Analysis of Finite Periodic Structures of Graphene with Dielectric Substrate Using EFIE-PMCHW-SED Method

Wu Yang[1], Yaohui Ding[1], Weijun Wu[2], Yangyang Li[1], Weibing Lu[1]

[1]State Key Laboratory of Millimeter Waves, Southeast University, Nanjing, China.

[2] Science and Technology on Electromagnetic Compatibility Laboratory, China Ship Development and Design Center, Wuhan, China

Yangwu@seu.edu.cn

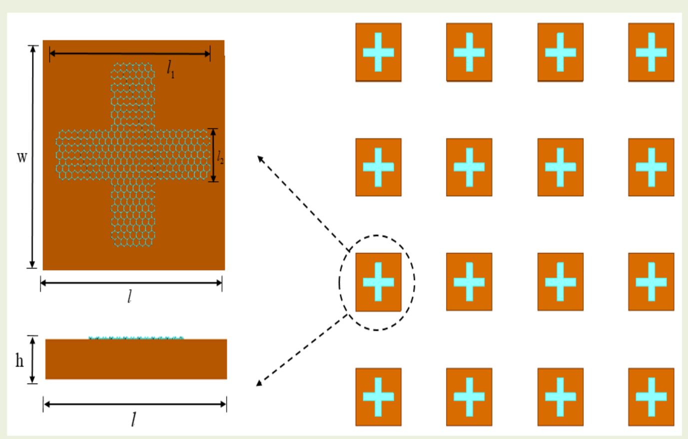
Introduction:

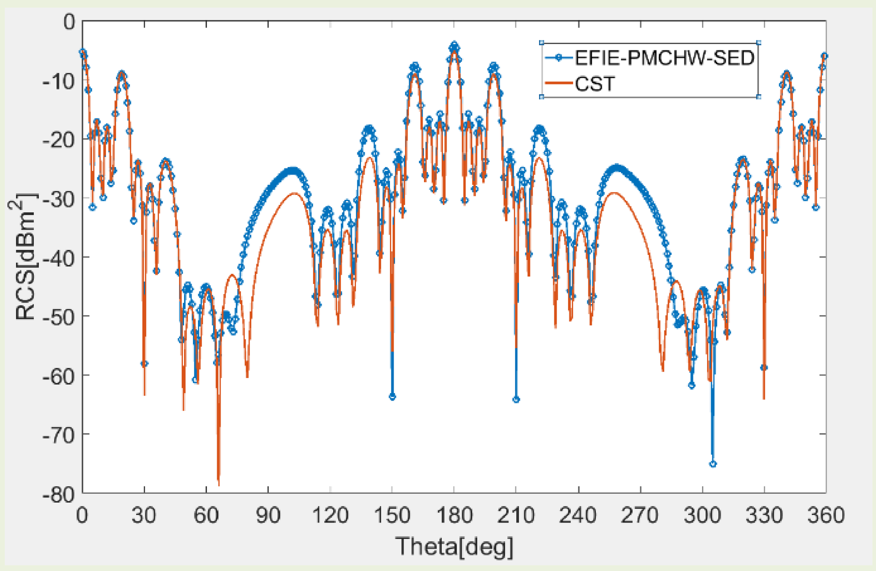
The finite periodic structure of graphene with dielectric substrate have a broad application in EM engineering such as metamaterials, phased arrays, frequency selective surfaces(FSS), etc. Efficient electromagnetic simulation is important to understand the electromagnetic characteristics of these structures.

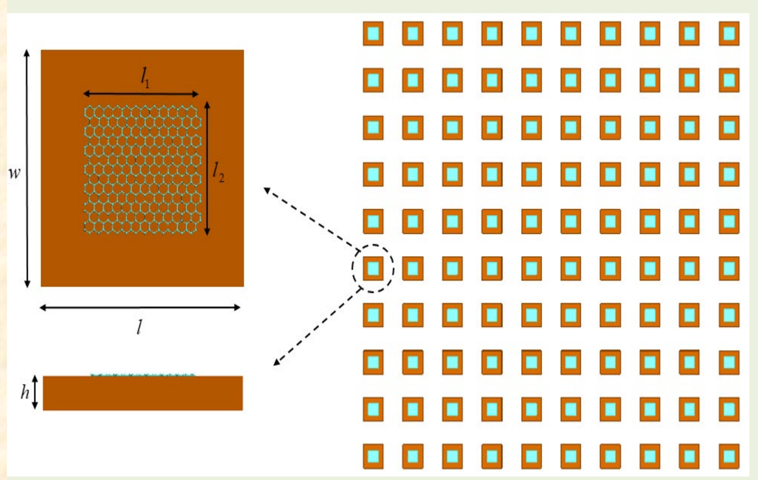
However, the MoM method is unsuitable for large periodic structure or complex composite structure due to large memory cost. Several physically meaningful bases have been proposed to reduce the number of unknowns, such as the Sub-entire-domain(SED) method. The traditional SED method was proposed for rapid analysis of finite periodic array of PEC structures.

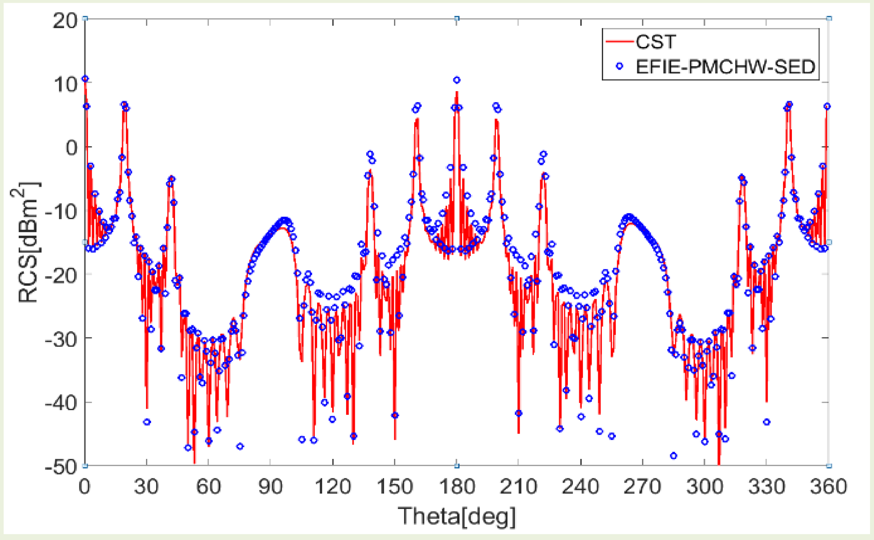
The EFIE-PMCHW-SED Method is proposed to analyze the finite periodic structure of graphene with dielectric substrate. To avoid the computationally expensive volume discretization for graphene structures, we transform the VSIE into SIE, Then, the sub-entire domain(SED) basis function method and EFIF-PMCHW method are combined to analyze the finite periodic structure of graphene.

Results:









Conclusion:

In this paper, the EFIE-PMCHW equation is introduced for the graphene structure with dielectric substrate. Then the EFIE-PMCHW-SED method is proposed in the analysis of periodic structures of graphene. Numerical results illuminated the accuracy and efficiency of the method.

Formulation:

(1) EFIE-PMCHW for Analyzing Graphene with Dielectric Substrate

- surface integral equation is established on the outer surface of the medium
- volume-surface integral equation is established inside of the graphene
- rewrite the coupled volume-surface integral equation into the surface integral equation

$$\begin{cases} -\boldsymbol{n}_1\times\left[Z_1\boldsymbol{L}_1(\boldsymbol{J}_d)+Z_2\boldsymbol{L}_2(\boldsymbol{J}_d)+Z_1\boldsymbol{L}_1(\boldsymbol{J}_{g1})+Z_2\boldsymbol{L}_2(\boldsymbol{J}_{g2})\right. \\ \quad \left.-\boldsymbol{K}_1(\boldsymbol{M}_d)-\boldsymbol{K}_2(\boldsymbol{M}_d)\right]=\boldsymbol{n}_1\times\boldsymbol{E}^i \qquad ,on\ S_d \\ -\boldsymbol{n}_1\times\left[\dfrac{1}{Z_1}\boldsymbol{L}_1(\boldsymbol{M}_d)+\dfrac{1}{Z_2}\boldsymbol{L}_2(\boldsymbol{M}_d)+\boldsymbol{K}_1(\boldsymbol{J}_d)+\boldsymbol{K}_2(\boldsymbol{J}_d)\right. \\ \quad \left.+\boldsymbol{K}_1(\boldsymbol{J}_{g1})+\boldsymbol{K}_2(\boldsymbol{J}_{g2})\right]=\boldsymbol{n}_1\times\boldsymbol{H}^i \qquad ,on\ S_d \end{cases}$$

$$\begin{cases} \left[Z_1\boldsymbol{L}_1(\boldsymbol{J}_d)-\boldsymbol{K}_1(\boldsymbol{M}_d)+Z_1\boldsymbol{L}_1(\boldsymbol{J}_{g1})\right]_{\tan}=\left[\dfrac{1}{\sigma_g}\boldsymbol{J}_{g1}-\boldsymbol{E}^i\right]_{\tan} \quad ,on\ S_{g1} \\ \left[Z_2\boldsymbol{L}_2(\boldsymbol{J}_d)-\boldsymbol{K}_2(\boldsymbol{M}_d)+Z_2\boldsymbol{L}_2(\boldsymbol{J}_{g2})\right]_{\tan}=0,on\ S_{g2} \end{cases}$$

S_{g1}: interface between the graphene and the free space
S_{g2}: interface between the graphene and the medium
S_d: interface between the medium and the free space

(2) EFIE-PMCHW-SED for Analyzing Finite Periodic Structure

- equivalent current on the entire surface of the periodic structure is approximated in terms of the SED basis functions
- the SED basis be constructed by solving a 3*3 cells problem with the EFIE-PMCHW method
- the EFIE-PMCHW equation on the whole structure be converted into a small matrix equation by the Galerkin procedure

$$\begin{bmatrix} Z_1P_1^{TE}+Z_2P_2^{TE} & -Q_1^{TE}-Q_2^{TE} & Z_1P_1^{TE} & Z_2P_2^{TE} \\ Q_1^{TH}+Q_2^{TH} & \dfrac{1}{Z_1}P_1^{TH}+\dfrac{1}{Z_2}P_2^{TH} & Q_1^{TH} & Q_2^{TH} \\ Z_1B_1^{TE} & -Q_1^{TE} & Z_1B_1^{TE} & 0 \\ Z_2P_2^{TE} & -Q_2^{TE} & 0 & Z_2P_2^{TE} \end{bmatrix}\bullet\begin{bmatrix} \boldsymbol{I}^J \\ \boldsymbol{I}^M \\ \boldsymbol{I}^{J_{g1}} \\ \boldsymbol{I}^{J_{g2}} \end{bmatrix}=\begin{bmatrix} \boldsymbol{V}^J \\ \boldsymbol{V}^M \\ \boldsymbol{V}^{J_g} \\ 0 \end{bmatrix}$$

$$\begin{cases} P_{imn}^{TE}=\iint_S \boldsymbol{f}_m^{SED}\cdot\boldsymbol{L}_i(\boldsymbol{f}_n^{SED})ds=\mathrm{Q}_{imn}^{TH} \\ Q_{imn}^{TE}=\iint_S \boldsymbol{f}_m^{SED}\cdot\boldsymbol{K}_i(\boldsymbol{f}_n^{SED})ds=P_{imn}^{TH} \\ B_1^{TE}=\iint_S \boldsymbol{f}_m^{SED}\cdot\boldsymbol{L}_1(\boldsymbol{f}_n^{SED})ds+ \\ \qquad \dfrac{1}{\sigma_g}\iint_{T_m=T_n}\boldsymbol{f}_m^{SED}(\boldsymbol{r})\cdot\boldsymbol{f}_n^{SED}(\boldsymbol{r}')ds \end{cases} \qquad \begin{cases} \boldsymbol{V}^J=-\iint_S \boldsymbol{f}_m^{SED}\cdot\boldsymbol{E}^i ds \\ \boldsymbol{V}^M=-\iint_S \boldsymbol{f}_m^{SED}\cdot\boldsymbol{H}^i ds \\ \boldsymbol{V}^{J_g}=-\iint_S \boldsymbol{f}_m^{SED}\cdot\boldsymbol{E}^i ds \end{cases}$$