APPENDIX

A. **The theoretical thickness limit for broadband microwave absorption in the frequency range 8.2 GHz to 12.4 GHz**

The minimum thickness limit of a dielectric microwave absorber for broadband absorption in a particular frequency ranges f_1 and f_2, corresponding to λ_1 and λ_2 is given as

$$\left|\int_0^\infty ln|R(\lambda)|d\lambda\right| \leq 2\pi^2 \sum_i t_i \tag{A.1}$$

Where t_i is the thickness of the i^{th} layer of the absorber, $R\ (\lambda)$ is the frequency dependent reflectance and $d\lambda=\lambda_1-\lambda_2$

Introducing decibel scale of the reflectance i.e $RL_c = 20\log\ R\ (\lambda) RL_c = 20\log|R\ (\lambda)|$ and since $ln|R\ (\lambda)| = 2.303\log|R\ (\lambda)|$, equation (A.1) is modified to

$$\left|\int_0^\infty 2.303\frac{RL_c}{40\pi^2}d\lambda\right| \leq \sum_i t_i \tag{A.2}$$

For RL_c =-30dB absorption over the wavelength ranges $\lambda_1 =$ 36.58 mm and $\lambda_2 =$ 24.19 mm, the minimum total thickness limit of the absorber is derived as

$$2.303\frac{RL_c}{40\pi^2}(\lambda_1 - \lambda_2) \leq t \tag{A.3}$$

Substituting the values of RL_c, λ_1 and λ_2, we get

$$t > 2.1 \text{ mm}$$

Thus, to achieve RL_c = -30dB over the X-band, the thickness of the absorber will not be less than 2.1 mm [1, 2].

References:

[1] Zhang, L., Zhu, H., Song, Y., Zhang, Y. and Huang, Y. (2008). The electromagnetic characteristics and absorbing properties of multi-walled carbon nanotubes filled with Er_2O_3 nanoparticles as microwave absorbers, *Material Science and Engineering B*, 153: 78–82.

[2] Rozanov, N. K. (2000). Ultimate Thickness to Bandwidth Ratio of Radar Absorbers. *IEEE Transaction on Antennas and Propagation*, 48(8): 1230-1234.

B. **MATLAB program for reflection loss optimization with varying individual layer thickness of multilayer layer absorber system**

The input impedance and reflection loss of a conductor backed multilayer microwave absorber can be calculated using Transmission Line Model. The following program is written based on the reflection loss expression for a triple layer microwave absorber.

```
clear all
load('c:\users\one.txt');
load('c:\users\two.txt');
load('c:\users\three.txt');

c=3*10^8
result=[];
f=aa60(:,1);
e1=aa60(:,2);
e2=a(:,2);
e3=ax(:,2);
e11=aa60(:,3);
e12=a(:,3);
e13=ax(:,3);
u1=aa60(:,4);
u2=a(:,4);
u3=ax(:,4);
u11=aa60(:,5);
u12=a(:,5);
u13=a(:,5);
d1=1.0*10^-3;
d2=1.0*10^-3;
d3=1.0*10^-3;
er1=complex(e1,-e11);
er2=complex(e2,-e12);
er3=complex(e3,-e13);
ur1=complex(u1,-u11);
ur2=complex(u2,-u12);
ur3=complex(u3,-u13);
k=ur1./er1;
kk=sqrt(k);
q=ur1.*er1;
qq=sqrt(q);
k1=ur2./er2;
kk1=sqrt(k1);
```

```
q1=ur2.*er2;
qq1=sqrt(q1);
k2=ur3./er3;
kk2=sqrt(k2);
q2=ur3.*er3;
qq2=sqrt(q2);
qqq=qq.*d1;
p=2*f*pi;
pp=p./c;
ppp=qqq.*pp;
pppp=tan(ppp);
aaaa=1i.*pppp;
ppppp=kk.*aaaa;
qqq1=qq1.*d2;
ppp1=qqq1.*pp;
pppp1=tan(ppp1);
aaaa1=1i.*pppp1;
ppppp1=kk1.*aaaa1;
qqq2=qq2.*d3;
ppp2=qqq2.*pp;
pppp2=tan(ppp2);
aaaa2=1i.*pppp2;
ppppp2=kk2.*aaaa2;
s=ppppp.*aaaa1;
ss=ppppp+ppppp1;
sss=kk1+s;
ssss=ss./sss;
sssss=kk1.*ssss;
g=sssss.*aaaa2;
gg=sssss+ppppp2;
ggg=kk2+g;
gggg=gg./ggg;
ggggg=kk2.*gggg;
r1=ggggg-1;
r2=ggggg+1;
r=r1./r2;
rr=abs(r);
rl=20*log(rr)
result=[f,rl];
plot(f,rl,'-ks','LineWidth',2,'MarkerEdgeColor','k','MarkerFaceColor','k')
```

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