Bachelor Thesis

Analogue Phase-Shifter Circuit for 7-Tesla Magnetic Resonance Tomograph (MRT)

by

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Outlines

HFT

- Problem Introduction
- Aim of the Thesis
- Design Details
- Simulation & Test Results
- Conclusions

Problem Introduction

Why are we interested in designing phase shifters in MRT system?

- Inhomogeneous materials such as tissues, bones, fat and etc in the body
- RF signals are diffracted and the phase is shifted when RF signals are applied
- The inhomogeneous field distributions are occurred inside the patient's body due to the superposition effect of all the RF signals

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Aim of the Thesis

HFT

To design a 90°- and 180° -bits of the phase shifter by using PIN diodes and other SMD components at 300MHz operating frequency in order to compensate the inhomogeneous field distributions inside the patient's body.

Design Details

Phase Shifters

Ferrite Phase Shifters

- change the ferrite permeability to obtain a required phase shift

Semiconductor Device Phase Shifters

- PIN Diodes
- GaAs
- FET
- Schottky Diodes
  - used as electronics switches

Design Details

Phase Shifters

PIN Diode Phase Shifters

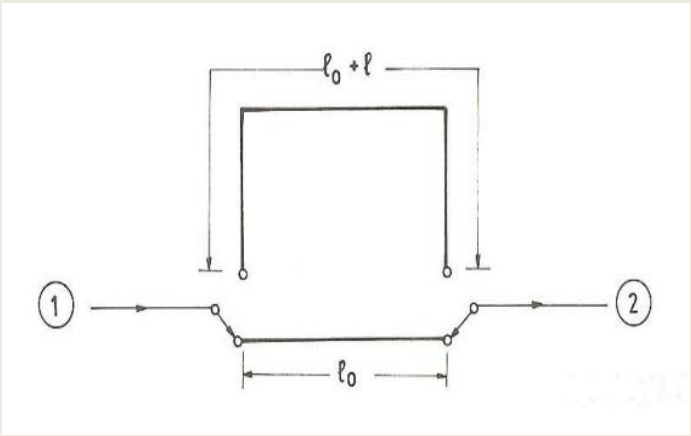
Advantages are:

- low losses
- high power resist
- low temperature drift
- fast switching speed
- low cost of production

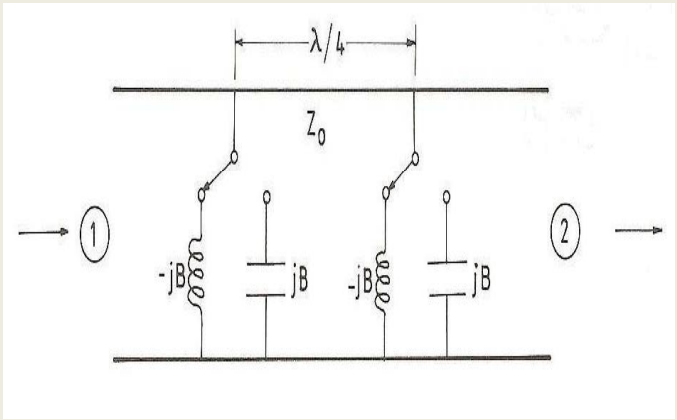
Design Details

Phase Shifters

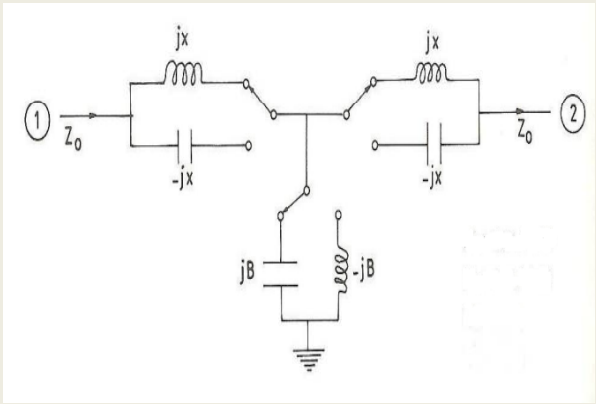
PIN Diode Phase Shifters



Switched line



Loaded line

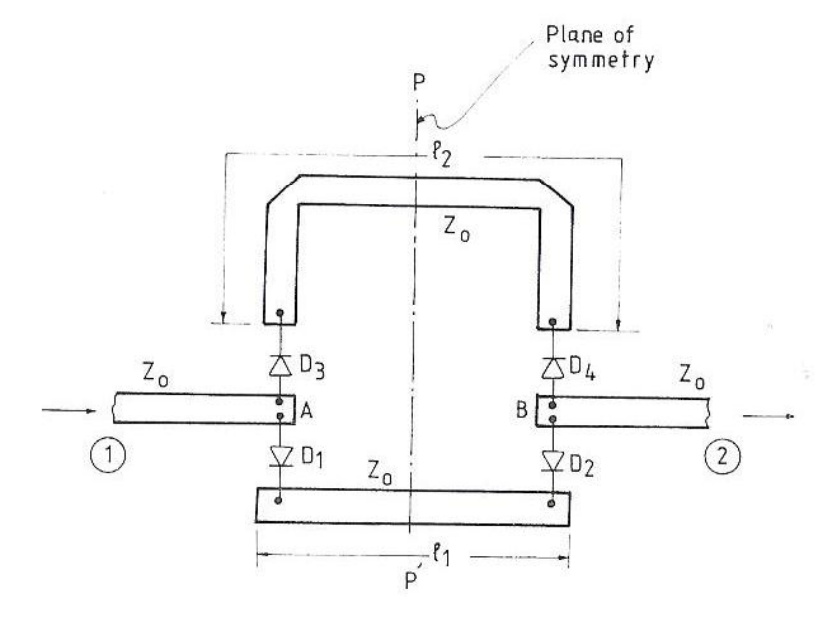


High-pass low-pass

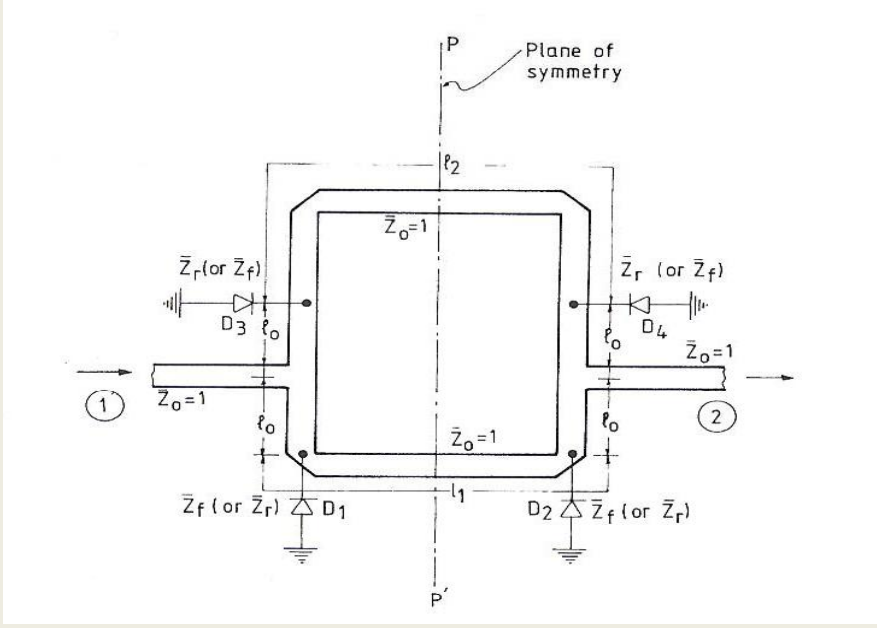
Design Details

Phase Shifters

PIN Diode Phase Shifters



Series PIN diode switched line phase shifter



Shunt PIN Diode switched line phase shifter

$$\Delta\theta = \beta(l_2 - l_1)$$

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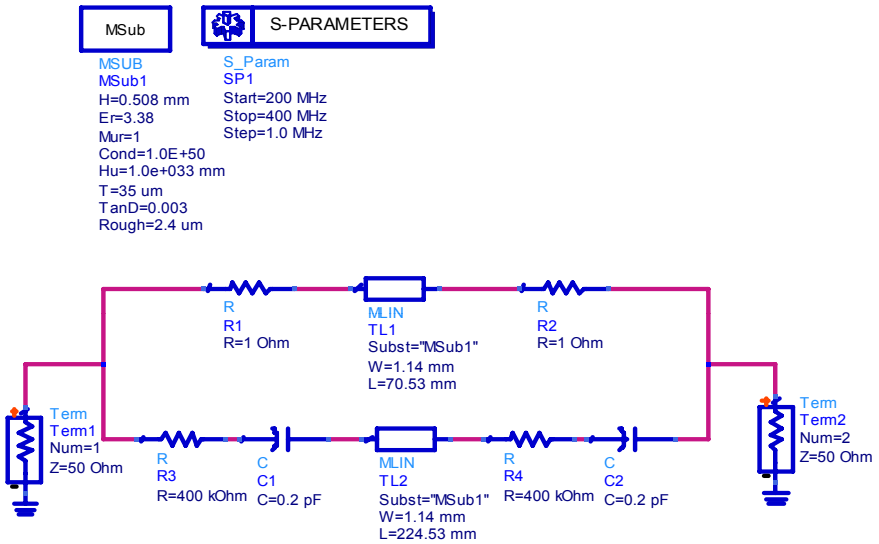
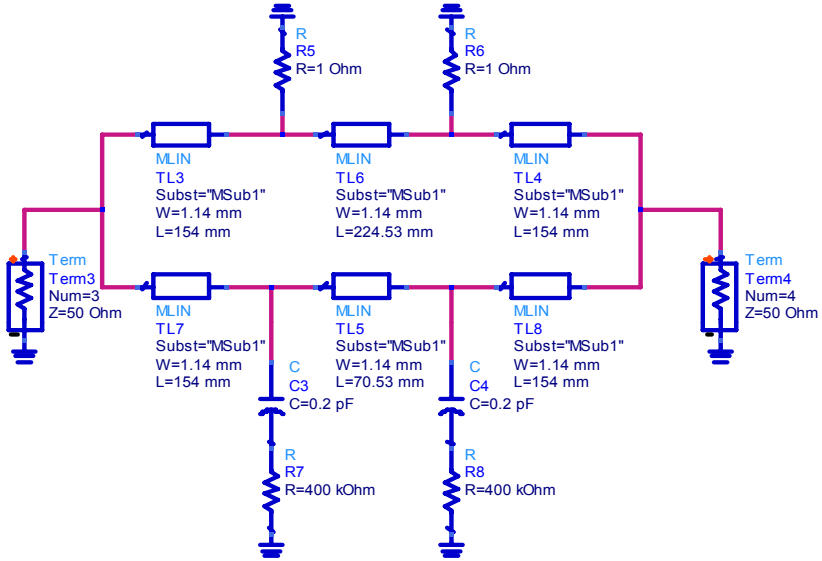
Design Details

HFT

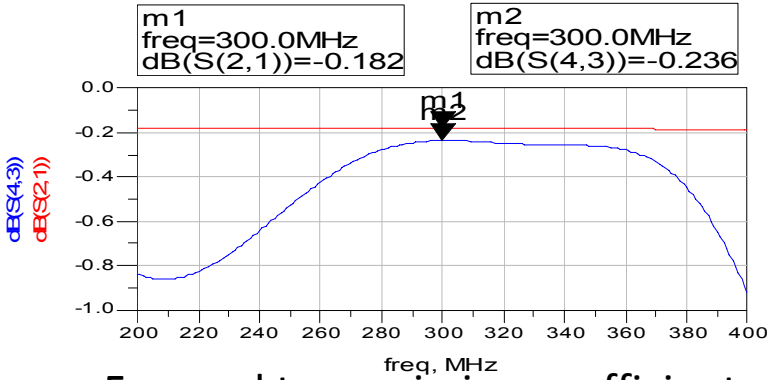
PIN Diode Phase Shifters



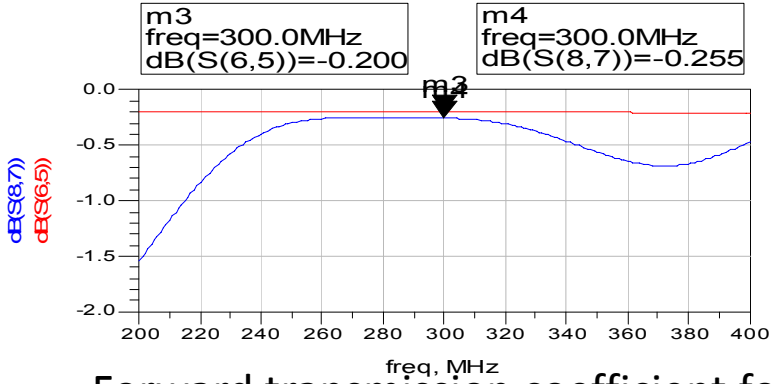
Series PIN diode switched line phase shifter



Shunt PIN Diode switched line phase shifter



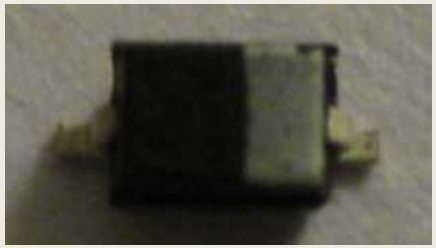
Forward transmission coefficient for reference line, state 1



Forward transmission coefficient for 90° phase shift line, state2

Design Details

PIN Diode and SMD Components



BAR63-03W PIN Diode

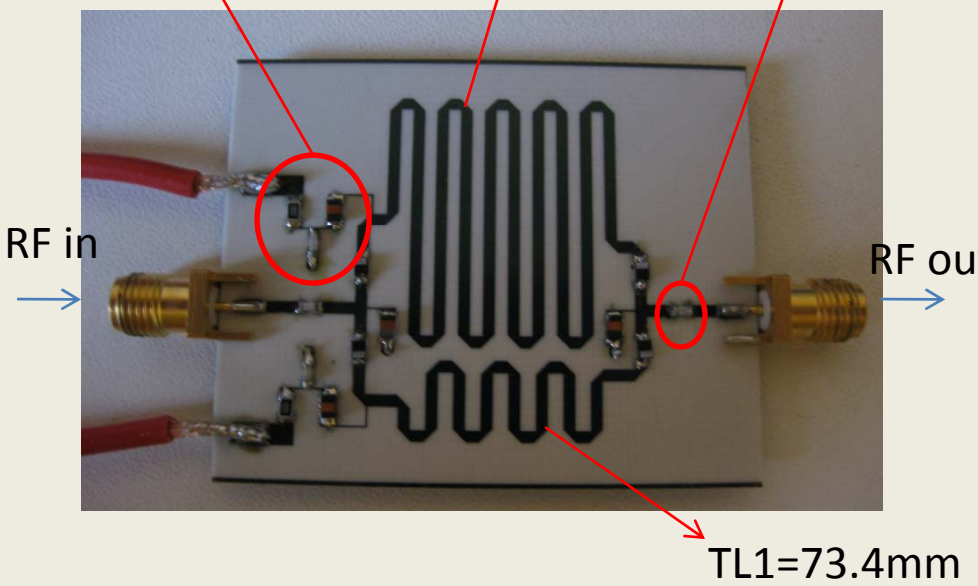
SMD 0603 Kemet Capacitor 680pF

SMD 0805 EPCOS Inductor 1uH

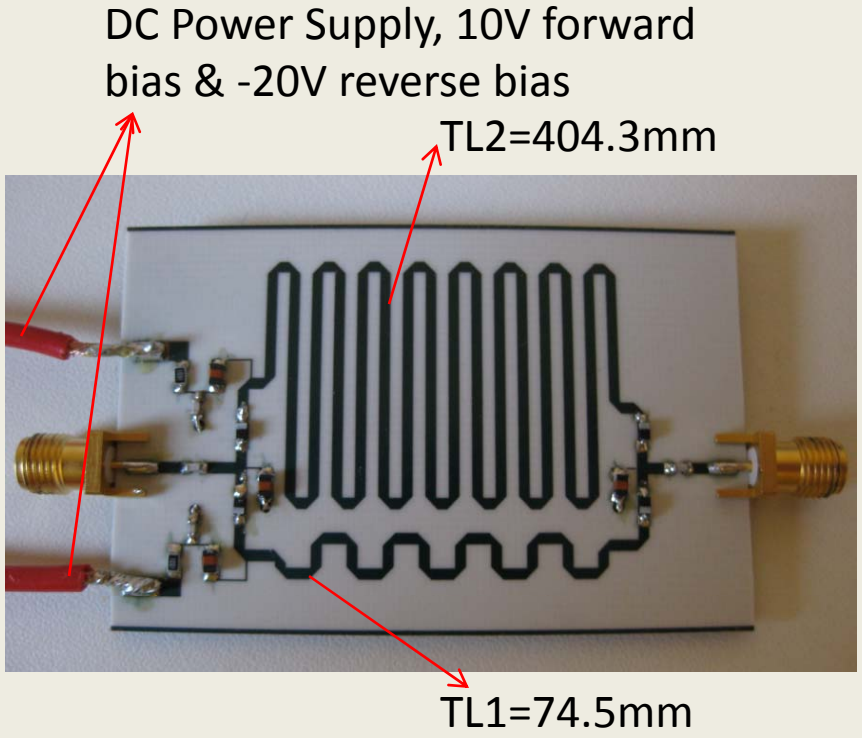
SMD 0805 Resistor 1kΩ

Design Details

Printed Circuit Test Board



90°-bit Phase Shifter



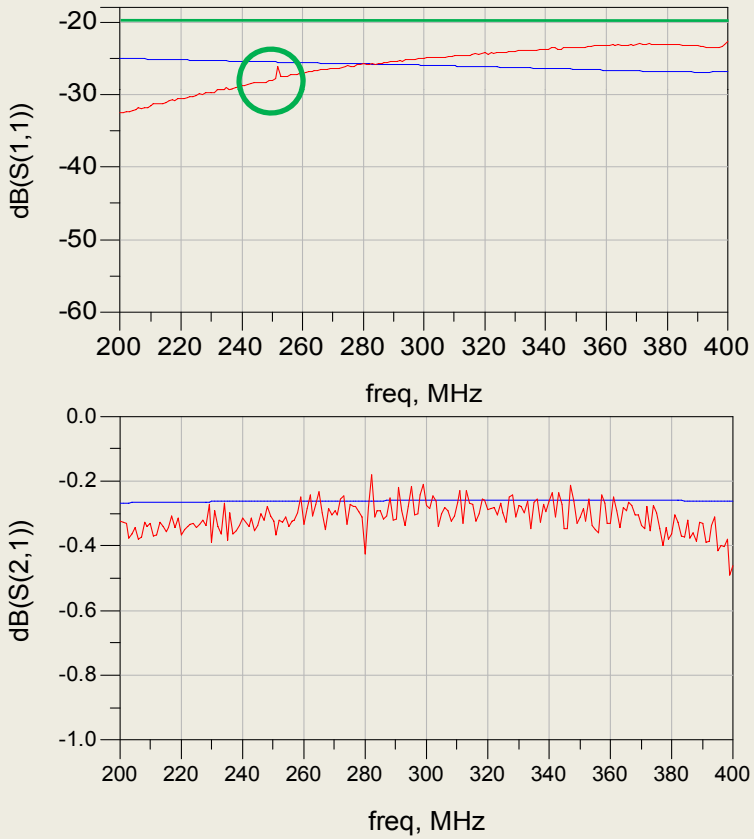
180°-bit Phase Shifter

Simulation & Test Results

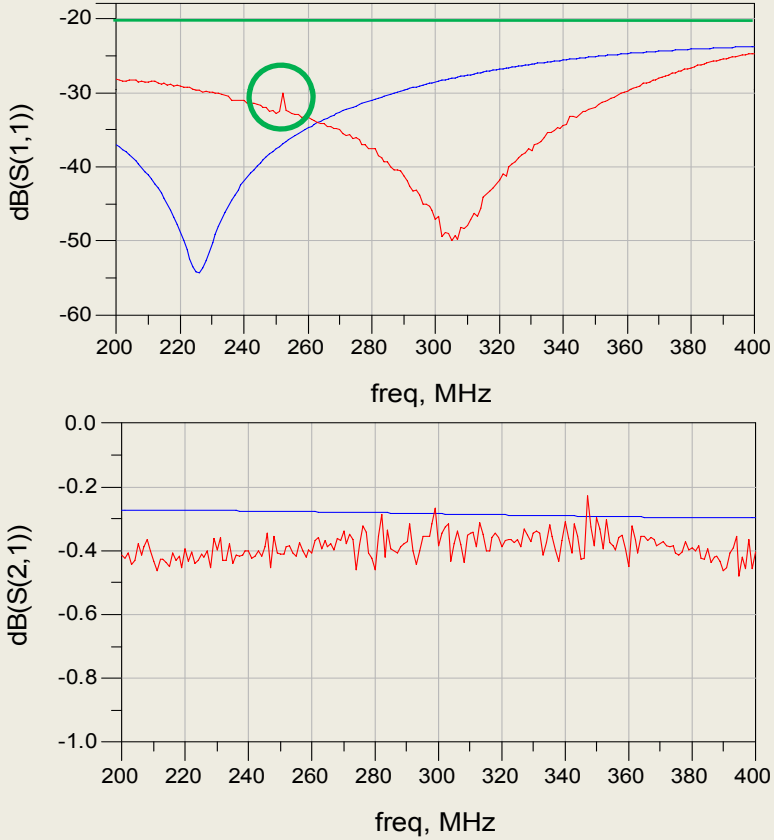
90°-bit Phase Shifter

PCB vs EM co-simulation

Reference line length, state 1



90° phase shift line length, state 2

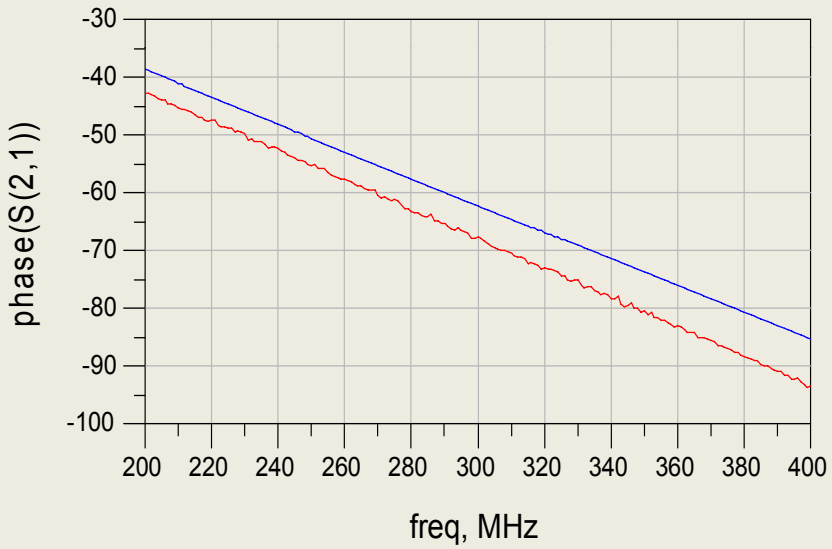


Simulation & Test Results

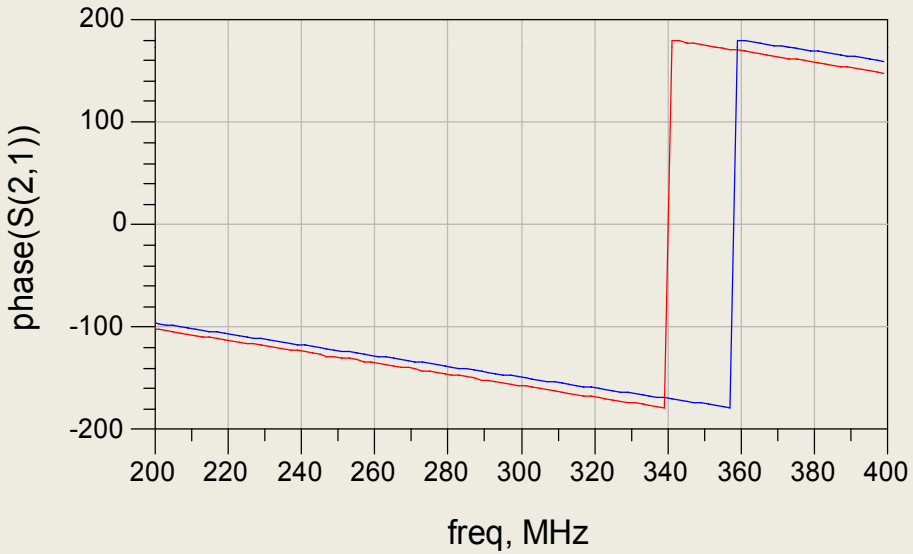
90°-bit Phase Shifter

PCB vs EM co-simulation

Reference line length, state 1



90° phase shift line length, state 2



Simulation & Test Results

90°-bit Phase Shifter

PCB's phase error at frequency range between 290MHz and 310MHz

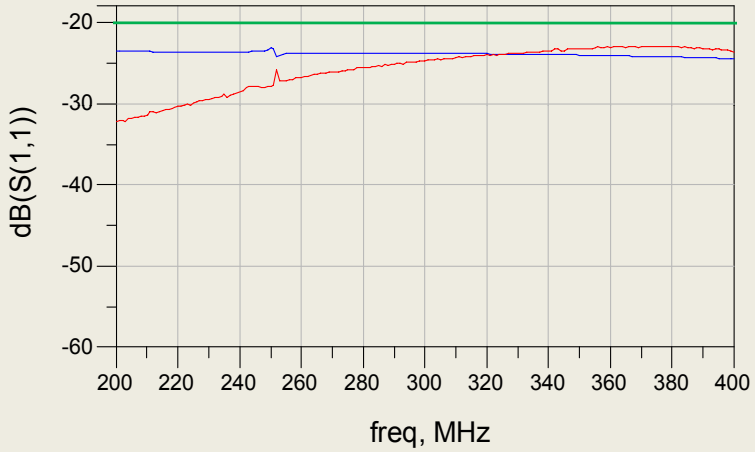
Frequency MHz	90 Degree		
	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$
290	86.5020	86.4917	3.5083
295	87.8697	87.8969	2.1031
300	89.3424	89.4236	0.5764
305	91.0482	90.9686	0.9686
310	92.6765	92.4820	2.4820

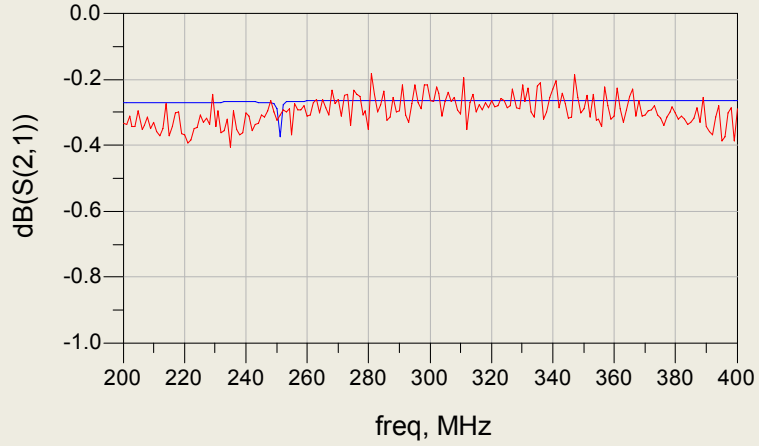
Simulation & Test Results

180°-bit Phase Shifter

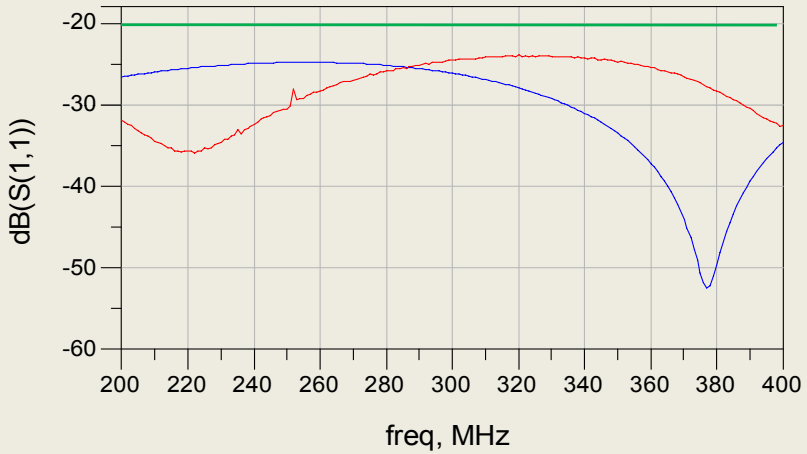
PCB vs EM co-simulation

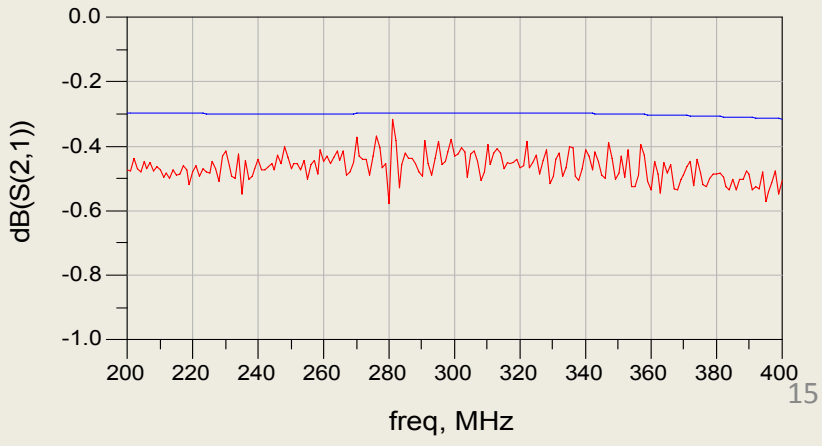
Reference line length, state 1





180° phase shift line length, state 2



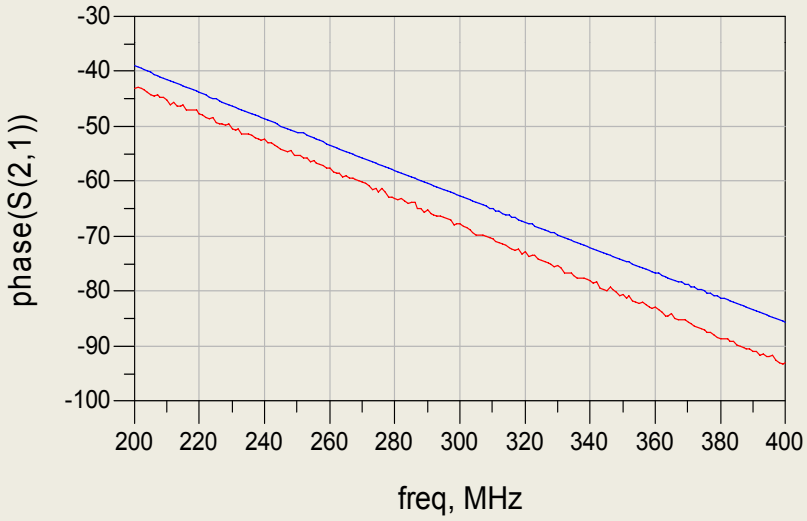


Simulation & Test Results

180°-bit Phase Shifter

PCB vs EM co-simulation

Reference line length, state 1



180° phase shift line length, state 2

Simulation & Test Results

180°-bit Phase Shifter

PCB's phase error at frequency range between 290MHz and 310MHz

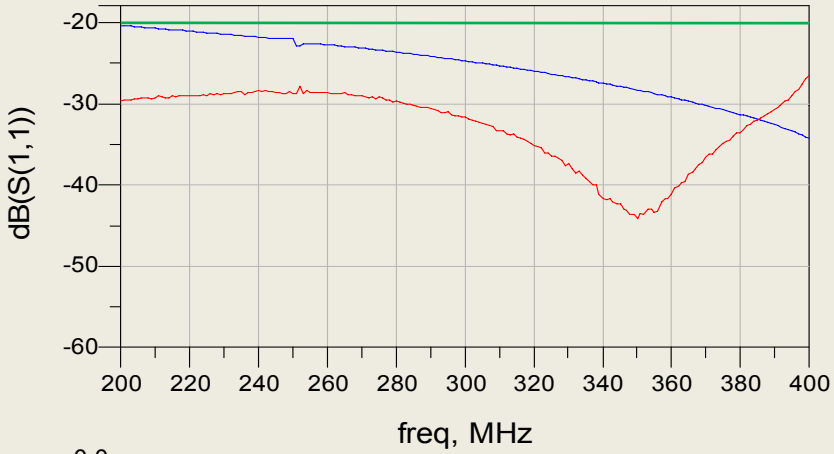
Frequency MHz	180 Degree		
	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$
290	173.4653	173.4043	6.5957
295	176.5811	176.5380	3.4620
300	179.4722	179.5680	0.4320
305	182.6472	182.5031	2.5031
310	185.4777	185.4117	5.4117

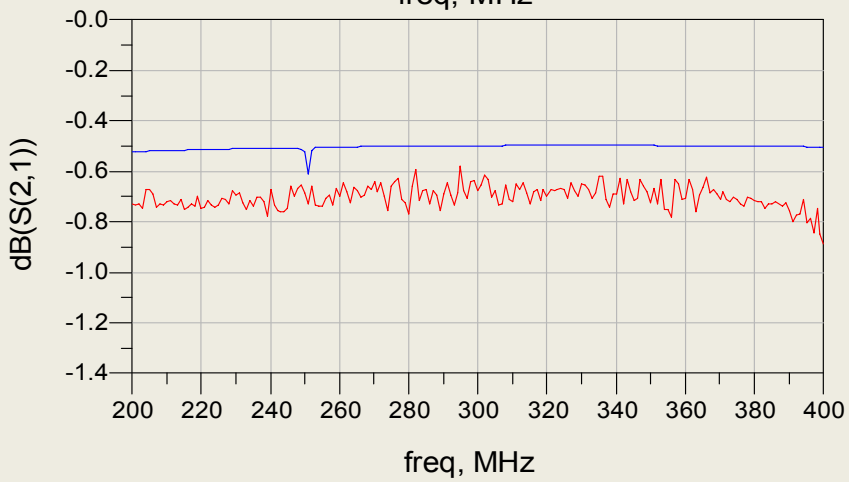
Simulation & Test Results

Cascaded 2-bits Phase Shifter

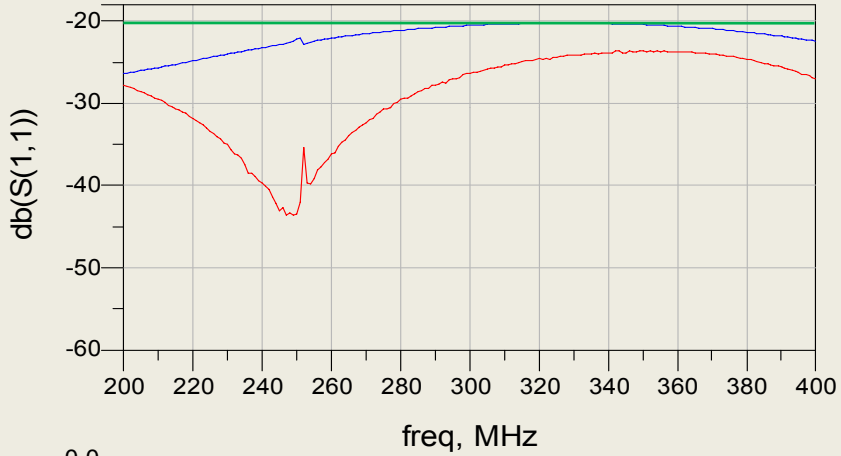
PCB vs EM co-simulation

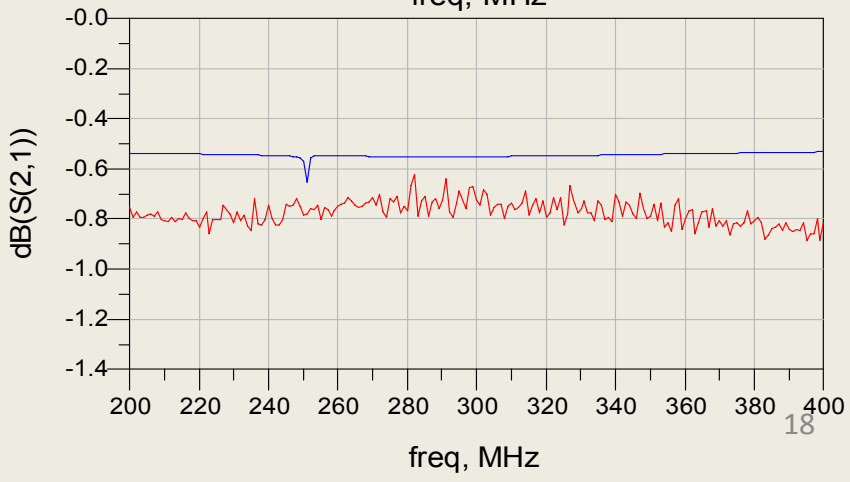
Reference line length





90° phase shift line length



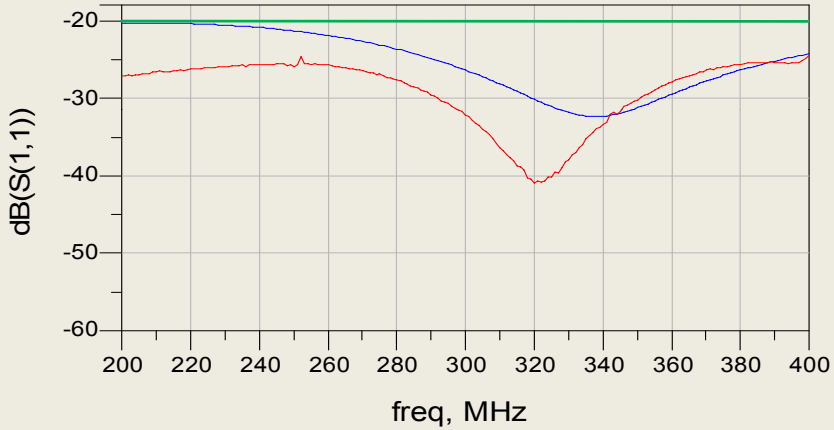


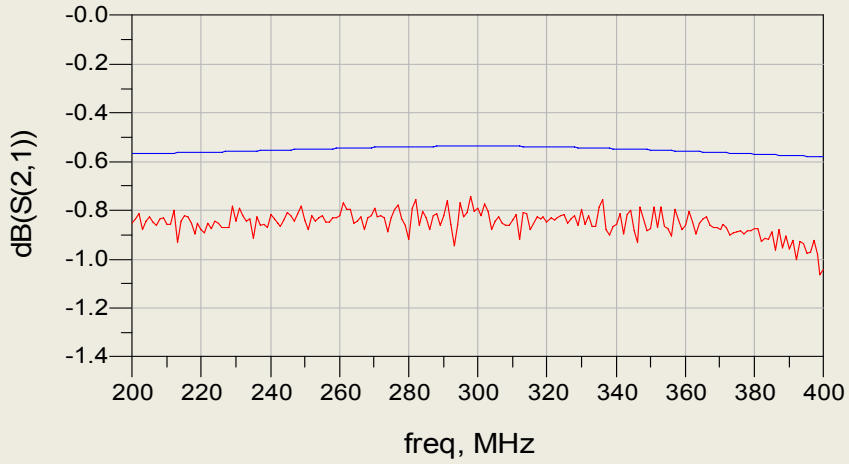
Simulation & Test Results

Cascaded 2-bits Phase Shifter

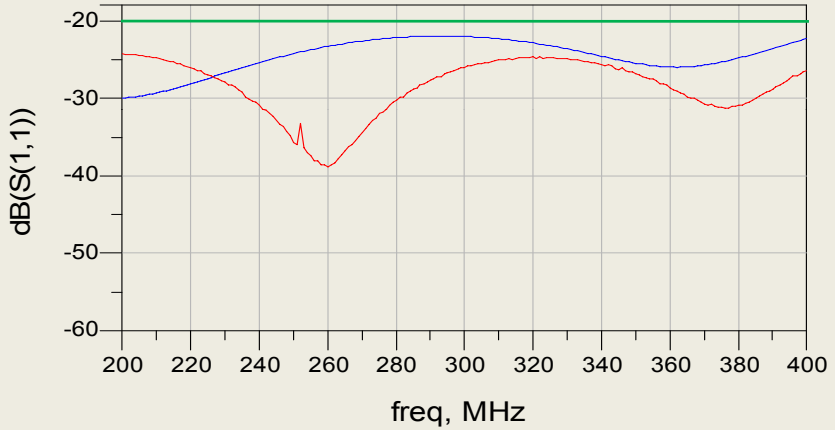
PCB vs EM co-simulation

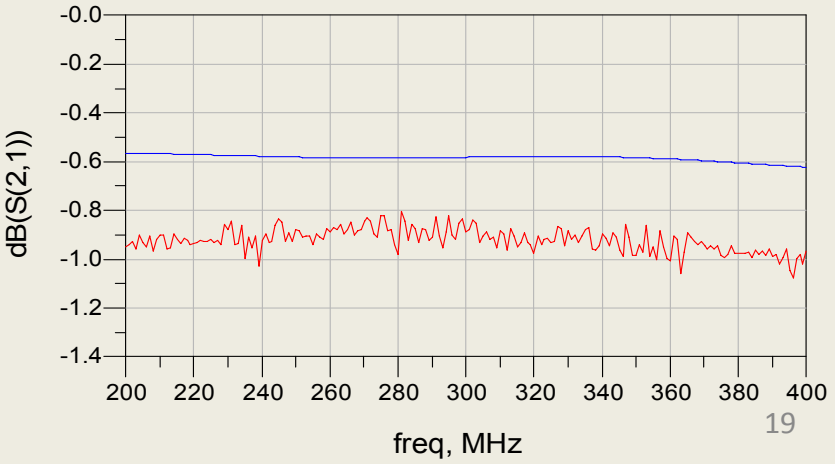
180° phase shift line length





270° phase shift line length





Simulation & Test Results

Cascaded 2-bits Phase Shifter

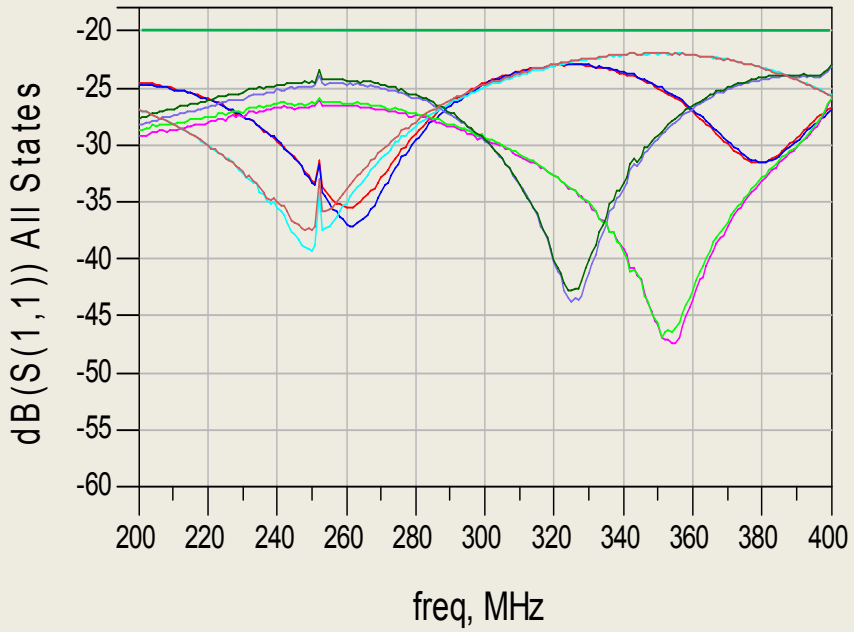
PCB's phase error at frequency range between 290MHz and 310MHz

Frequency MHz	Phase Shift								
	90 Degree			180 Degree			270 Degree		
	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$
290	86.5524	86.3457	3.6543	173.5324	173.1432	6.8568	260.2125	259.9570	10.043
295	88.0546	87.9665	2.0335	176.4230	176.4981	3.5019	264.5772	264.5076	5.4924
300	89.6168	89.5634	0.4366	179.5180	179.4775	0.5225	269.1107	269.0407	0.9593
305	91.2662	91.2381	1.2381	182.6181	182.8797	2.8797	273.7418	273.7317	3.7317
310	92.6713	92.7136	2.7136	185.6050	185.4813	5.4813	278.1669	278.2889	8.2889

Simulation & Test Results

Cascaded 2-bits Phase Shifter

Forward Bias Voltage at 8V and 12V



Simulation & Test Results

Cascaded 2-bits Phase Shifter

PCB's phase error at 8V and 12V Forward Bias Voltage
for 300MHz operating frequency

Forward Bias Voltage	Phase Shift								
	90 Degree			180 Degree			270 Degree		
	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$	$\Delta\theta_{12}$	$\Delta\theta_{21}$	$\delta(\Delta\theta_{21})$
8	89.7564	89.6135	0.3865	179.6456	179.4211	0.5789	269.1624	268.8689	1.1311
12	89.9344	89.5293	0.4707	179.7206	179.4107	0.5893	269.3717	268.9930	1.0070

Conclusions

Specifications of the Phase Shifter

90°-bit Phase Shifter

- Insertion loss < 0.5dB
- Phase error < 1° at 300MHz
- Forward bias Voltage, $10V_{DC} \pm 2V_{DC}$

180 °-bit Phase Shifter

- Insertion loss < 0.6dB
- Phase error < 1° at 300MHz
- Forward bias Voltage, $10V_{DC} \pm 2V_{DC}$

Conclusions

Cascaded 2-bits Phase Shifter

- Insertion loss < 1.1dB
- Phase error < 2° at 300MHz
- Forward bias Voltage, $10V_{DC} \pm 2V_{DC}$

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End

HFT

Thank You For Your Attention!