HOCHFREQUENZTECHNIK

INGENIEURWISSENSCHAFTEN

UNIVERSITÄT
DUISBURG
ESSEN

HFT

Switchable Array Antennas for 24 GHz Radar Applications

Master Thesis

By Bo Zhou

04.09.2012

IMST
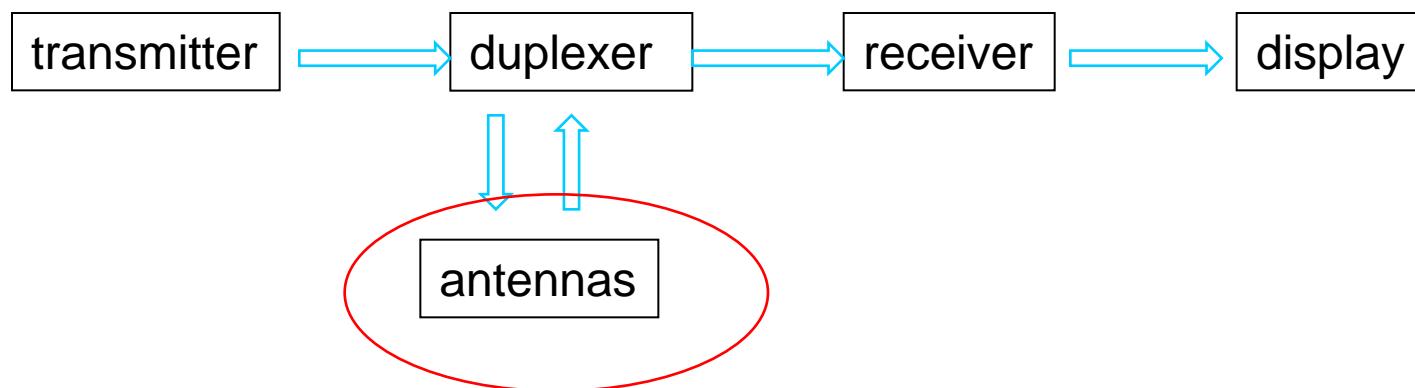
Outline

→Basic Theory and Concepts

→Phased Array Antennas

→Switching Concept

→Network Distribution and Components

→Final Design and Analysis

→Conclusion

HOCHFREQUENZTECHNIK

INGENIEURWISSENSCHAFTEN

UNIVERSITÄT
DUISBURG
ESSEN

H F T

Radar System Requirements

Radar systems

| transmitter | → | duplexer | → | receiver | → | display |

antennas

Radar System Requirements

Automotive or security applications

High resolution

Not only range, speed

But also angular position

Small size

Low cost

flexable

....
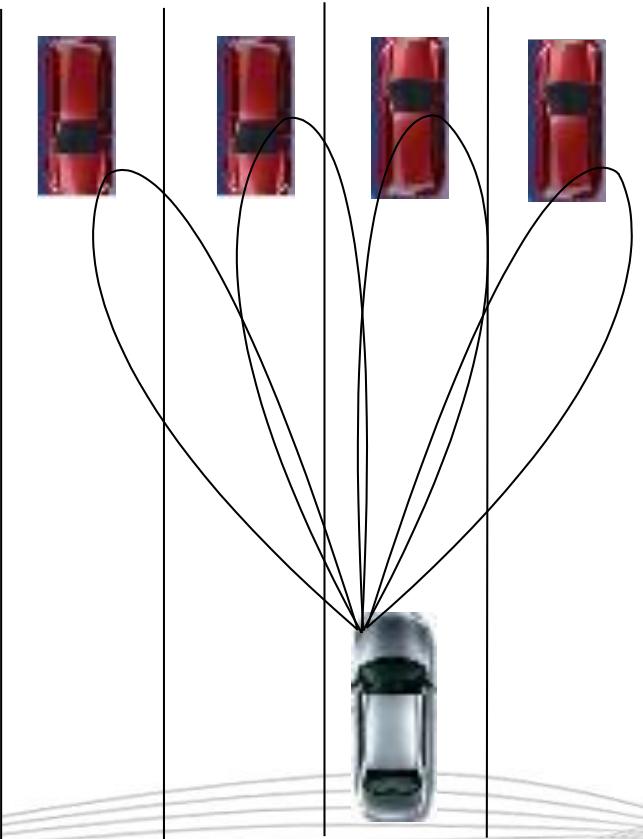
4 beams

Narrowbeam
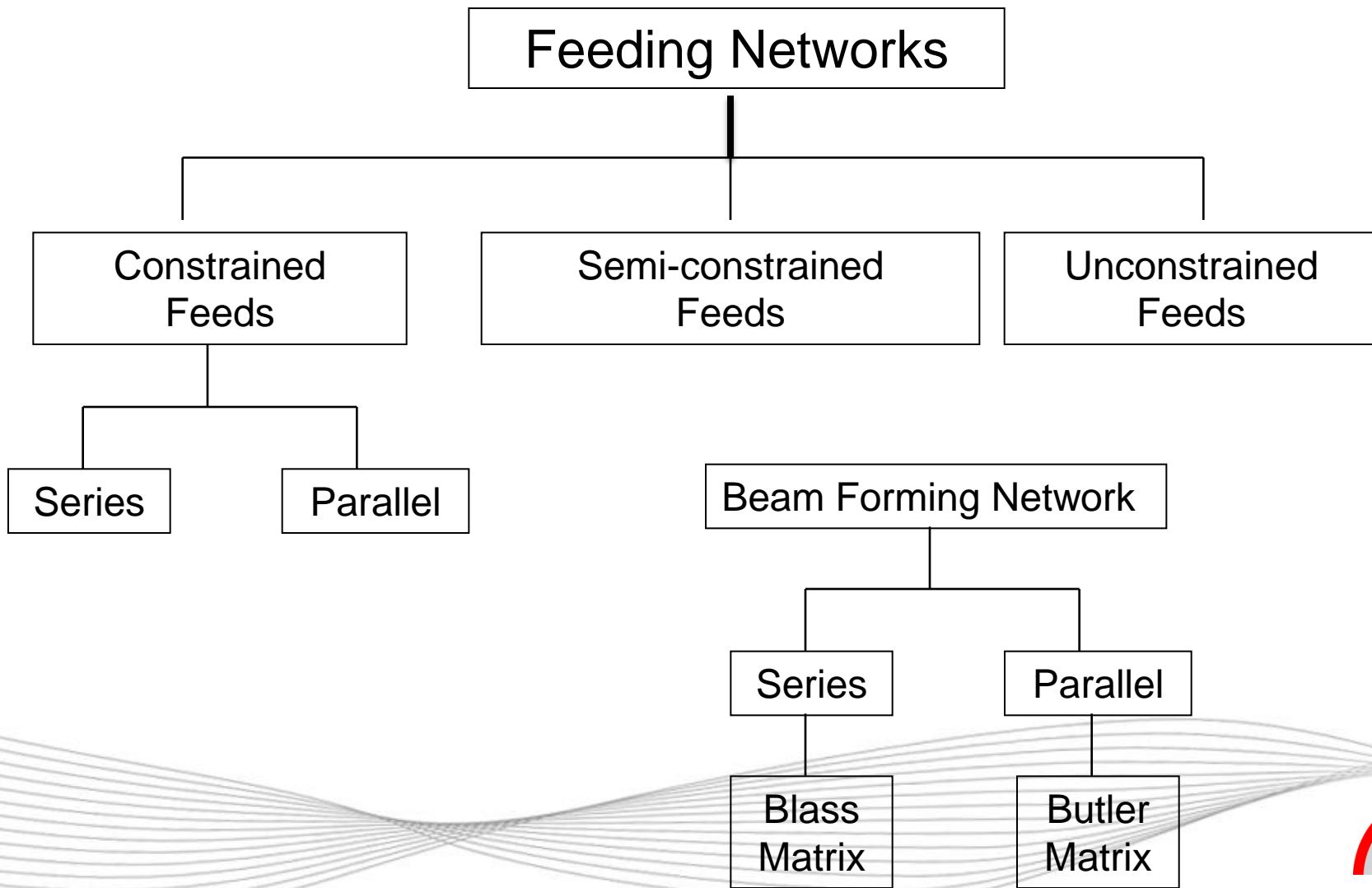
High directivity
(more than 20dB)
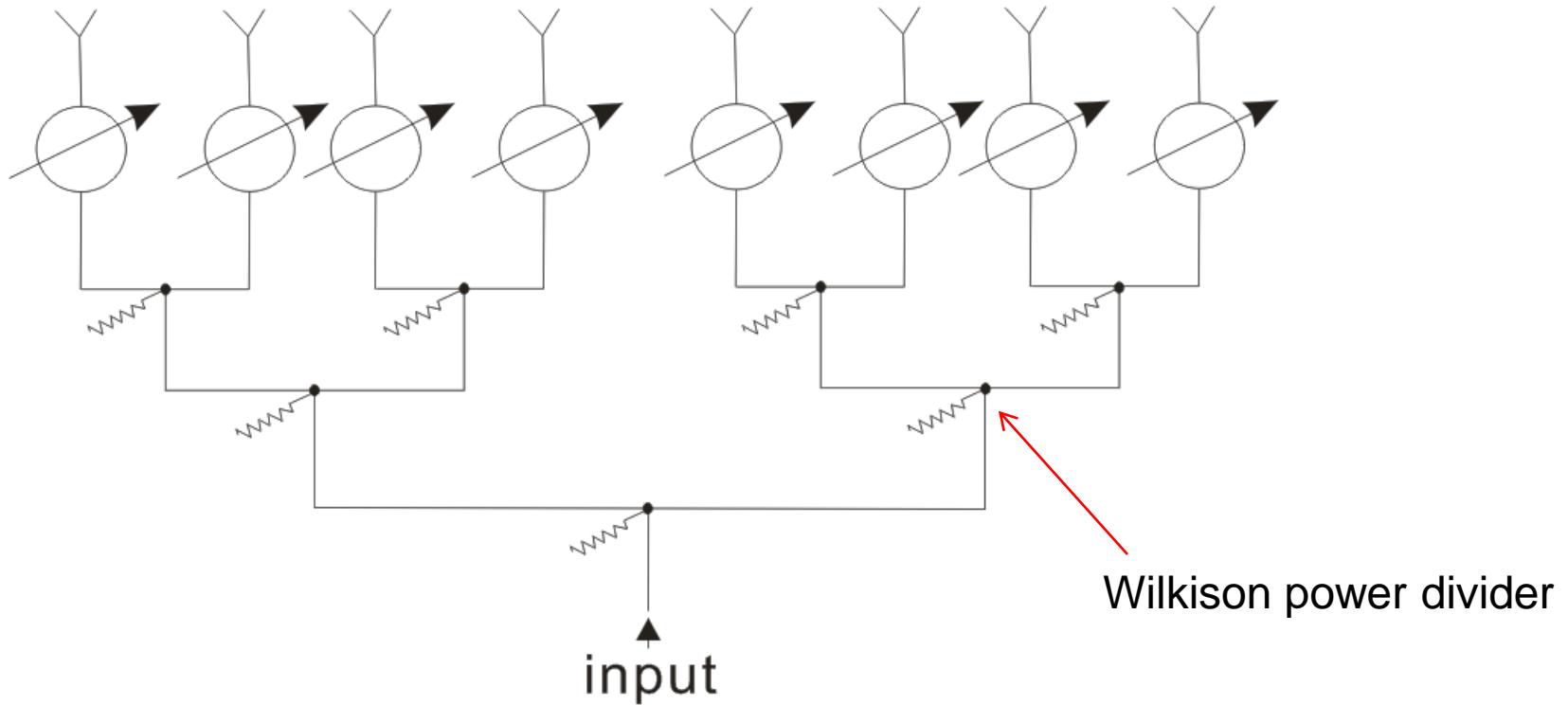
Good isolation between beams
(at least 3dB)

HOCHFREQUENZTECHNIK

INGENIEURWISSENSCHAFTEN

UNIVERSITÄT
DUISBURG
ESSEN

H F T

Network Concepts

```
                    ┌─────────────────────┐
                    │  Feeding Networks   │
                    └─────────────────────┘
        ┌────────────────────┼────────────────────┐
┌───────────────┐   ┌───────────────┐   ┌───────────────┐
│  Constrained  │   │Semi-constrained│   │ Unconstrained │
│     Feeds     │   │     Feeds     │   │     Feeds     │
└───────────────┘   └───────────────┘   └───────────────┘
   ┌──────┴──────┐
┌────────┐  ┌──────────┐      ┌─────────────────────┐
│ Series │  │ Parallel │      │ Beam Forming Network│
└────────┘  └──────────┘      └─────────────────────┘
                              ┌──────────┴──────────┐
                         ┌────────┐          ┌──────────┐
                         │ Series │          │ Parallel │
                         └────────┘          └──────────┘
                              │                    │
                         ┌────────┐          ┌──────────┐
                         │ Blass  │          │  Butler  │
                         │ Matrix │          │  Matrix  │
                         └────────┘          └──────────┘
```

Network Concepts

Wilkison power divider

input

Matched corporate feed

Parallel constraind feeds

HOCHFREQUENZTECHNIK

INGENIEURWISSENSCHAFTEN

UNIVERSITÄT
DUISBURG
ESSEN

HFT

Phased Array Antennas

Equal phase array
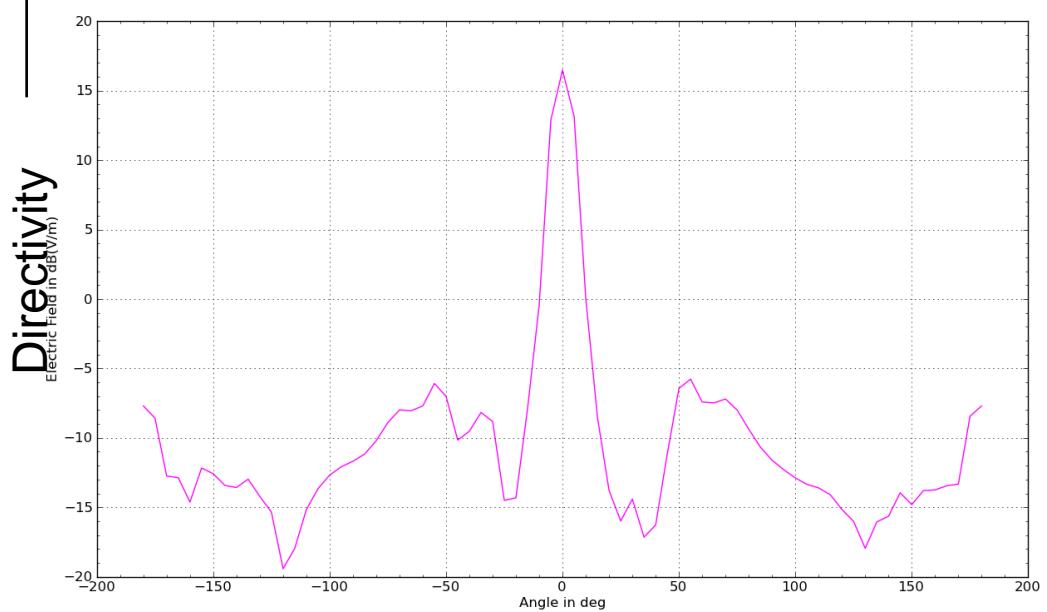
Phase increase by $\triangle \varphi$

$$\Delta\phi = \frac{360° \cdot d \cdot sin\Theta_s}{\lambda}$$

Phased Array Antennas
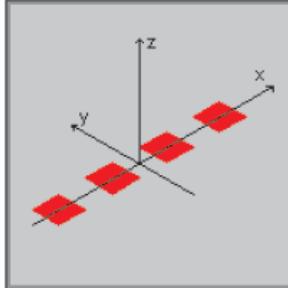
Empire model of single column

Phased Array Antennas

UNIVERSITÄT
DUISBURG
ESSEN

H F T
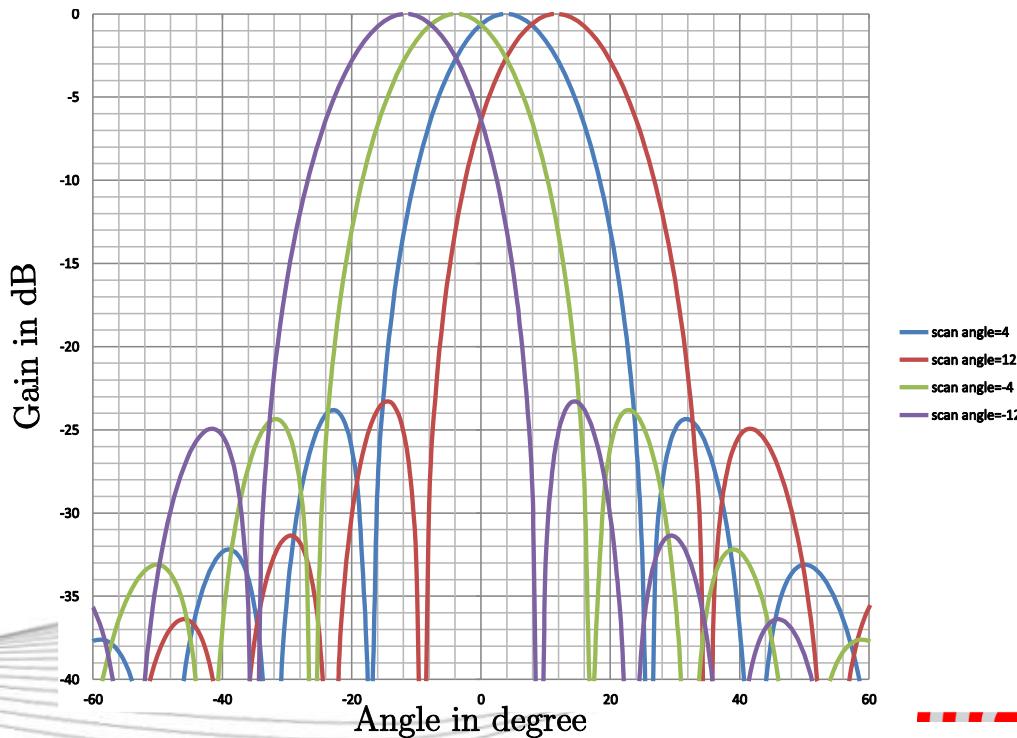
Uniform Linear Array Antenna Analysis

Array Parameters . . .

Frequency (GHz)	24,0
Number of elements	8
Element spacing (cm)	0.6

Amplitude taper:	Cosine: Ped=-20,0 dB	Select
Phase taper:	Phase shift: 12,0°	Select
Element type:	Rectangular patch (X-pol)	Select
Pattern type:	Polar; Et/Ep; Az=0; Step=1,0	Select

Azimuth distribution
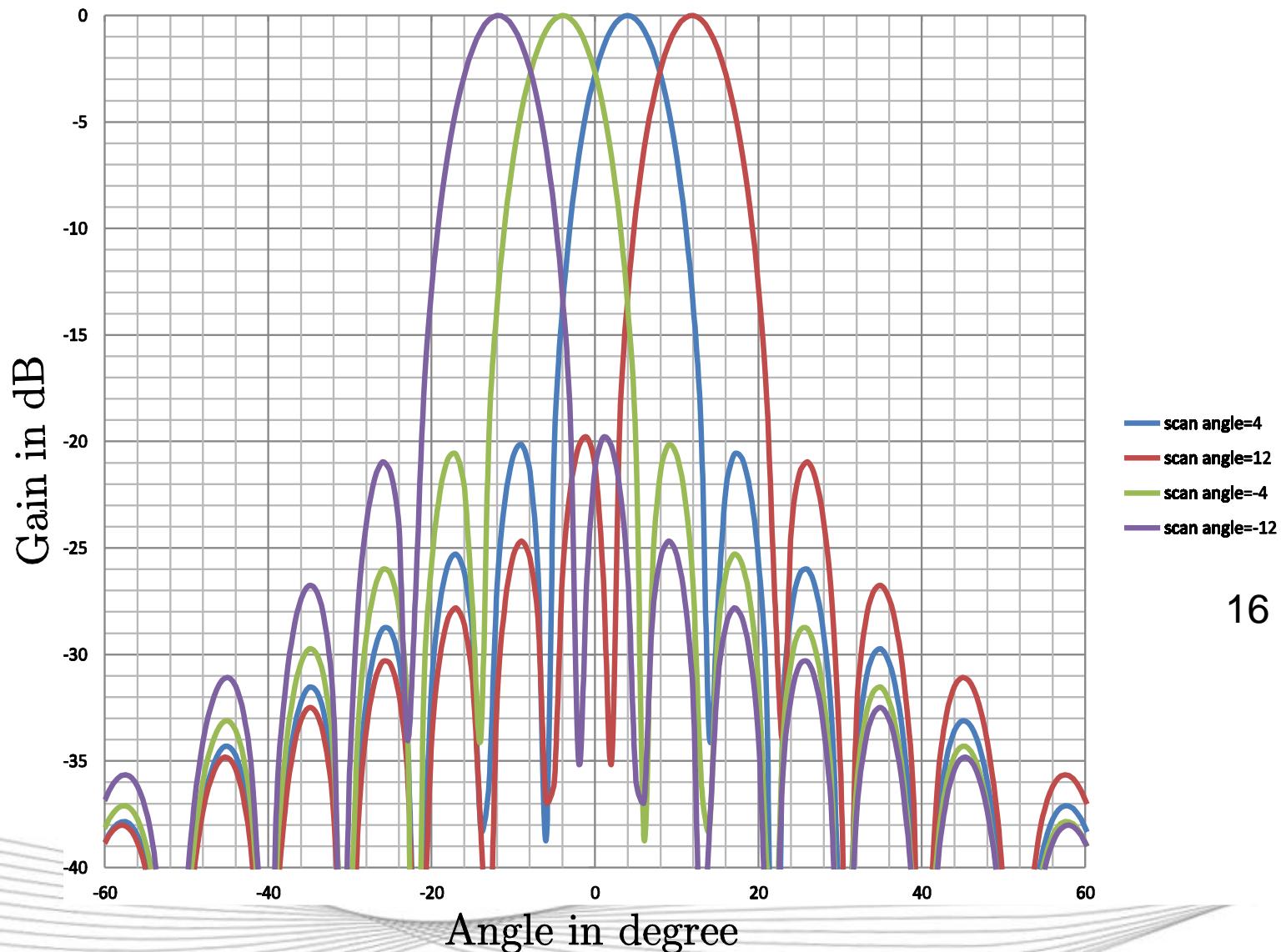
Determination of the
number of columns

8 elements

scan angle=4
scan angle=12
scan angle=-4
scan angle=-12

Gain in dB

Angle in degree

9

I
M
S
T

Phased Array Antennas

Azimuth distribution
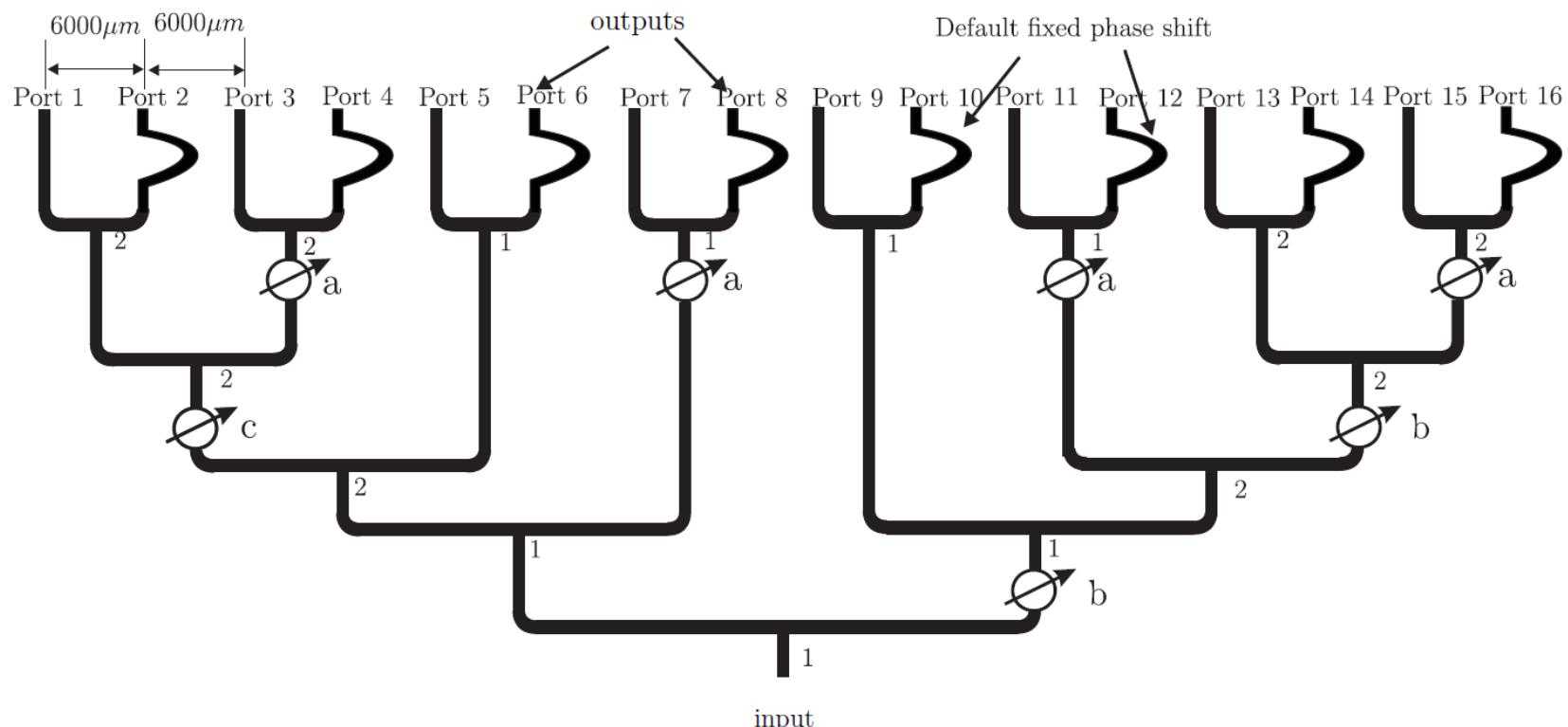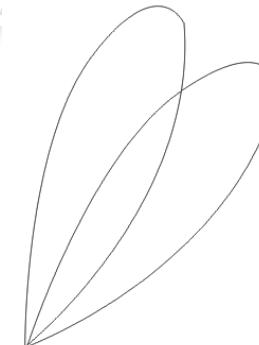
16 elements

Phased Array Antennas
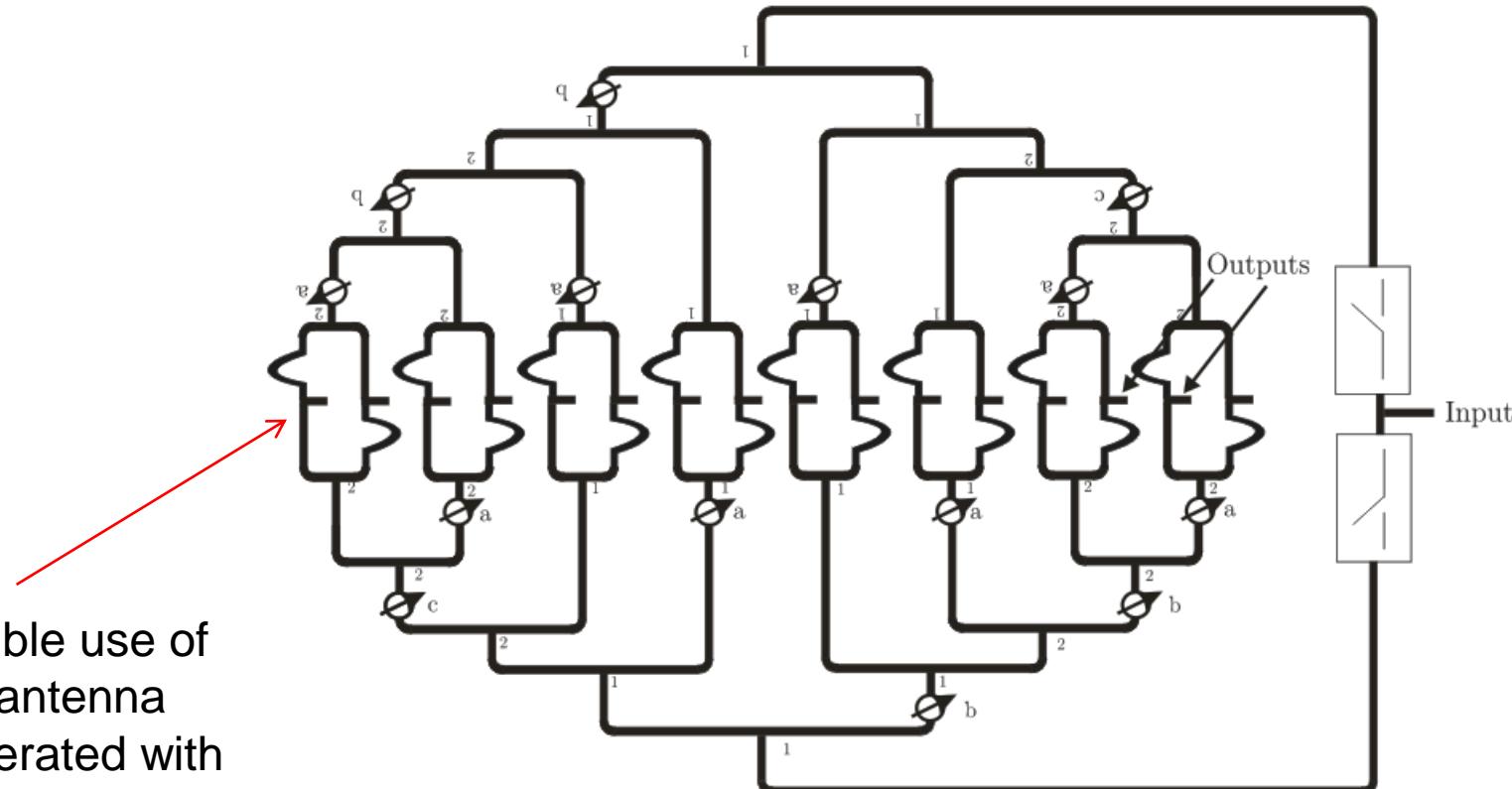

Azimuth distribution

Network Distribution

Phased Array Antennas

Outputs

Input

Double use of the antenna seperated with Wilkison power divider
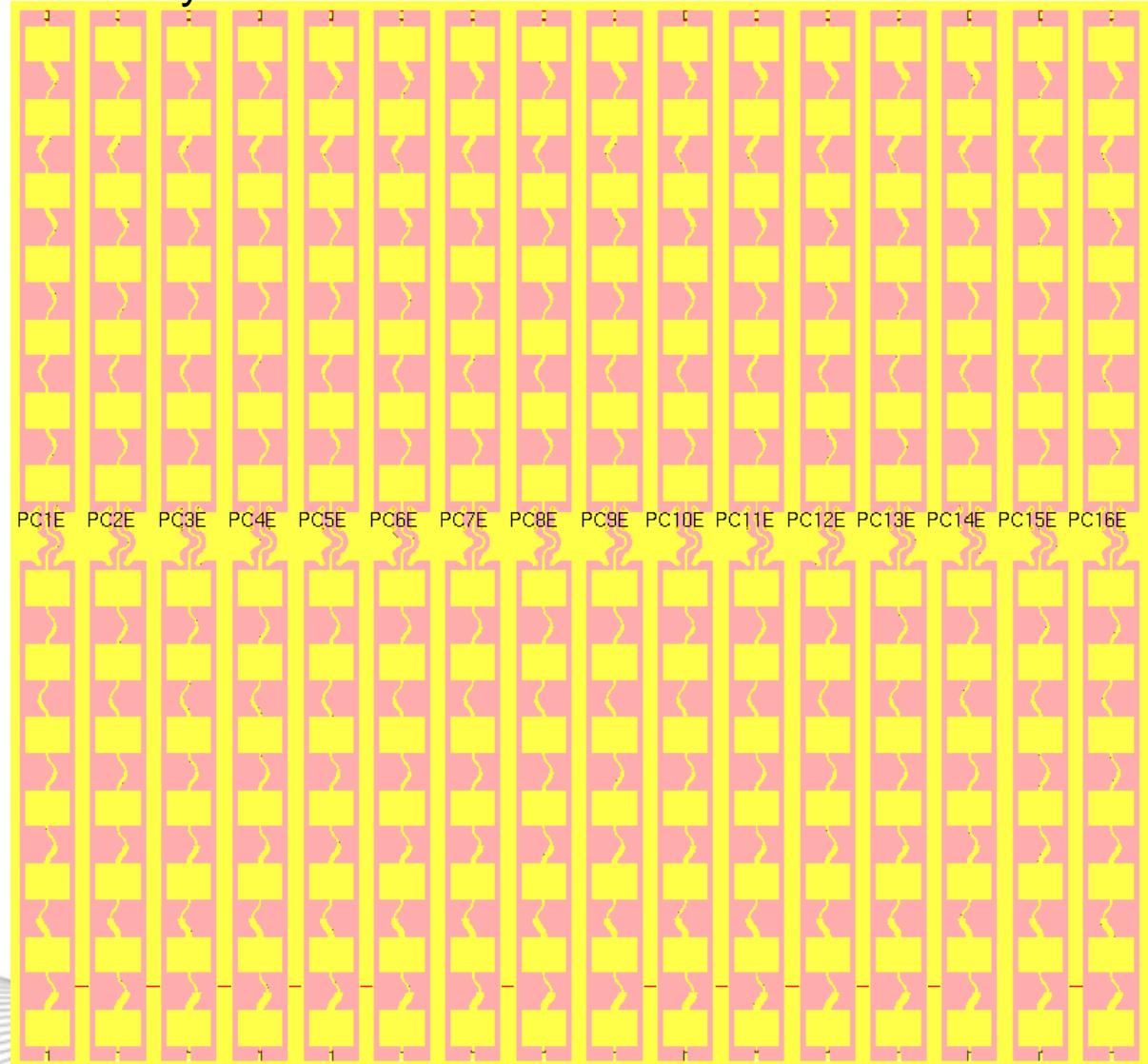
Design of the whole network

Phased Array Antennas

Simulation of the antenna array

Only with ports
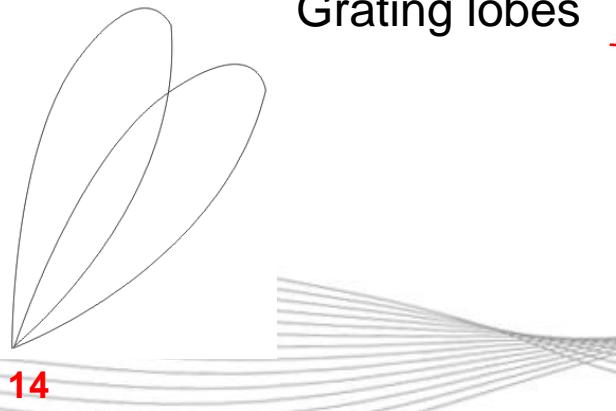
Phased Array Antennas
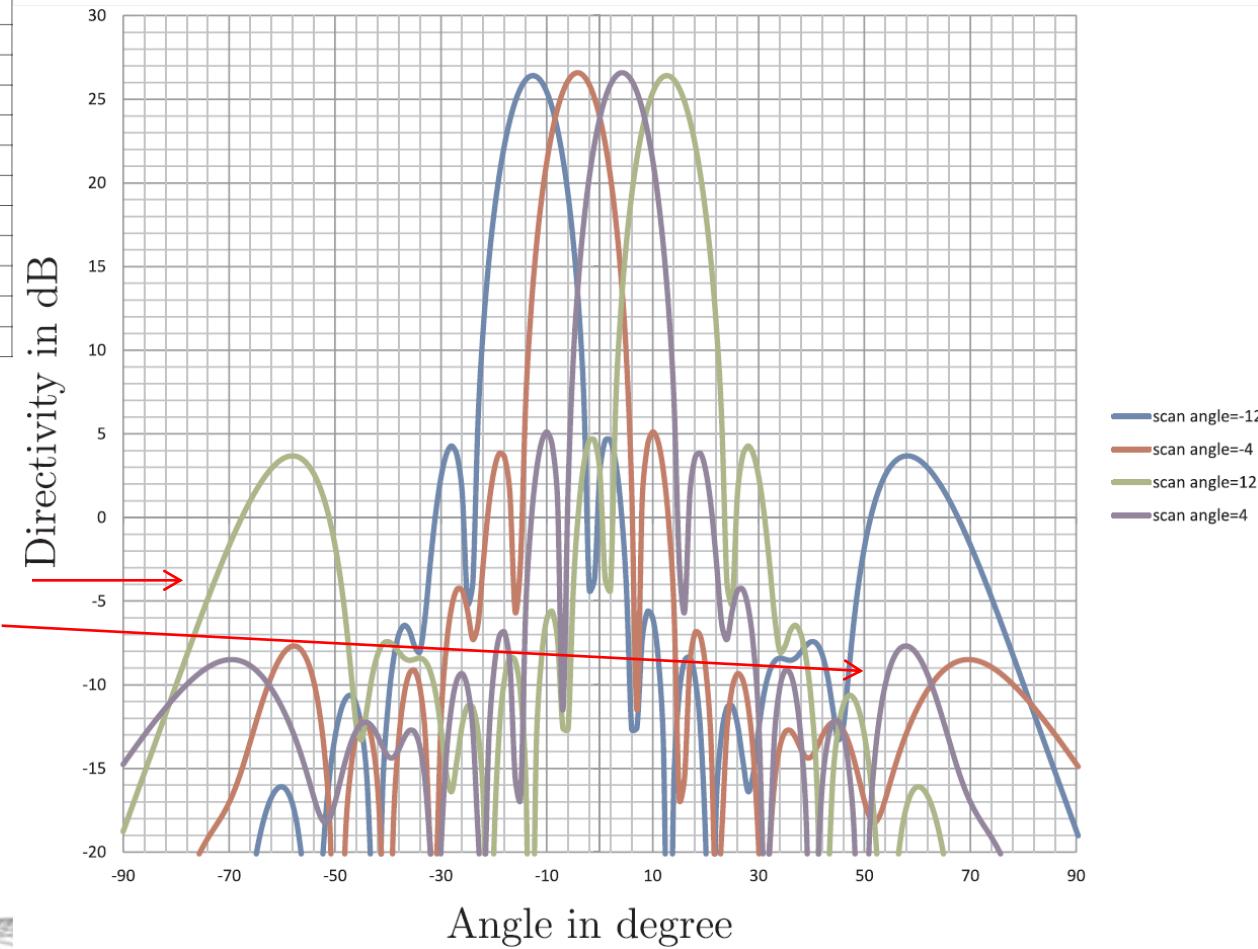
Port	Amplitude	Phase 1 in degree	Phase 2 in degree
1	0.19	0	0
2	0.36	24	24
3	0.53	24	72
4	0.67	48	96
5	0.8	48	144
6	0.9	72	168
7	0.96	72	216
8	1	96	240
9	1	96	288
10	0.96	120	312
11	0.9	120	360/0
12	0.8	144	24
13	0.67	144	72
14	0.53	168	96
15	0.36	168	144
16	0.19	172	168

Amplitude and phase distribution of the ports

Grating lobes
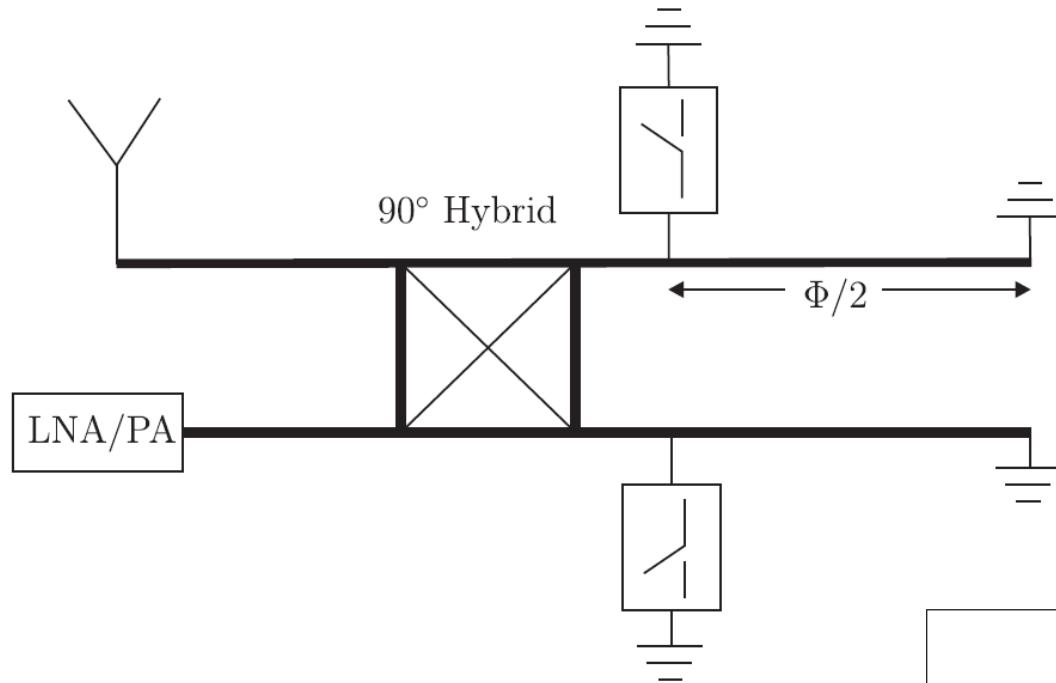
Simulated farfield patterns

scan angle=-12
scan angle=-4
scan angle=12
scan angle=4

Switching Concepts

Phase shifters

90° Hybrid

$\Phi/2$

LNA/PA
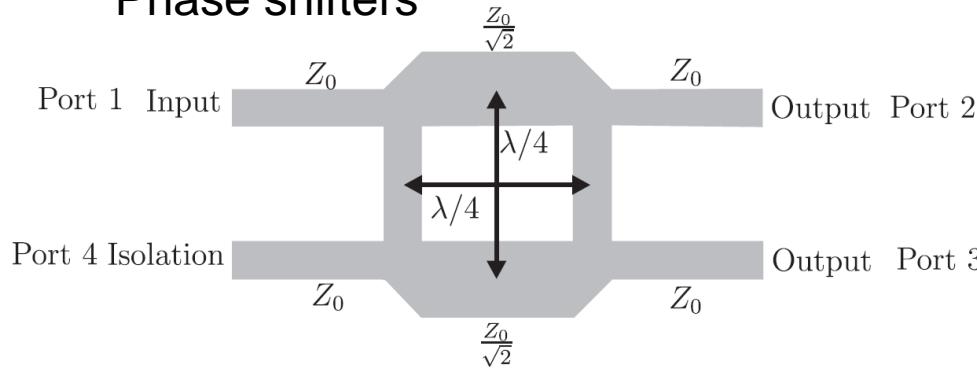
Hybrid coupled phase shifter

	MEMS	electronic Switching
Absorption	√	√
Isolation	√	√
Operating Voltage	X	√
Switching Speed	X	√
Life Circle	X	√

HOCHFREQUENZTECHNIK

INGENIEURWISSENSCHAFTEN

Switching Concepts

Phase shifters

$$\frac{Z_0}{\sqrt{2}}$$

Port 1 Input — Z_0 — $\lambda/4$ — Z_0 — Output Port 2

$\lambda/4$

Port 4 Isolation — Z_0 — Z_0 — Output Port 3

$$\frac{Z_0}{\sqrt{2}}$$

90° hybrid coupler

EMPIRE model of phase shifter

HOCHFREQUENZTECHNIK

INGENIEURWISSENSCHAFTEN

UNIVERSITÄT
DUISBURG
ESSEN

HFT

Switching Concepts

Phase shifters

MA910 AlGaAs Flip Chip PIN Diode

- Simulated S21 with diode on
- Simulated S21 with diode off
- Measured S21 with diode off
- Measuredd with S21 diode on

S-Parameters in dB vs Frequency in GHz

MA910 (Phase shift between diode on and off)

- Simulation
- Measurement

Phase shift in degree vs Frequency in GHz

IMST
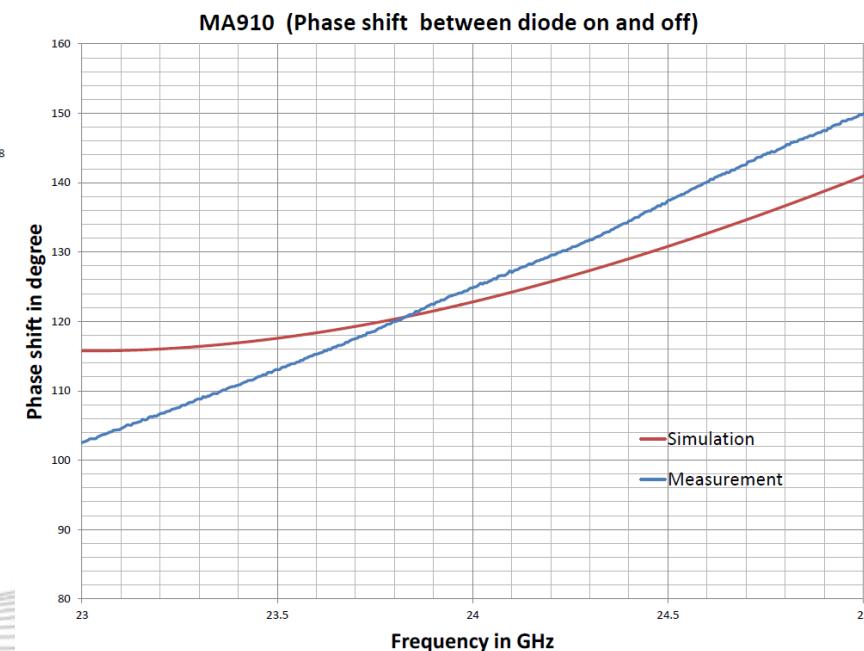
Network implementation

Port	Amplitude	Phase 1 in degree	Phase 2 in degree
1	0.26	0	0
2	0.38	30	30
3	0.38	30	90
4	0.54	60	120
5	0.8	60	180
6	0.8	90	210
7	1	90	270
8	1	120	300
9	1	120	360/0
10	1	150	30
11	0.8	150	90
12	0.8	180	120
13	0.54	180	180
14	0.38	210	210
15	0.38	210	270
16	0.26	240	300
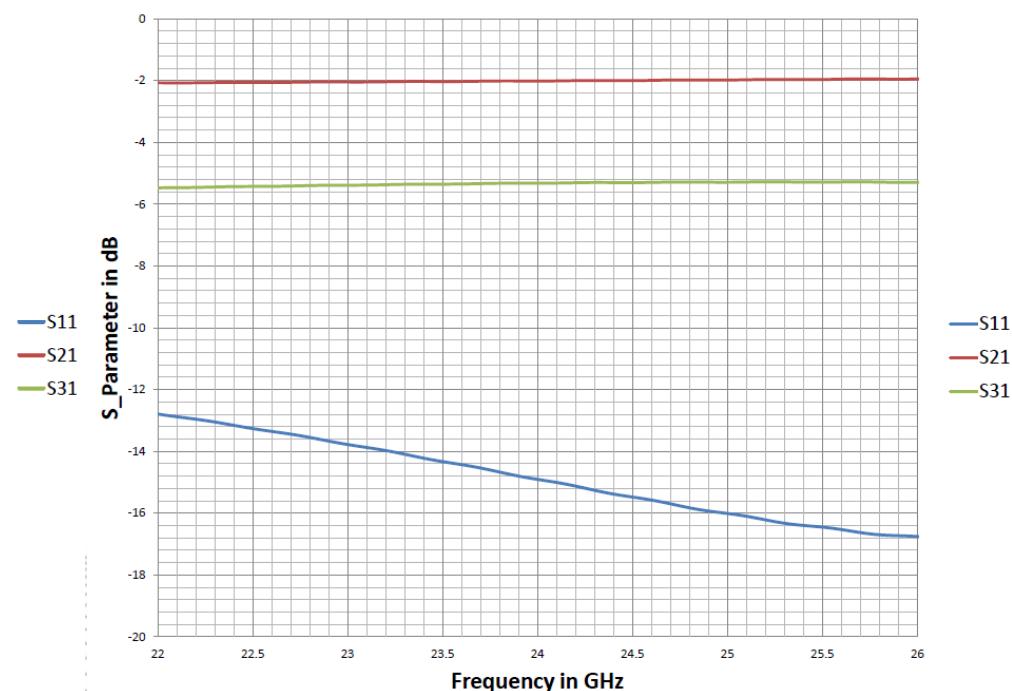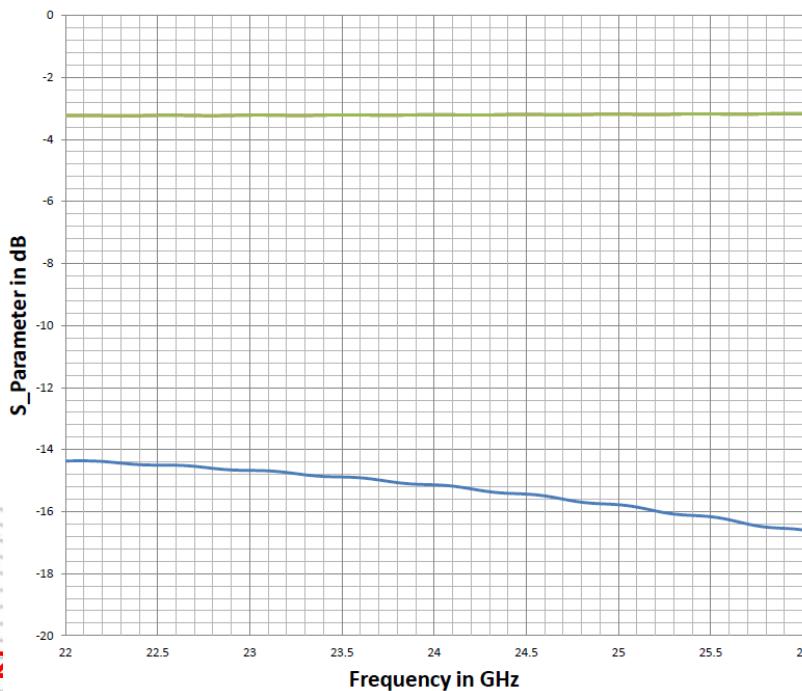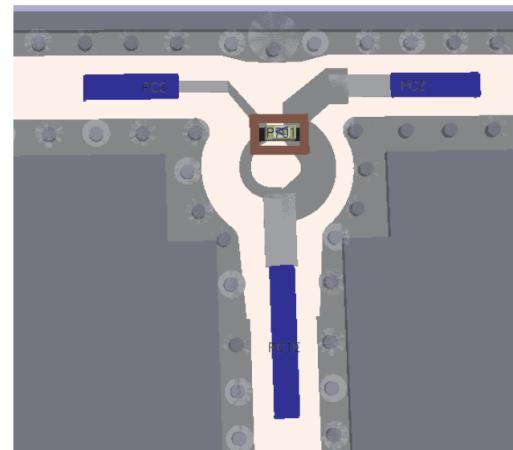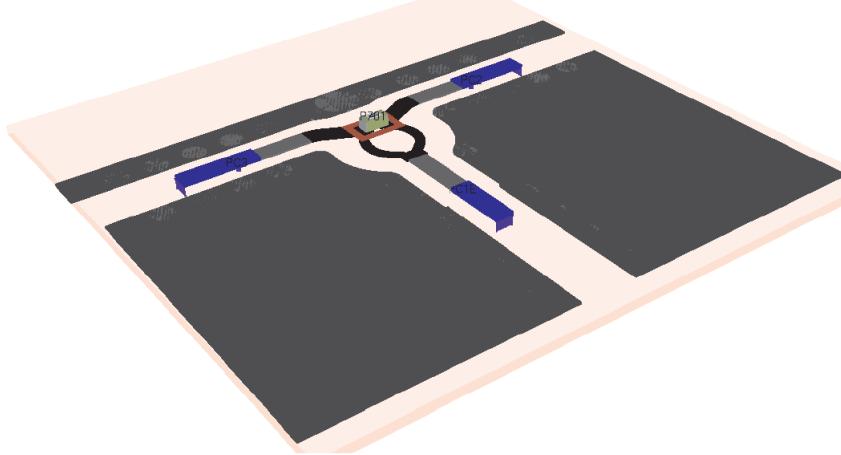
Simulation of antenna array
Only with ports definition

Network implementation

**HOCHFREQUENZTECHNIK**

INGENIEURWISSENSCHAFTEN

UNIVERSITÄT
DUISBURG
ESSEN

HFT
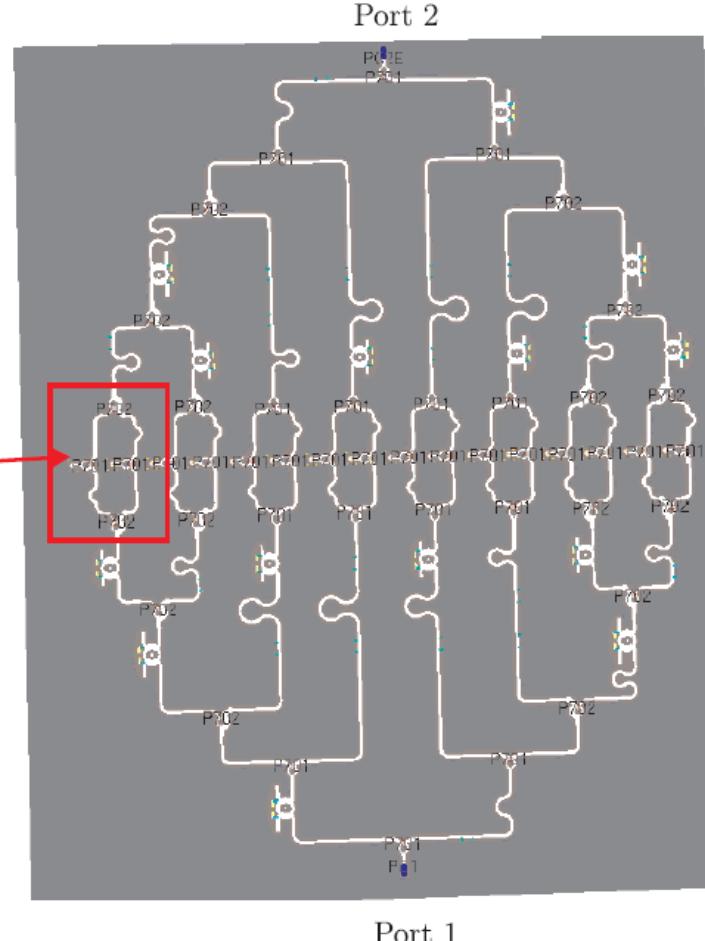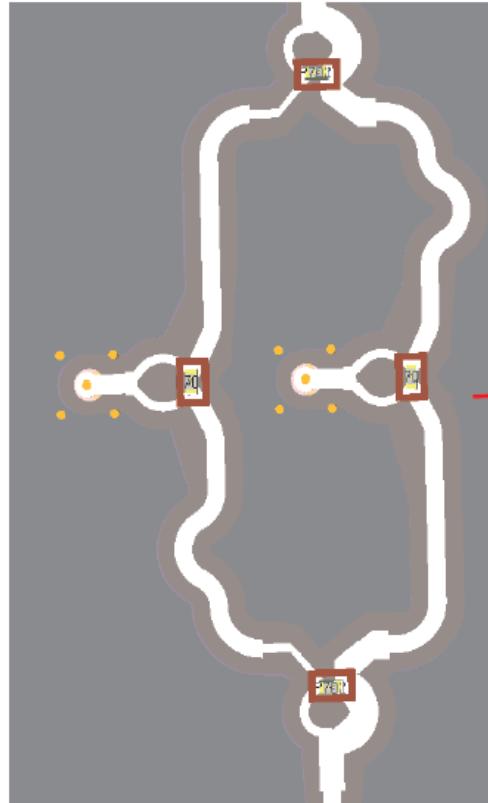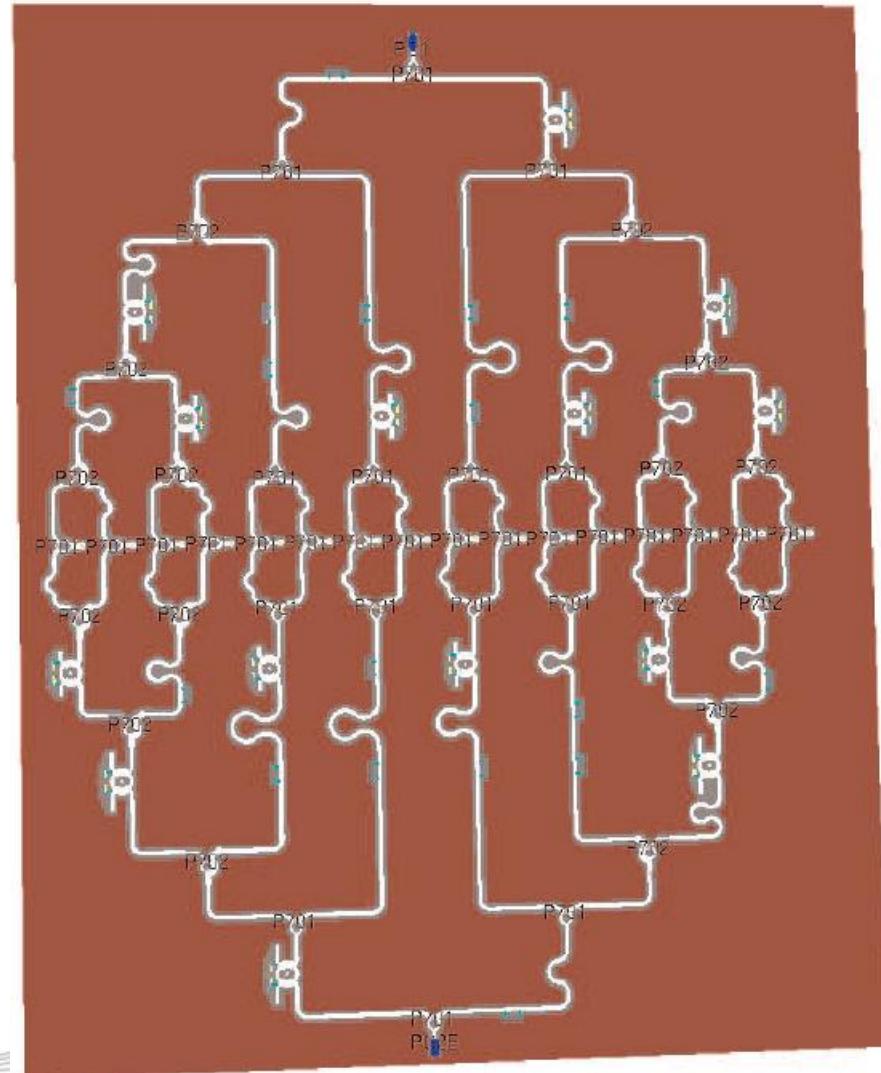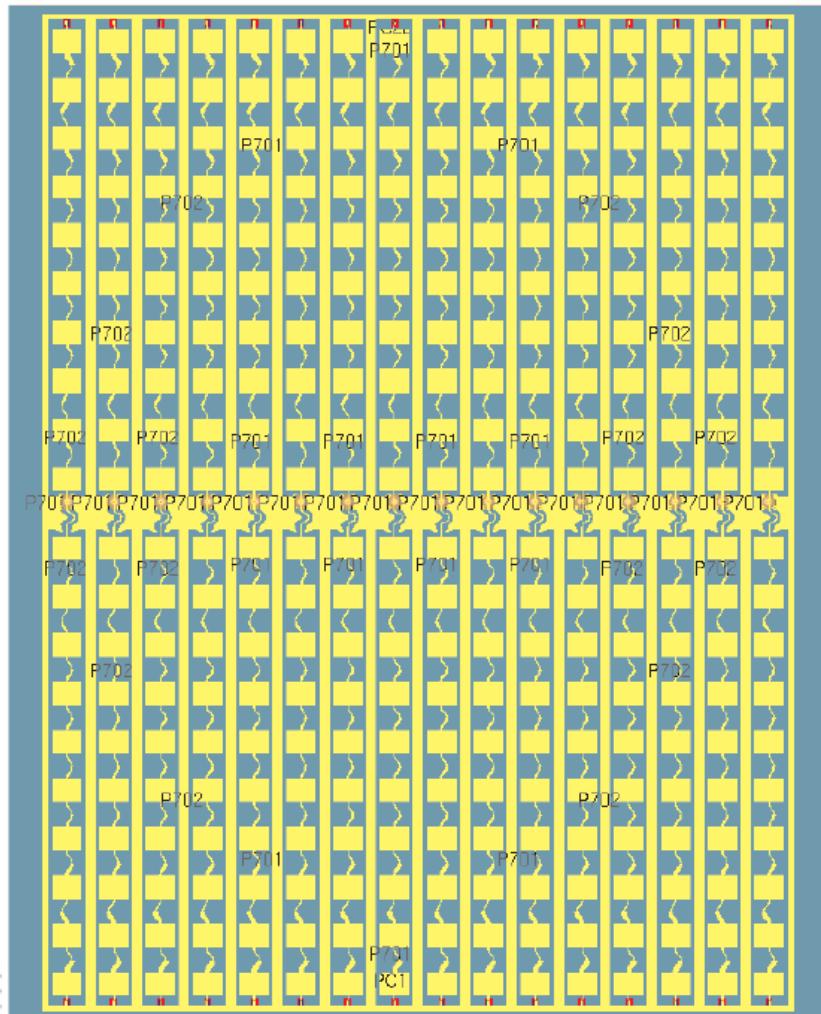
Network implementation
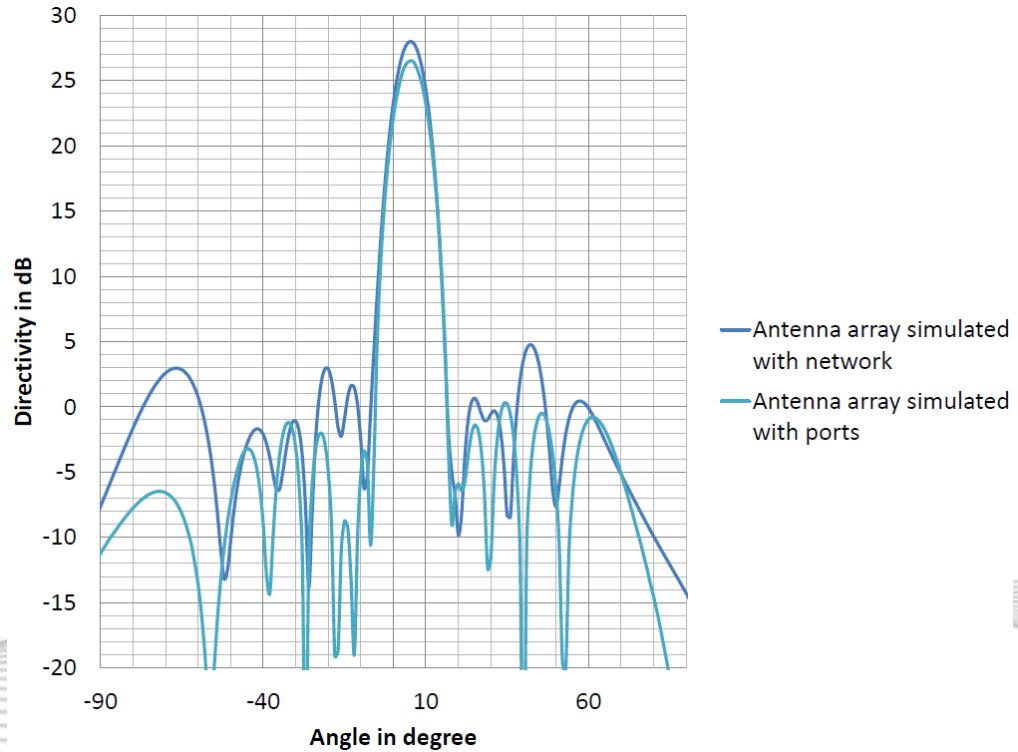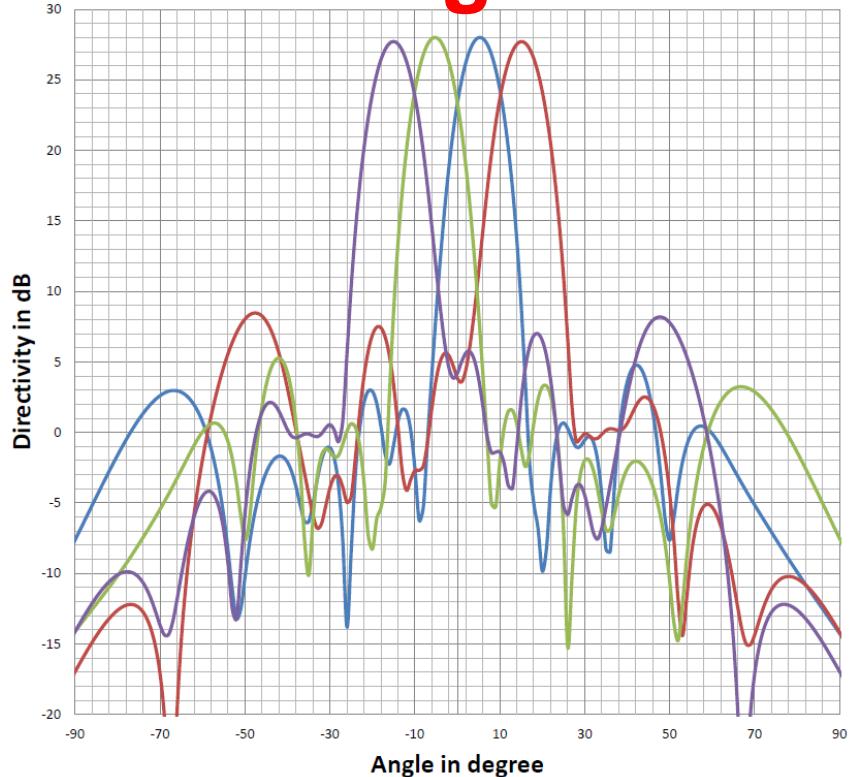
Network implementation

Final Design

HOCHFREQUENZTECHNIK
INGENIEURWISSENSCHAFTEN
UNIVERSITÄT
DUISBURG
ESSEN
HFT

Final Design

Conclusion

→ Different network concepts and switching concept are discussed

→ Phase shifters with PIN diode are simulated, fabricated and measured

→ The whole RF circuit is simulated

→ The radar system requirements are fulfilled

→ The PIN-diodes switching circuits will more detailed analyzed in near future

Reference

Balanis 2005

BALANIS, Constantine A.: *Antenna theory 3.ed.* Wiley, 2005

Bhattacharyya 2006

BHATTACHARYYA, Arun K.: *Phased Array Antennas.* 2006

Brookner 1991

BROOKNER, Eli: *Practical Phased Array Antenna System.* Artech House, 1991

Hansen 1998

HANSEN, R. C.: *Phased array antennas.* Wiley, 1998

Johson 1998

JOHSON, Richard C.: *Antenna Engineering Handbook Third Edition.* McGraw-Hill, 1998

Kraus 2009

KRAUS, John D.: *Antennas For All Application 3.ed.* McGraw-Hill, 2009

Mailloux 1994

MAILLOUX, Robert J.: *Phased array antenna handbook.* Artech House, 1994

Pozar 1998

POZAR, David M.: *Microwave Engineering.* 1998

radartutorial8

RADARTUTORIAL8: Phased Array Antenna. www.radartutorial.eu

Skolnik 2008

SKOLNIK, Merrill I.: *Radar Handbook 3.ed.* MaGraw-Hill, 2008

Solbach 2009
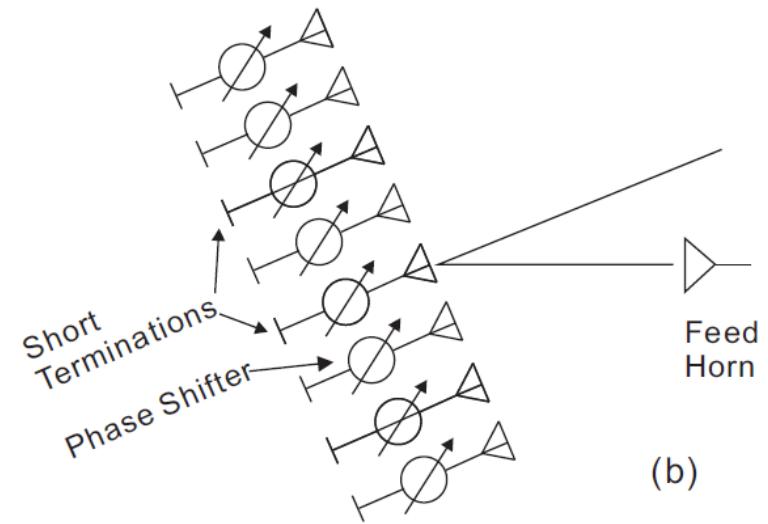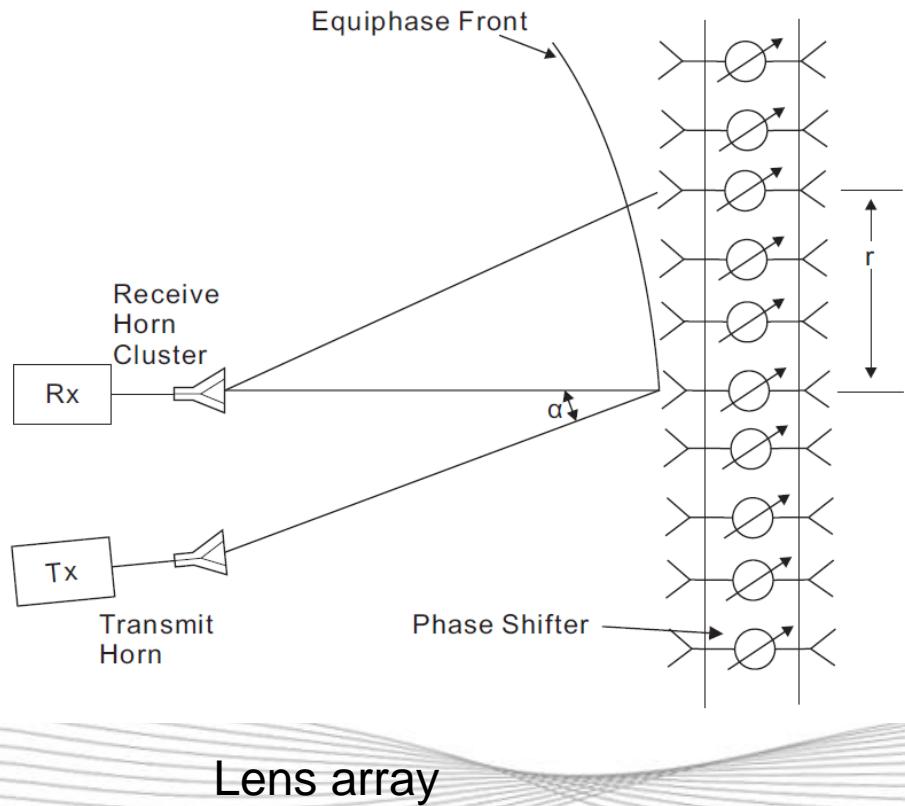
SOLBACH: *Antennas for Communication.* 2009

Thank you for attention!
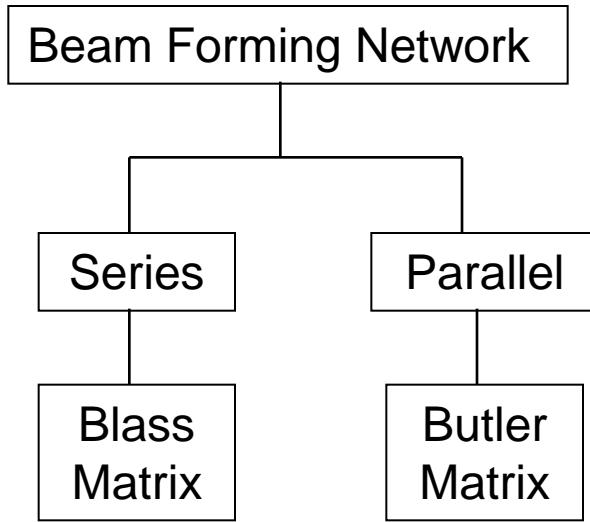
Network Concepts

Unconstrained
Feeds

Reflect array

Lens array

Network Concepts

Beam Forming Network

Series

Parallel

Blass Matrix
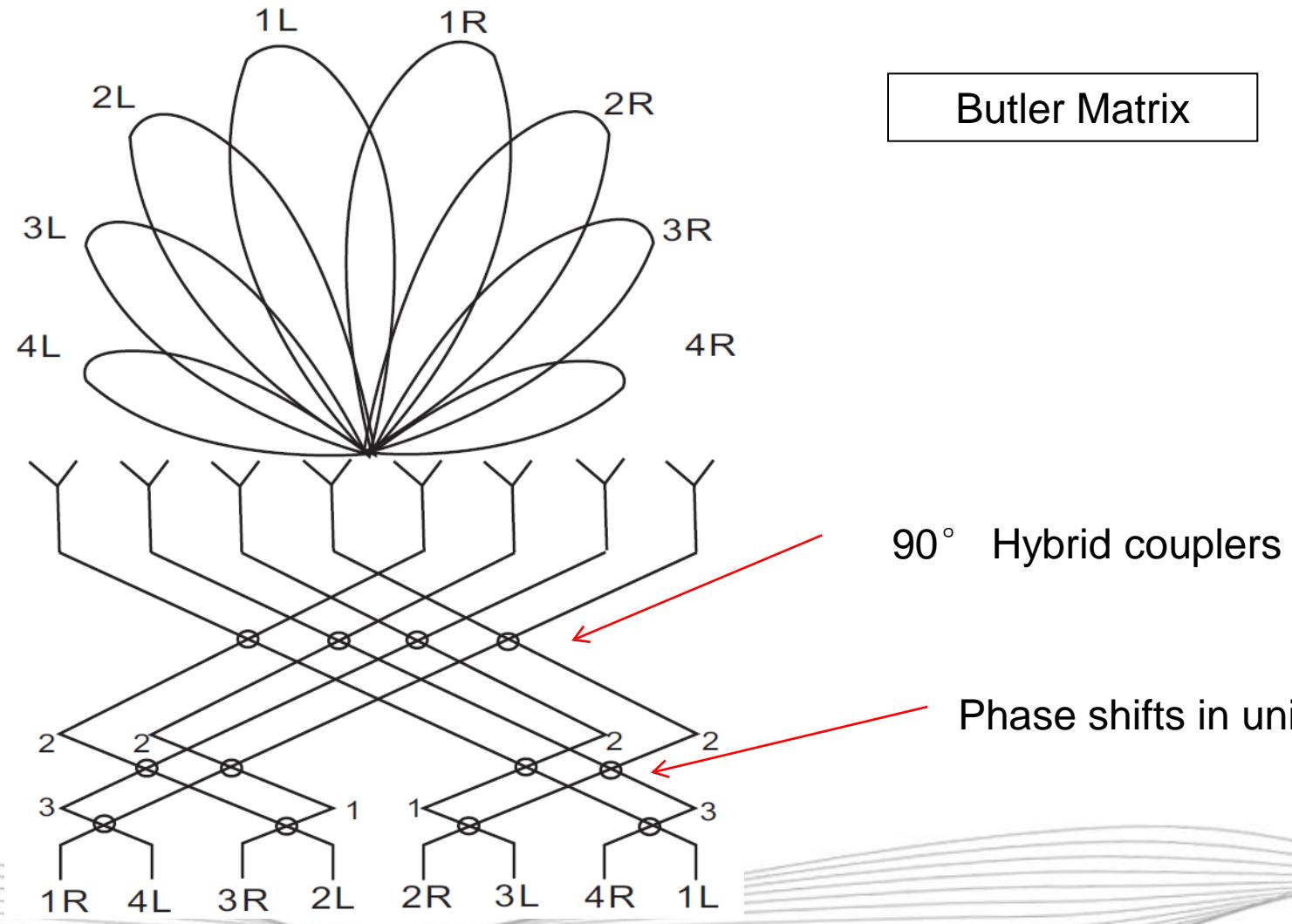
Butler Matrix

Butler Matrix

Schematic of Butler matrix

Network Concepts

Butler Matrix

90° Hybrid couplers

Phase shifts in unit $\pi/8$
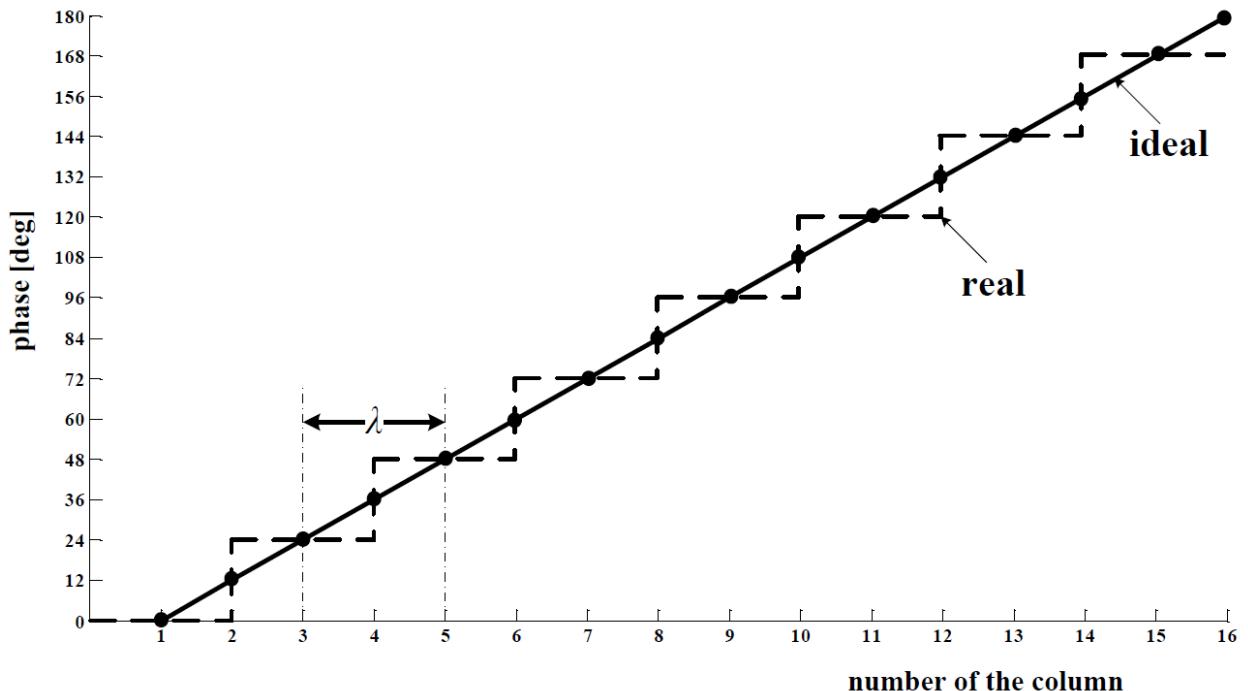
Network Concepts

Blass Matrix

Phased Array Antennas

Grating lobes

Phase distributions

Condition for appearence of grating lobes

$$\frac{d}{\lambda} = \frac{1}{1 + |cos\theta_0|}$$

31

Switching Concepts
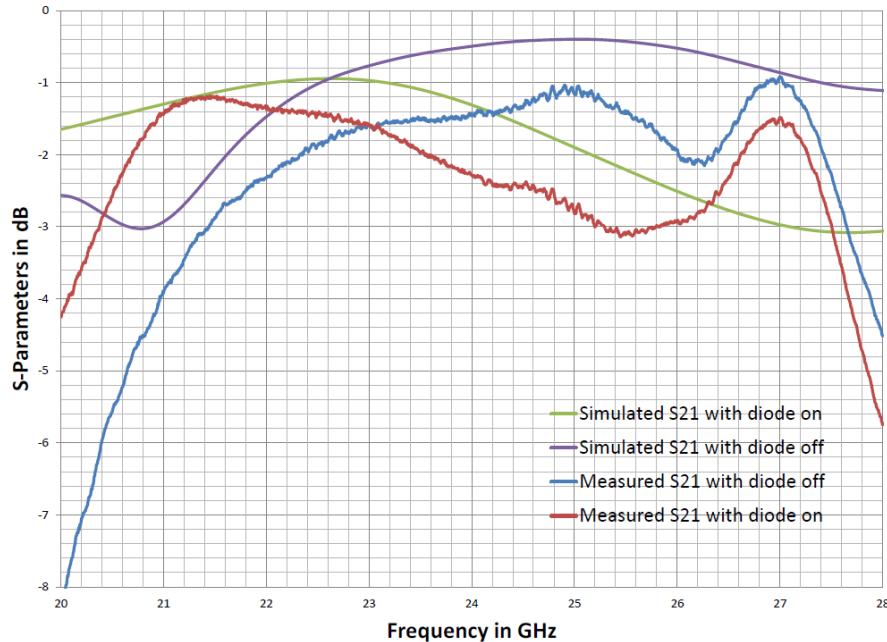
Components of phase shifters

RF-Switches							
Value	Unit	SoS	GaAs FET	GaAs pHEMT	GaAs PIN Diode	Si PIN Diode	RF-MEMS
insertion loss	dB	0.7-1	0.6-0.9	0.35-0.65	0.3-0.6	0.55-1	0.1-0.5
Isolation	dB	25-41	28-45	>30	12-25	37-45	45
Linearity (IP3)	dBm	24-70	55-72	58	50	70	>65
Actuation voltage	V	2.7-5.5	2-6	5	5	2.65-2.85	20-80
Switching speed	μs	0.004	<0.01	0.02-0.06	0.02	<0.01	2-10
Power consumption	μW	<10	<10	<100	<100	<1	$\sim 10^{-6}$
Power handling	dBm	42	38	36	33	45	38
Price	e	0.14	0.16	0.07	0.01-0.04	0.2	0.7

	MEMS	electronic Switching
Absorption	✓	✓
Isolation	✓	✓
Operating Voltage	X	✓
Switching Speed	X	✓
Life Circle	X	✓
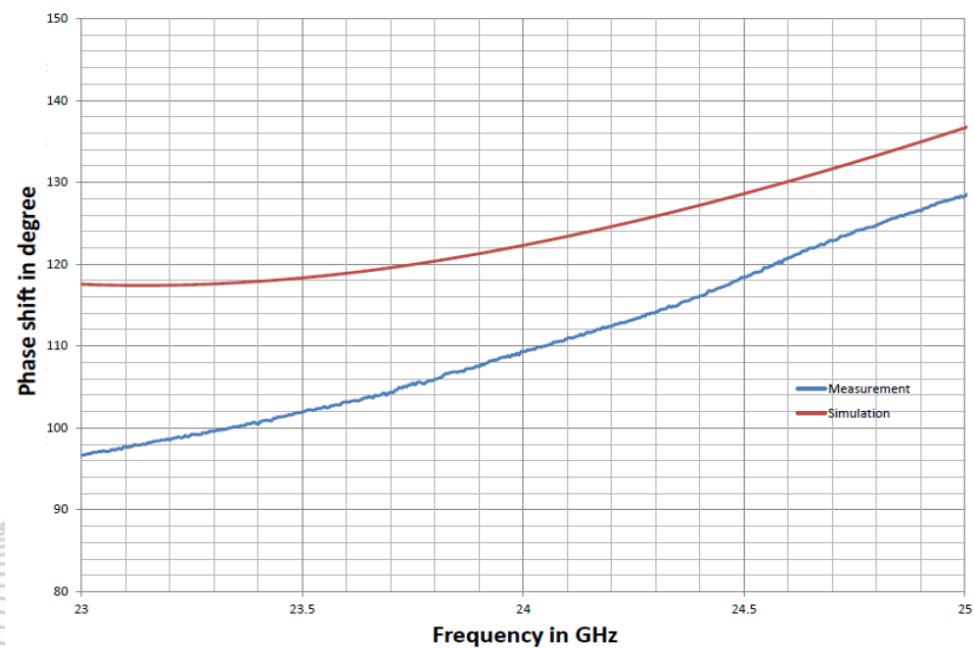
Switching Concepts

Phase shifters

MA200 Silicon FlipChip PIN Diode
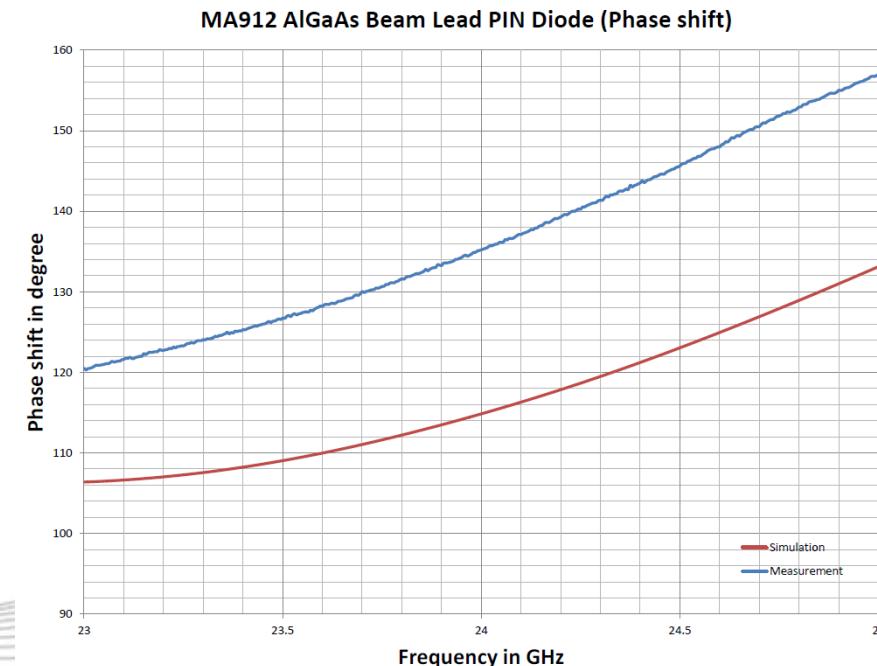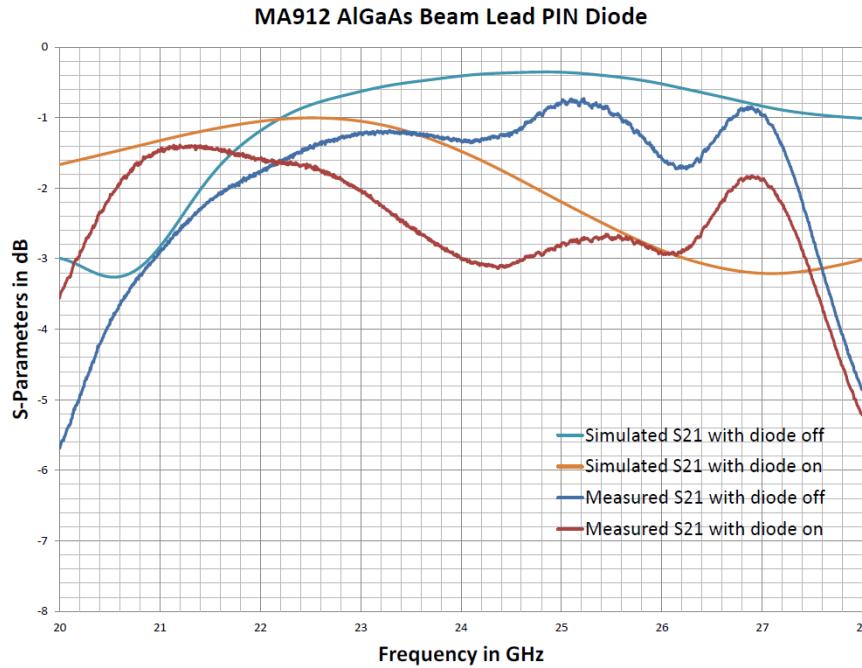
- Simulated S21 with diode on
- Simulated S21 with diode off
- Measured S21 with diode off
- Measured S21 with diode on

MA200 (Phase shift between diode on and off)

- Measurement
- Simulation

INGENIEURWISSENSCHAFTEN

Switching Concepts

Phase shifters

MA912 AlGaAs Beam Lead PIN Diode

MA912 AlGaAs Beam Lead PIN Diode (Phase shift)
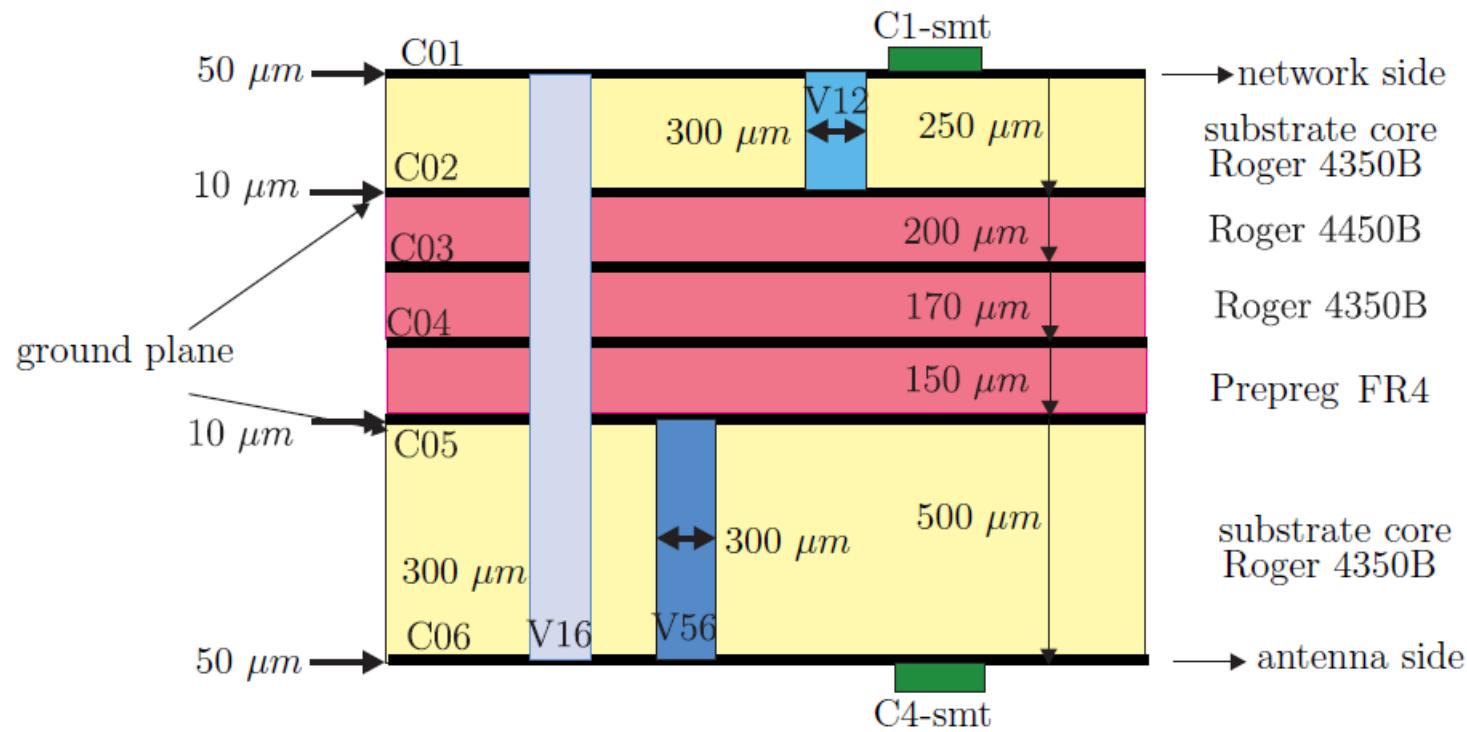
Final Design

# Network Concepts

Constrained Feeds

Series constraind feeds
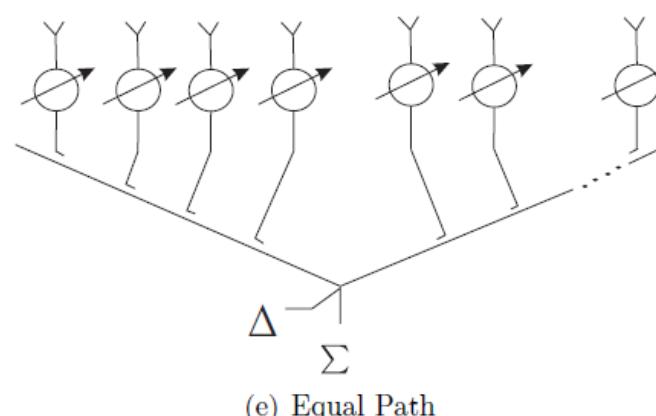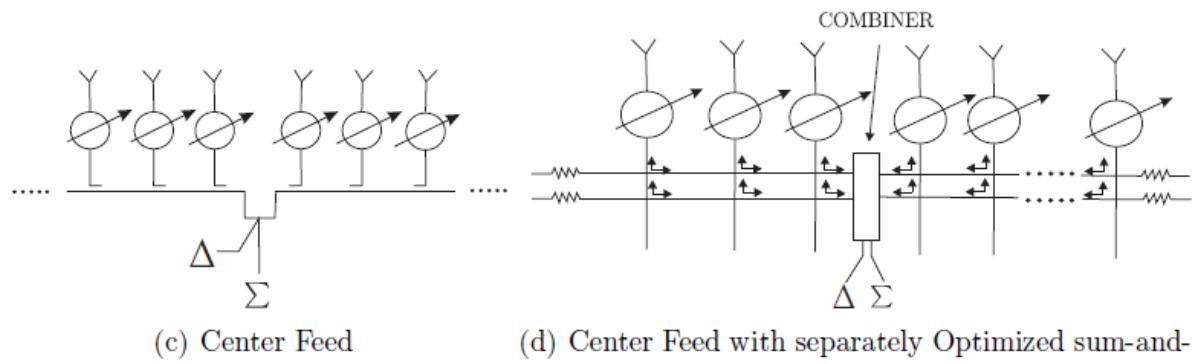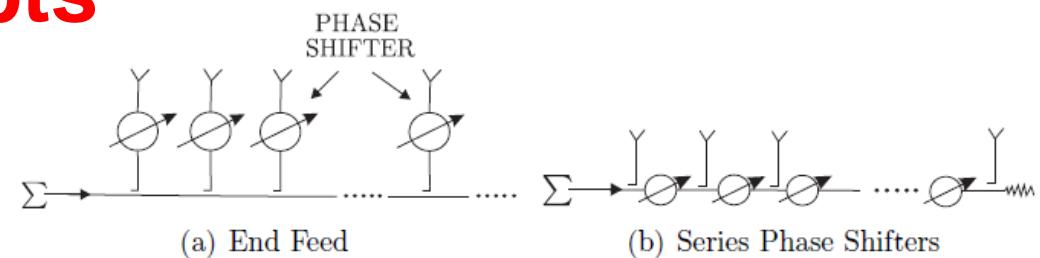
Figure 2.1: Series Feed [Skolnik (2008)]

Switching Concepts