Directional emissions achieved with anomalous reflection phases of metamaterials

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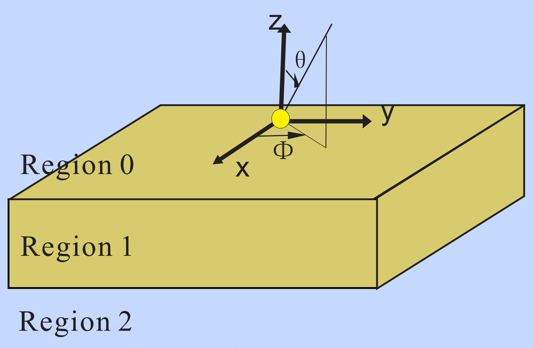
1. Background and Motivations

Recently using different material 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? — 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

Employ Green's Function to calculate $\vec{E}$ field in Region 0:

$$\vec{E}(\vec{r},\omega) = i\omega\mu_0 P_0 \overleftrightarrow{G}_{00}(\vec{r},0;\omega)\cdot\hat{\alpha} \quad (2.1)$$

in which $\hat{\alpha}$ is the polarized direction of point source, P_0 is the intensity of point source and $\overleftrightarrow{G}_{00}(\vec{r},0;\omega)$ 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):

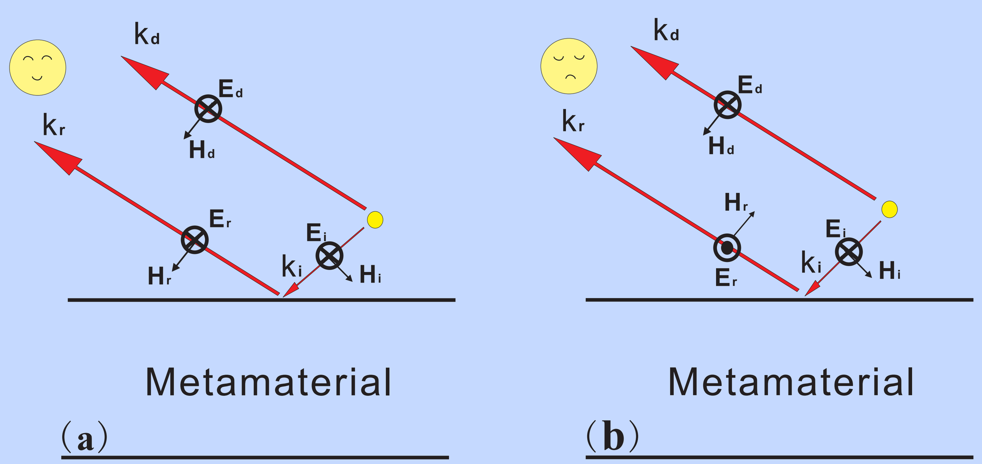
$$E_y(x,z;\omega) \approx -\frac{\mu_0\omega_0 P_0}{8\pi^2}\int \frac{e^{ik_x x + ik_z z}}{k_z}\frac{k_x^2}{k_\parallel^2}\left[1+\mathcal{R}^{TE}(\vec{k}_\parallel)\right] \quad (2.2)$$

in which $\mathcal{R}^{TE} \equiv E_\parallel^r/E_\parallel^{in}$ and $\mathcal{R}^{TM} \equiv H_\parallel^r/H_\parallel^{in}$. From Eq.(2.2) it is obvious that radiation pattern depends on both **reflection amplitude** $|\mathcal{R}|$ and **reflection phase** φ.

For convenience we assume $\mathcal{R}$ has the form $|\mathcal{R}|e^{i\varphi}$, then

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

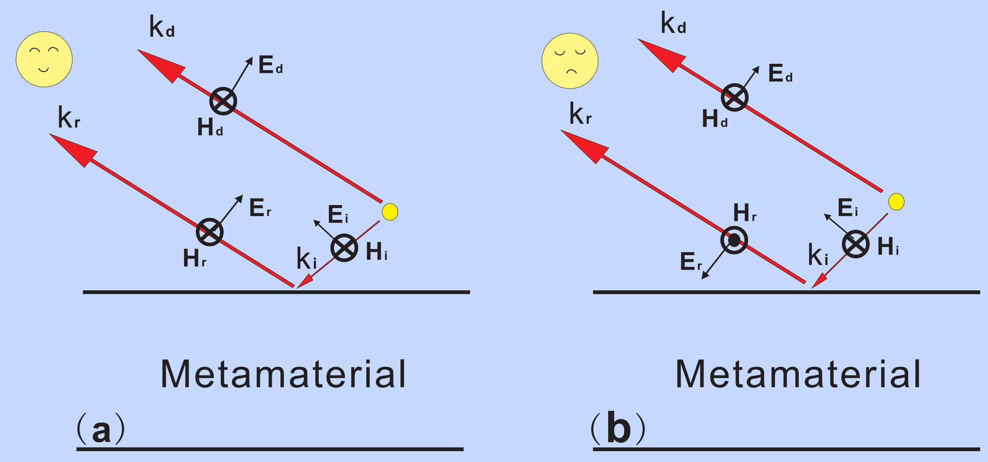
(b) If $\mathcal{R}^{TE}=-1$, *i.e.* $|\mathcal{R}|=1, \varphi=\pi$, $\vec{E}$ has minimum value (PEC-like).



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

(a) If $\mathcal{R}^{TM}=1$, *i.e.* $|\mathcal{R}|=1, \varphi=0$, $\vec{H}$ has maximum value (PEC-like);

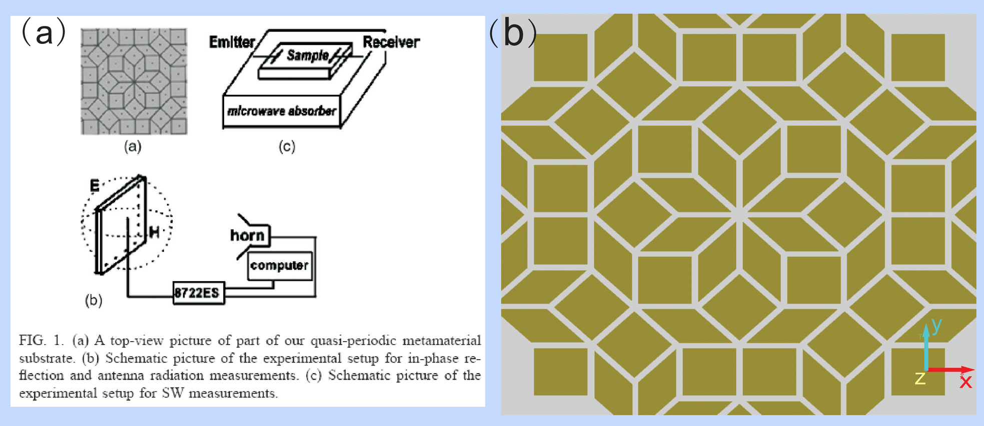
(b) If $\mathcal{R}^{TM}=-1$, *i.e.* $|\mathcal{R}|=1, \varphi=\pi$, $\vec{H}$ has minimum value (PMC-like).



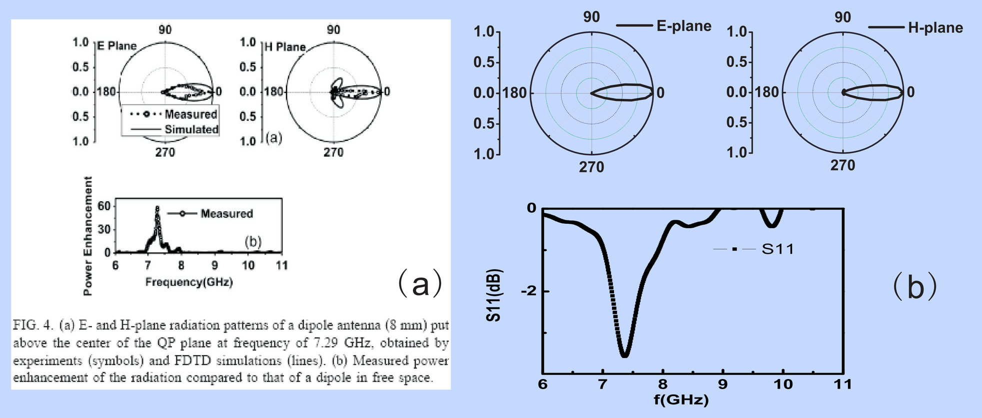
Summary: **If Reflection Phase provided by the substrate strongly depends on the $\vec{k}_{inc}$, then it can achieve our goal — Directional Emission.**

3. Realizations

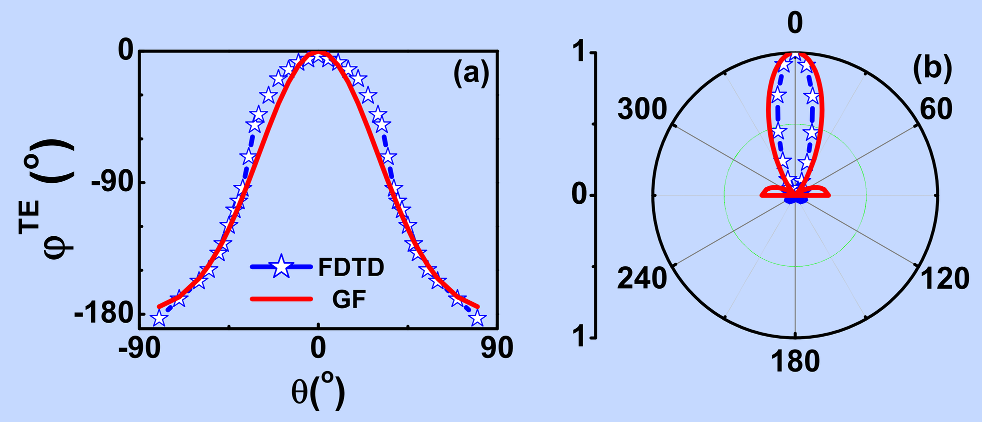
3.1 Y-Polarization — Employ Quasi-crystal[2].



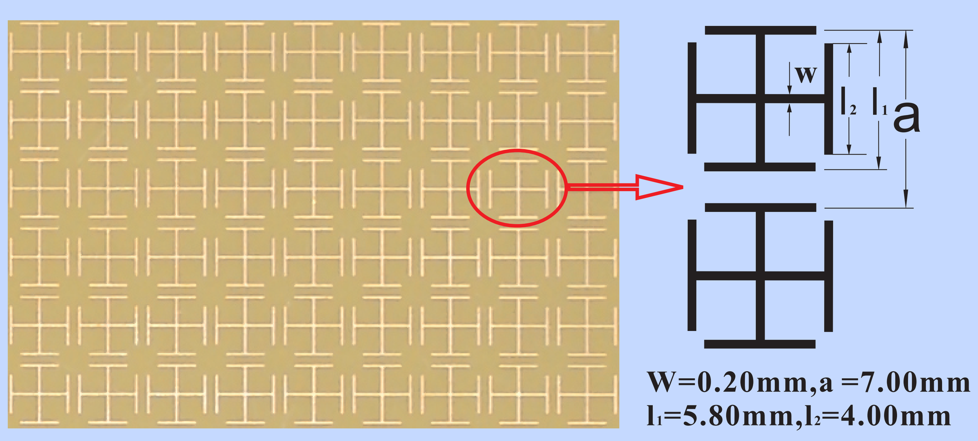
Results in Ref.[2] and our repeated ones!

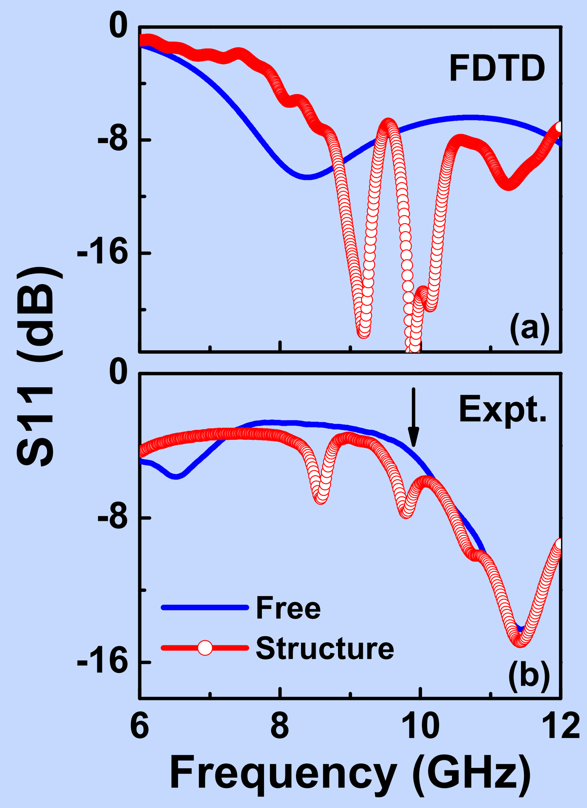


It can be explained by our theory!

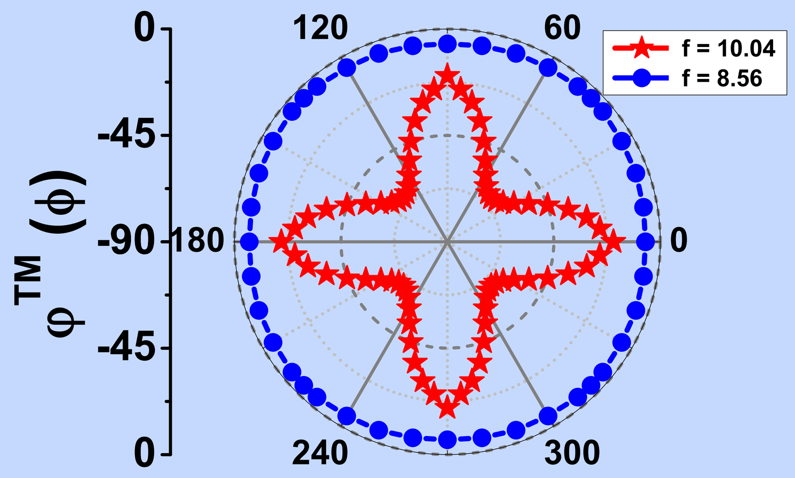


3.2 Z-Polarization — Employ Cross Structure.

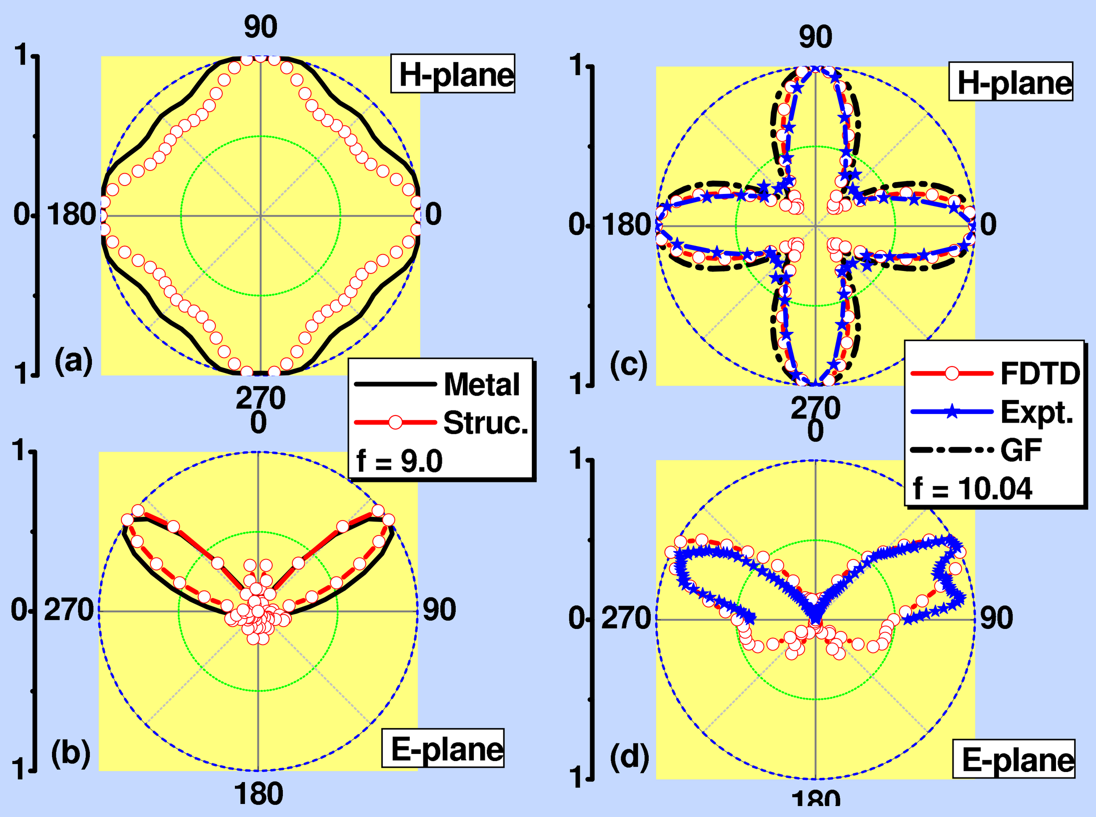




Two dips exsit in the Return Loss spectra. Straightforward, reflection phases are different at these two frequencies!



Radiation patterns are also different!



The second resonance is just what we have expected!

4. Conclusions

- Green Function predicts the existence of high efficiency and directional emission of antenna radiations if the substrate possesses specific reflection phase.
- Two samples, namely Quasi-crystal and Cross structure, testify our theory from both FDTD and experiment.
- Understanding the origin of this anomalous reflection phase is required.

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References

[1] Y. Zhang *et. al.*, Electromagn. Waves **35**, 271 (2002).

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