DESIGN AND FABRICATION OF LOW-PROFILE LOW-COST 3D PRINTED RISLEY PRISM IN THE X-BAND

Member:
Nicholas Koh (Raffles Institution)

Mentors:
Chia Tse Tong, Tay Chai Yan (DSO National Laboratories)

1. Introduction

Beam Steering: a technique for changing the main lobe of a radiation pattern

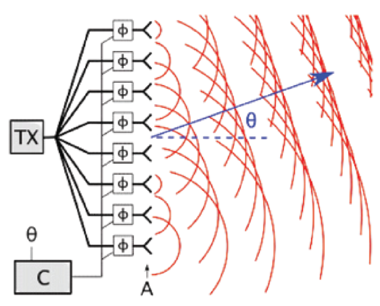
Beam Steering Technology Selection	Motivations for Beam Steering
Cost	Target Tracking
Space	Object Detection
Speed	Satcom

General Approaches to Beam Steering

Electronic

Phased Array
Pros:
- High speed
- Sleek

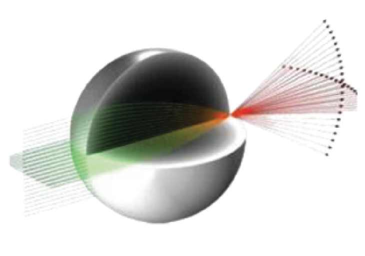
Cons:
- High cost
- Thermal management issues



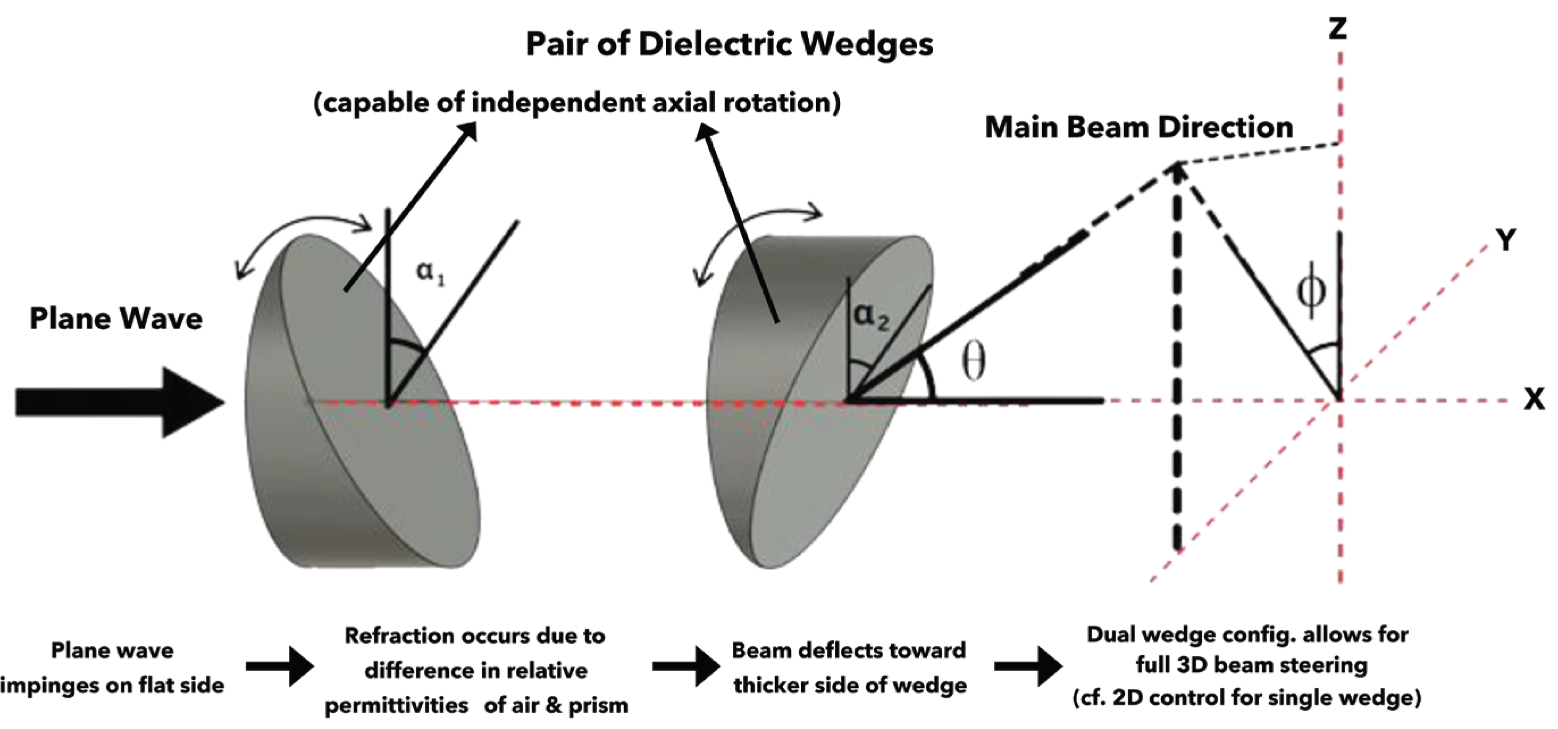
Mechanical

Luneberg Lens
Pros:
- Wide field of view

Cons:
- Spherical shape limits applications



2. Risley Prism



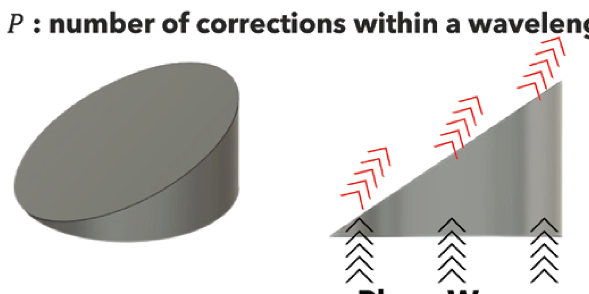
Conventional Risley Prism

Disadvantages:
- High material waste
- Bulky profile

$$d = \frac{\Delta\varphi \cdot \lambda}{2\pi \cdot \sin\theta} \quad (1)$$

$$s = \frac{\lambda}{P(\sqrt{\varepsilon}-1)} \quad (2)$$

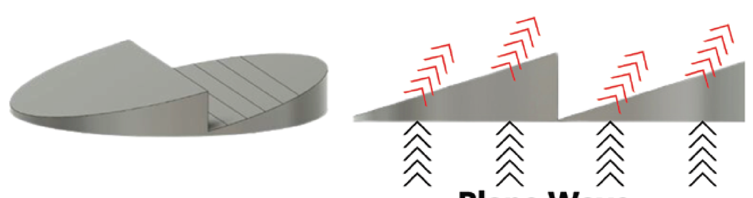
θ : desired beam tilt per lens
d : width of each wedge
$\Delta\varphi$: phase shift
λ : wavelength at desired frequency of 11 GHz
P : number of corrections within a wavelength



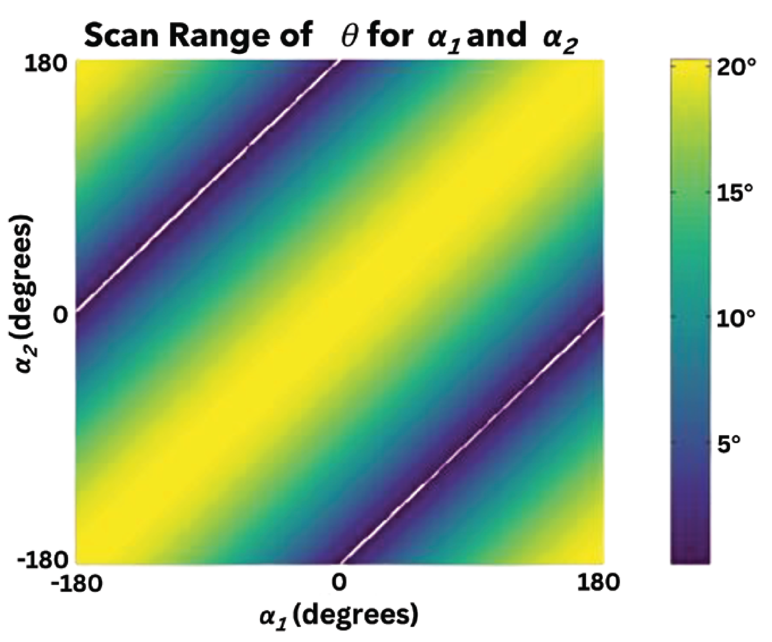
Reduced-profile Risley Prism

Proposed Design:
- Phase wrap every 360°, reduces profile by at least 50%
- Corresponding savings in space and cost
- Uncomplicated design and manufacturing process

PLA
- Relative Permittivity: 2.65
- Loss Tangent: 0.00755 (Extremely Low Energy Loss)
- Affordable and very accessible to many consumers



3. Theoretical Beam Direction



$$\alpha_1 = \phi + \frac{1}{2}\cos^{-1}\left[\frac{(k\sin\theta)^2}{2p^2} - 1\right] \quad (3)$$

$$\alpha_2 = \phi - \frac{1}{2}\cos^{-1}\left[\frac{(k\sin\theta)^2}{2p^2} - 1\right] \quad (4)$$

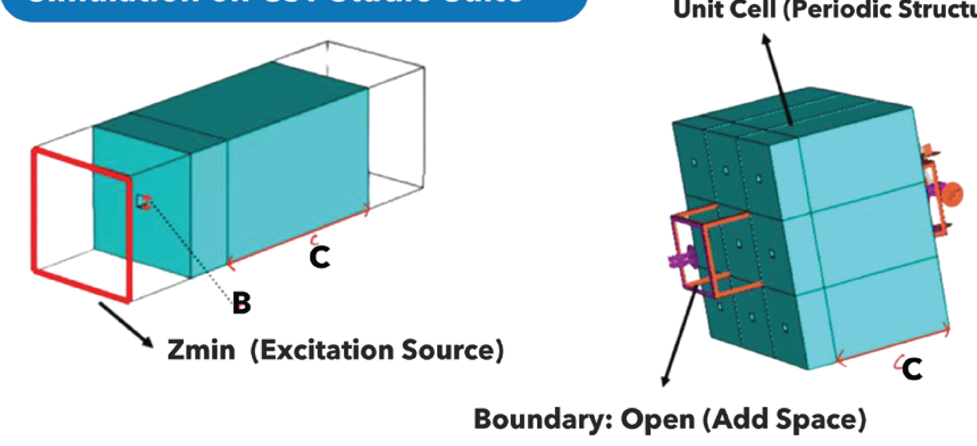
Phase Method
- used to calculate relative rotation of the two Risley prisms α_1 and α_2 for desired beam direction (θ, ϕ)
- p is the phase delay gradient, which is the same for both identical wedges RP1 & RP2

4. Anti-Reflection Coating

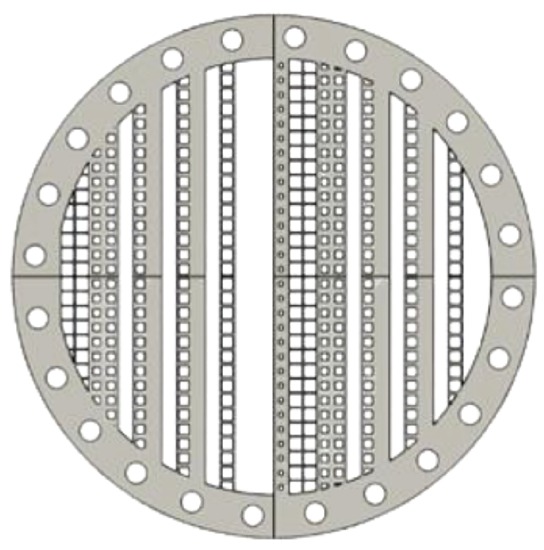
Optimum Relative Permittivity $\varepsilon_{ARC} = \sqrt{\varepsilon_0 \varepsilon_1}$

Optimum Thickness of ARC $t_{ARC} = \frac{\lambda}{4\varepsilon_{ARC}}$

Simulation on CST Studio Suite



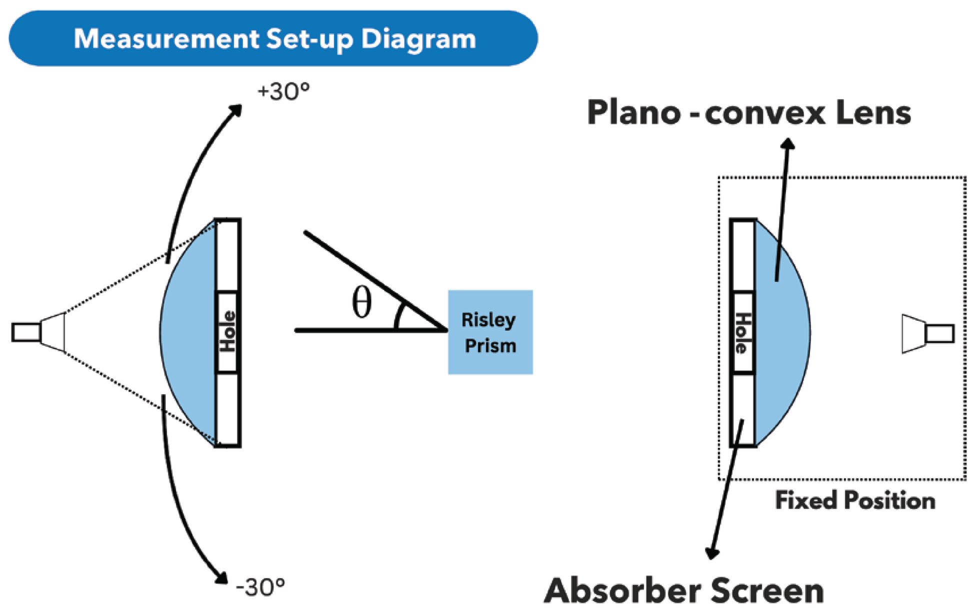
ARC



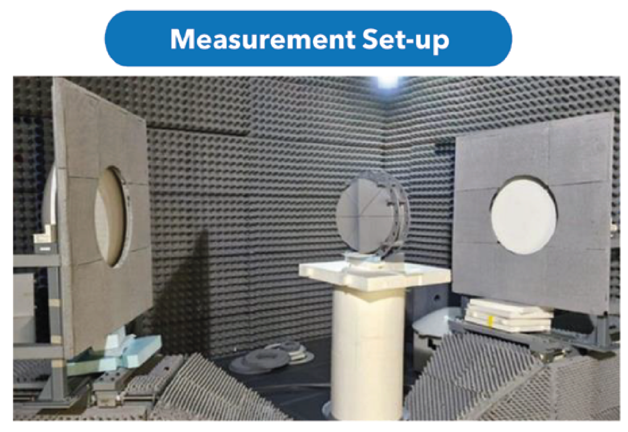
- Variables:
  - Unit cell hole size (B mm)
  - Height of prism above ARC (C mm)
- Aim: To find the optimum hole size at every height of prism above ARC

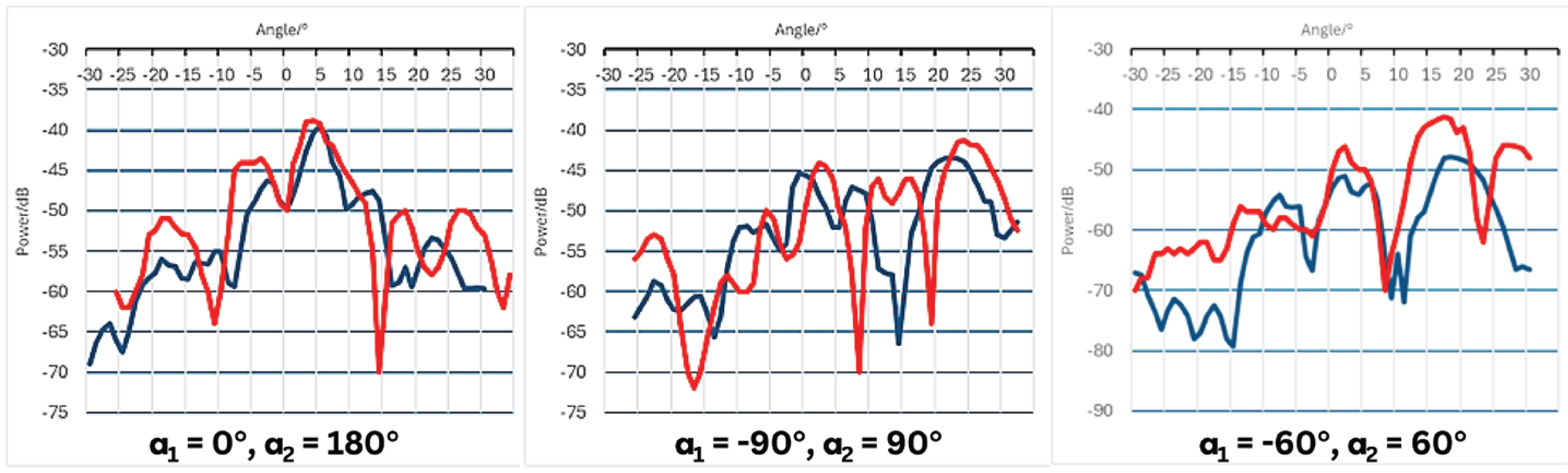
5. Measurement Results

Measurement Set-up Diagram



Measurement Set-up

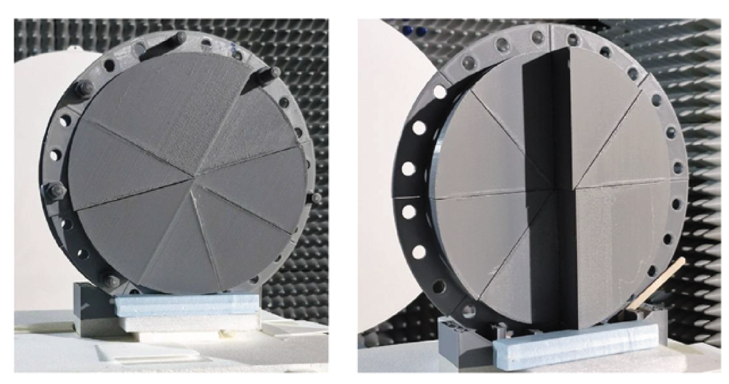




			Without ARC		With ARC	
α_1/°	α_2/°	Expected θ/ °	Measured θ/°	Measured Power/dB	Measured θ/°	Measured power/dB
0	180	0	3	-39.6	-1	-38.8
-90	90	19.9	20	-43.4	20	-43.2
-60	60	17.5	16	-47.9	15	-41.2

6. Conclusions

Proposed Risley Prism
- Reduced profile of regular dielectric wedge by more than half, resulting in space & cost savings
- Achieved maximum scanning angle of 20°
- Measurement agrees with theory (beam direction)
- With ARC, performance improved by up to 14%
- Design can be used in many beam scanning applications, especially when cost, ease of design & manufacturability, and space need to be prioritized



7. Future Work

Further Optimisation
- Other low-loss materials other than PLA such as COC could be explored to enhance the efficiency of the Risley Prism
- The implementation of a uniformly designed ARC could be experimented with to further minimize disruption of steered beam due to minor deviations in theoretical phase shift with the ARC layer