Directive emissions of antennas on metamaterial ground planes: Role of anomalous reflection phases

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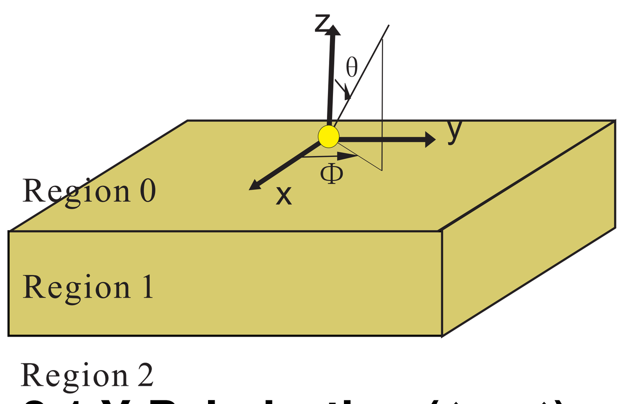
1. Background and Motivations

The development of artificial material in recent decades has led to more freedoms in controlling the emissions of antenna. In this flow of research, using different material, such as Photonic Crystal, Metamaterial, Transformation Medium and so on, as the antenna substrate to enhance efficiency and manipulate directivity has been widely studied. However, some limitations still exist, such as bulky for microwave applications, not easy to realize and so on. In order to surpass these, the motivations are:

- **Which kind of property does the substrate need to possess in order to achieve high efficiency and directivity?** — Certain Reflection Phase.
- **Which structure can make it easy to realize and not too complicated for application?** — Employ Metamaterial.

2. The Role of Anomalous Refection Phase



Origin of xyz: A point source
Region 0: Vacuum
Region 1: Metamaterial
Region 2: Vacuum

Schematic picture of the problem considered is shown in the left.
Employ Green's Function to calculate $\vec{E}$ field in Region 0:

$$\vec{E}(\vec{r},\omega) = -\mu_0 \overleftrightarrow{G}_{00}(\vec{r},0;\omega)\cdot\hat{\alpha} \tag{2.1}$$

in which $\hat{\alpha}$ is the polarized direction of point source, $\overleftrightarrow{G}_{00}(\vec{r},0;\omega)$ is Green's Function in Region 0 (explicit form is in [1]).

2.1 Y-Polarization ($\hat{\alpha}=\hat{y}$)

E field in the H-plane (y=0):

$$E_{0y}(x,z;\omega) = -\frac{i\mu_0}{8\pi^2}\int \frac{e^{i\vec{k}_\parallel\cdot\vec{r}}}{k_{0z}}[(e^{-ik_{0z}z}+\mathcal{R}^{TE}e^{ik_{0z}z})\cos^2\psi + \frac{k_{0z}^2}{k^2}(e^{-ik_{0z}z}-\mathcal{R}^{TM}e^{ik_{0z}z})\sin^2\psi]\mathrm{d}\vec{k}_\parallel \tag{2.2}$$

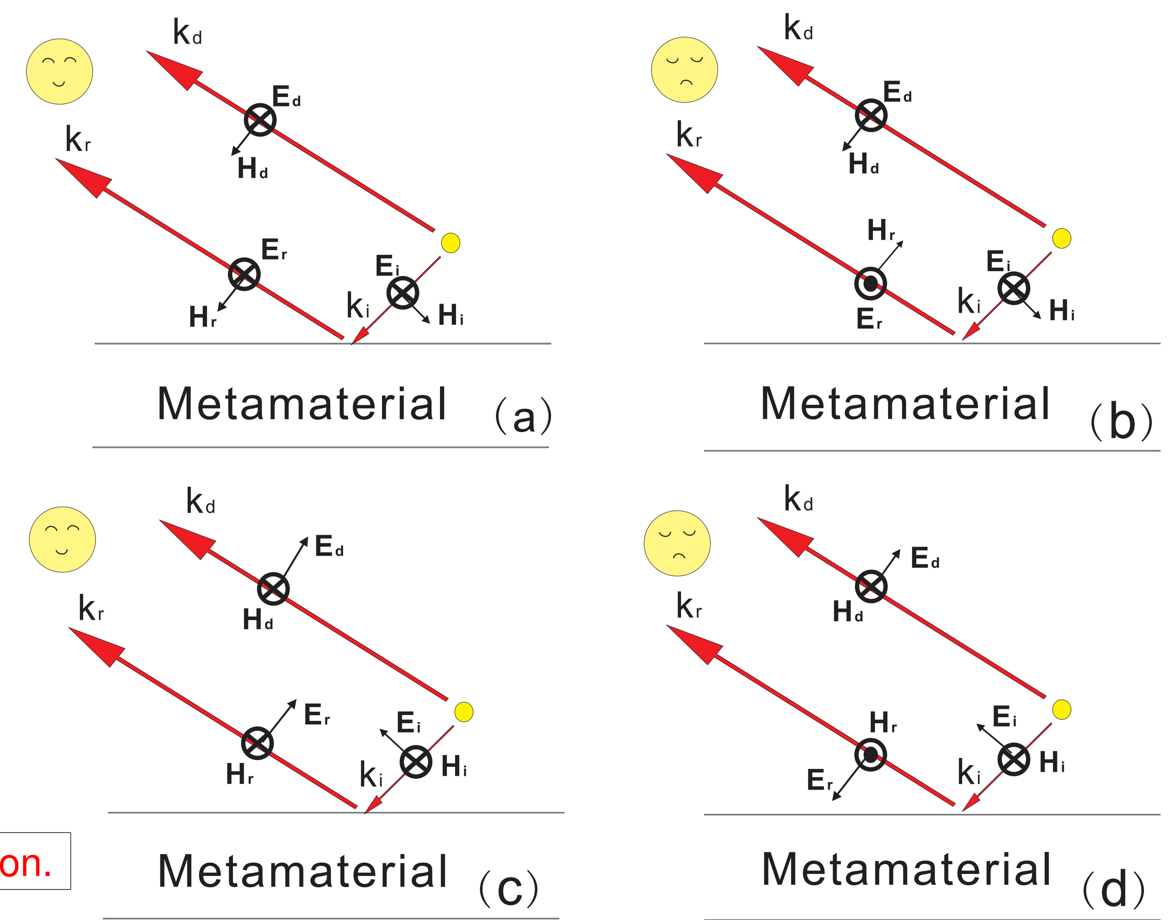
where $\mathcal{R}^{TE}$ and $\mathcal{R}^{TM}$ are reflection coefficients provided by the substrate. Generally they possess the form $\mathcal{R}=|\mathcal{R}|e^{i\varphi}$, in which $|\mathcal{R}|$ is **Reflection Amplitude** and φ is **Reflection Phase**.

(a) If $\mathcal{R}^{TE}=1$, *i.e.* $|\mathcal{R}|=1, \varphi=0$, $\vec{E}$ has maximum value;
(b) If $\mathcal{R}^{TE}=-1$, *i.e.* $|\mathcal{R}|=1, \varphi=\pi$, $\vec{E}$ has minimum value.

2.2 Z-Polarization ($\hat{\alpha}=\hat{z}$)

Similar to Y-Polarization, the following is get:

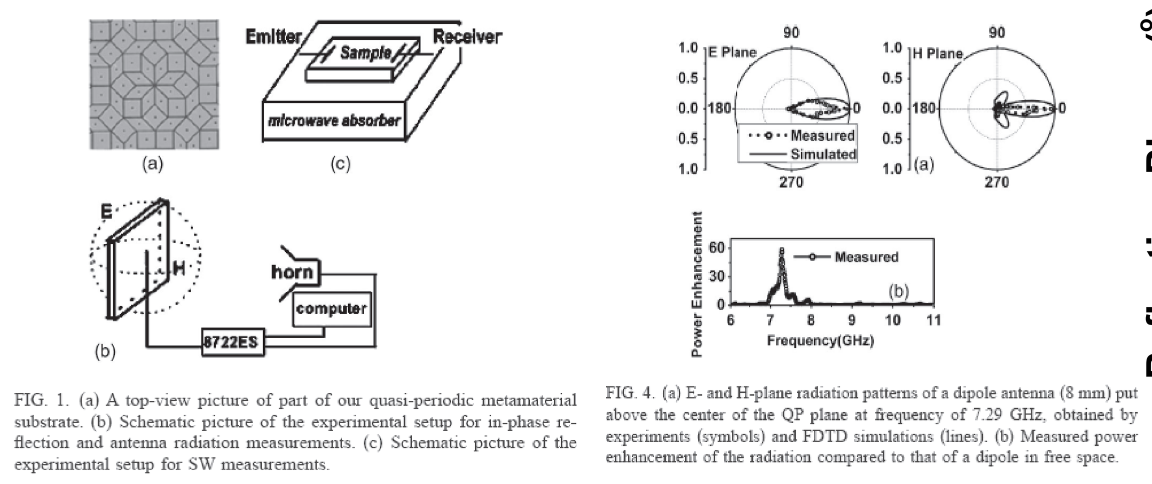
(c) If $\mathcal{R}^{TM}=-1$, *i.e.* $|\mathcal{R}|=1, \varphi=\pi$, $\vec{E}$ has maximum value;
(d) If $\mathcal{R}^{TM}=1$, *i.e.* $|\mathcal{R}|=1, \varphi=0$, $\vec{E}$ has minimum value.

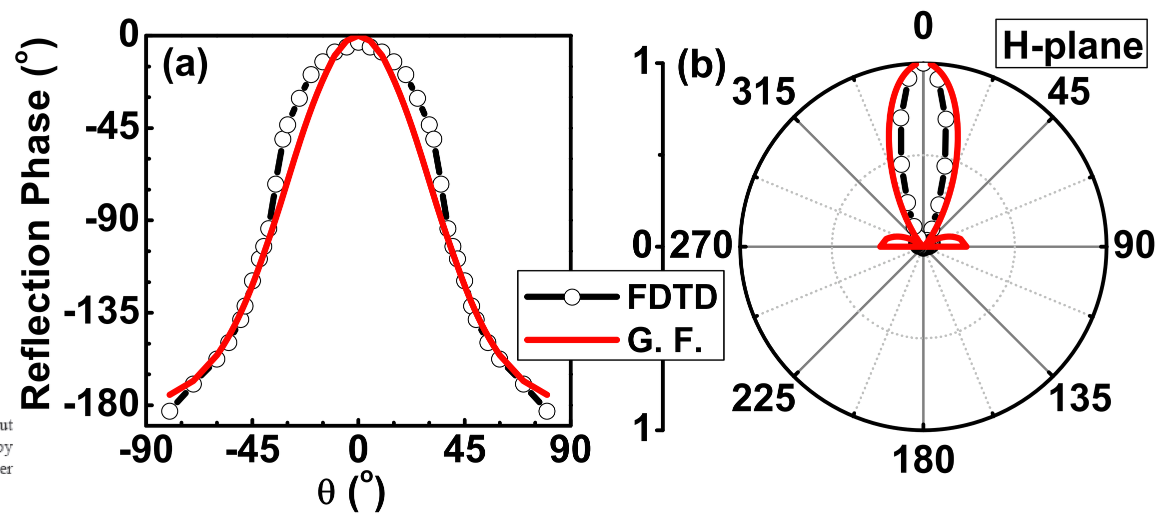


Summary: If Reflection Phase provided by the substrate strongly depends on the $\vec{k}_{inc}$, then it can achieve our goal — Directive Emission.

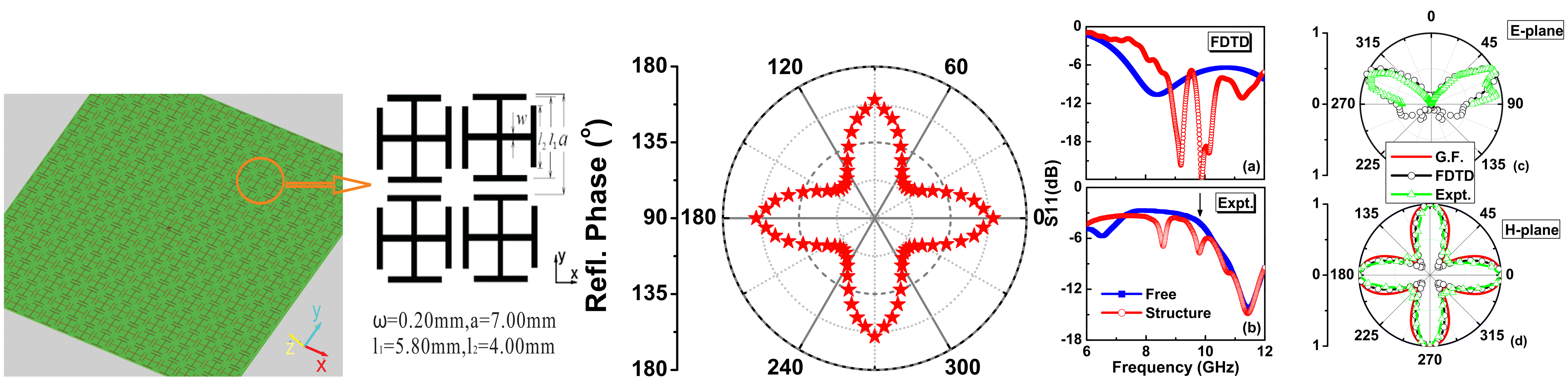
3. Realizations

3.1 Y-Polarization ($\hat{\alpha}=\hat{y}$) — Employ Quasi-crystal [2].





3.2 Z-Polarization ($\hat{\alpha}=\hat{z}$) — Employ Cross Structure.



4. Conclusions

- Green Function predicts the existence of high efficiency and directive emission of antenna radiation.
- Two samples, namely Quasi-crystal and Cross structure, verify our theory from both FDTD and experiment.
- Understanding the origin of this anomalous reflection phase is required.

References

[1] Y. Zhang *et. al.*, Electromagn. Waves **35**, 271 (2002).
[2] Hongqiang Li *et. al.*, Appl. Phys. Lett. **86**, 121108 (2005).