Analysis of Normally Incident EM Waves Reflected from a Conformal Meta-Surface

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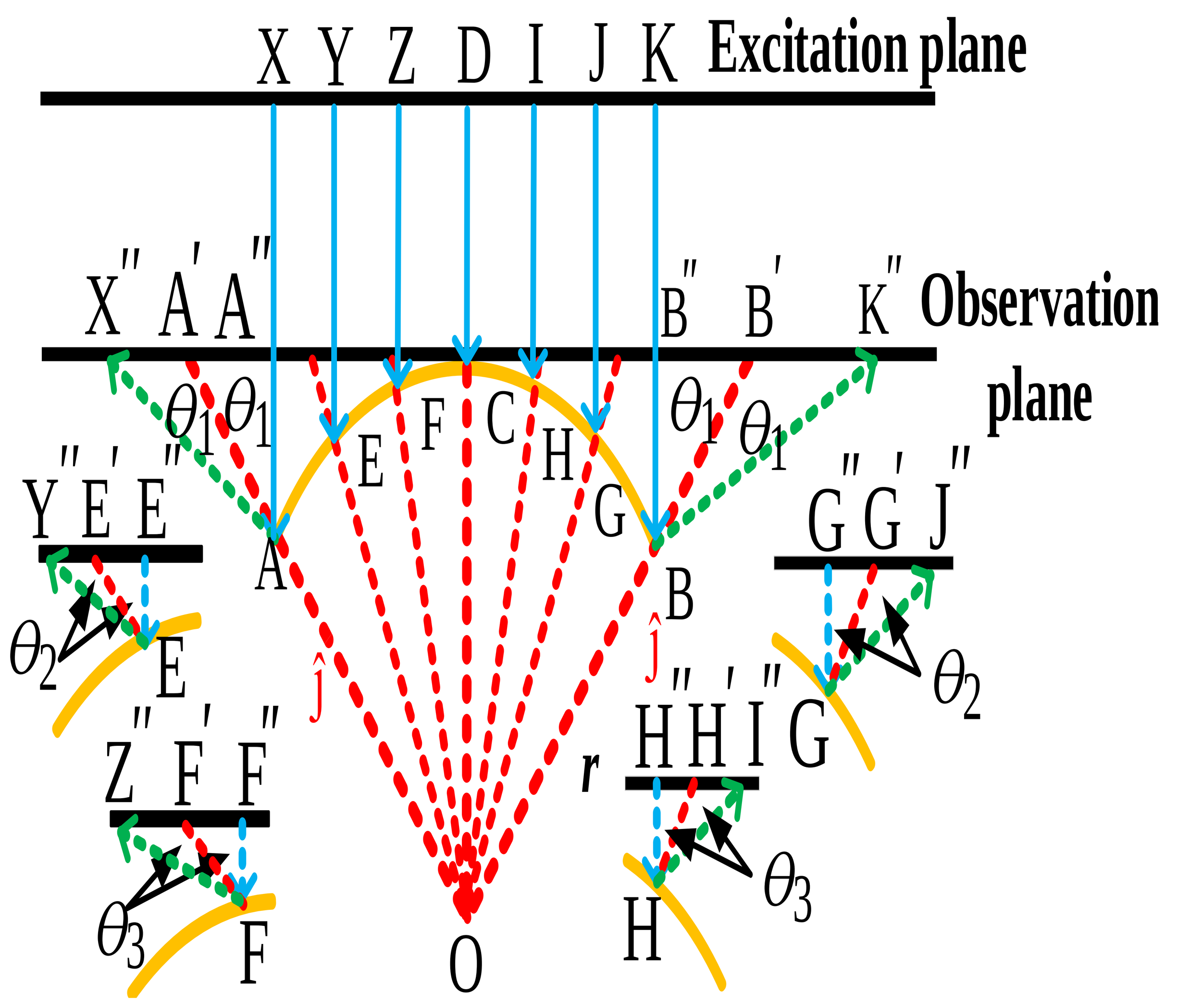
Abstract

- Shift in in-phase reflection frequency of conformal metasurface is determined with geometrical approach
- Analysis of the proposed approach is demonstrated for three types of conformal meta-surfaces
- Faster than full wave analysis to plot reflection phase of conformed meta-surfaces
- Model works equivalently well for both TE and TM mode of EM wave polarization
- The close agreement of measured and calculated reflection phases validates the accuracy of the proposed geometrical approach

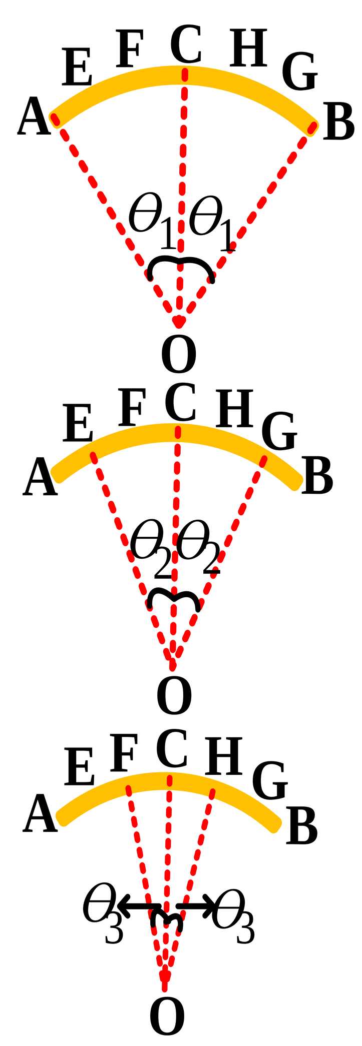
Introduction

- In-phase (0^o) reflection phase of meta-surface enhances radiation properties of antenna.
- The incident and reflected waves meets constructively at the far-field for antenna incorporated with metasurface ground plane.
- Conformability (bendability), an essential attribute of body worn antennas necessitate design of conformal meta-surfaces ➡ shift in in-phase reflection frequency ➡ degradation of antenna performance
- Large meta-surfaces are possible solution to cover the intended band even after bending ➡ overall increased size of antenna ➡ inconsistent with body worn device standards
- Present analytical solutions are complex and works for large antenna arrays
- Proposed approach works well on smaller meta-surface cells and arrays

Proposed Geometrical Approach for Arrays



Computational points on C-array



Angles formed between arcs at the center **O**

Law of Reflection of EM wave at the points: A – B, E – G, F – H

$$\angle A'AX'' = \angle A''AA' = \angle B'BK'' = \angle B''BB' = \theta_1$$

$$\angle E'EY'' = \angle E''EE' = \angle G'GJ'' = \angle G''GG' = \theta_2$$

$$\angle F'FZ'' = \angle F''FF' = \angle H'HI'' = \angle H''HH' = \theta_3$$

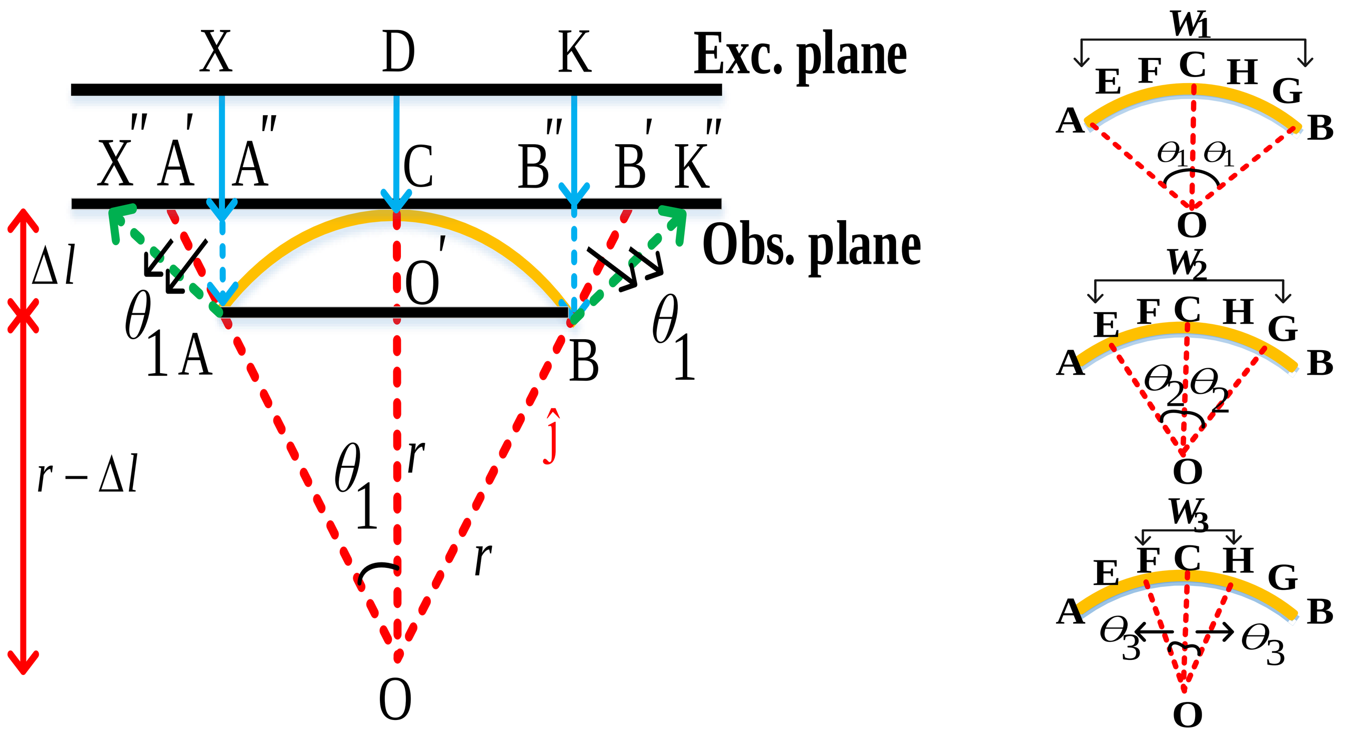
Formula for θ_1, θ_2, and θ_3 and Path Delays Δl_1, Δl_2, and Δl_3

$$W_j = \frac{2\theta_m}{360^o} \times 2\pi r \;\Rightarrow\; 2\theta_m = \frac{W_j \times 360^o}{2\pi r} \qquad (m, j = 1\ldots3)$$

$$\Delta\theta_{\text{incident}} = \beta \times (A''A) = \beta\Delta l \qquad \Delta\theta_{\text{reflected}} = \beta \times AX''$$

$$\cos\left(X''AA''\right) = \cos 2\theta_1 = \frac{\Delta l}{AX''} \;\Rightarrow\; AX'' = \frac{\Delta l}{\cos 2\theta_1}$$

Proposed Geometrical Approach for Arrays



$$\cos\theta_1 = \frac{OO'}{OA} = \frac{r - \Delta l}{r} \;\Rightarrow\; \Delta l = r - r\cos\theta_1$$

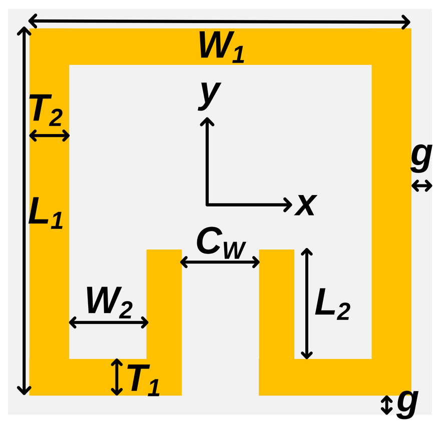
$$\boxed{\Delta l_k = r - r\cos\theta_m} \qquad (k, m = 1\ldots3)$$

Formula for θ_{shift}

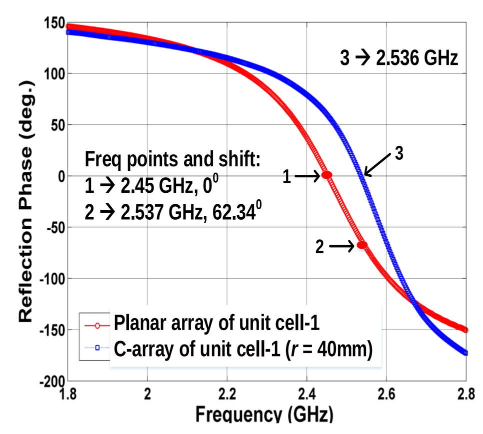
$$\theta_{\text{shift}} = 2\cdot\begin{pmatrix} \Delta\theta_{\text{in}}\big|_A + \Delta\theta_{\text{in}}\big|_E + \Delta\theta_{\text{in}}\big|_F + \\ \Delta\theta_{\text{ref}}\big|_A + \Delta\theta_{\text{ref}}\big|_E + \Delta\theta_{\text{ref}}\big|_F \end{pmatrix}$$

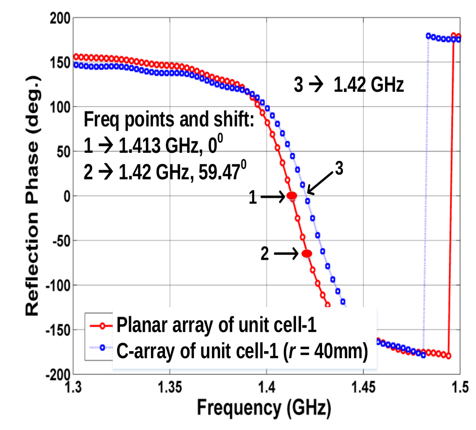
$$\theta_{\text{shift}} = 2\cdot\begin{pmatrix} \beta\Delta l_1 + \beta\Delta l_2 + \beta\Delta l_3 + \\ \dfrac{\beta\Delta l_1}{\cos 2\theta_1} + \dfrac{\beta\Delta l_2}{\cos 2\theta_2} + \dfrac{\beta\Delta l_3}{\cos 2\theta_3} \end{pmatrix}$$

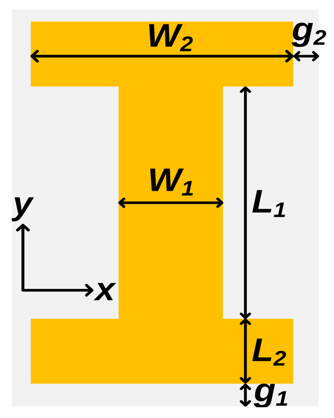
Theoretical, Simulation and Measured Results



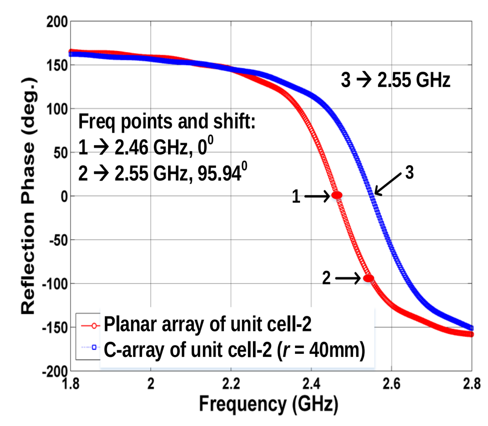
x- and y-pol ➡

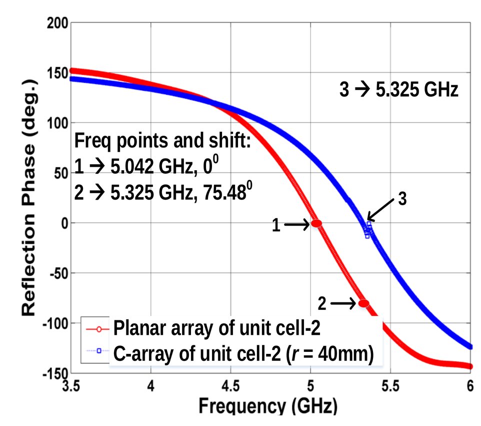


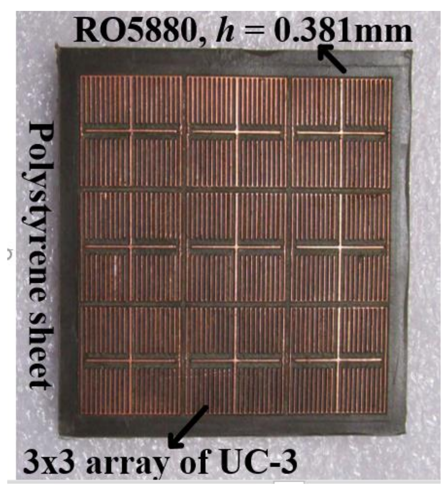


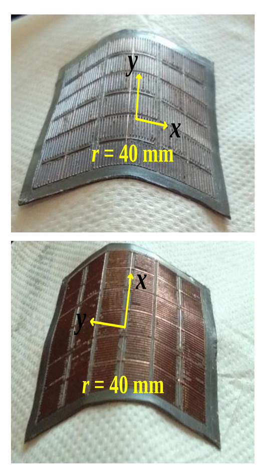


x- and y-pol ➡



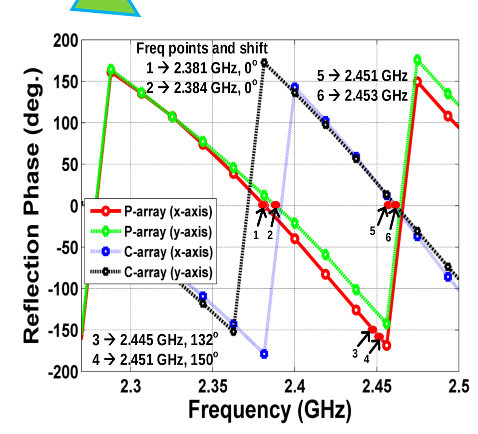


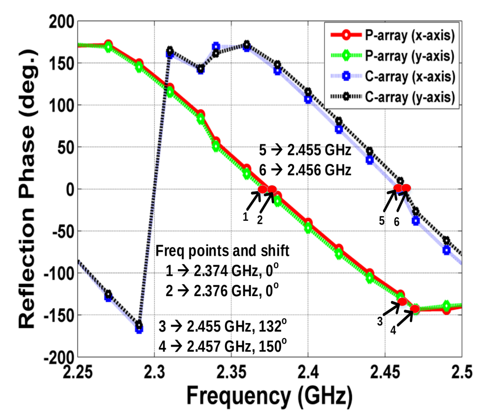




x-pol ➡

y-pol ➡





Conclusion

- Geometrical approach to determine shift in the reflection phase of conformal array is proposed
- Proposed technique makes use of the law of reflection of EM wave at the interface
- Technique is applicable for both the polarization of EM wave i.e. x- and y- and TE and TM polarized waves
- Simulated, theoretical and measured results are in good agreement

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