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Design of End-fire Antennas on Laminated Substrate

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Outline

- Introduction
  - Goal
  - LTCC technology
  - Radiating element for chosen array architecture
- Models for HFSS
  - Non-radiating laminated waveguides
  - Radiating laminated waveguides
- Results
  - Simulation with HFSS
  - Measurements

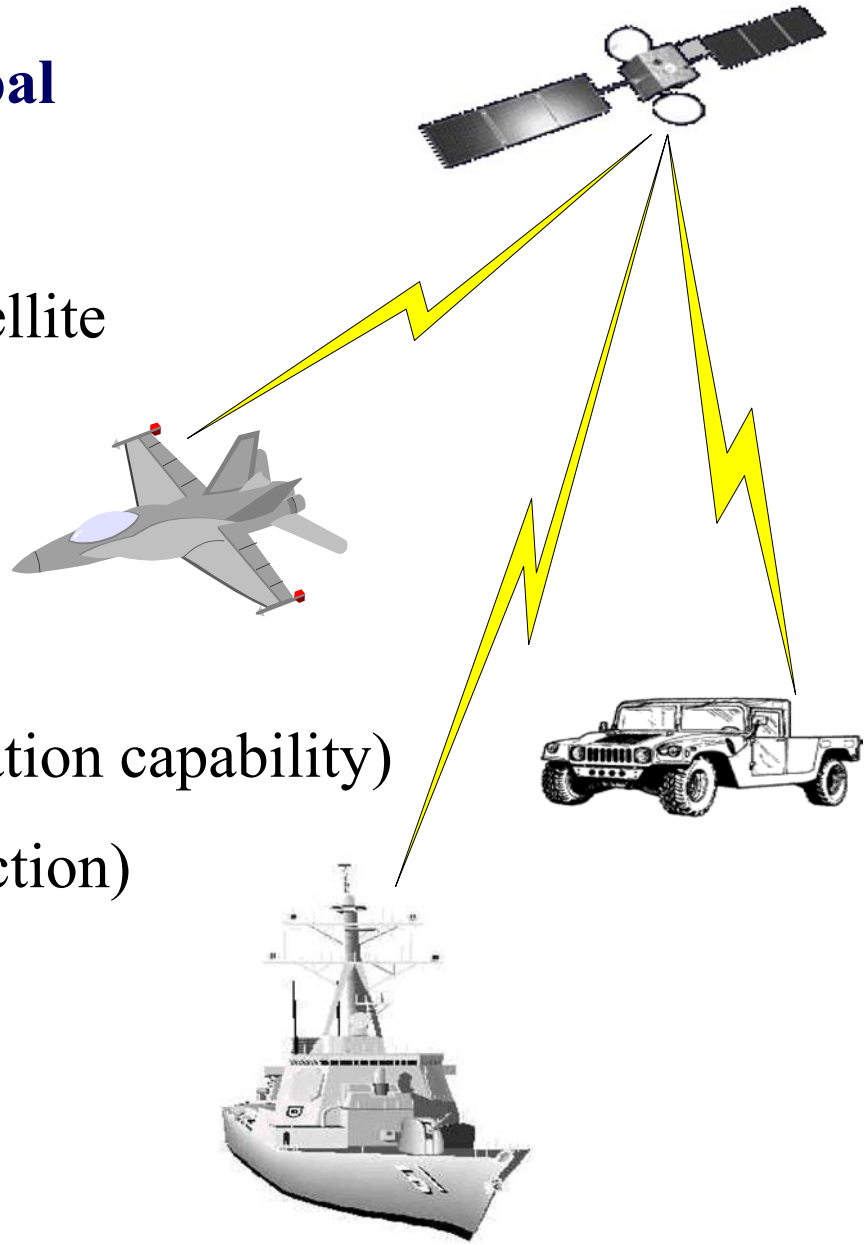
Introduction - Goal

Realise phased arrays for satellite communications

- 20 GHz downlink
- 44 GHz uplink

⇨ Compactness (high integration capability)

⇨ Low cost (for mass-production)

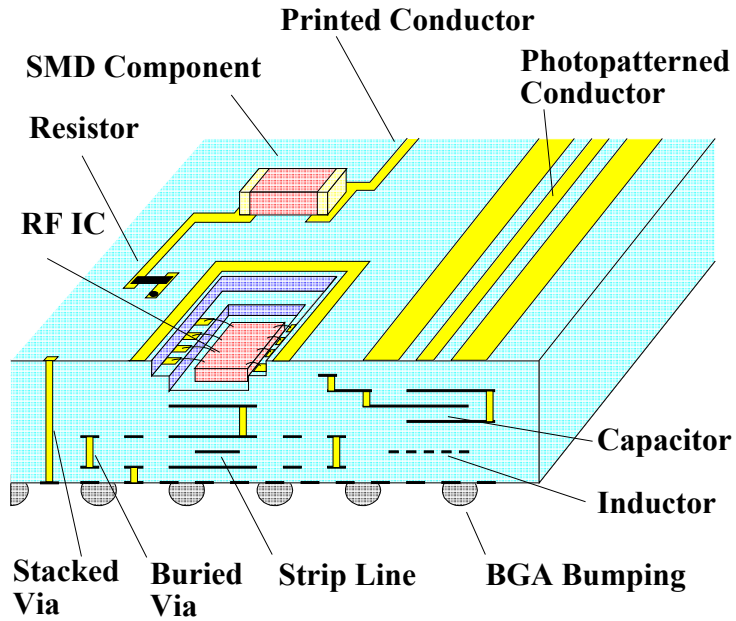


Introduction - LTCC Technology

LTCC: Low Temperature Co-fired Ceramic

Some technological advantages

- Multi-layer technology with a single firing step (<1000°C)
- High packaging flexibility (wire bonding, flip chip, PGA, BGA, …)
- High electrical performance (low resistivity conductor, low loss tangent)
- High integration density (buried passive components and vias, small conductor dimensions)

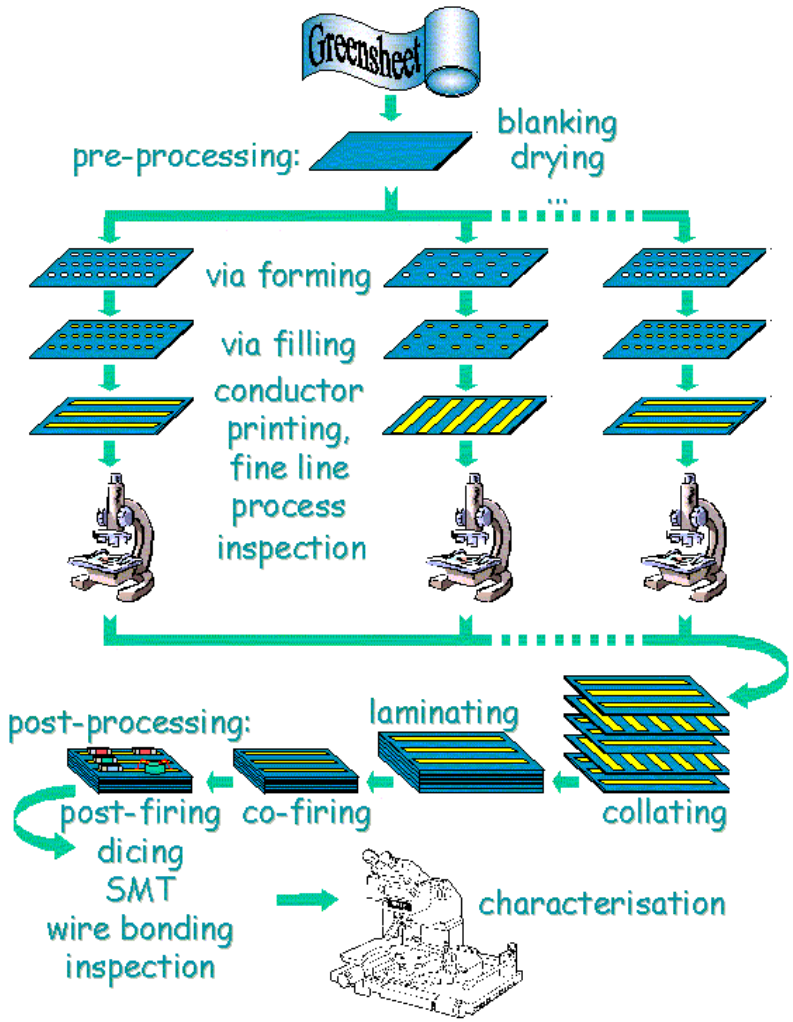


Source (drawing): VTT Electronics

Introduction - LTCC Technology

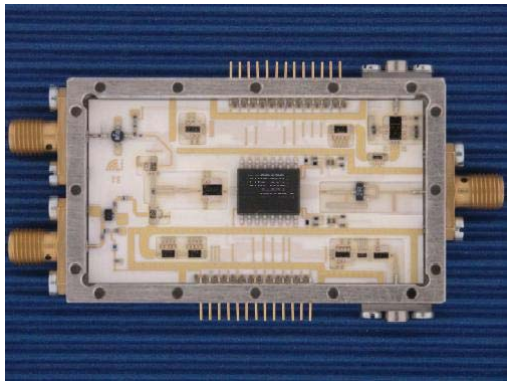
Manufacturing process

- Blanking (marks, dimensions)
- Via forming
- Via filling
- Conductor printing
- Collating (alignment)
- Laminating (under pressure and heated water)
- Co-firing (850ºC)
- Post-processing
- Characterization



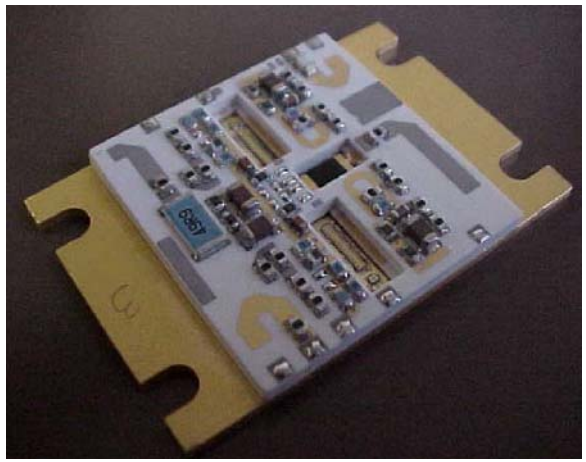
Source:
www.ltcc.de/what-is-ltcc/ltcc-process/ltcc-process.htm

Introduction - LTCC Technology



Point-to-multipoint transceiver for 24.5 to 26.5 GHz

Source: IMST, Germany



LTCC RF power amplifier module for base station applications

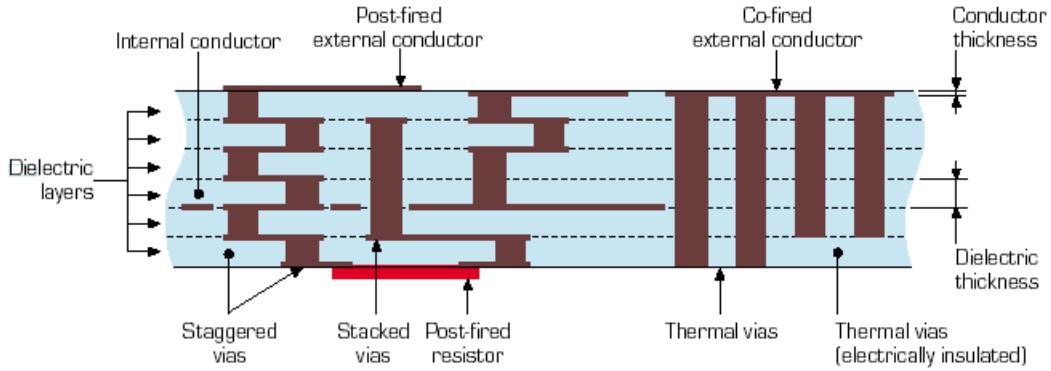
Source: “RF and Microwave Components in LTCC”,
L. Devlin, G. Pearson, J. Pittock - Plextek Ltd.
B. Hunt - CMAC Micro Technology
April, 2001

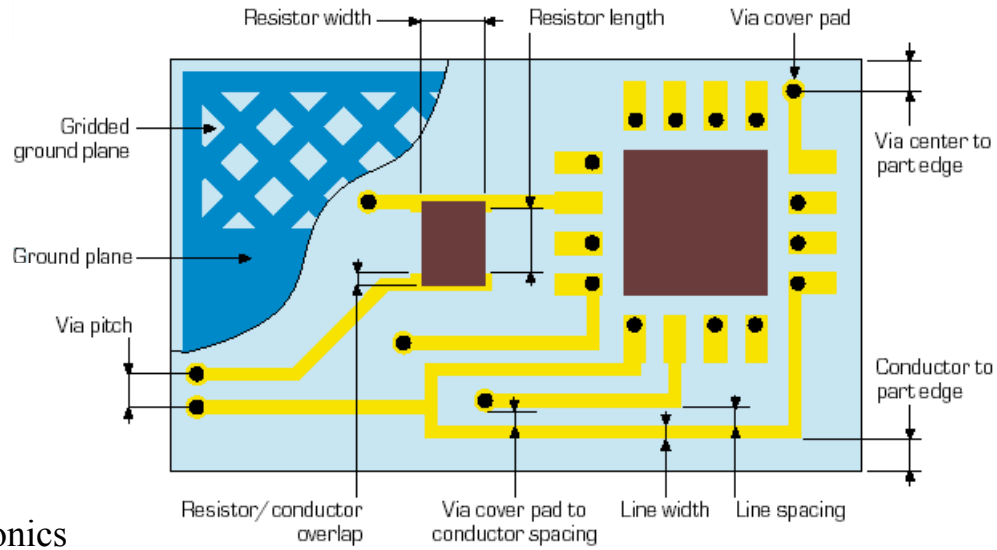
Source: http://www.dilabs.com/Dipak/benefits/1dipak.htm

Introduction - LTCC Technology

Design Constraints with LTCC process (DuPont 943 process)

- Dielectric Characteristics:
  $\varepsilon_r = 7.1$, $tg\delta = 0.002$
- dielectric thickness: 107 µm
- min. line width: 100 µm
- min. line spacing: 150 µm
- Conductor to edge distance: 380 µm
- min. via diameter (D) : 150 µm
- min. via spacing
  - – on same layer : 2.5 x D
  - – on consecutive layer : 2 x D
- max. part size: 114 x 114 mm^2

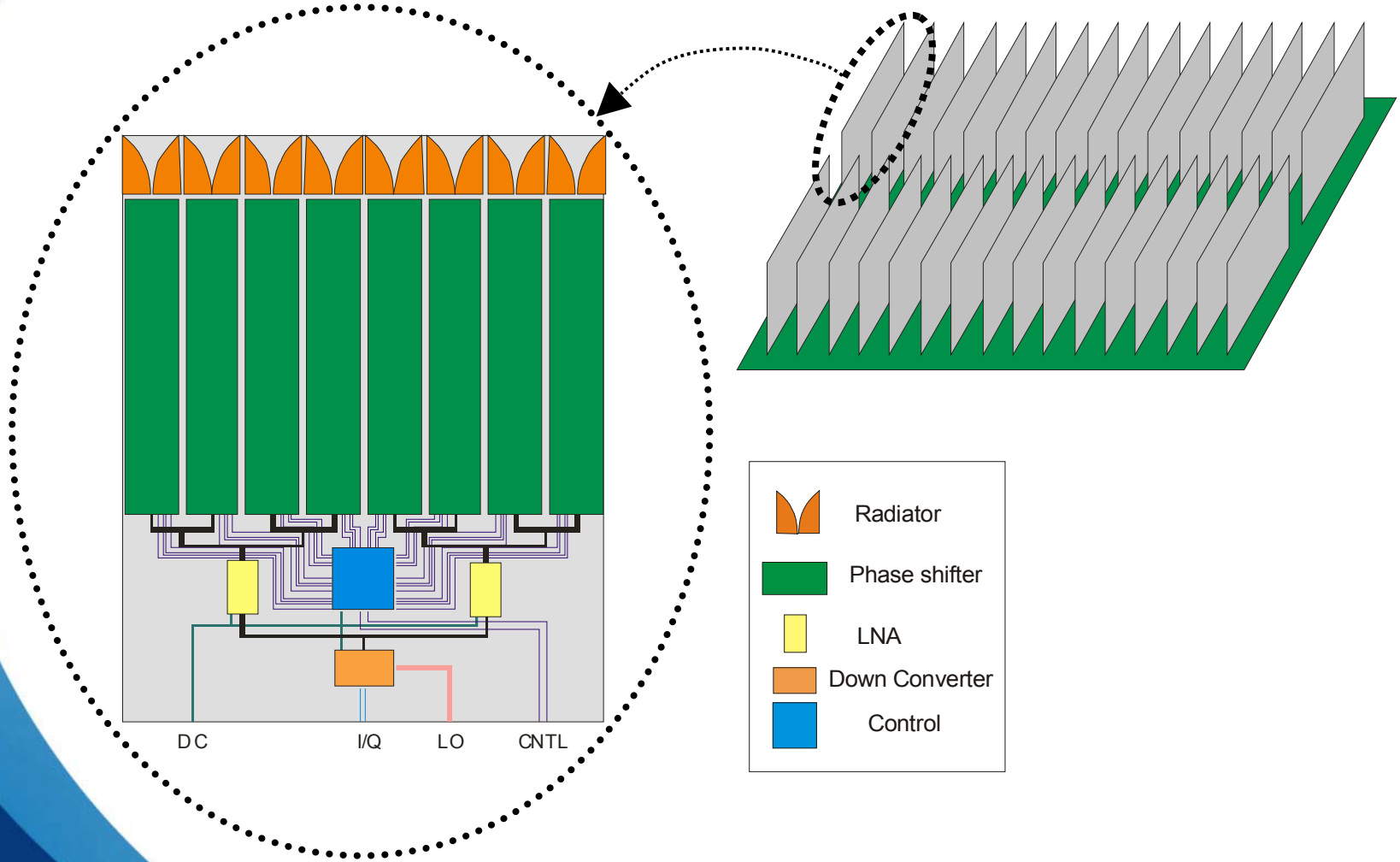




Source (drawings): Thales Microsonics

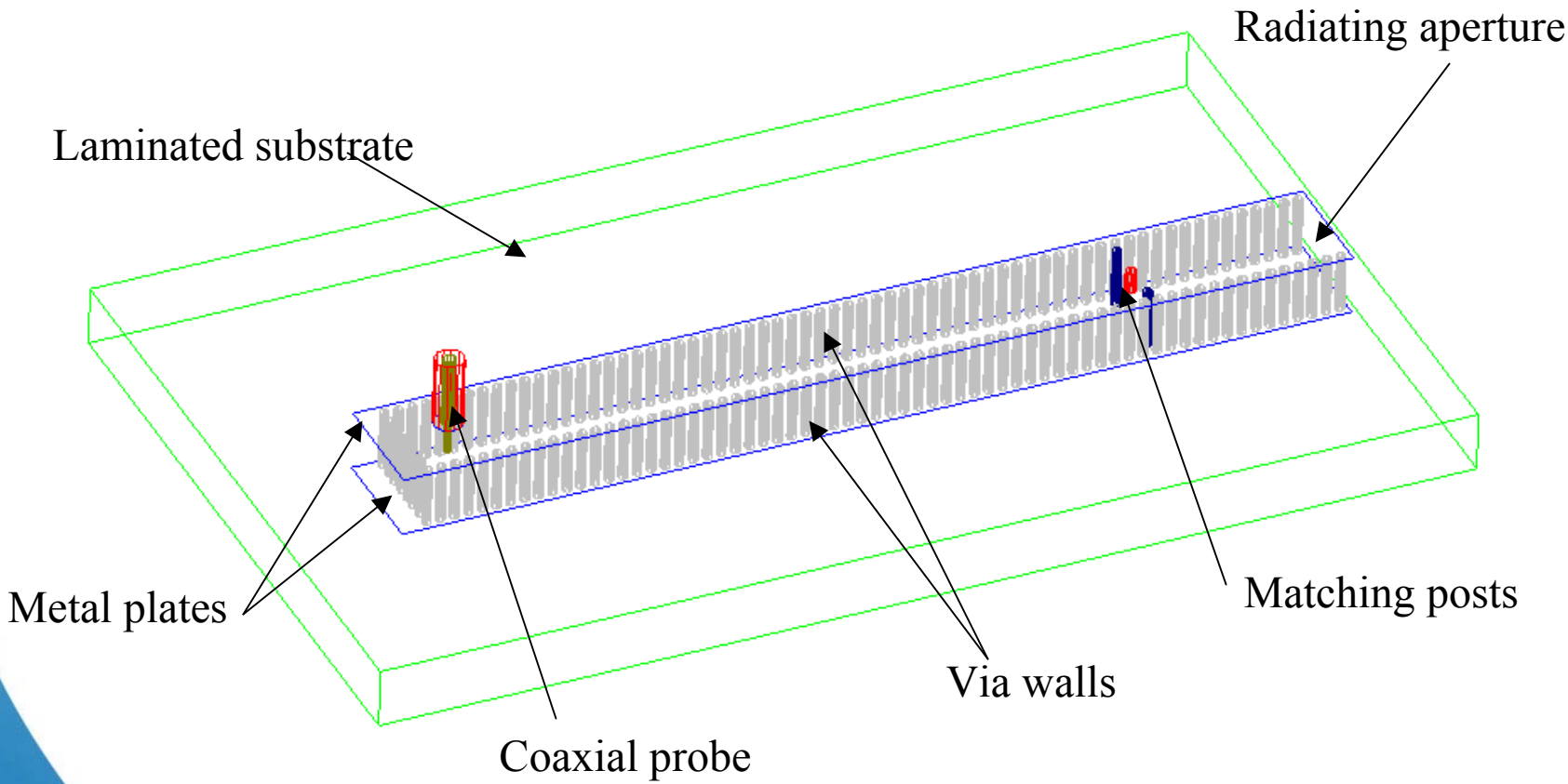
Introduction - Array configuration

- Brick architecture

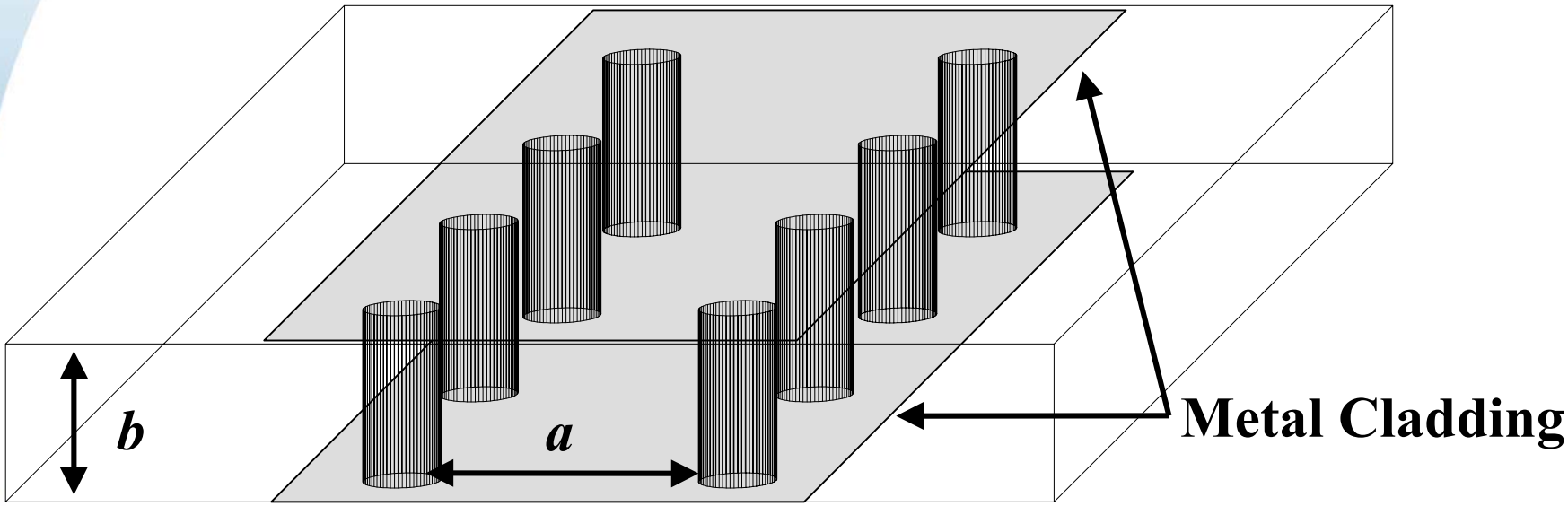


Introduction - The Radiating Element

- Radiating laminated waveguide

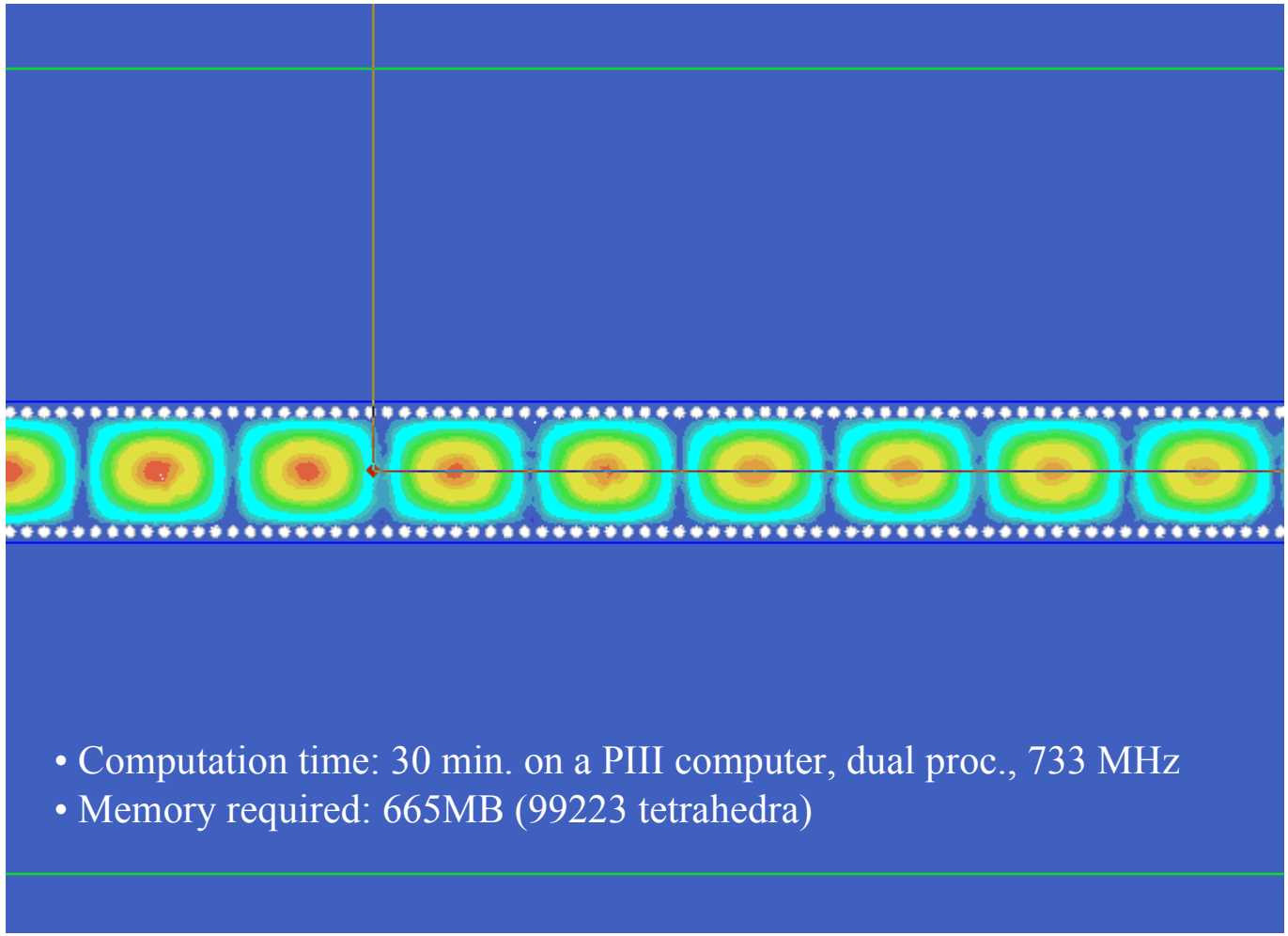


Models – The Laminated Waveguide



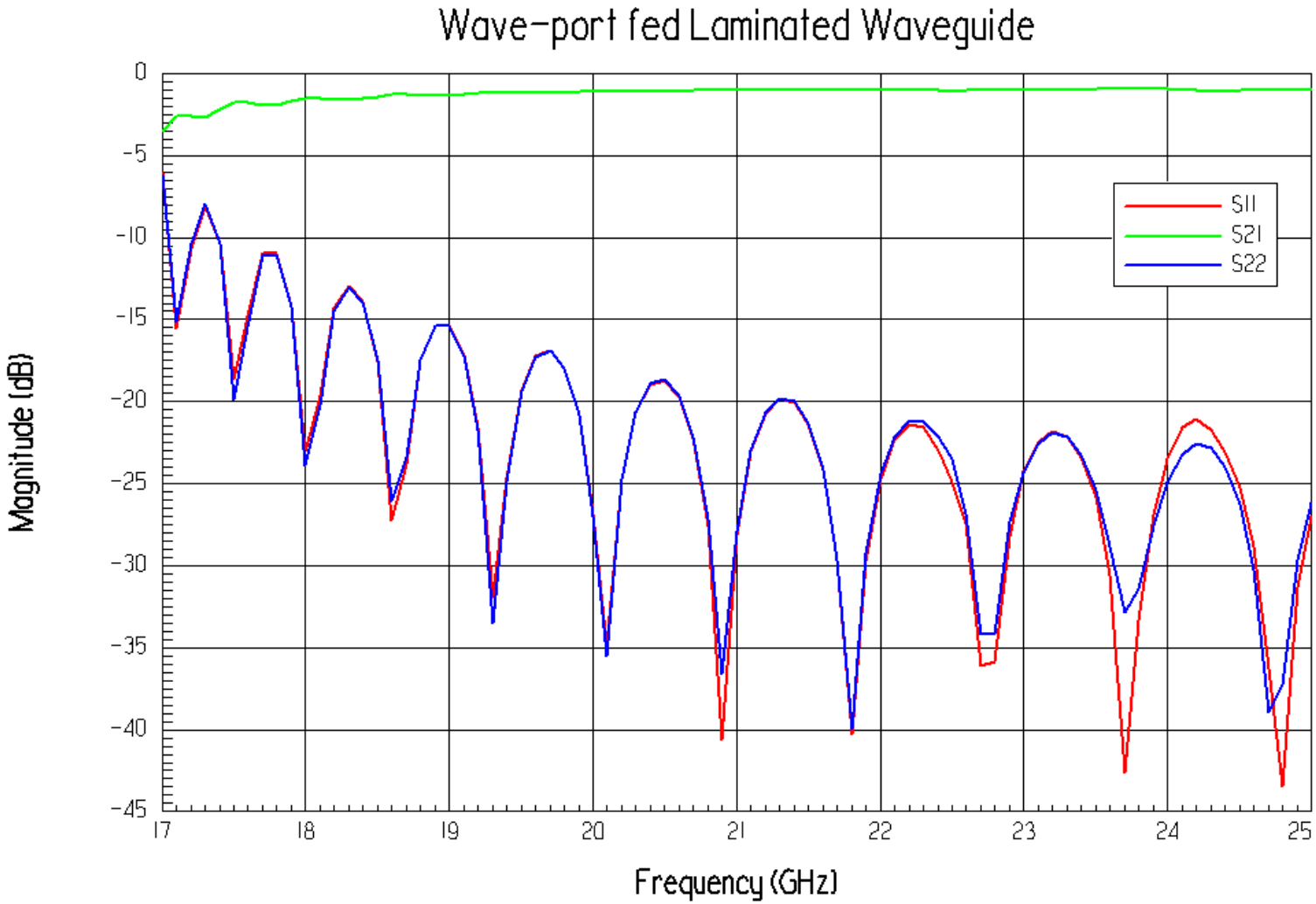
- Laminated waveguide parameters:
  - Width and height: defined by cut-off modes
  - Via diameter and spacing

Models – The Laminated Waveguide

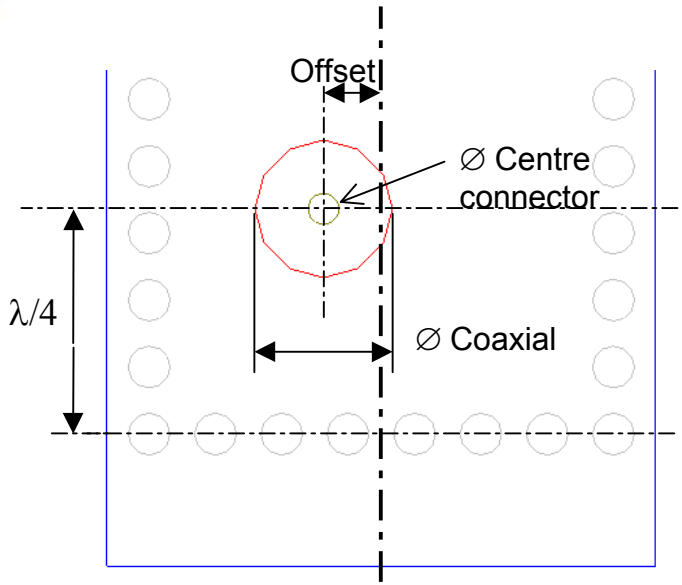


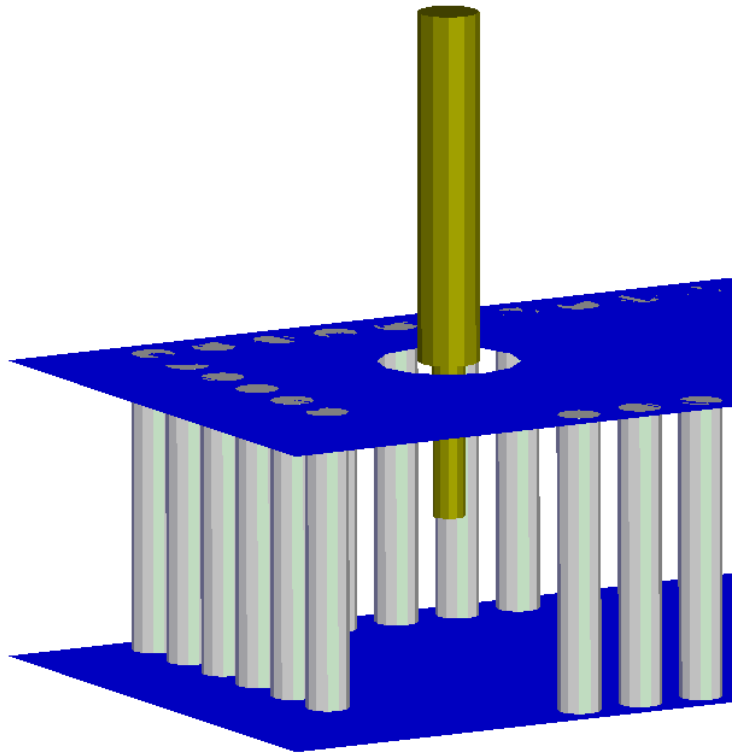
- Computation time: 30 min. on a PIII computer, dual proc., 733 MHz
- Memory required: 665MB (99223 tetrahedra)

Models – The Laminated Waveguide



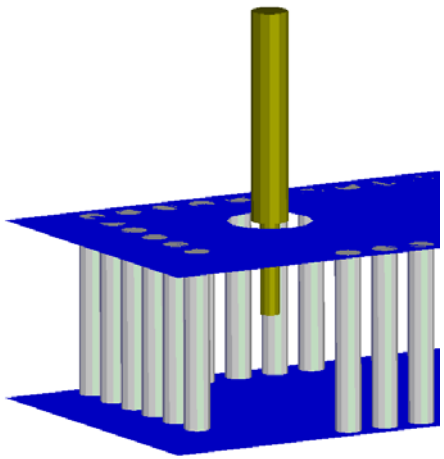
Models – The Coaxial to Waveguide Transition

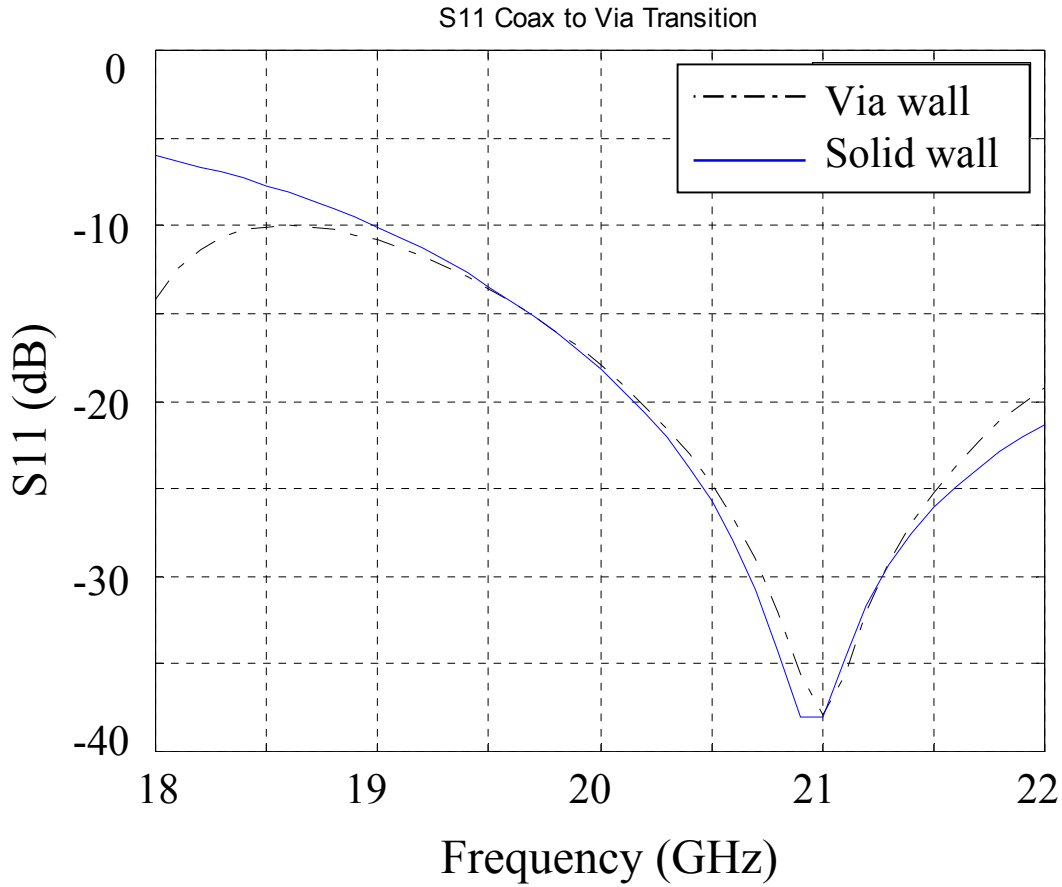




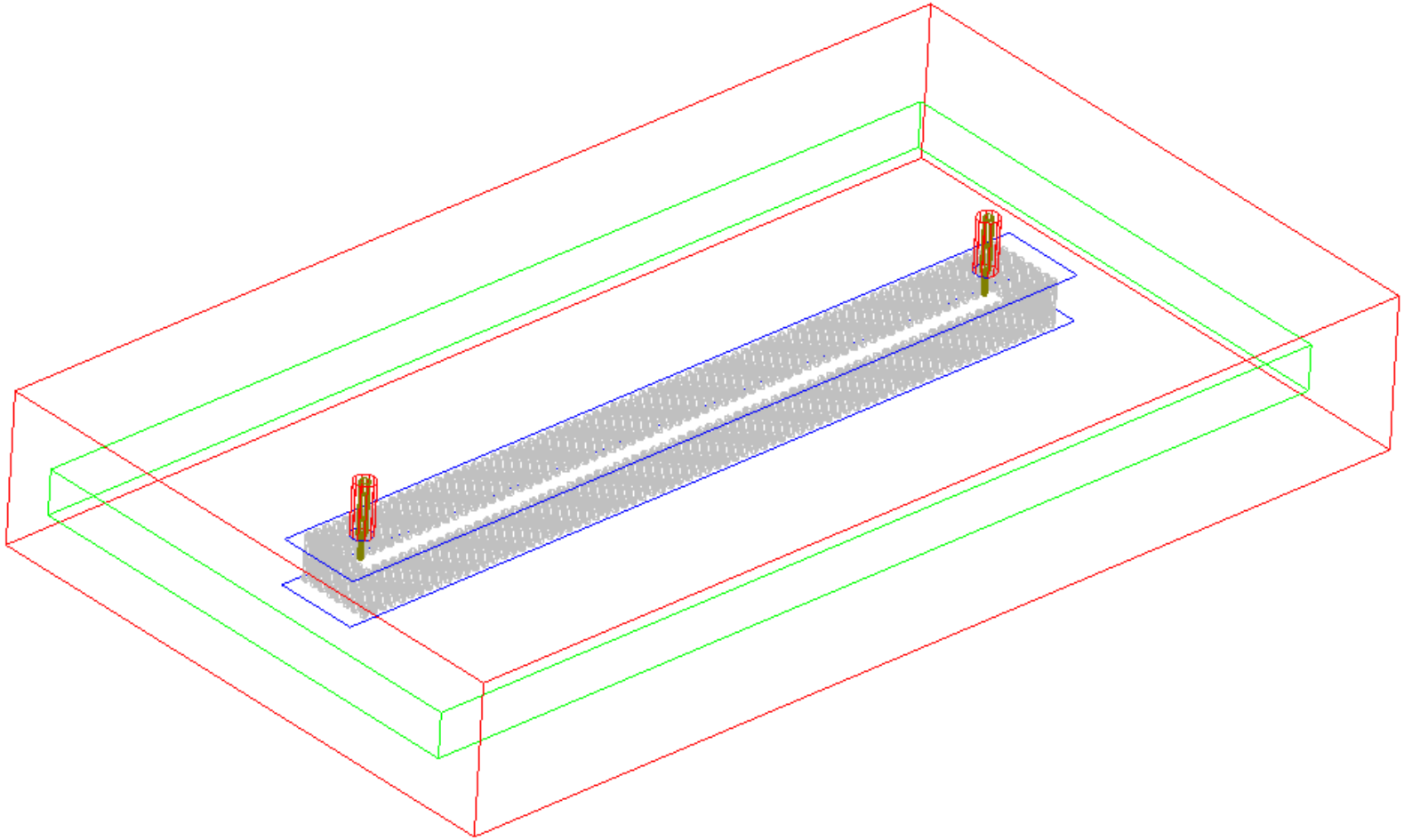
- Impedance matching realized by controlling the diameter, the length, and the position of the centre connector.

Models – The Coaxial to Waveguide Transition





Models – The Coaxial Fed Transmission Line Model



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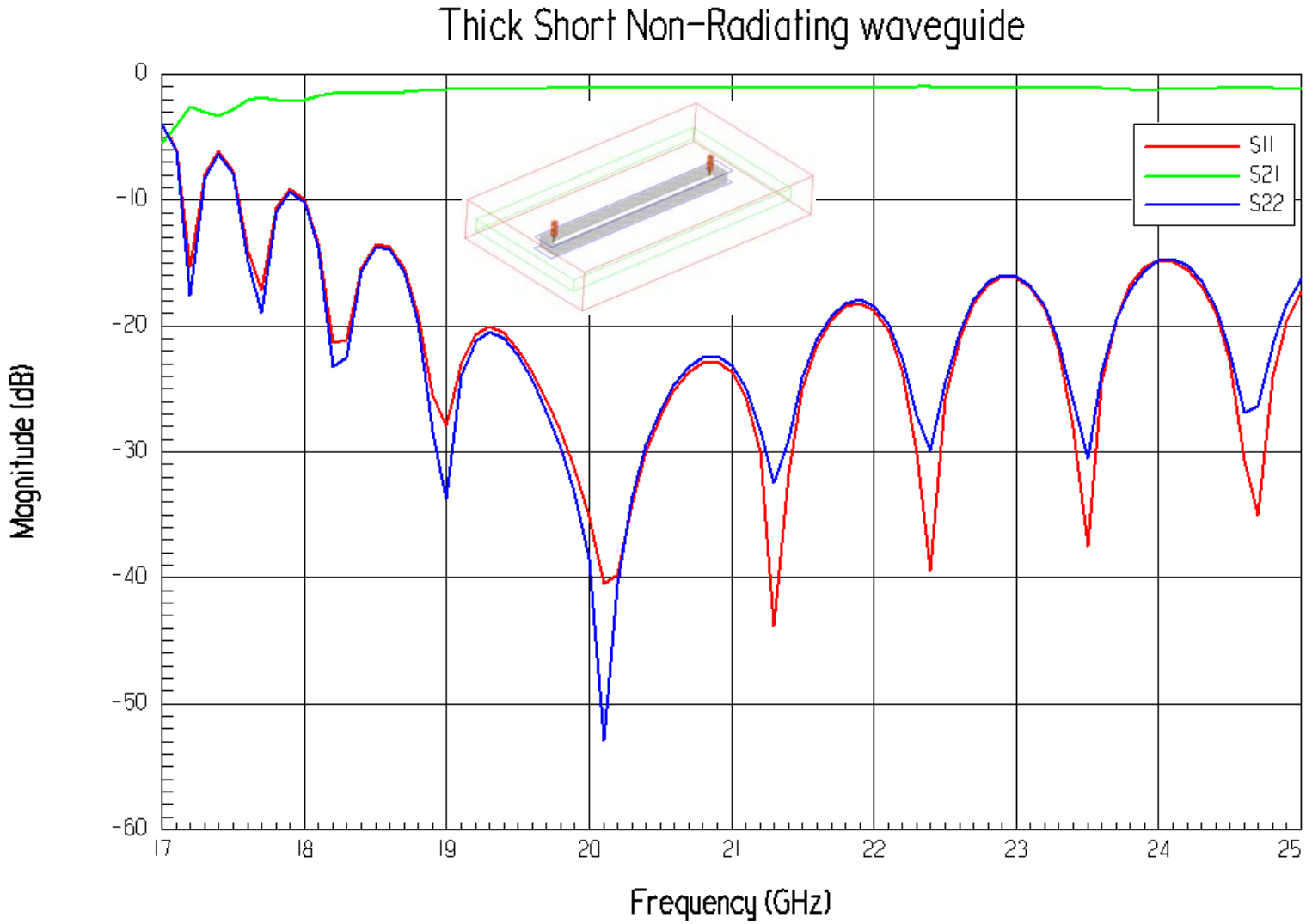
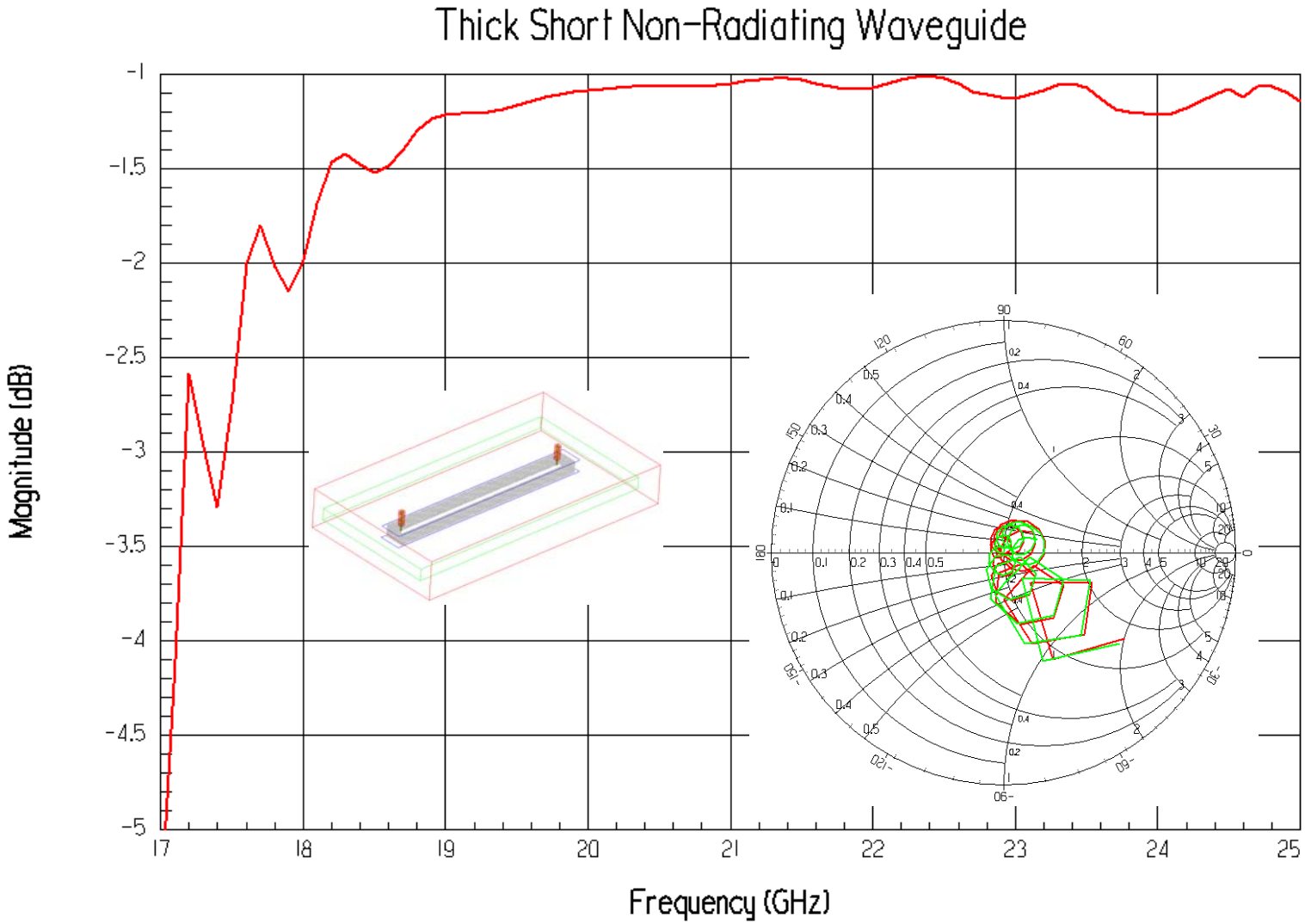


Models – The Coaxial Fed Transmission Line Model



Models – Aperture Matching

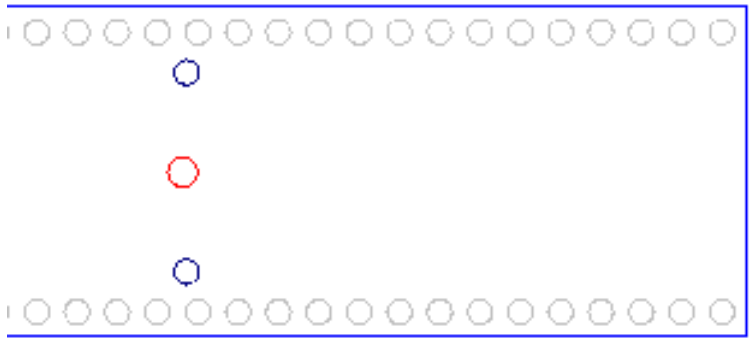
Match realised with:

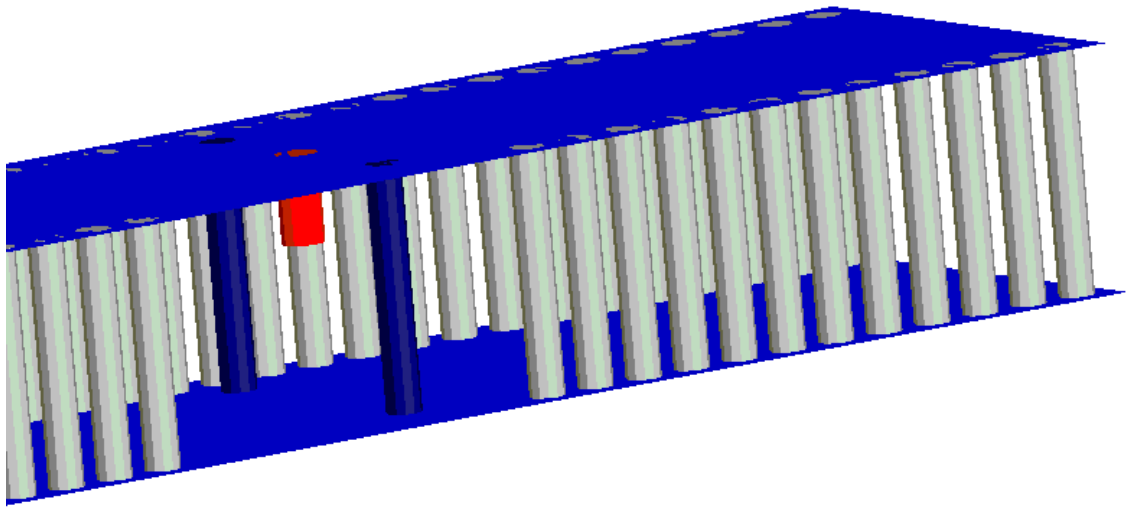
- Through vias forming an iris,

  introducing an inductance

- Centered blind via,

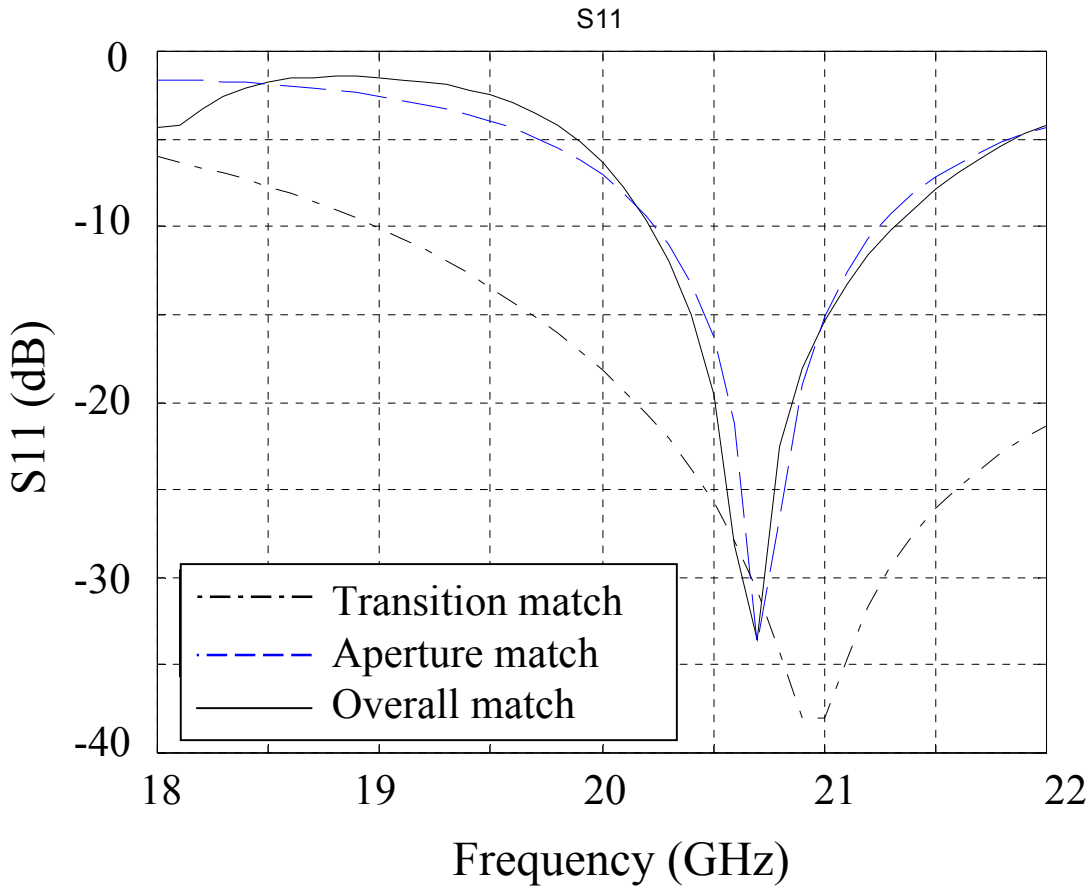
  introducing a capacitance





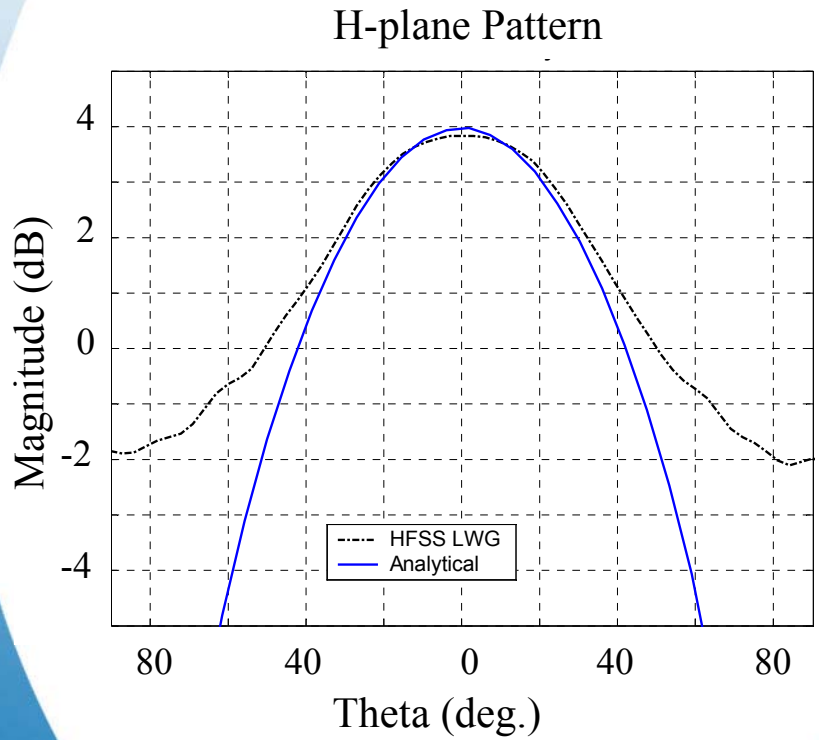
Models – The Laminated Waveguide Antenna

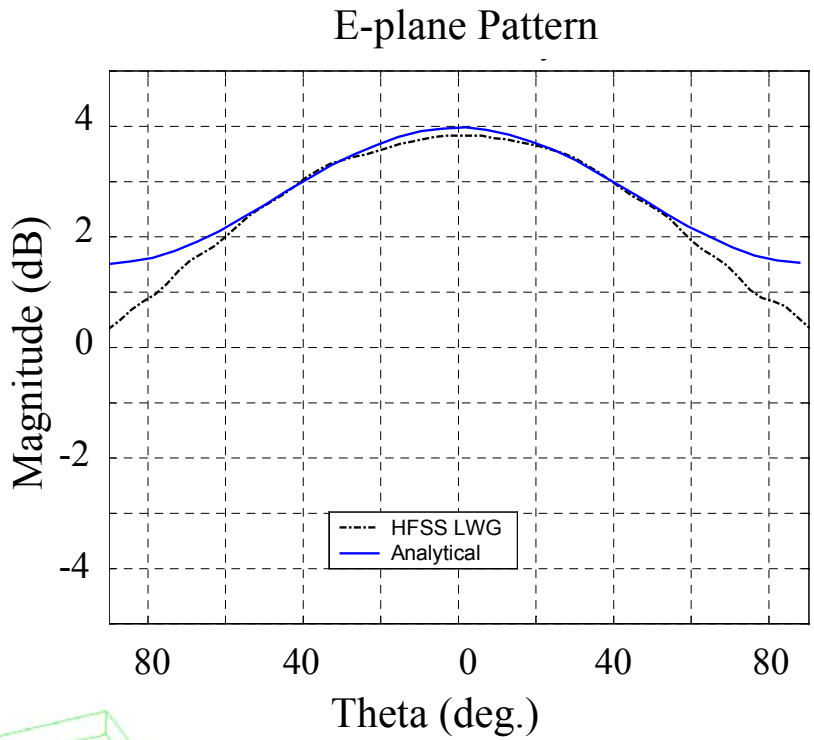
• Simulation with PEC walls instead of vias, to reduce the complexity of the problem

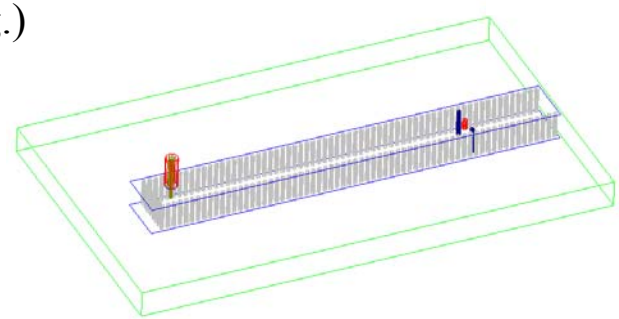


Models – The Laminated Waveguide Antenna

- Simulation with vertical walls formed with vias



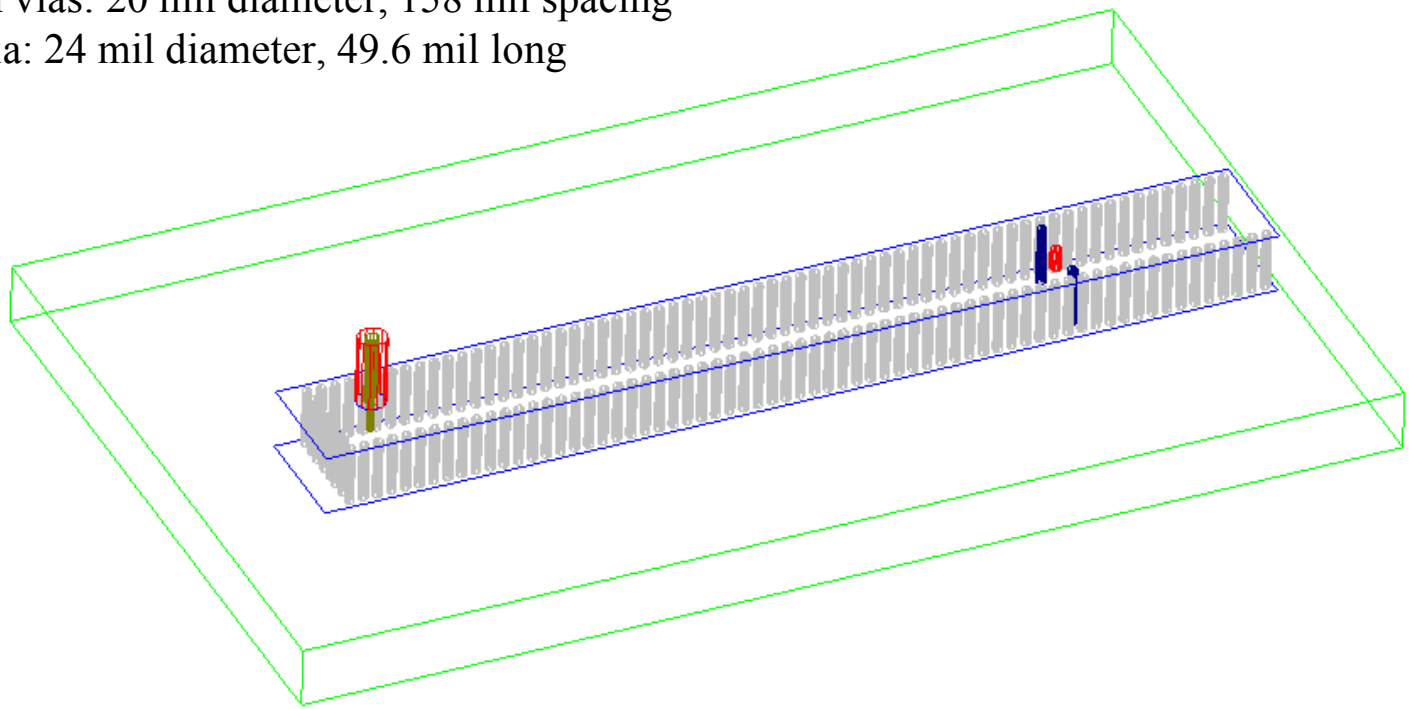




Models – The Laminated Waveguide Antenna

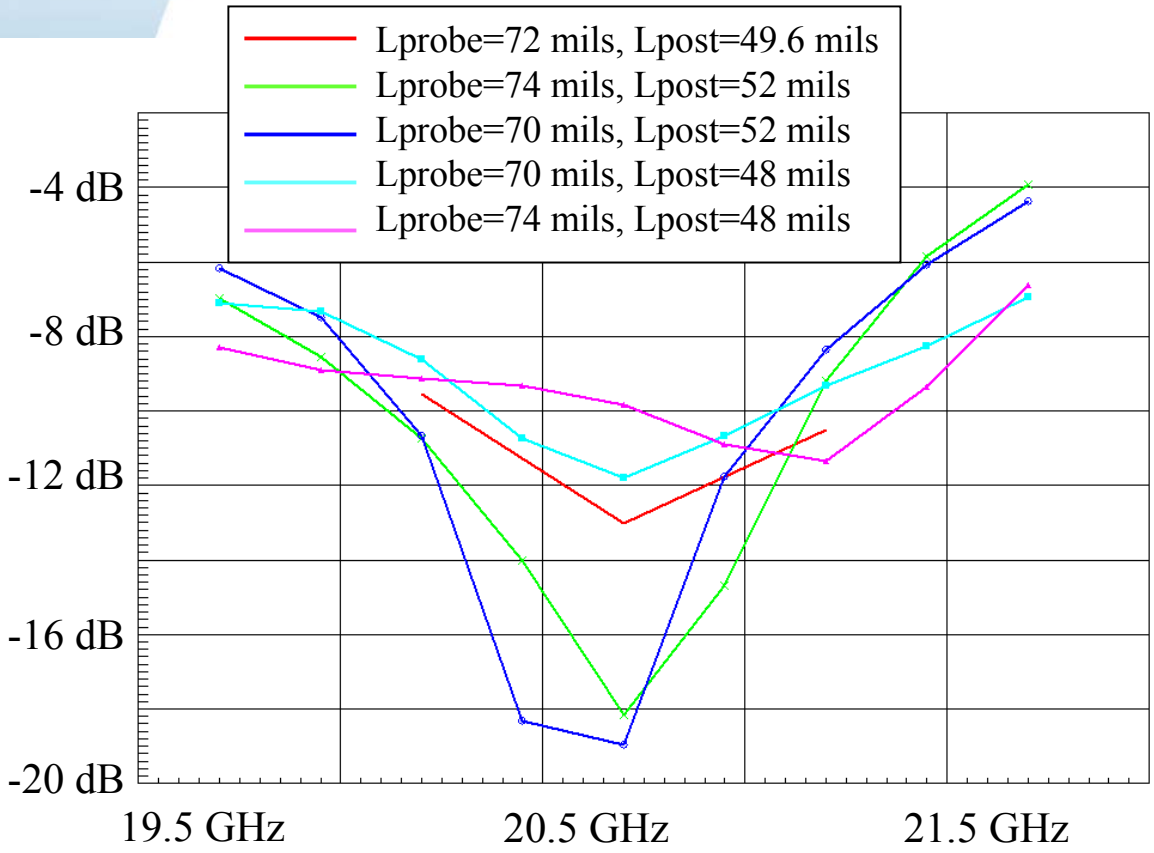
- **Final dimensions, taking into account the fabrication specifications, and based first on the use of CLTE substrate and bonding film (ARLON)**

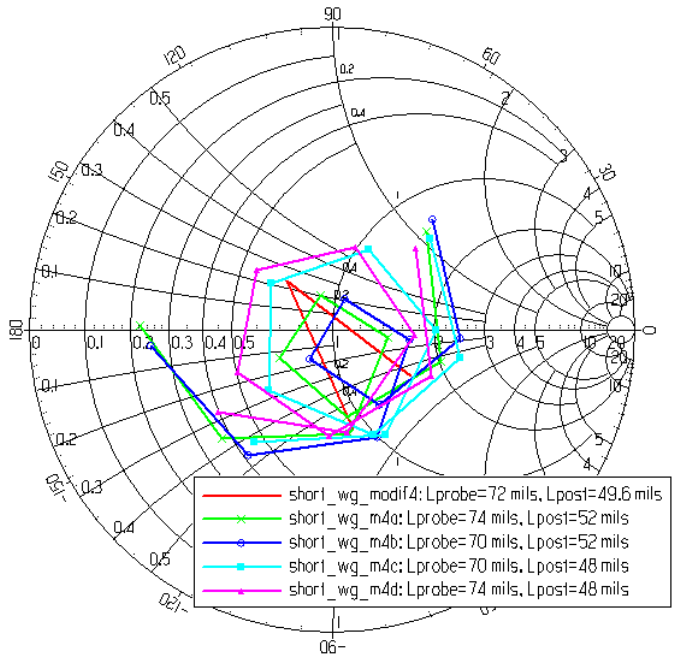
- Aperture: 222 mil wide, 134 mil high (the height depends on the number of layers)
- Wall vias: 20 mil diameter, 32 mil via pitch
- Coaxial probe: 15 mil diameter, 72 mil long, offset from centre: 27.6 mils
- through vias: 20 mil diameter, 158 mil spacing
- blind via: 24 mil diameter, 49.6 mil long



Models – The Laminated Waveguide Antenna: Fabrication Tolerances Analysis

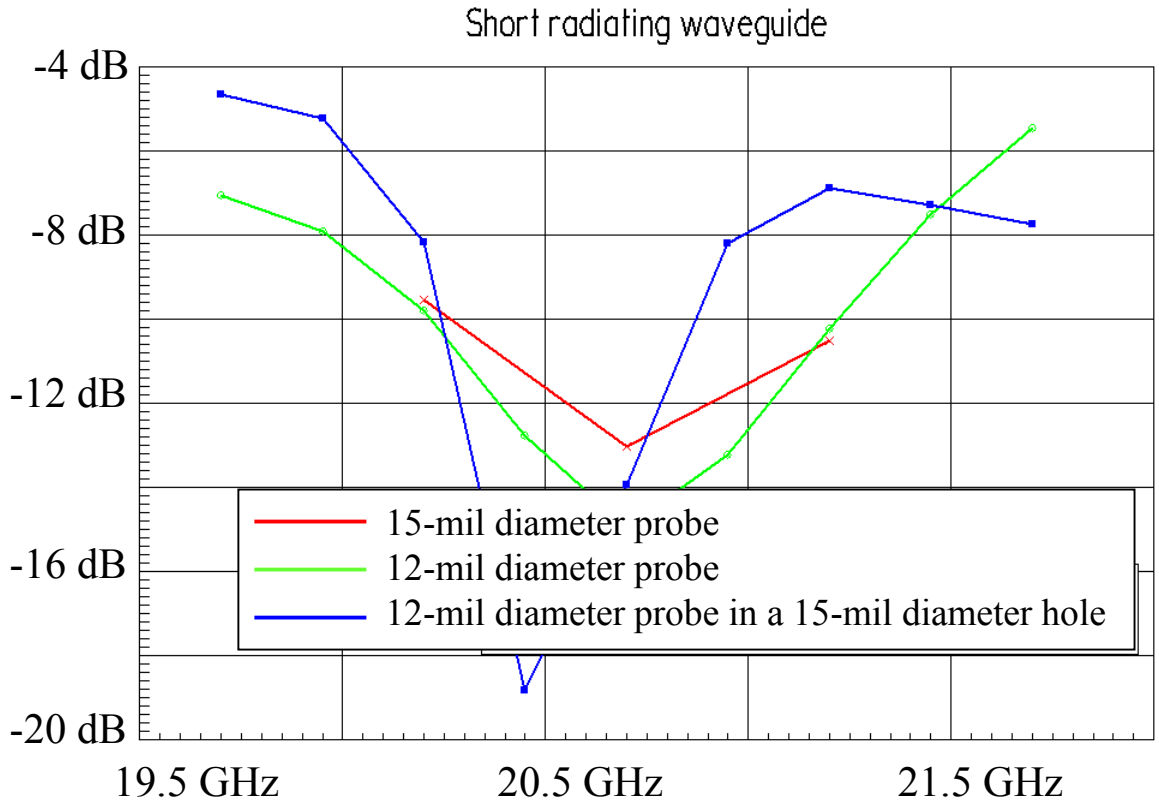
- Variation of the probe and the matching post lengths (realised in post-processing)

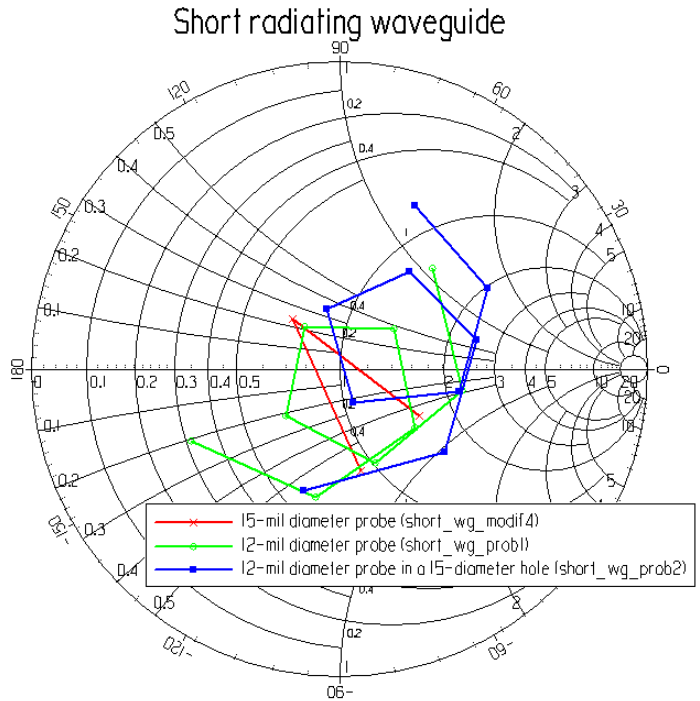




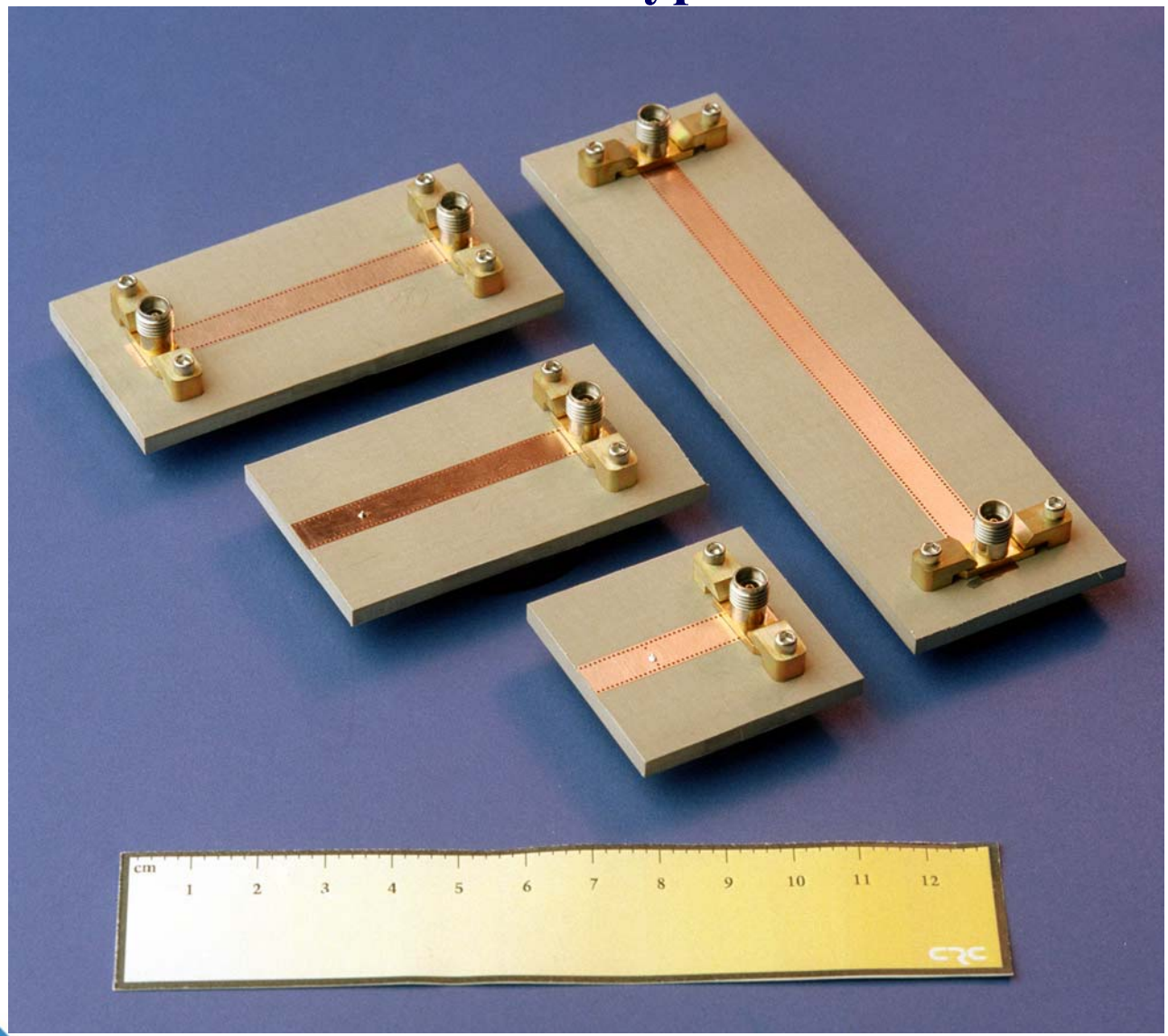
Models – The Laminated Waveguide Antenna: Fabrication Tolerances Analysis

- Variation of the probe diameter

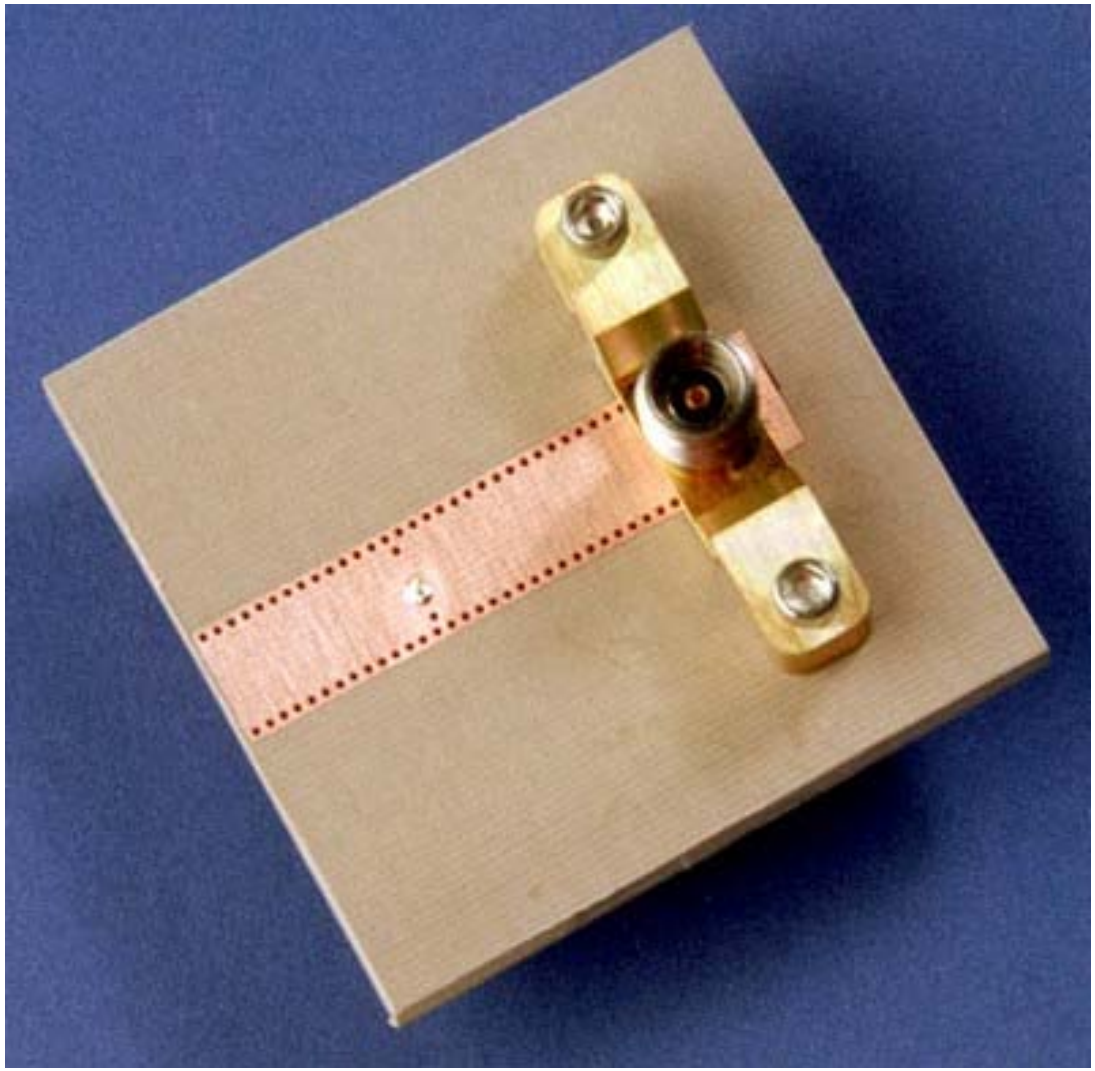




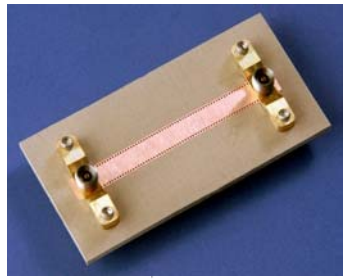
Results – The Prototypes

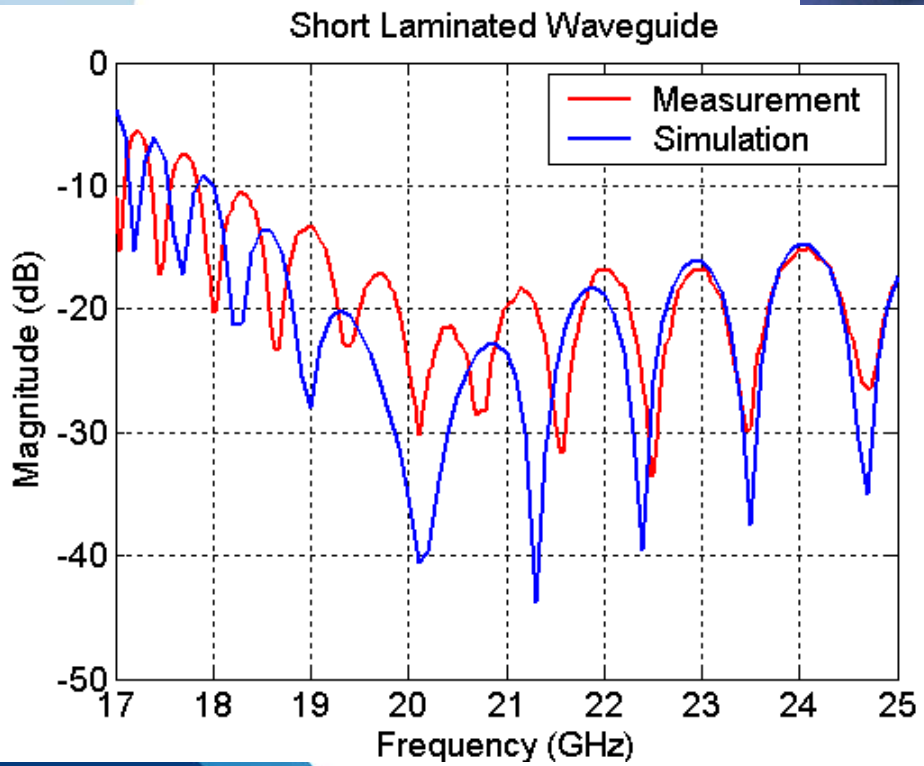


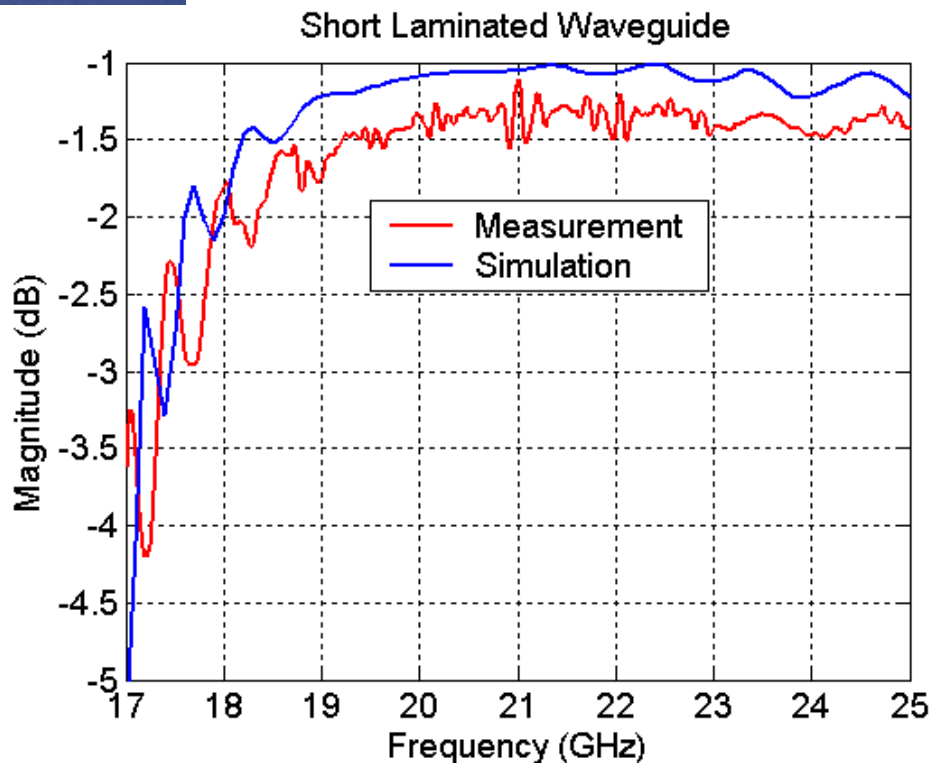
Results – The Short Radiating Waveguide



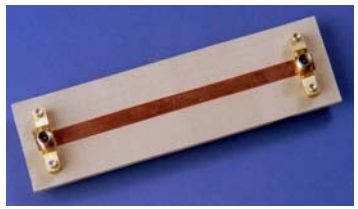
Results – The Short Laminated Waveguide

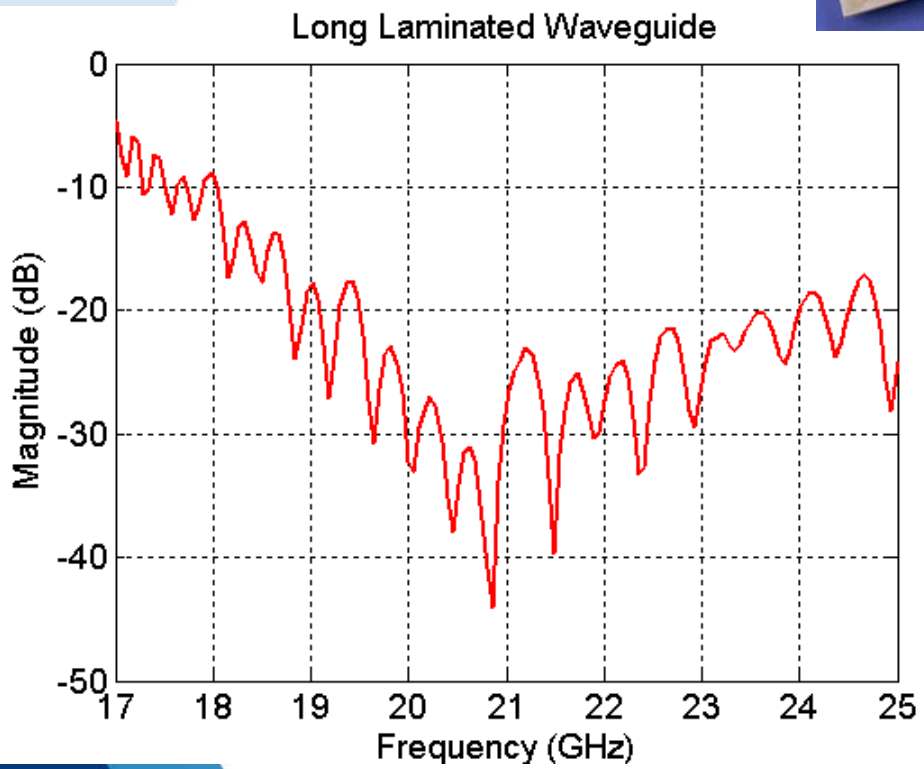


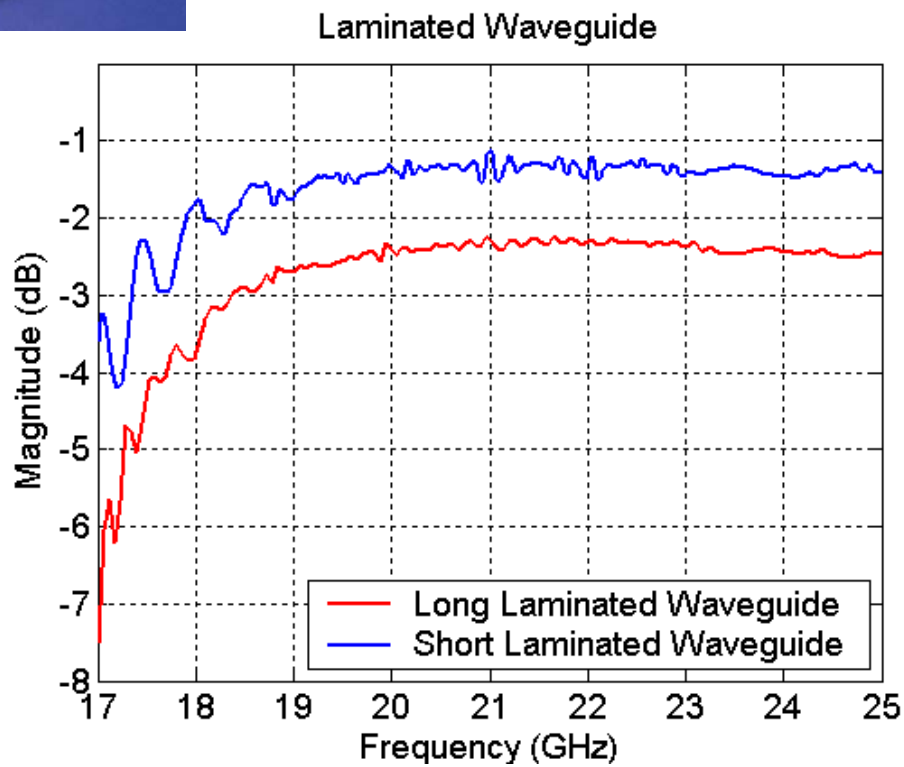




Results – The Long Laminated Waveguide



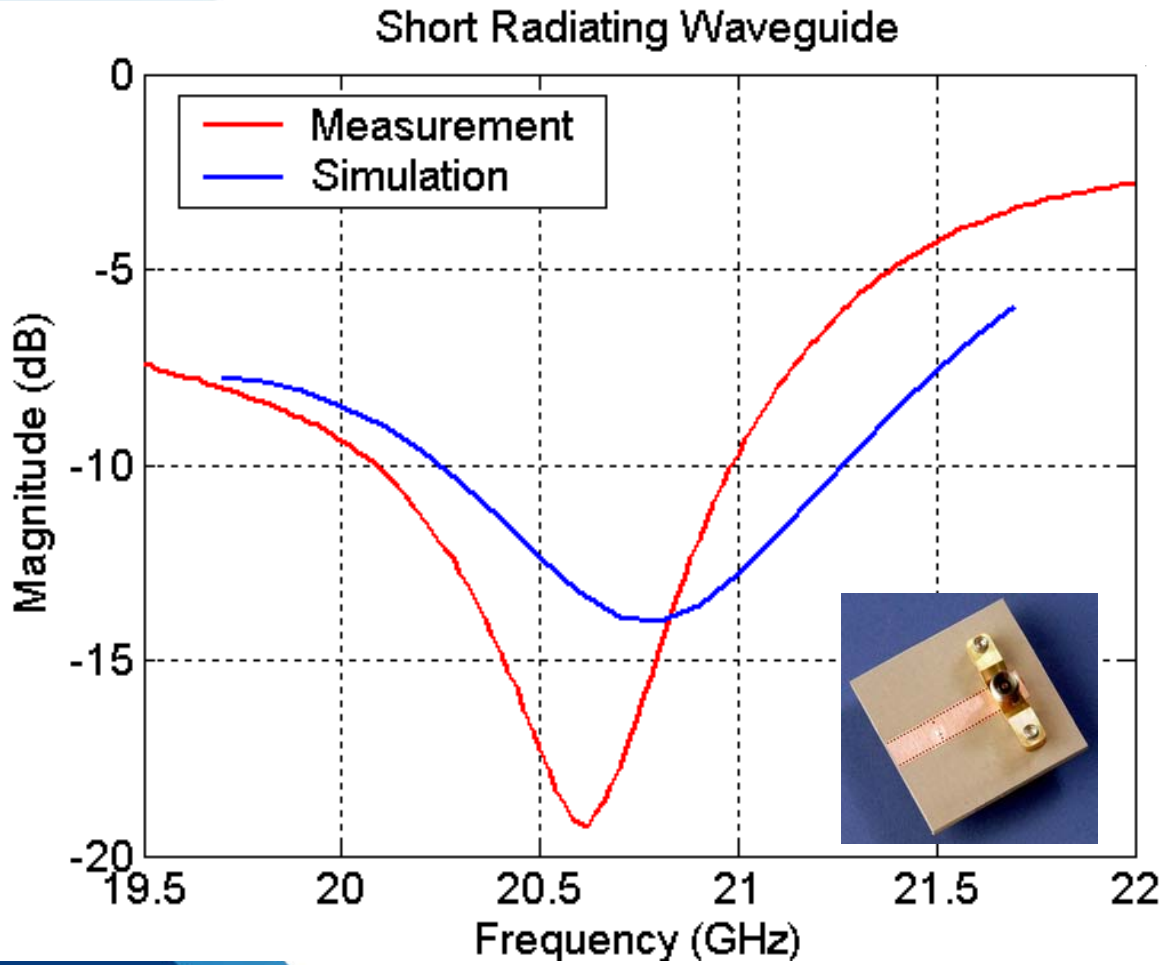


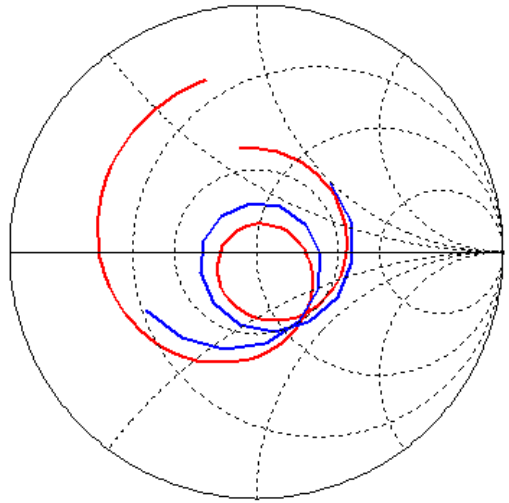


➔ Attenuation factor: $\alpha = 2.182$ Np/m

➔ Connector Loss: 0.157 dB

Results – The Short Radiating Waveguide : Input Impedance



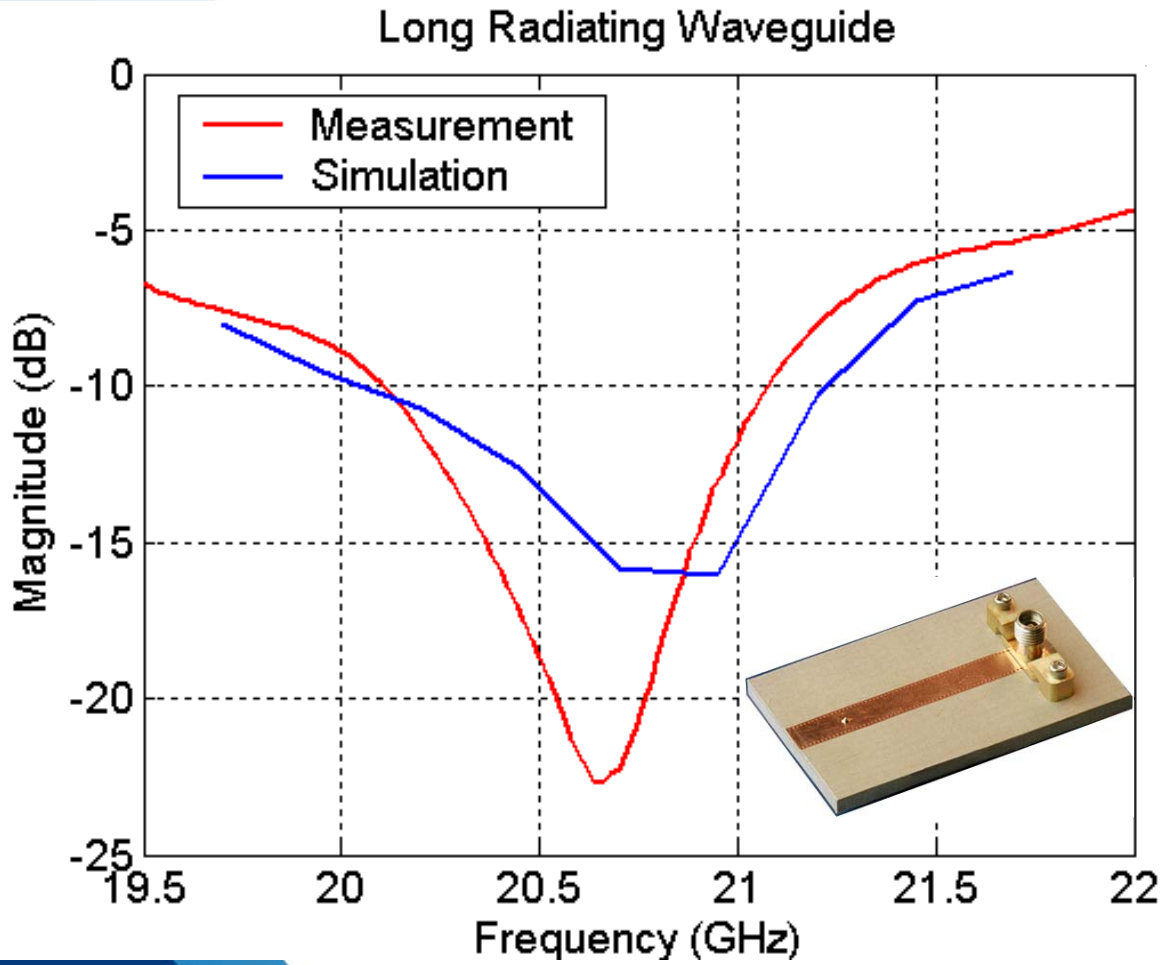


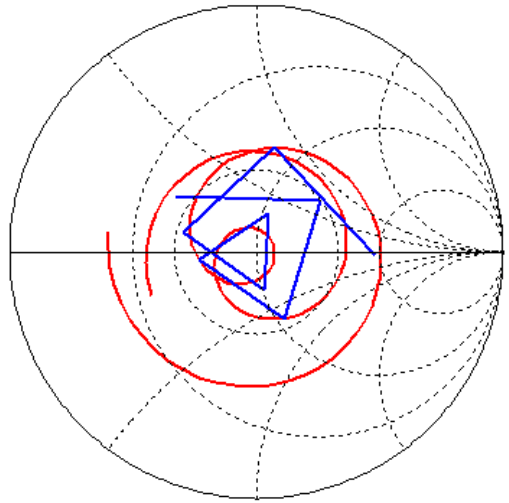
Bandwidth

Simulation : 20.25-21.25 GHz

Measurement : 20.1-21.0 GHz

Results – The Long Radiating Waveguide : Input Impedance



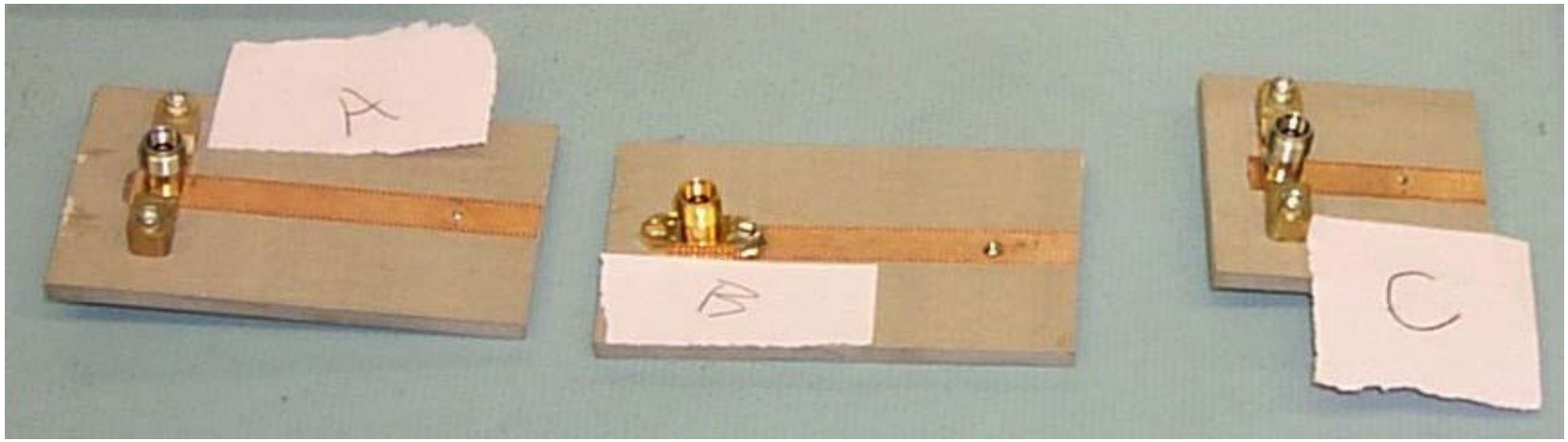


Bandwidth

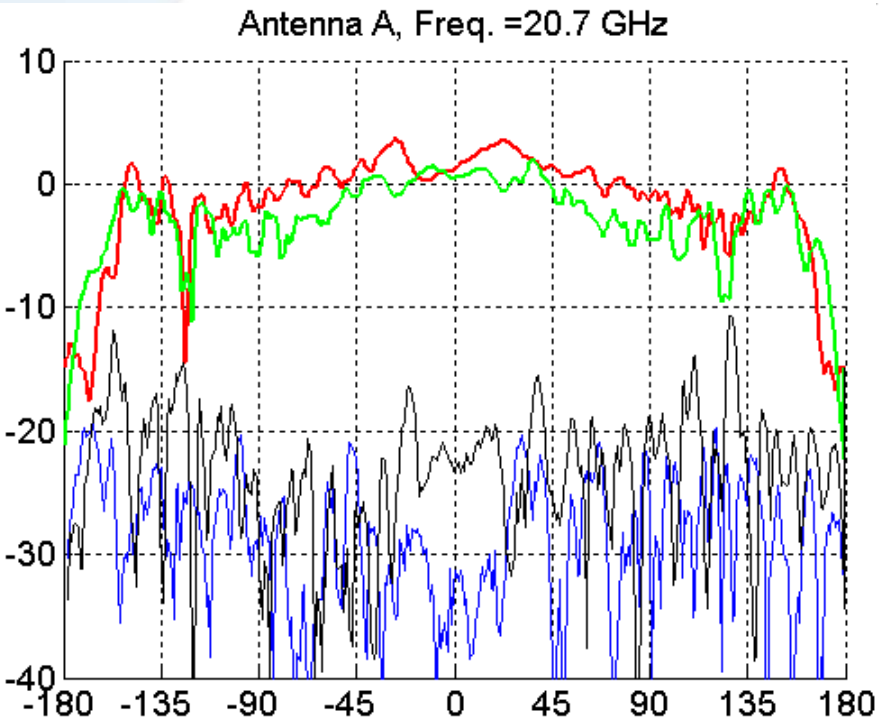
Simulation : 20.05-21.25 GHz

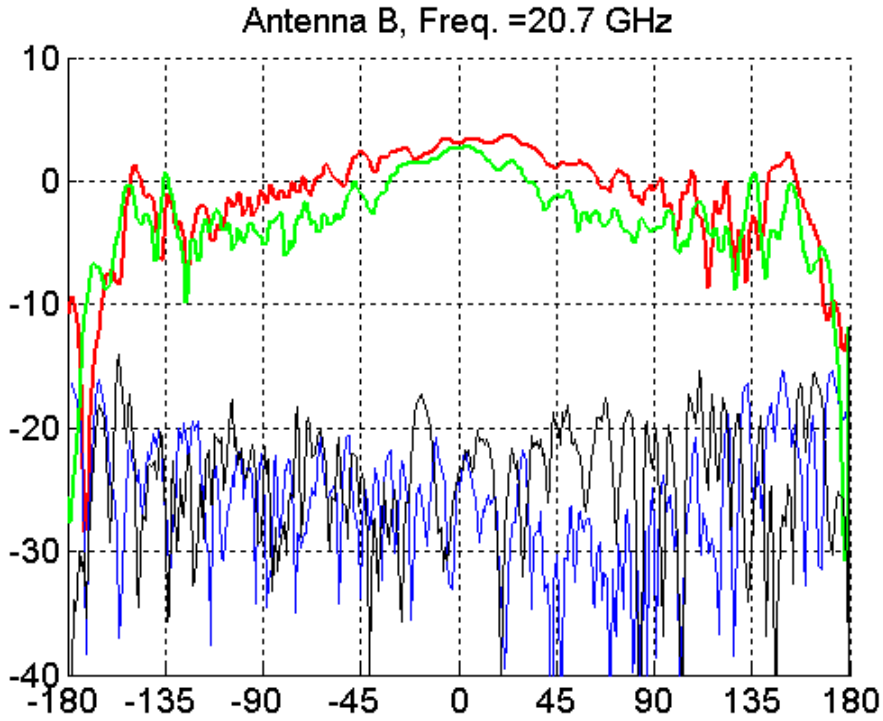
Measurement : 20.1-21.1 GHz

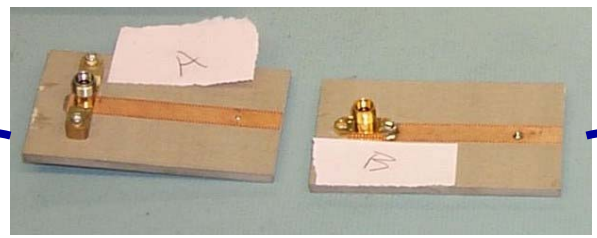
Results – The Radiating Waveguides : Radiation Patterns



Results – The Long Radiating Waveguide : Radiation Patterns







E-plane, Co-pol
E-plane, Co-pol
E-plane, Co-pol
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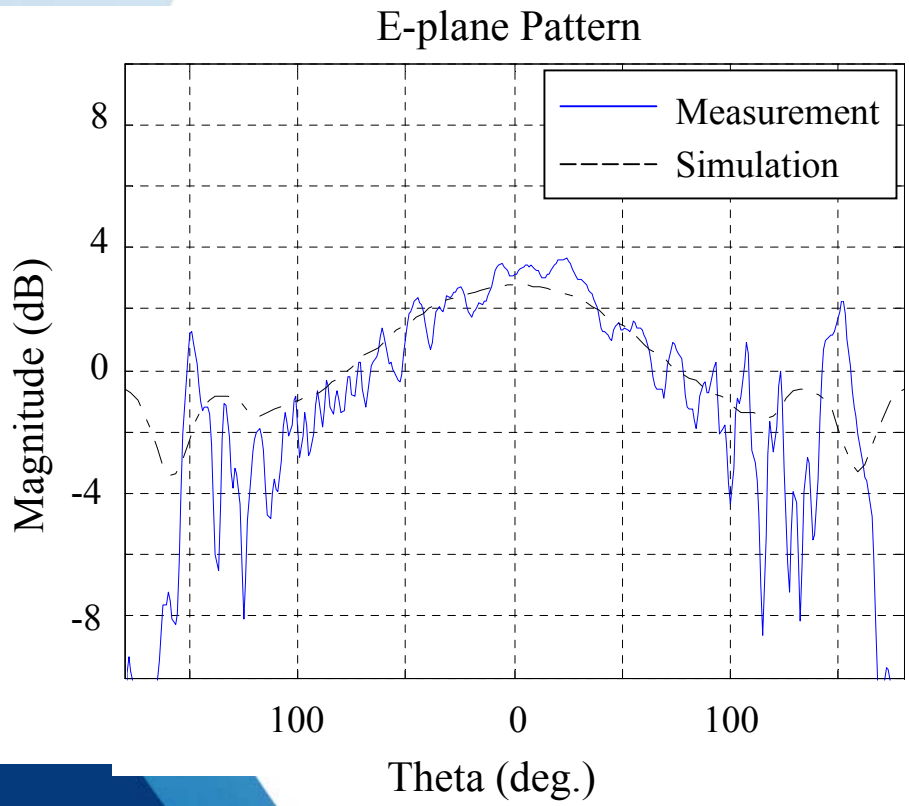
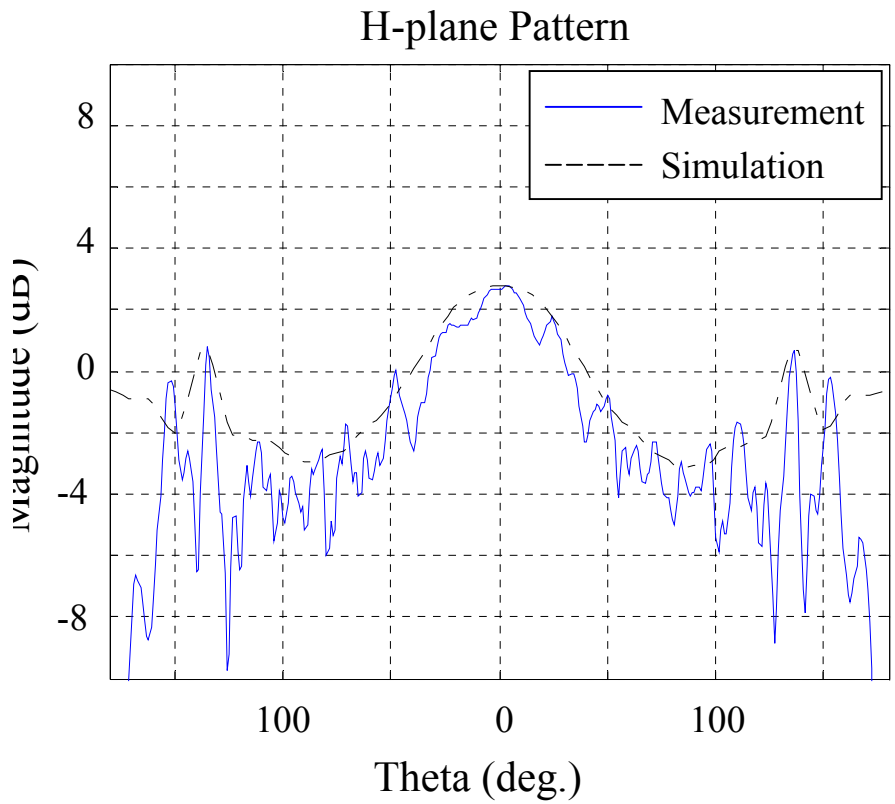
Results – The Long Radiating Waveguide : Radiation Patterns

- Antenna B with soldered connector

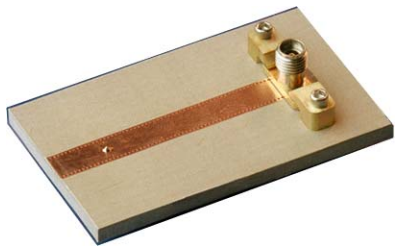


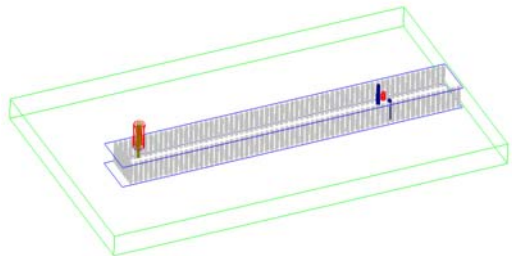


Summary and future work

- A waveguide antenna in laminated substrate has been studied:
  - Good matching but sensitive to fabrication tolerances,
  - Radiation patterns shows broad beam widths, low cross-polarisation,

➔ Good correlation between simulated results and measurement (impedance matching and radiation characteristics)





- This antenna element is currently studied in array configuration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