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A Review of Full-Wave and Reduced-Order Modelling Methodologies for Dense Aperture Arrays

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Outline

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Introduction

- Two main topologies being investigated for SKA Mid-frequency Aperture Arrays
  - Vivaldi Array
  - Octagonal Ring Antenna (ORA)
- Numerical Simulations necessary to conduct a thorough investigation of structures
- Different Modelling Methodologies are presented

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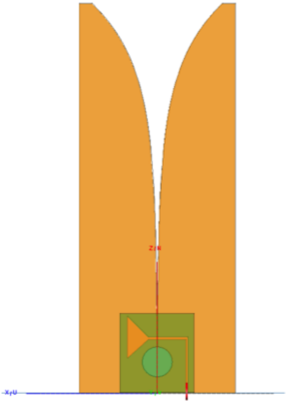
Microstrip-fed Vivaldi Array



- Full-wave analysis of large antenna arrays is challenging
- Microstrip-fed Vivaldi Array
  - Intricate Structure
  - Finite, Localised Dielectric
- Decompose structure into electrodynamic and electro-static field models, then solve seperately[a]

[a] Method Proposed by Rob Maaskant et al.

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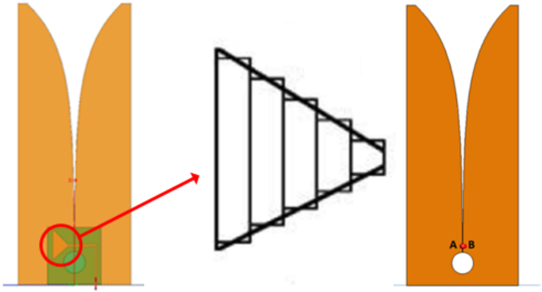
Microstrip-fed Vivaldi Array *(cont.)*

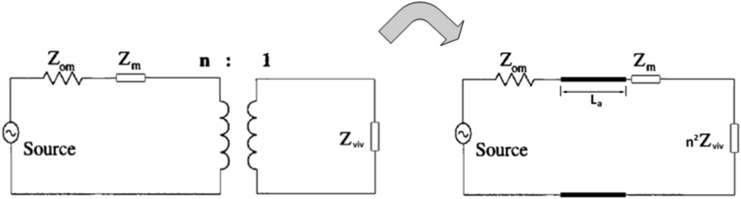


Decomposition of Microstrip-Fed Vivaldi:

- Impedance stub modelled by cascaded series of transmission lines with varying width
- Vivaldi Element excited by voltage-gap generator
- Impedance calculated between A and B, the exact position of the transition

Microstrip-fed Vivaldi Array *(cont.)*

Equivalent Circuit Model and Parameters:



- Z_{om} Characteristic Impedance of Microstrip line
- Z_m Impedance of Microstrip stub
- Z_{viv} Impedance of Vivaldi element as seen from transition
- n Transformation Coefficient
- L_a Length of transmission line between the feed and the transition

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Microstrip-fed Vivaldi Array *(cont.)*

Transformation Coefficient Calculation

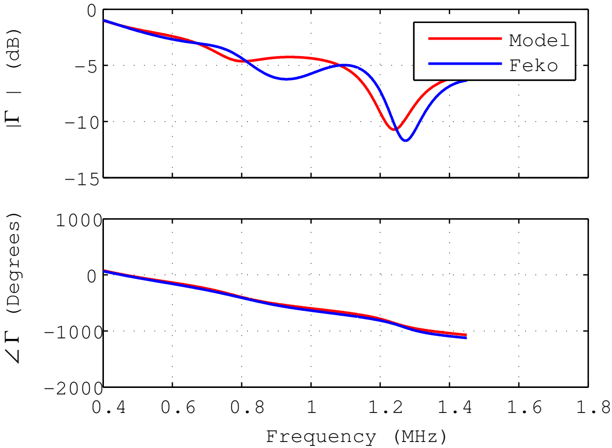
$$\Gamma = \frac{n^2 Z_{viv} + Z_m + jZ_{om}\tan(\beta L_a) - Z_{om} - j(n^2 Z_{viv} + Z_m)\tan(\beta L_a)}{n^2 Z_{viv} + Z_m + jZ_{om}\tan(\beta L_a) + Z_{om} + j(n^2 Z_{viv} + Z_m)\tan(\beta L_a)}$$

Transformation Coefficient:

- Represents coupling between microstrip and slotline
- Links electrodynamic and electrostatic field models
- Will stay constant as long as physical geometry of transition and frequency range stay constant
- Result for single element can be directly applied for array analysis

Microstrip-fed Vivaldi Array *(cont.)*

Results for Single Element:



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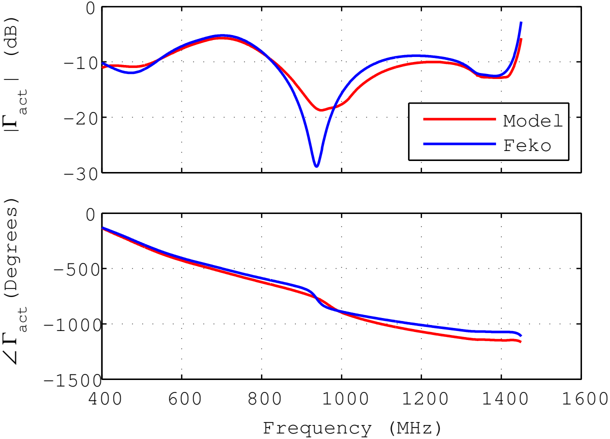
Microstrip-fed Vivaldi Array *(cont.)*

Results for 4×4 **Array at Broadside:**



Microstrip-fed Vivaldi Array *(cont.)*

Runtime and Memory Usage Statistics for 4×4 Array[1]:

Method	Runtime (Hours)	Memory Usage (GByte)
Feko MoM	543.4	15.1
Model	30.3	1.2

[1] Simulations run on 12-Core Intel Xeon with 256 GB of RAM

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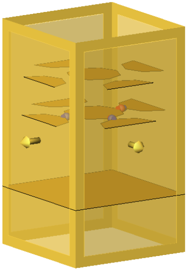
Infinite Array Approximation

- Proposed Dense Aperture Array Topologies are large regular structures
- Periodic Boundary Conditions (PBC) can be used to approximate structures as infinite structures
- PBC also suited to model implementations of Wheeler's Infinite Current Sheet Array
  - Instead of building up array of separate elements, infinite planar structure of electric current sources is designed as a whole
  - Scaled down to finite structure
  - Strong mutual coupling between elements are used to widen bandwidth
  - Example of CSA implementation with dual polarisation is the Octagonal Ring Antenna (ORA)

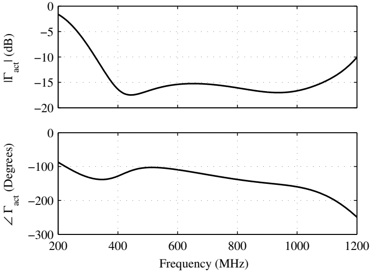
Infinite Array Approximation *(cont.)*

Simple ORA Unit Cell:



Note: PEC “Plates” in free space with no dielectric

Γ_{act} at Broadside



Infinite Array Approximation *(cont.)*

Runtime and Memory Usage Statistics for MS-Fed Vivaldi and ORA using PBC:

Topology	Runtime (Hours)	Memory Usage (GByte)
Vivaldi	84.6	0.58
ORA	0.032	1.58

- Runtime for Vivaldi is significantly higher than that of ORA
  - Vivaldi is intricate structure composed of both finite dielectrics and metal
  - ORA is simple, planar structure with no dielectric

Infinite Array Approximation *(cont.)*

General Comments:

- Accuracy of this method improves as the size of the array increases
- For very large arrays, this method will be more time- and memory efficient than those discussed in previous section.

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Domain Green's Function Method

- The Domain Green's Function Method (DGFM) is a deviation from the infinite array solution for large, phase-steered arrays
- Current on each element is assumed to be identical except for complex scaling value
- Results in compression of impedance matrix to obtain scan-impedance matrices which accounts for mutual coupling between active elements
- Dramatic improvements in memory usage and runtime have been illustrated for disjoint arrays
- Expansion of the method for connected elements is currently under development

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Conclusion

- Various full-wave and reduced-order methodologies were reviewed
- Accuracy, runtime and memory usage is determined by:
  - Type of element
  - Materials used (is it a mixture of metal and dielectrics)
  - Size of the array

Questions. . .

Thank You for listening!