Antenna on package for 60 GHz frequency band applications

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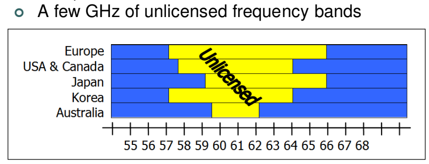
Outline

- Introduction
  - The 60 GHz band
  - 60 GHz antennas
  - CMOS antennas
- Possible solutions for 60 GHz antennas
- Simulation results
- Conclusions

Broadband communication in the 60 GHz band

- 802.15.3c IEEE standards group
  - specifications for 60 GHz radios
- A few GHz of unlicensed frequency bands



- Targeted data rate > 2 Gbps
- High-data-rate applications
  - wireless data bus to replace cables
    - Ethernet (1000Mbps), USB 2.0 (480Mbps), IEEE 1394 (~800Mbps)
  - high-speed internet access
  - wireless video (HDTV)

Benefits of 60 GHz

- Unlicensed spectrum
  - a few GHz of continuously unlicensed spectrum
- High security transmission
  - Oxygen absorption
    - short transmission distances
  - Narrow antenna beam width (typ.4-5°)
- High level of frequency reusability
  - High no. of users in a small geographical area
- High data transmission speeds
  - Gbps data rates
- Mature technology
  - Spectrum used for secure communications for years

Millimeter wave antenna requirements & applications

- Antenna requirements
  - Broadband operation
    - minimum 5 GHz bandwidth
  - High radiation efficiency
    - low dielectric constant
  - Low interconnect loss with Tx/Rx chip
    - coplanar feed
  - Easy integration into package
    - planar technology
- Applications
  - wireless gigabit ethernet (60 GHz, 80 GHz)
    - indoor / outdoor (point to point)
  - automotive radar (77 GHz)
  - imaging (94 GHz)

Package requirements

- Standard planar manufacturing technology
  - low-cost
- Small feature size
  - low tolerances
- Accurate alignment
- Candidates
  - advanced PCB
    - thin-film
  - Low Temperature Cofired Ceramic (LTCC)
  - Silicon-based

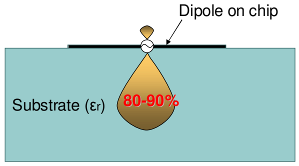
CMOS circuits for 60 GHz

- Trend towards deep sub-micron technologies
  - 130 nm
    - Razavi (2006): 60GHz radio transceiver chip
  - 90 nm
    - Toshiya et al. (2007): 60 GHz receiver chip
  - 65 nm
    - Varonen et al. (2007): building block circuits
  - 45nm, 22nm
    - higher power gain with lower power consumption at 60GHz
- Integrated CMOS RF circuits
  - Space, cost & power reduction
- Low-cost
- High performance

Integrated 60 GHz Antennas

- Integrated CMOS RF circuits
  - Antenna on Chip (AoC)
  - Antenna in Package (AiP)
- Problem: Silicon
  - Low resistivity
  - High permittivity

→ Very poor radiation efficiency and high losses



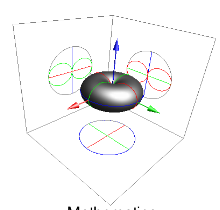
Antenna efficiency

- Can be improved by
  - substrate permittivity
    - different substrates
      - Teflon
      - Low Temperature Cofired Ceramic (LTCC)
      - Silicon
  - optimizing substrate thickness
  - adding a ground plane
  - adding a superstrate

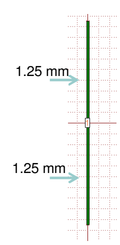
Simulation tool setup

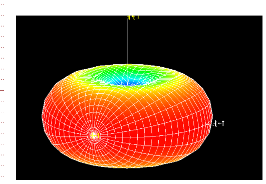
- Zeland IE3D
  - Based on the Method of Moments
- Setup
  - Simulation of well known antenna configurations
  - Comparison with theoretical values using the Mathematica analysis tool
  - Starting point for the meshing parameters

Radiation pattern for a ½ λ (f=60 GHz) dipole antenna



Mathematica



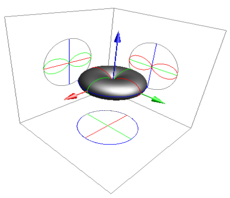


Zeland IE3D

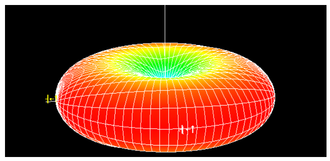
Mathematica:
- 3 dB Beamwidth = 78.1°
- Input impedance = 73.13Ω
- Directivity=1.64

Zeland IE3D:
- 3 dB Beamwidth = 78.4°
- Input impedance = 72.76Ω
- Directivity=2.14

Radiation pattern for a 1λ (120 GHz) dipole antenna



Mathematica

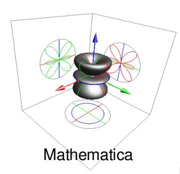


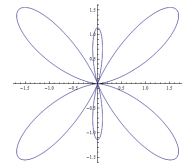
Zeland IE3D

- ➢3 dB Beamwidth = 47.84°
- ➢Input impedance = very high
- ➢Directivity=2.41

- ➢3 dB Beamwidth = 49°
- ➢Input impedance = 352Ω
- ➢Directivity=3.71

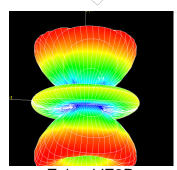
Radiation pattern for a 3/2 λ (180 GHz) dipole antenna



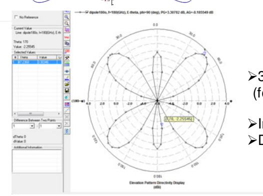


Mathematica

- ➢3 dB Beamwidth = 47.60° (for the maximum radiation direction)
- ➢Input impedance = 105.41 Ω
- ➢Directivity=3.46353



Zeland IE3D



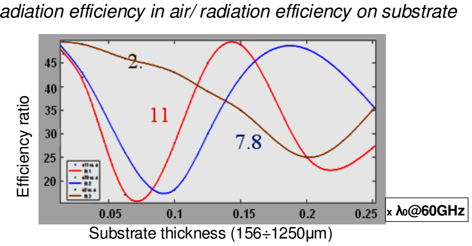
- ➢3 dB Beamwidth = 47° (for the maximum radiation direction)
- ➢Input impedance = 104.3Ω
- ➢Directivity=3.46

Next step…

- After obtaining a good agreement between theory and simulation
  - IE3D simulations for various configurations
    - Purpose: radiation efficiency maximization

Different dielectric substrates and heights

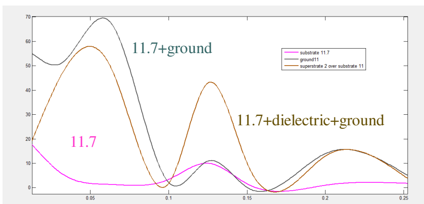
Radiation efficiency in air/ radiation efficiency on substrate



- ➢ lower substrate ε_r ➲ higher $(P_{r,air})_{average}$
- ➢ Power dissipated in the substrate > Power dissipated in air

Ground plane & superstrate

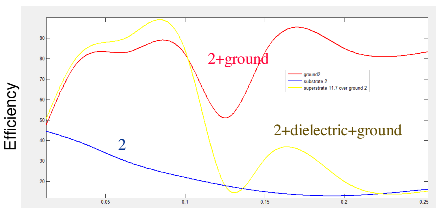
- *Zeland IE3D: radiation efficiency of the antenna for $\varepsilon_{substrate}$=11.7*



➢Ground plane ➲ radiation efficiency approaches 70% (limited by the high ε_r)
➢Adding a 100 μm superstrate with ε=2 doesn't improve the radiation efficiency

Ground plane & superstrate

- *Zeland IE3D: radiation efficiency of the antenna for $\varepsilon_{substrate}$=2*

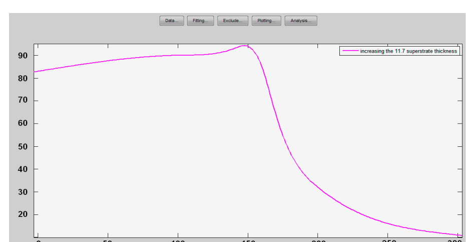


➢Ground plane ➲ radiation efficiency ~100%, for a superstrate of high ε_r
➢Adding a 100 μm superstrate with the dielectric permittivity of 11.7 increases the radiation efficiency for specific heights of the substrate

Radiation efficiency for different configurations

Best results:
✓Low permittivity substrate
✓Substrate thickness: 0.09 x λ_0
✓Ground plane
✓Superstrate of higher permittivity

Radiation efficiency in respect to superstrate height



Substrate
- *height=312μm=0.08λ_0*
- *ε_r =2*

Superstrate
- *ε_r =11.7*

Conclusions

- Comparison between Mathematica and Zeland IE3D
  - ✓ good agreement
  - ✓ Zeland IE3D offers control over almost all antenna parameters needed for the design
- Radiation efficiency for different configurations of a 60 GHz λ/2 dipole
  - ✓ The superstrate effect on different substrates
    - Increase of the radiation efficiency for low substrate permittivity and higher superstrate permittivity
    - Dependent on substrate and superstrate height
  - ✓ The presence of a ground plane improves the radiation efficiency substantially

Thank you for your attention!