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Phase-Controlled Beamforming Network for Continuous Beam-Steering in Conformal Arrays

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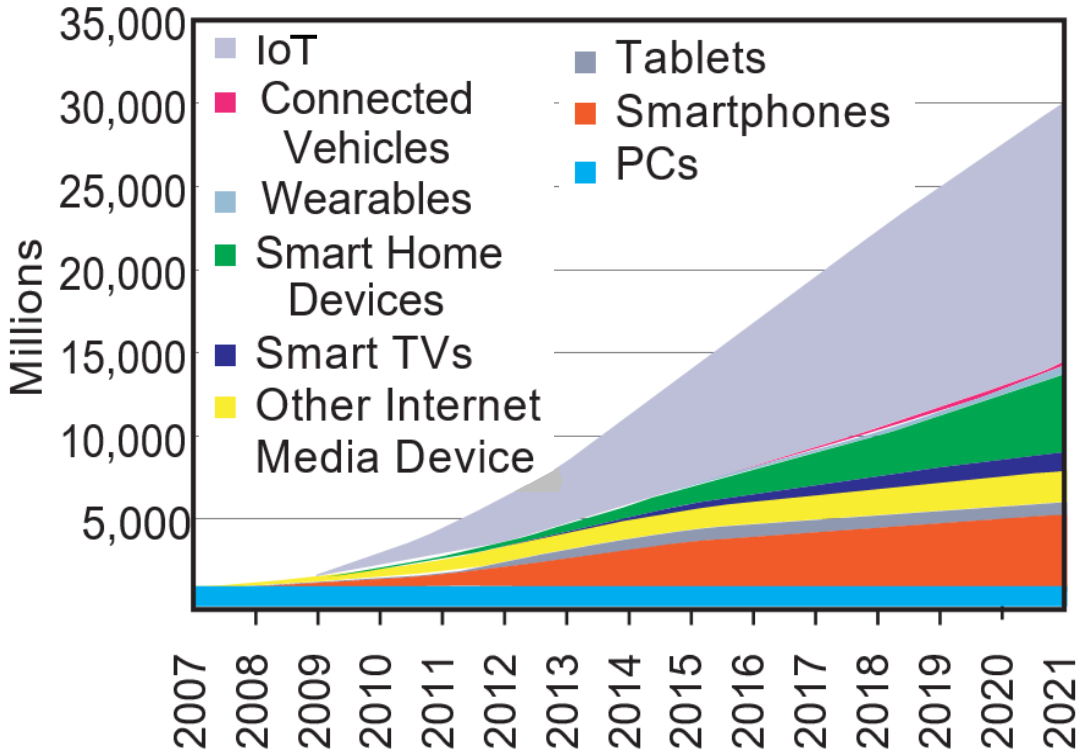
Motivations

It is expected that 30 billion devices will be connected to the Internet by 2021 [1]

Resources must be used efficiently to reduce the risks of resource shortage and interference

Need for directive antennas with **steerable beams**



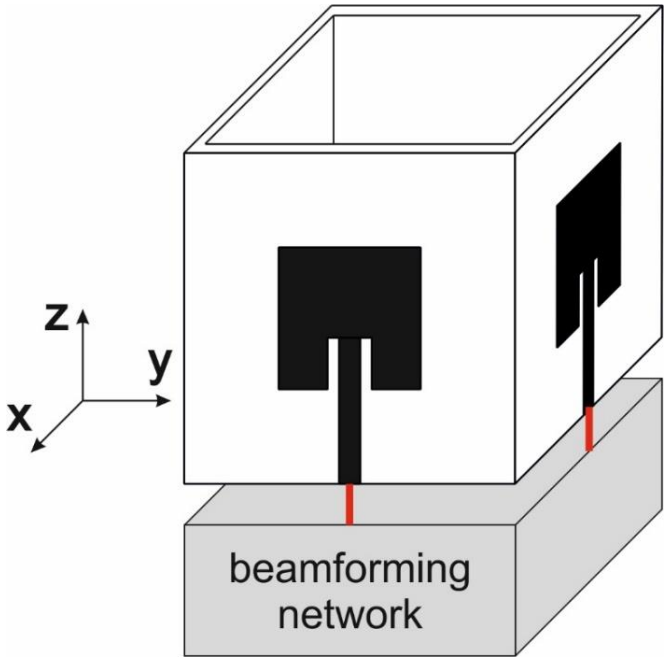
Source: Strategy Analytics Research Services, October 2017; IoT Strategies, Connected Home Devices, Table and Touchscreen Strategies, Wireless Smartphone Strategies, Wearable Device Ecosystem, Smart Home Strategies

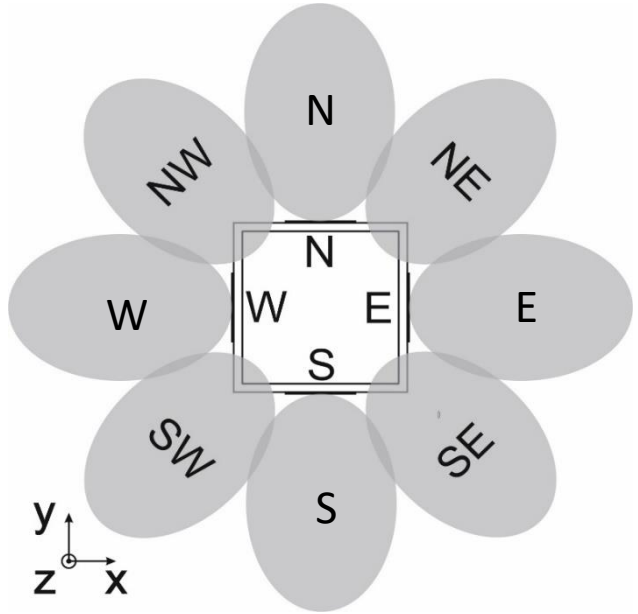
Conformal arrays

The radiation patterns of conformal antenna arrays can be modified using **reconfigurable power dividers**

Goal of the present work: realize continuous beam-steering in a four-element conformal array

Need for a network able to activate couples of adjacent output ports with arbitrary power ratios





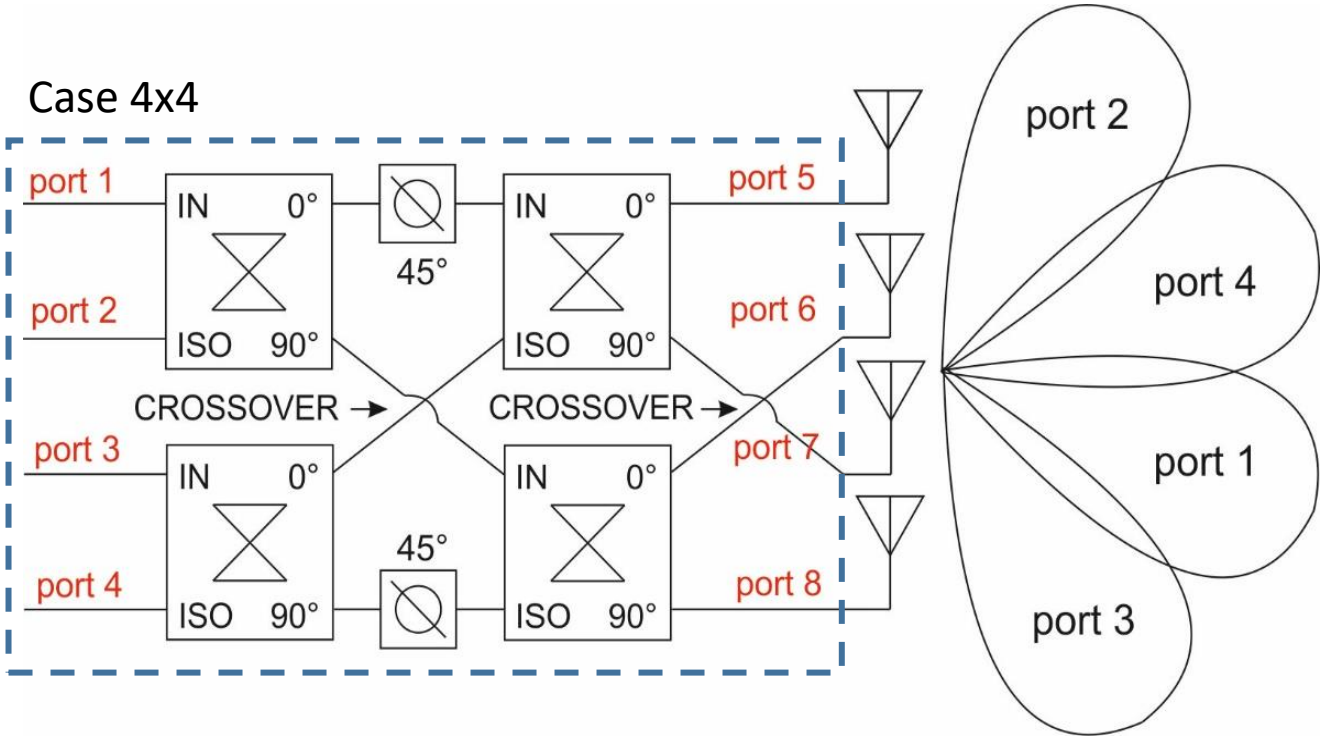
- N, S, W, E are generated by single antennas
- SW, NW, NE, SE corresponds to couples of adjacent antennas fed with equal power

Photo source: V. Palazzi, P. Mezzanotte and L. Roselli, "A Novel Agile Phase-Controlled Beamforming Network Intended for 360° Angular Scanning in MIMO Applications," *2018 IEEE/MTT-S International Microwave Symposium - IMS*, Philadelphia, PA, 2018, pp. 624-627.

Reverse Engineering on Butler Matrix

In a Butler matrix:

- All output ports activated with equal power
- Relative phase among output ports depends on the selected input port

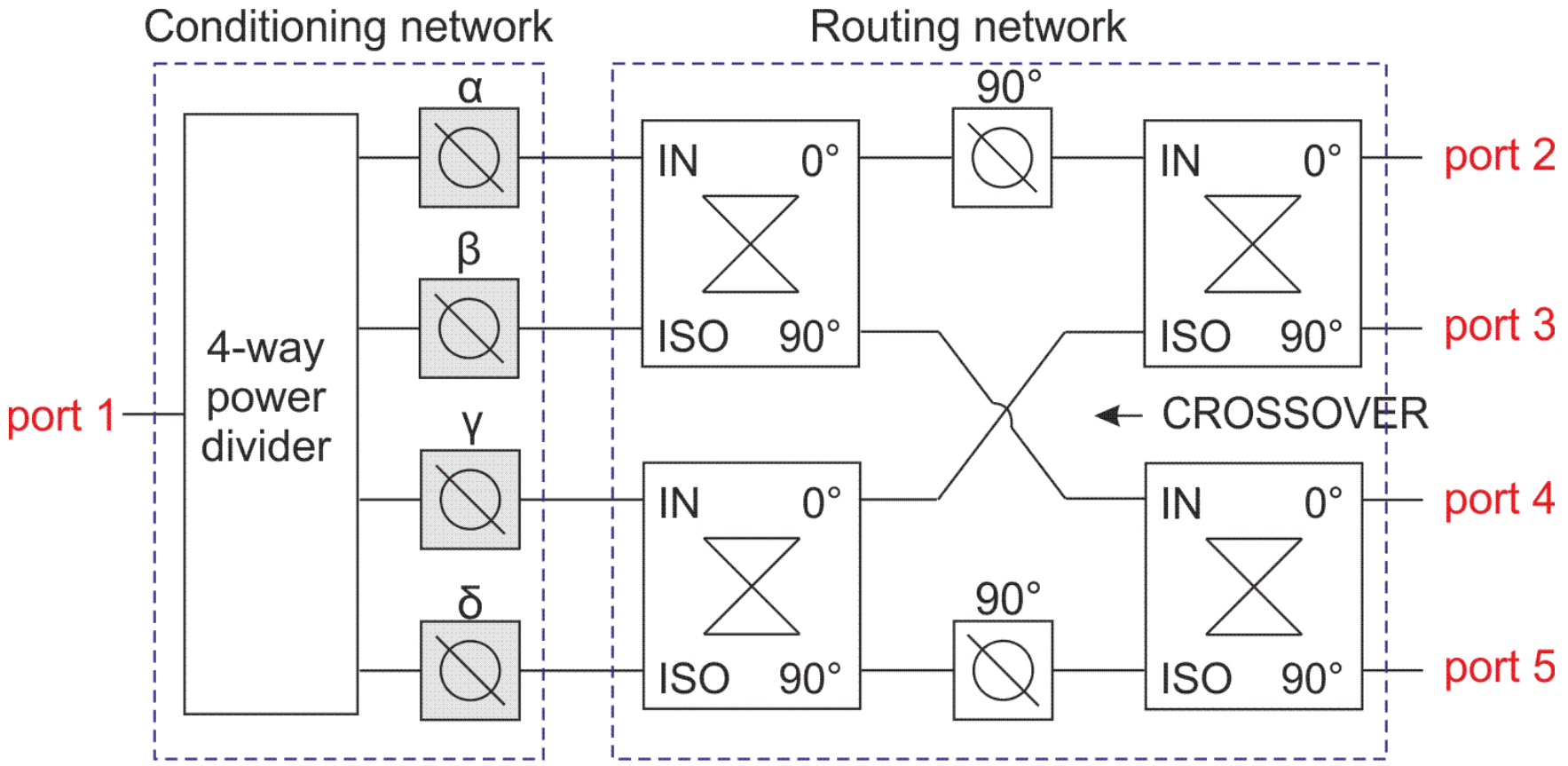


Activated input port y	$\angle S_{x,y} - \angle S_{(x+1),y}$ for x=5,…8
1	-45°
2	135°
3	-135°
4	45°

- Idea: the output ports can be logically exchanged with the input ports
- The input power is evenly divided among the input ports and specific phase differences are imposed among the input signals to activate selected output ports

Proposed 1 x 4 Feed Network

- One 4-way power divider
- **Four variable phase shifters**
- Two fixed 90° phase shifters
- Four 90° hybrid junctions



1 x 4 Feed Network: Theory

Under the assumptions:

- Lossless components
- Ports matched at 50 Ohms
- Ideal interconnections
- Hybrid junctions with infinite isolation

the S-parameters of the circuit can be expressed as follows:

$$[S] = \begin{bmatrix} 0 & S_{21} & S_{31} & S_{41} & S_{51} \\ S_{21} & 0 & 0 & 0 & 0 \\ S_{31} & 0 & 0 & 0 & 0 \\ S_{41} & 0 & 0 & 0 & 0 \\ S_{51} & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$S_{21} = \frac{1}{4}\left[-je^{-j\alpha} - e^{-j\beta} - je^{-j\gamma} - e^{-j\delta}\right]$$

$$S_{31} = \frac{1}{4}\left[-e^{-j\alpha} + je^{-j\beta} + e^{-j\gamma} - je^{-j\delta}\right]$$

$$S_{41} = \frac{1}{4}\left[-je^{-j\alpha} + e^{-j\beta} + je^{-j\gamma} - e^{-j\delta}\right]$$

$$S_{51} = \frac{1}{4}\left[-e^{-j\alpha} - je^{-j\beta} - e^{-j\gamma} - je^{-j\delta}\right]$$

1 x 4 Feed Network: Theory

We define the auxiliary variables x, y and z as follows:

$$x = \alpha - \beta$$
$$y = \gamma - \delta$$
$$z = \alpha - \gamma$$

The squared magnitude of the transmission coefficients are expressed as follows:

$$|S_{21}|^2 = \frac{1}{4} + \frac{1}{8}(a + b)$$
$$|S_{31}|^2 = \frac{1}{4} + \frac{1}{8}(a - b)$$
$$|S_{41}|^2 = \frac{1}{4} + \frac{1}{8}(-a + c)$$
$$|S_{51}|^2 = \frac{1}{4} + \frac{1}{8}(-a - c)$$

where

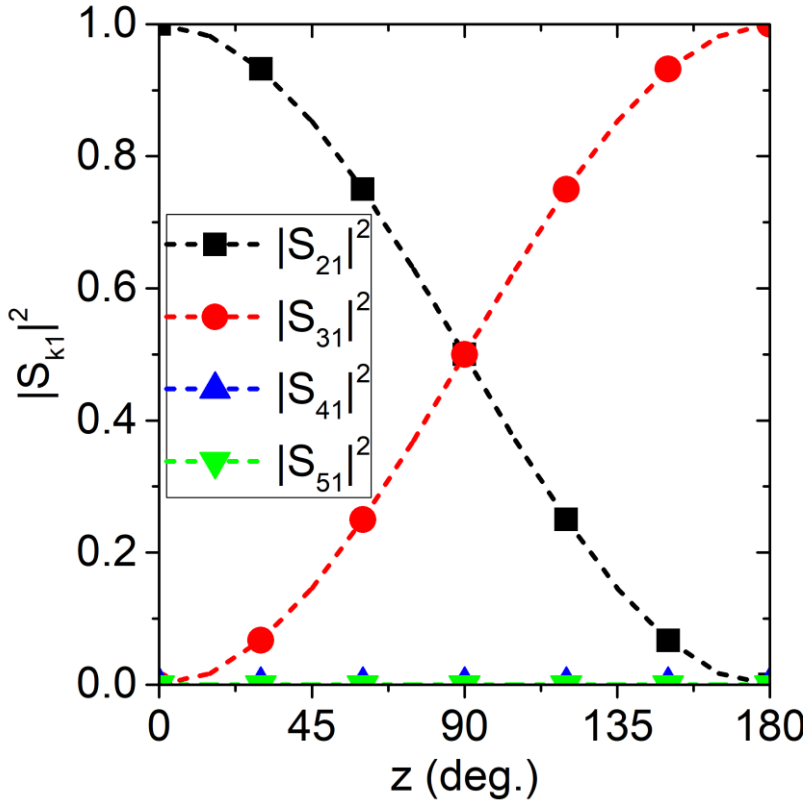
$$a = \sin(x) + \sin(y)$$
$$b = \cos(z) + \sin(z + y) - \sin(z - x) + \cos(z + y - x)$$
$$c = -\cos(z) + \sin(z + y) - \sin(z - x) - \cos(z + y - x)$$

1 x 4 Feed Network: Theory

The auxiliary variables must satisfy the following conditions:

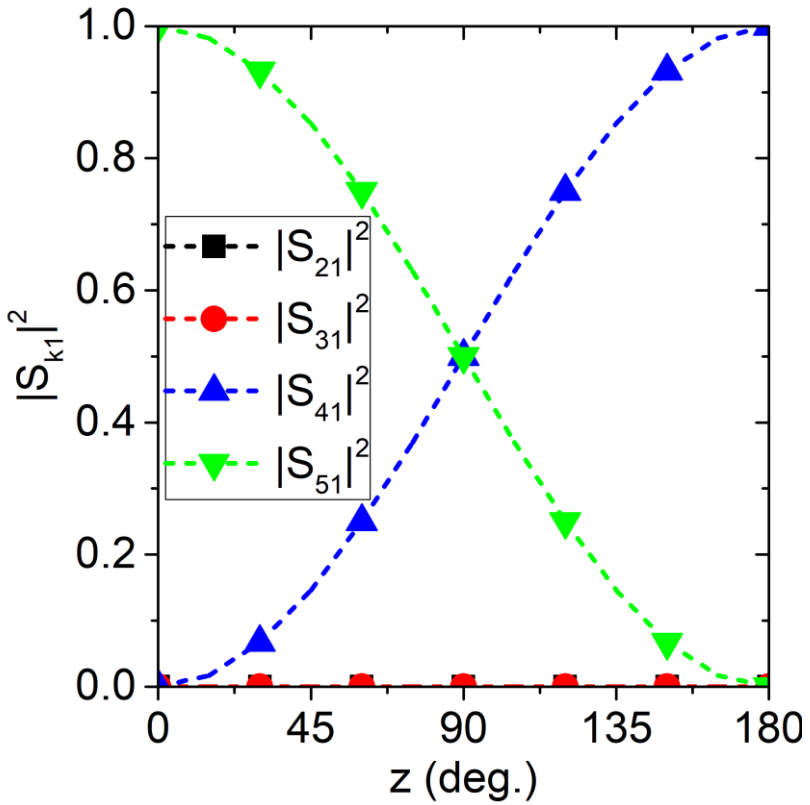
To activate ports 2 and 3

$$x = y = 90°$$
$$0° < z < 180°$$



To activate ports 4 and 5

$$x = y = 270°$$
$$0° < z < 180°$$



1 x 4 Feed Network: Theory

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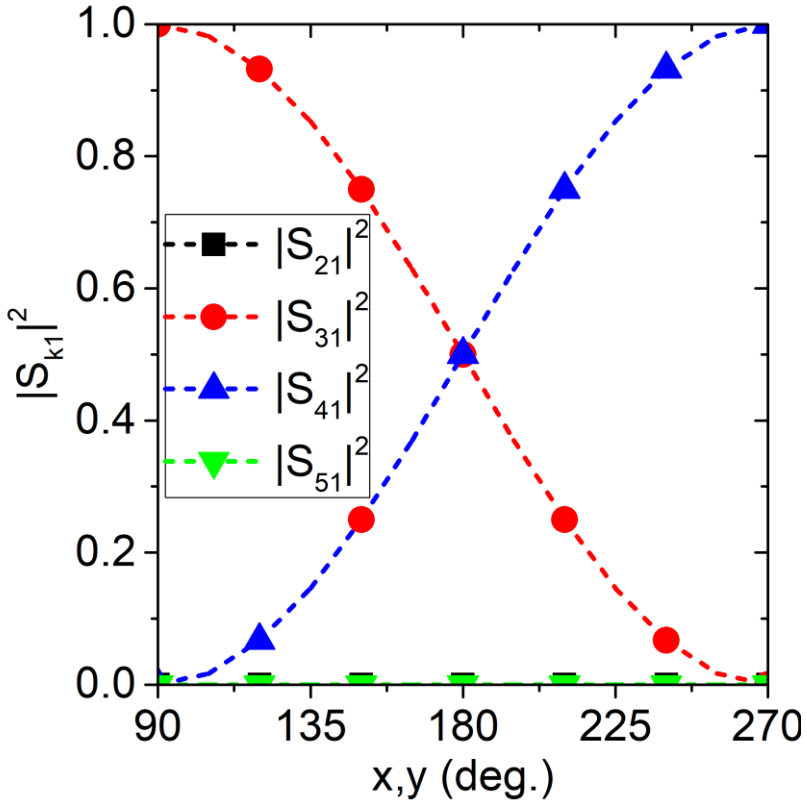
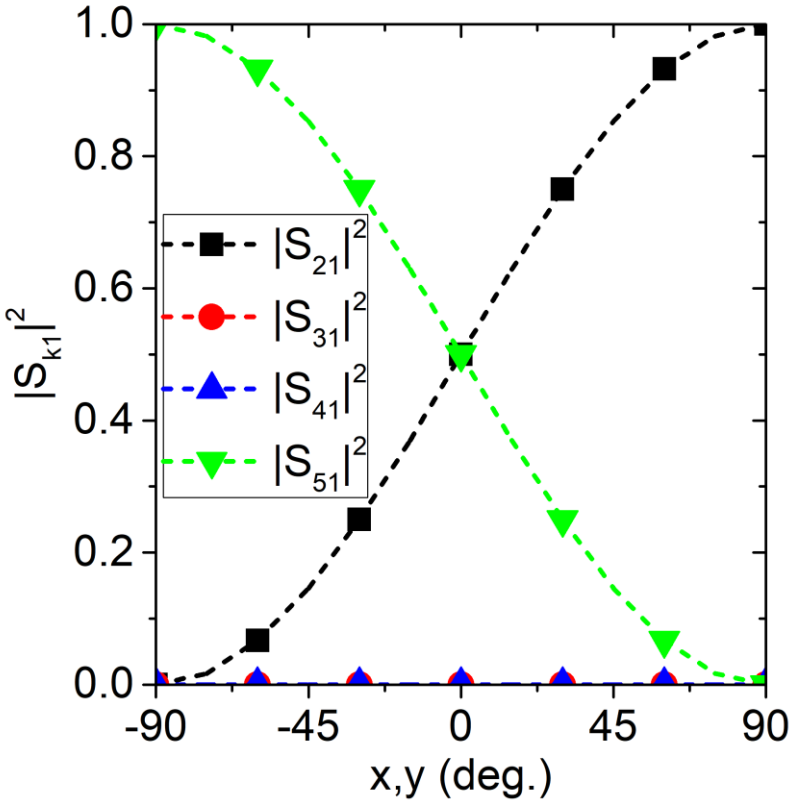


To activate ports 2 and 5

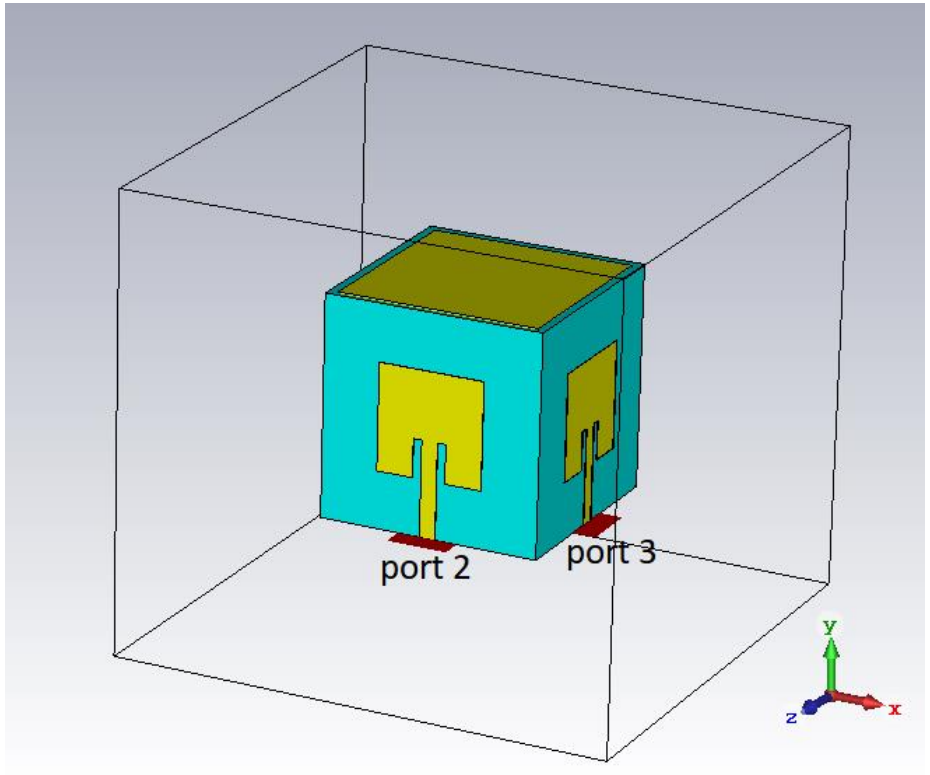
$$z = 0°$$
$$-90° < x = y < 90°$$



Proposed antenna system

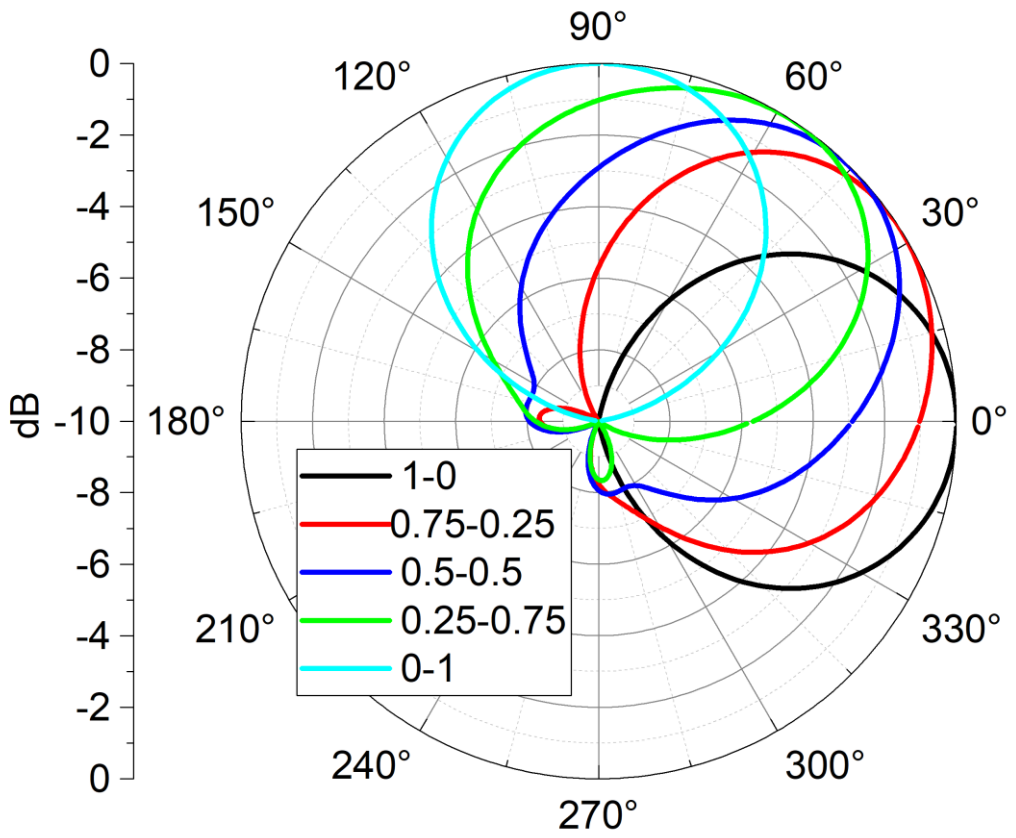
The proposed 1x4 feed network is designed to be connected to a conformal four-element antenna array:

- Four patch antennas on the lateral sides of a cube
- Full wave simulation (CST microwave suite)
- Ports 2 and 3 excited with different power ratios

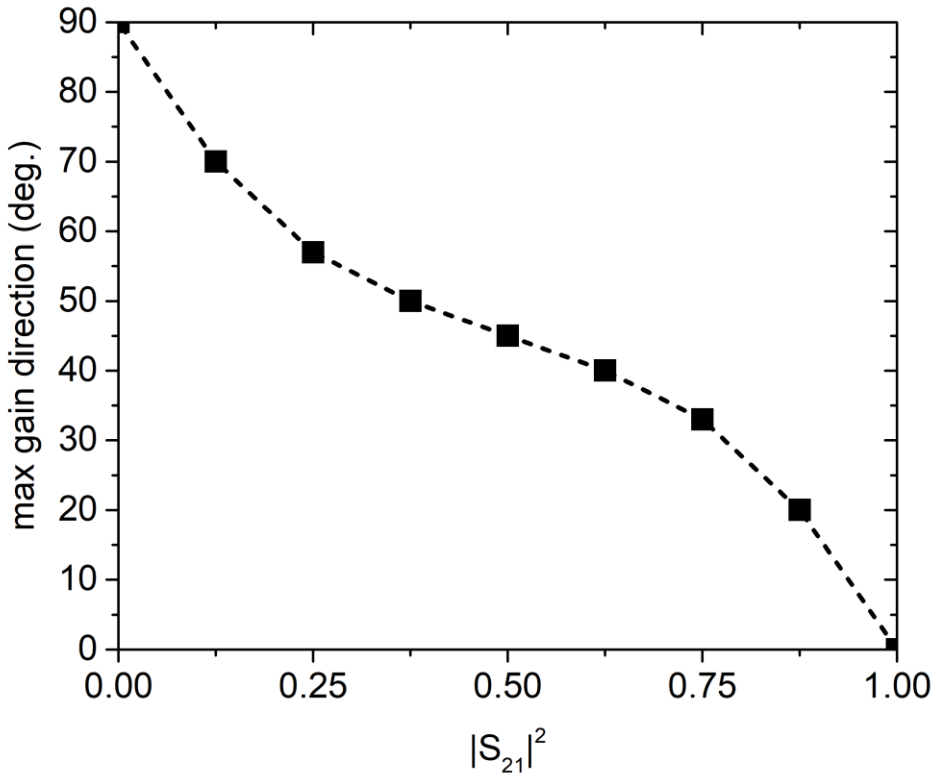


Proposed antenna system

H-plane radiation patterns for different power ratios



Direction of the maximum gain versus the power ratio between the activated ports



Warning! $|S_{21}|^2 + |S_{31}|^2 = 1$, therefore $|S_{31}|^2$ can be retrieved from $|S_{21}|^2$

Conclusions

A reconfigurable 14 feed network intended for conformal arrays has been presented.

The network proved to be able to activate couples of adjacent output ports with arbitrary power ratios, while keeping in-phase signals. Different power ratios are achieved only by changing the phase shift introduced by four variable phase shifters (i.e., α, β, γ, and δ), without needing any line switch.

The capability of such a network to perform beam-steering with conformal arrays has been investigated as well, and the angular dependence of the maximum gain on the power ratio between the two signals has been shown.

This way, a new class of feed networks is shown, which make it possible to modify the power ratios among the output ports without requiring any attenuator/amplifier or tangled switching networks, and are suitable for low-power beam-steering in conformal arrays.