Maximizing the Capacity Performance of Compact Multi-Antenna Platforms

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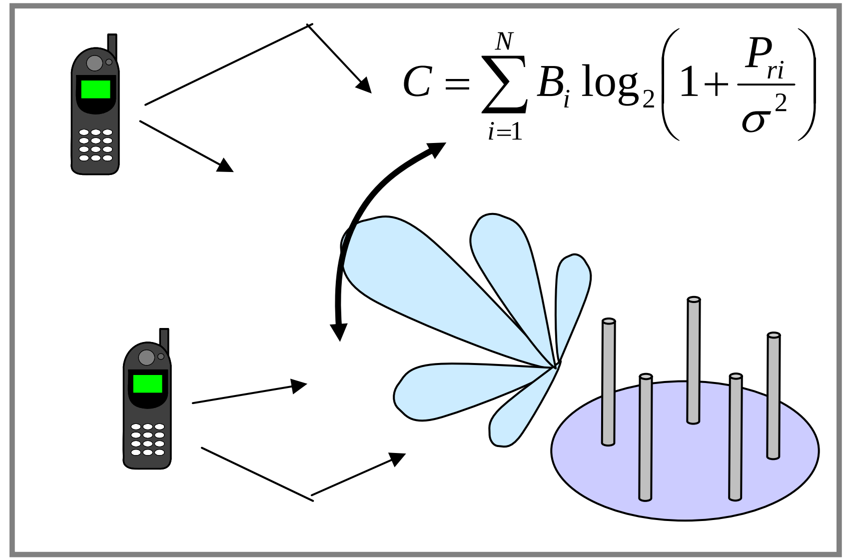
Multi-Antenna Wireless Systems

Smart antennas & MIMO systems

Multiple antenna channels that can be either coherently combined to transmit a greater amount of power or fed individually for the parallelism of information transmission



- How many antennas can fit into a platform with still the benefit of the multiple antenna channels?
- For a given constraint of the platform size, what eventually limits the capacity throughput?
- Is there any way one can go beyond the limit?

Parallel Channels in Multi-Antenna Systems

- In the traditional Smart Antenna or MIMO system setup, the information port is attached to each antenna
- At small antenna element spacing, mutual coupling and spatial correlation may reduce the capacity significantly
- The radiation platform size limits the number of antennas in practice or because of the spacing requirement of the antenna elements
  - Spatial Diversity
    - space required, ex: λ/2
  - Polarization Diversity & field Diversity
    - 2001 Nature, Andrew et al: 6-fold cap. from 3 e-dipoles & 3 m-dipoles
  - Pattern Diversity - a much more general concept, including the above two

- Use the orthogonal radiation modes as the parallel information channels, assuming they can be independently excited

Pattern Orthogonality & Parallel Channels

If $f^{(p)}(\theta,\phi), f^{(q)}(\theta,\phi)$ are the patterns of the *p*th and the *q*th modes,

Orthogonality: $\oiint f^{(p)}(\theta,\phi) \bullet f^{(q)}(\theta,\phi)^* d\Omega = 0 \text{ when } p \neq q$

Mutual coupling free

$$\mathrm{Re}\{Z_{pq}\} = \mathrm{Re}\{\frac{1}{\eta}\oiint f^{(p)}(\Omega) \bullet f^{(q)}(\Omega)^* d\Omega\}$$

- There is no real power exchange in the radiation
- Radiation pattern from each mode is addable
- Constructive combination in some directions can enhance the gain
- Supergain beamforming possible

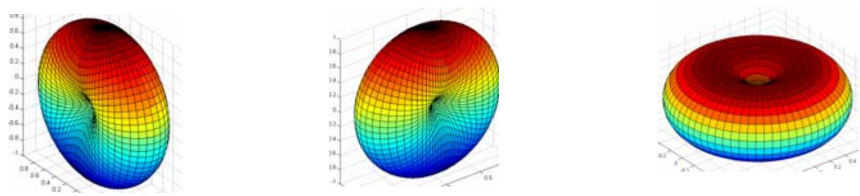
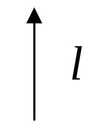
Zero spatial correlation @ full angular spread

$$\rho = \oiint S(\Omega) f^{(p)}(\Omega) \bullet f^{(q)}(\Omega)^* d\Omega$$

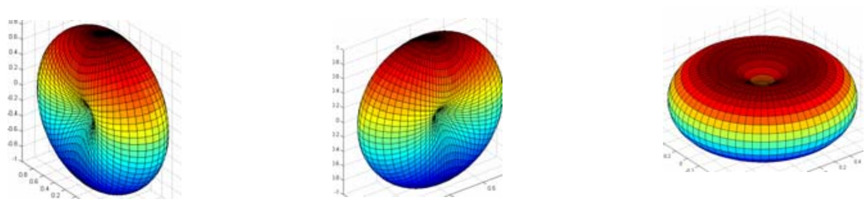
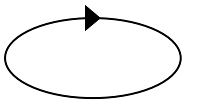
- Can be used to carry independent, uncorrelated information channels
- Capacity approaches to uncorrelated case @full angular spread
- Concept of pattern diversity

Patterns of the Multipolar Modes

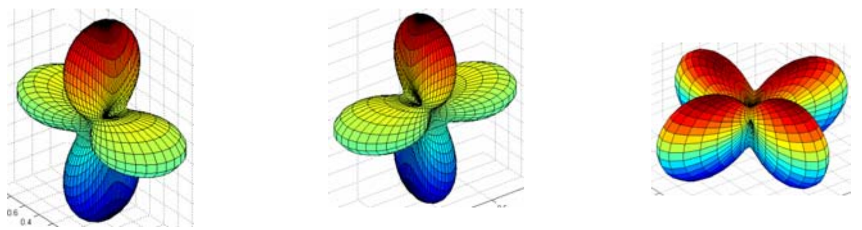
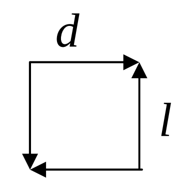
- ***Electric Dipoles***

- ***Magnetic Dipoles***

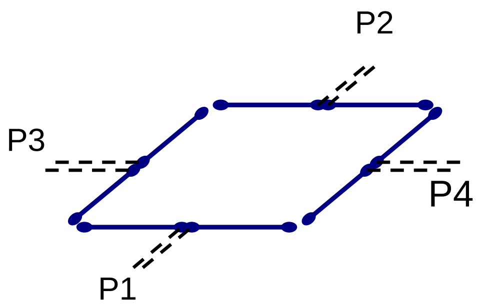
- ***Electric Quadrupoles***

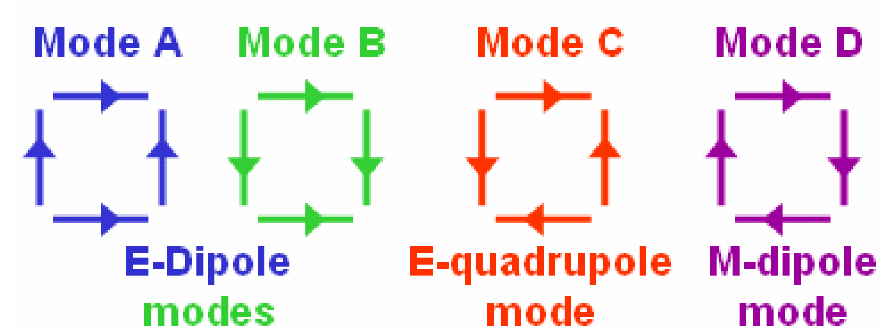



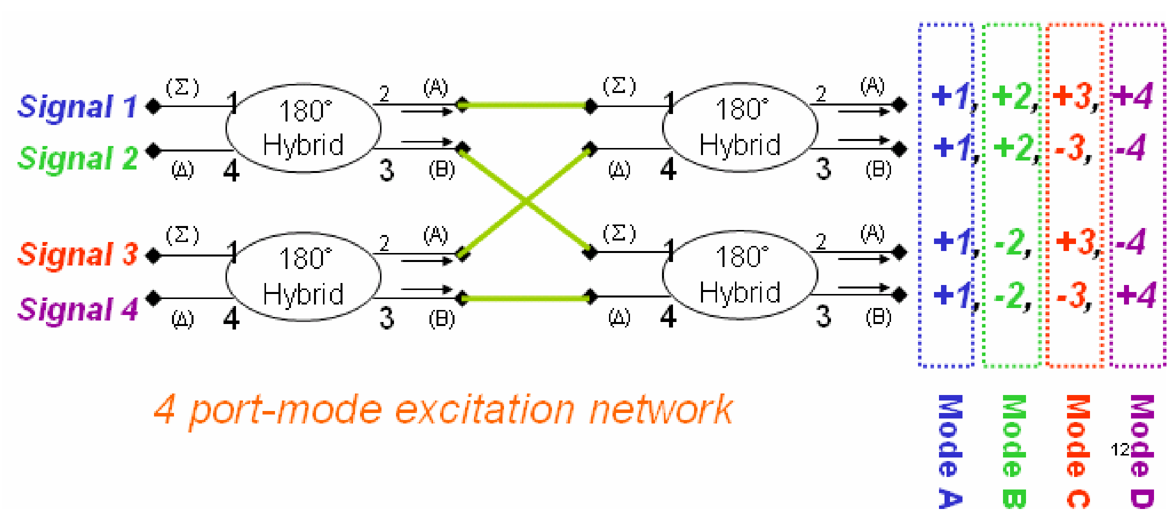
It is difficult in general to co-locate several antennas with different patterns, however, a coupled antenna system can be used to generate multiple radiation modes under certain excitations fed by a mode decomposition network

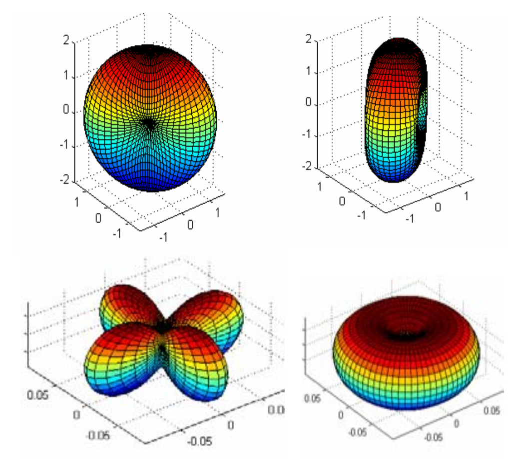
A Planar Version of Multipolar Antennas

- Dipole Square (4 elements)

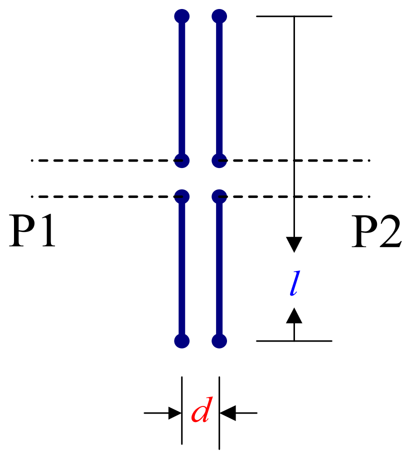


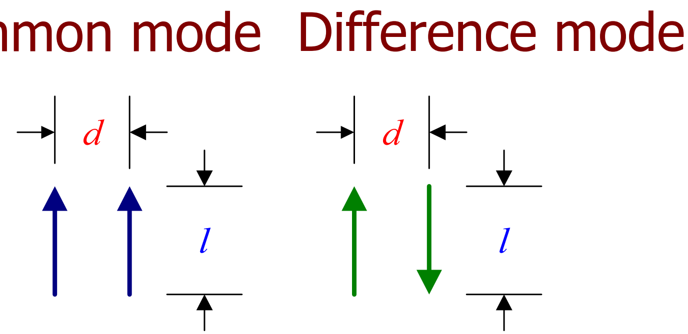






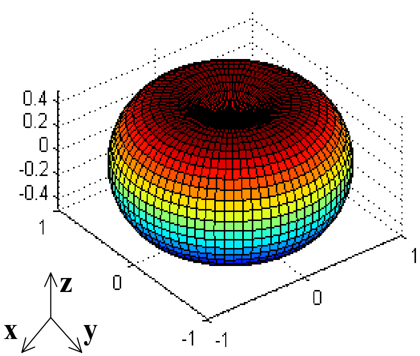
Parallel Coupled Dipoles



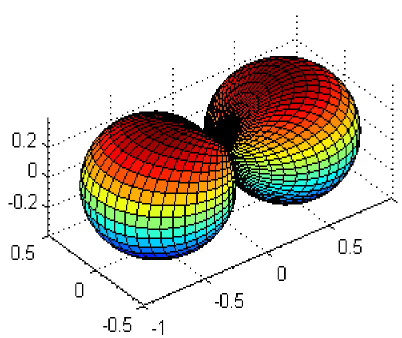


Excitation

Common Mode



Difference Mode

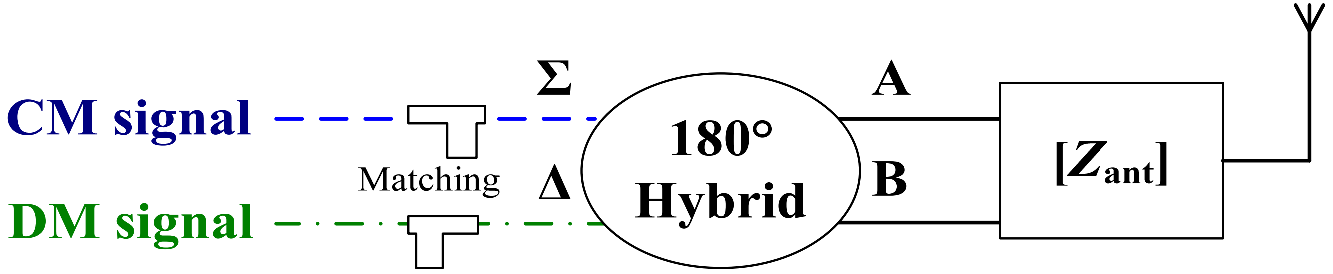


$$\begin{cases} \overrightarrow{Pat_{CM,z}} = \hat{\theta}\,\dfrac{1}{\sqrt{2\pi}}\sin\theta \\ \overrightarrow{Pat_{DM,z}} = \hat{\theta}\,\dfrac{1}{\pi}\,j\sin^2\theta\cos\phi \end{cases}$$

$$\Downarrow$$

$$\oiint \overrightarrow{Pat_{CM}(\Omega)} \bullet \overrightarrow{Pat_{DM}}^{\,*}(\Omega)\,d\Omega = 0$$

Mode Decomposition Network

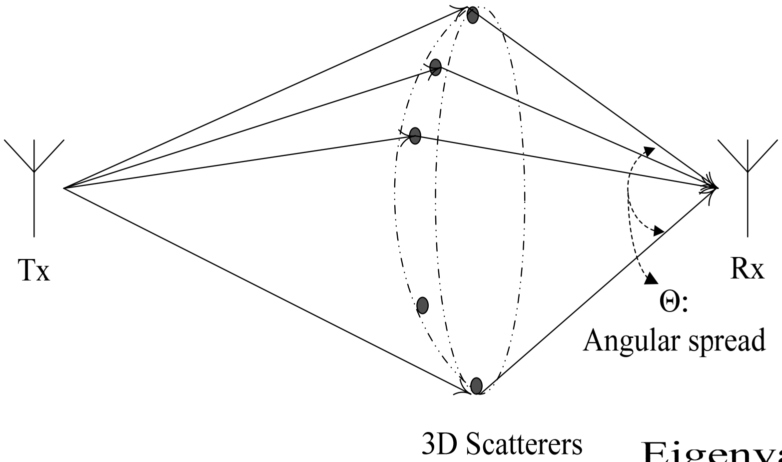


$$\begin{bmatrix} V_\Sigma \\ V_\Delta \end{bmatrix} = \begin{bmatrix} Z_{\Sigma\Sigma} & 0 \\ 0 & Z_{\Delta\Delta} \end{bmatrix} \begin{bmatrix} I_\Sigma \\ I_\Delta \end{bmatrix}$$

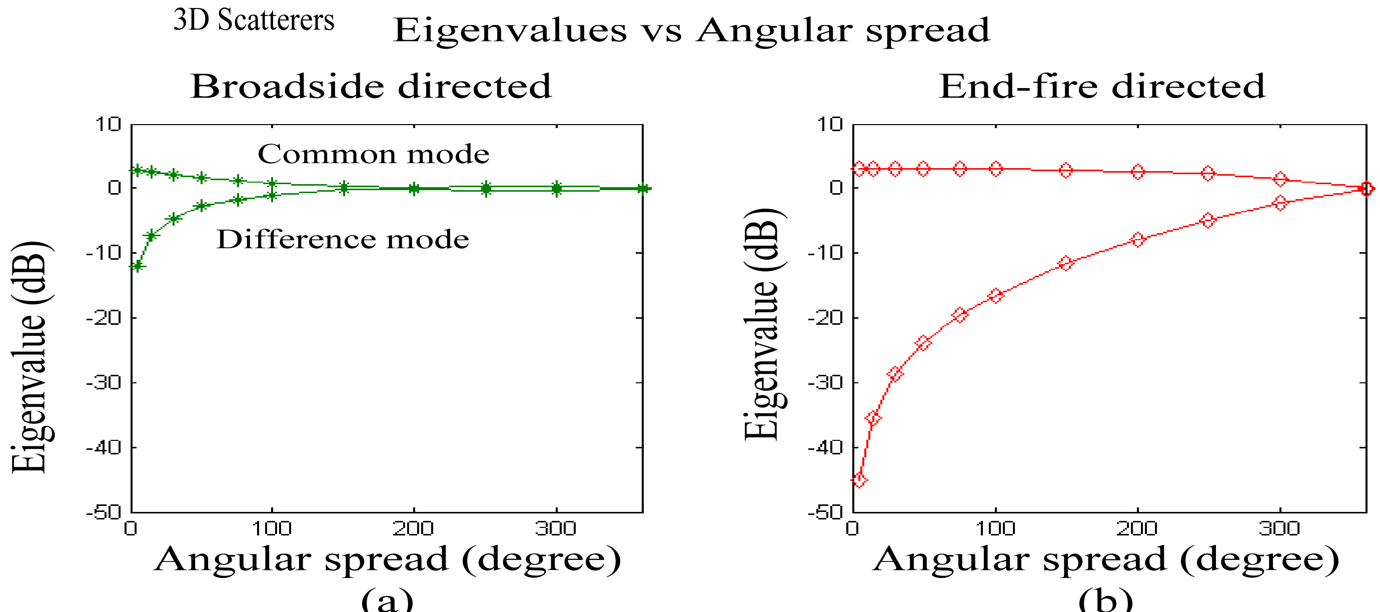
$$Z_{\Sigma\Sigma} = \frac{Z_0^{\,2}}{2Z_{CM}}, \qquad Z_{\Delta\Delta} = \frac{Z_0^{\,2}}{2Z_{DM}}$$

- Separate the common and difference modes into different ports so both modes can be matched individually
- Network itself is not antenna specific, requires only symmetry of array configuration
- Broadband isolation allows adaptive tuning of each mode for different band
- Extendable as a building block for more than 2 elements

Simulation of Scatterings and Channels

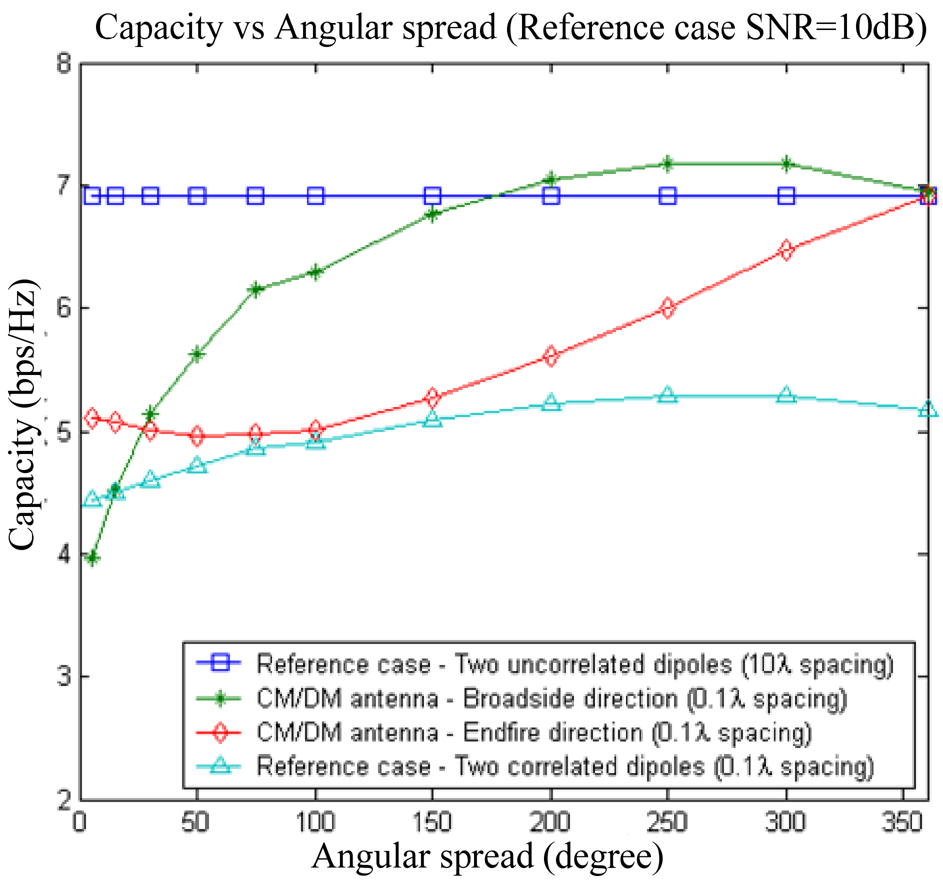


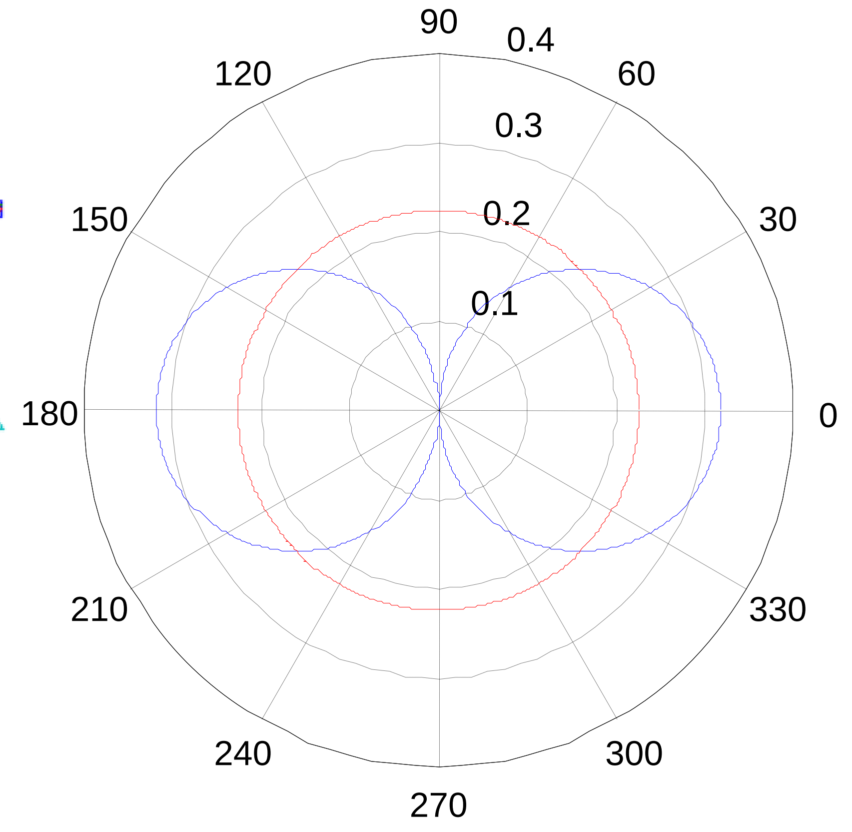
- Point scatterers randomly distributed in a spherical surface with 3D random scattering coefficient
- Dipoles at 10λ spacing used as transmitter and reference receiver
- Coupled dipoles at 0.1λ spacing used in testing



Simulated Capacity vs. Angular Spread

Capacity defined: $C = \log_2 \det\left[I_{n_R} + (\rho / n_T) H \cdot H^T\right]$

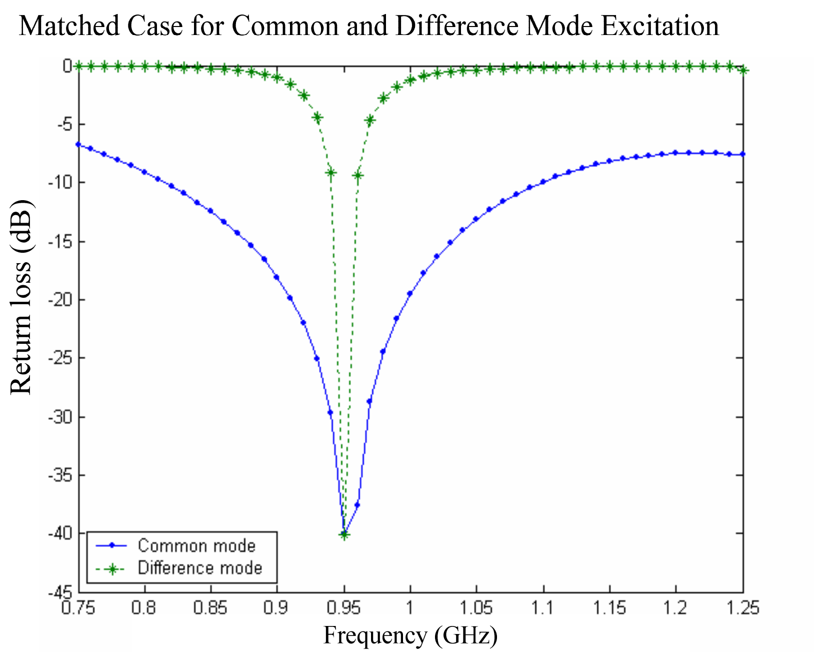




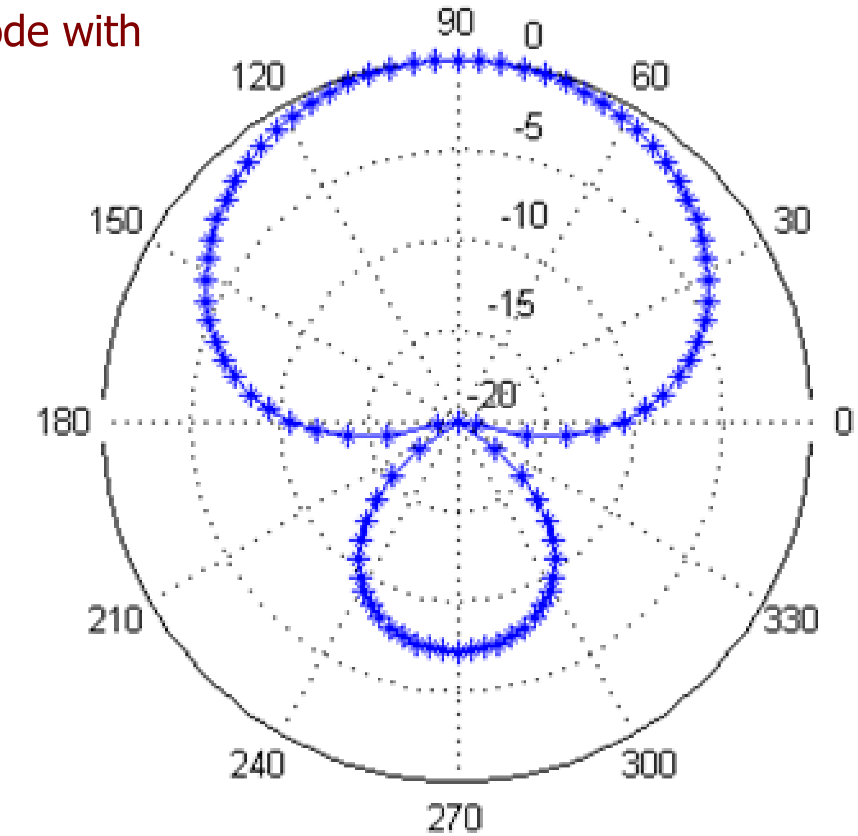
Mode based Supergain

In the end-fire direction, for a pair of coupled l/2 dipoles at 0.1λ spacing

The maximum directivity or gain can be achieved from combining the common mode and difference mode with certain power ratios



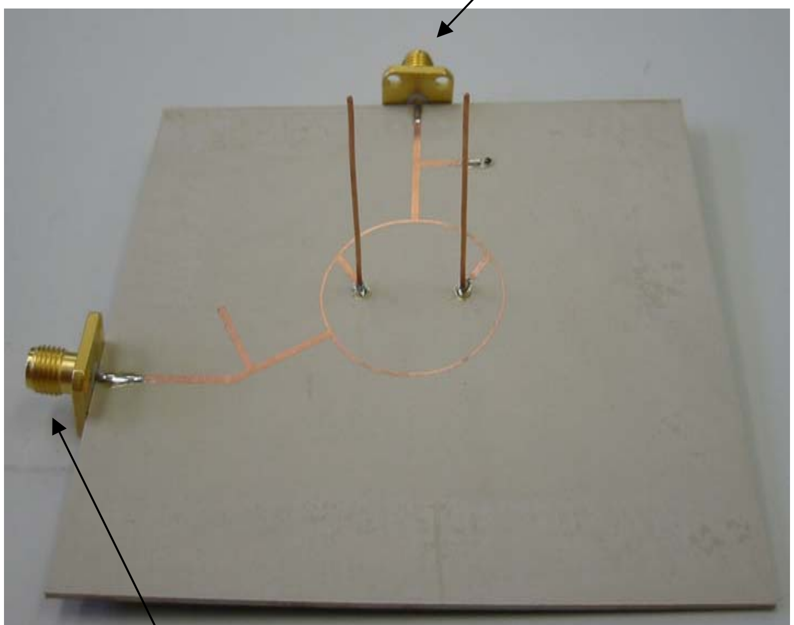
(η=2.54, D=5.45) ← 7.36dBi



Experimental Results

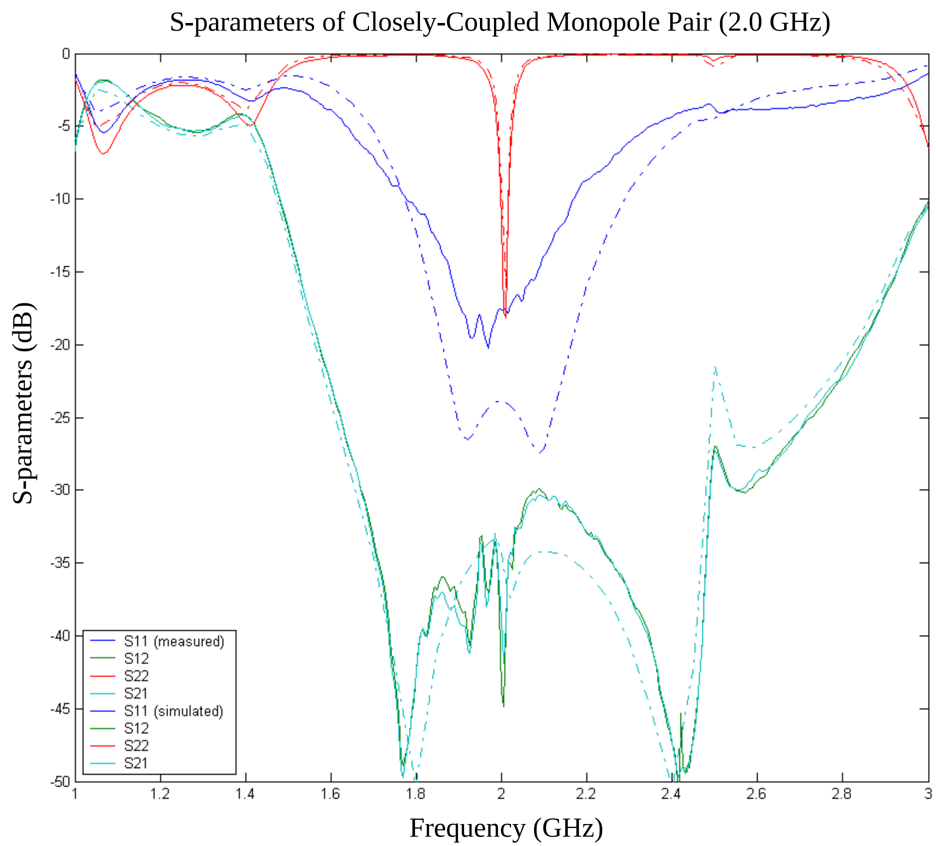
Picture of Supergain Coupled Monopoles

Common port



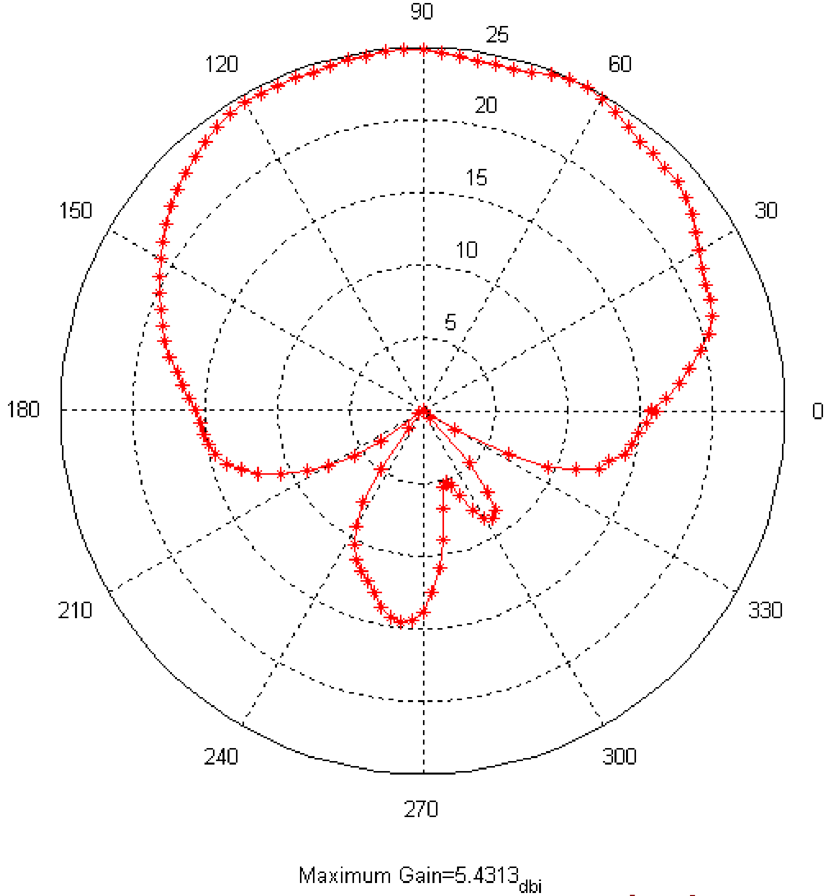
Difference port

Measured S parameters

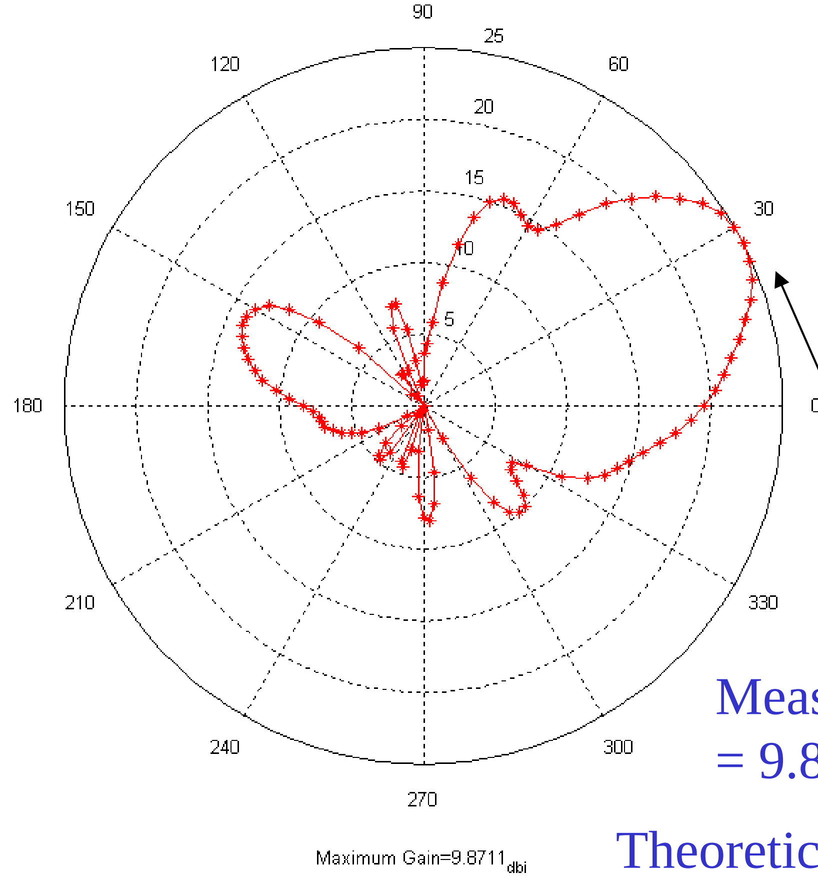


Measuremed Pattern & Gain

Φ Plane



Θ Plane



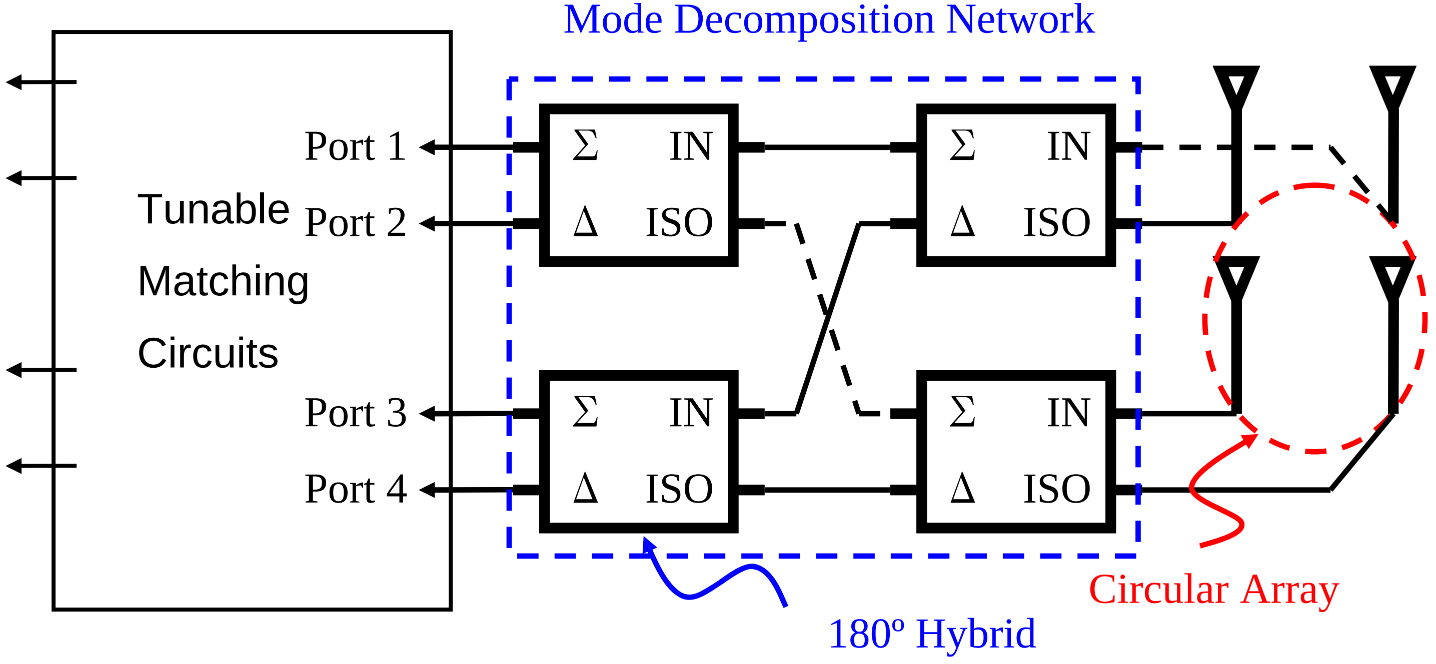
Measured Gain = 9.87dBi

Theoretical 10.8dBi

1dB loss ~ 80% efficiency

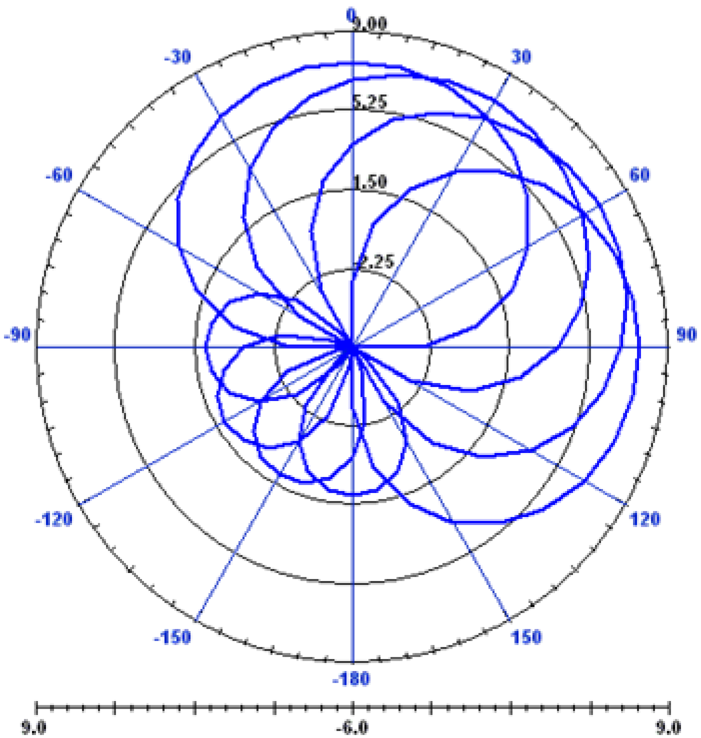
Intelligent Multi-Antenna Front-End

- ➢Tunable matching components such as varactors can be used to change the matching condition
- ➢Same hardware platform can be reconfigured in software among three operating modes e.g. broadband, MIMO and smart beamforming for maximum capacity throughput

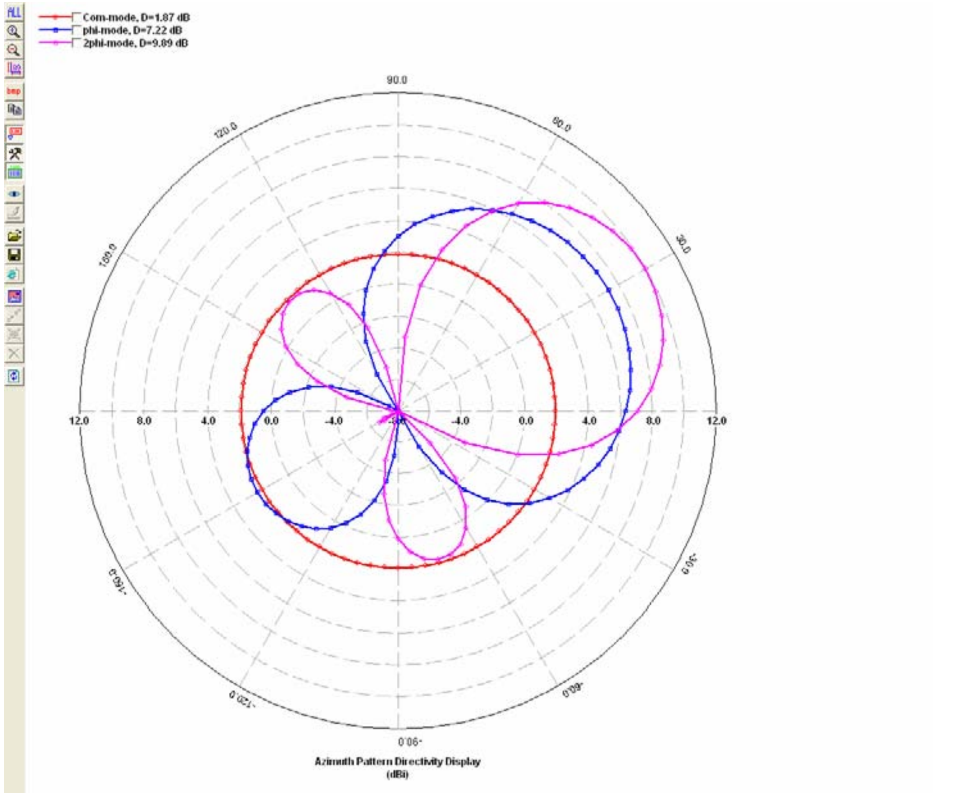


Intelligent Multi-Antenna Front-End

Continuous Electronic Scanning

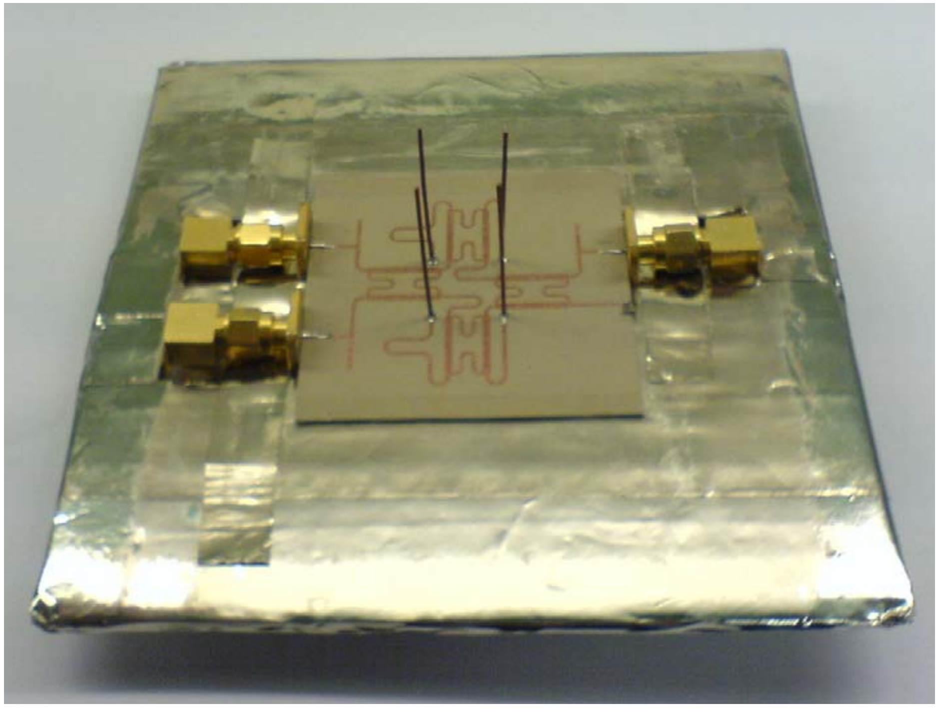


"Zoom in" beam shaping

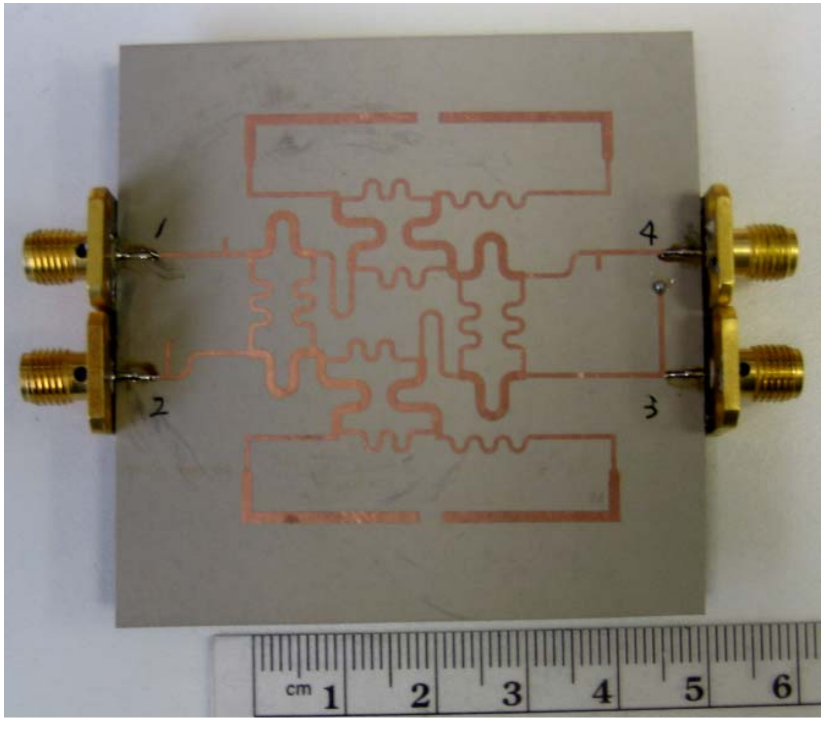


More Mode-Based Antenna Configurations

Supergain Scanning Array



Planar 4 channel MIMO Array



Conclusions

- The number of parallel information channels are determined by the number of orthogonal modes that are excited by the antennas
- There is no theoretical up-bound in the number of the existing modes for a particular platform
- However, for an small platform, the high Q associated with the higher order modes will eventually limit the efficiency bandwidth products for those modes, thus the total number of channels that can be of practical use is still fundamentally limited