td><td>1.006</td><td>0.981</td><td>-0.079</td><td>0.110</td><td>0.030</td></tr>
</table>

The obtained minimum linear magnitude are 0.074 dB at 8 GHz, 0.973 dB at 9.5 GHz, 0.005 dB at 8 GHz, 0.947 dB at 9.5 GHz and 0.981dB at 12 GHz for the parameters *S11(MAG)*, *S21(MAG)*, *|X11|^2*, *|X21|^2* and *1 -|X11|^2* respectively are presented. The resultant final maximum values - 0.099 dB at 8.5 GHz, - 0.05 dB at 12 GHz and - 0.27 dB at 10 GHz for the *SE(Refln)*, *SE(Absn)* and *SE(Total)* respectively are presented, is shown in table 2.

Table 3 Shows PET+Conductive Paint material linear values of S11 and S21 alongwith calculated all type of SE's in WGM method.

<table>
<tr><th>F(GHz)</th><th>S11</th><th>S21</th><th>|X11|^2</th><th>|X21|^2</th><th>(1 -</th><th>SE(Refln)</th><th>SE(Absn)</th><th>SE(Total)</th></tr>
</table>

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

| | *(MAG)* | *(MAG)* | | | *\|X11\|^2\|)* | | | |
|---|---|---|---|---|---|---|---|---|
| 8 | 0.086 | 0.885 | 0.0074 | 0.783 | 0.992 | -0.0323 | -1.027 | -1.057 |
| 8.5 | 0.150 | 0.925 | 0.0227 | 0.855 | 0.977 | -0.099 | -0.58 | -0.678 |
| 9 | 0.096 | 0.962 | 0.0092 | 0.924 | 0.990 | -0.040 | -0.30 | -0.34 |
| 9.5 | 0.071 | 0.935 | 0.0049 | 0.876 | 0.995 | -0.023 | -0.553 | -0.57 |
| 10 | 0.089 | 0.968 | 0.0080 | 0.938 | 0.991 | -0.035 | -0.241 | -0.27 |
| 10.5 | 0.057 | 0.966 | 0.0033 | 0.934 | 0.996 | -0.015 | -0.28 | -0.29 |
| 11 | 0.11 | 0.912 | 0.0126 | 0.832 | 0.987 | -0.055 | -0.74 | -0.79 |
| 11.5 | 0.097 | 0.99 | 0.009 | 0.978 | 0.990 | -0.041 | -0.052 | -0.094 |
| 12 | 0.083 | 0.991 | 0.0070 | 0.981 | 0.993 | -0.031 | -0.05 | -0.081 |

Table 3, shows the third RAM material PETCP tabular analysis of linear values of scattering parameters (S - parameters). The minimum obtained linear values of *S11 (MAG)*, *S21 (MAG)*, *|X11|^2*, *|X21|^2* and *(1 - |X11|^2|)* are 0.057 dB at 10.5 GHz, 0.885 dB at 8 GHz, 0.0033 dB at 10.5 GHz, 0.783 dB at 8 GHz and 0.977 dB at 8.5 GHz respectively for PETCP RAM material in WGM method. Further, the RAM material PE, PET and PETCP is characterized using OATS method. In this method the real world analysis of RAM materials are charatcetrised. During all the RAM material in OATS experiment, the input power is kept at + 20 dBm (0.1 watt), in the 8 to 12 GHz frequency range. The measurement distance between transceiving (Tx/Rx) antenna and RAM material is 6 feet (R = 6 ft). Table 4, shows the EM characterization of transmitted power *(Ptrans)*, at which the power is transmitted through the PE material. The transmitted power is measured by the third receiving antenna, which is kept behind the PE film at a distance of 0.5 feet. For PE material, the minimum obtained values of *Ptrans*, *P(trans)/P(in)* (watt), *S21*, *|X21|^2*, and *1 - |X11|^2* are – 42 dB at 9.2 GHz, - 62 dB at 9.2 GHz, 2.18E-7 dB at 8.2 GHz and 0.90 at 8 /8.4 / 10 GHz respectively are analysed. The maximum values of *SE(Absn)*, *SE(Refln)* and *SE(Total)* are – 68.94 dB at 8.4 GHz, 1.09E-06 dB at 11.8 GHz and -6.89E+01dB at 8.4 GHz respectively are presented in PE material characterization. In this measurements the + 20 dBm (0.1 watt) input power is kept during the entire measurement procedures.

Table 4 Shows PE material transmitted power (Ptrans) through material alongwith calculated all type of SE's in OATS method.

| *F(GHz)* | *Ptrans (dB)* | *Ptrans (watt)* | *Pin (watt)* | *P(trans)/P(in) (watt)* | *S21 (dB)* | *\|X21\|^2* | *1-\|X11\|^2* | *SE(Absn)* | *SE(Refln)* | *SE(Total)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | -46.79 | 2.09E-8 | 0.1 | 2.09E-7 | -66.79 | 2.09E-7 | 0.90 | -66.79 | -7.63E-07 | -6.68E+01 |
| 8.2 | -46.62 | 2.17E-8 | 0.1 | 2.18E-7 | -66.62 | 2.18E-7 | 0.91 | -66.62 | -6.09E-07 | -6.66E+01 |
| 8.4 | -48.94 | 1.28E-8 | 0.1 | 1.28E-7 | -68.94 | 1.28E-7 | 0.90 | -68.94 | -1.15E-06 | -6.89E+01 |
| 8.6 | -47.71 | 1.70E-8 | 0.1 | 1.70E-7 | -67.71 | 1.69E-7 | 0.92 | -67.71 | -5.13E-07 | -6.77E+01 |
| 8.8 | -46.66 | 2.16E-8 | 0.1 | 2.16E-7 | -66.66 | 2.16E-7 | 0.98 | -66.66 | -6.90E-07 | -6.67E+01 |

DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | -46.15 | 2.43E-8 | 0.1 | 2.43E-7 | -66.15 | 2.43E-7 | 0.99 | -66.15 | -5.44E-07 | -6.62E+01 |
| 9.2 | -42 | 6.31E-8 | 0.1 | 6.31E-7 | -62 | 6.31E-7 | 0.99 | -62 | -6.98E-07 | -6.20E+01 |
| 9.4 | -45.16 | 3.05E-8 | 0.1 | 3.11E-7 | -65.16 | 3.05E-7 | 0.97 | -65.16 | -1.35E-06 | -6.52E+01 |
| 9.6 | -46.02 | 2.5E-8 | 0.1 | 2.51E-7 | -66.02 | 2.5E-7 | 0.95 | -66.02 | -4.74E-07 | -6.60E+01 |
| 9.8 | -45.78 | 2.64E-8 | 0.1 | 2.65E-7 | -65.78 | 2.64E-7 | 0.93 | -65.78 | -8.93E-07 | -6.58E+01 |
| 10 | -48.16 | 1.53E-8 | 0.1 | 1.53E-7 | -68.16 | 1.53E-7 | 0.90 | -68.16 | -7.27E-07 | -6.82E+01 |
| 10.2 | -45.75 | 2.67E-8 | 0.1 | 2.67E-7 | -65.75 | 2.66E-7 | 0.98 | -65.75 | -1.45E-06 | -6.58E+01 |
| 10.4 | -45.54 | 2.80E-8 | 0.1 | 2.80E-7 | -65.54 | 2.79E-7 | 0.93 | -65.54 | -9.44E-07 | -6.55E+01 |
| 10.6 | -45.74 | 2.67E-8 | 0.1 | 2.67E-7 | -65.74 | 2.67E-7 | 0.93 | -65.74 | -1.31E-06 | -6.57E+01 |
| 10.8 | -46.32 | 2.33E-8 | 0.1 | 2.34E-7 | -66.32 | 2.33E-7 | 0.91 | -66.32 | -1.25E-06 | -6.63E+01 |
| 11 | -47.45 | 1.80E-8 | 0.1 | 1.80E-7 | -67.45 | 1.8E-7 | 0.96 | -67.45 | -1.25E-06 | -6.74E+01 |
| 11.2 | -45.6 | 2.75E-8 | 0.1 | 2.75E-7 | -65.6 | 2.75E-7 | 0.97 | -65.6 | -7.36E-07 | -6.56E+01 |
| 11.4 | -46.84 | 2.071E-8 | 0.1 | 2.07E-7 | -66.84 | 2.07E-7 | 0.96 | -66.84 | -1.27E-06 | -6.68E+01 |
| 11.6 | -43.3 | 4.68E-8 | 0.1 | 4.68E-7 | -63.3 | 4.68E-7 | 0.97 | -63.3 | -2.32E-06 | -6.33E+01 |
| 11.8 | -43.56 | 4.41E-8 | 0.1 | 4.41E-7 | -63.56 | 4.41E-7 | 0.98 | -63.56 | -1.09E-06 | -6.36E+01 |
| 12 | -43.91 | 4.06E-8 | 0.1 | 4.07E-7 | -63.91 | 4.06E-7 | 0.99 | -63.91 | -2.22E-06 | -6.39E+01 |

Table 5, shows the transmitted power (Ptrans) analysis of PET material for the OATS measurement method. The OATS operates in the X – band from 8 to 12 GHz frequency range. The OATS

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

characterization of PET RAM is analysed in terms of foremost EM parameter such as ‘Ptrans’. The minimum values of *Ptrans, Pin, P(trans)/P(in), S21, |X21|^2 and 1 - |X11|^2* are - 49.1 dB at 9.2 GHz, 0.1 watt at 8 to 12 GHz, 1.23E-7 dB at 9.2 GHz, - 69.1 dB at 9.2 GHz, 1.23E-7 at 9.2 GHz, 0.998 dB at 8 to 12 GHz respectively are obtained. The maximum value - 69.099 dB at 9.2 GHz, - 9.57E-07 at 10.2 GHz, - 6.91E+01 at 9.2 GHz for the *SE (Absn), SE(Refln)* and *SE(Total)* respectively are analysed.

Table 5 Shows PET material transmitted power (Ptrans) through material alongwith calculated all type of SE’s in OATS method.

| *F(GHz)* | *Ptrans (dB)* | *Ptrans (watt)* | *Pin(watt)* | *P(trans)/ P(in)* | *S21 (dB)* | *\|X21\|^2* | *1-\|X11\|^2* | *SE (Absn)* | *SE(Refln)* | *SE(Total)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | -45.78 | 2.64E-8 | 0.1 | 2.64E-7 | -65.78 | 2.64E-7 | 0.999888 | -65.7799995 | -4.85E-07 | -6.58E+01 |
| 8.2 | -48.62 | 1.37E-8 | 0.1 | 1.37E-7 | -68.62 | 1.37E-7 | 0.999999853 | -68.6199994 | -6.36E-07 | -6.86E+01 |
| 8.4 | -48.62 | 1.37E-8 | 0.1 | 1.37E-7 | -68.62 | 1.37E-7 | 0.999999892 | -68.6199995 | -4.69E-07 | -6.86E+01 |
| 8.6 | -46.93 | 2.03E-8 | 0.1 | 2.028E-7 | -66.93 | 2.02E-7 | 0.999999872 | -66.9299994 | -5.54E-07 | -6.69E+01 |
| 8.8 | -45.02 | 3.15E-8 | 0.1 | 3.15E-7 | -65.02 | 3.14E-7 | 0.999999808 | -65.0199992 | -8.33E-07 | -6.50E+01 |
| 9 | -46.48 | 2.25E-8 | 0.1 | 2.25E-07 | -66.48 | 2.24E-7 | 0.999999846 | -66.4799993 | -6.68E-07 | -6.65E+01 |
| 9.2 | -49.1 | 1.23E-8 | 0.1 | 1.23E-7 | -69.1 | 1.23E-7 | 0.999999849 | -69.0999993 | -6.54E-07 | -6.91E+01 |
| 9.4 | -46.37 | 2.31E-8 | 0.1 | 2.31E-07 | -66.37 | 2.30E-7 | 0.999999695 | -66.3699987 | -1.32E-06 | -6.64E+01 |
| 9.6 | -41.55 | 7.08E-8 | 0.1 | 6.99E-7 | -61.55 | 6.99E-7 | 0.999999876 | -61.5499995 | -5.37E-07 | -6.15E+01 |
| 9.8 | -47.71 | 1.69E-8 | 0.1 | 1.69E-7 | -67.71 | 1.69E-07 | 0.999999785 | -67.7099991 | -9.35E-07 | -6.77E+01 |
| 10 | -45.92 | 2.56E-8 | 0.1 | 2.56E-7 | -65.92 | 2.55E-7 | 0.999999894 | -65.9199995 | -4.59E-07 | -6.59E+01 |
| 10.2 | -45.75 | 2.67E-8 | 0.1 | 2.67E-7 | -65.75 | 2.66E-7 | 0.99999978 | -65.749999 | -9.57E-07 | -6.58E+01 |
| 10.4 | -45.2 | 3.01E-8 | 0.1 | 3.01E-7 | -65.2 | 3.011E-7 | 0.999999661 | -65.2099 | -1.47E | -6.52E+ |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | | 1 | | | 985 | -06 | 01 |
| 10.6 | -43.52 | 4.45E-8 | 0.1 | 4.44E-7 | -63.52 | 4.44E-7 | 0.999999748 | -63.5199989 | -1.09E-06 | -6.35E+01 |
| 10.8 | -45.28 | 2.97E-8 | 0.1 | 2.96E-7 | -65.28 | 2.96E-7 | 0.99999981 | -65.2799992 | -8.26E-07 | -6.53E+01 |
| 11 | -47.02 | 1.99E-8 | 0.1 | 1.99E-7 | -67.02 | 1.98E-7 | 0.999999852 | -67.0199994 | -6.42E-07 | -6.70E+01 |
| 11.2 | -48.12 | 1.55E-8 | 0.1 | 1.54E-7 | -68.12 | 1.54E-7 | 0.999999577 | -68.1199982 | -1.84E-06 | -6.81E+01 |
| 11.4 | -47.84 | 1.65E-8 | 0.1 | 1.64E-7 | -67.84 | 1.64E-7 | 0.999999784 | -67.8399991 | -9.39E-07 | -6.78E+01 |
| 11.6 | -44.65 | 3.43E-8 | 0.1 | 3.43E-7 | -64.65 | 3.42E-7 | 0.999999801 | -64.6499991 | -8.63E-07 | -6.46E+01 |
| 11.8 | -45.55 | 2.79E-8 | 0.1 | 2.79E-7 | -65.55 | 2.78E-7 | 0.999999585 | -65.5499982 | -1.80E-06 | -6.55E+01 |
| 12 | -46.79 | 2.09E-8 | 0.1 | 2.09E-7 | -66.79 | 2.09E-7 | 0.999999768 | -66.789999 | -1.01E-06 | -6.68E+01 |

Table 6 shows, the transmitted power characterization of PETCP RAM material in terms of shielding effectiveness analysis, in OATS measurements. In this experiment, the input power is kept at + 20 dBm during the experiment in X – band operation from 8 to 12 GHz frequency range. The minimum value are - 50.75 dB at 8.2 GHz, 0.1 watt at 8 to 12 GHz, 9.84011E-08 dB at 9.2 GHz, -70.75 dB at 8.2 GHz, 9.8401E-08 dB at 9.2 dB and 0.999 dB at 8 to 12 GHz frequency range for *Ptrans, Pin, P(trans)/P(in), S21, |X21|^2 and 1-|X11|^2* respectively are analysed in the X – band frequency. The maximum values of *SE (Absn), SE (Refln)* and *SE(Total)* are -64.77dB at 11.6 GHz, -8.69E-07 dB at 10.6 GHz and -6.59E+01 dB at 12 GHz respectively are presented in this measurement method.

Table 6 Shows PET + Conductive Paint (PETCP) material transmitted power (Ptrans) through material alongwith calculated all type of SE's in OATS method.

| *F(GHz)* | *Ptrans (dB)* | *Ptrans (watt)* | *Pin (watt)* | *P(trans) /P(in)* | *S21 (dB)* | *\|X21\|^2* | *1-\|X11\|^2* | *SE (Absn)* | *SE (Refln)* | *SE(Total)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | -48.42 | 1.44 E-08 | 0.1 | 1.4388E-07 | -68.42 | 1.4388 E-07 | 0.99999993 | -68.42 | -2.92 E-07 | -6.84E+01 |
| 8.2 | -50.75 | 8.41 E-09 | 0.1 | 8.41395 E-08 | -70.75 | 8.414E-08 | 0.99999992 | -70.75 | -3.51 E-07 | -7.07E+01 |
| 8.4 | -47.27 | 1.88 E-08 | 0.1 | 1.87499 E-07 | -67.27 | 1.875E-07 | 0.99999995 | -67.27 | -2.03 E-07 | -6.73E+01 |

DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

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|---|---|---|---|---|---|---|---|---|---|---|
| 8.6 | -47.08 | 1.96E-08 | 0.1 | 1.95884E-07 | -67.08 | 1.9588E-07 | 0.99999995 | -67.08 | -1.99E-07 | -6.71E+01 |
| 8.8 | -48.72 | 1.34E-08 | 0.1 | 1.34276E-07 | -68.72 | 1.3428E-07 | 0.99999991 | -68.72 | -3.95E-07 | -6.87E+01 |
| 9 | -49.34 | 1.16E-08 | 0.1 | 1.16413E-07 | -69.34 | 1.1641E-07 | 0.99999996 | -69.34 | -1.83E-07 | -6.93E+01 |
| 9.2 | -50.07 | 9.84E-09 | 0.1 | 9.84011E-08 | -70.07 | 9.8401E-08 | 0.99999994 | -70.07 | -2.43E-07 | -7.01E+01 |
| 9.4 | -46.49 | 2.24E-08 | 0.1 | 2.24388E-07 | -66.49 | 2.2439E-07 | 0.99999995 | -66.49 | -2.32E-07 | -6.65E+01 |
| 9.6 | -47.26 | 1.88E-08 | 0.1 | 1.87932E-07 | -67.26 | 1.8793E-07 | 0.99999995 | -67.26 | -2.28E-07 | -6.73E+01 |
| 9.8 | -48.01 | 1.58E-08 | 0.1 | 1.58125E-07 | -68.01 | 1.5812E-07 | 0.99999994 | -68.01 | -2.46E-07 | -6.80E+01 |
| 10 | -50.02 | 9.95E-09 | 0.1 | 9.95405E-08 | -70.02 | 9.9541E-08 | 0.99999994 | -70.02 | -2.59E-07 | -7.00E+01 |
| 10.2 | -48 | 1.58E-08 | 0.1 | 1.58489E-07 | -68 | 1.5849E-07 | 0.99999987 | -67.999 | -5.85E-07 | -6.80E+01 |
| 10.4 | -49.2 | 1.20E-08 | 0.1 | 1.20226E-07 | -69.2 | 1.2023E-07 | 0.99999992 | -69.2 | -3.56E-07 | -6.92E+01 |
| 10.6 | -48.47 | 1.42E-08 | 0.1 | 1.42233E-07 | -68.47 | 1.4223E-07 | 0.9999998 | -68.47 | -8.69E-07 | -6.85E+01 |
| 10.8 | -48.76 | 1.33E-08 | 0.1 | 1.33045E-07 | -68.76 | 1.3305E-07 | 0.99999968 | -68.76 | -1.40E-06 | -6.88E+01 |
| 11 | -47.86 | 1.63E-08 | 0.1 | 1.63682E-07 | -67.86 | 1.6368E-07 | 0.99999975 | -67.86 | -1.09E-06 | -6.79E+01 |
| 11.2 | -46.59 | 2.19E-08 | 0.1 | 2.1928E-07 | -66.59 | 2.1928E-07 | 0.99999965 | -66.59 | -1.54E-06 | -6.66E+01 |
| 11.4 | -47.14 | 1.93E-08 | 0.1 | 1.93197E-07 | -67.14 | 1.932E-07 | 0.99999985 | -67.139 | -6.70E-07 | -6.71E+01 |
| 11.6 | -44.77 | 3.33E-08 | 0.1 | 3.33426E-07 | -64.77 | 3.3343E-07 | 0.99999969 | -64.769 | -1.35E-06 | -6.48E+01 |
| 11.8 | -48.01 | 1.58E-08 | 0.1 | 1.58125E-07 | -68.01 | 1.5812E-07 | 0.99999967 | -68.009 | -1.44E-06 | -6.80E+01 |

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

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|---|---|---|---|---|---|---|---|---|---|---|
| 12 | -45.93 | 2.55E-08 | 0.1 | 2.5527E-07 | -65.93 | 2.5527E-07 | 0.99999946 | -65.929 | -2.35E-06 | -6.59E+01 |

Table 7, shows the radar cross section (RCS) analysis of PE material reflected power, in which it is calculated in terms of the incident power – input power (i.e. power incident on PE RAM material or power incident on target) and reflected power (i.e. power reflected from PE RAM material or power reflected from the target) in OATS measurements. In this case, the minimum and maximum reflected power *(Prefln)* is - 49.62 dB and - 42.92 dB at frequency 9.6 GHz and 12 GHz respectively is measured. The minimum and maximum values of RCS (σ1) is 0.01937247 $m^2$ and 0.16313625 $m^2$ at frequency 8.6 GHz and 12 GHz respectively are obtained. The maximum value of RCS (*σ2*) is 300000 $m^2$ between 8 to 12 GHz frequency range are obtained. The value of *'σ1'* divided by *'σ2' (σ1/ σ2)* is equal to the main value of RCS (*σ*), at which the minimum value of 'σ' is 9.0998E-08 $m^2$ at 8.8 GHz frequency and maximum value is 1.0061E-07 at 9.2 GHz frequency are obtained in OATS measurements.

Table 7 Shows PE material reflected power (Prefl) from the material alongwith calculated RCS and all type of SE's in OATS method.

| *F (GHz)* | *Prefln (dB)* | *Prefln (watt)* | *Pin (watt)* | *P(Refln) / P(In)* | *S11 (dB)* | *\|X11\|^2* | *1-\|X11\|^2* | *SE (Refln)* | *RCS (σ1)* | *RCS (σ2)* | *σ = (σ1)/(σ2)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | -47.55 | 1.75792E-08 | 0.1 | 1.75792E-07 | -67.55 | 1.75792E-07 | 0.9999982 | -7.63457E-07 | 0.02496709 | 300000 | 8.32236E-08 |
| 8.2 | -48.53 | 1.40281E-08 | 0.1 | 1.40281E-07 | -68.53 | 1.40281E-07 | 0.99999986 | -6.09234E-07 | 0.02093224 | 300000 | 6.97741E-08 |
| 8.4 | -45.78 | 2.64241E-08 | 0.1 | 2.64241E-07 | -65.78 | 2.64241E-07 | 0.99999974 | -1.14758E-06 | 0.04137582 | 300000 | 1.37919E-07 |
| 8.6 | -49.28 | 1.18032E-08 | 0.1 | 1.18032E-07 | -69.28 | 1.18032E-07 | 0.99999988 | -5.12607E-07 | 0.01937247 | 300000 | 6.45749E-08 |
| 8.8 | -47.99 | 1.58855E-08 | 0.1 | 1.58855E-07 | -67.99 | 1.58855E-07 | 0.99999984 | -6.89897E-07 | 0.02729941 | 300000 | 9.0998E-08 |
| 9 | -49.02 | 1.25314E-08 | 0.1 | 1.25314E-07 | -69.02 | 1.25314E-07 | 0.99999987 | -5.44232E-07 | 0.02252543 | 300000 | 7.50848E-08 |
| 9.2 | -47.94 | 1.60694E-08 | 0.1 | 1.60694E-07 | -67.94 | 1.60694E-07 | 0.99999984 | -6.97886E-07 | 0.03018309 | 300000 | 1.0061E-07 |
| 9.4 | -45.06 | 3.11889E-08 | 0.1 | 3.11889E-07 | -65.06 | 3.11889E-07 | 0.99999969 | -1.35452E-06 | 0.06115665 | 300000 | 2.03856E-07 |
| 9.6 | -49.62 | 1.09144E-08 | 0.1 | 1.09144E-07 | -69.62 | 1.09144E-07 | 0.99999989 | -4.74007E-07 | 0.02232186 | 300000 | 7.44062E-08 |
| 9. | - | 2.0558 | 0. | 2.0558 | - | 2.0558 | 0.99999 | - | 0.04381 | 3000 | 1.4605 |

DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 46.87 | 9E-08 | 1 | 9E-07 | 66.87 | 9E-07 | 979 | 8.92862E-07 | 675 | 00 | 6E-07 |
| 10 | -47.76 | 1.67494E-08 | 0.1 | 1.67494E-07 | -67.76 | 1.67494E-07 | 0.99999983 | -7.27419E-07 | 0.03716961 | 300000 | 1.23899E-07 |
| 10.2 | -44.77 | 3.33426E-08 | 0.1 | 3.33426E-07 | -64.77 | 3.33426E-07 | 0.99999967 | -1.44805E-06 | 0.07698185 | 300000 | 2.56606E-07 |
| 10.4 | -46.63 | 2.1727E-08 | 0.1 | 2.1727E-07 | -66.63 | 2.1727E-07 | 0.99999978 | -9.43592E-07 | 0.05215004 | 300000 | 1.73833E-07 |
| 10.6 | -45.22 | 3.00608E-08 | 0.1 | 3.00608E-07 | -65.22 | 3.00608E-07 | 0.9999997 | -1.30552E-06 | 0.07495485 | 300000 | 2.49849E-07 |
| 10.8 | -45.4 | 2.88403E-08 | 0.1 | 2.88403E-07 | -65.4 | 2.88403E-07 | 0.99999971 | -1.25252E-06 | 0.07465098 | 300000 | 2.48837E-07 |
| 11 | -45.41 | 2.8774E-08 | 0.1 | 2.8774E-07 | -65.41 | 2.8774E-07 | 0.99999971 | -1.24964E-06 | 0.07726332 | 300000 | 2.57544E-07 |
| 11.2 | -47.71 | 1.69434E-08 | 0.1 | 1.69434E-07 | -67.71 | 1.69434E-07 | 0.99999983 | -7.35842E-07 | 0.04716546 | 300000 | 1.57218E-07 |
| 11.4 | -45.35 | 2.91743E-08 | 0.1 | 2.91743E-07 | -65.35 | 2.91743E-07 | 0.99999971 | -1.26702E-06 | 0.08413907 | 300000 | 2.80464E-07 |
| 11.6 | -42.72 | 5.34564E-08 | 0.1 | 5.34564E-07 | -62.72 | 5.34564E-07 | 0.99999947 | -2.32158E-06 | 0.15962612 | 300000 | 5.32087E-07 |
| 11.8 | -46.01 | 2.50611E-08 | 0.1 | 2.50611E-07 | -66.01 | 2.50611E-07 | 0.99999975 | -1.08839E-06 | 0.07743762 | 300000 | 2.58125E-07 |
| 12 | -42.92 | 5.10505E-08 | 0.1 | 5.10505E-07 | -62.92 | 5.10505E-07 | 0.99999949 | -2.2171E-06 | 0.16313625 | 300000 | 5.43788E-07 |

Table 8, shows the PET material RCS value analysis interms of reflected power in the 8 to 12 GHz frequency range in OATS measurements. The reflected power *(Prefln)* minimum is - 49.76 dB at 10 GHz and maximum is - 44.7 dB at 10.4 GHz frequency are obtained. The minimum value of *σ1, σ2* and *σ* are 0.117659 $m^2$ at 11.2 GHz, 300000 $m^2$ between 8 to 12 GHz frequency range and 1.0991E-07 $m^2$ at 8.8 GHz frequency. The maximum value of *σ1, σ2* and *σ* are 0.081331 $m^2$ at 10.4 GHz, 300000 $m^2$ between 8 to 12 GHz frequency range and 9.4328E-08 $m^2$ at 8.8 GHz frequency are calculated.

Table 8. Shows PET material reflected power (Prefln) from the material alongwith calculated RCS and all type of SE's in OATS method.

| *F(GHz)* | *Prefln (dB)* | *Prefln (watt)* | *Pin (watt)* | *P (Refln)/P(In)* | *S11 (dB)* | *\|X11\|^2* | *1-\|X11\|^2* | *SE(Refln)* | *RCS (σ1)* | *RCS (σ2)* | *σ=(σ1)/(σ2)* |
|---|---|---|---|---|---|---|---|---|---|---|---|

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | -49.52 | 1.11686E-08 | 0.1 | 1.11686E-07 | -69.52 | 1.11686E-07 | 1 | -4.85048E-07 | 0.015862 | 300000 | 5.2875E-08 |
| 8.2 | -48.34 | 1.46555E-08 | 0.1 | 1.46555E-07 | -68.34 | 1.46555E-07 | 1 | -6.36479E-07 | 0.021868 | 300000 | 7.2894E-08 |
| 8.4 | -49.67 | 1.07895E-08 | 0.1 | 1.07895E-07 | -69.67 | 1.07895E-07 | 1 | -4.68581E-07 | 0.016895 | 300000 | 5.6315E-08 |
| 8.6 | -48.94 | 1.27644E-08 | 0.1 | 1.27644E-07 | -68.94 | 1.27644E-07 | 1 | -5.5435E-07 | 0.02095 | 300000 | 6.9833E-08 |
| 8.8 | -47.17 | 1.91867E-08 | 0.1 | 1.91867E-07 | -67.17 | 1.91867E-07 | 1 | -8.33267E-07 | 0.032973 | 300000 | 1.0991E-07 |
| 9 | -48.13 | 1.53815E-08 | 0.1 | 1.53815E-07 | -68.13 | 1.53815E-07 | 1 | -6.68012E-07 | 0.027649 | 300000 | 9.2162E-08 |
| 9.2 | -48.22 | 1.50661E-08 | 0.1 | 1.50661E-07 | -68.22 | 1.50661E-07 | 1 | -6.54311E-07 | 0.028299 | 300000 | 9.4328E-08 |
| 9.4 | -45.16 | 3.04789E-08 | 0.1 | 3.04789E-07 | -65.16 | 3.04789E-07 | 1 | -1.32368E-06 | 0.059765 | 300000 | 1.9922E-07 |
| 9.6 | -49.08 | 1.23595E-08 | 0.1 | 1.23595E-07 | -69.08 | 1.23595E-07 | 1 | -5.36765E-07 | 0.025277 | 300000 | 8.4258E-08 |
| 9.8 | -46.67 | 2.15278E-08 | 0.1 | 2.15278E-07 | -66.67 | 2.15278E-07 | 1 | -9.34941E-07 | 0.045882 | 300000 | 1.5294E-07 |
| 10 | -49.76 | 1.05682E-08 | 0.1 | 1.05682E-07 | -69.76 | 1.05682E-07 | 1 | -4.5897E-07 | 0.023452 | 300000 | 7.8175E-08 |
| 10.2 | -46.57 | 2.20293E-08 | 0.1 | 2.20293E-07 | -66.57 | 2.20293E-07 | 1 | -9.56719E-07 | 0.050861 | 300000 | 1.6954E-07 |
| 10.4 | -44.7 | 3.38844E-08 | 0.1 | 3.38844E-07 | -64.7 | 3.38844E-07 | 1 | -1.47158E-06 | 0.081331 | 300000 | 2.711E-07 |
| 10.6 | -45.99 | 2.51768E-08 | 0.1 | 2.51768E-07 | -65.99 | 2.51768E-07 | 1 | -1.09341E-06 | 0.062777 | 300000 | 2.0926E-07 |
| 10.8 | -47.21 | 1.90108E-08 | 0.1 | 1.90108E-07 | -67.21 | 1.90108E-07 | 1 | -8.25628E-07 | 0.049208 | 300000 | 1.6403E-07 |
| 11 | -48.3 | 1.47911E-08 | 0.1 | 1.47911E-07 | -68.3 | 1.47911E-07 | 1 | -6.42369E-07 | 0.039717 | 300000 | 1.3239E-07 |
| 11.2 | -43.74 | 4.22669E-08 | 0.1 | 4.22669E-07 | -63.74 | 4.22669E-07 | 1 | -1.83563E-06 | 0.117659 | 300000 | 3.922E-07 |

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 11.3 | -47.02 | 1.98609E-08 | 0.1 | 1.98609E-07 | -67.02 | 1.98609E-07 | 1 | -8.6255E-07 | 0.056279 | 300000 | 1.876E-07 |
| 11.4 | -46.65 | 2.16272E-08 | 0.1 | 2.16272E-07 | -66.65 | 2.16272E-07 | 1 | -9.39257E-07 | 0.062373 | 300000 | 2.0791E-07 |
| 11.6 | -47.02 | 1.98609E-08 | 0.1 | 1.98609E-07 | -67.02 | 1.98609E-07 | 1 | -8.6255E-07 | 0.059307 | 300000 | 1.9769E-07 |
| 11.8 | -43.82 | 4.14954E-08 | 0.1 | 4.14954E-07 | -63.82 | 4.14954E-07 | 1 | -1.80212E-06 | 0.128219 | 300000 | 4.274E-07 |
| 12 | -46.34 | 2.32274E-08 | 0.1 | 2.32274E-07 | -66.34 | 2.32274E-07 | 1 | -1.00875E-06 | 0.074225 | 300000 | 2.4742E-07 |

Table 9 shows the reflected power (*Prefln*) analysis for calculation of RCS of PETCP RAM material in OATS measurements method. In this measurements the reflected power (reflected power from material/target) *(Prefln)* is measured by spectrum analyser, which is ($R$ = 6 feet) away from the PETCP RAM material. Both, transmitting (Tx) and receiving (Rx,) antenna are kept at one place, and RAM material to be measured are kept at other place, which is 6 feet ($R$ = 6 feet) away from Tx /Rx antenna. The minimum and maximum values of *'Prefln'* are - 53.76 dB at 9 GHz and -42.66 dB at 12 GHz respectively are measured. The minimum and maximum values of *'SE (Refln)'* are - 8.68529E-07 dB at 10.6 GHz and - 1.08839E-06 dB at 11 GHz respectively are calculated. The minimum values of *σ1, σ2* and final *σ* are 0.007307 $m^2$ at 8.4 GHz, 300000 $m^2$ in 8 to 12 GHz frequency range, and 6.5635E-08 $m^2$ at 10.4 GHz. The maximum values of *σ1, σ2* and final *σ* are 0.173201 $m^2$ at 12 GHz, 300000 $m^2$ in 8 to 12 GHz frequency range, and 1.0358E-07 $m^2$ at 10.4 GHz, are shown in table 9.

Table 9 Shows PET+Conductive Paint (PETCP) material reflected power (Prefln) from the material alongwith calculated RCS and all type of SE's in OATS method.

| *F (GHz)* | *Prefln (dB)* | *Prefln (watt)* | *Pin (watt)* | *P(Refln) /P(In)* | *S11 (dB)* | *\|X11\|^2* | *1-\|X11\|^2* | *SE (Refln)* | *RCS (σ1)* | *RCS (σ2)* | *σ=(σ1)/ (σ2)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | -51.73 | 6.71429E-09 | 0.1 | 6.71429E-08 | -71.73 | 6.71429E-08 | 0.99999993 | -2.91598E-07 | 0.009536 | 300000 | 3.1787E-08 |
| 8.2 | -50.92 | 8.09096E-09 | 0.1 | 8.09096E-08 | -70.92 | 8.09096E-08 | 0.99999992 | -3.51386E-07 | 0.012073 | 300000 | 4.0243E-08 |
| 8.4 | -53.31 | 4.66659E-09 | 0.1 | 4.66659E-08 | -73.31 | 4.66659E-08 | 0.99999995 | -2.02668E-07 | 0.007307 | 300000 | 2.4357E-08 |
| 8.6 | -53.39 | 4.58142E-09 | 0.1 | 4.58142E-08 | -73.39 | 4.58142E-08 | 0.99999995 | -1.98968E-07 | 0.007519 | 300000 | 2.5065E-08 |
| 8.8 | -50.41 | 9.09913E-09 | 0.1 | 9.09913E-08 | -70.41 | 9.09913E-08 | 0.99999991 | -3.9517E-07 | 0.015637 | 300000 | 5.2123E-08 |

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | -53.76 | 4.20727E-09 | 0.1 | 4.20727E-08 | -73.76 | 4.20727E-08 | 0.99999996 | -1.82719E-07 | 0.007563 | 300000 | 2.5209E-08 |
| 9.2 | -52.53 | 5.5847E-09 | 0.1 | 5.5847E-08 | -72.53 | 5.5847E-08 | 0.99999994 | -2.42541E-07 | 0.01049 | 300000 | 3.4966E-08 |
| 9.4 | -52.73 | 5.33335E-09 | 0.1 | 5.33335E-08 | -72.73 | 5.33335E-08 | 0.99999995 | -2.31624E-07 | 0.010458 | 300000 | 3.486E-08 |
| 9.6 | -52.79 | 5.26017E-09 | 0.1 | 5.26017E-08 | -72.79 | 5.26017E-08 | 0.99999995 | -2.28446E-07 | 0.010758 | 300000 | 3.586E-08 |
| 9.8 | -52.47 | 5.66239E-09 | 0.1 | 5.66239E-08 | -72.47 | 5.66239E-08 | 0.99999994 | -2.45915E-07 | 0.012068 | 300000 | 4.0227E-08 |
| 10 | -52.25 | 5.95662E-09 | 0.1 | 5.95662E-08 | -72.25 | 5.95662E-08 | 0.99999994 | -2.58693E-07 | 0.013219 | 300000 | 4.4062E-08 |
| 10.2 | -48.71 | 1.34586E-08 | 0.1 | 1.34586E-07 | -68.71 | 1.34586E-07 | 0.99999987 | -5.845E-07 | 0.031073 | 300000 | 1.0358E-07 |
| 10.4 | -50.86 | 8.20352E-09 | 0.1 | 8.20352E-08 | -70.86 | 8.20352E-08 | 0.99999992 | -3.56274E-07 | 0.01969 | 300000 | 6.5635E-08 |
| 10.6 | -46.99 | 1.99986E-08 | 0.1 | 1.99986E-07 | -66.99 | 1.99986E-07 | 0.9999998 | -8.68529E-07 | 0.049865 | 300000 | 1.6622E-07 |
| 10.8 | -44.92 | 3.22107E-08 | 0.1 | 3.22107E-07 | -64.92 | 3.22107E-07 | 0.99999968 | -1.39889E-06 | 0.083375 | 300000 | 2.7792E-07 |
| 11 | -46.01 | 2.50611E-08 | 0.1 | 2.50611E-07 | -66.01 | 2.50611E-07 | 0.99999975 | -1.08839E-06 | 0.067294 | 300000 | 2.2431E-07 |
| 11.2 | -44.51 | 3.53997E-08 | 0.1 | 3.53997E-07 | -64.51 | 3.53997E-07 | 0.99999965 | -1.53739E-06 | 0.098543 | 300000 | 3.2848E-07 |
| 11.4 | -48.12 | 1.5417E-08 | 0.1 | 1.5417E-07 | -68.12 | 1.5417E-07 | 0.99999985 | -6.69552E-07 | 0.044463 | 300000 | 1.4821E-07 |
| 11.6 | -45.08 | 3.10456E-08 | 0.1 | 3.10456E-07 | -65.08 | 3.10456E-07 | 0.99999969 | -1.34829E-06 | 0.092705 | 300000 | 3.0902E-07 |
| 11.8 | -44.8 | 3.31131E-08 | 0.1 | 3.31131E-07 | -64.8 | 3.31131E-07 | 0.99999967 | -1.43808E-06 | 0.102318 | 300000 | 3.4106E-07 |
| 12 | -42.66 | 5.42001E-08 | 0.1 | 5.42001E-07 | -62.66 | 5.42001E-07 | 0.99999946 | -2.35388E-06 | 0.173201 | 300000 | 5.7734E-07 |

## 3. Materials and Methods

**International Journal of Engineering Technology and Management Sciences**
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
**DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621**

The novel Polyethylene (PE) material of thickness 0.08 mm are proposed in this paper as a base material to design an other composite material. The PE material is used as RAM by synthesis, design and fabrication for EMI shielding and small vehicle’s low signature’s applications. Due to the EM wave absorbing capability of PE composites, the material helps to reduce the radar cross section (RCS) of small air vehicles such as small aircrafts, sUAV (small unmanned aerial vehicle), µUAV (micro unmanned aerial vehicle), drones, hexcopter, spy birds, ships etc. In view of small vehicle’s low signature realization, the controlling parameters of material are arranged such as permittivity ($\varepsilon$), permeability ($\mu$), thickness ($t$), Conductivity (□) etc. With very minimum thickness of base material i.e. 0.08 mm, the RAM composites are designed and fabricated. Fumed silica (1g) having a molecular weight 60.08 g / mol, which is used as an additive was obtained from sigma Aldrich company, acetone obtained from SRL chemicals company, Aluminium spray paint (ABRO) and Conductive paint, which consist of acrylic resin having molecular weight 298.33g/mol, 20 wt% of carbon black (Vulcan*C72) and 0.5wt% of multiwall carbon nanotube (i.e. 12.01g/mol) are used to enhance the conductive nature of the PE and its composites. The experimental analysis of polyethylene (PE) and their composites are characterized as RAM. The PE is used as base material to design of polyethylene terephthalate (PET) and PET + Conductive Paint (PETCP). The contact angle & material thickness ($t$) 78.50 & 0.08 mm; 66.18 & 0.09 mm and 93.45 & 0.12 mm for PE, PET and PETCP respectively, are proposed in this experiments. Figure 1, shows the experimental test bed set up of OATS measurements for PE, PET and PETCP RAM material. The OATS method helps in analysing of on – site, real and optimistic data evaluation analysis to characterise the RAM material. OATS experiment is carried out in open - field atmosphere, hence optimum, designed and expected data are collected and used for further analysis. The OATS


**Figure 1. Experimental test bed set up of OATS measurements.**

experiment site is free from the EM environment and other direct radiations. During the OATS experiments outside weather was sunshiny, good, clean and free from any direct natural interferences. In this OATS test bed set up the X – band equipments and instruments are used such as RF signal generator of 9 KHz to 13 GHz frequency range at - 135 dBm to + 30 dBm measurement power range and input power set to + 20 dB during the transmissions, - 3 dB RF power Splitter, three identical X - band horn antennas of having 20 dB gain, remotely located 3 RAM material (films), mounted tripod stand - wooden stool and three identical spectrum analysers, RF cables and connectors etc are used. The RAM material (films) to source distance (R) (i.e. RAM material to transmitting antenna distance) is 6 feet (i.e. $R$ = 6 ft). The 3 RAM films dimension such as (width x length) are same (262 mm x 210 mm) is presented. With the different RAM material thicknesses ($t$) 0.08 mm, 0.09 mm and 0.12 mm for PE, PET and PETCP respectively are used and designated EM characteristics

DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

**Figure 2. Experimental test bed set up of WGM measurements.**

are achieved in OATS method. Figure 2, shows the experimental test bed set up of wave guide measurement (WGM) method. In the WGM experimental test bed set - up the RF equipment's, cables and connectors are used, such as vector network analyser (VNA) of 10 MHz to 26.5 GHz frequency range, X - band rectangular waveguides, screws (nuts and bolts) to tighten the two waveguides, RF coaxial cables of 10 MHz to 26.5 GHz frequency range, RF connectors, PE base RAM material films and graphical user interface unit (GUI) data processing computer are used. The VNA is calibrated before the experimentation, in terms of RF connectors, RF cables, screws, waveguides, X - band frequency range setting to VNA and with the help of graphical user interface (GUI) unit installed in the data processing computer.The dimension of all 3 PE based films are same (length x width = 23 mm x 10 mm) instead the different thicknesses (t) is 0.08 mm, 0.09 mm and 0.12 mm for PE, PET and PETCP respectively are used for WGM method. By using WGM experiment, the S – parameters such as reflection coefficient (*S11*) and transmission coefficient (*S21*) are measured. In the X – band frequency, the 0.2 GHz is used as resolution frequency to carry out the experiment at 8 to 12 GHz frequency range. The *S11* and *S21* experimental datas are obtained from the GUI unit interfaced to the computer and further to the VNA. Further analysis using *S11* and *S21* are calculated for, *SEabs*, *SErefln* and *SEtot*, are proposed in equation (1) (2) and (3).

$$SE_{refle} = 10\ Log_{10}\ (1 - \ |X_{11}|^2)[\text{dB}] \qquad (1)$$

$$SE_{ab} = 10\ Log_{10}\ (\frac{|X_{21}|^2}{1- \ |X_{11}|^2})\ \ [\text{dB}] \qquad (2)$$

$$SE_{tot} = \ SE_{ab} + SE_{refle} \quad [\text{dB}] \qquad (3)$$

Where, $SE_{ab}$ is effective shielding due to absorption, and $SE_{refle}$ is shielding due to reflection, $SE_{tot}$ is the toal shielding effectiveness. The small vehicle's low signature (i.e., low RCS level) of the designed RAM material for the X - band frequency is calculated by using the radar cross section (σ) equation (4)

$$\sigma = \frac{4\pi^3 R^4 P_{refle}}{P_{in} G_t\ G_r \lambda^2} m^2 \qquad (4)$$

Where, σ is RCS, $G_t$ is gain of transmitting (Tx) antenna, $G_r$ is gain of receiving (Rx) antenna, $R$ is distance between Tx antenna and PE RAM material, and $\lambda$ is the X - band wavelength are presented. The RAM material are designed and fabricated based on the controlling parametrs of PE, PET and PETCP material such as conductivity (□), permittivity ($\varepsilon$), permeability ($\mu$), electric field ($E$), magnetic field ($M$) and frequency of operation ($f$). These materials are suitable for EMI shielding and small vehicles low signature (low RCS level) applications.

## 4. Conclusion

The novel radar absorbing material (RAM) is proposed in this paper. The PE based RAM is used further to design and fabricate of composite material required for small air vehicle's low signature's (low RCS) applications. The low vehicles such as small aircrafts, sUAV, µUAV, drones,

DOI:10.46647/ijetms.2023.v07i04.017 ISSN: 2581-4621

hexcopter, spy birds, ships etc, are the prime requirement for its low target signature in military and defence sector applications. The low target signature (low RCS value) is acquired by using novel PE and PE based composite RAM material. The controlling parameters such as permittivity ($\varepsilon$), permeability ($\mu$), thickness ($t$), conductivity (□), electric field ($E$) and magnetic field ($M$) etc of material are designed arranged in such a way that, will get the novel RAM material for EMI shielding and low target signature applications. While design and fabrication of RAM, the contact angle and thickness maintained are 78.50 & 0.08 mm; 66.18 & 0.09 mm and 93.45 & 0.12 mm for PE, PET and PETCP respectively, are described in this paper. The dimensions of entire PE based films are same, which is Length x Width = 262 mm x 210 mm), in OATS measurement method. While, the dimensions of entire PE based films are same, which is Length x Width = 23 mm x 10 mm, in WGM measurement method. There are two measurement methods such as WGM and OATS are used for analysis and characterisation of PE, PET and PETCP RAM material in the X – band operation of 8 to 12 GHz frequency range. By using these RAM materials, the shielding effectiveness for absorbtion (*SEabs*), shielding effectiveness for reflection *(SErefln)*, total shielding effectiveness (*SEtot)* and radar cross section *(*σ*)* are analysed and calculated. The obtained values of RCS (σ) are 1.0358E-07 $m^2$ at 10.4 GHz, 9.4328E-08 $m^2$ at 8.8 GHz and 1.0061E-07 at 9.2 GHz, of material PETCP, PET, PE respectively of RAM material are presented in OATS measurement method. The value of total shielding effectiveness (SEtotal) are -6.89E+01dB at 8.4 GHz, -6.91E+01 at 9.2 GHz and - 6.59E+01 dB at 12 GHz of PE, PET and PETCP respectively of RAM material are obtained in OATS method. It is the good agreement between the design & fabrication methodology & technique used and the results data analysis obtained. This RAM material is very much suitable for EMI shielding, small vehicle's (i.e. small air vehicle target) low signature applications.

## 5. Acknowledgements

This work was supported by DIAT, the authors of this manuscript are very much thankful to the Vice Chancellor, DIAT to support and allow us to complete this research work. The authors are also thankful to the PhD students and all staff members of the Materials Engineering Department, Physics Department and Electronics Engineering Department for timely helping in completion of this manuscript.

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