Bachelor Thesis

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

by

Poh Seng Pua

Supervised by

Prof. Dr. -Ing Klaus Solbach

Department of Microwave and RF- Technology

University of Duisburg-Essen

Duisburg, 08-December-2008
Outlines

• 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
Aim of the Thesis

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

\[ \Delta \theta = \beta (l_2 - l_1) \]
Design Details

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, state 2
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

Bias Circuit  TL2=237.5mm  DC Blocking

DC Power Supply, 10V forward bias & -20V reverse bias  TL2=404.3mm

RF in

TL1=73.4mm  90°-bit Phase Shifter

RF out

TL1=74.5mm  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
90°-bit Phase Shifter

PCB vs EM co-simulation

Reference line length, state 1

90° phase shift line length, state 2
90°-bit Phase Shifter

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

<table>
<thead>
<tr>
<th>Frequency MHz</th>
<th>90 Degree</th>
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<tbody>
<tr>
<td></td>
<td>$\Delta \theta_{12}$</td>
<td>$\Delta \theta_{21}$</td>
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<tr>
<td>290</td>
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<td>310</td>
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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
### 180°-bit Phase Shifter

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

<table>
<thead>
<tr>
<th>Frequency MHz</th>
<th>180 Degree</th>
<th>( \Delta \theta_{12} )</th>
<th>( \Delta \theta_{21} )</th>
<th>( \delta(\Delta \theta_{21}) )</th>
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</table>
Cascaded 2-bits Phase Shifter

PCB vs EM co-simulation

Reference line length

90° phase shift line length

$\text{dB}(|S(1,1)|)$ vs freq, MHz

$\text{dB}(|S(2,1)|)$ vs freq, MHz
Cascaded 2-bits Phase Shifter

PCB vs EM co-simulation

180° phase shift line length

270° phase shift line length
Cascaded 2-bits Phase Shifter

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

| Frequency MHz | Phase Shift 90 Degree |  | Phase Shift 180 Degree |  | Phase Shift 270 Degree |  |
|---------------|-----------------------|--|-----------------------|--|-----------------------|--|-----------------------|--|-----------------------|--|
|               | $\Delta \theta_{12}$ | $\delta(\Delta \theta_{21})$ | $\Delta \theta_{12}$ | $\delta(\Delta \theta_{21})$ | $\Delta \theta_{12}$ | $\delta(\Delta \theta_{21})$ | $\Delta \theta_{12}$ | $\delta(\Delta \theta_{21})$ | $\Delta \theta_{12}$ | $\delta(\Delta \theta_{21})$ | $\Delta \theta_{12}$ | $\delta(\Delta \theta_{21})$ |
| 295           | 88.0546               | 2.0335                   | 176.4230              | 3.5019                 | 264.5772              | 5.4924                  | 264.5076              | 5.4924                  | 264.5076              | 5.4924                  | 264.5076              | 5.4924                  |
| 300           | 89.6168               | 0.4366                   | 179.5180              | 0.5225                 | 269.1107              | 0.9593                  | 269.0407              | 0.9593                  | 269.0407              | 0.9593                  | 269.0407              | 0.9593                  |
| 310           | 92.6713               | 2.7136                   | 185.6050              | 5.4813                 | 278.1669              | 8.2889                  | 278.2889              | 8.2889                  | 278.2889              | 8.2889                  | 278.2889              | 8.2889                  |
Cascaded 2-bits Phase Shifter

Forward Bias Voltage at 8V and 12V
Cascaded 2-bits Phase Shifter

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

<table>
<thead>
<tr>
<th>Forward Bias Voltage</th>
<th>90 Degree</th>
<th>180 Degree</th>
<th>270 Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \Delta \theta_{12} )</td>
<td>( \Delta \theta_{21} )</td>
<td>( \delta(\Delta \theta_{21}) )</td>
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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, $10V_{dc} \pm 2V_{dc}$
Thank You For Your Attention!