Analysis of a Patch Array Dielectric Lens Antenna for Mobile Applications

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MBS - Mobile Broadband Systems

- A proposed standard from the International Telecommunication Union (ITU) for a fourth-generation mobile wireless communication system

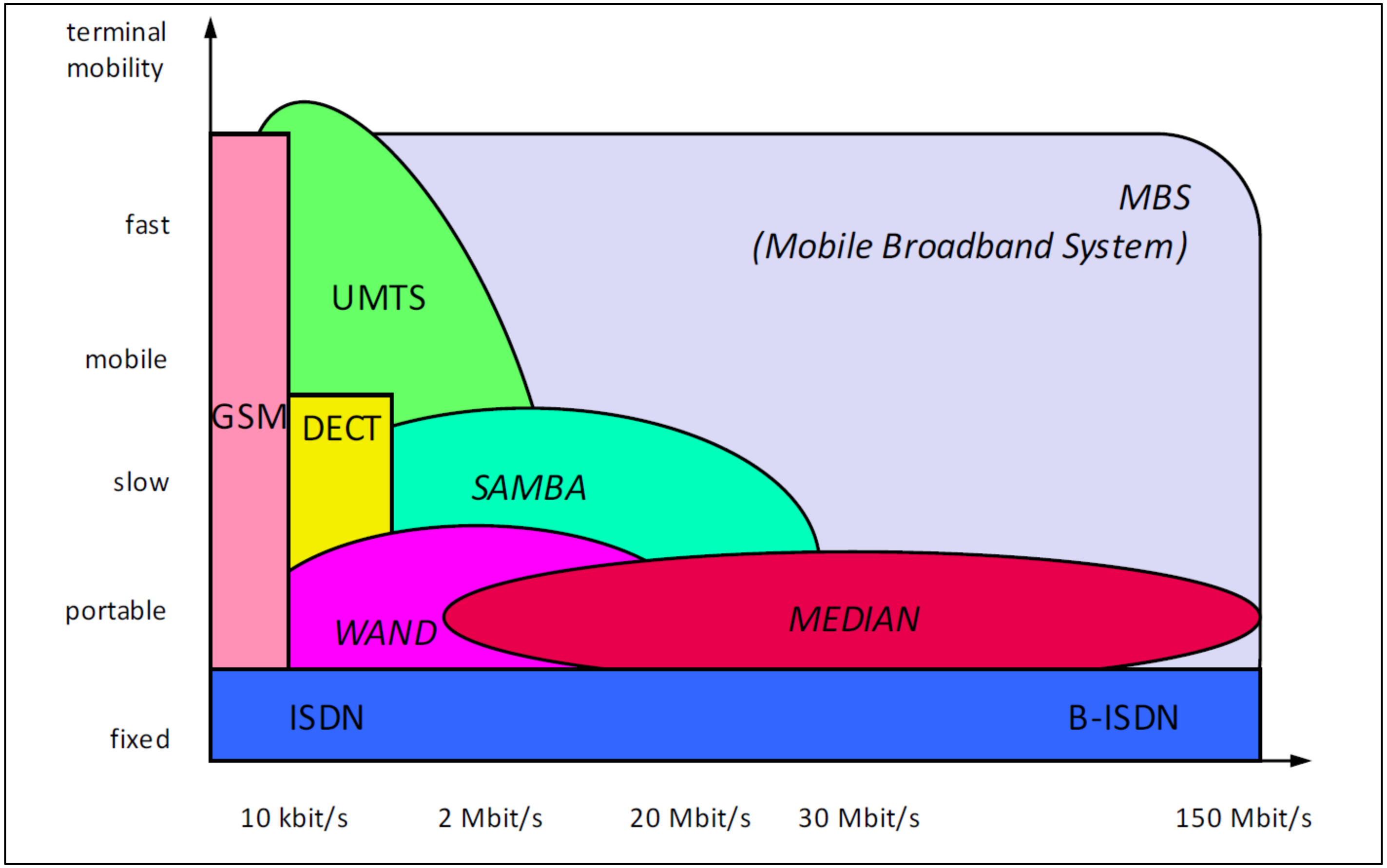
- MBS is a wireless extension to broadband ISDN (B-ISDN) communication

- MBS Bands: 5 -5.2, 11-11.5,20-22,28-30, 50- 52, and 60-64 GHz (Recently opened up)

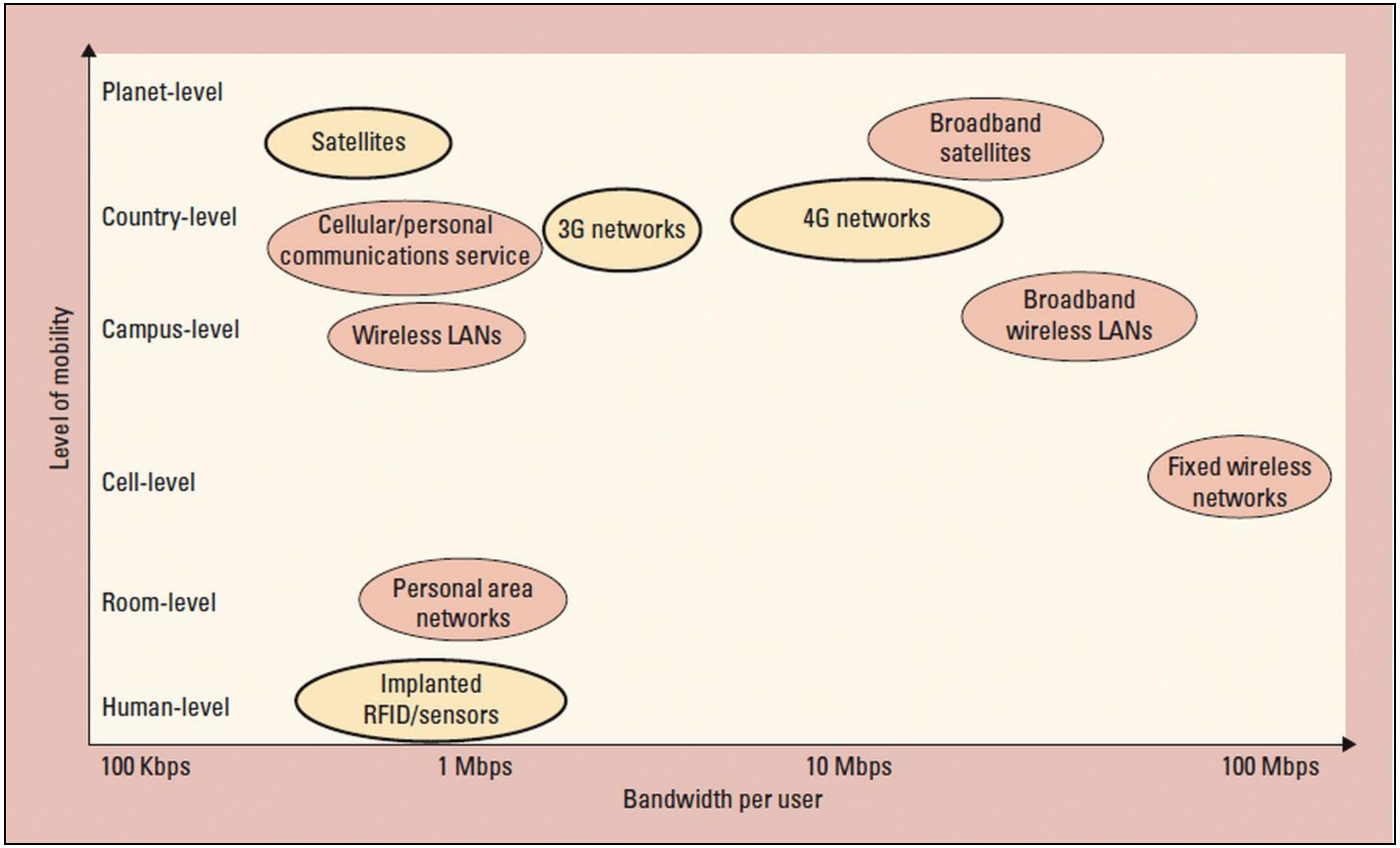
- It extends mobile telecommunications to include broadband communication

- Offers multimegabit data transmission rates of up to 155 Mbps for wireless transmission of multimedia video and audio content.

MBS – Bit rate versus Mobility



MBS – Applications/Mobility/Data Rate



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Antennas Requirements of MBS

- MBS bands of upto 64 GHz implies Millimetre Wave antenna design challenges
- At millimetre waves, antenna losses can be quite high, adversely affecting noise figure and consequently the receiver sensitivity
- At these frequencies, power level that solid state devices can deliver is limited
- The antenna radiation characteristics must not restrict the mobile terminal movement.
- The operating bandwidth of the antenna must be sufficient to accommodate both the transmitting and receiving frequency bands.
- The antenna must be based on affordable technology with viable manufacturing tolerances.

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Dielectric lens antenna

- There is no best antenna solution to cope with all the above said requirements

- Shaped dielectric lens antennas are found to provide an acceptable compromise among the above said conflicting requirements

- Shaped Lens Antennas are cost effective for microwave & millimetre wave bands and offer a good compromise between simplicity and system performance

- Lenses are quite inexpensive, since they can be moulded and have a good fabrication tolerance.

Dielectric lens antenna

- Dielectric lenses can be used for beam shaping and providing a collimation solution.

- Lenses are quite inexpensive, since they can be moulded and have a good fabrication tolerance.

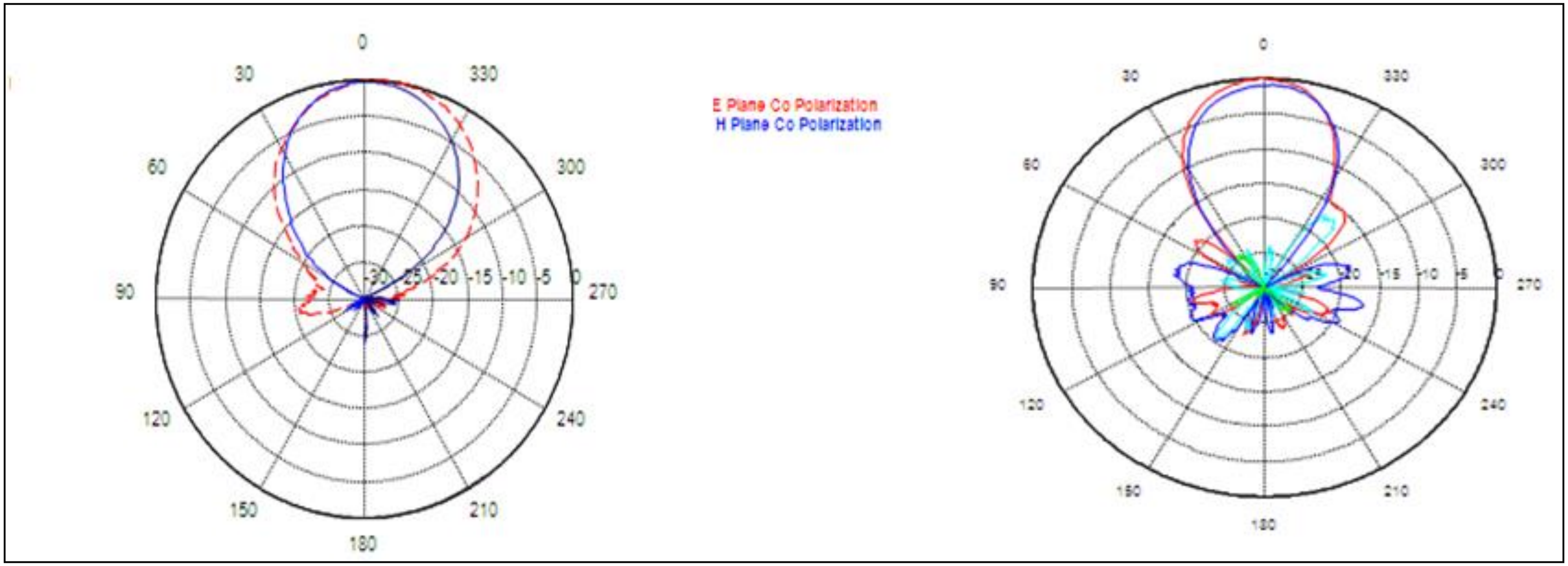
- The feed is located behind the radiating surface and can be easily embedded in the lens to favour wide angle radiation required in most situations.

- Lenses can easily accommodate large bandwidths required by high data rate systems – Inherently Broadband

- Lens solutions are mechanically more robust and also double up as protective radome for primary radiators.

Dielectric lens antenna:

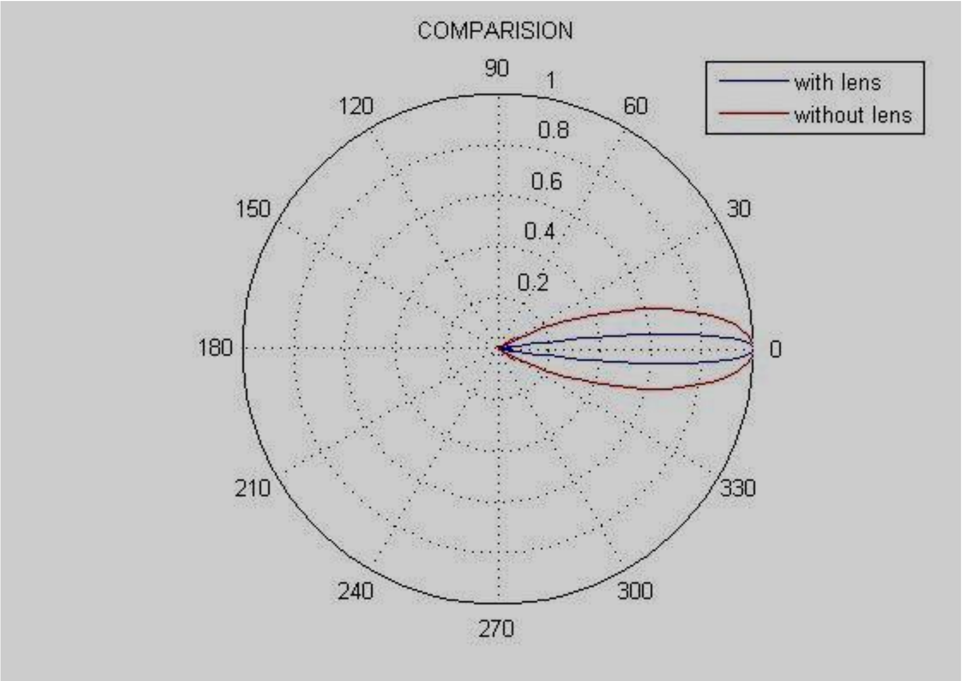
2 x 2 Array Test Patterns: Co-Polarization with and without Lens



Antenna Configuration	Gain in dB
4 element (2x2) array antenna without lens	8.735
4 element (2x2) array with lens	12.6

Dielectric lens antenna:

Lens Collimation



	Without Lens	With Lens
Gain (SGH = 10 dbi)	**6.3 dbi**	**9.4 dbi**
Beam width H – Plane	**102 degrees**	**80 degrees**

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Antenna Analysis Methods

- Integral Equation Method(Current integration over aperture)
- Finite-Difference Time Domain Method
- Finite Element Method
- Ray Tracing Method and Geometrical Theory of Diffraction(GTD)
- Spherical Modal Expansion (SME) Method

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Why SME ?

- Earlier Methods approximate the primary radiators as point sources or Huygens sources, which is not the case in this technique.

- The fields completely surrounding the radiator are reckoned for obtaining the coefficients, hence it has the complete signature of the source.

- Methods like Ray Tracing can explain phenomenon like Reflection and Refraction but, fails to explain scattering ,diffraction etc.

- In these methods Near fields are approximated from the equations of far field

- In SME Near fields can be obtained accurately without any approximations.

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SME Analysis

- The SME analysis involves the following steps in order:

1. Formulation of Primary Radiator Fields
2. Characterization of Fields in terms of Spherical modal complex co-efficient (SMCC)
3. Radial Translation of the SMCC
4. Spatial Rotation of the SMCC
5. Evaluation of the Scattered Fields

The fields Ei and Hi radiated by the patch array at any point P (near or far) in its own coordinate system are given by

$$E_i\left(R^{'},q^{'},f^{'}\right) = S_n\left(a_n\, M^{'}{}_{mn} + b_n\, N^{'}{}_{mn}\right) \qquad (1)$$

$$H_i\left(R^{'},q^{'},f^{'}\right) = (-jY_0)S_n\left(a_n\, M^{'}{}_{mn} + b_n\, N^{'}{}_{mn}\right) \qquad (2)$$

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SME Analysis

Formulation of Primary Radiator Fields

- The fields over an enclosing sphere cantered at the aperture centre is considered and is obtained by aperture field integration

θ: Angle
W: Width of the patch
h: Height of the patch
l_e: Effective length of the patch
K_0: Wave Number

↓

f (θ, W, h, l_e,K_0)

↓

Antenna Fields

SME Analysis

Characterization of Fields in terms of Spherical modal complex co-efficient (SMCC) using Orthogonality Conditions for SVWF

(r, θ, Φ)	Spherical Co-ordinates
Pn	Associated Legendre
dPn	Differential Pn
j_n, n_n	Spherical Bessel Function
m(+ /– 1)	Azimuthal Index
n(1:1:30)	Modal Index

↓

f ((r, θ, Φ), Pn, dPn, j_n, n_n, m, n)

↓

M_{mn} , N_{mn}	The mutually orthogonal TE and TM Spherical Vector Wave Functions (SVWF)

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n(1:1:30)	Modal Index
θ, Φ)	Spherical Co-ordinates

↓

f (M_{mn} , N_{mn},θ, Φ, m, n)

↓

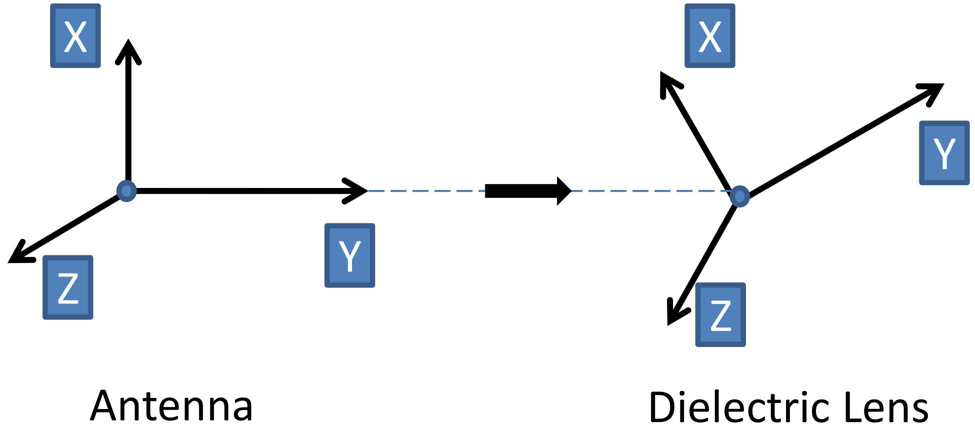
a_n , b_n	Spherecal Modal Complex Co-efficients (SMCC)

SME Analysis

Radial Translation of the SMCC

- The SMCC of the primary radiator are to be translated to the phase center of the dielectric sphere, as it is the reference point for evaluating the fields finally scattered by the lens

- This is accomplished by translation addition theorems and a recursion method of computation



SME Analysis

Radial Translation of the SMCC

- Note that the translated origin may not be spatially aligned to lens coordinate system.

- The translated SMCC A_{tn} and B_{tn} are computed using the expressions below with subscript ‘n’ as the modal index. The index ‘v’ is up to Nmax (function of lens diameter)

$$A_{tn} = \sum_v (a_n A_{vn} + b_n A_{vn})$$

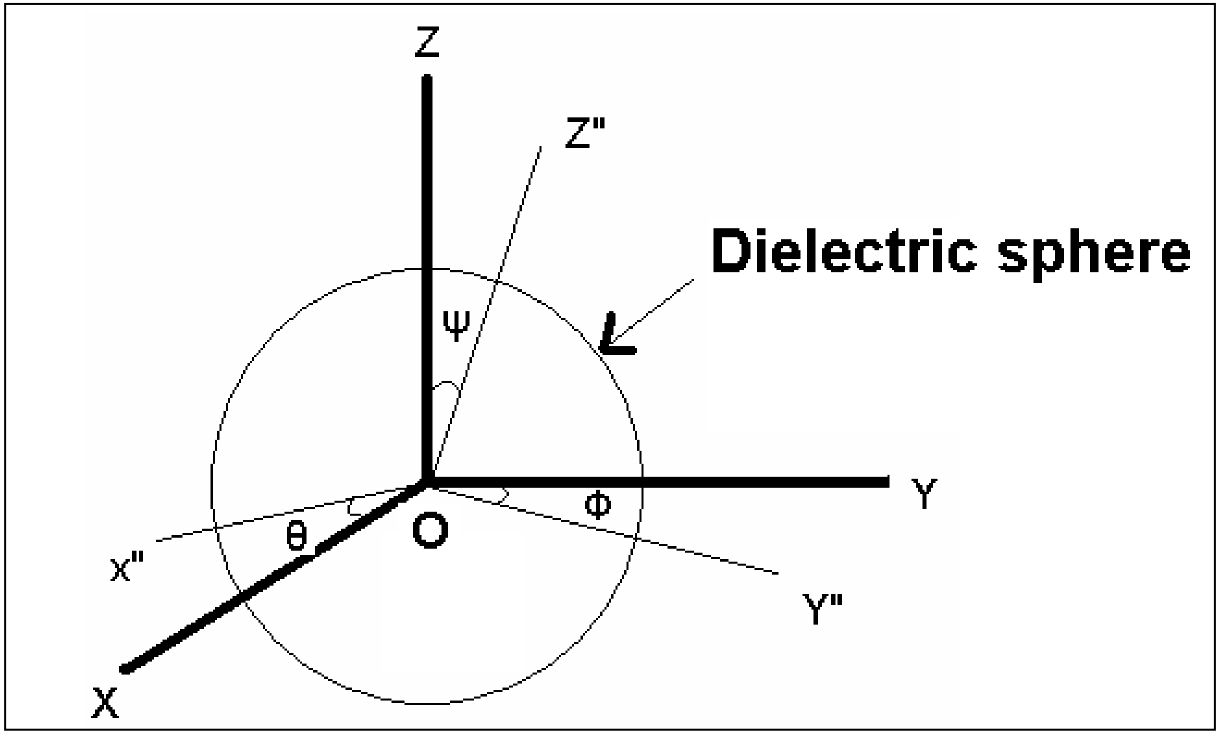
$$B_{tn} = \sum_v (a_n B_{vn} + b_n A_{vn})$$

- After radial translation the field is characterised by the translated SMCC A_{tn} and B_{tn}

SME Analysis

Spatial Rotation of the SMCC

- The translated SMCC are now referred to the lens phase centre coordinate system by performing a spatial rotation.



SME Analysis

Spatial Rotation of the SMCC:

- This is accomplished by $D_{mu}(R)$ the matrix of rotation coefficients.
- This matrix is defined by a set of three Euler's angles(Φ,θ,Ψ) that would align the translated primary radiator coordinate system with the lens phase centre coordinate system
- The primary radiator's translated and rotated coefficients are computed using

$$A_{nm} = \sum_u (A_{tn} \, D^n_{mu}(R))$$

$$B_{nm} = \sum_u (\, B \, D^n_{mu}(R))$$

$$D^n_{mu}(R) = \left(e^{-jm\Phi}\right) * d^n_{mu}(\Theta) * \left(e^{-jm\Psi}\right)$$

'u' is the polarization index and 'm' the azimuthal index. The rotation factors $d^n_{mu}(\Theta)$ are
computed using the recursion relations for Jacobi Polynomials for small values of 'n'

- After Spatial Rotation the field is characterised by rotated SMCC A_{nm} and B_{nm}

SME Analysis

Evaluation of the Scattered Fields

- The dielectric spherical lens in our case acts as a scatterer

- This scattered field can be thought of as the field produced by the currents (conduction and polarization) on the obstacle

- The incident field E_i is now characterized by its SMCC $[A_{mn}, B_{mn}]$ The unknown scattered fields E_s outside the lens and E_d inside the lens are represented by their unknown SMCC $[A_{ns}, B_{ns}]$ and $[A_{nd}, B_{nd}]$ respectively.

$$E_i + E_s = E_d$$

SME Analysis

Evaluation of the Scattered Fields

- Employing the procedure of substitution and application of orthogonality of Spherical vector wave functions (SVWF) we obtain the SMCC $[A_{ns}, B_{ns}]$ and $[A_{nd}, B_{nd}]$

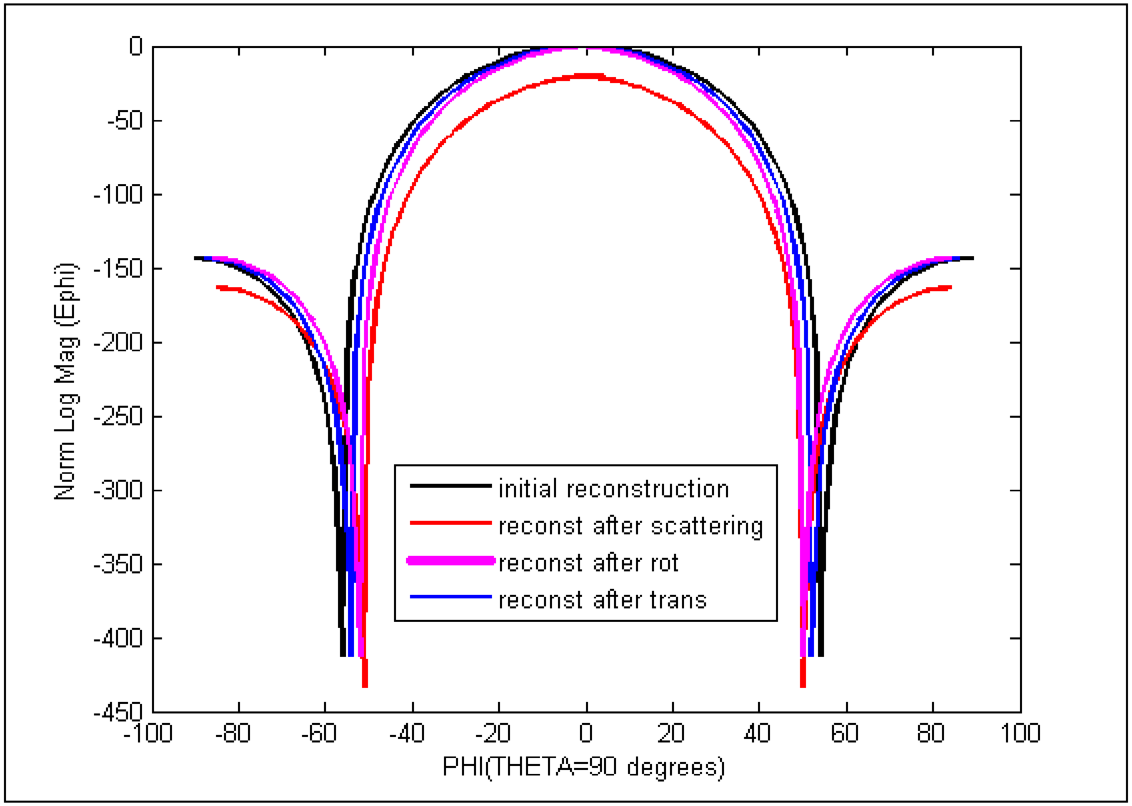
- With all spherical modal coefficients for E_i as $[A_{mn}, B_{mn}]$ and E_s as $[A_{ns}, B_{ns}]$ now known, the total field at any point in space in the near or far field is computed using the Spherical Modal expansion described in (1) and (2).

SME Analysis

Reconstruction of fields using SMCC:

$$E_i\left(R', q', f'\right) = \ S_n(a_n\, M'_{mn} \ + \ b_n\, N'_{mn} \ ) \qquad (1)$$

$$H_i\left(R', q', f'\right) = (-jY_0)S_n(a_n\, M'_{mn} \ + \ b_n\, N'_{mn} \ ) \qquad (2)$$



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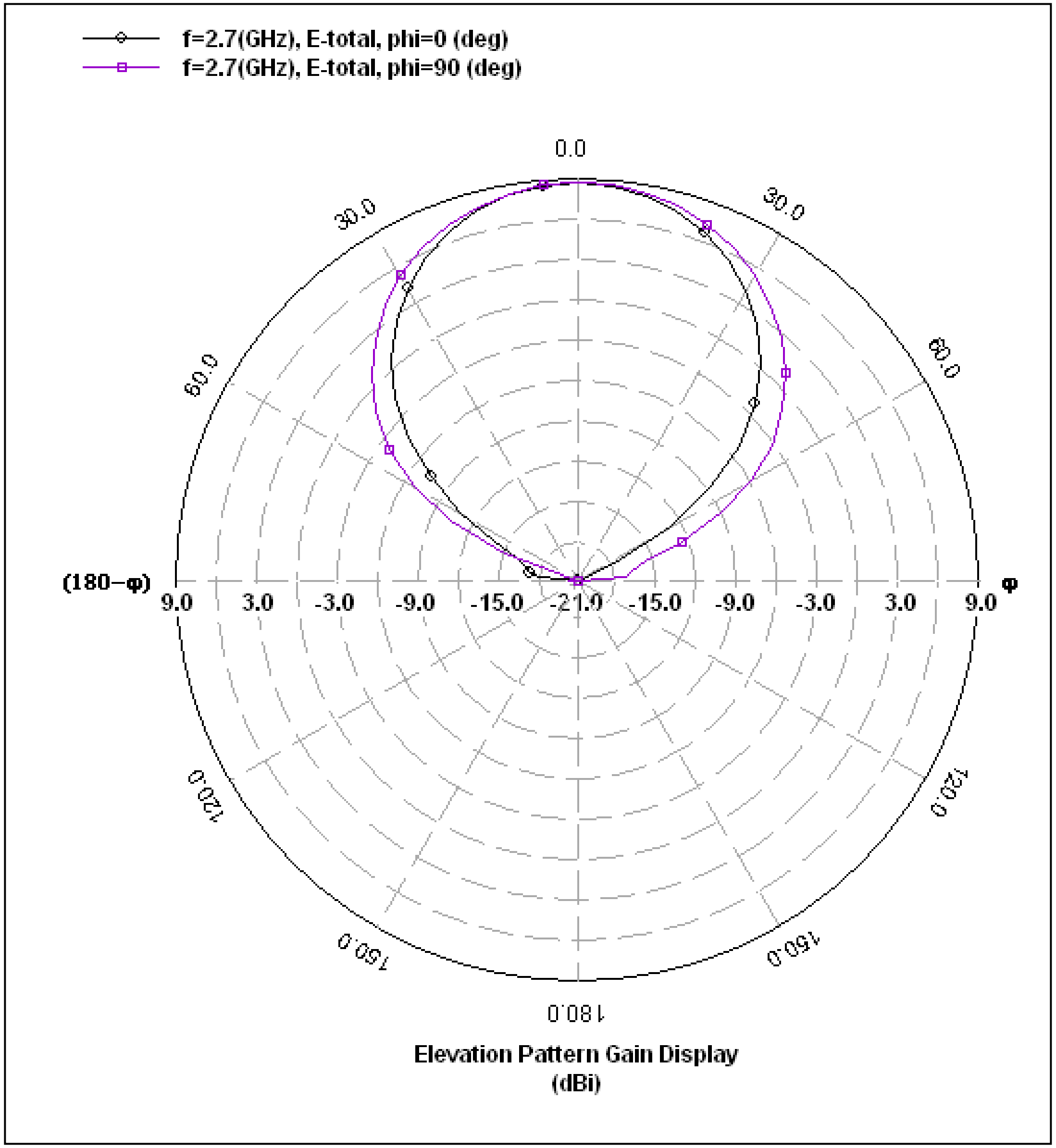
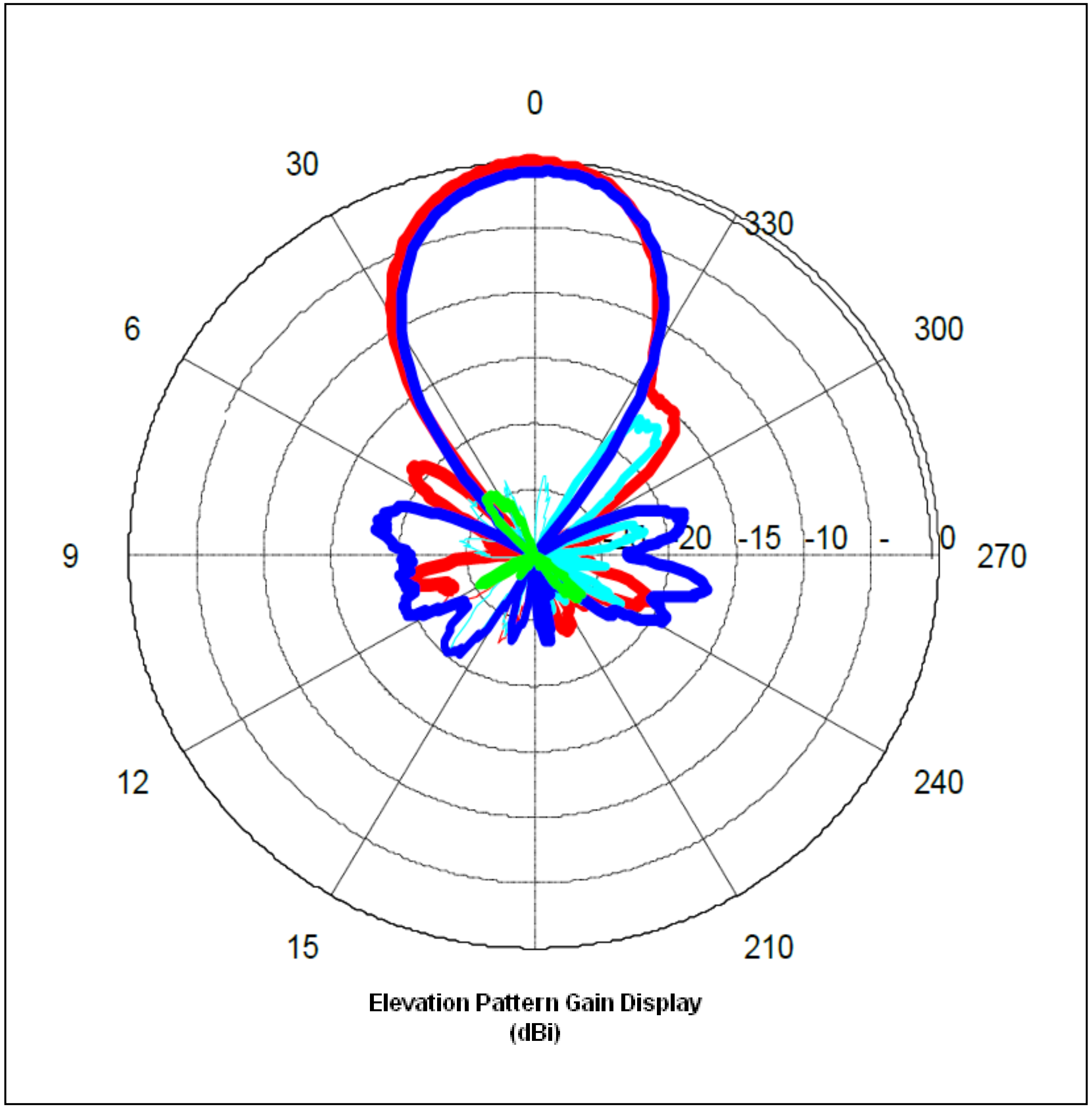
Conclusion

- Field computed using SME for a Rectangular Patch



Conclusion

- Field computed using SME for array lens combination



Questions

Thank You !!!

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