Development of Software Package for Conformal Array Analysis

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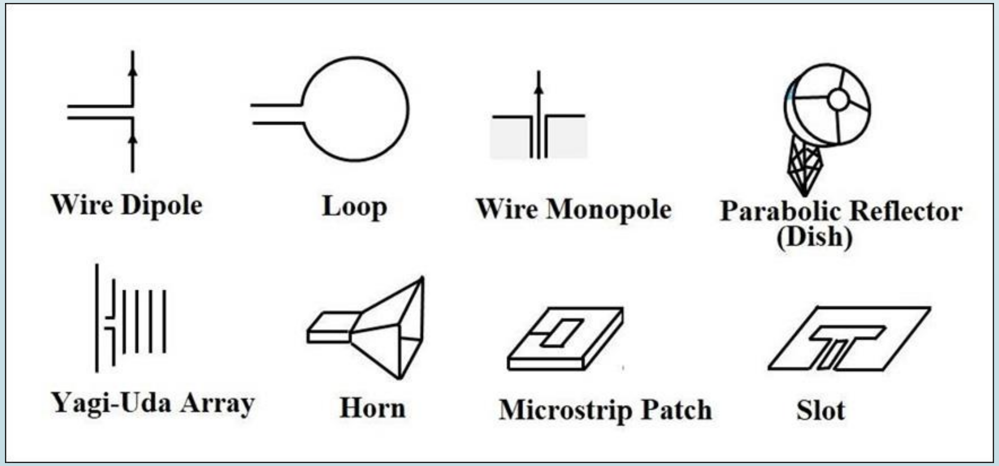
Introduction

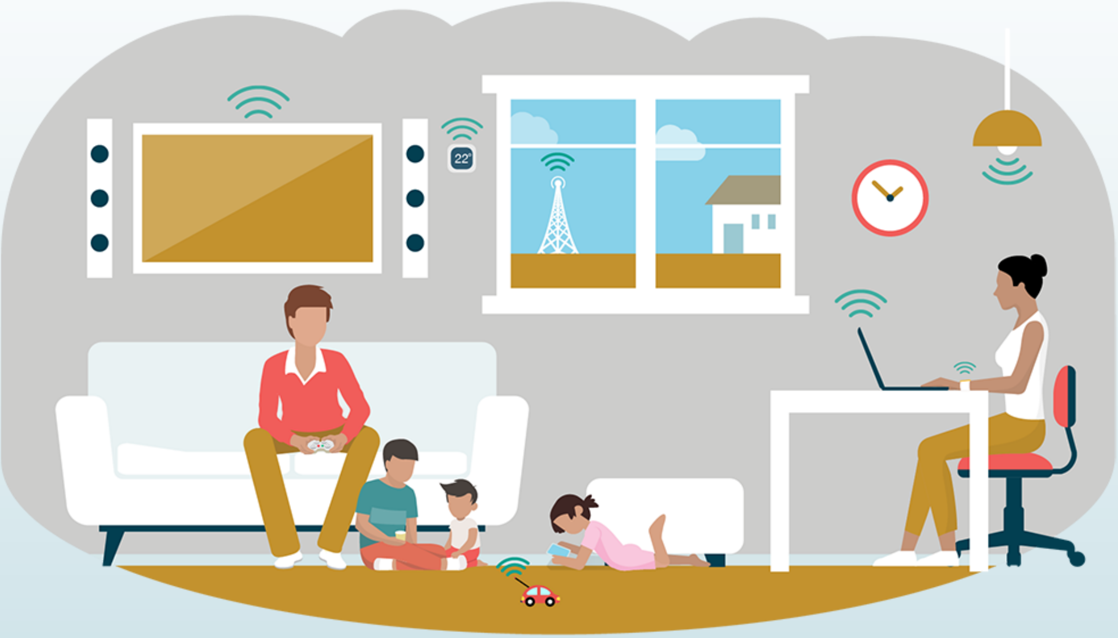
Antenna

- An antenna is a metallic structure that captures and/or transmits radio electromagnetic waves.
- Antennas come in all shapes and sizes from little ones that can be found on your roof to watch TV to really big ones that capture signals from satellites millions of miles away.
- Antenna systems are often required to have large apertures with significant radiated power levels, sensitive receive capability, and rapid beam scanning.
- While reflector antenna systems with single or multiple feeds can meet many requirements, phased array antenna systems with thousands of individual radiating antenna elements provide increased beam agility and graceful degradation.



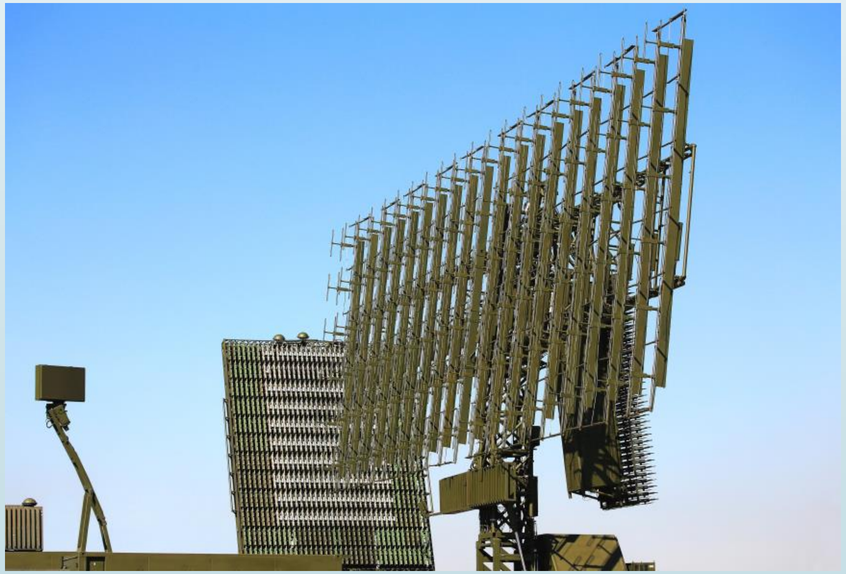
Importance of Antennas

- Antennas dominate our everyday life, and you are probably using an antenna right now if you're reading this article online.
- We often use antennas, especially when it comes to our mobile devices. There are at least four in your mobile phone and two on your computer.
- Apart from their popularity in TV broadcasting and home Wi-Fi network, they are also found in tablets, global positioning systems (GPS) in cars, highway toll devices and the security tag attached to merchandise.



Phased Array Antennas

- An antenna array is a radiating system, which consists of individual radiators and elements that are located on a planar or conformal surface.
- Phased array antenna systems with thousands of individual radiating antenna elements offer significant benefits over traditional antennas like:
  - Increased signal strength
  - Higher directivity
  - Reduced Minor lobes
  - Higher Signal-to-noise ratio
  - Higher gain
  - Lower power consumption
  - Better performance



Motivation

- Design of phased array antennas requires an iterative process of modeling, simulation, fabrication, and testing.
- Antenna array and the supporting electronics need to be designed and simulated using a 3D field solver and a circuit simulator, respectively.
- Simulating the antenna array itself is a tedious task.
- For example, the typical steps involved in simulating an antenna array using HFSS are as follows:
    1) Find an Antenna Unit Template Using the HFSS Antenna Toolkit
    2) Bring the Antenna Unit into an Antenna Array
    3) Design a Finite Antenna Array Using Doman Decomposition Method
    4) Calculate the Beam Angle of the Finite Antenna Array
    5) Design the Antenna Array’s Circuit
    6) Connect All Antenna Array Models into One Simulation
    7) Push the Antenna Array Excitations to HFSS
    8) Test the Antenna in Its Environment

RESPOND BASKET 2022

RES-ISTRAC-2022-006

Name of ISRO Centre/Unit
ISRO Telemetry Tracking and Command Network, Bengaluru

Title of the research proposal
Development of software package for conformal array analysis.

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Area of Research
Antennas and Radomes

Summary of the proposed research and expected deliverables

Spherical phased array antennas are useful for hemispherical coverage requirements in radar. But it has the disadvantages of manufacturing and alignment in a spherical surface with higher accuracy. For ease of realization, the geodesic dome phased array antenna is preferred which has the same advantage of hemispherical coverage with planar subarrays. This is technically and economically viable because the design avoids fabrication complexity associated with conformal array because the subarray fabrication is based on well-developed easily manufacturable planar array technology.

Scope of the Work:

- Development of GUI as per user requirement
- Various array geometry generation
- Importing the data file for single element antenna pattern from 3rd party software in standard formats
- Selection of active elements, beam steering inputs and computation for the radiation patterns accordingly

Deliverables:

- Software coding with GUI as per user requirement.
- Integrated Software Tool with Visualization

Literature Review

1. RadPat4W (2010)
   - Named after Radiation Patterns for Windows.
   - Support for Wine environment of Linux.
   - The tool uses by default the working formulas produced by the analysis method of the authors' alternative exposition of fundamental Antenna Theory.
2. ArrayTool (2015)
   - To examine and analyze the variety of radiation, it computes the radiation pattern in 2D and 3D space using the discrete/continuous Fourier transform.
   - The tool is designed to offer different levels of flexibility, including support for circular arrays with phase modes and linear-planar-circular arrays with varied nonuniform excitation coefficients, excitation phase, and element spacing.

Literature Review Contd.

3. MATLAB- Sensor Array Analyzer
   - Sensor Array Analyzer is an application developed for Matlab. It is supplied with the Phased Array System Toolbox.
   - This tool provide instruments to design and simulate beamforming system and sensor array to wireless communication, radar, sonar, acoustic and image diagnostic.
   - It is possibile to model and analyze active and passive array, included subarray and particular geometry.

Research Gap

- The tools develop till date are focused on analysing the radiation pattern for well-known array geometries like, rectangular, linear, circular planar, but not much attention is paid to developing tools that could support other geometries as well.
- Also, some of these don't support analysis using custom radiating elements.
- The major aspects that needs to improve include:
  - Support for arbitrary array geometry
  - Active element selection
  - Ease of usage

Objective

- The objective is to develop a python-based simulation software package for analyzing the 3-D radiation pattern of a randomly configured phased antenna array.
- The major features include:
  - A highly interactive and easy-to-use GUI
  - Ability to configure the antenna array layout
  - Active element selection
  - Beam steering specification
  - Importing array element radiation patterns from third-party software
  - Interactive 3-D pattern plots

Methodology

System Architecture (MVC)

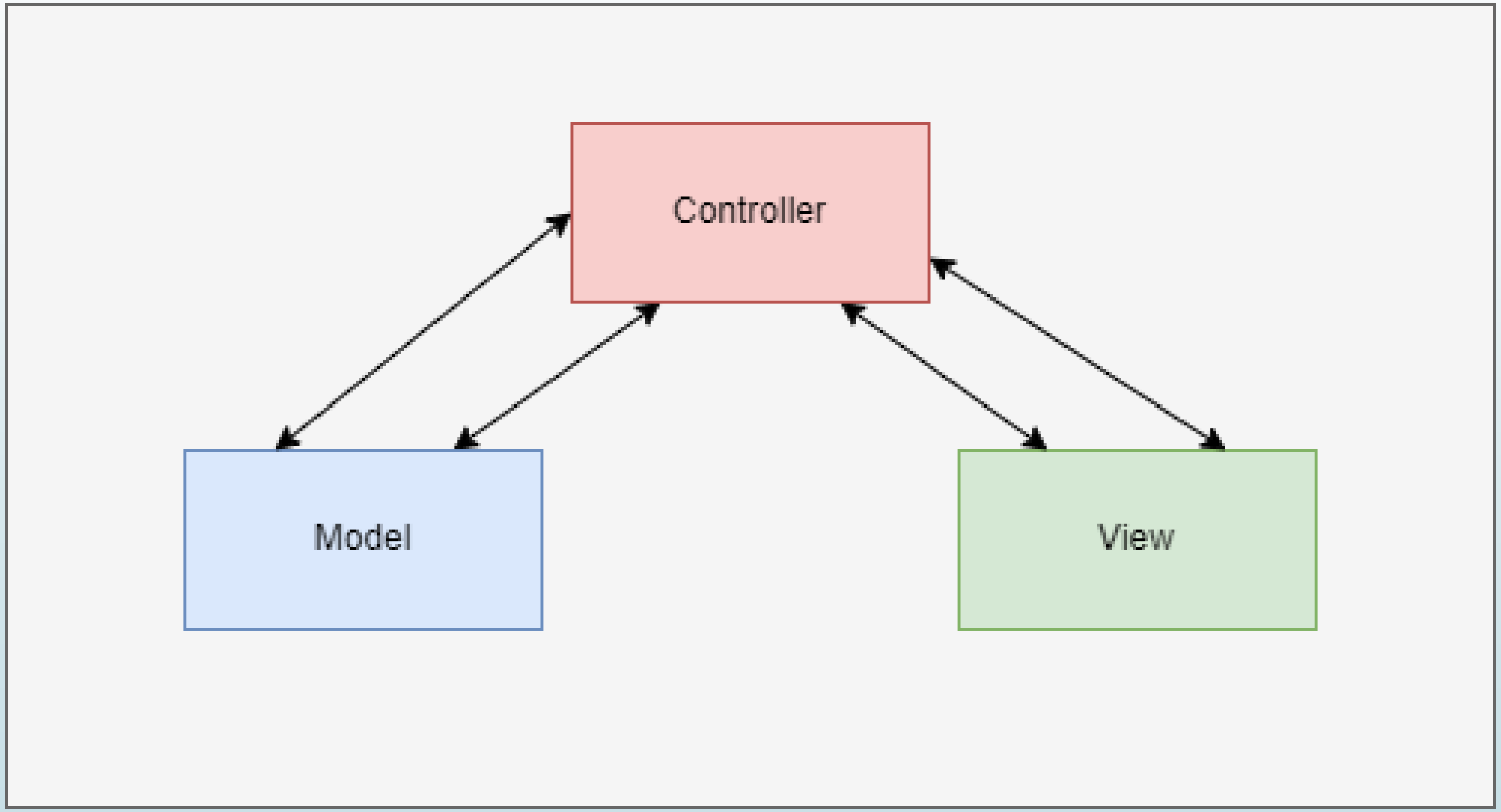


Fig.1 Model-View-Controller Architecture Diagram

Phased Array Antenna

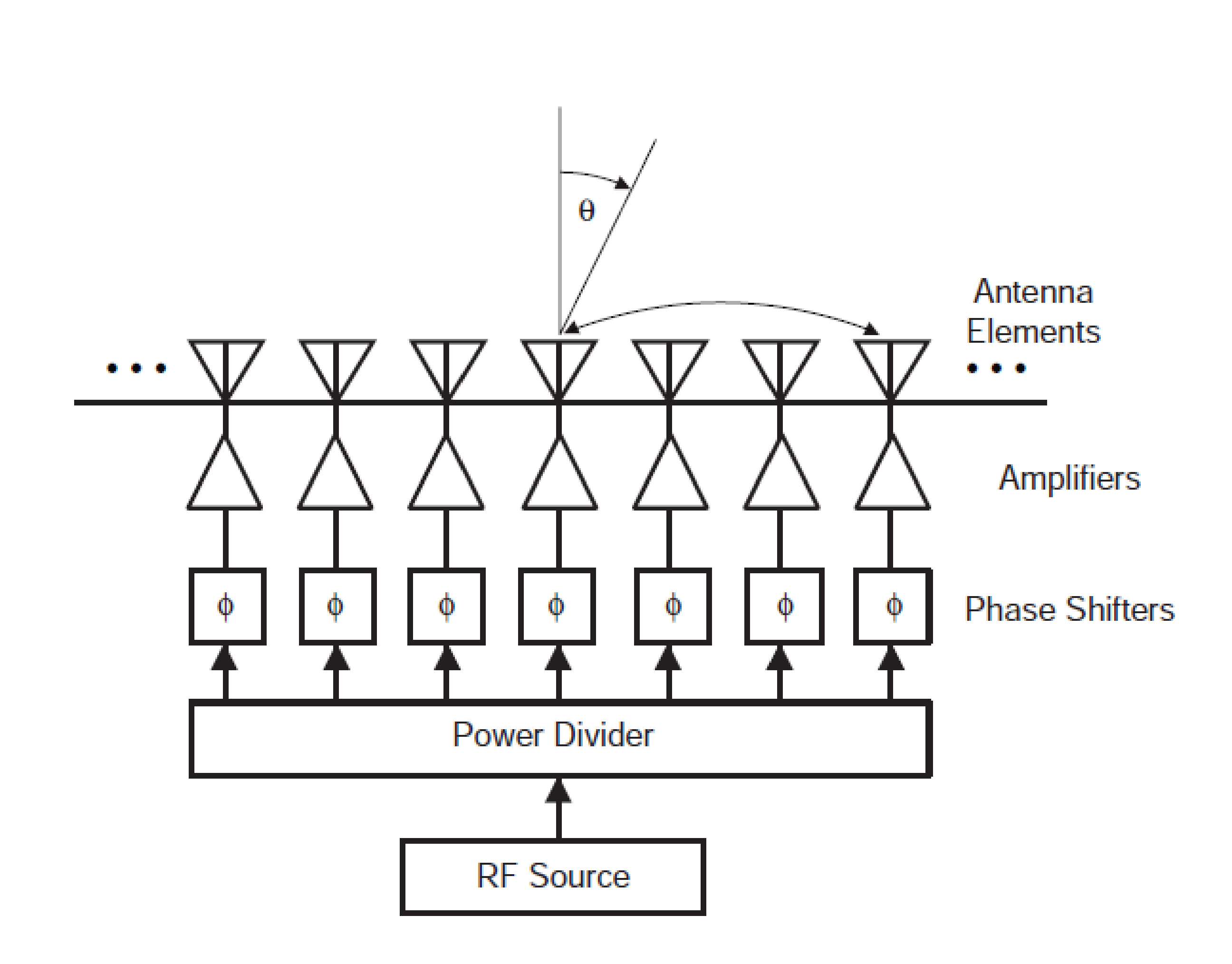


Fig.1 Block diagram of a transmitting phased array antenna

Working Principle

- Principle of Superposition of Waves

The superposition principle states that when two or more waves overlap in space, the resultant disturbance is equal to the algebraic sum of the individual disturbances.

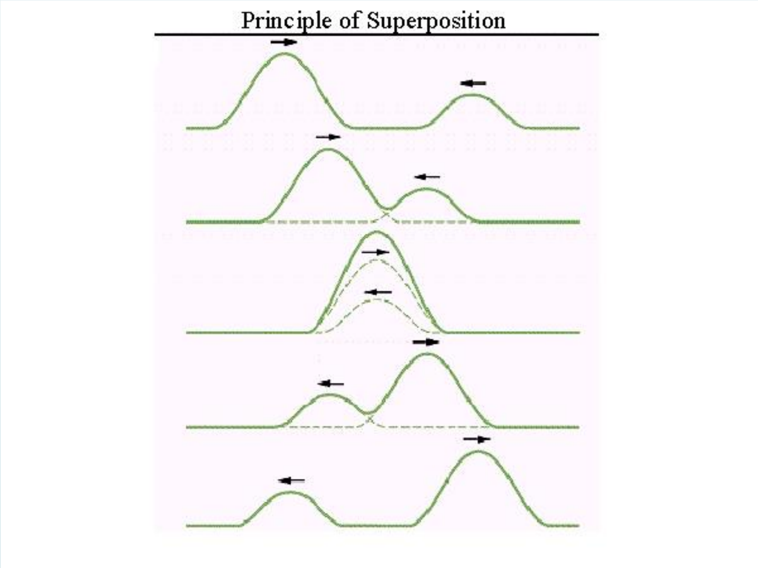


Fig.1 Principle of Superposition

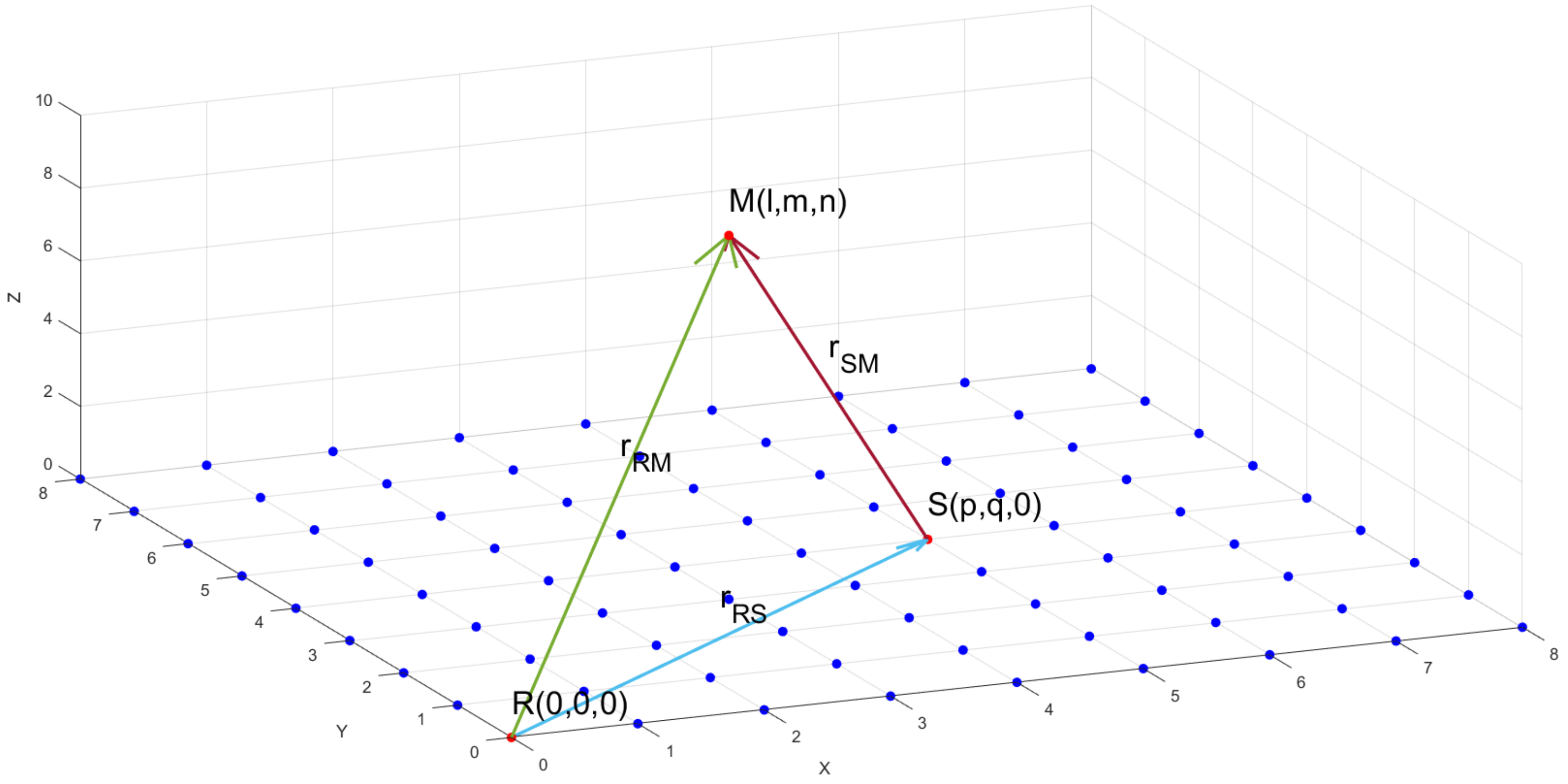
Working Principle Contd.

- Principle of Pattern Multiplication

The pattern multiplication principle states that the radiation pattern $P(\theta,\varphi)$, of an array of N identical antennas is equal to the product of the element pattern $P_e(\theta,\varphi)$ (pattern of individual antennas) and the array factor AF, where AF is the pattern obtained upon replacing all of the actual antennas with isotropic sources.

$$P(\theta,\varphi) = P_e(\theta,\varphi) \times AF$$

Antenna Array Layout



Working Formula

$$M(\theta,\varphi) = \left| m(t) \cdot S_e(\theta,\varphi) \cdot e^{j\omega_\circ t} \cdot \left(\sum_{i=1}^{N} w_i \cdot e^{jk(p_i(u-u_s)\hat{x}+q_i(v-v_s)\hat{y})} \right) \right|$$

where,

$u = \sin\theta \cos\varphi,$

$\mathrm{v} = \sin\theta \sin\varphi,$

$u_s = \sin\theta_s \cos\varphi_s,$

$v_s = \sin\theta_s \sin\varphi_s,$

$M(\theta,\varphi)$, represents the radiation pattern of the antenna array along (θ,φ) direction,

$S_e(\theta,\varphi)$, represents the radiation pattern of the individual antenna element, and

$\sum_{i=1}^{N} w_i \cdot e^{jk(p_i(u-u_s)\hat{x}+q_i(v-v_s)\hat{y})}$, represents the Array Factor of the array

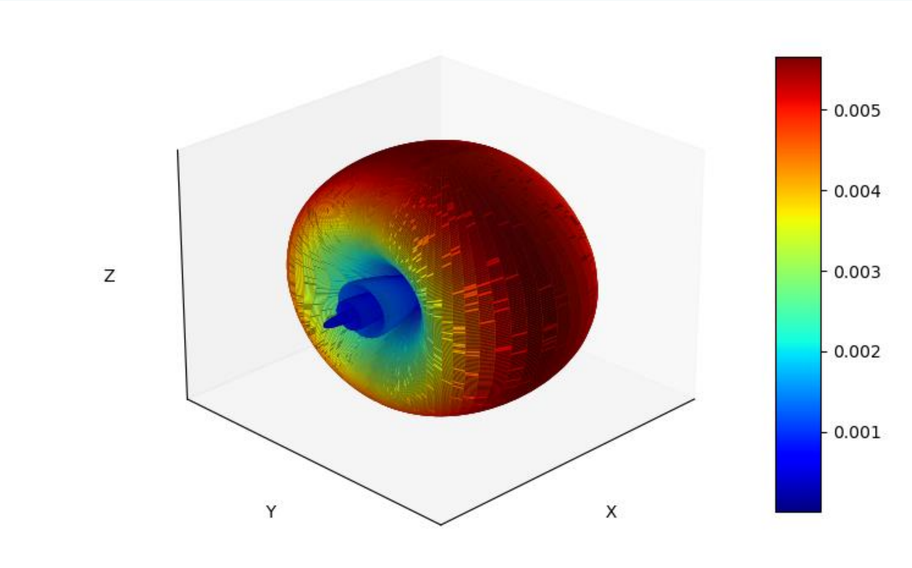
Results

The subsequent slides presents a comparison of the output generated by the proposed software and the MATLAB-Sensor Array Analyzer for some regular antenna array geometries.

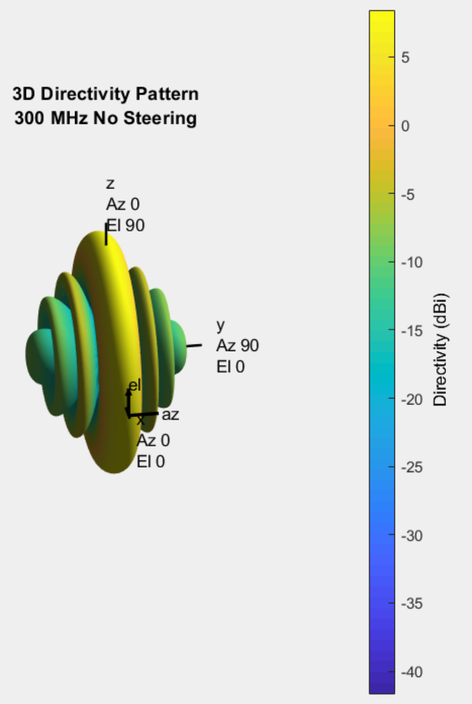
Results Contd.

3D radiation pattern for linear array antenna (separation = 0.5λ, N = 7)

Generated Output



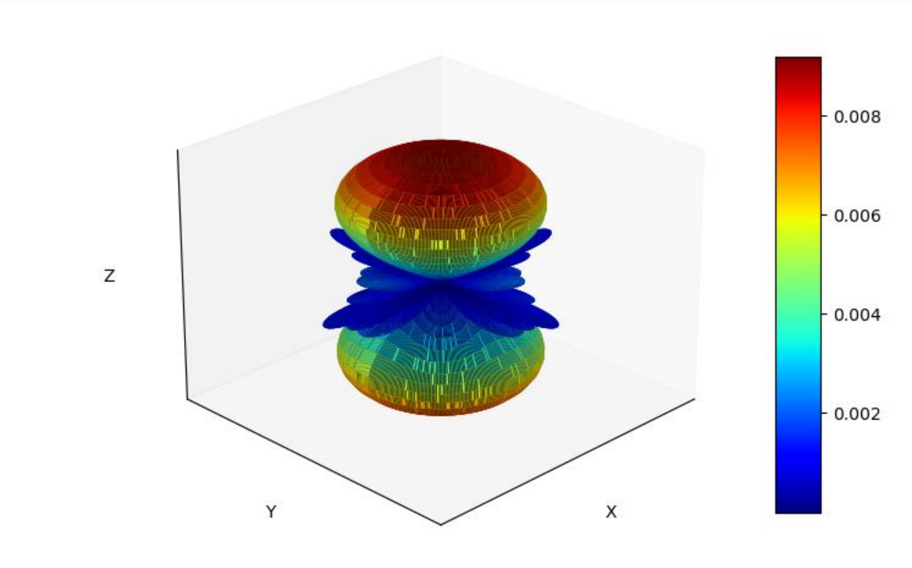
MATLAB-SAA Output



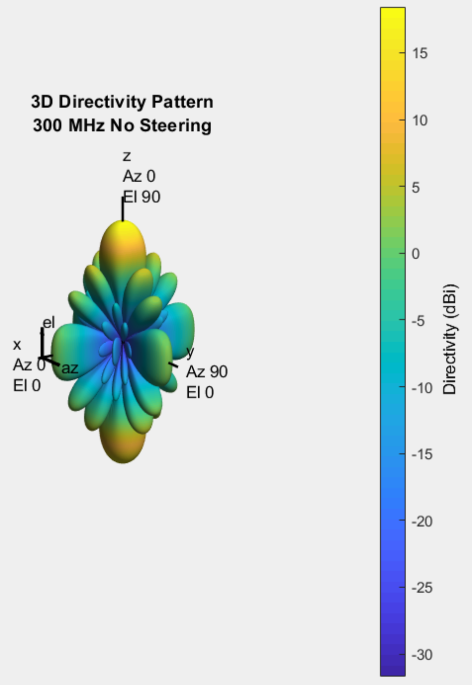
Results Contd.

3D radiation pattern for rectangular array antenna (separation = 0.5λ, Dim = 7×7)

Generated Output



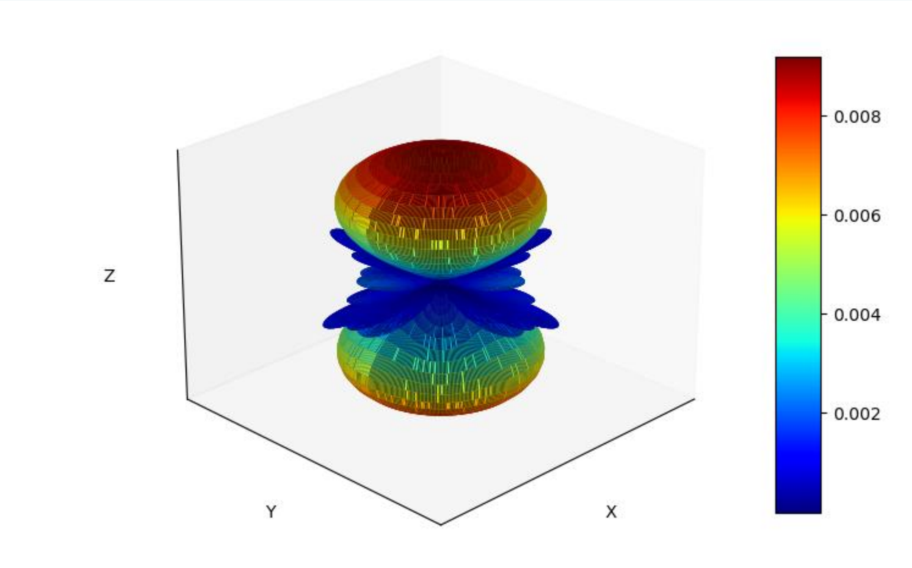
MATLAB-SAA Output



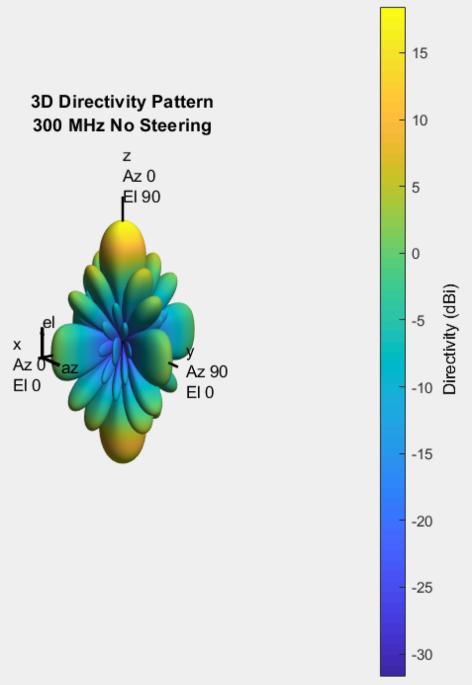
Results Contd.

3D radiation pattern for circular planar array antenna (separation = 0.5λ, R = 2λ)

Generated Output



MATLAB-SAA Output



Conclusion

- The proposed software is developed using Python and works on the Principle of Superposition of Waves and the Principle of Pattern Multiplication.
- As evident from the results presented here, the software tool performs considerably well and produces outputs comparable to those produced by the MATLAB-Sensor Array Analyzer.
- The software offers greater flexibility and ease of usage, which come in handy while testing for any planar antenna array.
- Overall, coupled with an interactive GUI, the software is a breakthrough in the field of Analysis tools, offering great flexibility and better user experience while sustaining quality and accuracy standards.
- In essence, the tool conforms to the requirements specified in the objective and generates justifiable results.

Future Scope

- With the advent of 5G technology, the use of phased array antennas has witnessed a huge surge, thus, the need for tools like the one proposed here is deemed to increase.
- The software currently relies on mathematical modeling to obtain the radiation pattern of the array antennas using the Principles of Superposition of Waves and the Principle of Pattern Multiplication, which is somewhat time-consuming. In future, it could be extended to use some AI-based techniques to generate outputs quickly and to enable adaptive beamforming.

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Thank you