TECHNISCHE UNIVERSITÄT DRESDEN

RANGER

Fakultät ET&IT , Institut für Grundlagen der Elektrotechnik , Professur für Schaltungstechnik und Netzwerktheorie

RANGER Antenna Design

23rd CCN workshop

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Dresden, 2018/07

Outline

1. Introduction

Problem Description

- Application:
  20 TX + 20 RX Antennas MIMO Radar with digital beamforming for coastal surveillance

- Antennas are available off-the-shelf for many standard frequency bands (e.g. ISM bands, GSM, LTE...)
- RANGER project has dedicated frequency band *around 3 GHz with around 100 MHz of bandwidth*
- No commercial antennas available for this band!
- Design own antennas!

1. Introduction

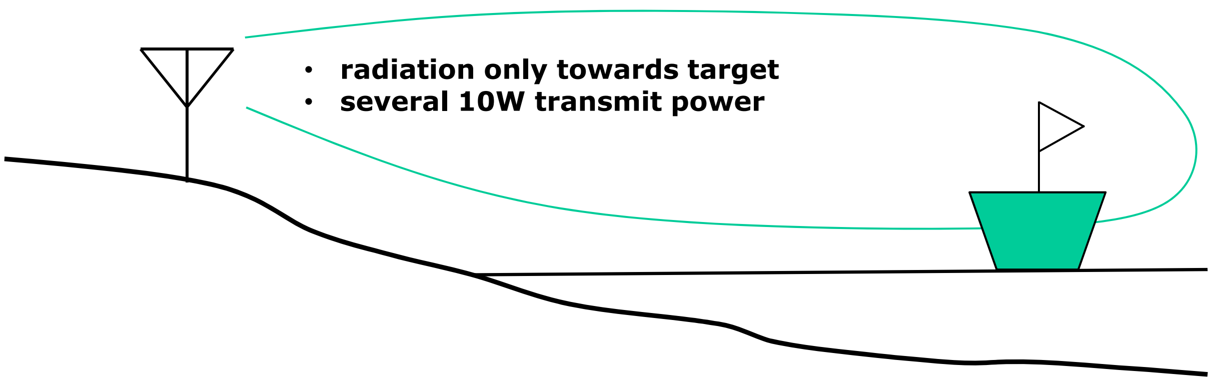
exact specifications are classified as EU Restricted

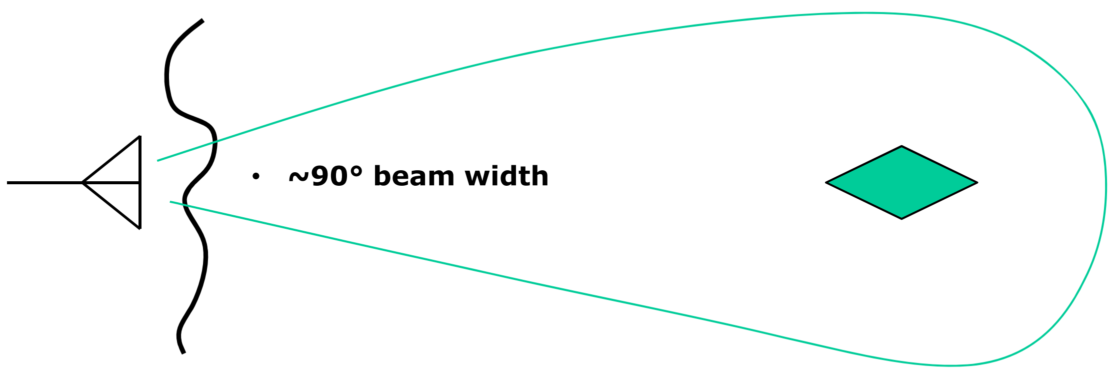
Specifications

- Frequency around 3 GHz
- Transmit power of several 10W
- Bandwidth of around 100 MHz
  (which is defined as the borders where the input reflection coefficient reaches -10 dB)
- Directivity (radiation only to the front, not to the back)
- Beam width of around 90°
  (to illuminate a large field-of-view at once)
- Minimal group delay variation in the pass band
  (to minimize phase distortion in digital beamforming)
- Repeatability of parameters for array manufacturing
- Resistance against sea conditions (water, salt)
- Cheap and easy series manufacturing
- Easy integration into housing without complex mounting

1. Introduction

Specifications





2. Antenna Basics

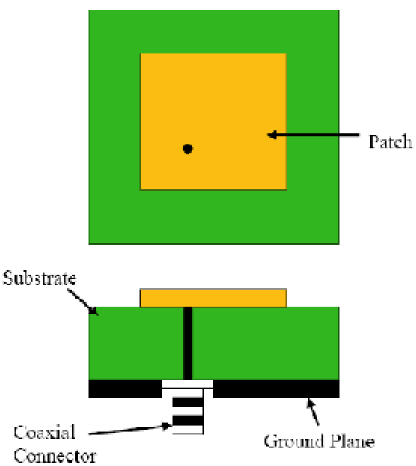
Antenna Type Selection

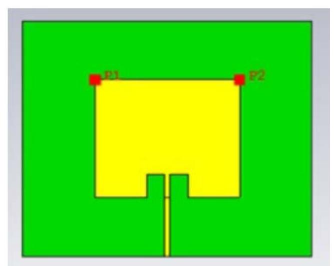
- Wire antenna (e.g. Rod)
  - simple design, easy tuning
  - complex manufacturing for rugged applications
  - radiates in all directions
- Horn antenna
  - high gain, very high bandwidths possible
  - very high directivity, results in (too) small beam width
  - available for sale in required frequency band!
  - very expensive (~900€ per piece)
- PCB antenna (e.g. Patch, F-shaped, Vivaldi)
  - large range of gain/directivity and beam widths possible
  - cheap mass fabrication
  - more complex design and difficult tuning

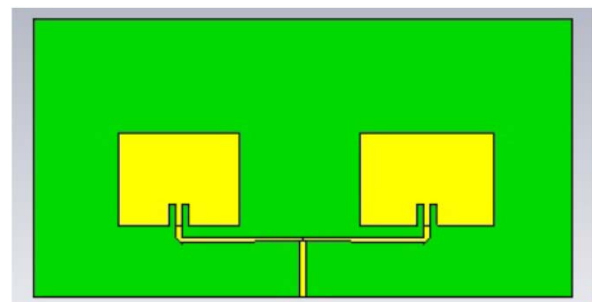
2. Antenna Basics

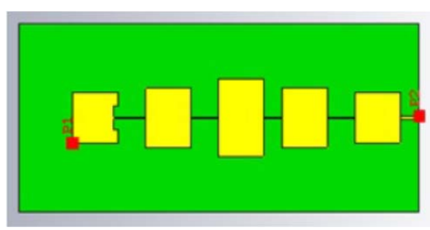
Antenna Type Selection

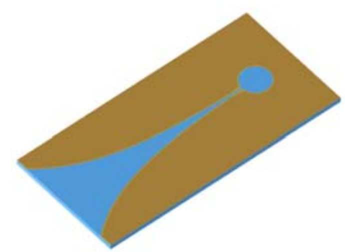
- Antenna on PCB seems like best choice, but which one?







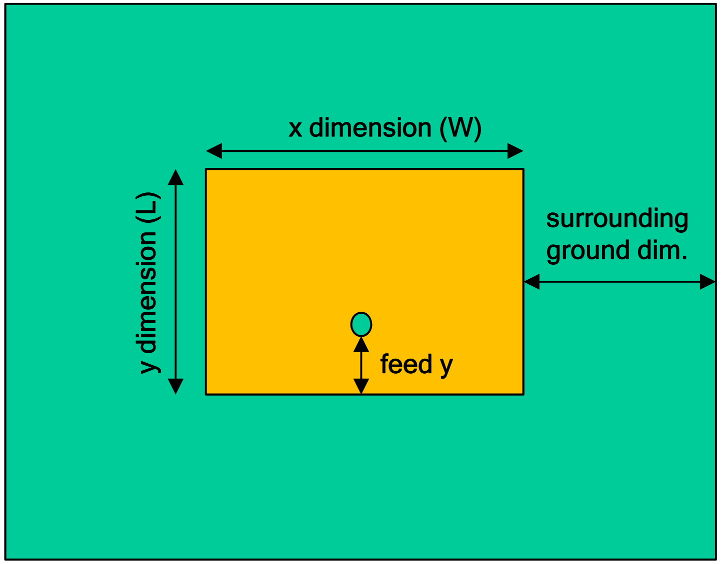


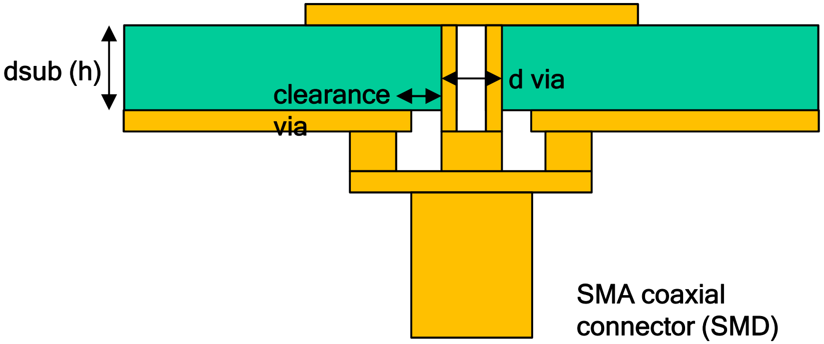


3. Design & Simulation

Patch Antenna with Coaxial Feed - Geometry

- Rectangular geometry on substrate with signal feed through via and ground plane on the back





3. Design & Simulation

Patch Antenna with Coaxial Feed – Design Equations

- Many online patch antenna calculators
  (e.g. https://www.pasternack.com/t-calculator-microstrip-ant.aspx)
- Width x and length y depend on substrate dielectric and height and the required resonance frequency

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}}; \quad \varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

Example @3GHz on 1.51mm RO4350B

Width ~ 31.2mm
Length ~24.4mm

- Feed point has to be found such that the impedance at this point of the patch matches to 50 Ohms (by EM simulation)
  (or your required system impedance)

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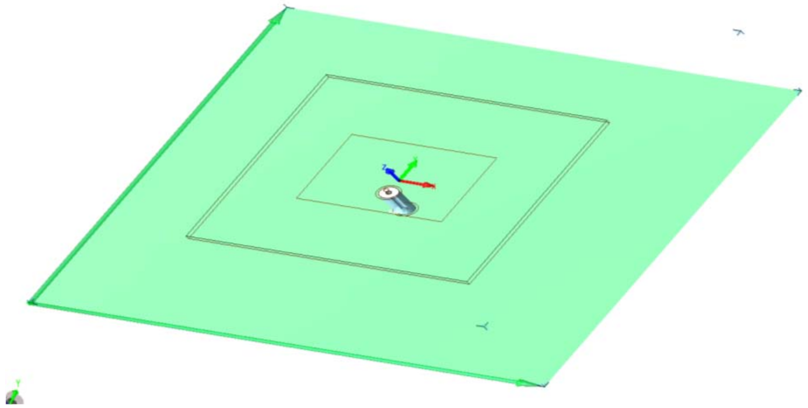
3. Design & Simulation

Patch Antenna with Coaxial Feed – Simulation

- 3D EM Simulation with Keysight EMPro 2017
- Model includes coaxial connector
- Example on Mitarbeiter drive: Y:\Anleitungen_Dokumentation\EMPro
- Test of FR-4 (cheap) and Rogers RO4350B (low loss RF substrate)



3. Design & Simulation

Patch Antenna with Coaxial Feed – Simulation

Observations during simulations around 3 GHz:

- Design equations give only a rough estimate, around 100 MHz away from the calculated frequency
- Bandwidth increases with dielectric thickness
  (use thick material, e.g. 1.55mm for FR4, or use air as dielectric and add patch with spacer)
- Maximum practical bandwidth of substrate patch is around 70-80 MHz
- Ground plane needs to surround patch with at least half its length for good return loss and validity of the design equations
- Gold plating of the copper makes for some 10 MHz of resonance frequency shift
- Via diameter and clearance has negligible influence, if resonably sized (not overly large or overly small)
- Feed position in y direction mainly changes return loss, but also resonance frequency; there is an optimum feed point for a certain range of patch widths and lengths

3. Design & Simulation

Patch Antenna with Coaxial Feed – Simulation

- Fabrication tolerances, variation of:
  - Dielectric thickness
  - Dielectric constant
  - Copper thickness
  - Under/over-etching

Thickness / mm	**Frequency Band/ GHz**
1.51	3.120-3.184
1.55	3.091-3.157
1.60	3.088-3.154

Dielectric const.	**Frequency Band/ GHz**
4.2	3.163-3.231
4.4	3.101-3.167
4.6	3.013-3.077

4. Assembly & Measurement

Manufacturing Issues

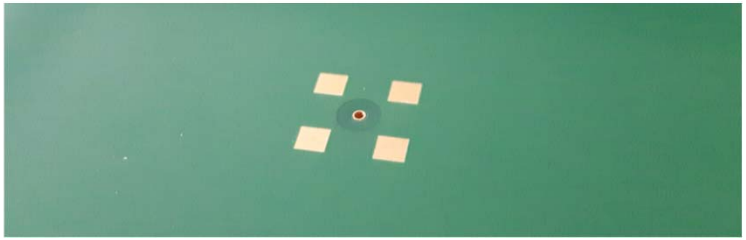
- Multi-CB
  - FR-4 (50€/100cm²), Rogers RO4350B (~200€/100cm²)
  - FR-4 material composition and thickness changes severely over several runs, no optimization possible
  - Comparably cheap Rogers fabrication
- Contag
  - FR-4 (119€/100cm²), Rogers RO4003 (~256€/100cm²)
  - FR-4 material stays constant between runs, if requested!
  - More expensive Rogers fabrication

- Fabricate Rogers prototypes at Multi-CB, FR-4 prototypes at Contag

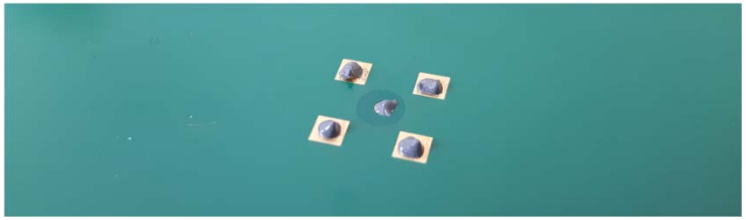
4. Assembly & Measurement

Assembly in Reflow Oven

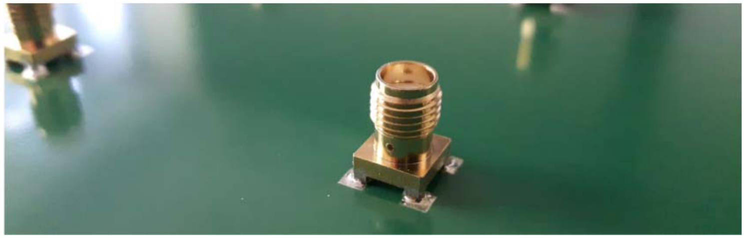
Pad geometry for SMD connector
Via for feed in the middle



Apply solder paste from syringe



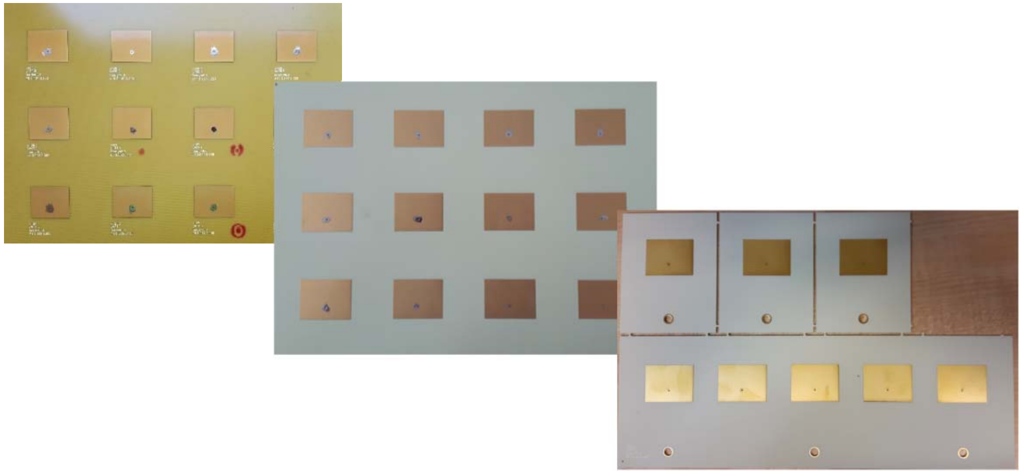
Place connector and bake in the oven



4. Assembly & Measurement

Some optimization steps later…

- Slightly different widths, lengths and feed positions
- +/-150 MHz spread of resonance frequency
  (to compensate for thickness and dielectric variations)
- Conformal coating with Plastik70 spray lacquer



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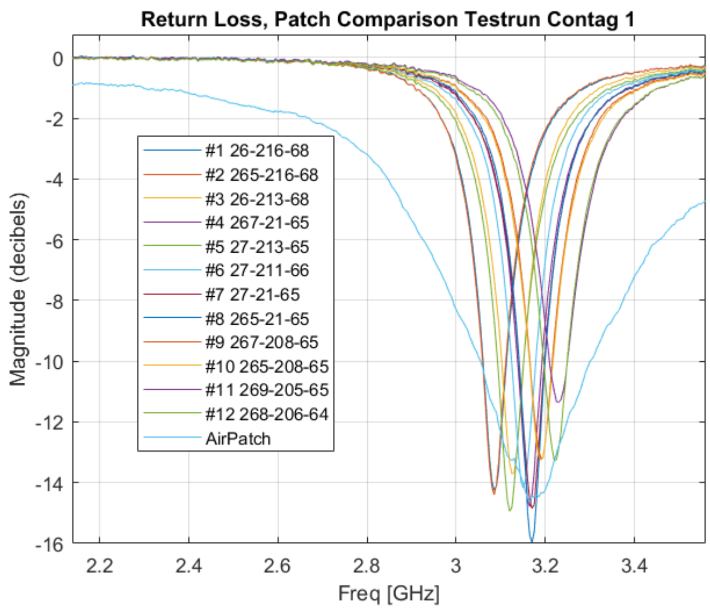
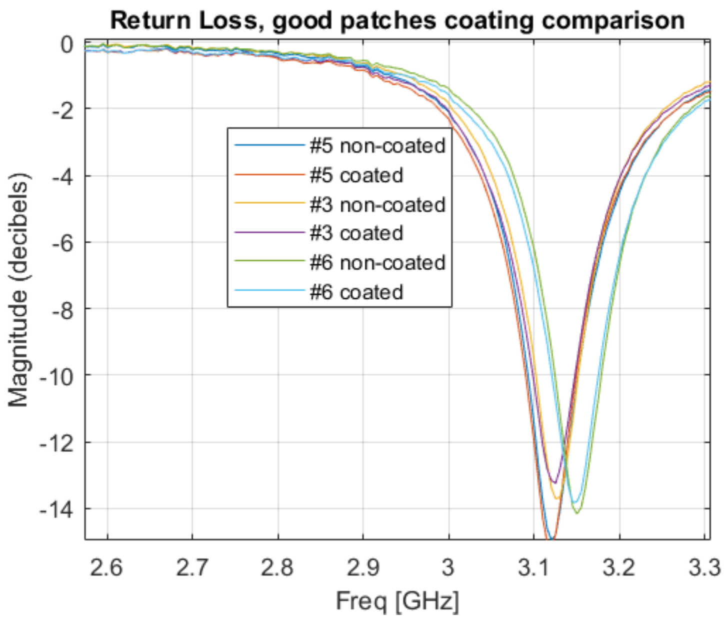
4. Assembly & Measurement

Results – FR-4

- Simulation predicted resonance frequency ~100 MHz too high
- Conformal coating reduces frequency by 5-10 MHz

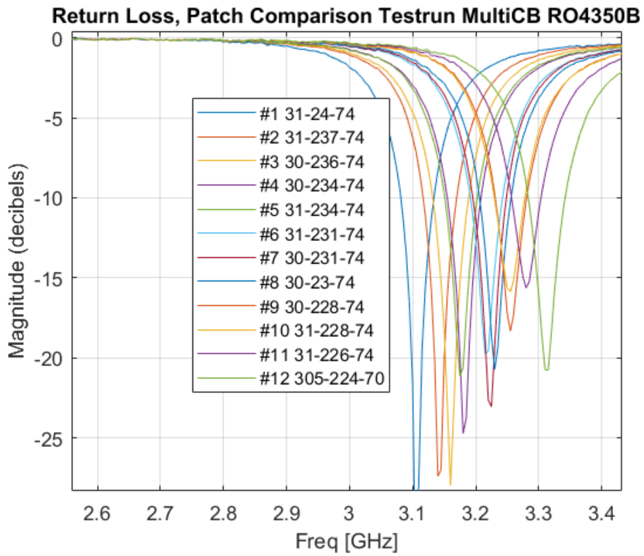


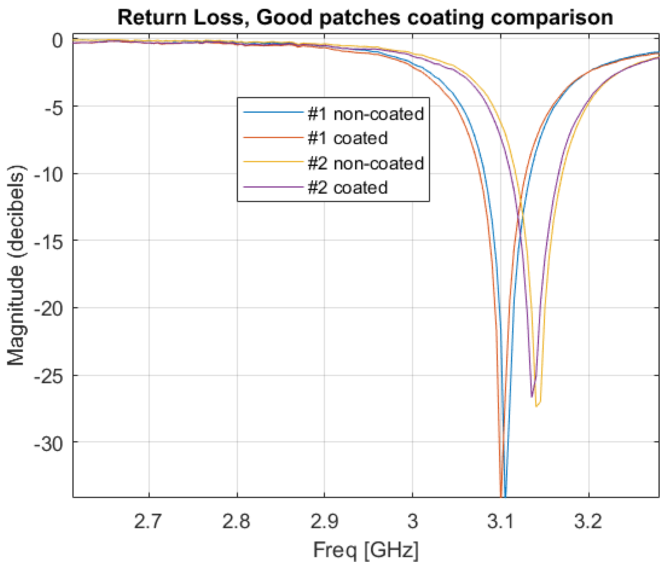


4. Assembly & Measurement

Results – Rogers RO4350B

- Simulation predicted resonance frequency ~100 MHz too high
- Conformal coating reduces frequency by 5-10 MHz
- Much better return loss than FR-4

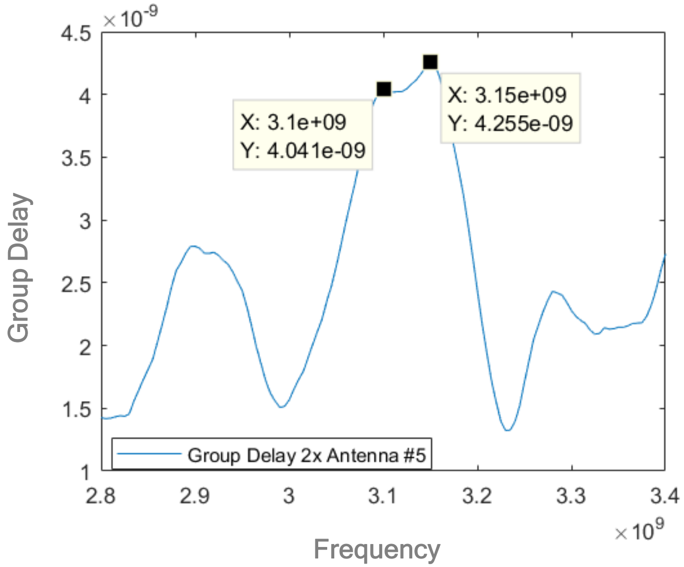




4. Assembly & Measurement

Results – Group Delay

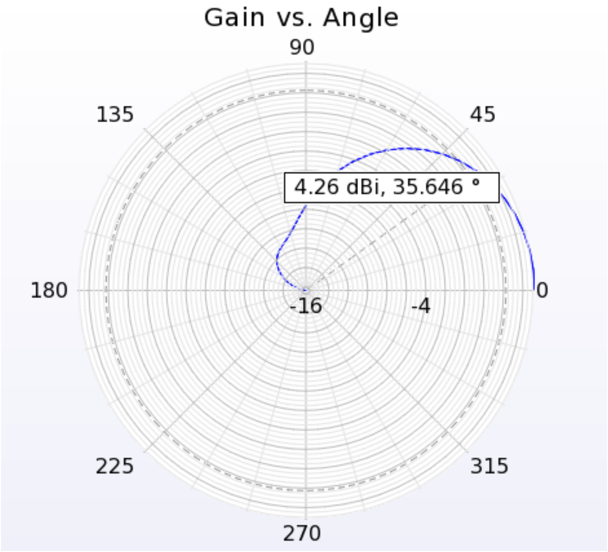
- Measured with two equal patch antennas
- Variation of only ~200ps in the band of interest
  (similar magnitude as of RF bandpass filters)

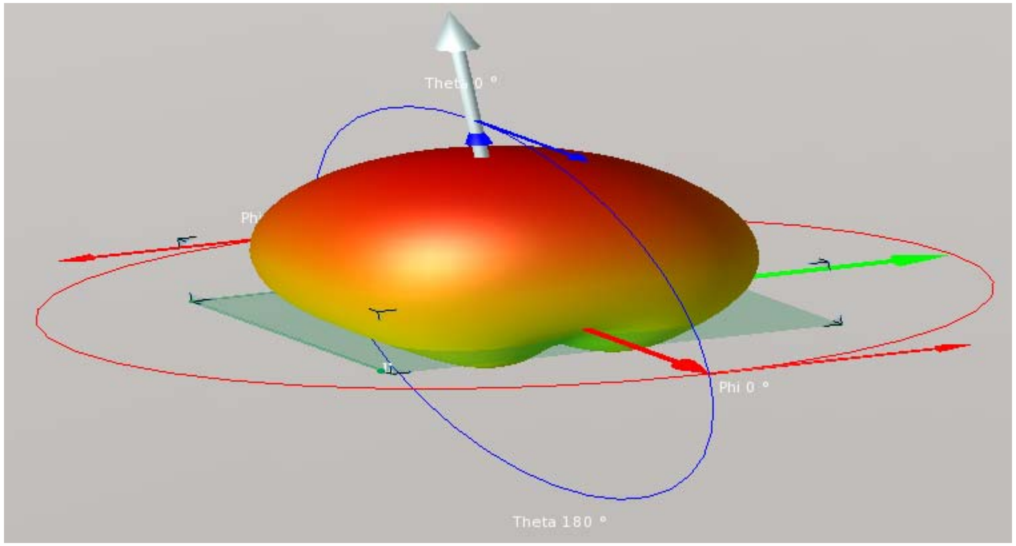


4. Assembly & Measurement

Results – Directivity (simulated)

- Very limited radiation to the back of the antenna
- 3 dB beam width of 70°, gain of 7.2 dBi





5. Conclusion

- Reached specifications:
  - RO4350B substrate with 1.51mm thickness
  - 60 MHz of useable bandwidth around 3 GHz
  - 200 ps group delay variation
  - 70° beam width
  - 7.2 dBi gain
  - Conformal coating
  - Repeatable manufacturing
  - Easy housing integration

- Antenna used successfully in 3x3 MIMO radar prototype