Master Thesis

Mobile Phone Antenna Modelling

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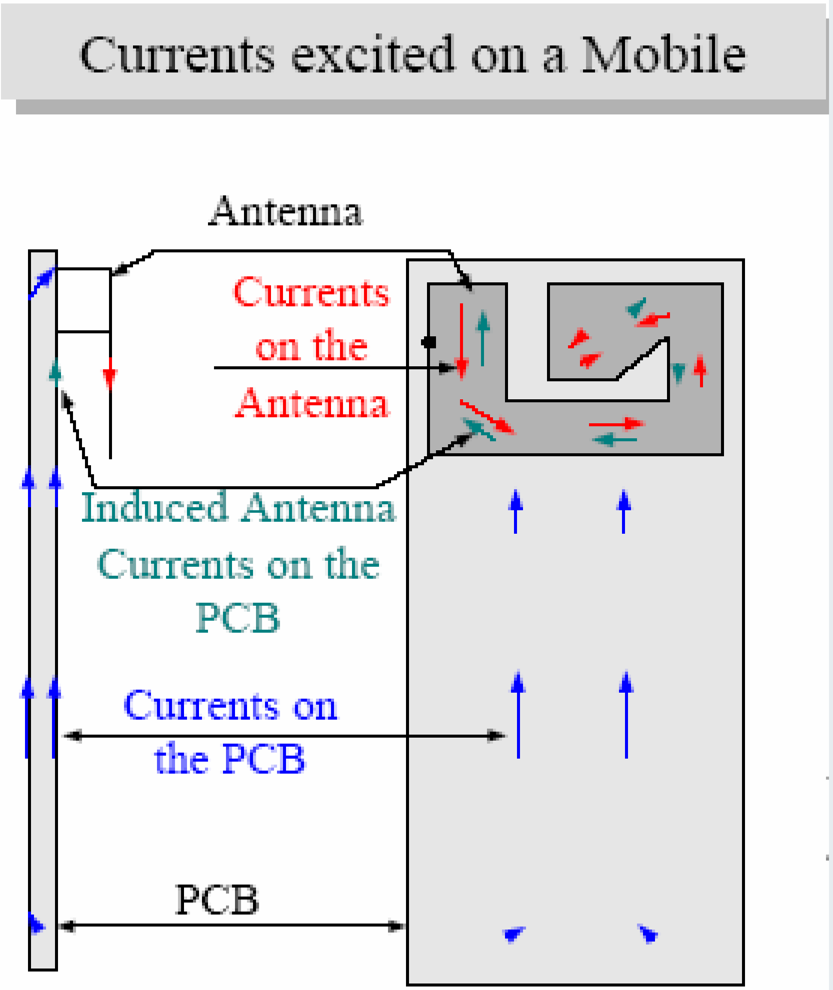
Contents

Introduction



- Integrated Antenna element couples strongly with the PCB
- PCB acts as a second radiator
  - More Efficiency
  - More Antenna Bandwidth

Introduction

The thesis task

- Design and test of Monopole and PIFA antennas on a large ground plane
- Reflection coefficient measurement of antennas mounted on PCB at
  - Different Positions
  - Orientations
  - PCB Length Variations
- Test of the PCB as a dipole antenna via a balun and coaxial cable
- Investigation of the coupling between the antenna element and PCB by 2 port measurements at different antenna element
  - Positions
  - Orientations
- Developing an equivalent circuit representation of the antenna element, the coupled PCB and the coupling mechanism

Theoretical Background

Potential Bandwidth:

- The bandwidth for the best matching case
- The impedance of the center frequency is selected as the characteristic impedance.
- The reflection coefficient is approximately zero for the center frequency
- So, the potential bandwidth could be found between the -10 dB frequency points.

Antenna Measurements on Different PCB Variations

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Antenna Designs on Large Ground Plane (42.5 cm X 50 cm)

- **No Simulation Tool**
- **Monopole Antenna**
  - Center Frequency: 1.047 GHz
  - Bandwidth: 12.3 %
  - Gain Maximum at 1 GHz: 2.261 Db
- **PIFA Antenna**
  - Center Frequency: 1.048 GHz
  - Bandwidth: 7.86 %
  - Gain Maximum at 1 GHz: 2.778 Db
- **C-Patch Antenna**
  - Center Frequency: 1.066 GHz
  - Bandwidth: 3.48 %
  - Gain Maximum at 1 GHz: 2.316 Db

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Antenna Measurements on Different PCB Variations

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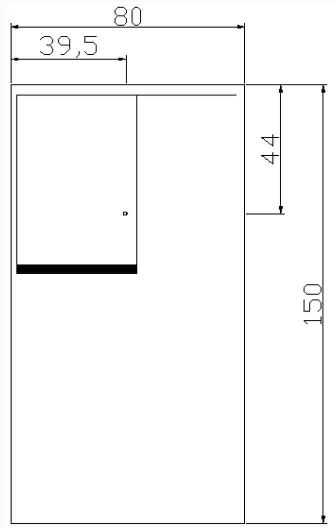
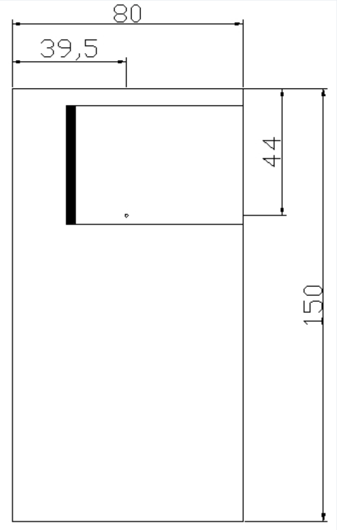
Orientation

- $\Delta F = f_{oriented} - f_{l\,arg\,e\;ground}$



Orientation Number 1



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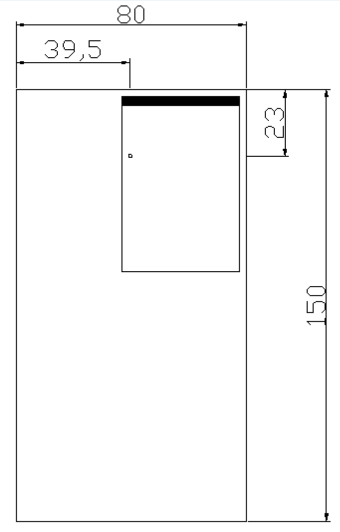

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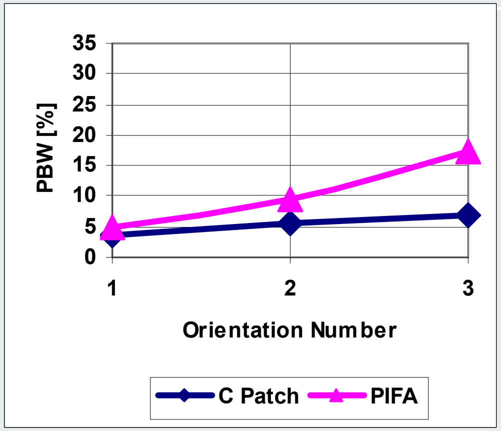

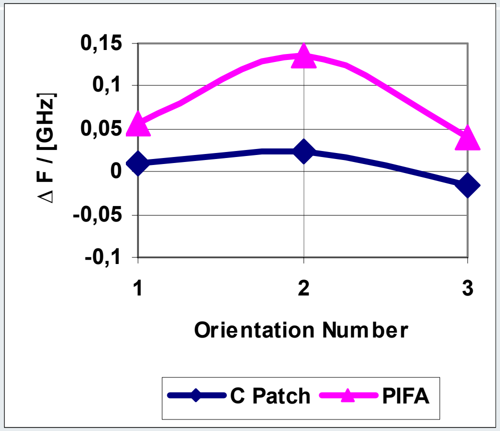

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Antenna Measurements on Different PCB Variations

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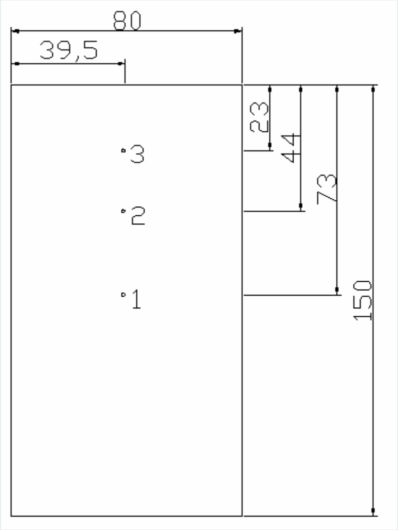
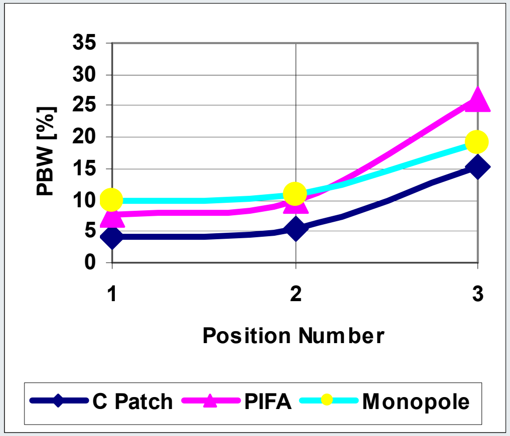
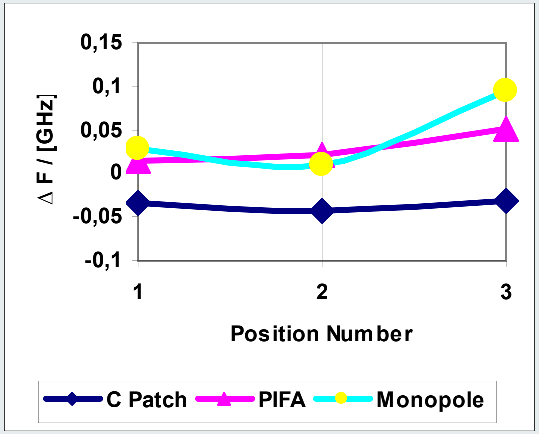
Antenna Position Change on the PCB

- Antennas at Orientation Number 3
- The dots indicate the Feed Points
- $\Delta F = f_{position} - f_{large\ ground}$



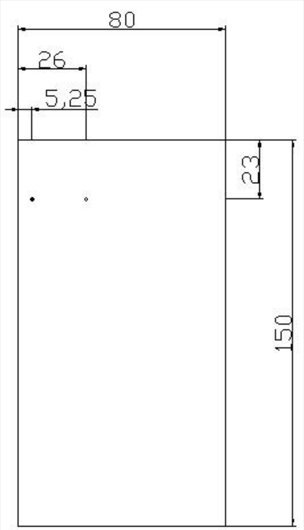


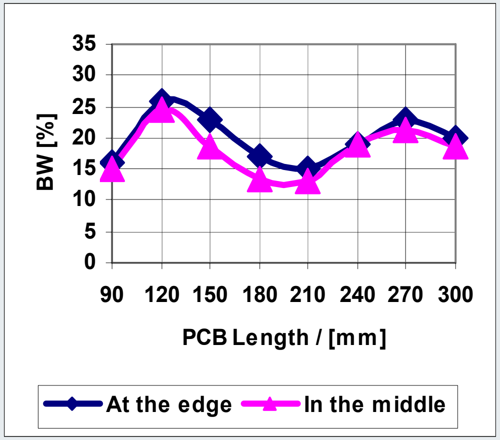


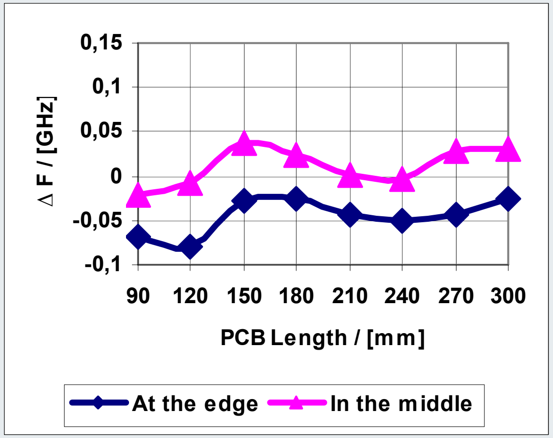
Antenna Measurements on Different PCB Variations

Variation of PCB Length

- Antennas at Orientation Number 3
- The dots indicate the Feed Points
- PCB is cut in every 30 mm between 300 mm to 90 mm
- $\Delta F = f_{PCB\ length} - f_{large\ ground}$

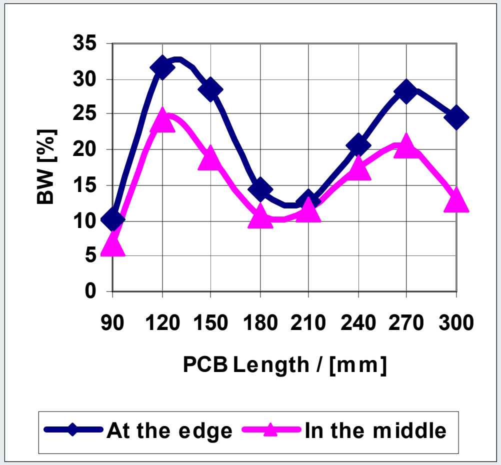


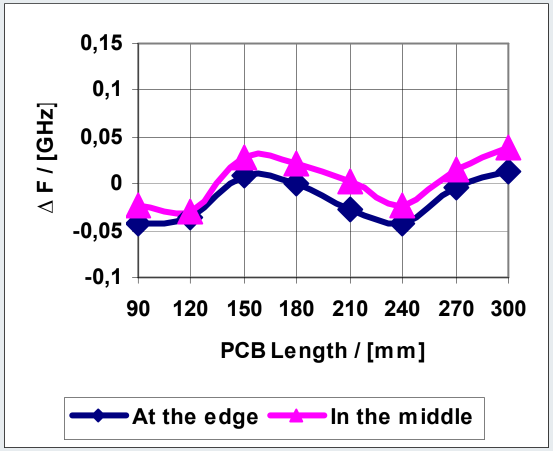




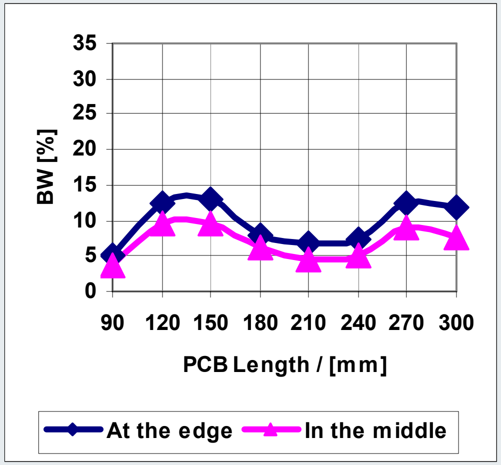
Monopole Antenna

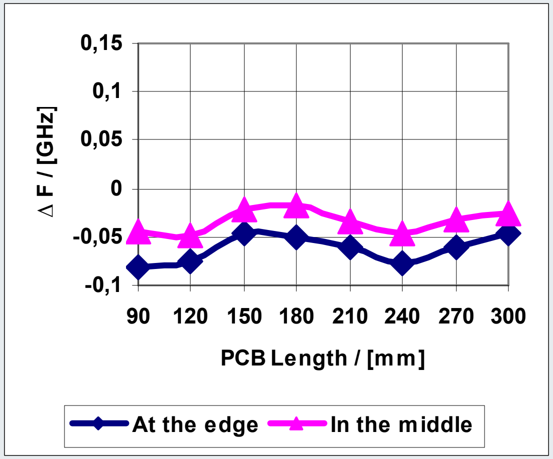
Antenna Measurements on Different PCB Variations





PIFA Antenna





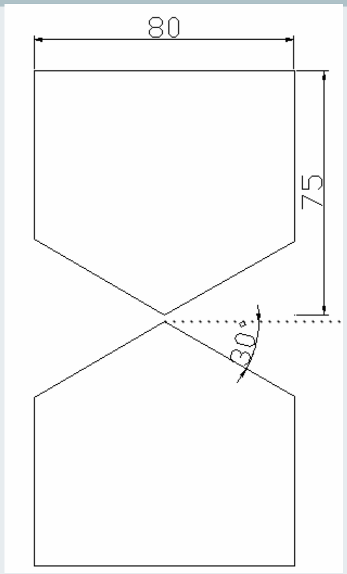
C-Patch Antenna

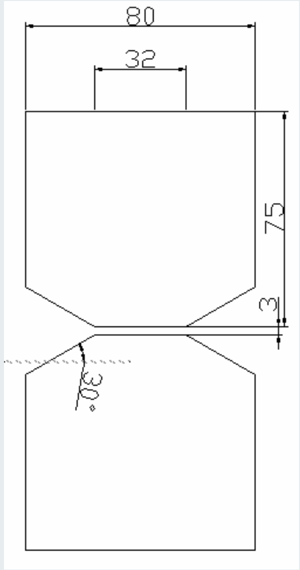
Most Bandwidth

- Orientation Number 3
- Antenna located at the top edge of the PCB
- Around 130 mm PCB Length

Investigation of the Chassis

- The chassis is cut into two arms and measured as a dipole antenna
    - 2 baluns and 4 different methods
- Providing Symmetric excitation using an unbalanced coaxial feeding cable

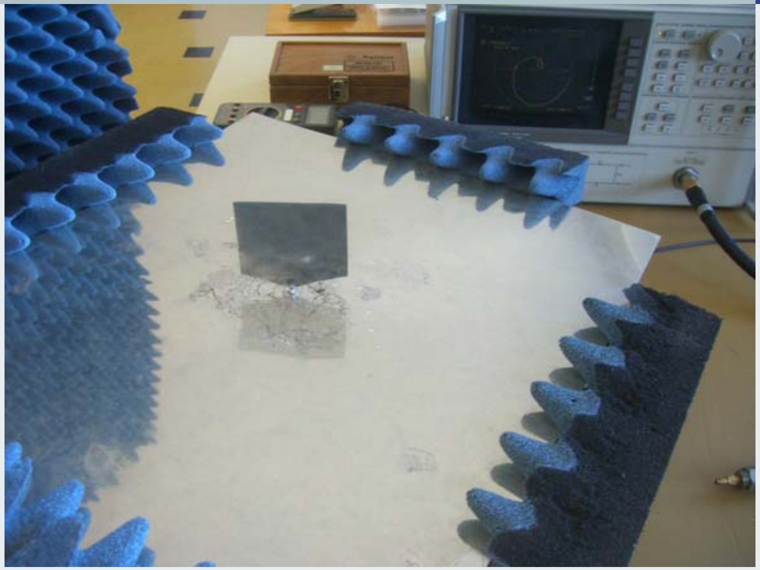


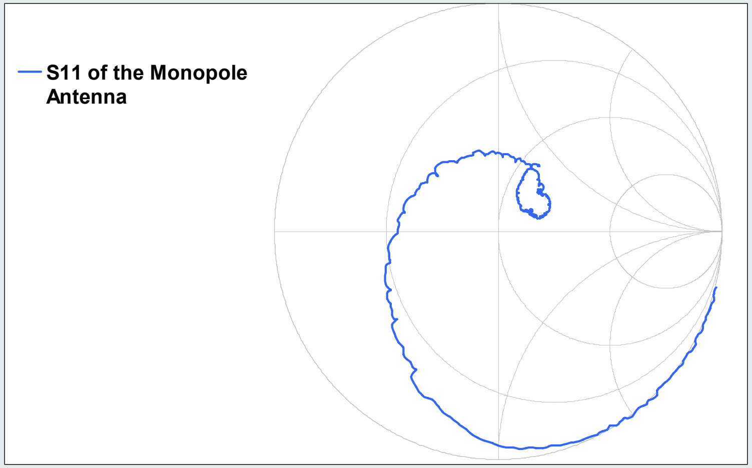


Investigation of the Chassis

First, **measuring the chassis as a monopole**

- Monopole is conversion of Dipole Antenna
- The possibility to use the unbalanced coaxial feed
- 15 degree dipole antenna measurement in the frequency range of 80-2000 MHz
- Resonance Impedance 19 ohm, so for dipole, it should be around 38 ohm
- Resonance frequency 646 MHz





Investigation of the Chassis

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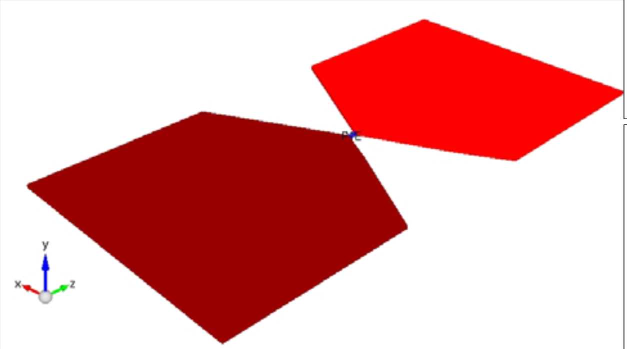
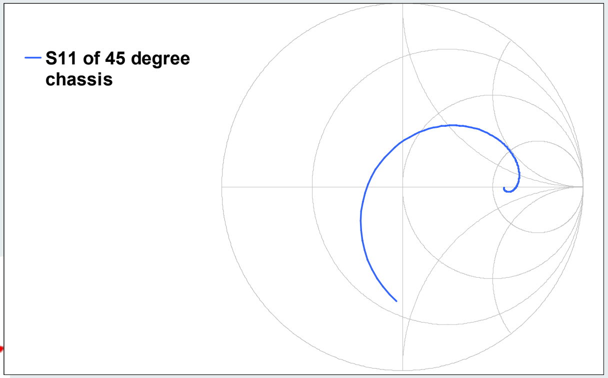
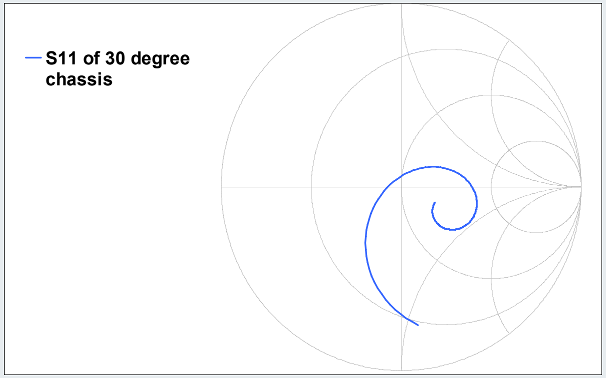
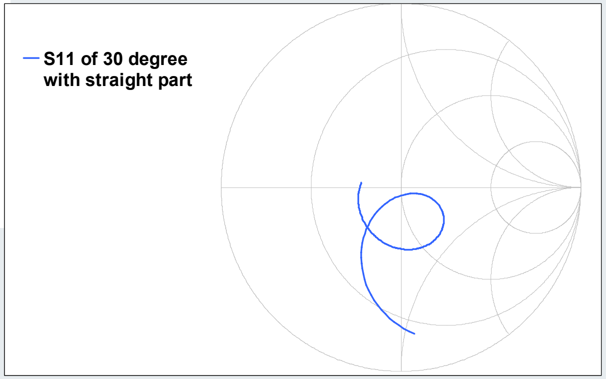
- Second, **Dipole Simulations of the Chassis at different angles** in the frequency range of 500-2000 MHz

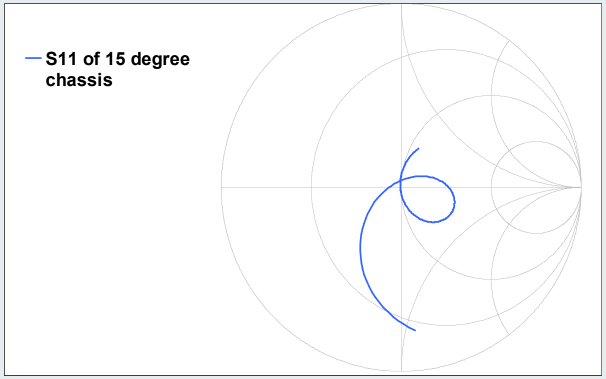


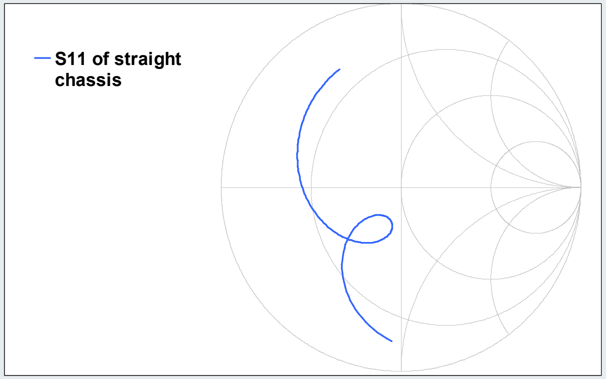
	Center Frequency	PBW
45 degree	620 MHz	20 %
30 degree	717 MHz	38 %
30 degree with straight	785 MHz	55 %
15 degree	762 MHz	67 %
Straight	860 MHz	82 %











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Investigation of the Chassis

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- Finally, **1:1 RF Transformer Method (350-1500 MHz)**

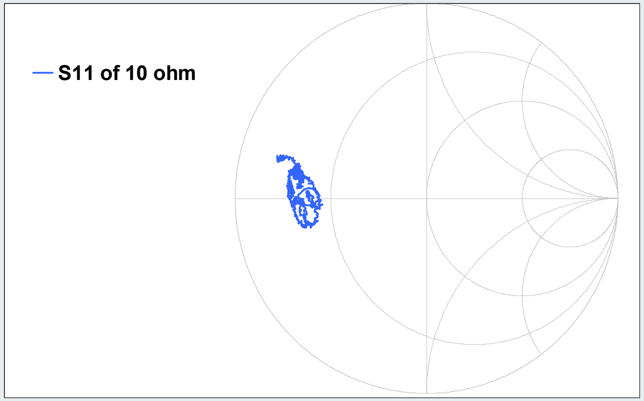
- The tests of open, short terminals and 10, 56, 220 ohm resistors are done.

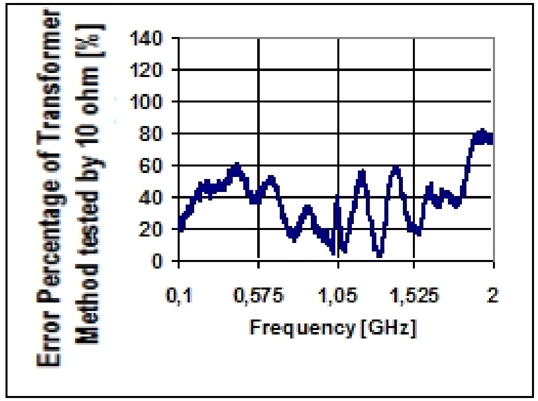
- Finally, the reference plane is selected as primary port of the transformer and the balun is excluded by the formula;

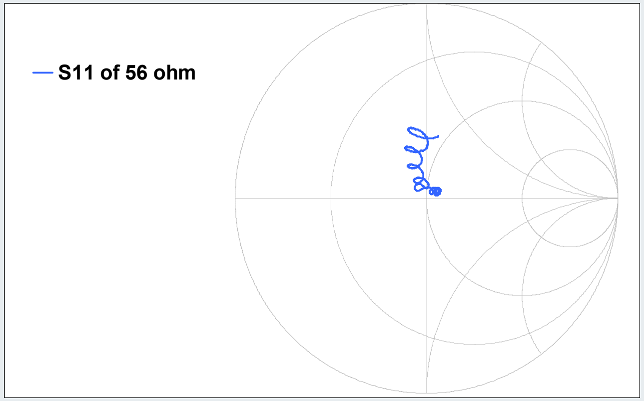
$$\Gamma_{in} = S_{11} + \frac{S_{21}S_{12}\Gamma_L}{1 - S_{22}\Gamma_L}$$

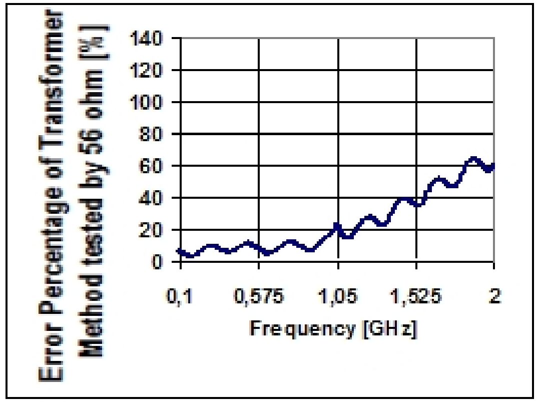
- Γ_{in} is the reflection coefficient of the dipole

- Improved by zeroizing S_{11} and S_{22} and by using a ferrite core to suppress the current flow on the outer part of the coaxial cable









Error percentage of the method [%] = $100 \dfrac{\left| Z_{Measured} - 220 \right|}{220}$

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Investigation of the Chassis

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- The reason of the spreads in the 10, 56, 220 ohm tests is analyzed as non-linear phase variation with frequency of the RF Transformer which is not correctly compensated by the electrical delay.

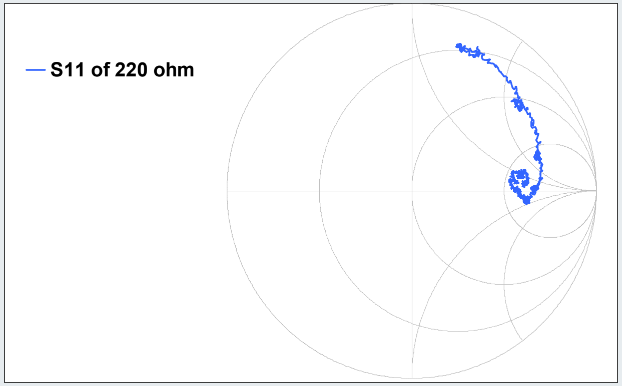
- 15 degree of non-linear insertion phase

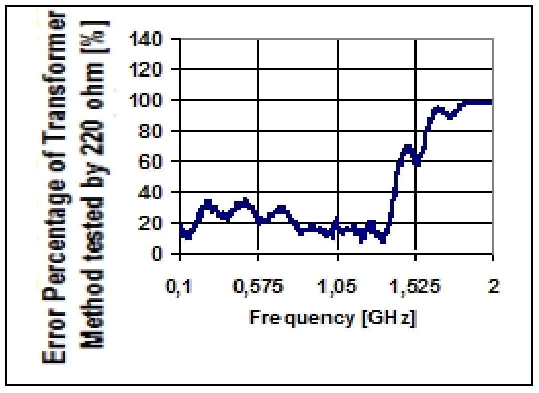
- In the simulation of 30 degree dipole;

  - Impedance value changes between 34.5 to 121.7 ohm
  - Average impedance is 84 ohm

- Very high error percentage at 10 ohm
- More accurate than 10 ohm at 220
- Acceptable error percentage closer to 56 ohm

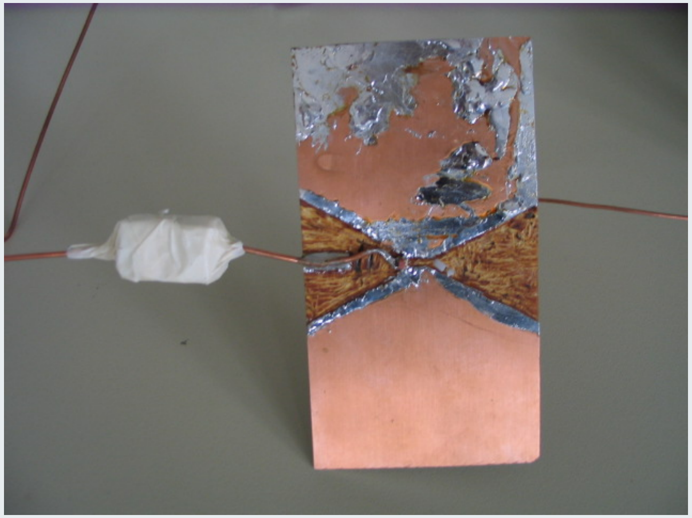
- 350-1200 MHz interval is found as acceptable

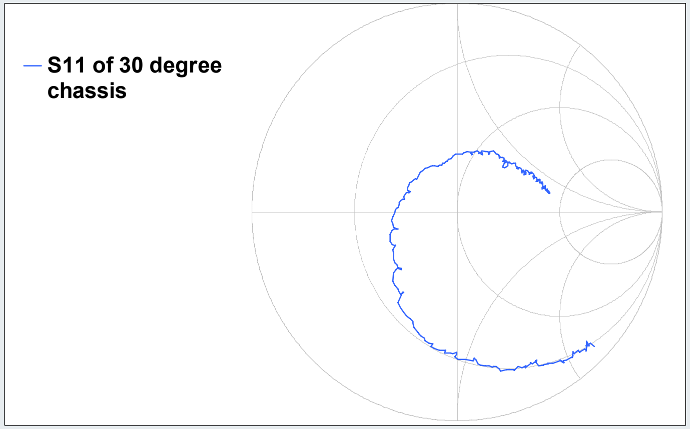




Investigation of the Chassis

- Reflection Coefficient of 30 degree dipole antenna measured in the frequency range of 350-1200 MHz
- The center frequency is 747 MHz and the resonance impedance is 27 ohm
- PBW is 42 %
- Comparable with the simulations





Investigation of the Chassis

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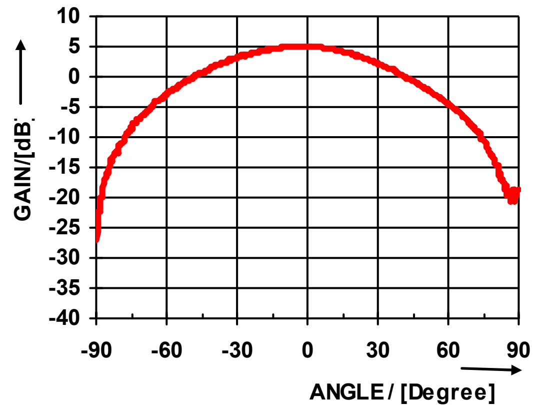
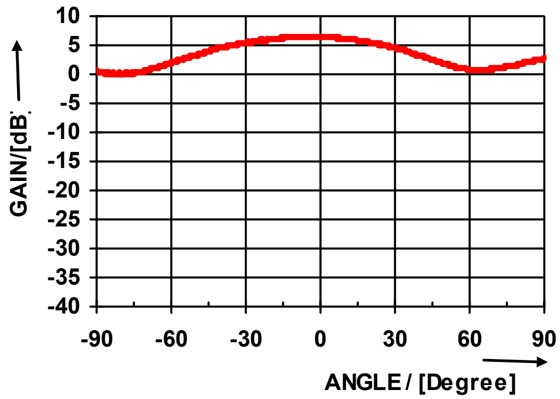
- The gain of the 30 degree dipole antenna measured at GHz
- E-Plane
  - 5 Db maximum gain
  - 70 degree HPBW
  - Dynamic range 32 Db
- H-Plane
  - 6.44 Db maximum gain
  - 87 degree HPBW
  - Dynamic range 6.5 Db
- Difference is because of the error in the measurement construction



E-Plane



H-Plane

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Investigation of Coupling between the Antenna Element and Chassis

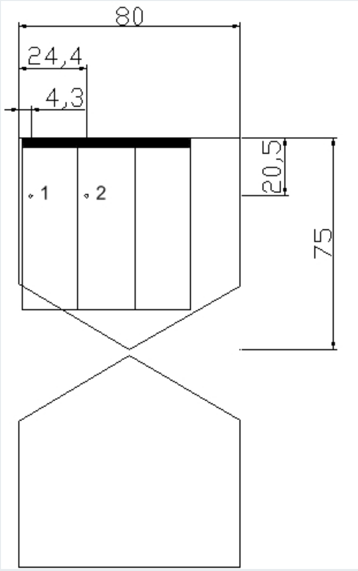
- Coupling between 30 degree Chassis and 1 GHz Antennas

- 2 port measurements to measure S_{12} and S_{21}

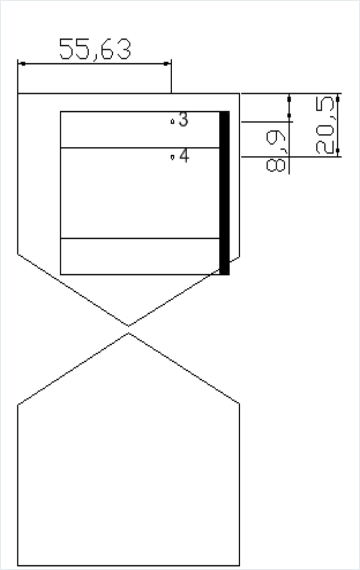
- RF Balun externalization

$$S_{12\,Coupling} = \frac{S_{12\,Measured}}{S_{12\,Transformer}}$$

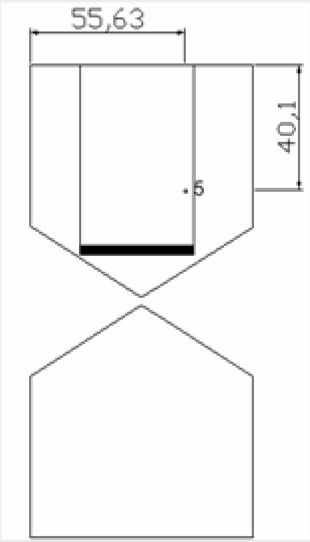
- Antenna elements located at 5 different positions at 3 different orientations on the dipole antenna



Position 1 and 2

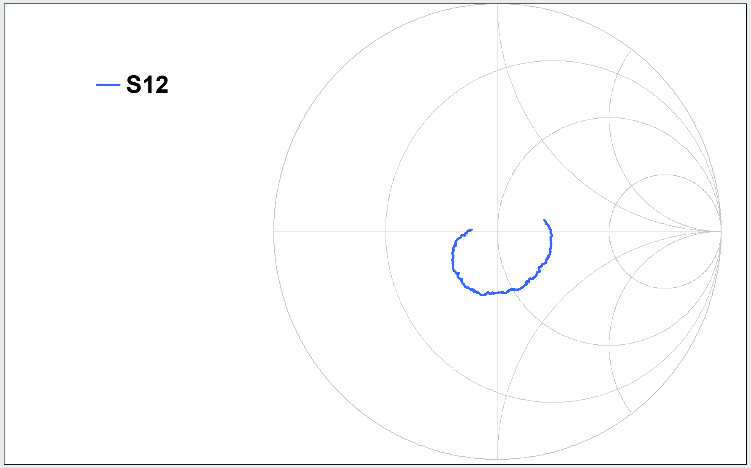


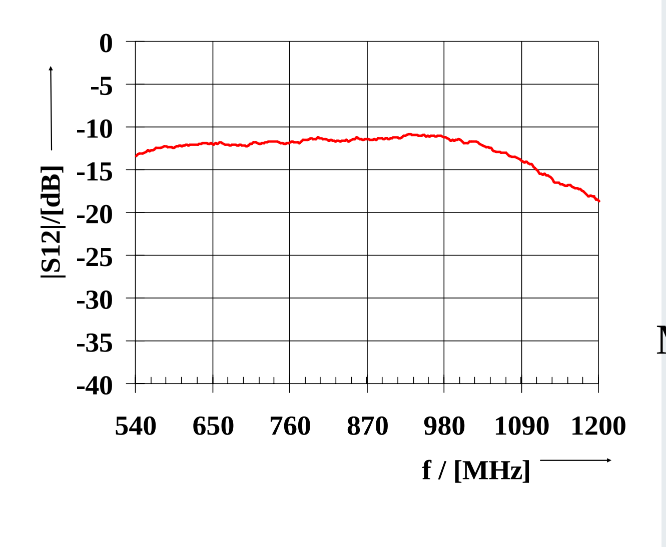
Position 3 and 4



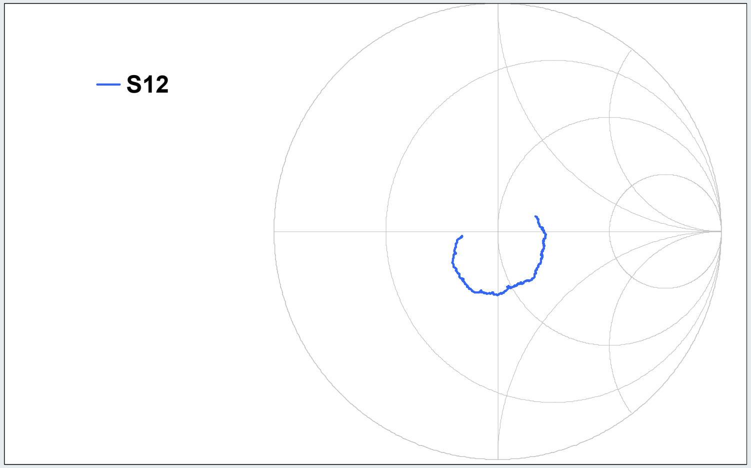
Position 5

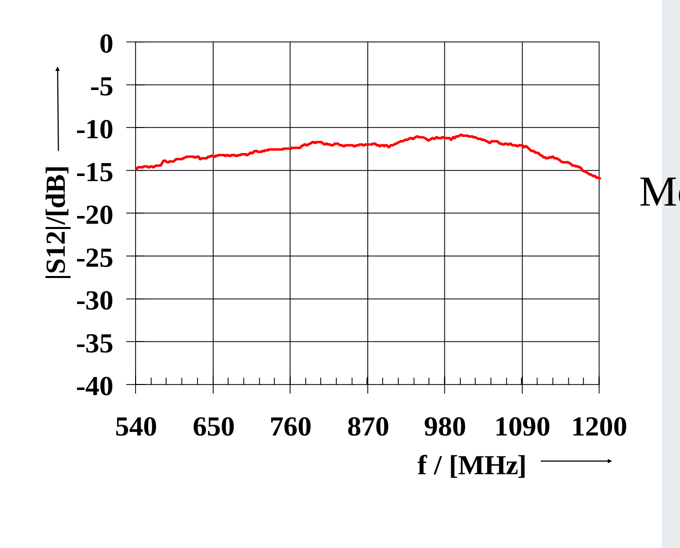
Investigation of Coupling between the Antenna Element and Chassis





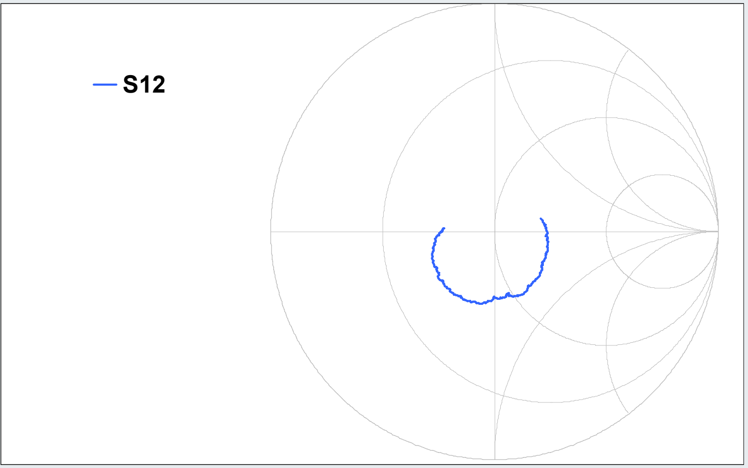
Monopole at position 1

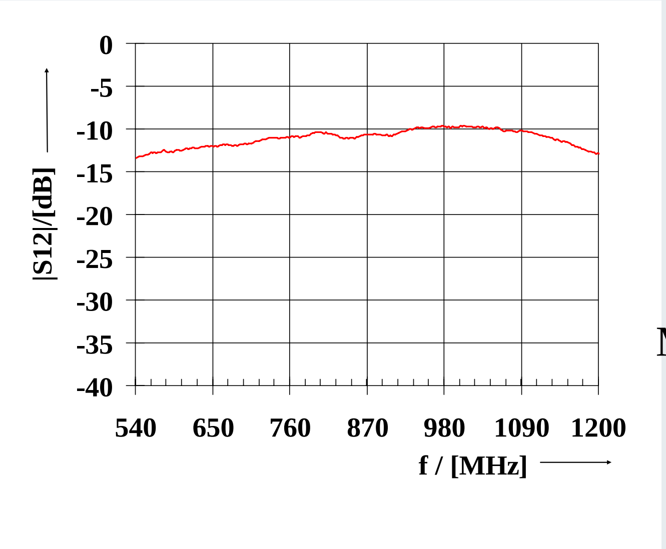




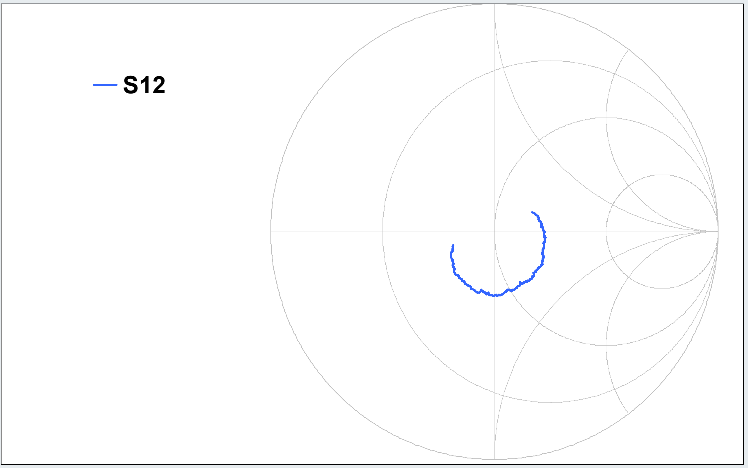
Monopole at position 2

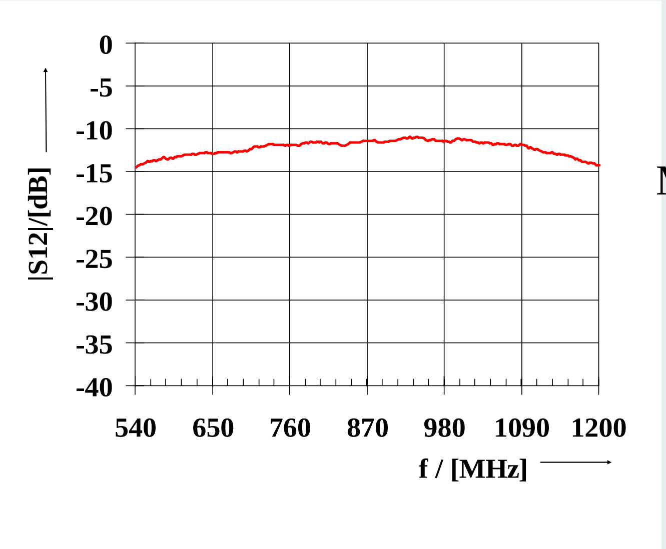
Investigation of Coupling between the Antenna Element and Chassis





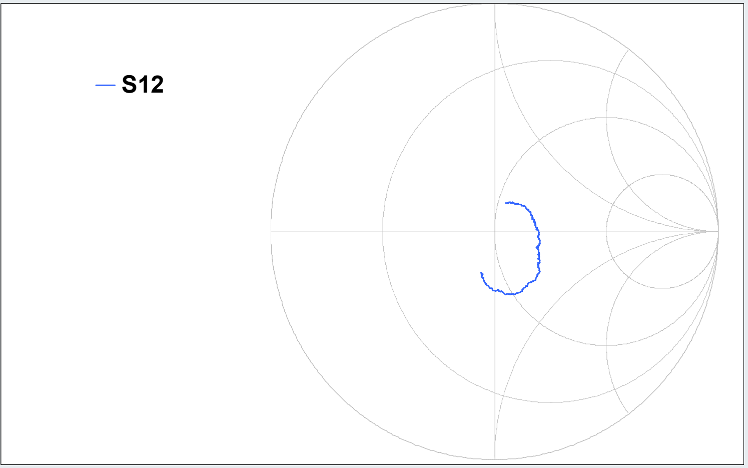
Monopole at position 3

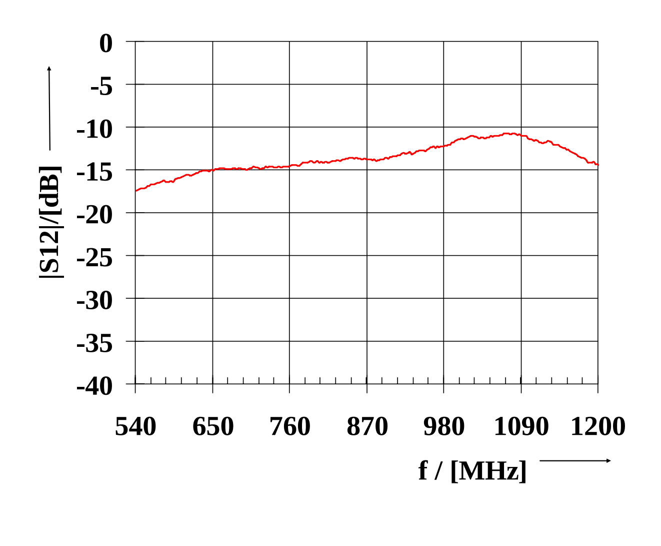




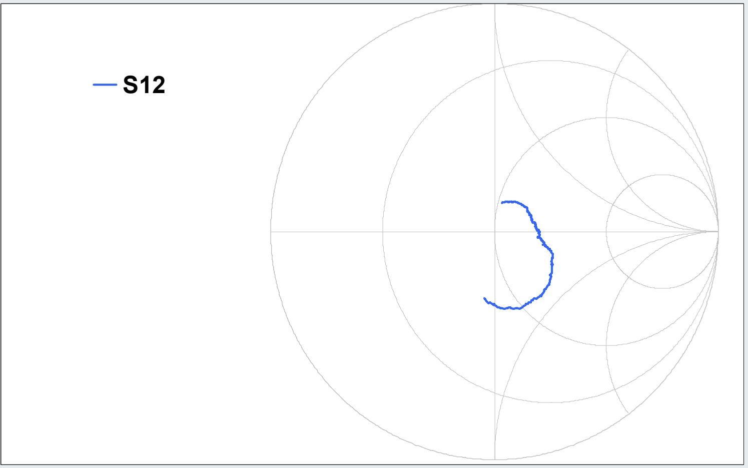
Monopole at position 4

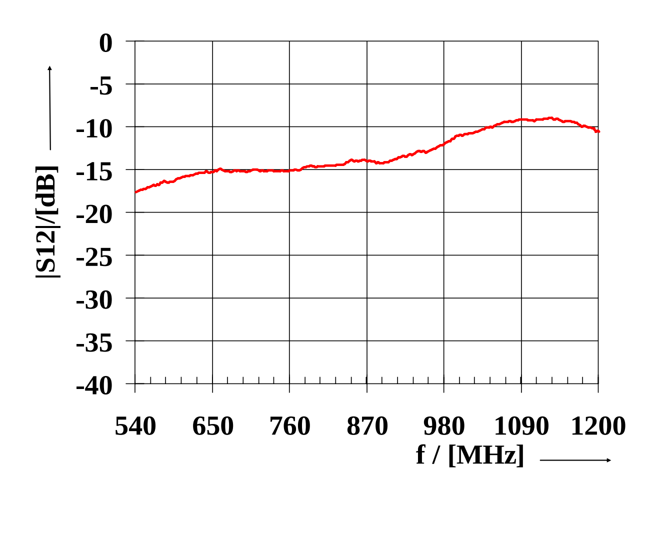
Investigation of Coupling between the Antenna Element and Chassis





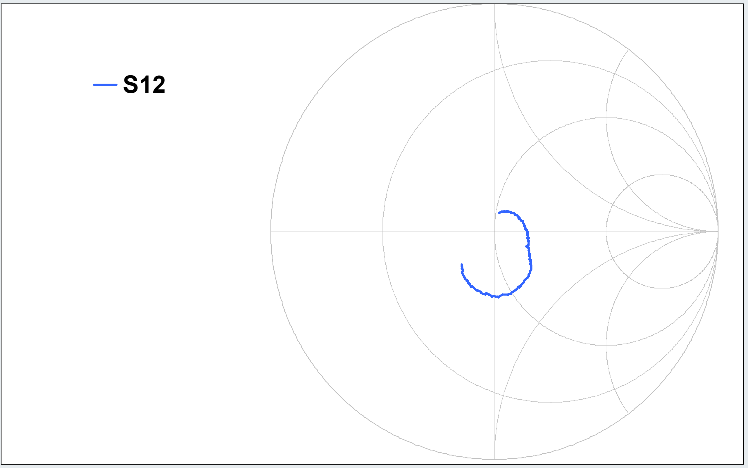
PIFA at position 1

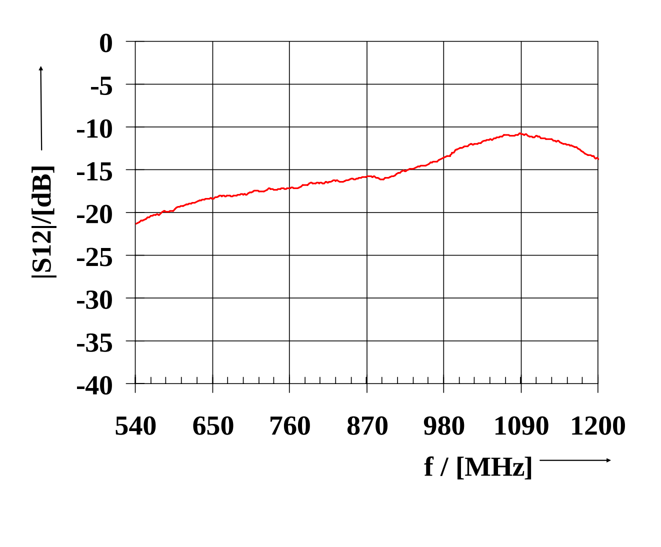




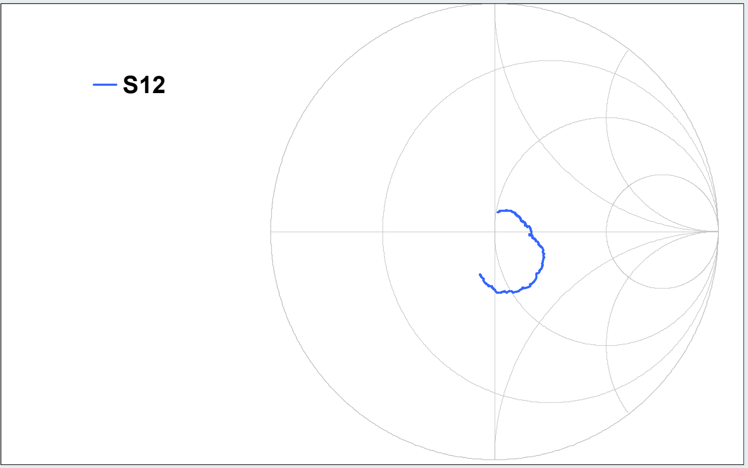
PIFA at position 2

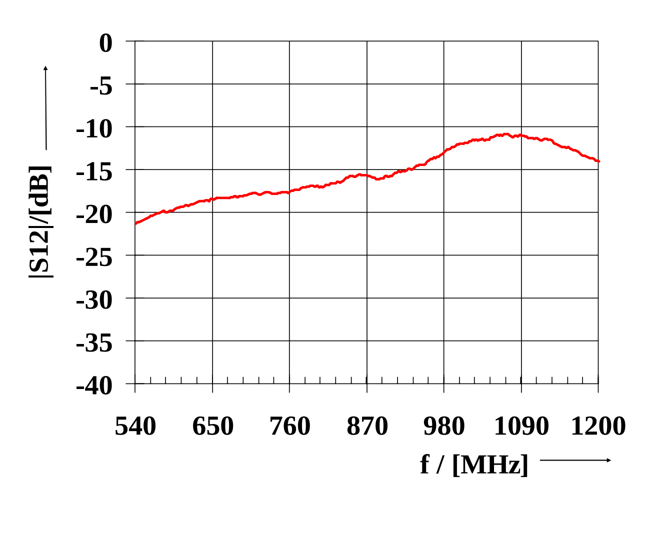
Investigation of Coupling between the Antenna Element and Chassis





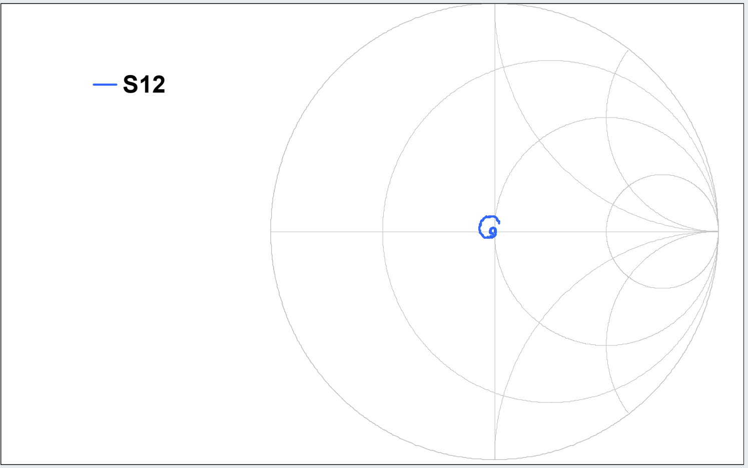
PIFA at position 3

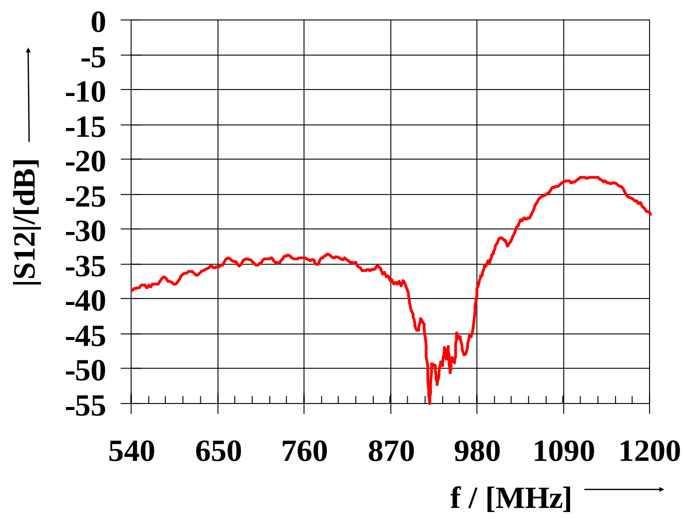




PIFA at position 4

Investigation of Coupling between the Antenna Element and Chassis





PIFA at position 5

- The **bandwidth** of the antenna-chassis system is related to the amount of **coupling**
- A part of the antenna element is not over the dipole at the first position
- At position 2, it is totally over the dipole, this is because position 2 has more coupling
- Two radiators at 747 and 1000 MHz frequencies

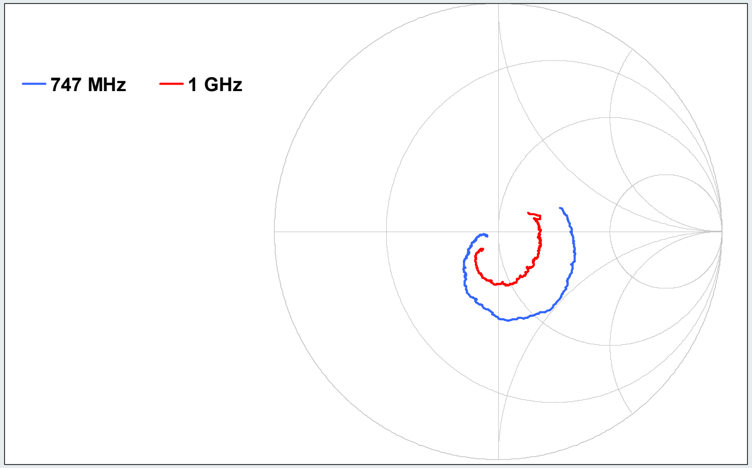
Investigation of Coupling between the Antenna Element and Chassis

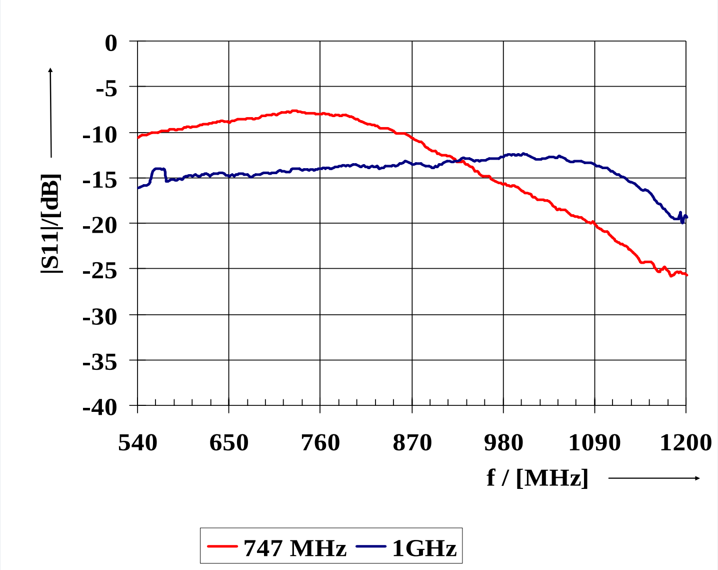
The coupling of 2 antennas at the same frequency

1. Realization at 747 MHz

- Monopole antenna at 747 MHz is tested on 747 MHz chassis

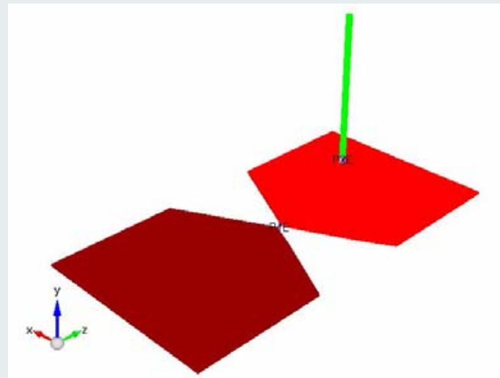
- The coupling is more if they are at the same frequency as expected. So, more BW is achieved

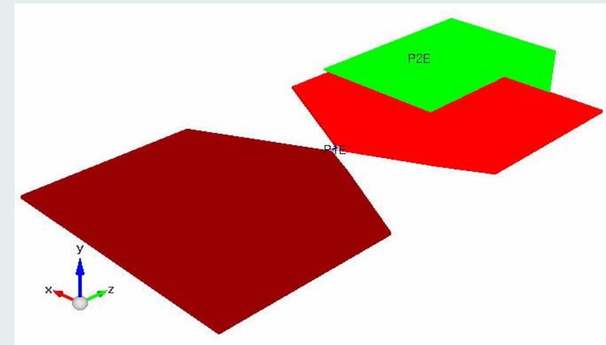


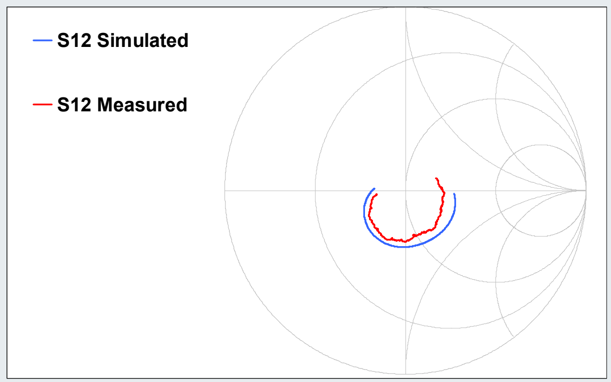


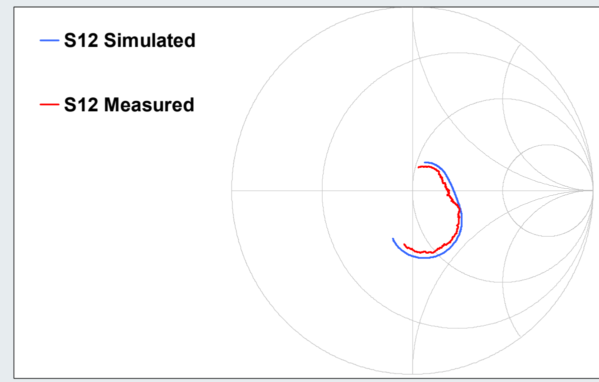
Investigation of Coupling between the Antenna Element and Chassis

- **2-port Simulations of Monopole-Dipole and Monopole-PIFA structures** at position 2
- Frequency range of 350-1200 MHz
- Very close results
- Simulation approves the measurement









Modeling and Optimizing the Structure

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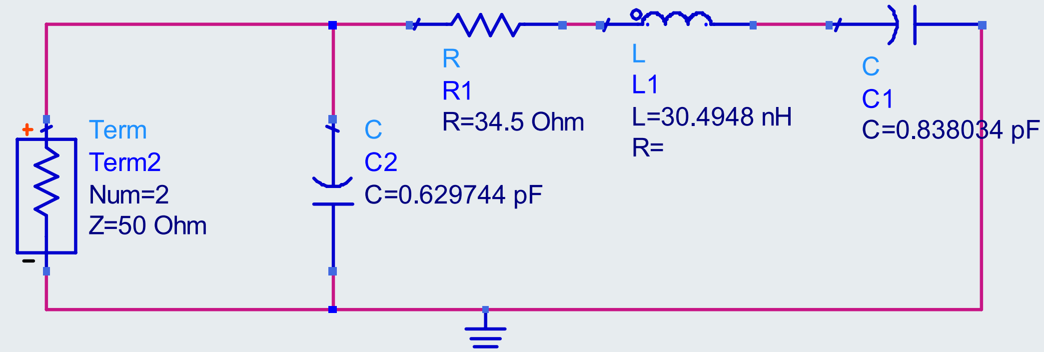
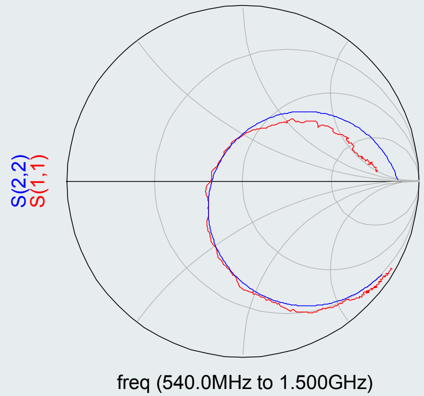
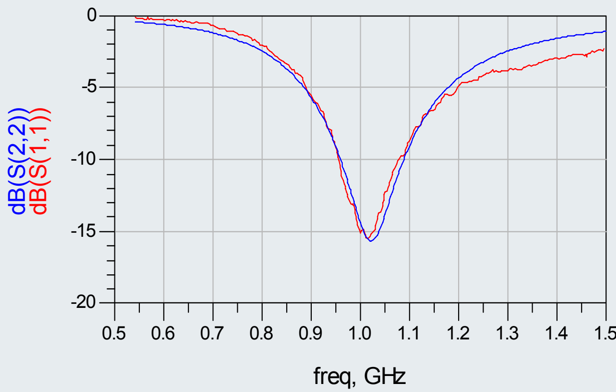
- **Monopole Antenna Model**
  - Series characterization at the first resonance
  - Resonance impedance is 34.5 ohm
  - $\omega = \sqrt{\dfrac{1}{LC}}$ corresponds to

    L1 C1 = 25.33 nH pF where the frequency is 1 GHz
  - A parallel capacity to match the measured results better

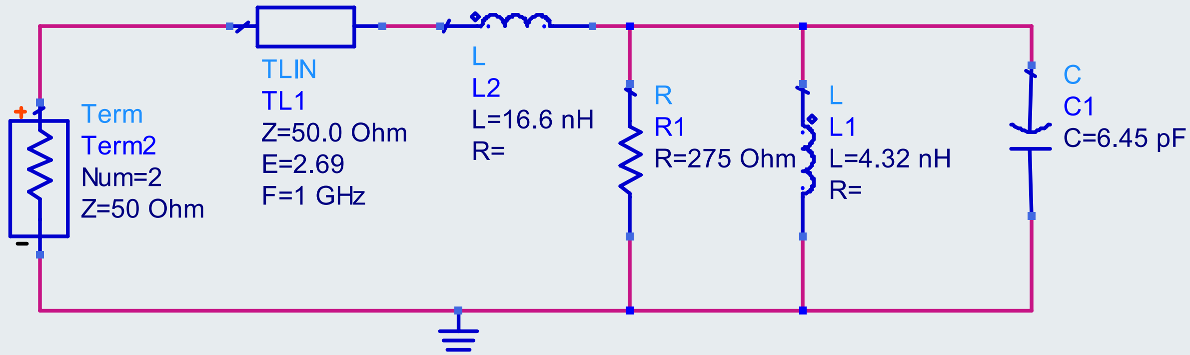


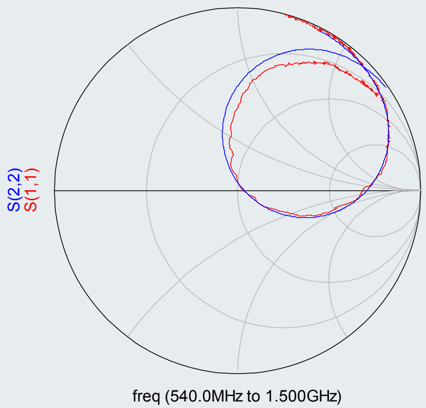


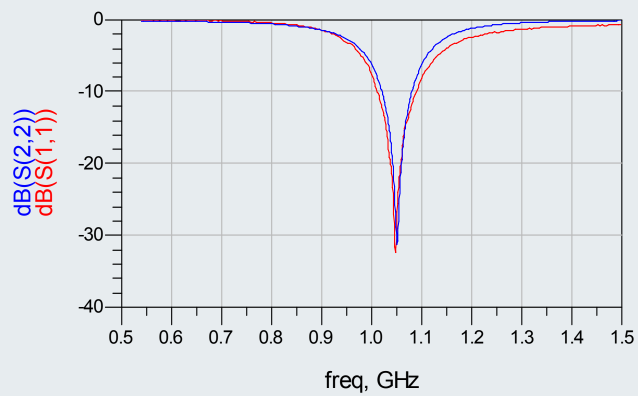


Modeling and Optimizing the Structure

- **PIFA Antenna Model**
  - Parallel characterization at the first resonance
  - A very short transmission line $\frac{\lambda}{133.8}$ at 1 GHz and a parallel inductance
  - Near to the inductance formula 0.75 nH per mm of the probe

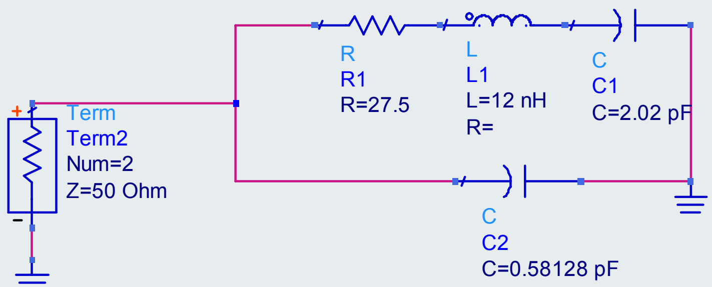


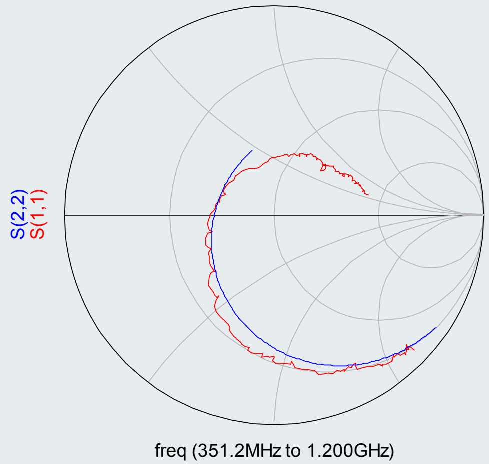


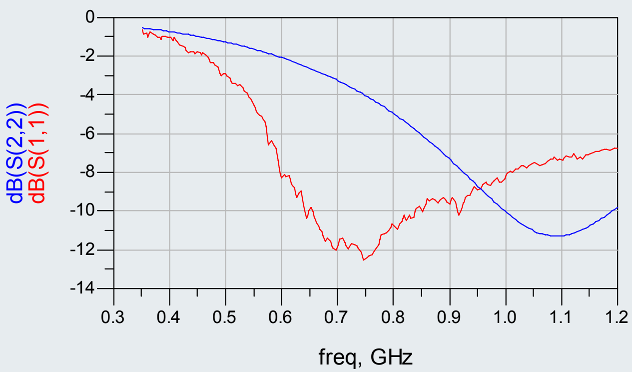


Modeling and Optimizing the Structure

- **Improved Chassis Model (at 1.09 GHz)**
- 30 degree dipole antenna
- Series characterization at the first resonance
- Same resistor value
- Series Capacitance and Inductance are tuned proportionally





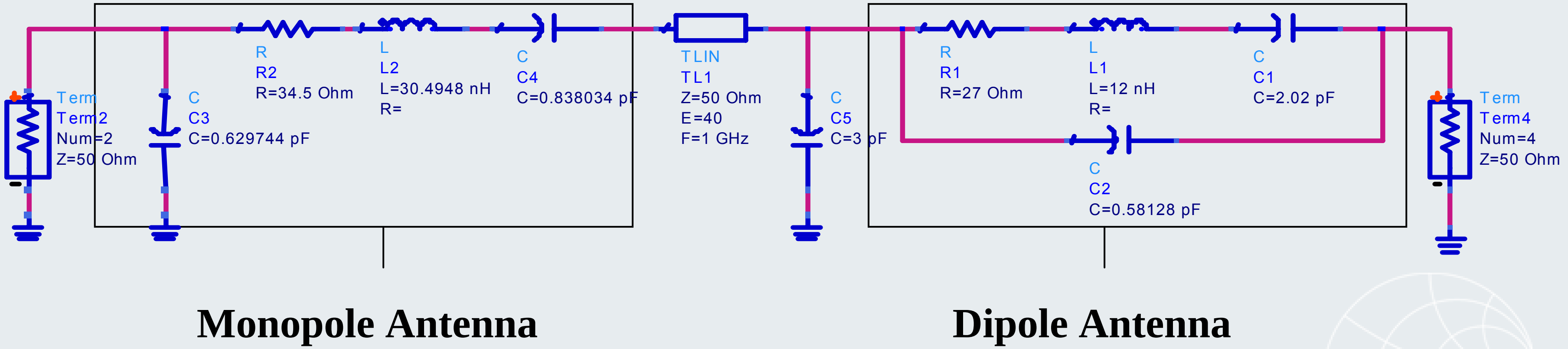


Modeling and Optimizing the Structure

Modeling of Coupling

- Two modeling parameters for the coupling;
  - Matching to the Transmission Parameters of the Measurements
  - 1-Port measurement from the antenna side when the dipole is shorted (chassis) must give more BW than the antenna alone
- Antenna Positions at position 2 are used

Monopole-Dipole Improved Model



Modeling and Optimizing the Structure

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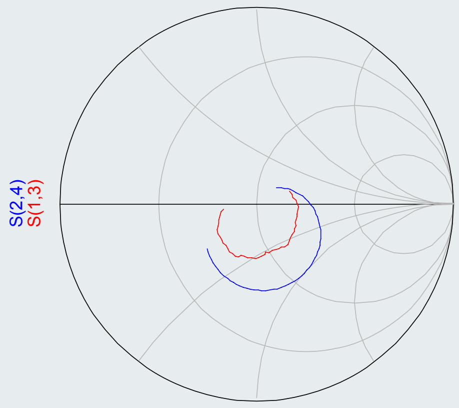
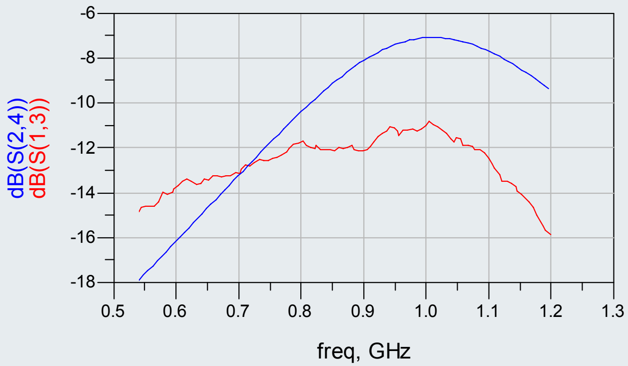
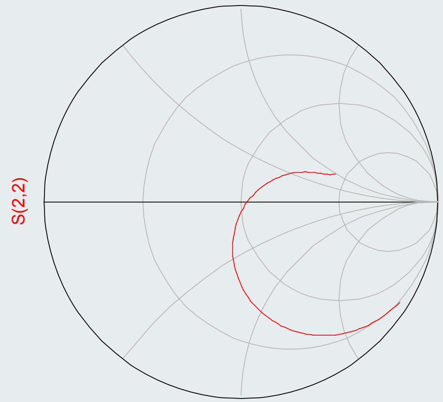
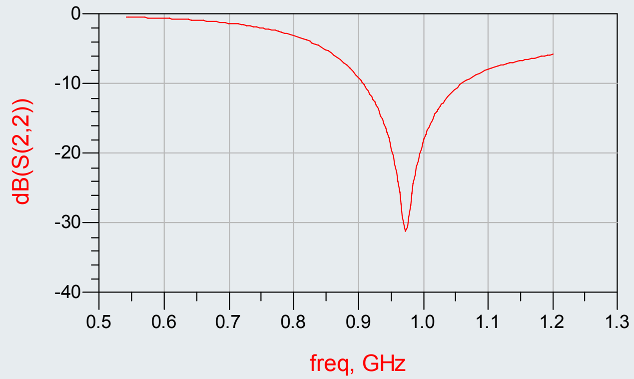
2 port coupling results;





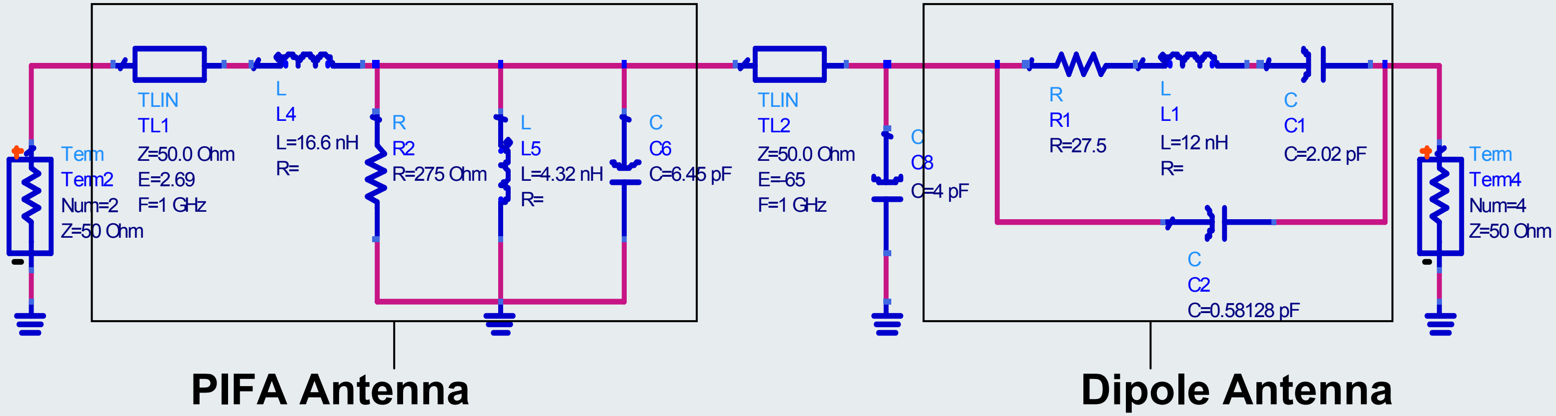
1-port measurement from the monopole side when the dipole (chassis) is shorted;



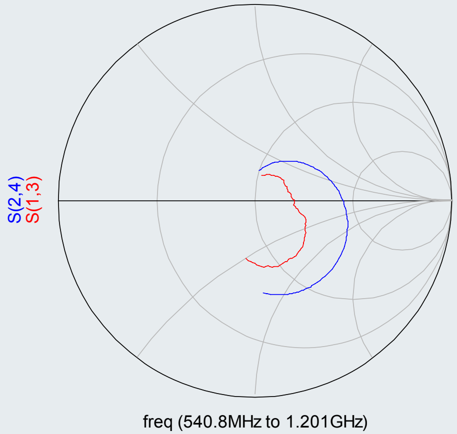


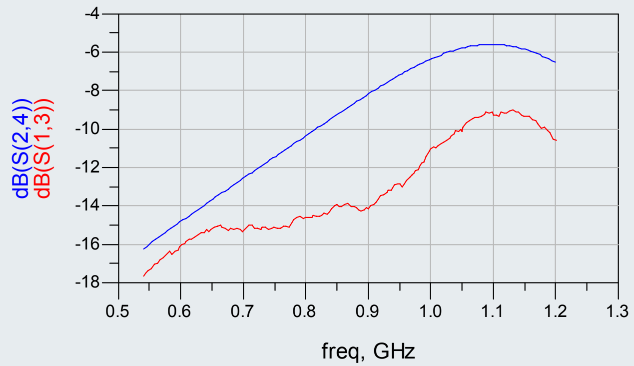
Modeling and Optimizing the Structure

PIFA-Dipole Improved Model



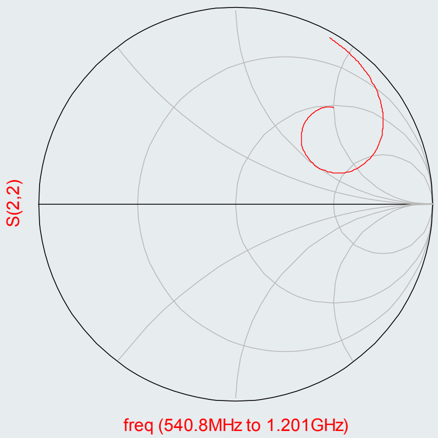
2-port coupling results;

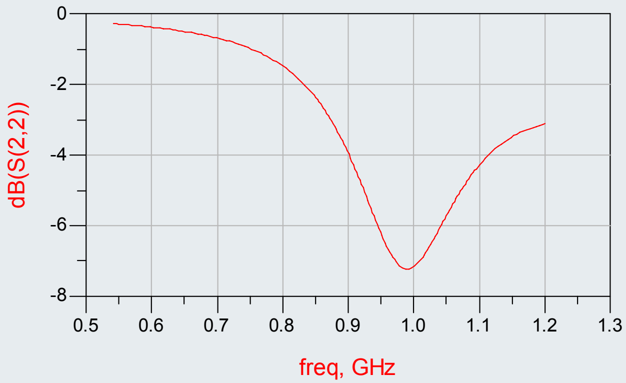




Modeling and Optimizing the Structure

- 1-port measurement from the PIFA side when the dipole (chassis) is shorted;





Comparison of the Model and Realization

	Antenna Element Alone	Antenna-Chassis Model	Antenna-Chassis Realization
Monopole	12.3 %	16 %	23 %
PIFA	7.86 %	29 %	25 %
C-Patch	3.48 %	17 %	10 %

Conclusion

- The antennas are tested on large and small ground plane variations
- The chassis is investigated as a dipole
- The couplings between the antenna element and chassis are measured. It is seen that the **bandwidth** is related to the **coupling**.
- The equivalent networks of antenna elements, coupled chassis and the coupling mechanism in between are designed
- The chassis and coupling equivalents are improved after tuning the chassis center frequency to 1.09 GHz

Thank you for your attention