A 94 GHz Aperture-Coupled Micromachined Microstrip Antenna

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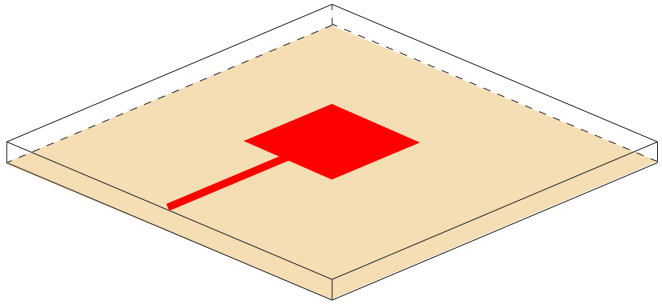
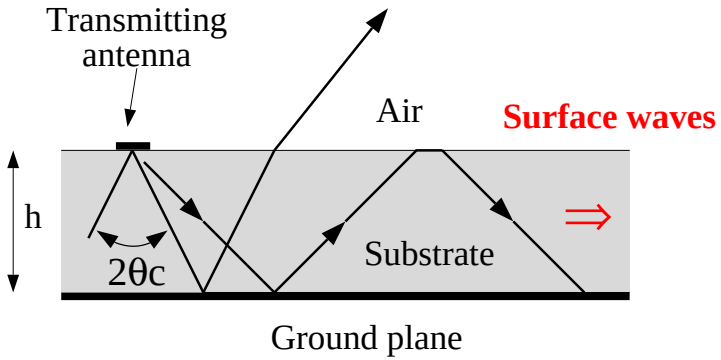
Outline



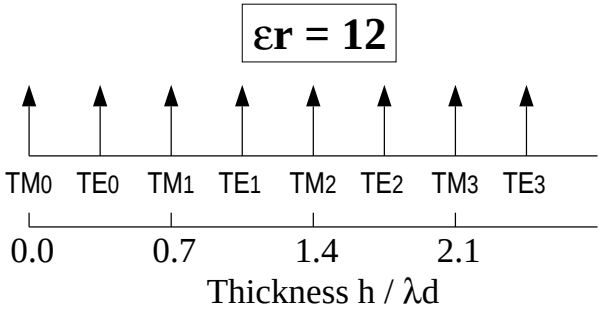
- Microstrip antennas and micromachining approach
- Micromachined microstrip antenna design
  - ⇒ Antenna
  - ⇒ Coupling slot
  - ⇒ Microstrip matching stub
  - ⇒ Microstrip to CPW line transition
- W-band antenna measurements at 94 GHz
  - ⇒ Input impedance
  - ⇒ Mutual coupling
  - ⇒ Radiation efficiency
  - ⇒ Radiation patterns
- Conclusion

Millimeter-Wave Microstrip Antennas: Micromachining Approach

SURFACE WAVES IN A GROUNDED DIELECTRIC SLAB:



PROPAGATING MODES:



MICROSTRIP ANTENNA:

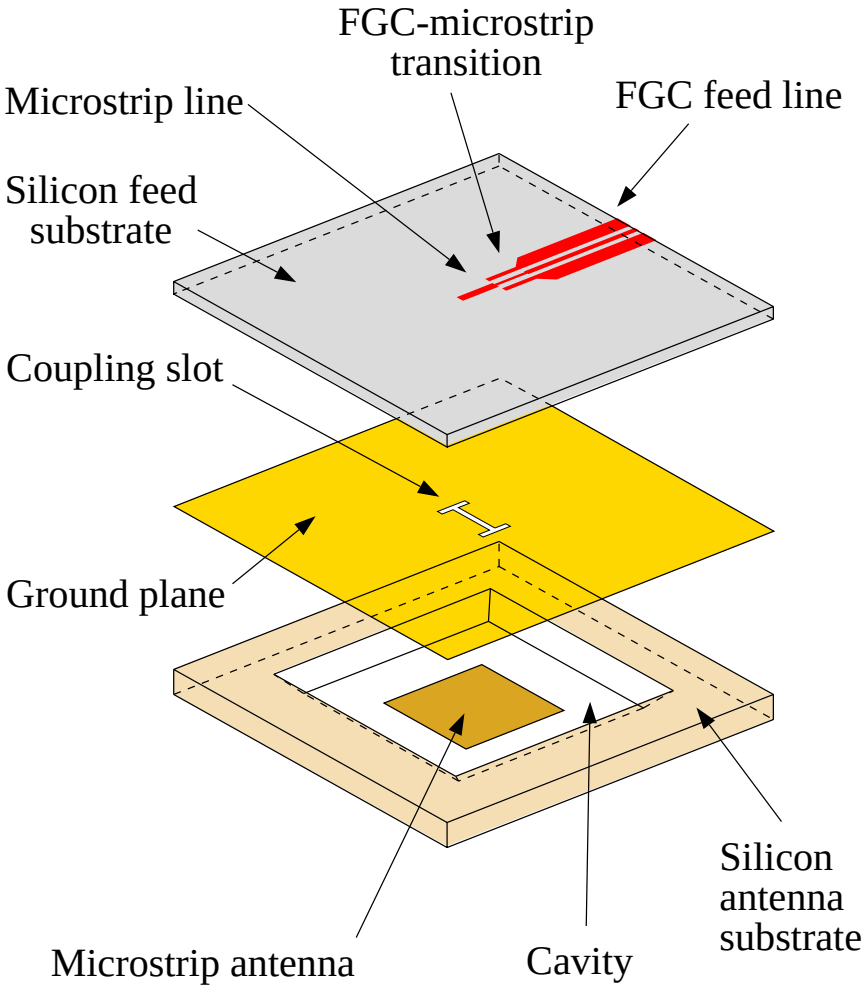
- Radiates into air
- Low gain antenna
- At millimeter-wave frequencies, standard IC fabrication techniques use silicon (εr = 11.7) and GaAs (εr = 12.9) substrates

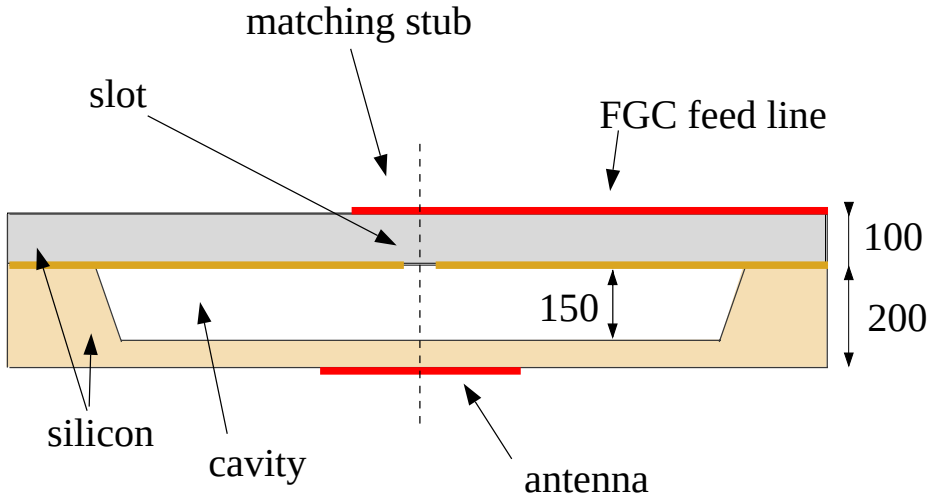
  ⇒ TM0 surface waves triggered into the substrate
  ⇒ loss of power
  ⇒ degradation of the radiation efficiency and patterns

- Choose thin substrates ($h \leq \lambda d / 10$ for silicon)
- Reduce the substrate εr around and below the antenna by etching a cavity in the silicon:

  ⇒ **micromachining approach**

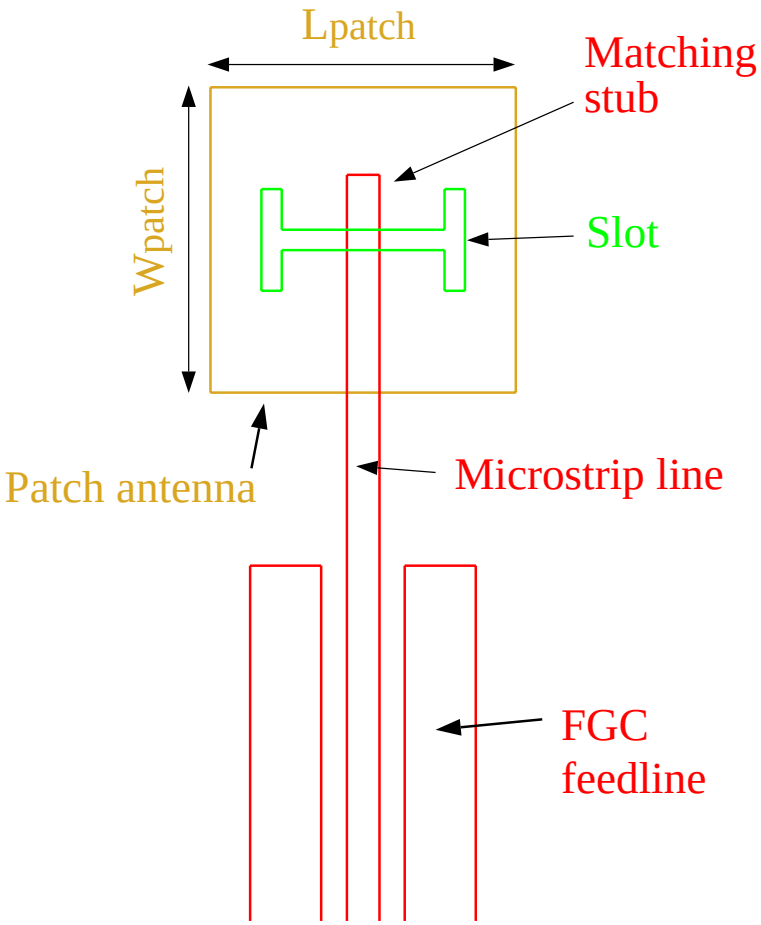
Microstrip Antenna Layout





- silicon feed substrate: 100 μm
- silicon antenna substrate: 200 μm
- cavity height: 150 μm

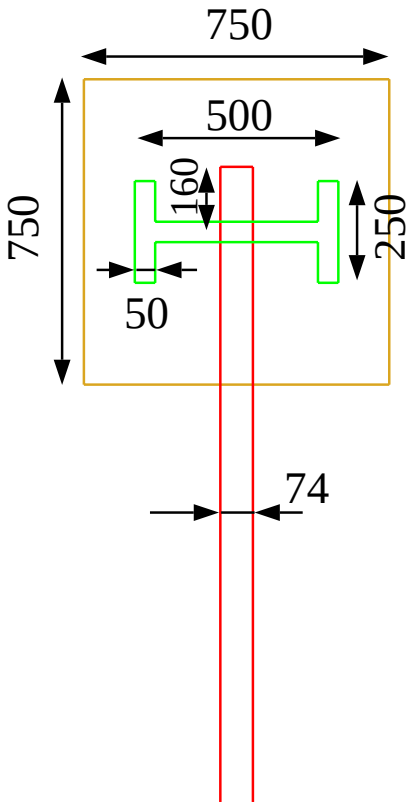
Aperture-Coupled Microstrip Antenna Design

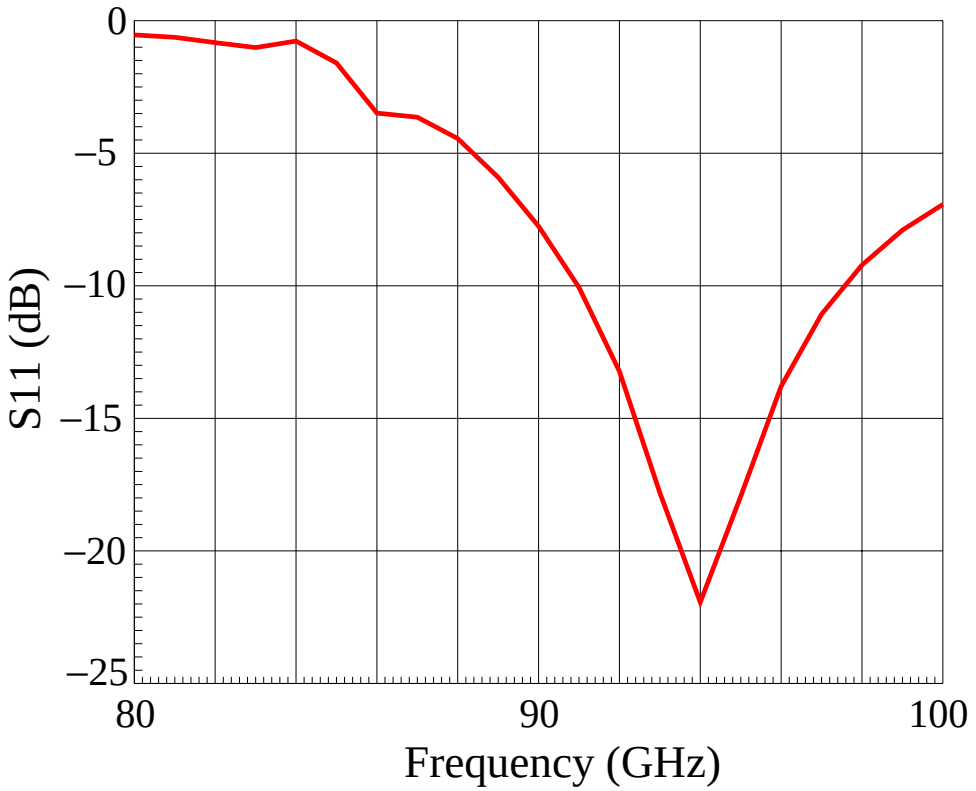


DESIGN PROCEDURE:

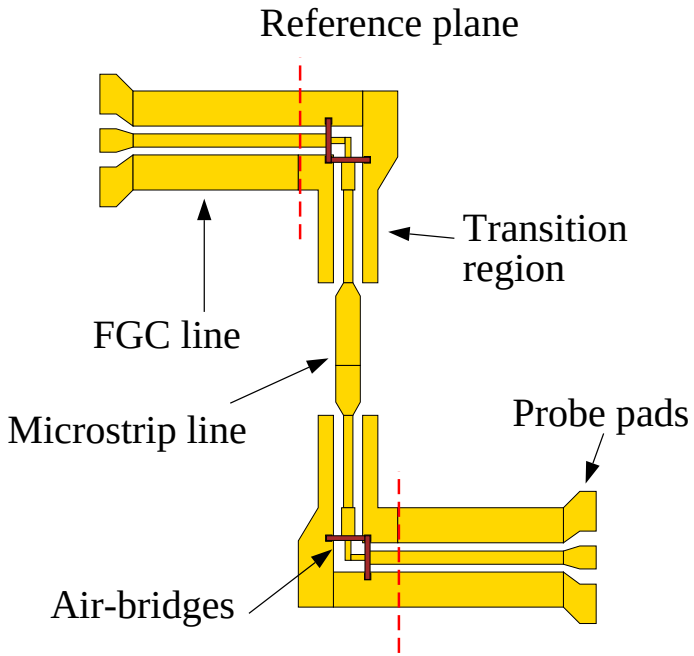
- Patch antenna size determines frequency of resonance
- H-shaped coupling aperture determines the coupling ratio. A small coupling is preferred to improve the radiation front-to back ratio
- Coupling aperture size determines the real part of the antenna
- Imaginary part compensated by microstrip open stub
- CPW-to-microstrip transition design

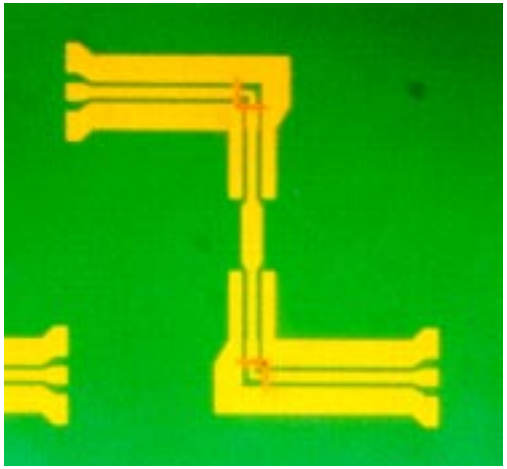
HFSS Simulations

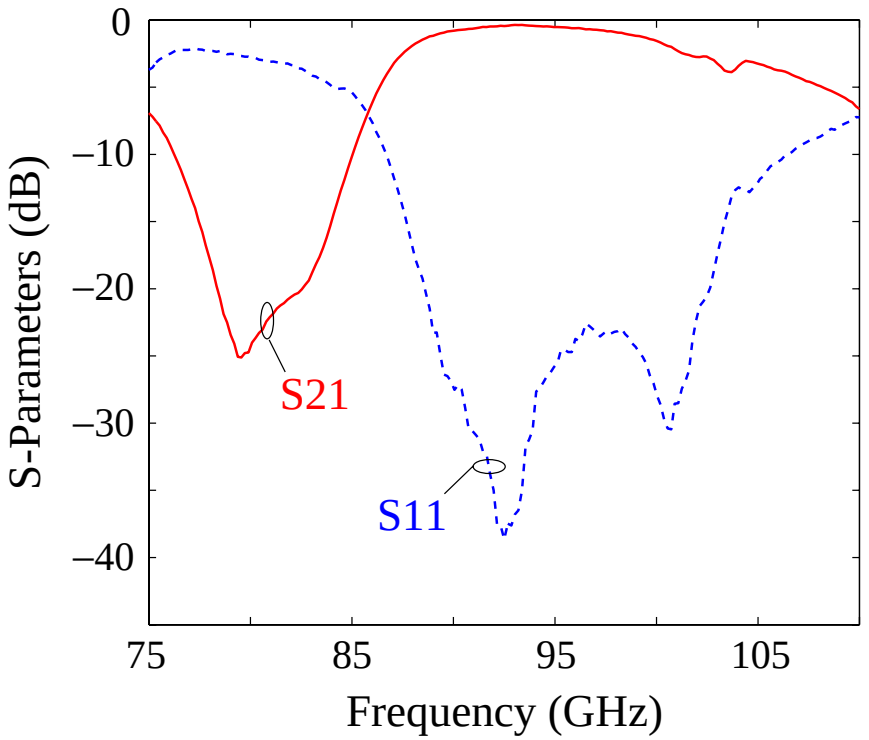




FGC-to-Microstrip Transition

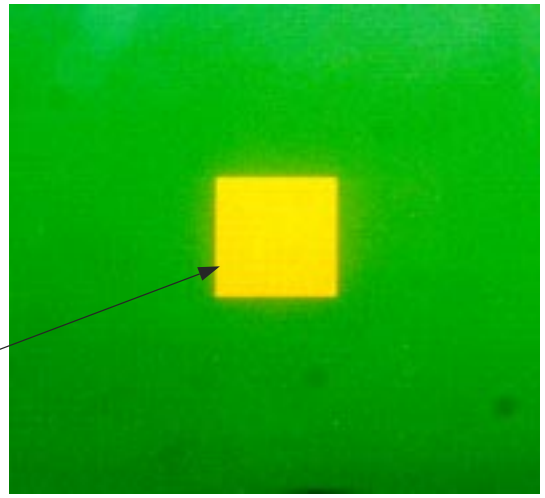


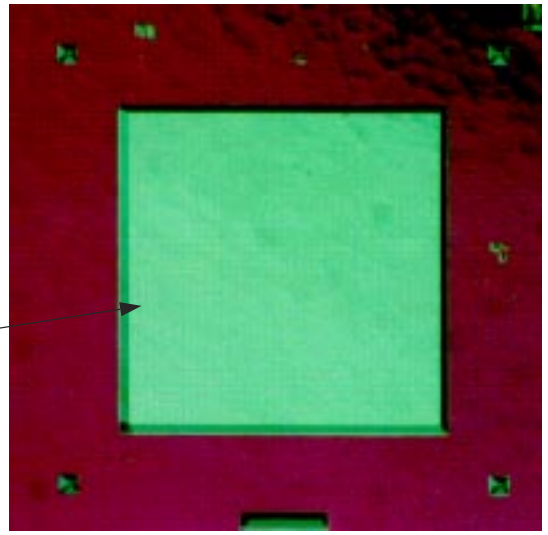


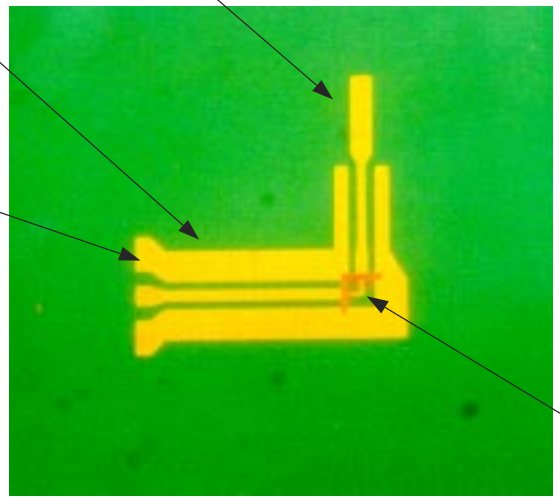


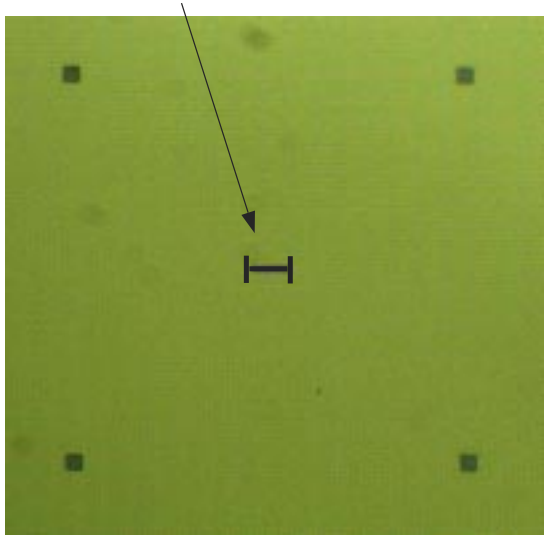
- Loss = –0.3 dB / transition

Micromachined Microstrip Antenna

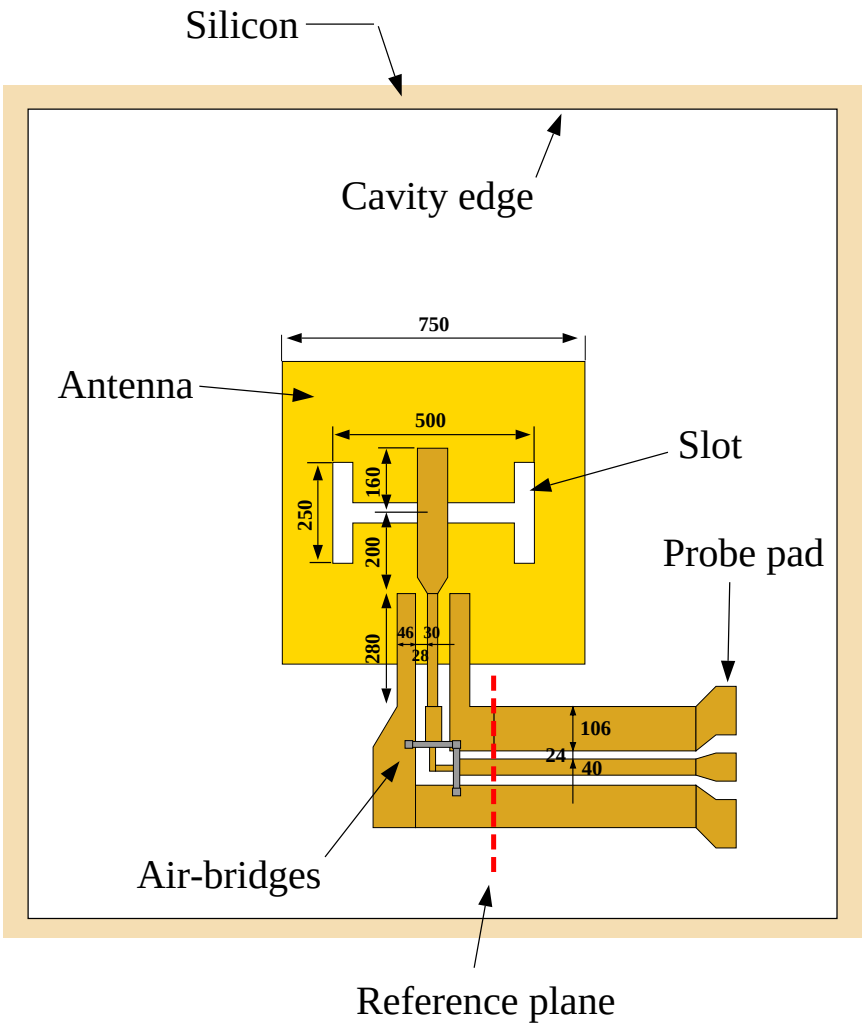


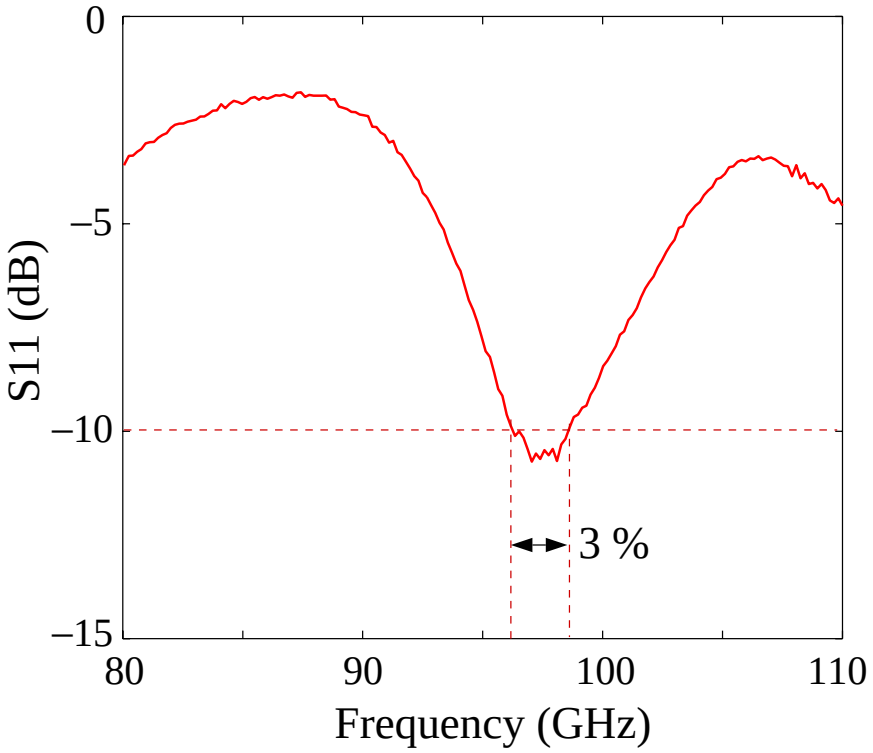






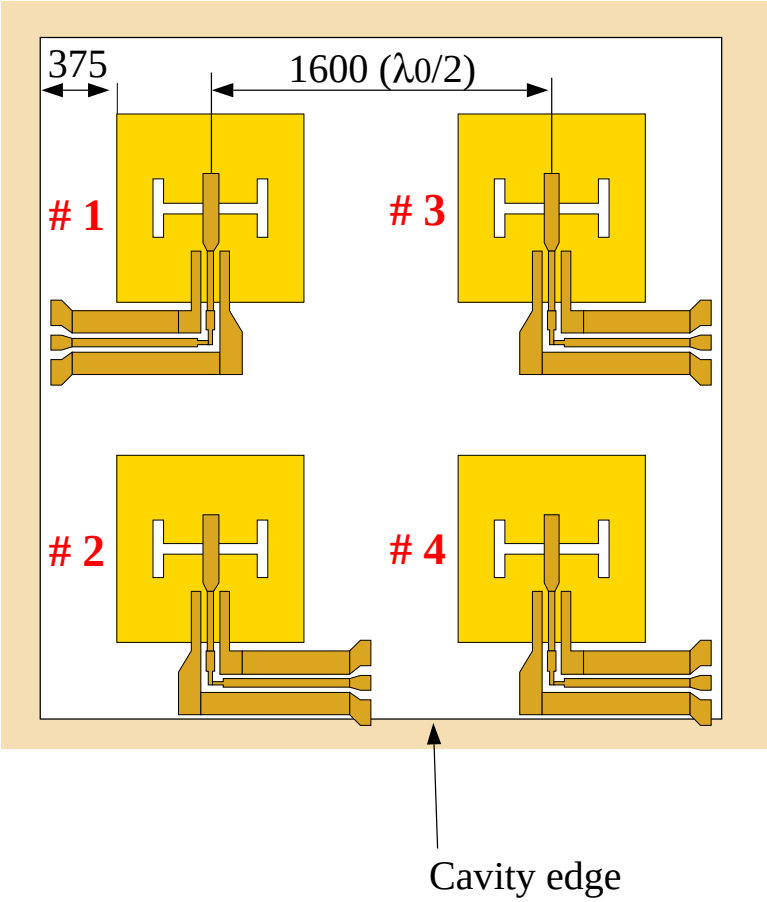
Microstrip Antenna Performance: Input Impedance

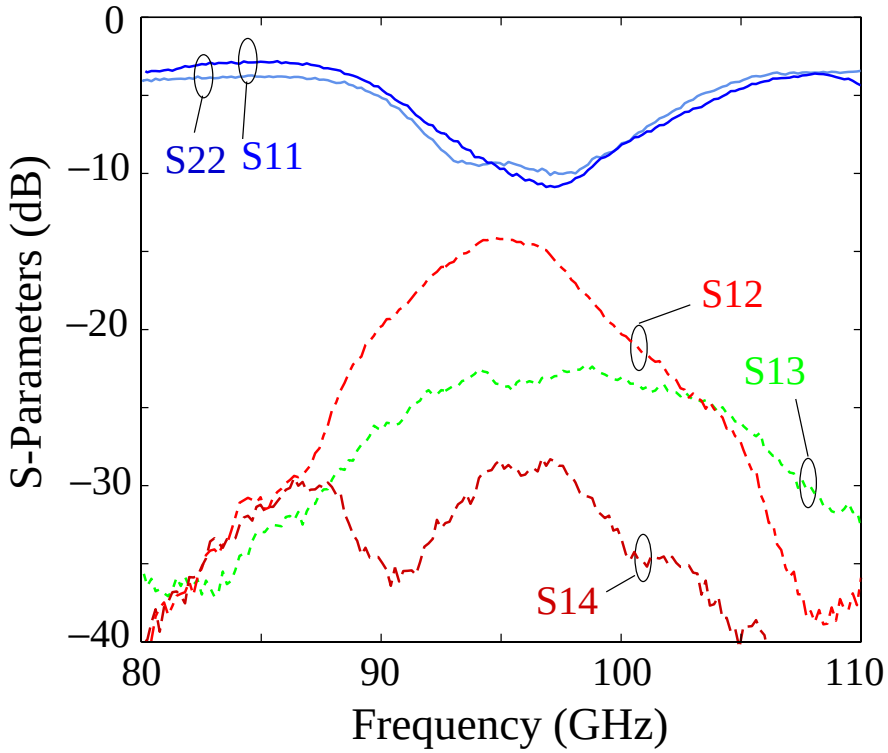




- −10 dB B/W = 3 GHz

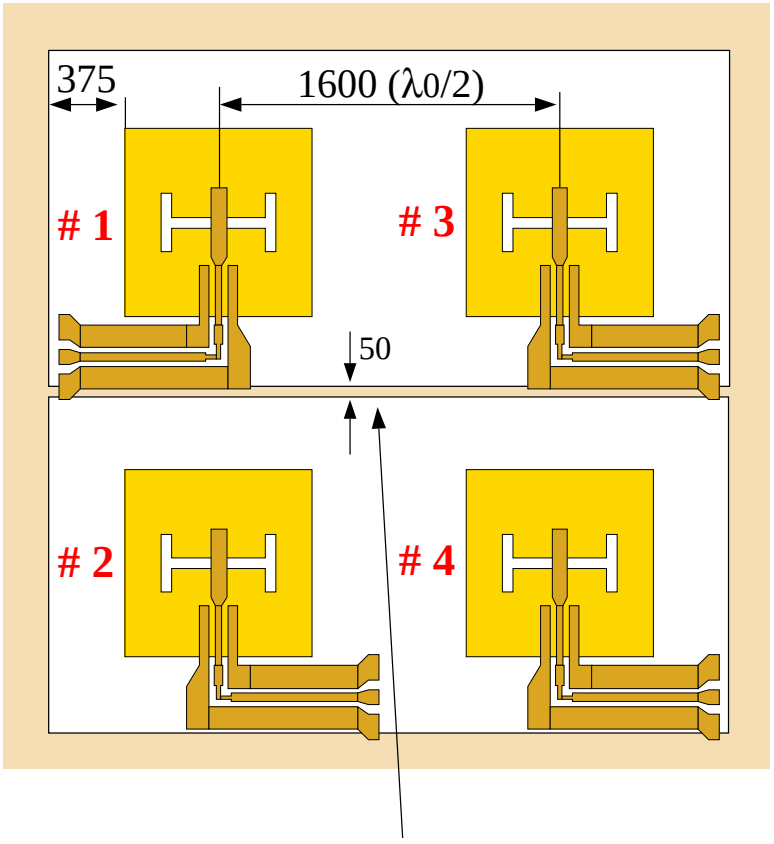
Antenna Array Integration: Mutual Coupling: no Silicon Beam

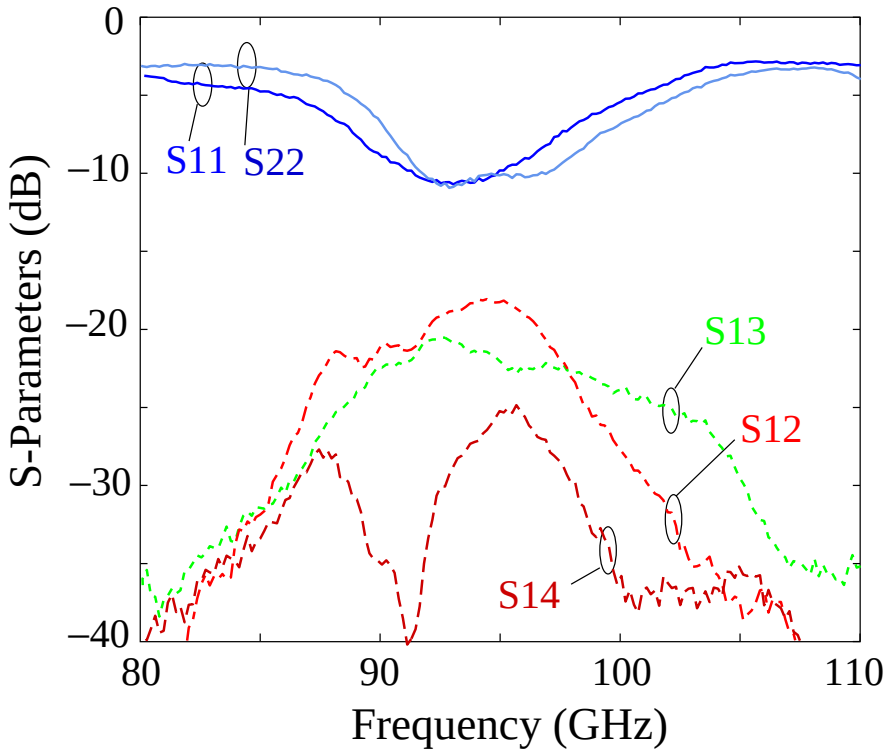




S12 ≡ E-plane coupling
S13 ≡ H-plane coupling
S14 ≡ 45°-plane coupling

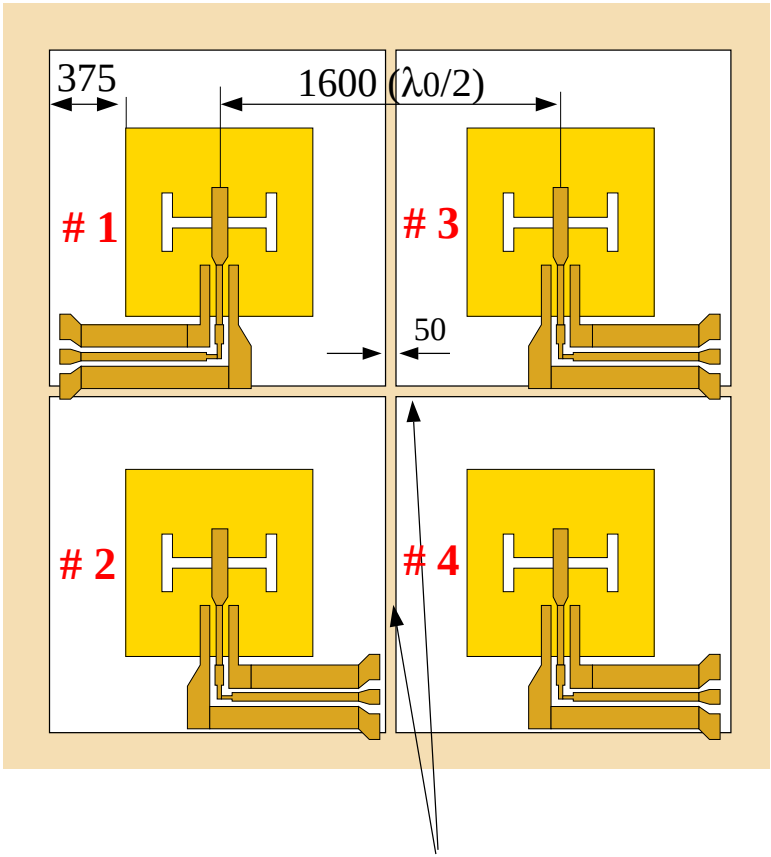
Antenna Array Integration: Mutual Coupling: with Silicon Beam

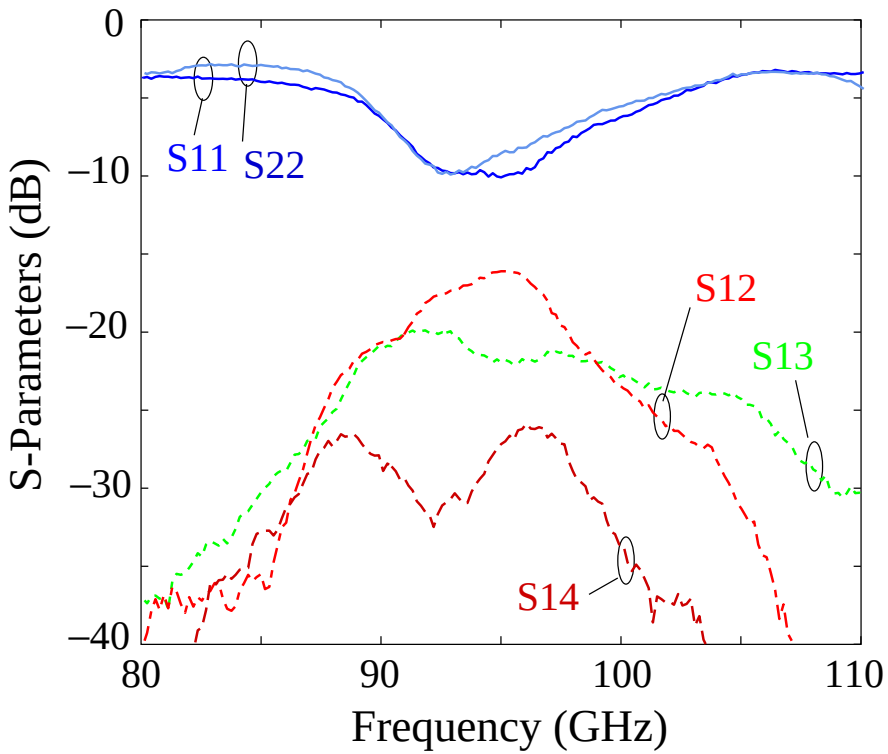




S12 ≡ E-plane coupling
S13 ≡ H-plane coupling
S14 ≡ 45°-plane coupling

Microstrip Antenna Performance: Mutual Coupling: with Crossed Silicon Beam





S12 ≡ E-plane coupling
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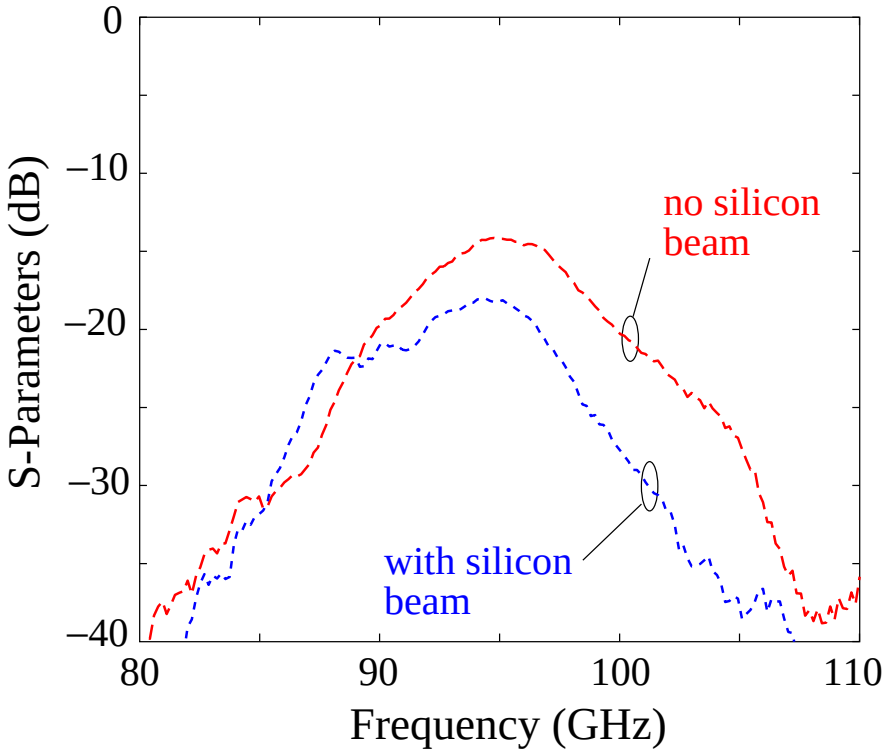
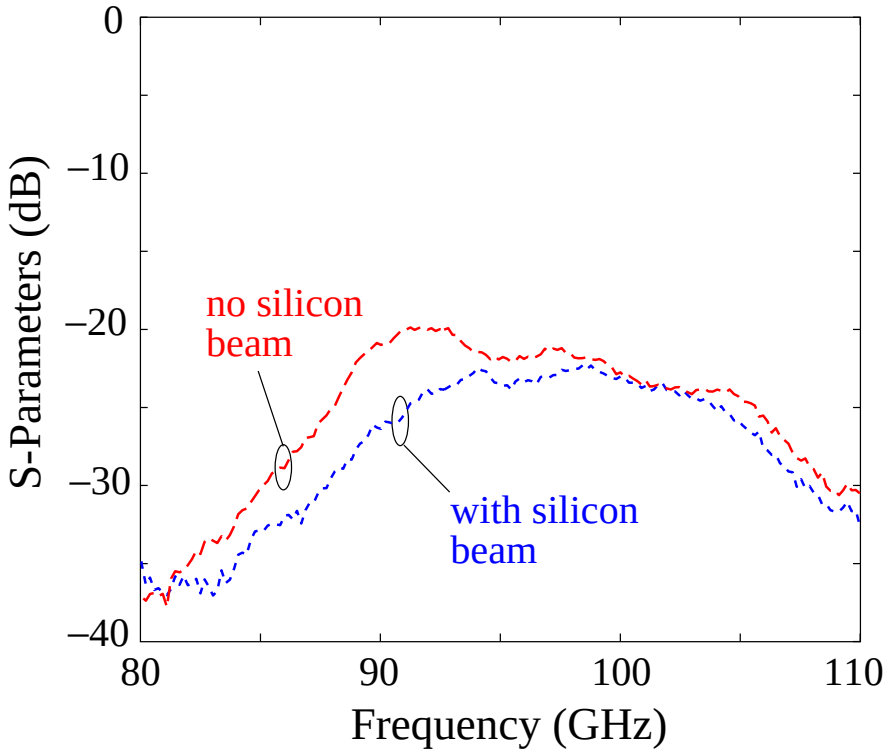
S14 ≡ 45°-plane coupling

Mutual Coupling Comparison

E-PLANE COUPLING

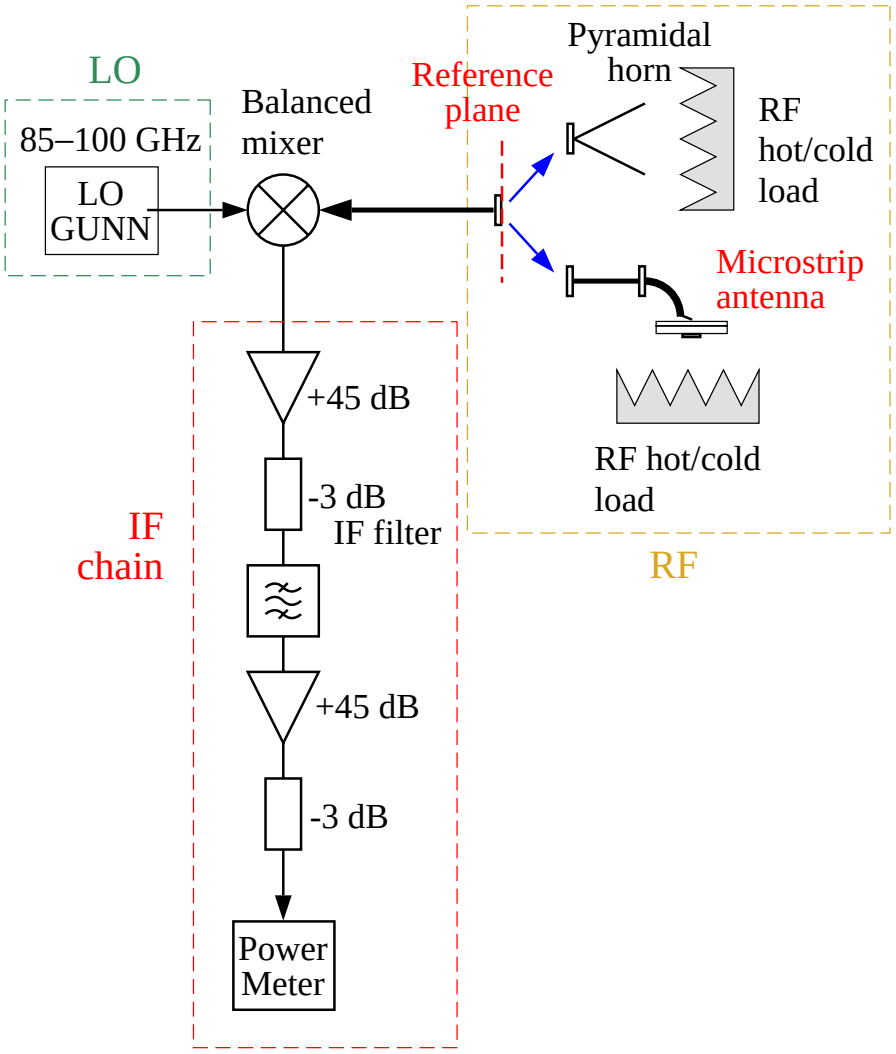


H-PLANE COUPLING



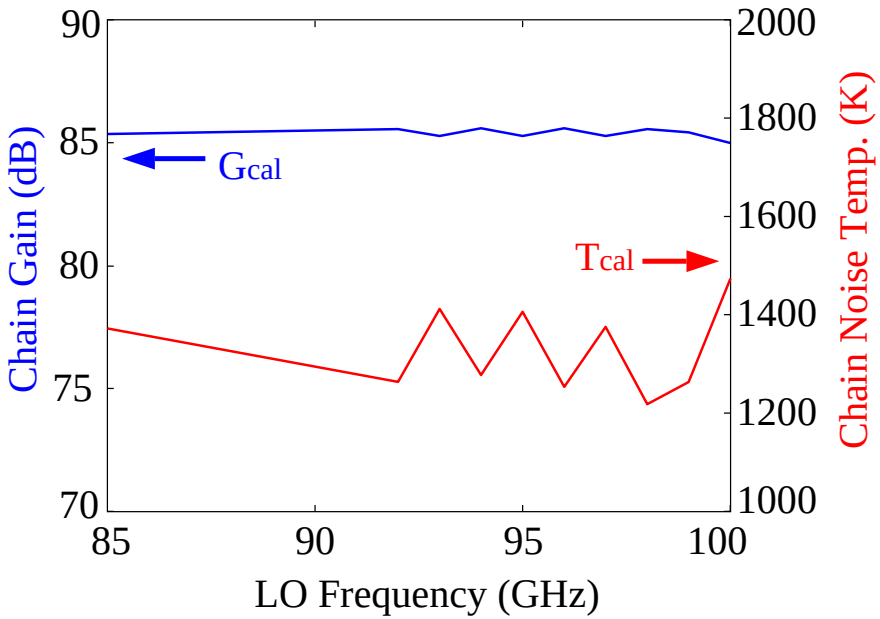
- Crossed silicon beams reduce the coupling in the E-plane direction to less than –20 dB

Radiation Efficiency: Radiometric Measurement Set-Up

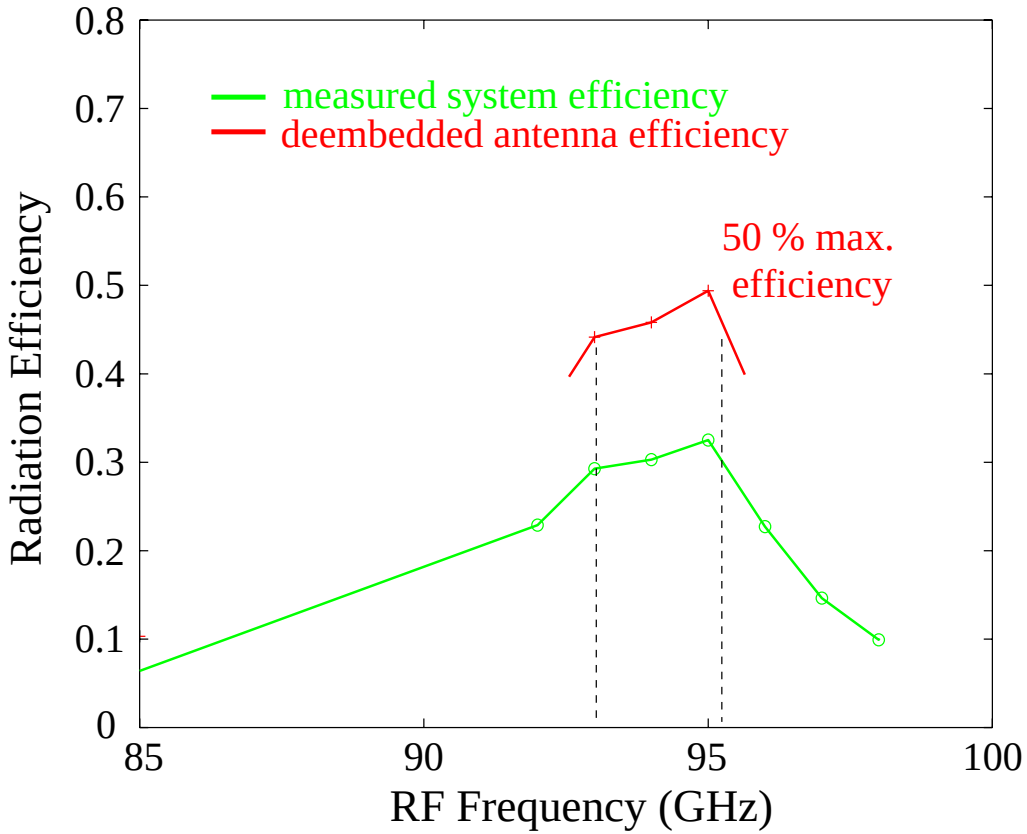


Radiometric Calibration:

- f_{IF} = 200 MHz
- IF chain:
  G = 86 dB, T = 111 K
- W-band balanced mixer:
  8 dB conversion loss
- DSB measurement

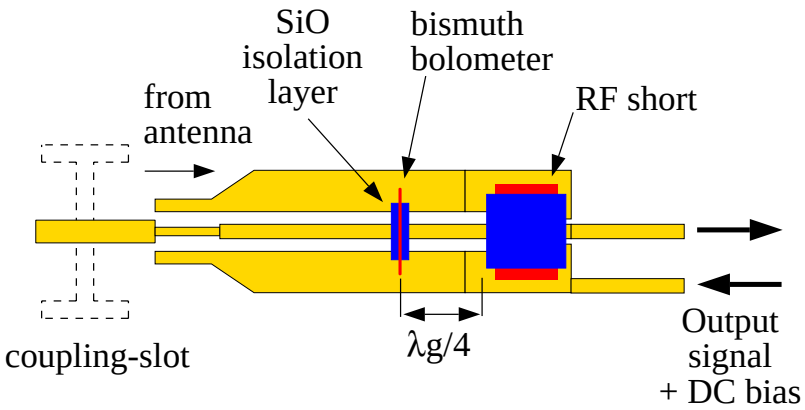


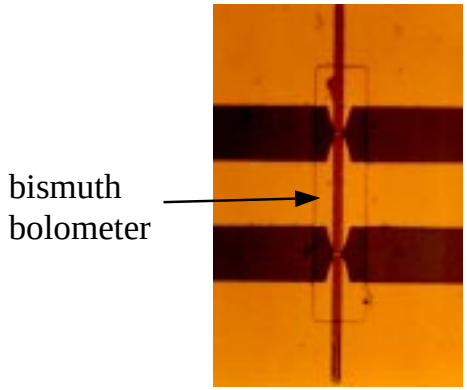
Radiation Efficiency



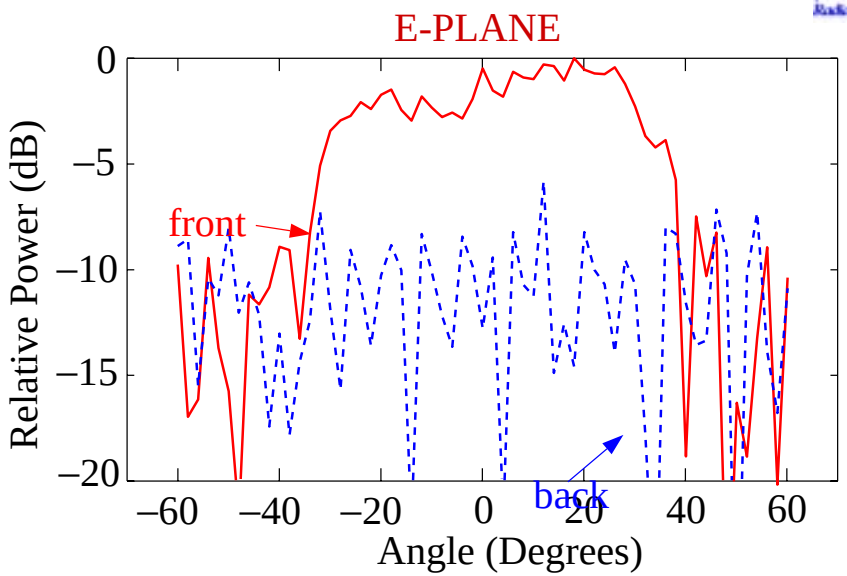
- Conductor loss 0.25 dB
- Probe losses 1.25 dB
- Mismatch losses 0.7 dB

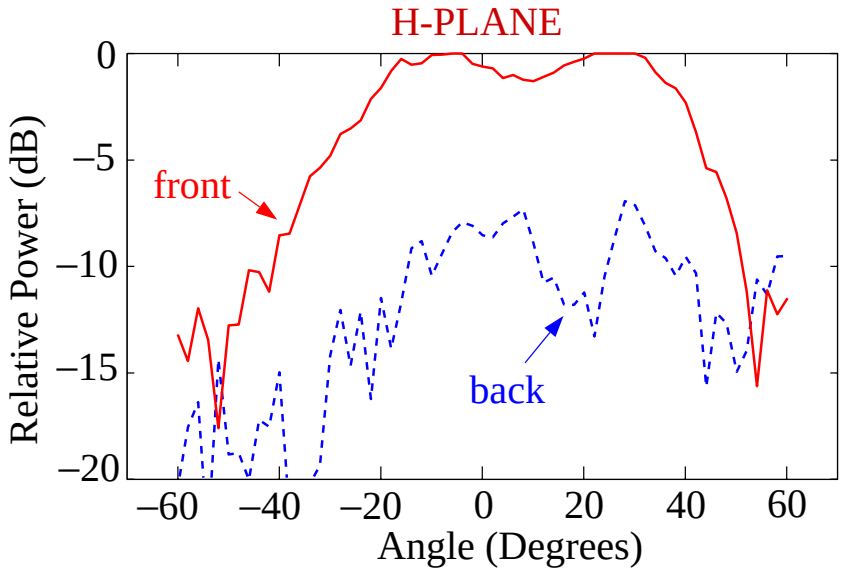
Radiation Patterns at 90 GHz





Front-to-back ratio = -10 dB





Conclusion / Future Work

- Micromachining techniques suitable for millimeter-wave aperture-coupled microstrip antennas
- Small volume, light weight
- Mutual coupling better than -20 dB
- 50 % radiation efficiency
- 10 dB front-to-back ratio
- Applications to fully micromachined millimeter-wave phased arrays