

Dielectric Lens for an H-plane Waveguide Horn Antenna

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Objective

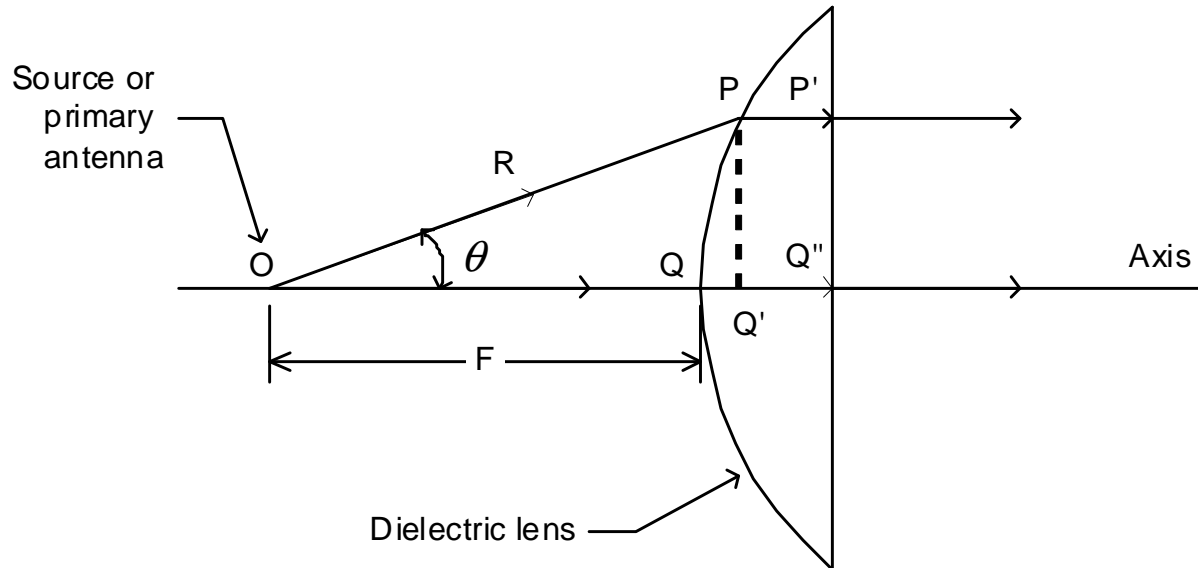
To develop a focusing dielectric lens for an H-plane waveguide horn antenna (X-band) in order to produce a focusing beam at 1 meter distance from the transmitting horn aperture. The dielectric lens will produce a focused beam for the maximum received signal power gain for the H-plane waveguide horn antenna

Basic Lens Design Theory

Single surface refracting lens

Single-surface refracting lens

- Lenses are used as collimating element in microwave antenna
- Dielectric lens is a delay lens, in which the wave velocity is retarded by the lens material
- Contour of a single-surface refracting lens is determined using the principle of equality of electrical path length (Fermat's principle)
- The field over the plane surface can be made everywhere in phase by shaping the lens so that all paths from the source to the plane are of equal electrical length



- Using the Fermat's principle, we got the following equation; $\frac{R}{\lambda_0} = \frac{F}{\lambda_0} + \frac{R \cos \theta - F}{\lambda_d}$

- The above equation can be simplified to

$$R = \frac{(n-1)F}{n \cos \theta - 1} \quad n = \sqrt{\epsilon_r}$$

- Through some algebraic manipulation, the equation can be expressed in Cartesian coordinate, as

$$x^2 (n^2 - 1) + 2F (n-1) x + y^2 = 0$$

Measurement of Complex Permittivity of the Lens Material

Measurement technique

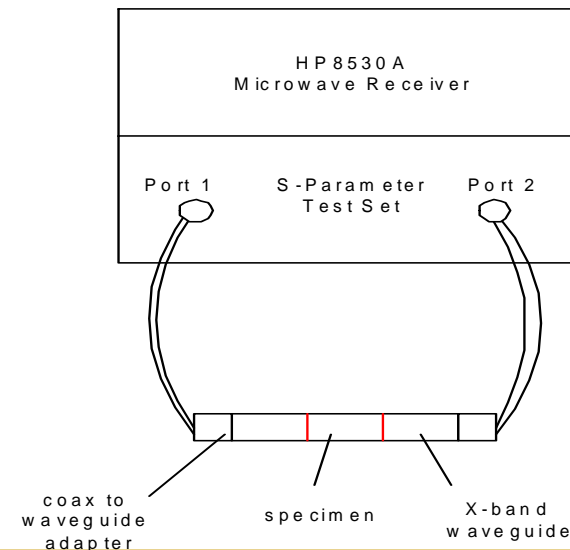
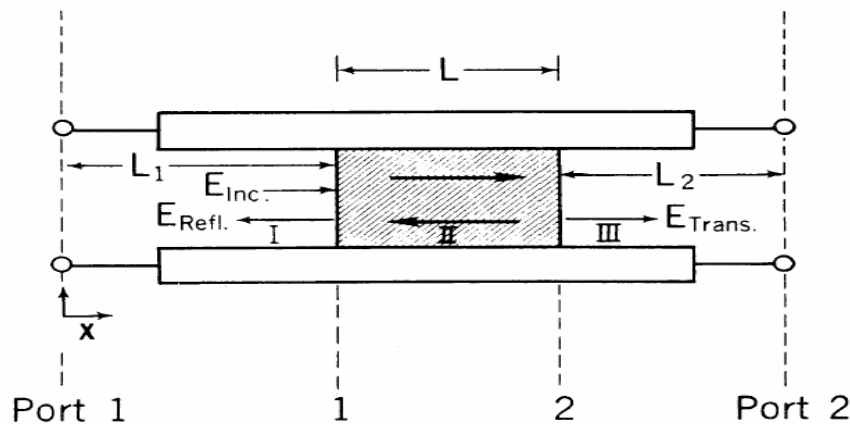
Measurement results

Technique of minimum reflection

Simulation of the measurement

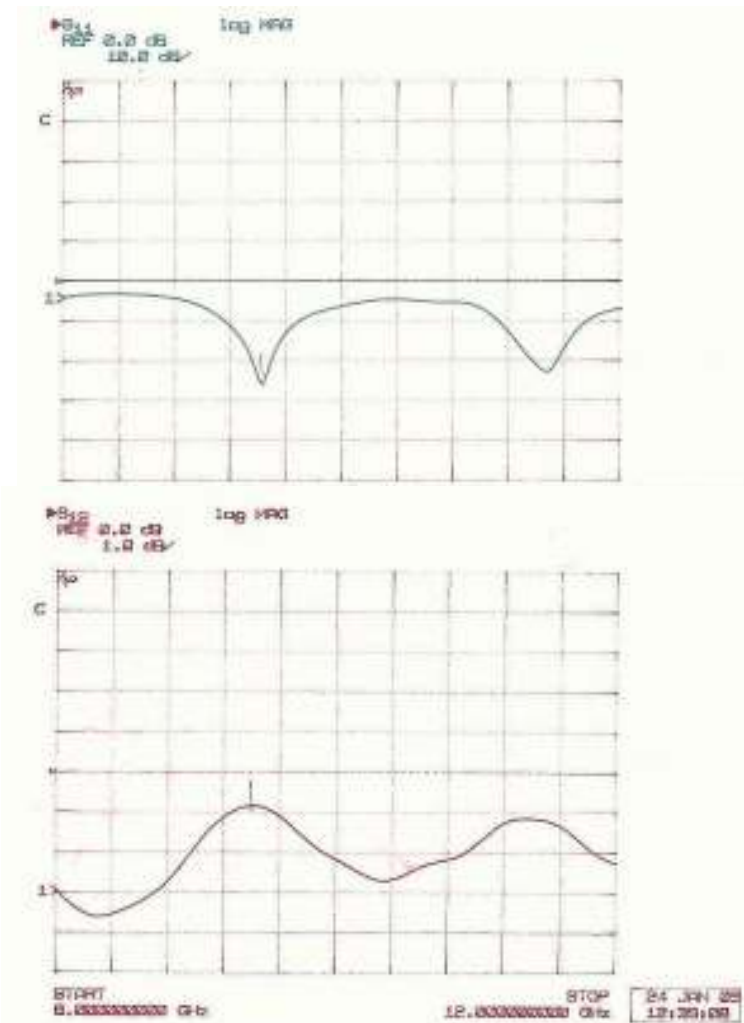
Measurement technique

- Material used: Black high-pressed polyethylene
- Dielectric constant is not precisely known at X-band frequency
- Measurement is done by using transmission/reflection (TR) method
- Measurement apparatus: HP8530A Microwave Receiver, HP8517B S-Parameter Test Set and X-band rectangular waveguide



Measurement results

- Frequencies of minimum reflection and maximum transmission are 9.44 and 11.48 GHz
- Technique of minimum reflection permits quick determination of real value of the permittivity of low-loss material
- This technique will give several value of dielectric constant and these values will be used in the simulation to find the correct one



Magnitude of S11 and S12 over X-band frequency range

Technique of minimum reflection

- The transmission is maximal and the reflection minimal for $L = \frac{n\lambda_{ld}}{2}$

with n is integer, L is the length of the specimen and λ_{ld} is the wavelength in the loaded waveguide, defined as

$$\lambda_{ld} = \frac{\lambda}{\sqrt{\epsilon_r - \left(\frac{\lambda}{2a}\right)^2}}$$

- The value of ϵ_r is extracted from these two equations:

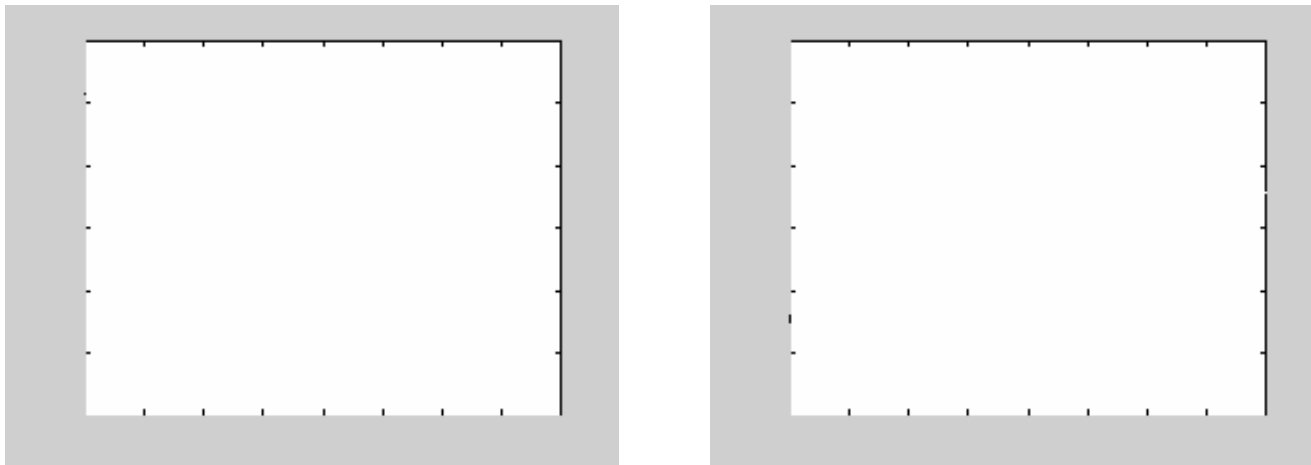
$$\epsilon_r = \lambda^2 \left[\left(\frac{n}{2L}\right)^2 + \left(\frac{1}{2a}\right)^2 \right]$$

- Results from the calculation;

n	ϵ_r (Relative permittivity)
1	0.64
2	1.11
3	1.90
4	3.00

Simulation of the measurement

- The simulation is done to get the exact value of the permittivity of the material
- By using the value of dielectric constant that is calculated before and adjusting the value of the loss tangent in the simulation, the result can be made the same as the measurement result
- Simulation results using dielectric constant 3.00 and loss tangent 0.008;

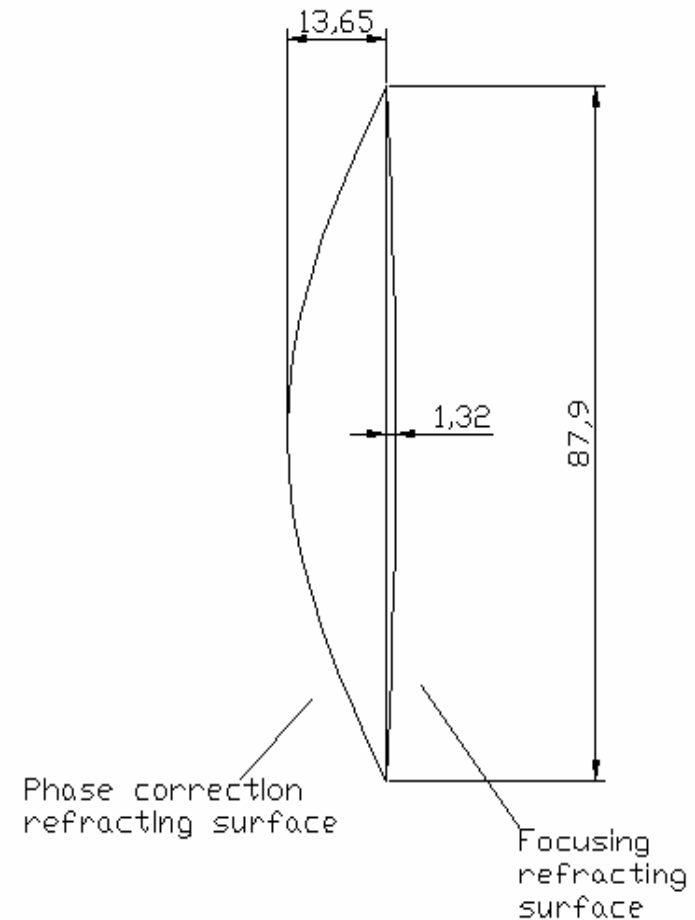


Magnitude of S11 and S12 over X-band frequency range

Focusing Lens Design

Proposed lens design

- 2 refracting, hyperbolic surfaces in the H-plane
- First surface (inside the horn aperture) - phase correction refracting surface to produce plane wave front
- Second surface - focusing refracting surface to produce focusing beam at 1 meter distance
- The lens is designed in the H-plane and then is 'swept' in E-field direction
- The lens contours are calculated using the equation from Basic Lens Design Theory



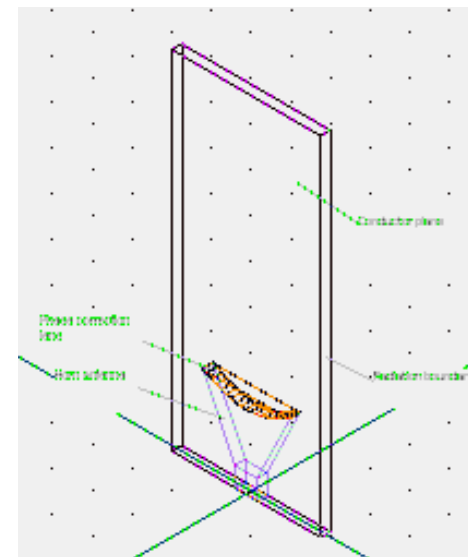
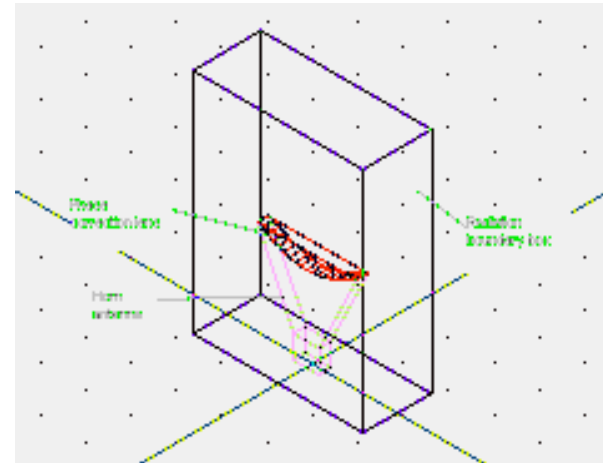
Lens simulation using Agilent HFSS

Phase correction lens simulation

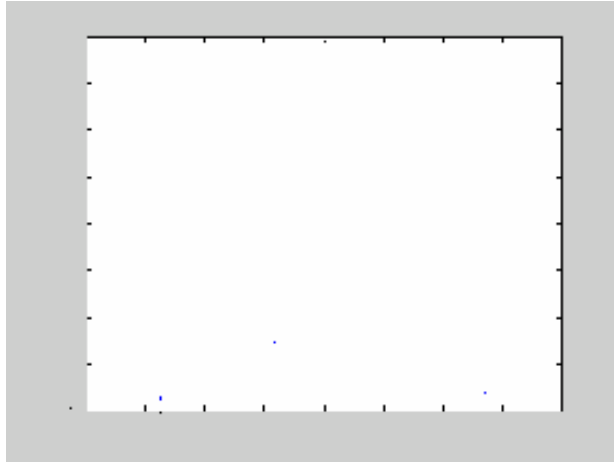
Focusing lens simulation

Phase correction lens simulation

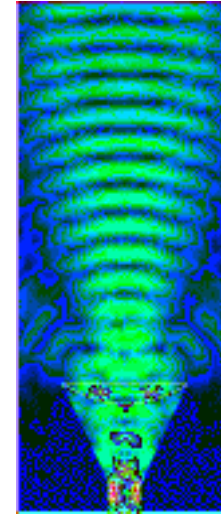
- The purpose of simulation is to optimize the proposed lens design
- Simulation of phase correction lens is divided into 2 categories; far field simulation and field simulation
- Far field simulation gives the far field radiation pattern of the horn antenna and the phase correction lens
- Field simulation will show the H-field distribution of the horn antenna and the lens
- Simulations require proper selection of boundaries, port along with impedance and calibration line to get the accurate results



Simulation results



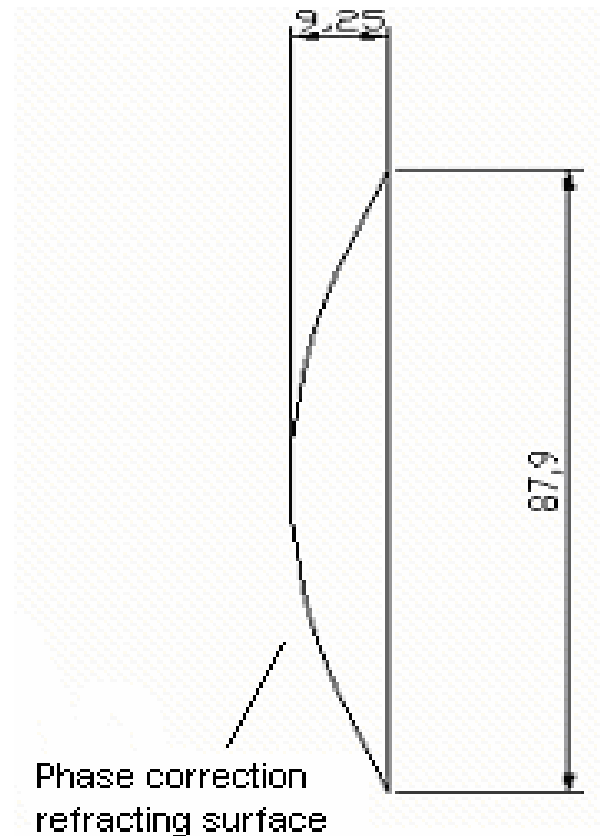
- Far field radiation pattern for the phase correction lens
- Radiation pattern has a wide main lobe



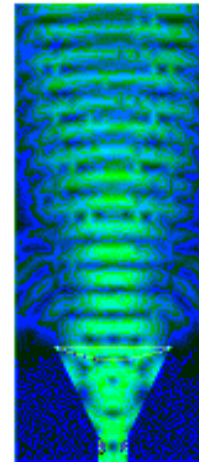
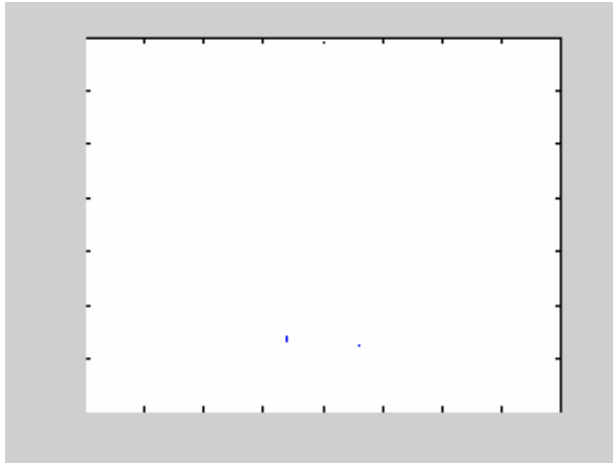
- Magnitude of H-field distribution for the phase correction lens
- There is a focusing of H-field in front of the horn aperture instead of plane wave front

Lens Design Improvement

- Both results show that the lens does not produce plane wave front
- The thickness of the lens need to be reduced to get plane wave front
- New thickness of the lens is given in the following figure



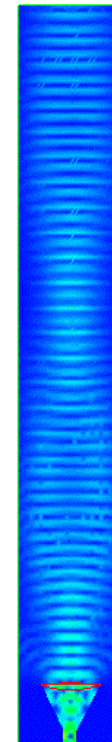
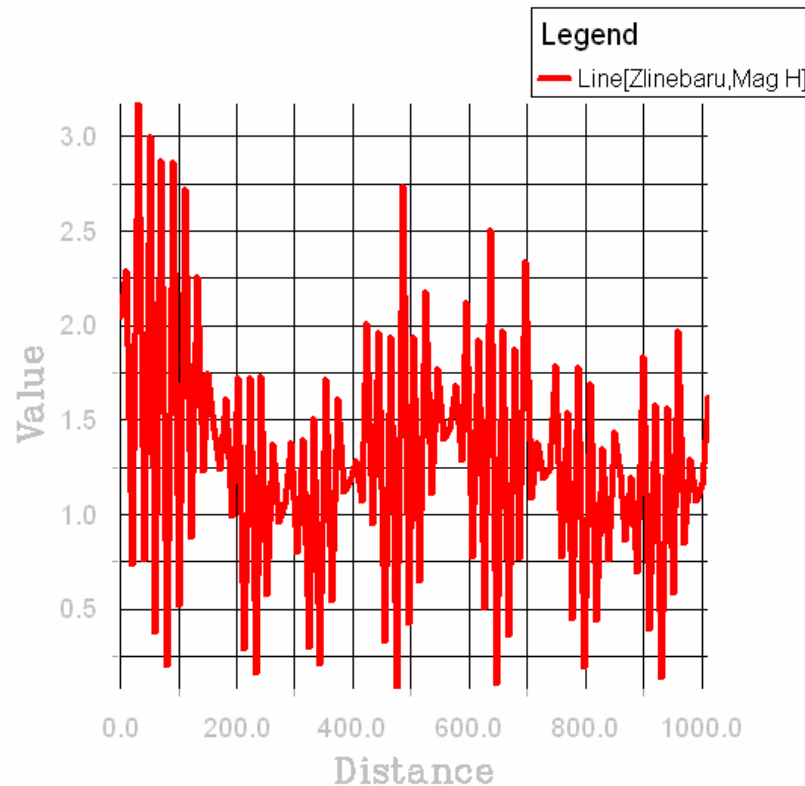
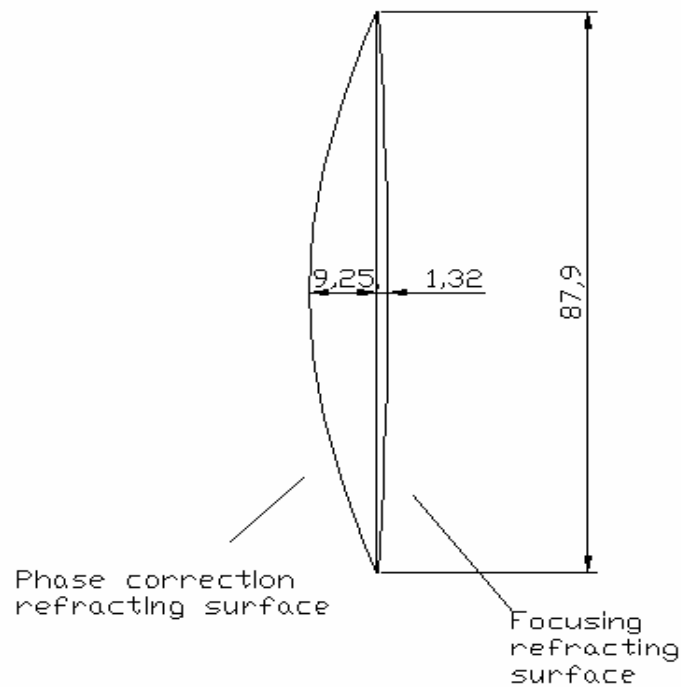
Simulation results for the new phase correction lens



- The far field radiation pattern has a narrower main lobe
- Plane wave front can be seen in front of the radiating horn aperture in the field simulation

Complete Focusing Lens Simulation

- Focusing lens is simulated using the same technique for the phase correction lens field simulation
- Simulation results

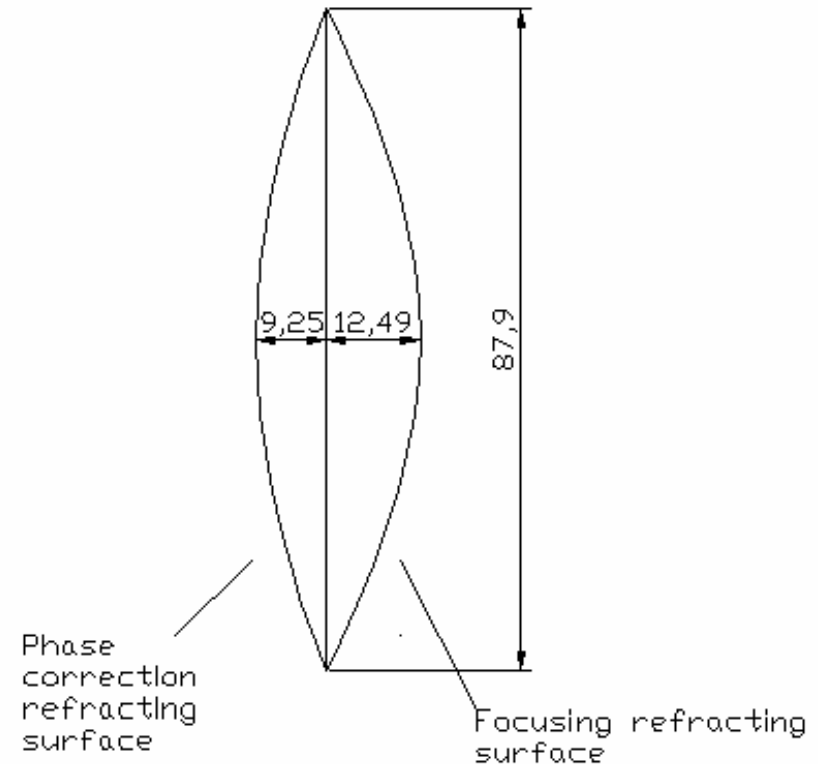


Analysis of the Simulation Results

- The focusing lens field simulation results does not show a focusing beam at 1 m distance
- The primary factor for the failure is the ratio between the radiating aperture, A and the wavelength is very small $A = (2.3 - 3.5)\lambda$
- Focusing distance of 1 m is not realistic for this horn antenna
- New focusing distance of 10 cm is chosen to test the antenna ability to produce a focusing beam

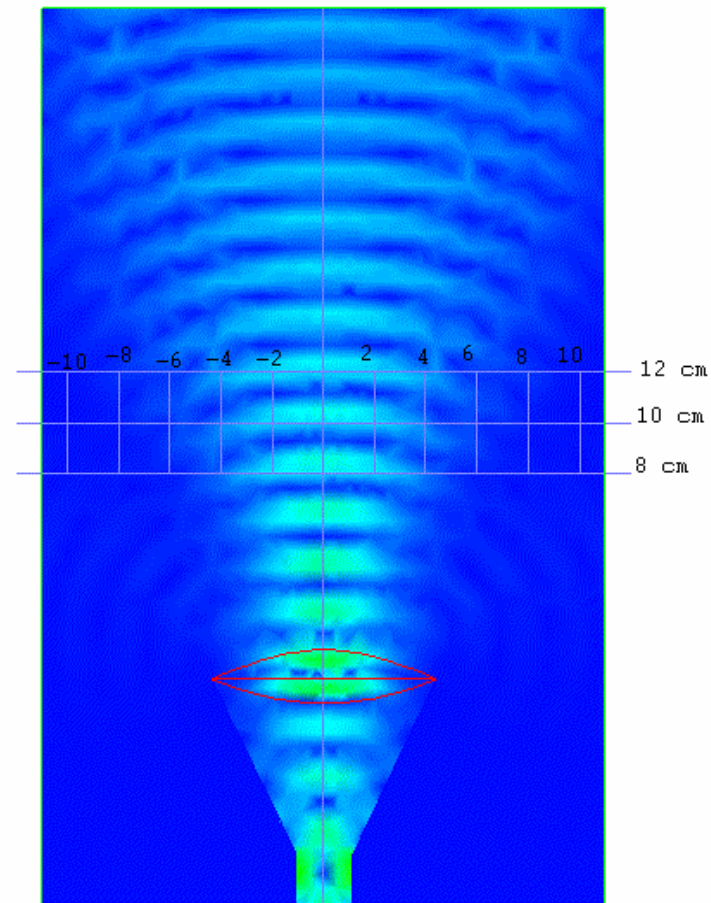
Simulation of dielectric lens with focusing distance of 10 cm

- The new thickness of the focusing lens for 10 cm distance is given in the following figure
- The phase correction refracting surface is the same as before



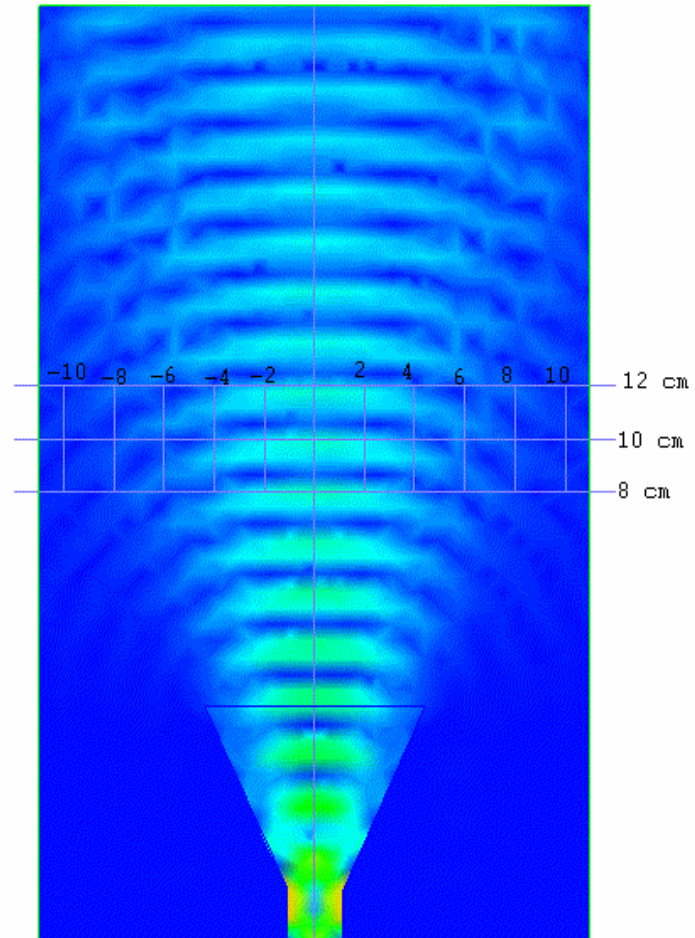
Simulation result

- At 10 cm distance, there is no focusing of H-field
- Simulation indicates higher concentration of H-field at the focal axis
- Higher concentration will increase the power density at the vicinity of focusing point axis



Comparison of simulation result

- Magnitude of H-field distribution of horn antenna without the lens
- Field diverges after the horn aperture
- No concentration of H-field along the focusing distance

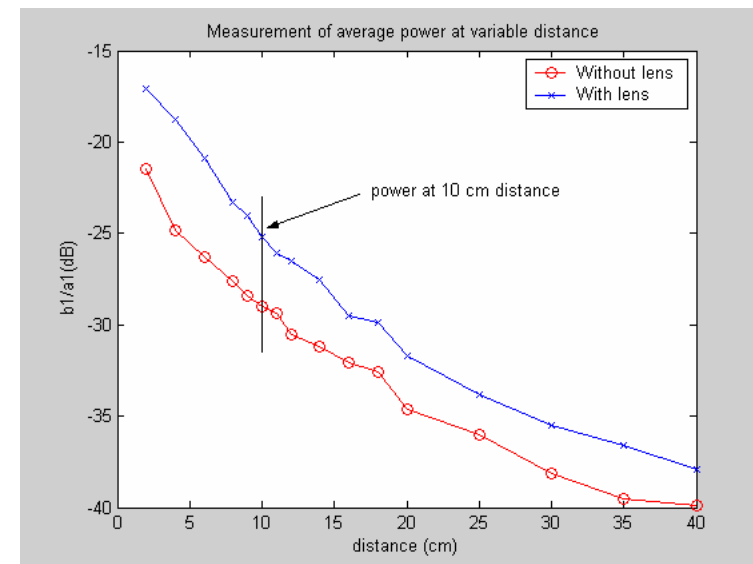
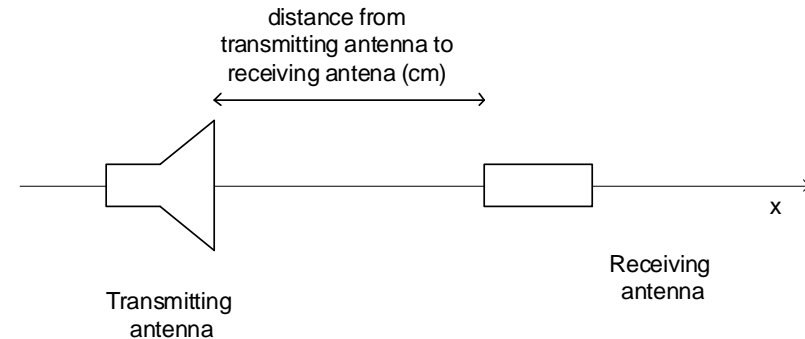


Testing and Measurement

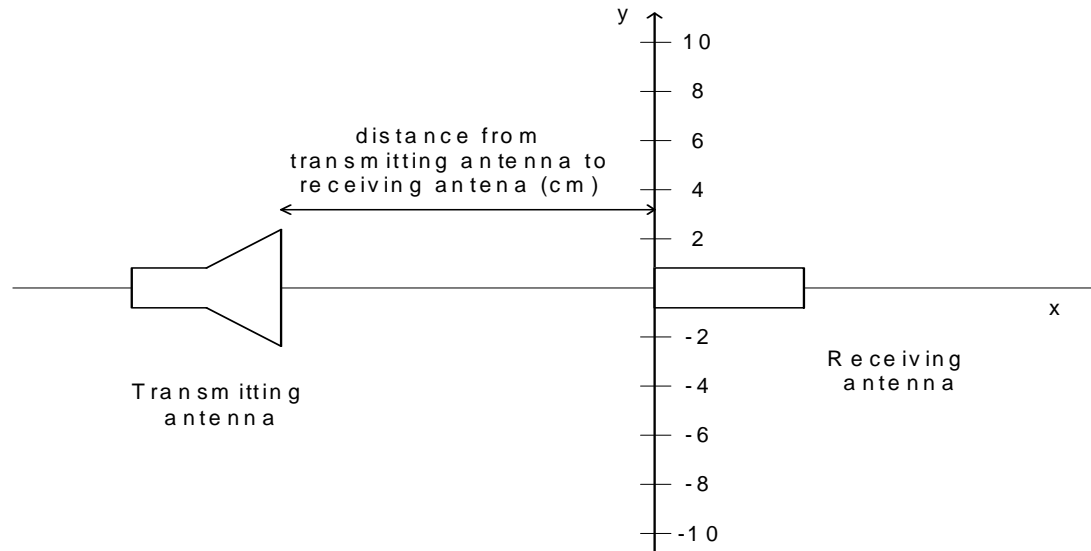
Testing of horn antenna and dielectric lens
with 10 cm focusing distance

Measurement of average received power at variable distance from horn aperture to the receiving antenna

- This measurement is to compare power received by the receiving antenna at variable distance when the H-plane waveguide horn antenna is fitted with focusing lens and without the lens
- Average received power along the distance is higher when the horn antenna is fitted with the focusing lens
- At 10 cm distance, the difference (3.8 dB) is lower than 2, 4, 6, 8, 9 and 12 cm distance
- Only able to confirm higher concentration of H-field along the axis



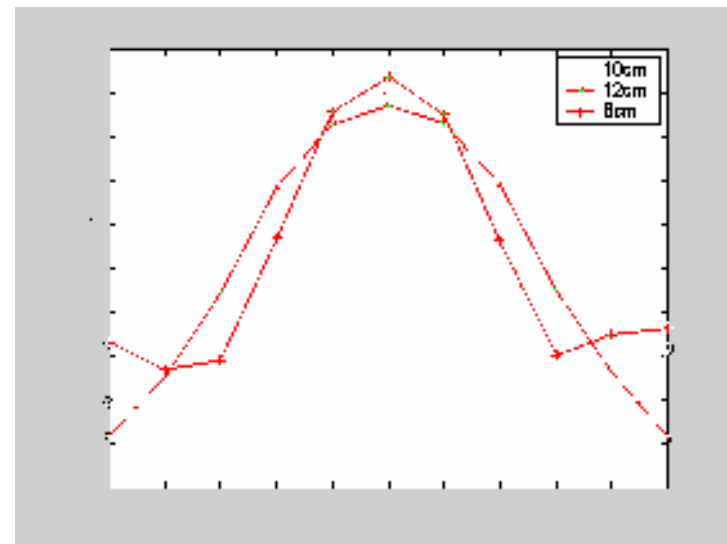
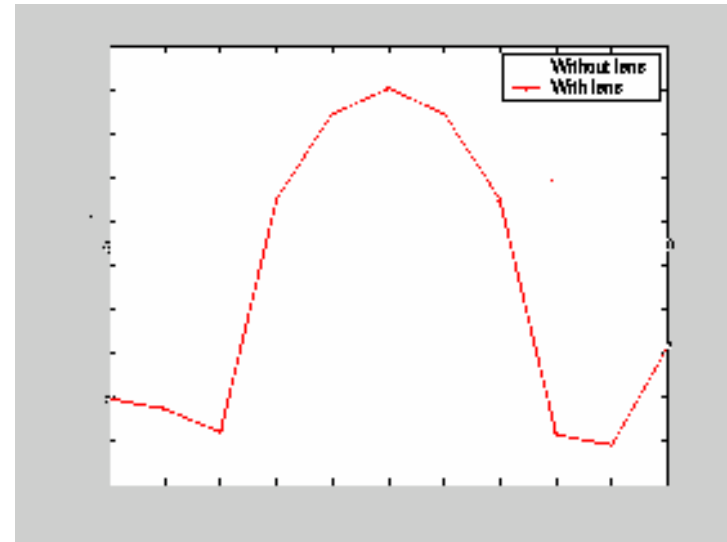
Measurement of average received power at fixed distance of 8, 10 and 12 cm from horn antenna but varies in the H-plane



- This configuration is to measure and compare the average received power by the receiving antenna at fixed distance from the transmitting horn aperture but varies at the H-plane
- For example, the receiving antenna is situated at 10 cm from the transmitting antenna aperture then the receiving antenna is moved horizontally to the left and to the right with the same length

Measurement results

- The first graph shows that average power concentration at 10 cm distance with and without the lens
- The lens produces sharper beamwidth of average power compared to the horn antenna without the lens
- Measurements are also taken at 8 and 12 cm distance from the horn aperture
- The second graph shows the variation of average received power at 8,10 and 12 cm distance when the horn antenna is fitted with the focusing lens.
- 8 cm distance measurement gives a sharper beamwidth than 10 cm and 12 cm distance result
- This result does show conclusively there is no focusing of field at 10 cm distance



Conclusion

- The focusing distance of 1 meter is not feasible for this H-plane waveguide horn antenna
- The antenna is also failed to produce a focusing beam at 10 cm distance based on the simulation and measurement results
- The results can only confirm higher concentration of H-field at the focusing distance when the horn is fitted with the focusing distance
- The failure of the dielectric lens to produce a focusing of H-field at a certain focusing distance is due to the small ratio of the horn aperture with the wavelength
- The aperture of a horn antenna needs to be much higher than the wavelength, if the horn antenna is to be used to produce a focusing beam

End of Presentation

Thank you for your attention
