Antenna Design Considerations for LTE Mobile Applications

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Presented to the Long Island Chapter of the IEEE Antennas & Propagation Society on November 8, 2011

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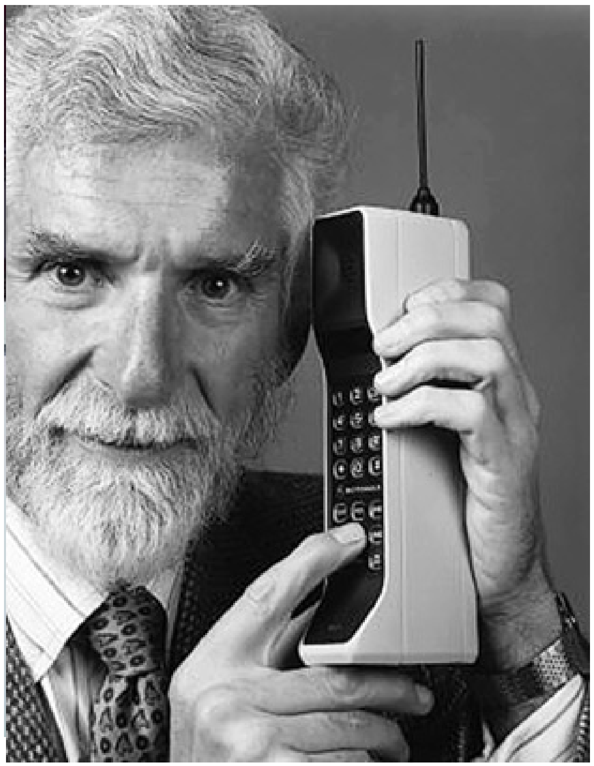
OUTLINE

- Introduction to 4G/LTE
- Antenna Design challenges
- Numerical Techniques
- Design & optimization of Antennas for Handset
- Handset with a head and SAR Calculations
- Handset & channel capacity
- Conclusion

History of Mobile Phones



Dr. Martin Cooper of Motorola, made the first US analogue mobile phone call on a larger prototype model in **1973**.
This is a reenactment in 2007

Analog Motorola DynaTAC 8000X Advanced Mobile Phone System mobile phone as of **1983**

http://en.wikipedia.org/wiki/History_of_mobile_phones

History of Mobile Phones

1997-2003

http://en.wikipedia.org/wiki/History_of_mobile_phones

Smart Phones

2003-2007

2007-2011

http://en.wikipedia.org/wiki/History_of_mobile_phones

1G, 2G and 3G

In 1G, Narrow band analog wireless network is used, with this we can have the voice calls and can send text messages.

Then in case of 2G Narrow Band Wireless Digital Network is used. Both the 1G and 2G deals with voice calls and has to utilize the maximum bandwidth as well as limited to sending messages i.e. SMS.

In 3G Wide Band Wireless Network *is used with which the clarity increases and gives the perfection as like that of a real conversation. In addition to verbal communication it includes data services, access to television/video, categorizing it into triple play service.*
3G operates at 2100MHz and has a bandwidth of 15-20MHz.

4G/LTE

- 4G is expected to provide a comprehensive and **secure all-IP based mobile broadband solution** to laptop computer wireless modems, smartphones, and other mobile devices.

- Facilities such as ultra-broadband Internet access, IP telephony, gaming services, and streamed multimedia may be provided to users.

- 4G technologies such as mobile WiMAX, HSPA+, and first-release Long term evolution (LTE) have been on the market.

- **Scalable channel bandwidth: 5 – 20 MHz (optionally up to 40 MHz) @ 2.6 GHz (for mobile applications)**

- **Peak data rates:**
  - **~ 100 Mbit/s for high mobility communications**
  - **~ 1 Gbit/s for low mobility communications**

Antenna Design Challenges for 4G/LTE Handsets

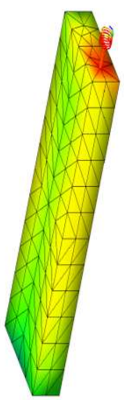
- Antenna Size
- Mutual Coupling
- In-Situ Performance
- Compliance with SAR Regulation
- Channel Capacity Improvements using MIMO

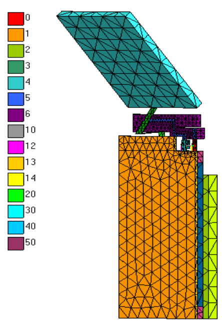
Peak data rates:
~ 100 Mbit/s for high mobility communications
~ 1 Gbit/s for low mobility communications

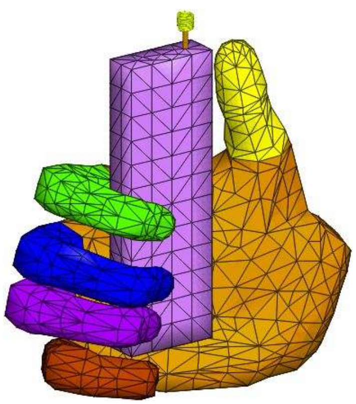
Computational Electromagnetics for Antenna Design and Optimization

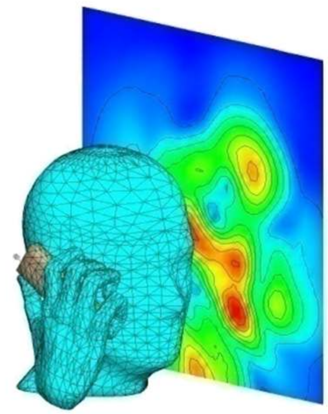
Meeting the Design Challenges

- **Numerical solution based on approximation of currents and/or fields**
- **Desirable properties of CEM methods:**
  - **Approximation may be reduced in order to increase accuracy, approaching the analytical result**
  - **Computational cost (CPU time & memory) must be as low as possible**





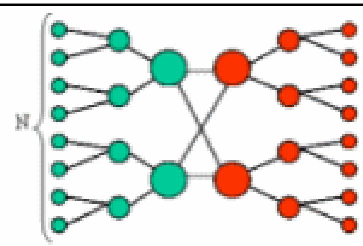




Computational Electromagnetics for Antenna Design and Optimization

Computer modeling

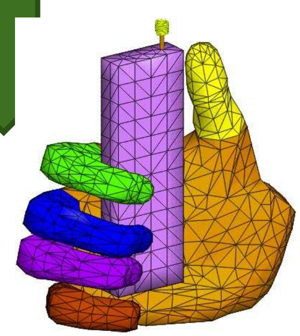
CEM tool



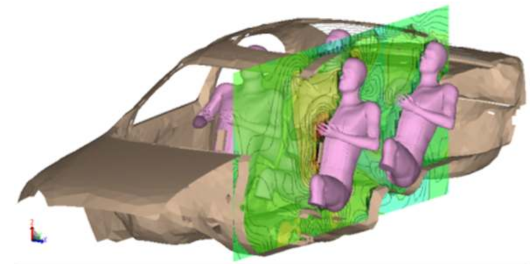
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

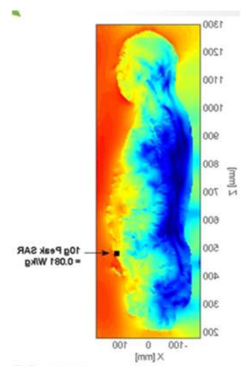
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

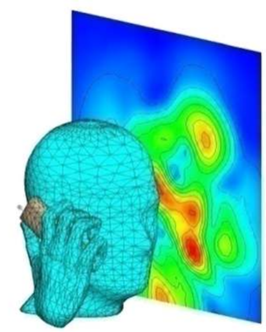
$$\oint_C \mathbf{E} \cdot d\mathbf{l} = -\frac{d}{dt}\int_S \mathbf{B} \cdot d\mathbf{A}$$



Discretized Model





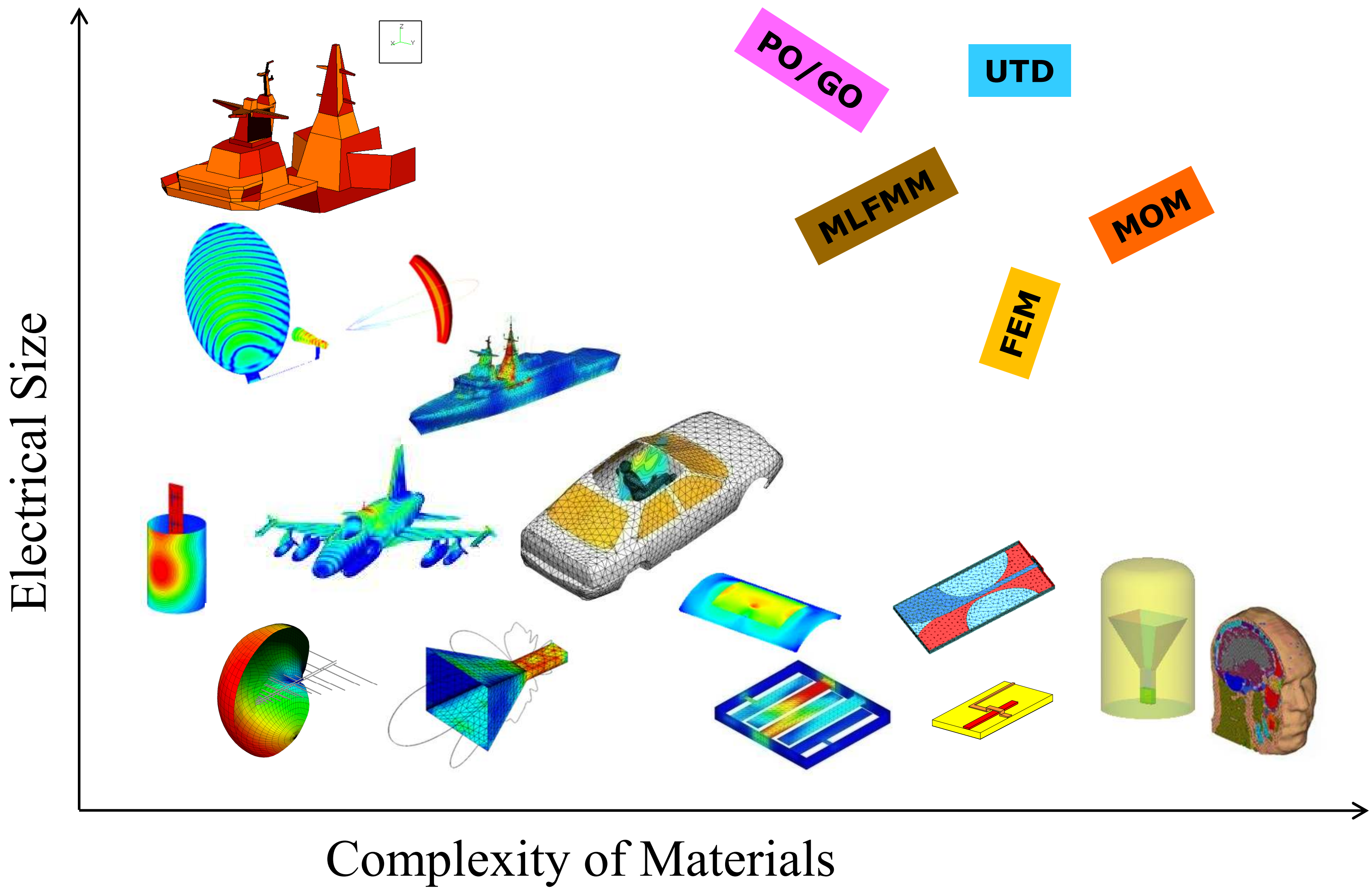


Numerical analysis

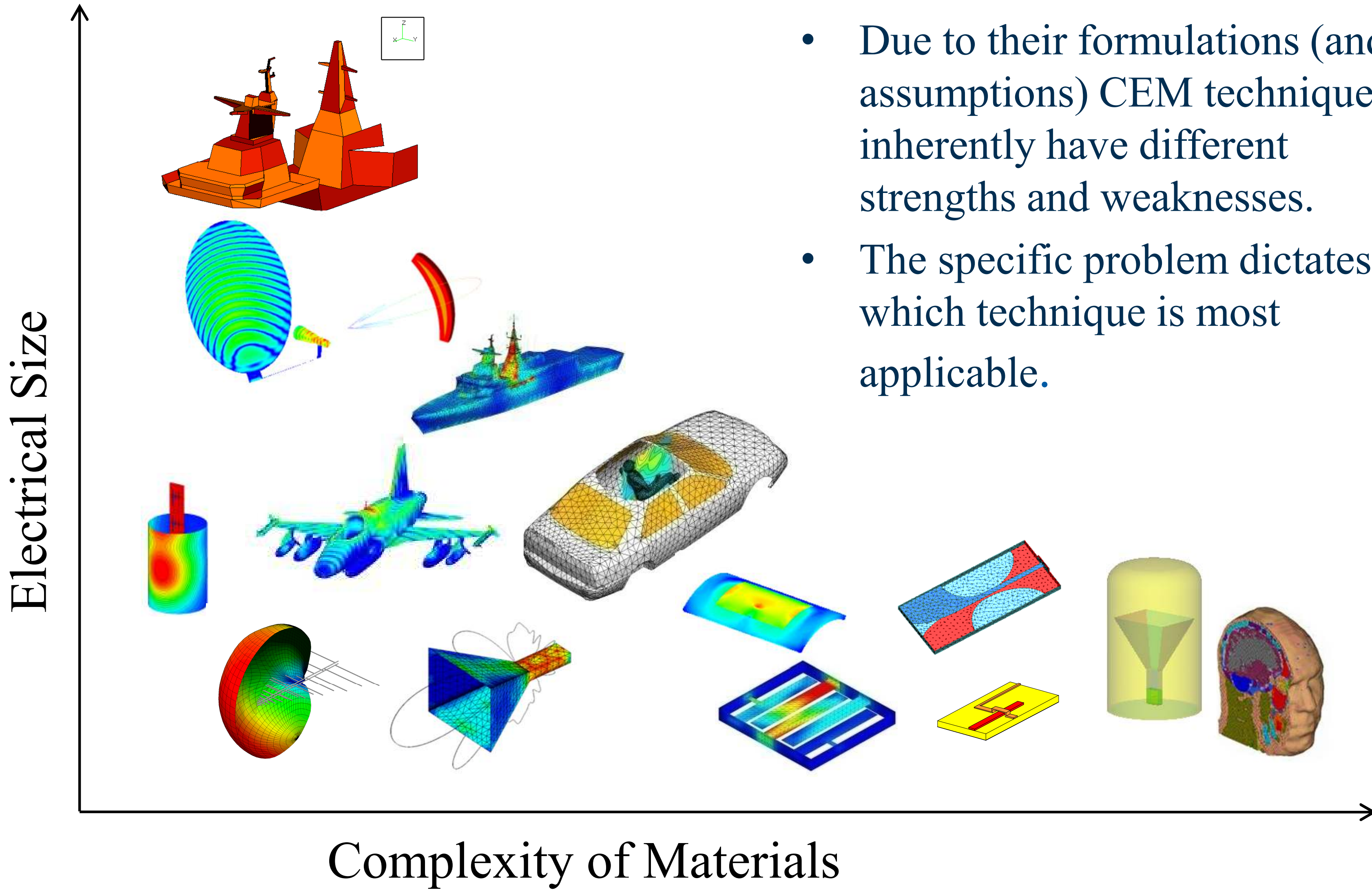
Comparison of Numerical Techniques

	Field method	Source method
Base	Electromagnetic fields	Currents and charges
Equations	Differential equations	Integral equations
Discretisation	Volumetric Mesh (cubes, tetrahedrals)	Surface Mesh (triangles, quads)
Infinity of space (open problem)	Special ABC's must be introduced or use exact radiation boundary condition	Exact treatment using exact radiation boundary condition
Methods	Finite Difference methods (FD) Finite Element methods (FEM)	Method of Moments (MoM)
Commercial Codes	HFSS, CST, FEKO, XFDTD, Empire, SEMCAD	FEKO, WIPL-D (IE3D, Sonnet, Designer etc – 2D

3D EM Simulation Map

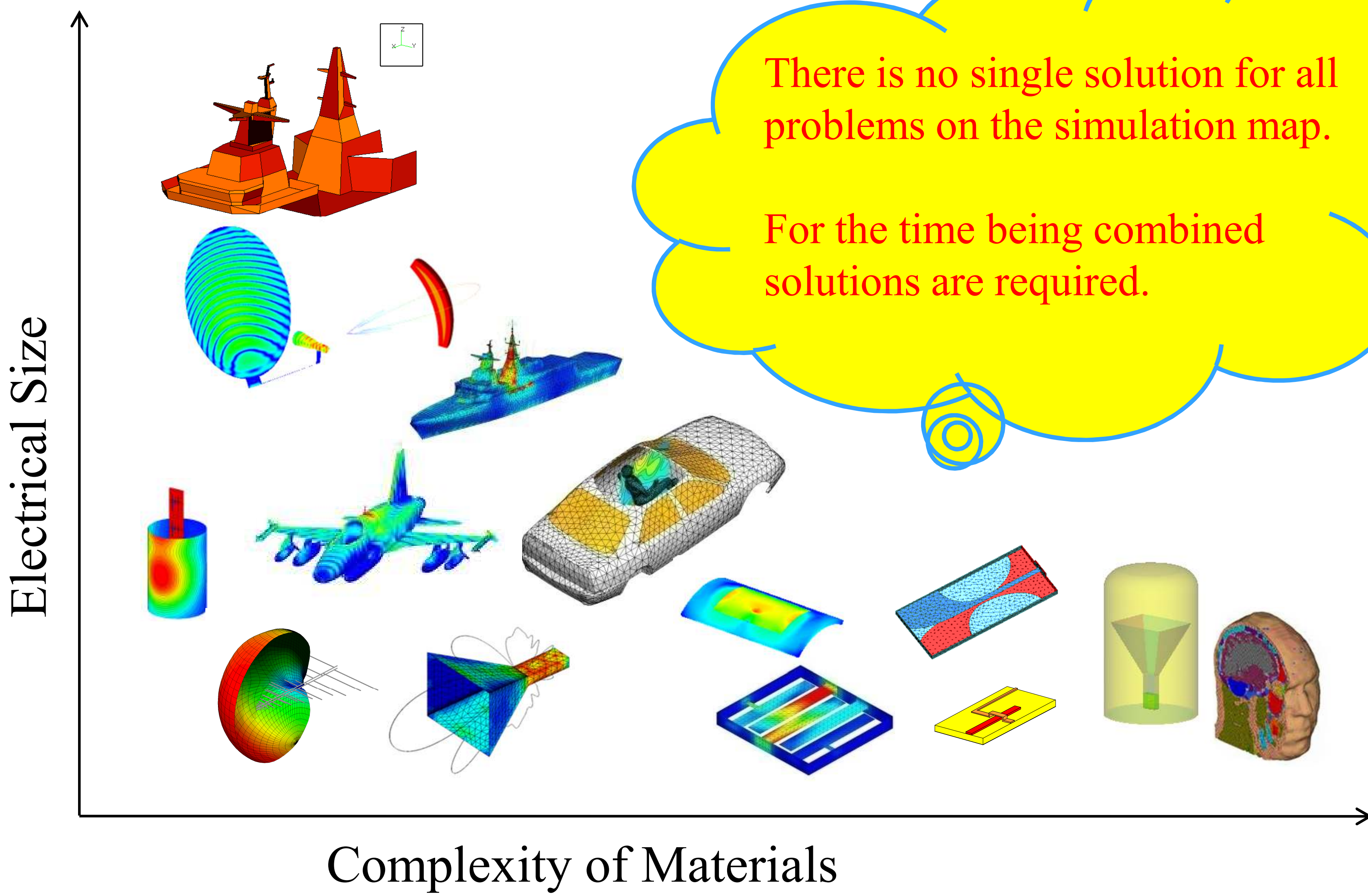


3D EM Simulation Map



- Due to their formulations (and assumptions) CEM techniques inherently have different strengths and weaknesses.
- The specific problem dictates which technique is most applicable.

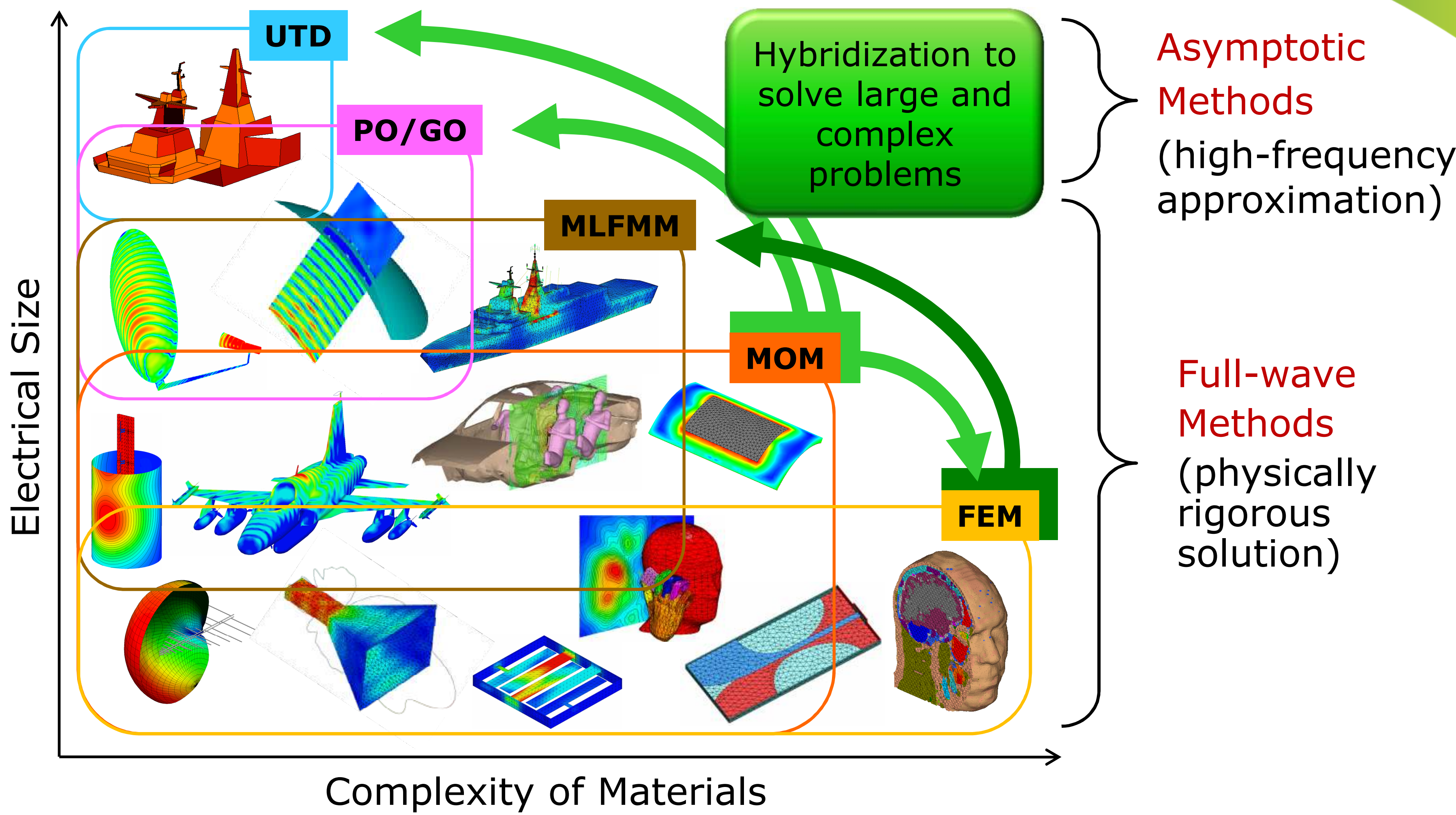
3D EM Simulation Map



There is no single solution for all problems on the simulation map.

For the time being combined solutions are required.

3D EM Simulation Map



Antenna Design for 4G/LTE

iPhone 4S

Dimensions	132 x 71 x 9 mm
Weight	139 g

Samsung Infuse

Dimensions	117.8 x 63.5 x 11 mm
Weight	135 g

Motorola Atrix

Dimensions	127.5 x 66.9 x 11 mm
Weight	158.8 g

Motorola Droid BIONIC

Thickness ~ 1cm
Length ~ 6cm

Electrically small antenna (ESA)

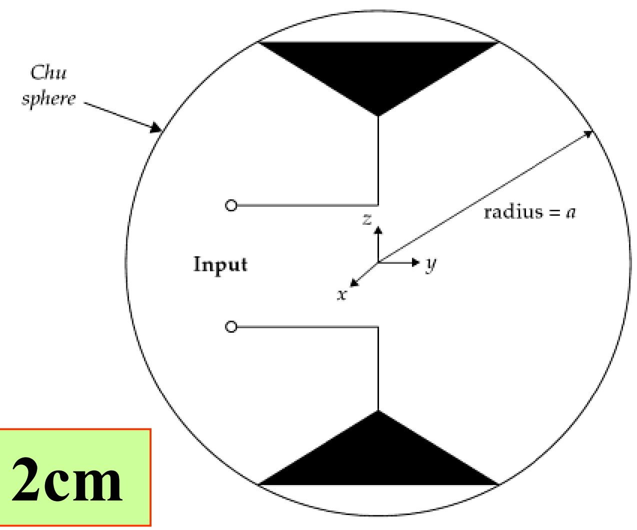
- **An ESA is an antenna that satisfies the condition**

  ka < 0.5

  '*k*' is the wave number 2π/λ

  '*a*' is the radius of the minimum size sphere that encloses the antenna

Chu sphere **is the minimum circumscribing sphere enclosing the antenna of maximum dimension 2a**

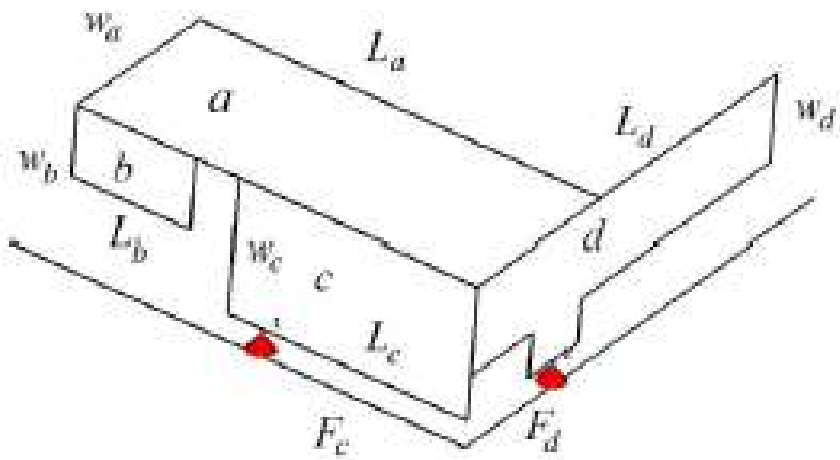


Frequency = 2.6GHz
Wavelength = 11.5cm

ka ~ 0.5, length (2a) ~ 2cm

John Leonidas Volakis, Chi-Chih Chen, and Kyōhei Fujimoto, *Small antennas: miniaturization techniques & applications*. The McGraw-Hill Companies, New York, NY, 2010

Dual-Port Antenna



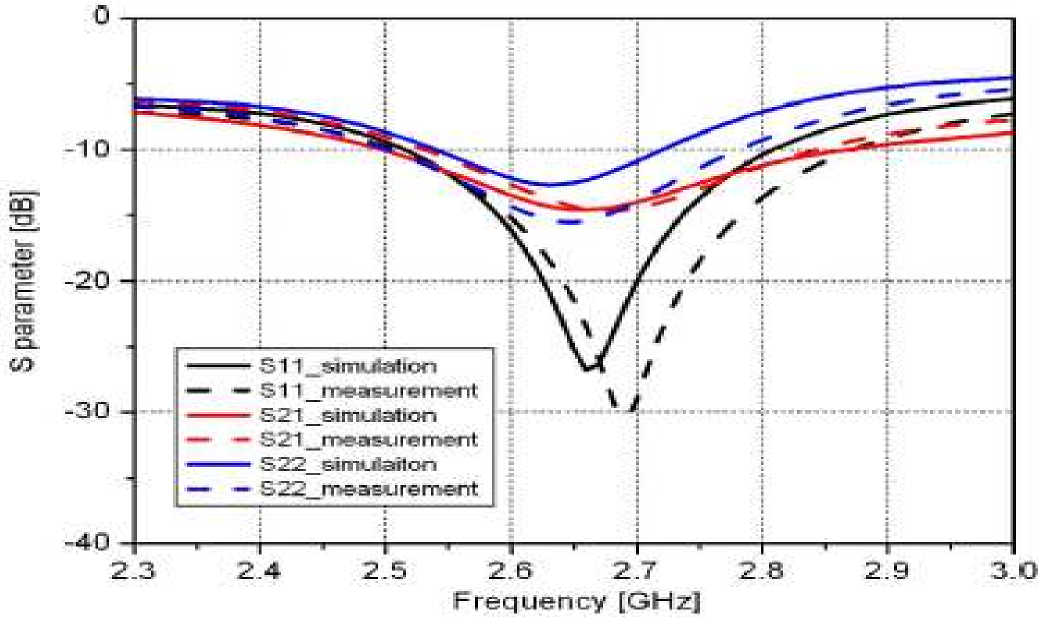
$L = 95$, $W = 55$, $L_a = 23.5$, $W_a = 10$, $L_b = 7$, $W_b = 4$, $L_c = 14$, $W_c = 7.5$, $L_d = 24.5$, $W_d = 5$, $F_c = 11$, and $F_d = 6$. The size of a matching stub for Port2 is 4 mm $\times$ 2.5 mm

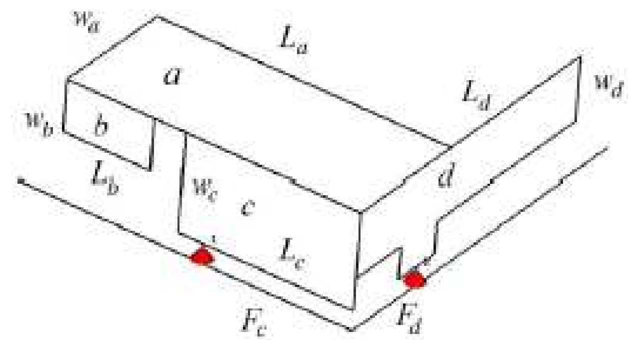
Antenna dimensions

Fabricated Model

Qinjiang Rao and Dong Wang, "A Compact Dual-Port Diversity Antenna for Long-Term Evolution Handheld Devices", *IEEE Transactions on Vehicular Technology, Vol. 59, No. 3, March 2010*

Dual-Port Antenna





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S-parameter results of the dual-port antenna

Thickness ~ 1cm

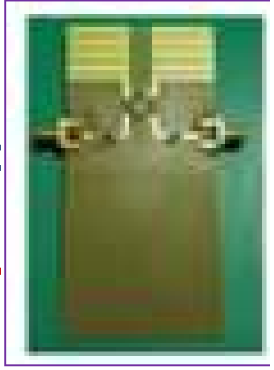
Thickness of current smart phones ~ 0.5cm

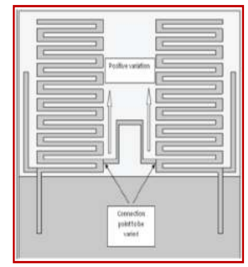
This antenna won't go with current day slim handheld devices for its size. We need an electrically small antenna (ESA)

Qinjiang Rao and Dong Wang, "A Compact Dual-Port Diversity Antenna for Long-Term Evolution Handheld Devices", *IEEE Transactions on Vehicular Technology, Vol. 59, No. 3, March 2010*

Challenge - Isolation Techniques

- **Placing the antennas half a wavelength apart as a rule of thumb for low enough correlation**
  - **Not attractive because of the space required for separation**
- **Orthogonally polarized elements offer significant port isolation**
  - **Finite-sized ground plane generates high cross-polar components that spoil the polarization purity resulting in high coupling**
- **Using branch line hybrid with passive inductors and capacitors to decouple the antenna ports[1]**
  - **Space required for the hybrid is a constraint**
- **Using a neutralization stub (or parasitic elements) between the antennas to achieve isolation[2]**
  - **Not attractive because of the space required for parasitic elements**

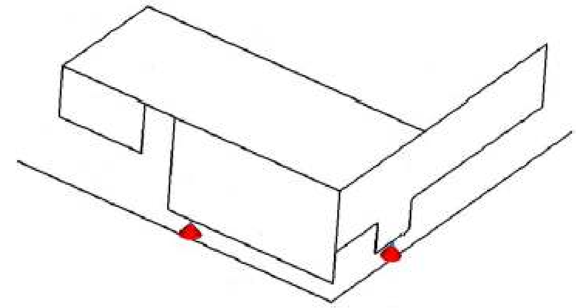




1. Rashid Ahmad Bhatti, Soongyu Yi, and Seong-Ook Park, "Compact Antenna Array With Port Decoupling for LTE-Standardized Mobile Phones", *IEEE Antennas & Wireless Propagation Letters, Vol. 8, 2009*
2. Ibra Dioum, Aliou Diallo, Cyril Luxey, and Sidi Mohamed Farsi, "Compact Dual-Band Monopole Antenna for LTE Mobile Phones", *Antennas & Propagation Conference, 8-9 November 2010, Loughborough, UK*

Dual-Port Antenna - Advantages

- **Two orthogonal radiating elements are used to achieve pattern diversity**
- **There are no additional neutralization stubs (or) hybrids used to provide isolation**
- **The zero separation leads to size reduction resulting in compact design**

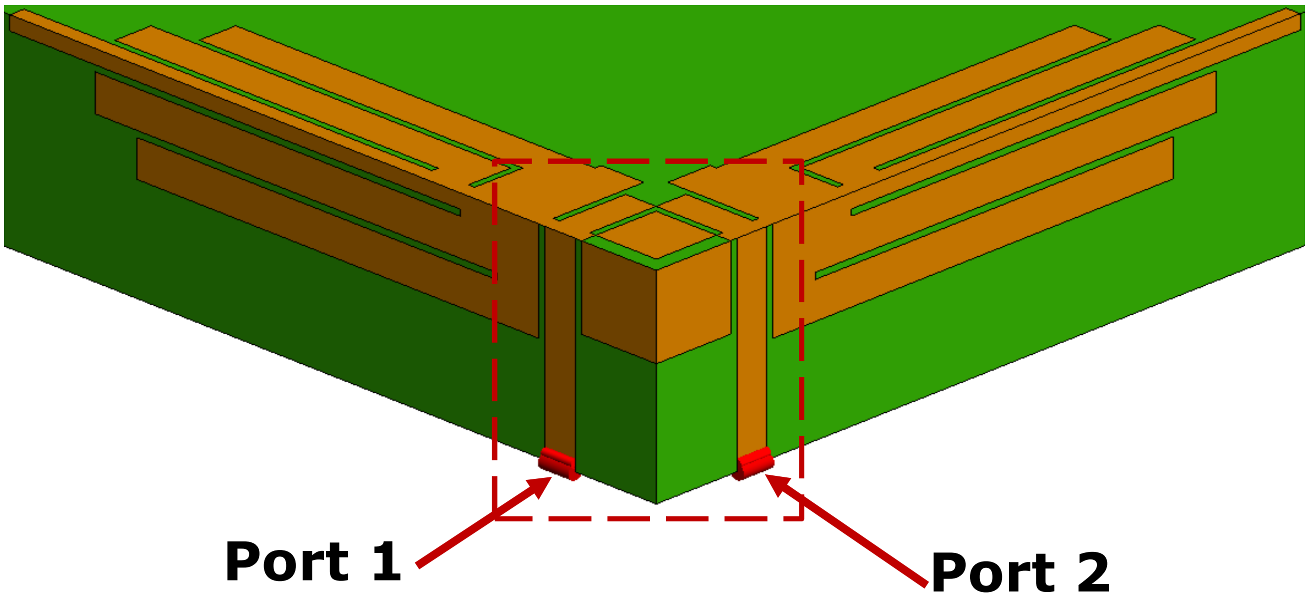


Dual port inverted PIFA

Qinjiang Rao and Dong Wang, "A Compact Dual-Port Diversity Antenna for Long-Term Evolution Handheld Devices", *IEEE Transactions on Vehicular Technology, Vol. 59, No. 3, March 2010*

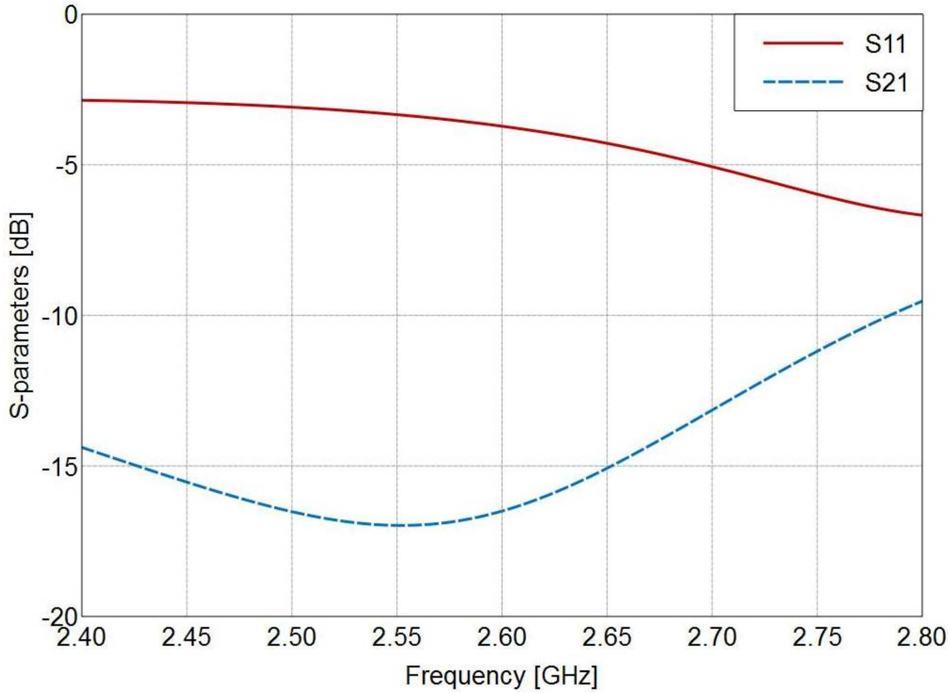
New Design - Dual-Port ESA

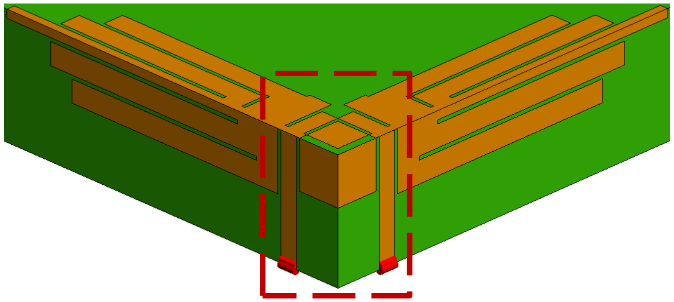
- **To go with present day typical handset (115x60x10 mm), we designed a dual-port ESA**
- **The symmetry in the novel design keeps the antenna characteristics identical for both radiating elements**



New Design

Port-to-Port Isolation – Initial Design

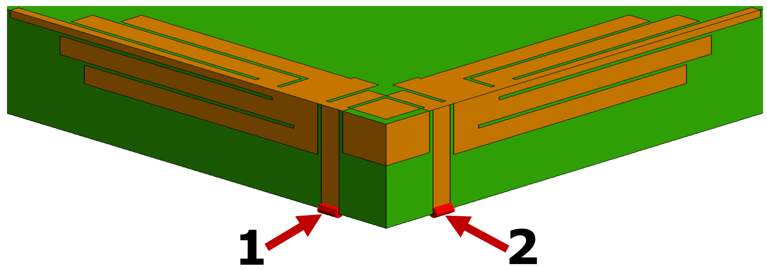




- **The novel feed design provides good port-to-port isolation even though the ports are physically connected**
- **But,**
  - **We need an antenna with low correlation and good matching at the same time**
  - **Therefore,**
    - **The design is optimized for matching**

Design and Optimization

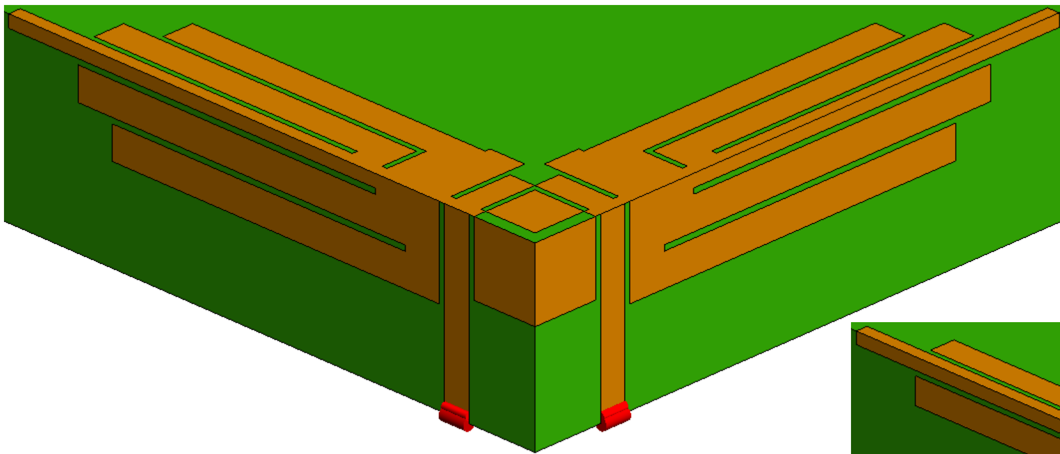
- **The dual port antenna design is optimized for both matching and isolation at the desired frequency of operation (2.6 GHz)**



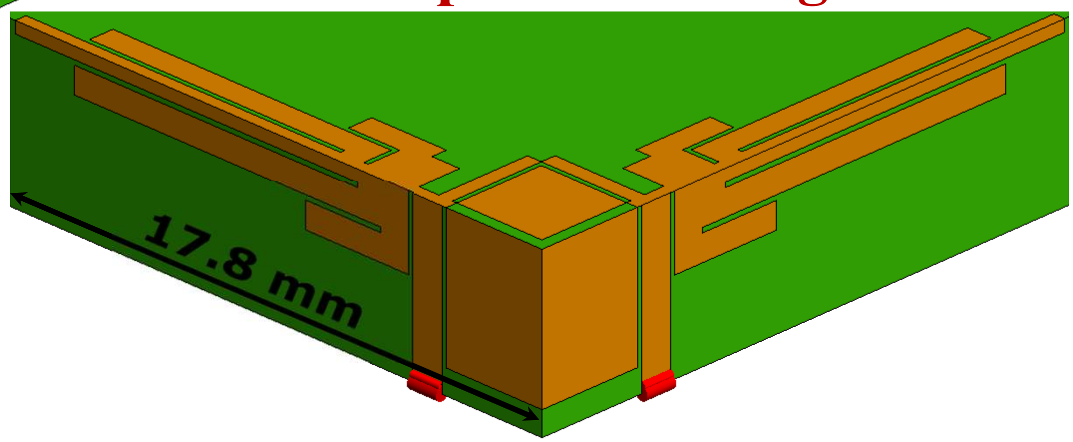
- **The optimization algorithms, PSO and Simplex (Nelder-Mead) are used in the process**
  - **PSO (Particle Swarm Optimization) being a global optimization algorithm requires many iterations to converge**
  - **Simplex is a local optimizer whose convergence is much faster compared to global optimizers**
  - **The success rate of Simplex depends on the starting point**
  - **As a trade off, PSO is ran for few iterations**
  - **The optimum of PSO is given as a starting point for Simplex**

Initial and Optimum Designs at 2.6 GHz

Initial design



Optimized design



Substrate (FR4)

Thickness = *5 mm*

Dielectric constant = *4.8*

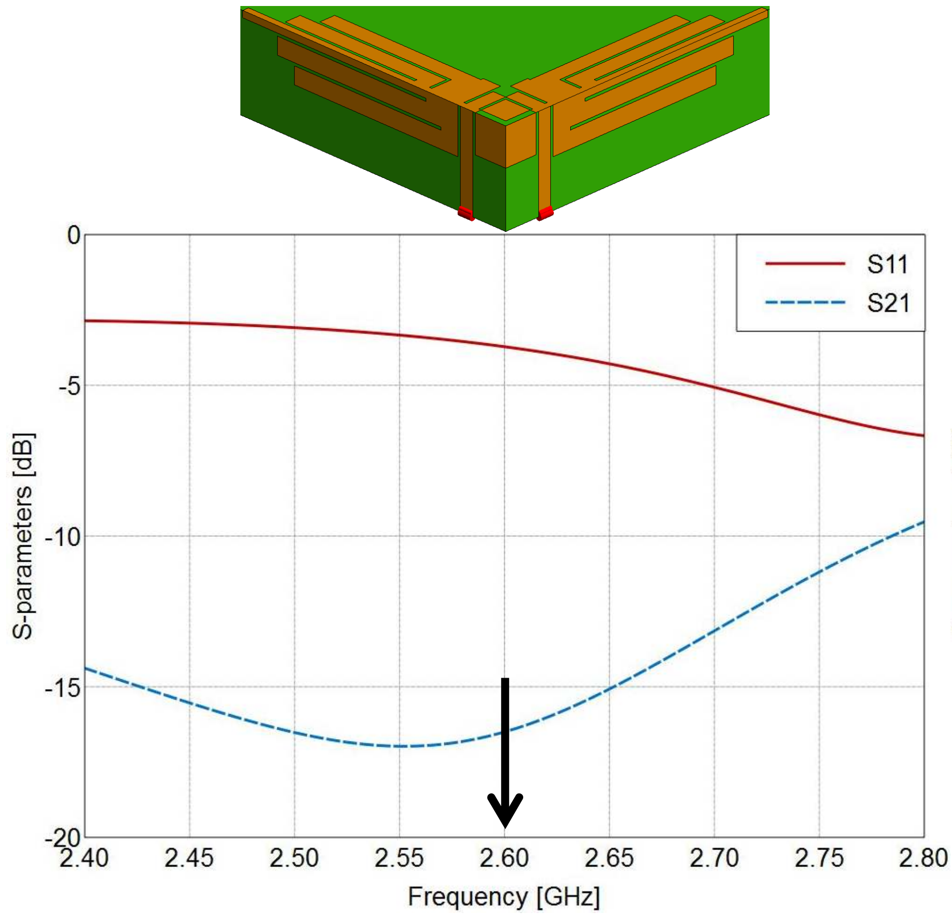
Loss tangent = *0.017*

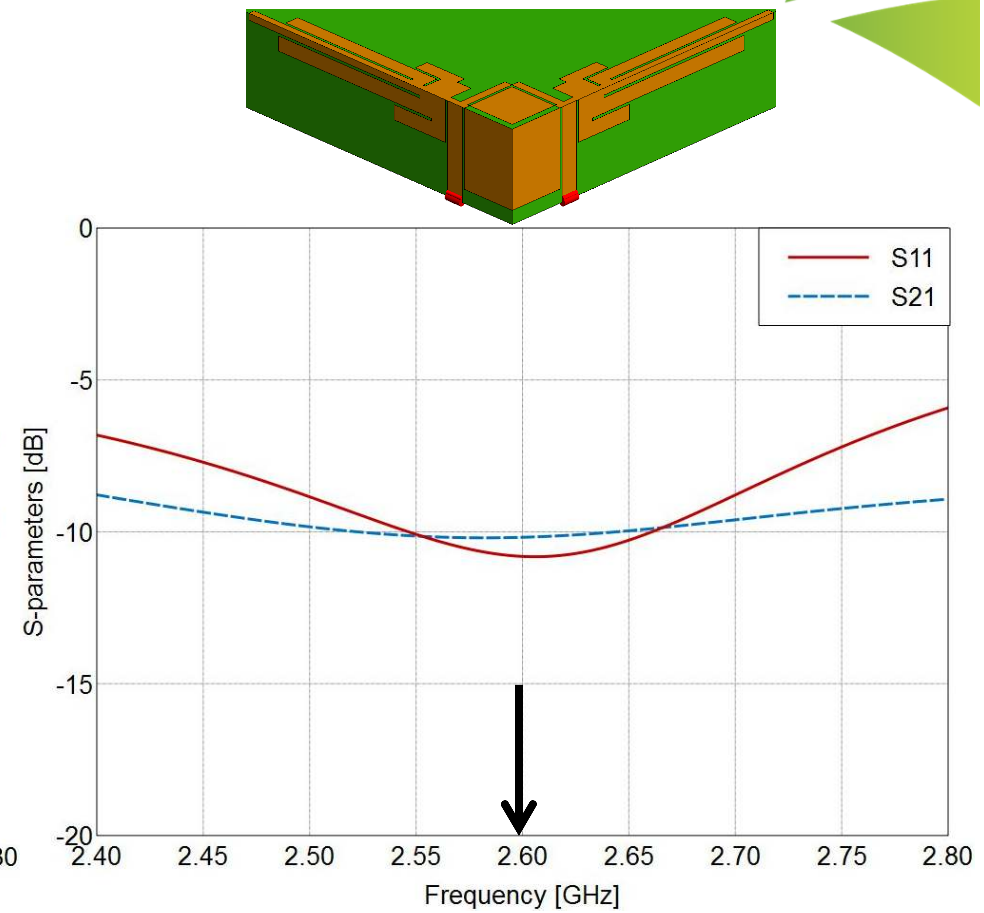
Max. length of the radiating element, 2a = 17.8 mm

Wave number, k = 2π/λ = 0.0545

ESA condition, ka = 0.0545*17.8/2 = 0.485 < 0.5

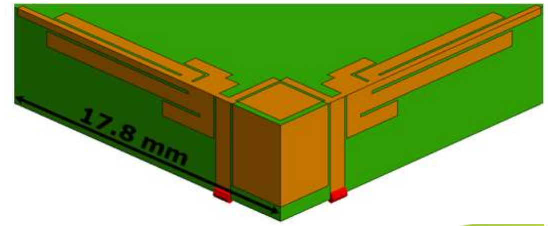
Initial Vs. Optimum





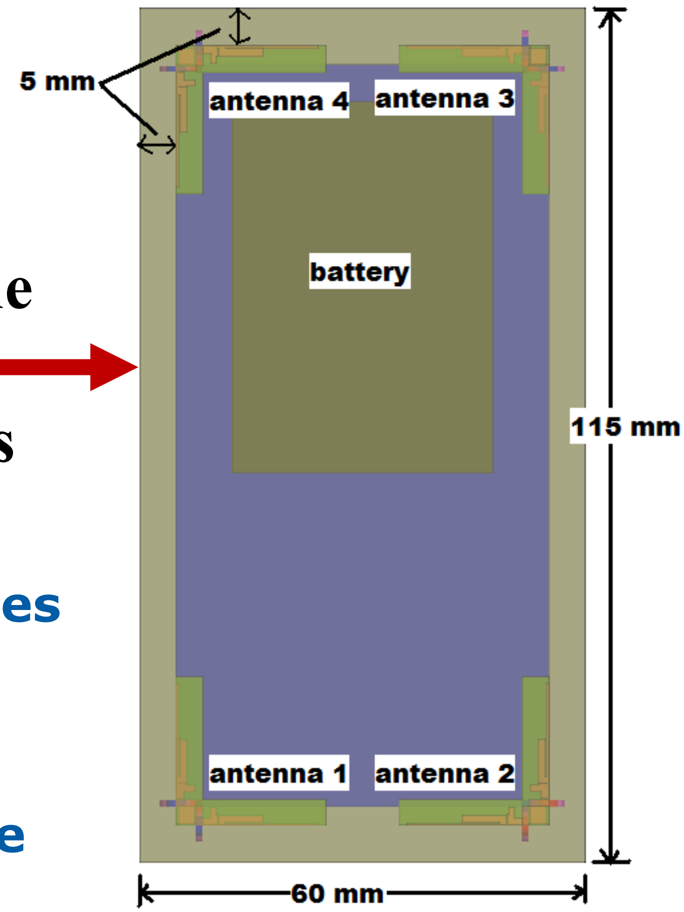
The optimized design provides good matching as well as better isolation at the desired frequency (2.6 GHz)

Dual-Port ESA in a Handset



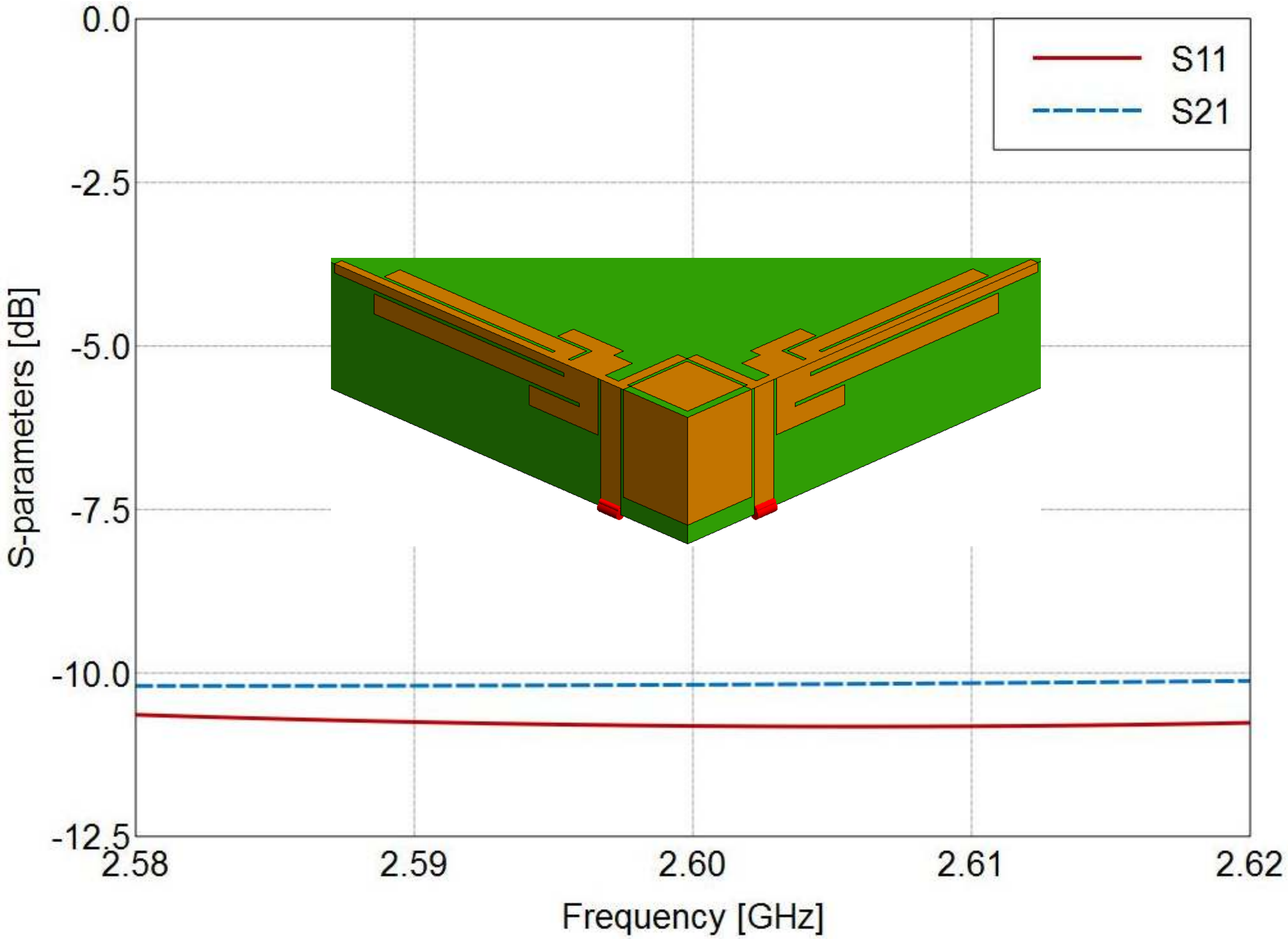
Side view

Bottom view of the handset with antenna positions



- **The novel ESA with ka = 0.485 (< 0.5) goes with the present day handsets occupying minimal space**
- **The dual-port design also offers the convenience of placing the antenna on the corners for maximizing usable space**

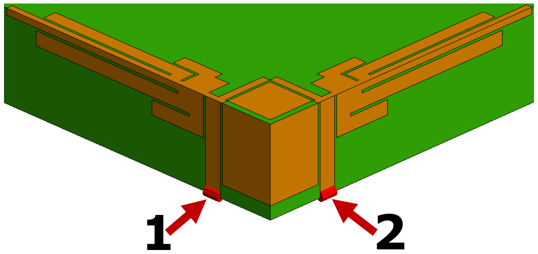
S-Parameters over usable LTE Bandwidth



The optimized design provides good matching as well as better isolation over the desired LTE bandwidth (maximum of 40 MHz)

Antenna Working Configurations

- The dual port antenna can be used in different configurations
  - 1, 2 excited
  - 1 excited, 2 terminated with a matched load
  - 1 matched loaded, 2 open (high impedance)

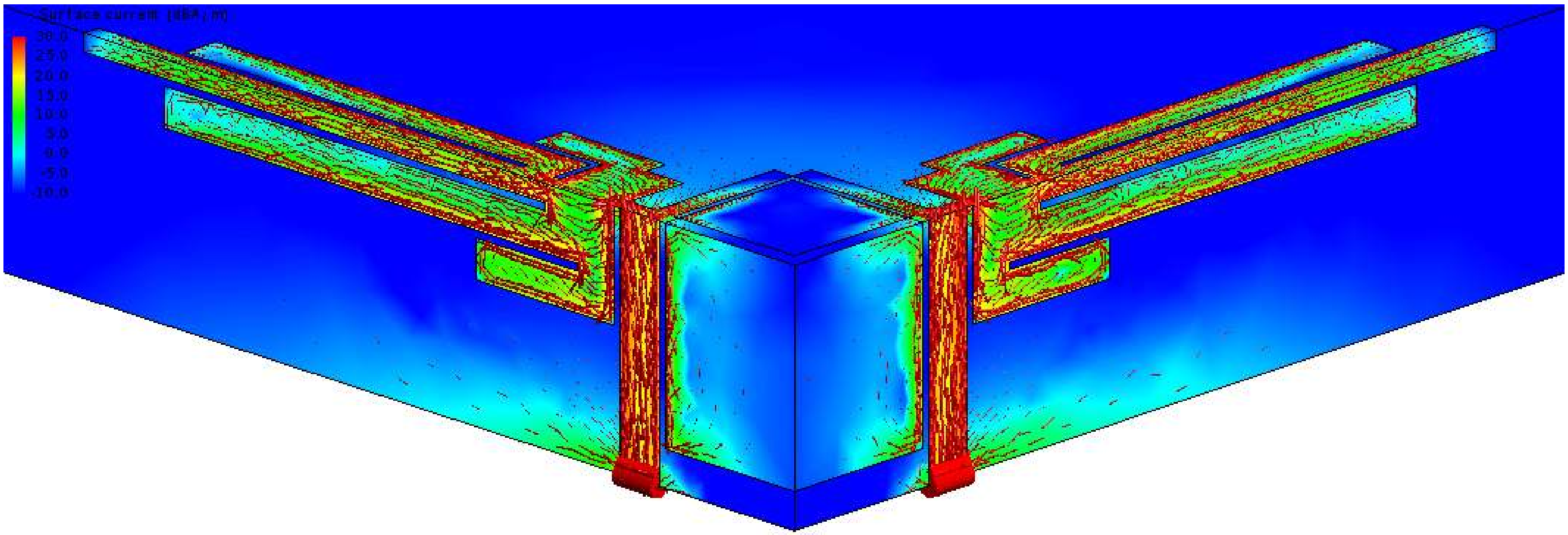


- When both the ports are excited, it acts as a dual feed antenna for MIMO applications

- In the second configuration, one antenna will be transmitter while the other is a receiver

- In the third configuration, both can be used as receiving antennas where you can switch between the ports based on the incoming signal polarization and strength

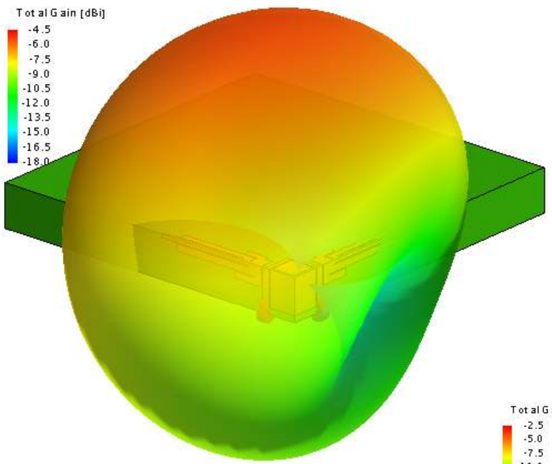
Surface Currents



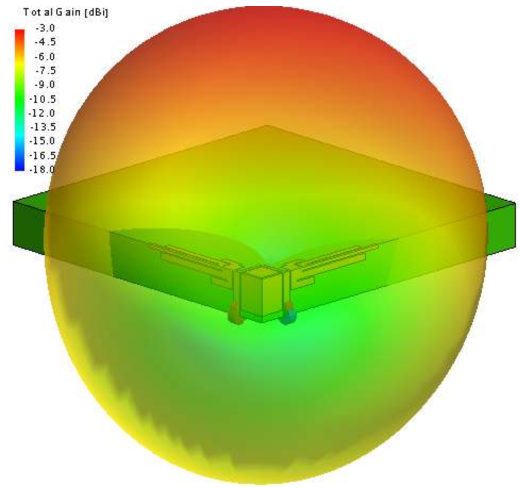
Even though the two antennas are connected, there is a clear voltage null between the two ports (isolation)

The phase of the two radiating element currents are in opposite directions (polarization diversity)

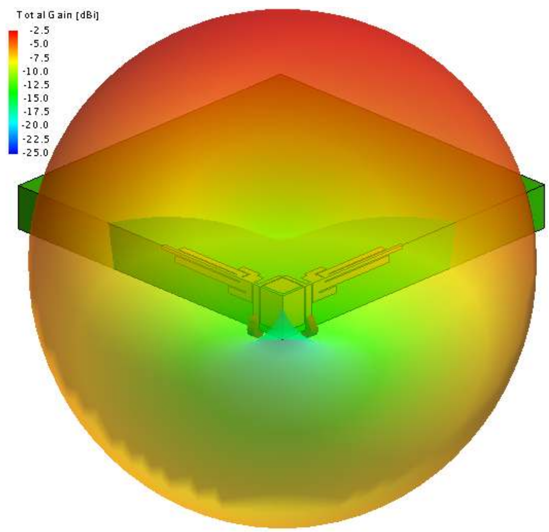
Radiation Patterns



Port 1 excited
Port 2 open



Port 1 excited
Port 2 short



Port 1 & Port 2 excited

Handset & Head

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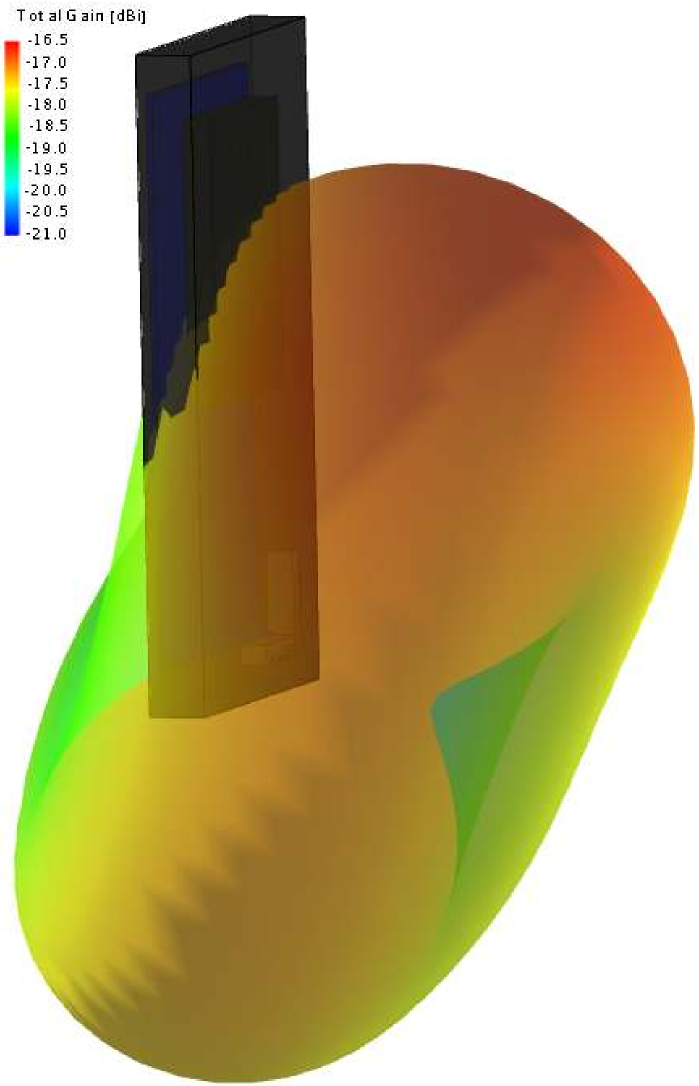
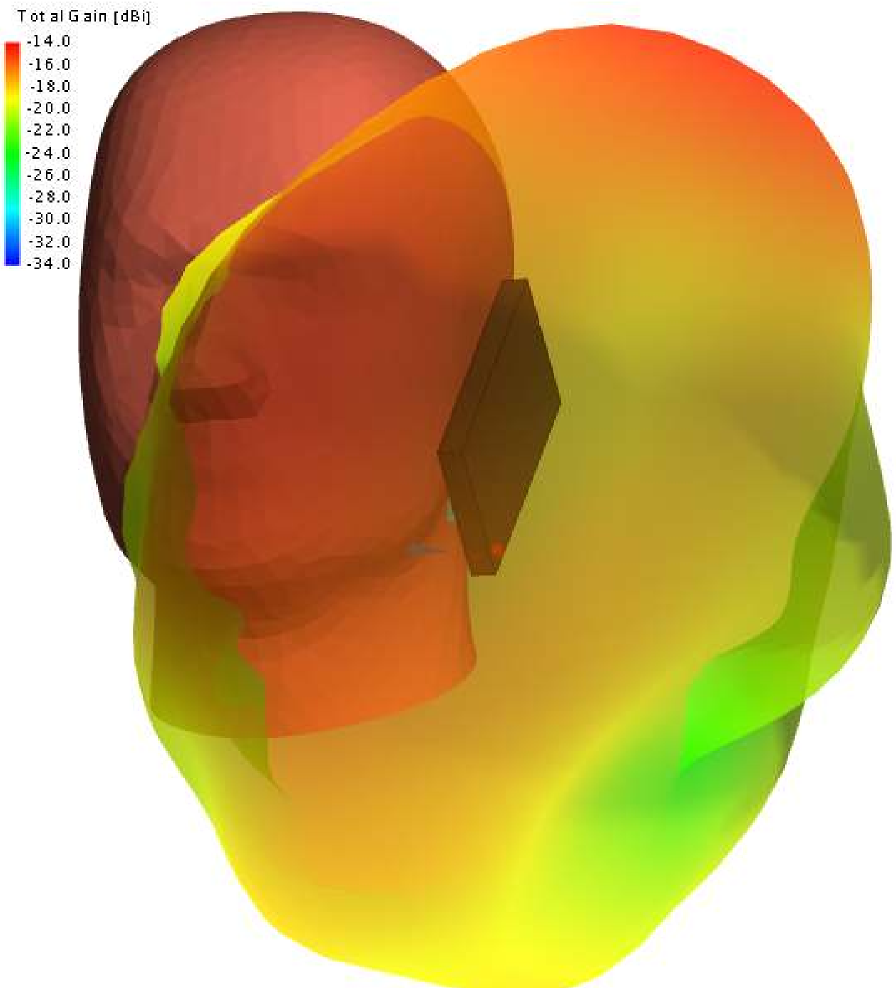
Dual Port ESA in Handset



Radiation pattern of the dual port antenna integrated into a mobile handset

At 2.6 GHz LTE frequency

Handset with Head



Radiation pattern of the handset when placed close to a head

At 2.6 GHz LTE frequency

Specific Absorption Rate

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Specific Absorption Rate (SAR)

$$\text{SAR} = \int_{\text{sample}} \frac{\sigma(\mathbf{r})|\mathbf{E}(\mathbf{r})|^2}{\rho(\mathbf{r})} d\mathbf{r}$$

σ is the electrical conductivity
E is the RMS electric field
ρ is the mass density

Units: Watts per kilogram (W/kg)

Average absorption of RF energy over a volume
(the Volume-average SAR)

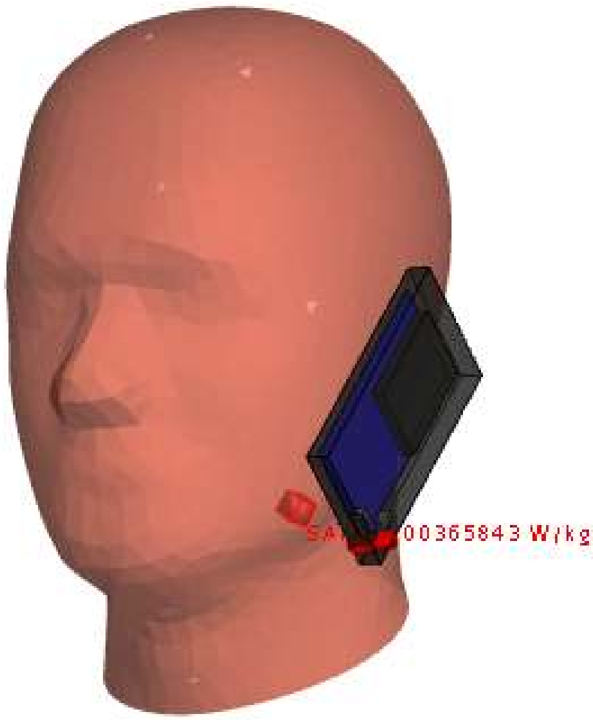
or

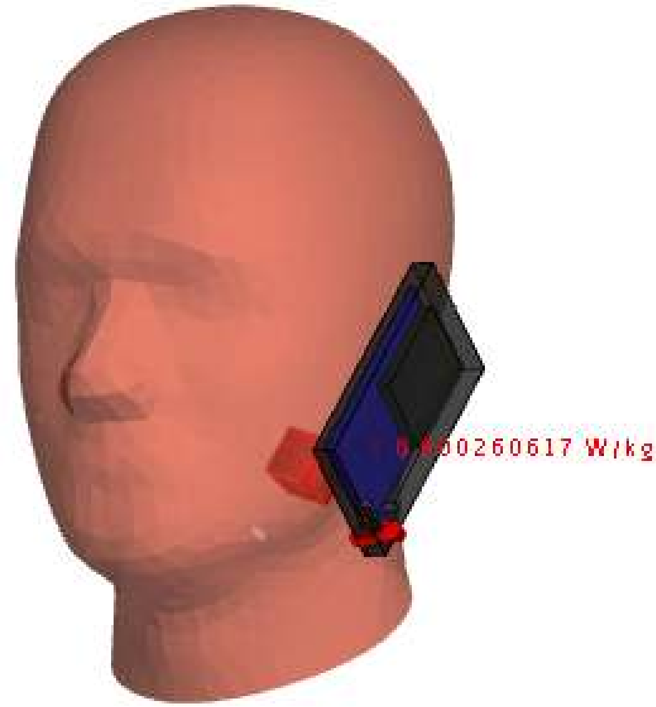
the maximum absorption in a 1 g or 10 g cube anywhere in a given volume
(the Spatial-peak SAR)

FCC regulations for SAR

- Working closely with federal health and safety agencies, the FCC has adopted limits for safe exposure to radio frequency (RF) energy
- The FCC requires cell phone manufacturers to ensure that their phones comply with these objective limits for safe exposure
- For Europe, the current limit is 2 W/kg for **10-g volume averaged SAR**
- For the United States and a number of other countries, the limit is 1.6 W/kg for **1-g volume-averaged SAR**
  - The lower U.S. limit is more stringent because it is volume-averaged over a smaller amount of tissue

SAR of 4G/LTE Handset





The volume averages SAR of 1 g cube (US standard) is 0.000365843 W/kg

The volume averages SAR of 10 g cube (European standard) is 0.000260617 W/kg

SAR of Popular Handsets

Phone	SAR (W/kg)
Apple iPhone 3G	0.878
Apple iPhone 3GS	1.100
Apple iPhone 4	0.930
Apple iPhone 4S	0.988
Samsung GT-i9000 Galaxy	0.268
Samsung GT-i9100 Galaxy SII	0.338
HTC Desire S	0.353
Sony Ericsson Xperia PLAY	0.360
Nokia 6700 Classic	0.410

The FCC limit for public exposure from cellular telephones is an SAR level of 1.6 watts per kilogram (1.6 W/kg)

http://www.sardatabase.com/

Channel Capacity

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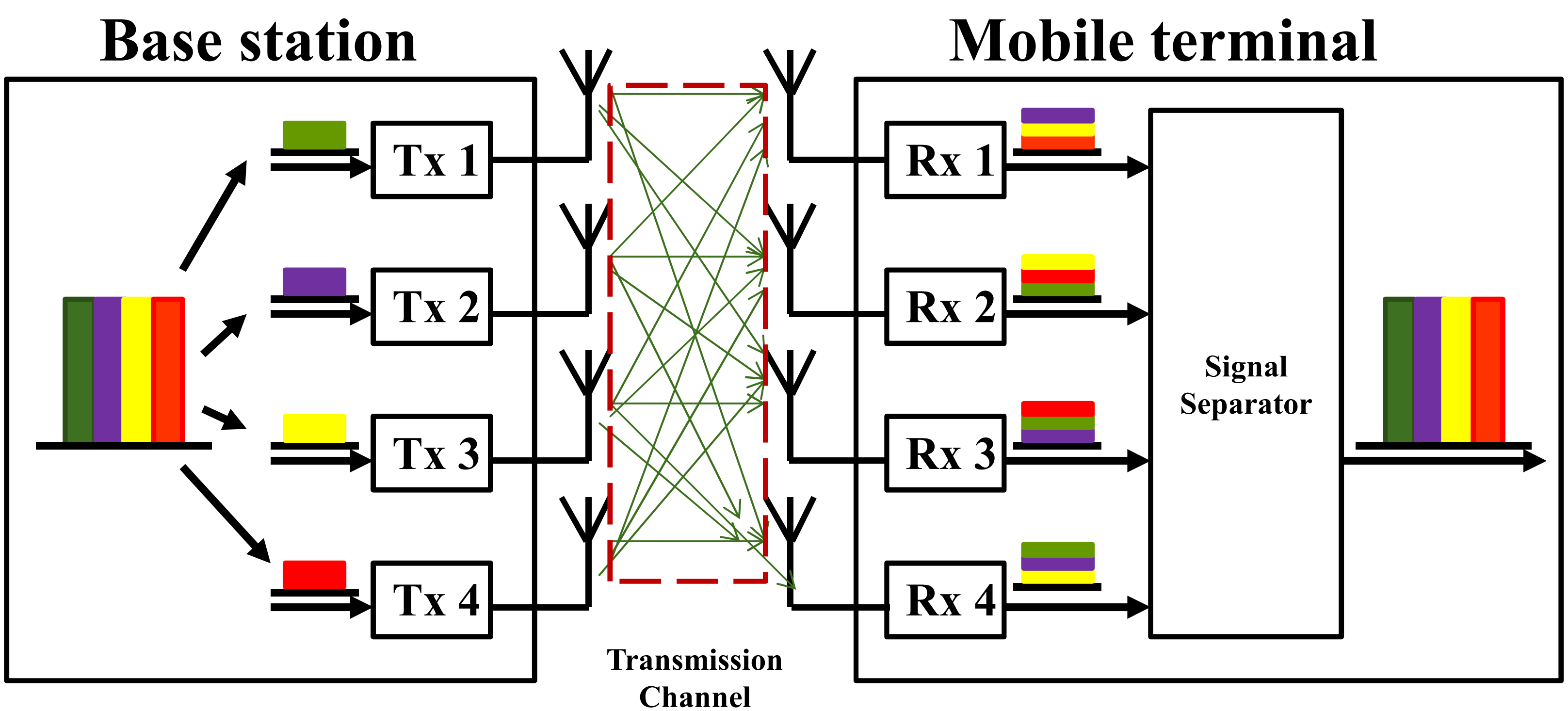
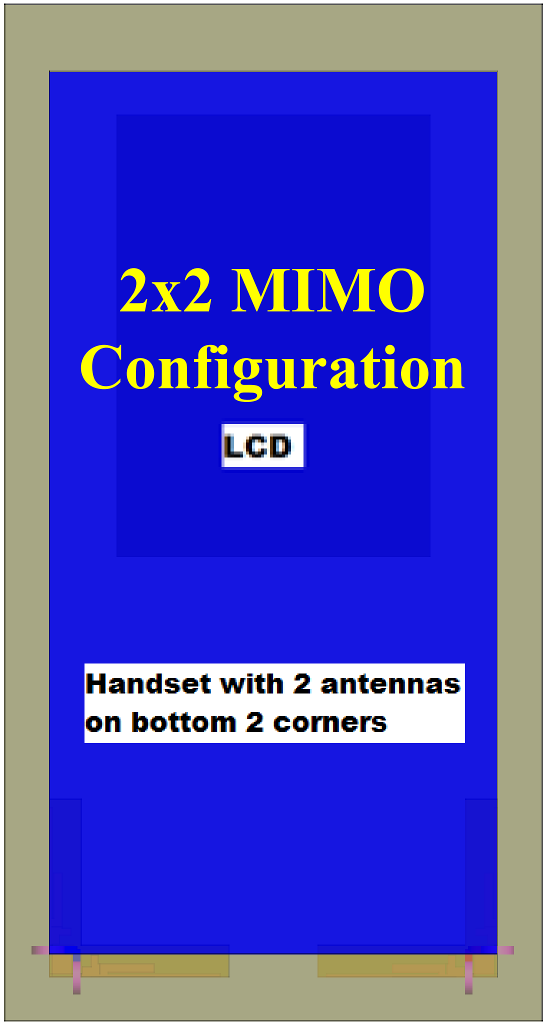
MIMO

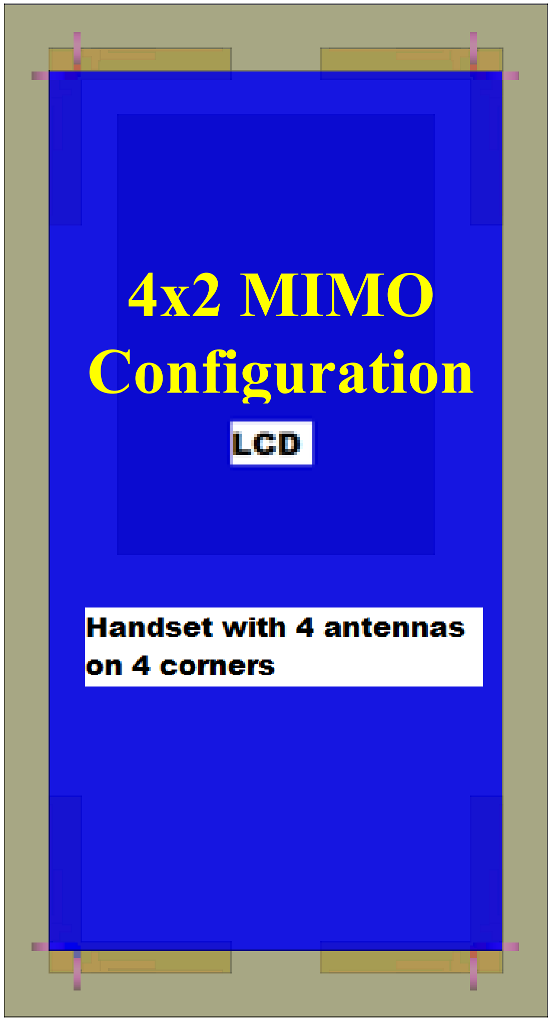
- **LTE standard allows multiple antennas on both ends of the wireless channel to support high data rate applications**
- **MIMO technologies have been widely used in LTE to improve downlink peak rate, cell coverage, as well as average cell throughput**



LTE MIMO Concept

MIMO Configurations





Top view of the handset

Channel Matrix

- **MIMO channel matrix describes the radio channel between each transmit and each receive antenna of the system**
- **Between every transmit antenna *m* and every receive antenna *n* of a MIMO system, the complex single-input-single-output (SISO) channel impulse response of length *L+1***

$$h_{n,m}(t) = \sum_{l=0}^{L} h_{n,m,l}(t)$$

- **The linear time-variant MIMO channel is represented by the channel matrix with dimension $N_R \times N_T$**

$$H(t) = \begin{pmatrix} h_{1,1}(t) & \dots & h_{1,N_T}(t) \\ \dots & \dots & \dots \\ h_{N_R,1}(t) & \dots & h_{N_R,N_T}(t) \end{pmatrix}$$

Channel Capacity

- **Channel capacity can be calculated from the 'channel matrices' obtained from measurements**

- **Alternatively,**
  - **The channel capacity is computed by post processing the ray data from a fixed transmitter in a certain environment (channel) for different positions of the receiver**

- **The channel capacity is computed as;**

$$C = \frac{1}{N_F} \sum_{l=0}^{N_F - 1} \log_2 \left(\det \left[I_{N_R} + \frac{\rho}{N_T} \cdot H_F(l) \cdot H_F(l)^H \right] \right) \text{ [bit/s/Hz]}$$

where,

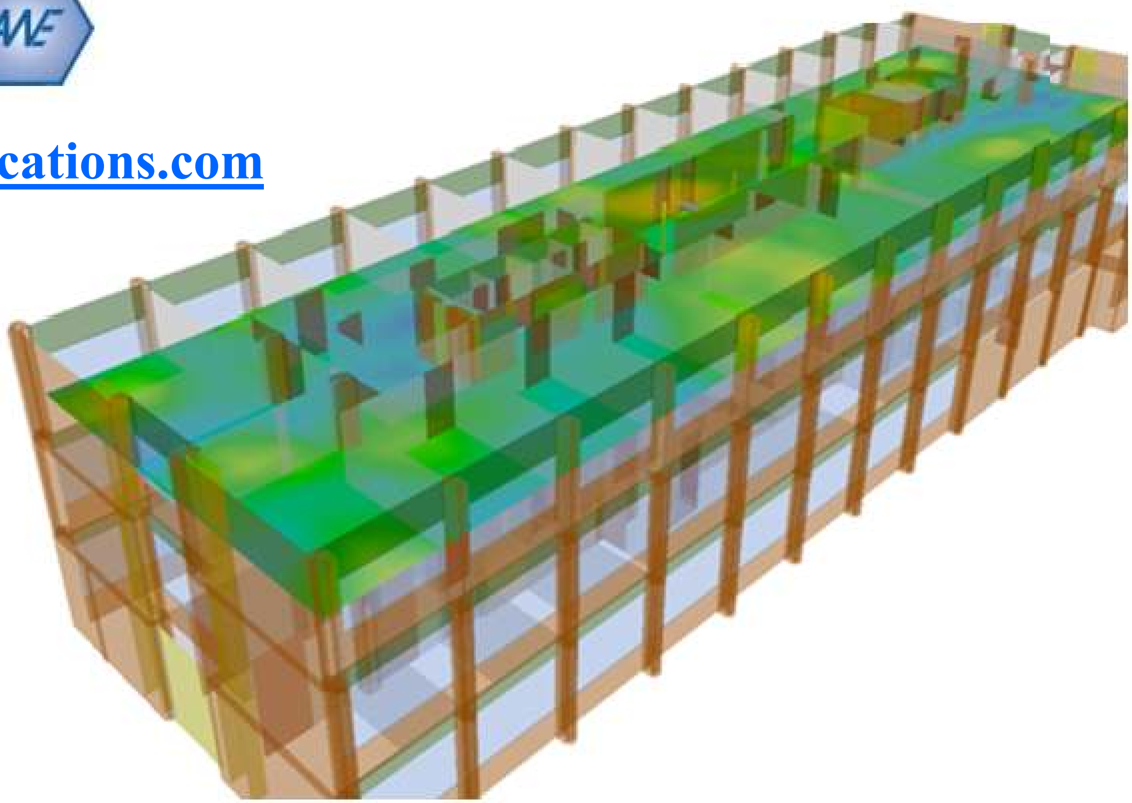
'H_F' is the channel matrix

'ρ' is the SNR

Indoor Environment

Commercial software 'WinProp' from AWE Communications is used to calculate the 'channel capacity'

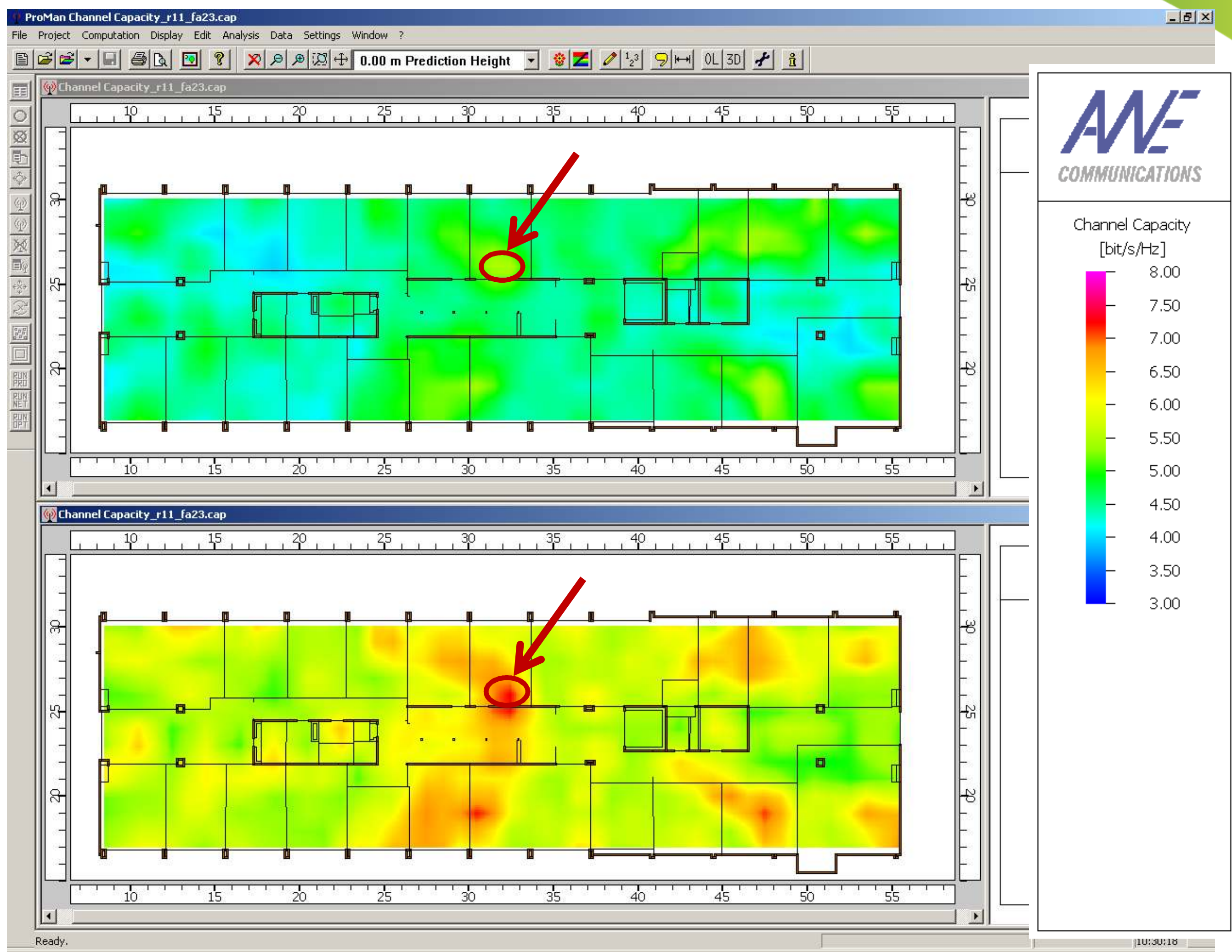
www.awe-communications.com



Channel Capacity in Indoor Environment

2x2 MIMO system
(antennas on bottom 2 corners of the handset)

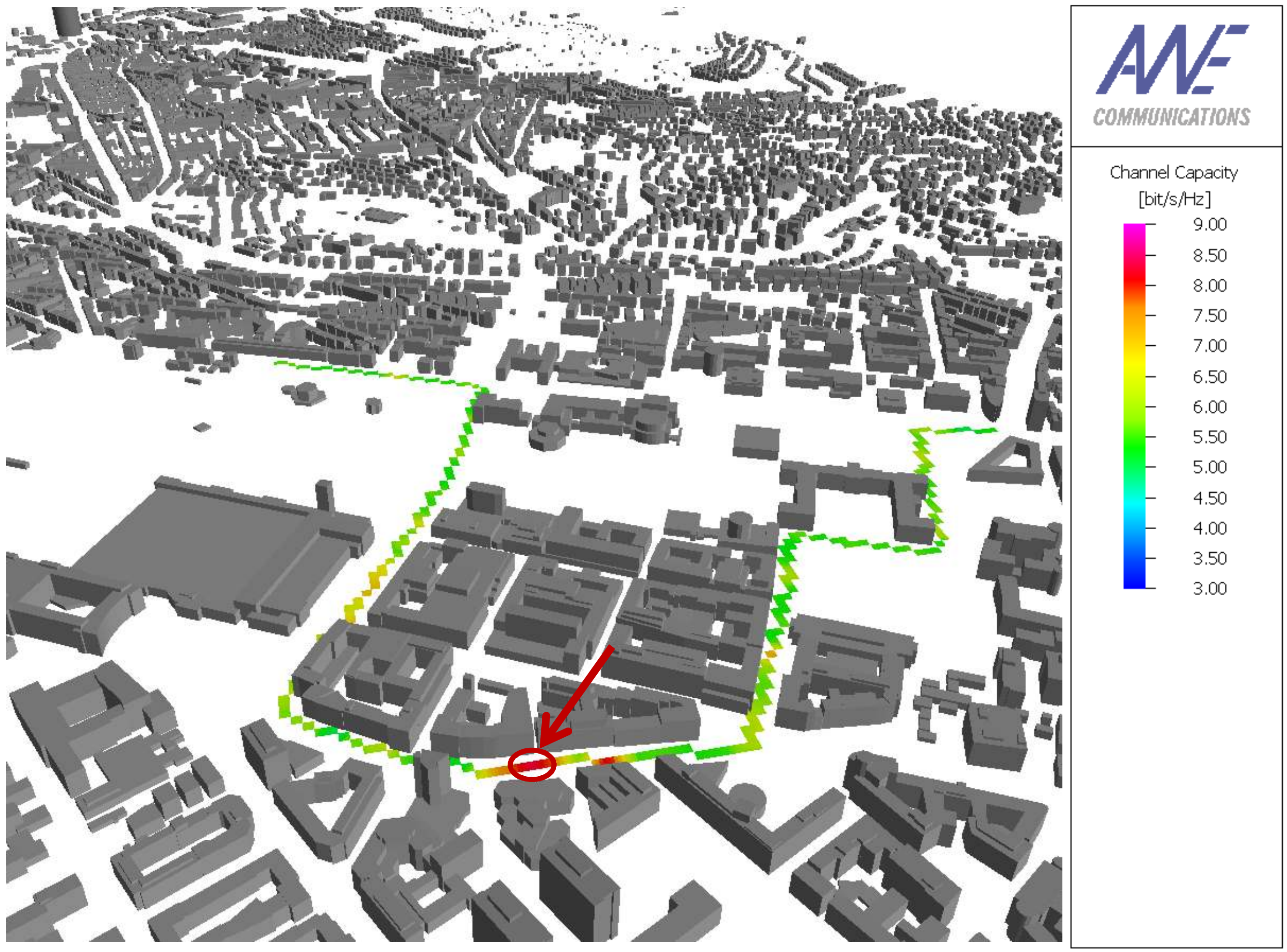
4x2 MIMO system
(antennas on 4 corners of the handset)



Channel Capacity in Urban Environment

Simulation along a trajectory in an urban area

Using 4 antenna elements on 4 corners as a 4x2 MIMO system



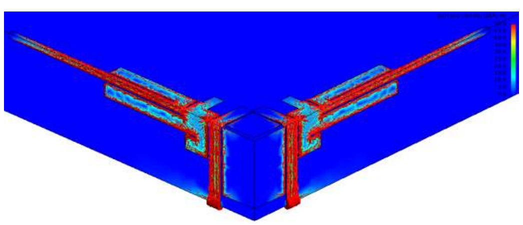
Conclusion

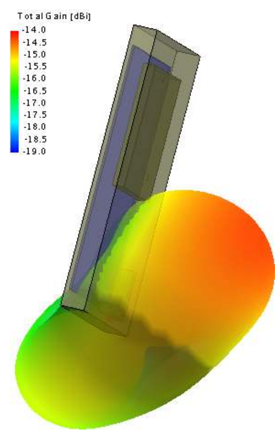
- **Challenges in designing an antenna for a LTE-MIMO system are discussed**

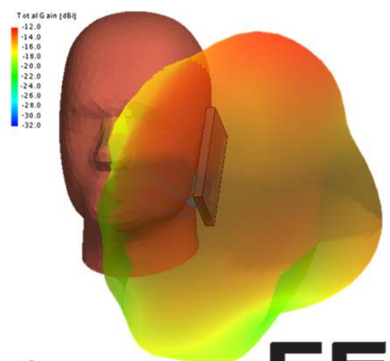
- **A novel dual port antenna for LTE-MIMO applications is introduced**

- **The performance of the antenna in a handset when placed close to a human head is analyzed from the radiation pattern**

- **The channel capacity of the novel antenna in a handset is computed in both indoor and urban environments**







Questions ??

AntennaMagus

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Version 3.3

FEKO

Comprehensive Electromagnetic Solutions

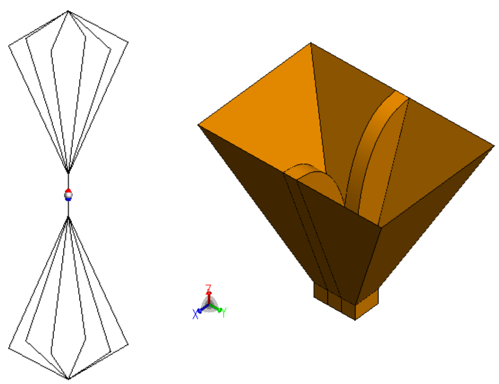
Design Parameters
Frequency,
Gain,
VSWR

Initial Geometry

EM Analysis

Optimization

Modification of Geometry



Final Geometry

Design Parameters
Frequency,
Gain,
VSWR

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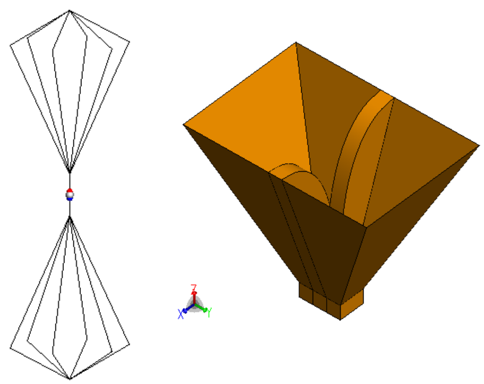

Final Geometry

FEKO – www.feko.info
Antenna Magus - http://www.feko.info/product-detail/antenna-magus

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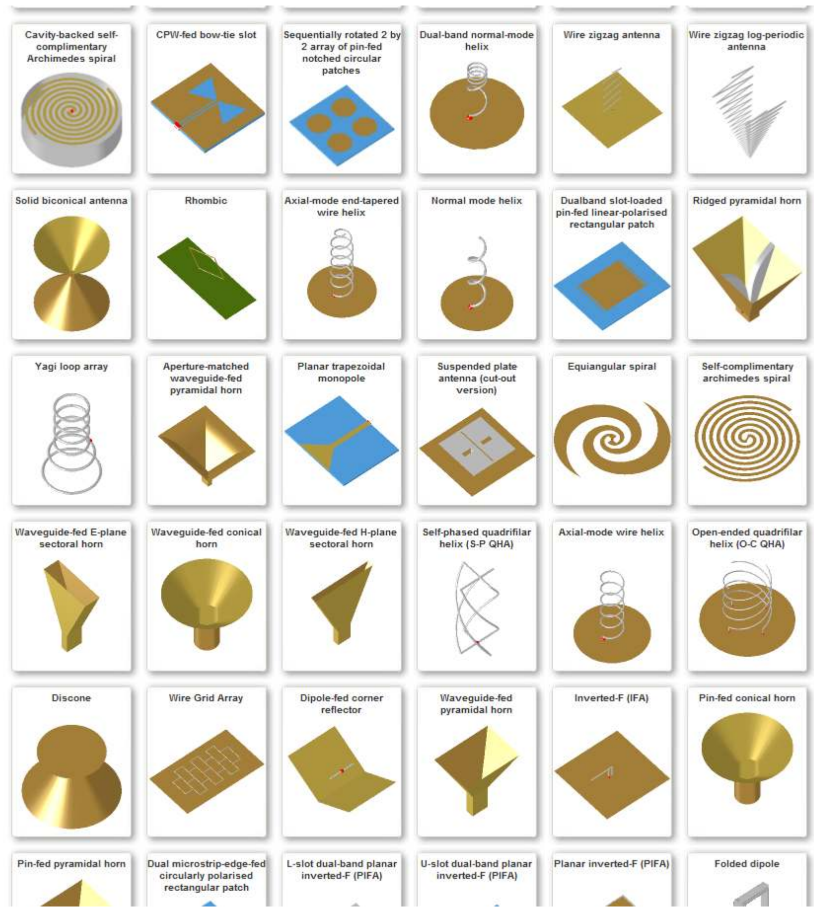
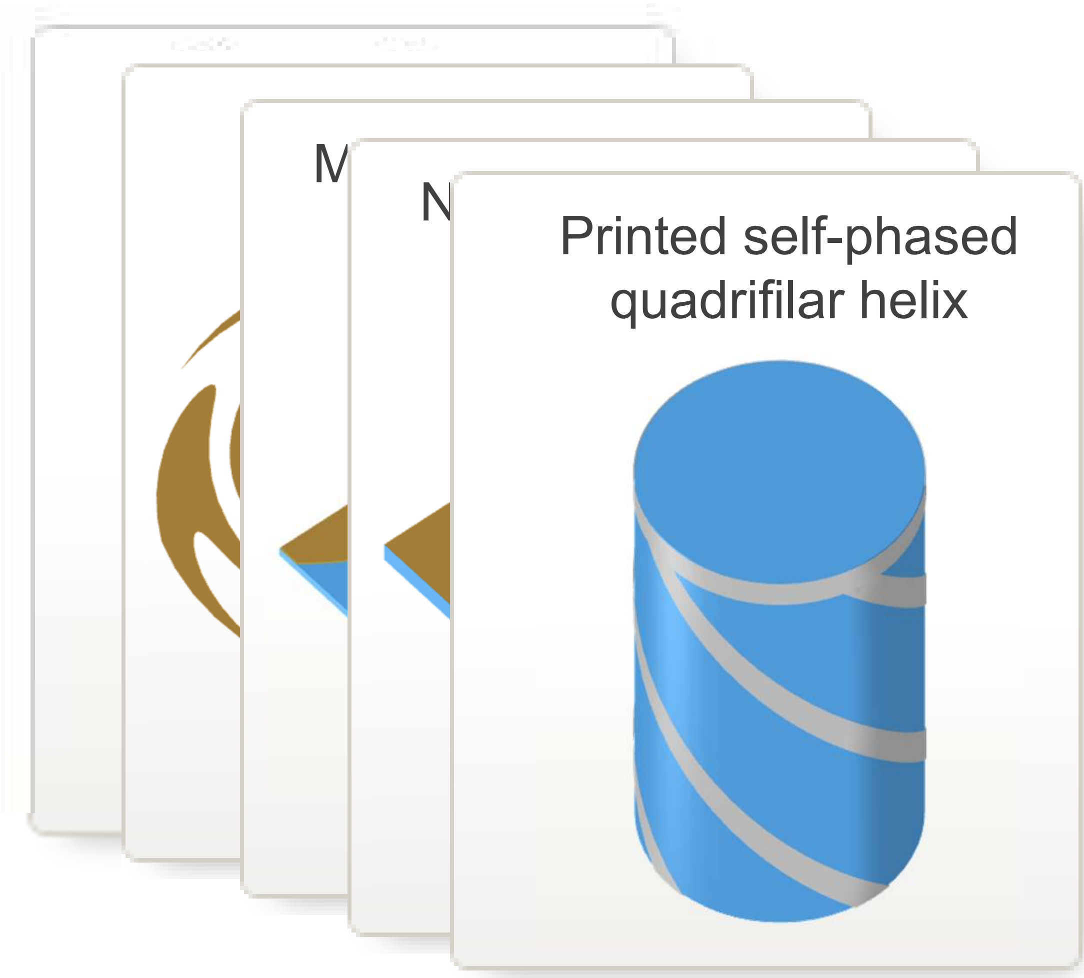
Extensive Antenna Database



More than 150 Antennas

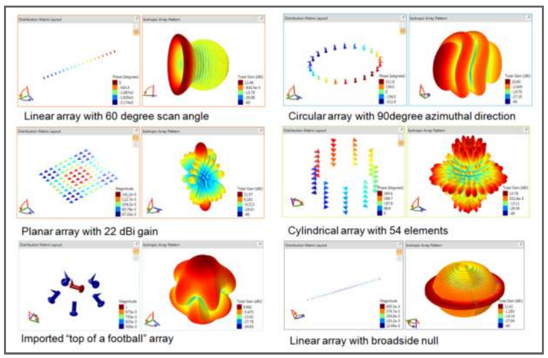
More complex, very useful additions



Engineering utilities

Tools

Array synthesis



Friis transmission equation

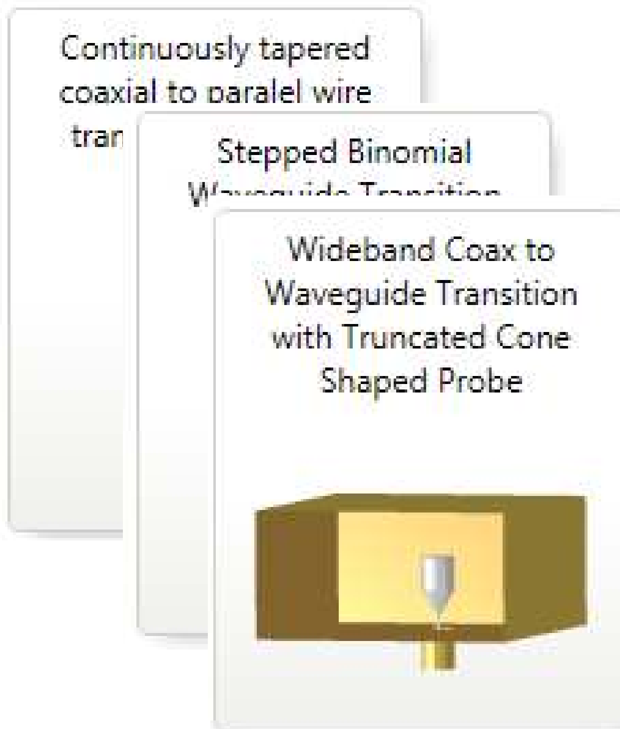
Radar range equation

Gain/Beamwidth Converter

Gain from a given Aperture

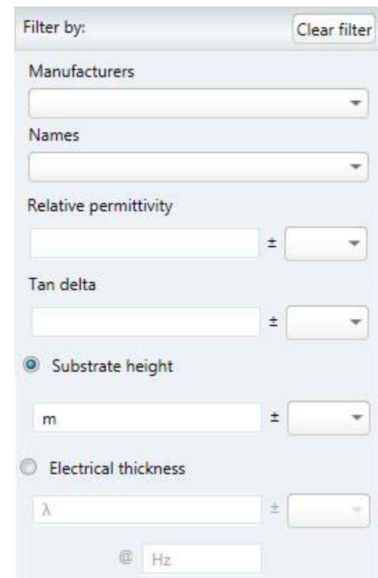
Charting Tool

Transitions



Libraries

- Substrates
- Waveguides

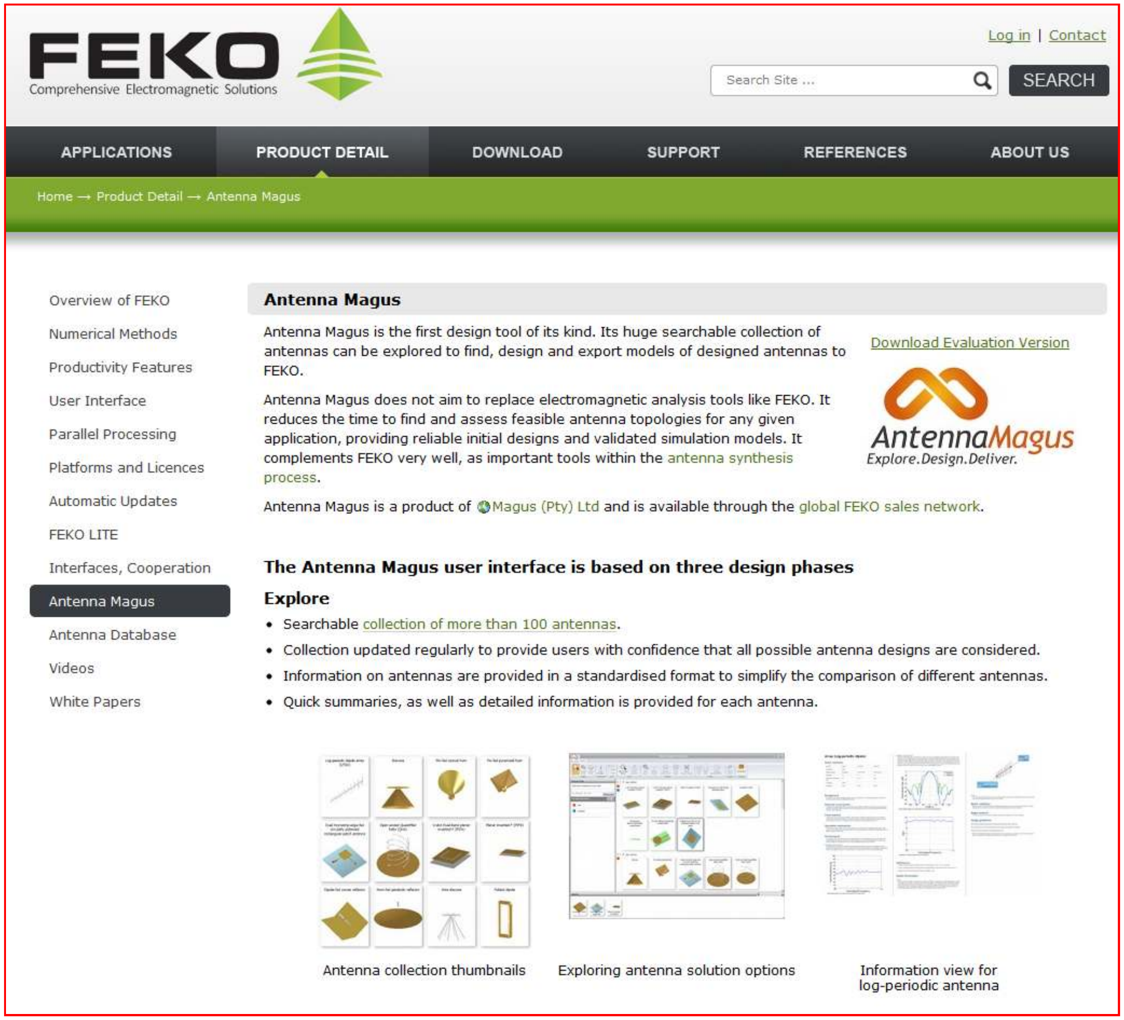


Evaluation

Free Evaluation Version can be downloaded from

www.feko.info/download

http://www.feko.info/product-detail/antenna-magus



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- Productivity Features
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- Parallel Processing
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- FEKO LITE
- Interfaces, Cooperation
- Antenna Magus
- Antenna Database
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Antenna Magus

Antenna Magus is the first design tool of its kind. Its huge searchable collection of antennas can be explored to find, design and export models of designed antennas to FEKO.

Download Evaluation Version

Antenna Magus does not aim to replace electromagnetic analysis tools like FEKO. It reduces the time to find and assess feasible antenna topologies for any given application, providing reliable initial designs and validated simulation models. It complements FEKO very well, as important tools within the antenna synthesis process.

Antenna Magus is a product of Magus (Pty) Ltd and is available through the global FEKO sales network.

The Antenna Magus user interface is based on three design phases

Explore

- Searchable collection of more than 100 antennas.
- Collection updated regularly to provide users with confidence that all possible antenna designs are considered.
- Information on antennas are provided in a standardised format to simplify the comparison of different antennas.
- Quick summaries, as well as detailed information is provided for each antenna.

Antenna collection thumbnails

Exploring antenna solution options

Information view for log-periodic antenna