Millimeter Wave MMIC Frequency Tunable Butler Matrix

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SPECTRUMX

BACKGROUND

A Butler matrix, a discrete multibeam beamforming network, uses couplers and phase shifters to produce different progressive phase shift at the output ports depending on which input is selected [1].

These designs are around 40 GHz which can be used for SATCOM and end user applications, i.e., 5G bands n259 (39.5-43.5 GHz), n260 (37-40 GHz), and MILSTAR satellites (44 GHz).

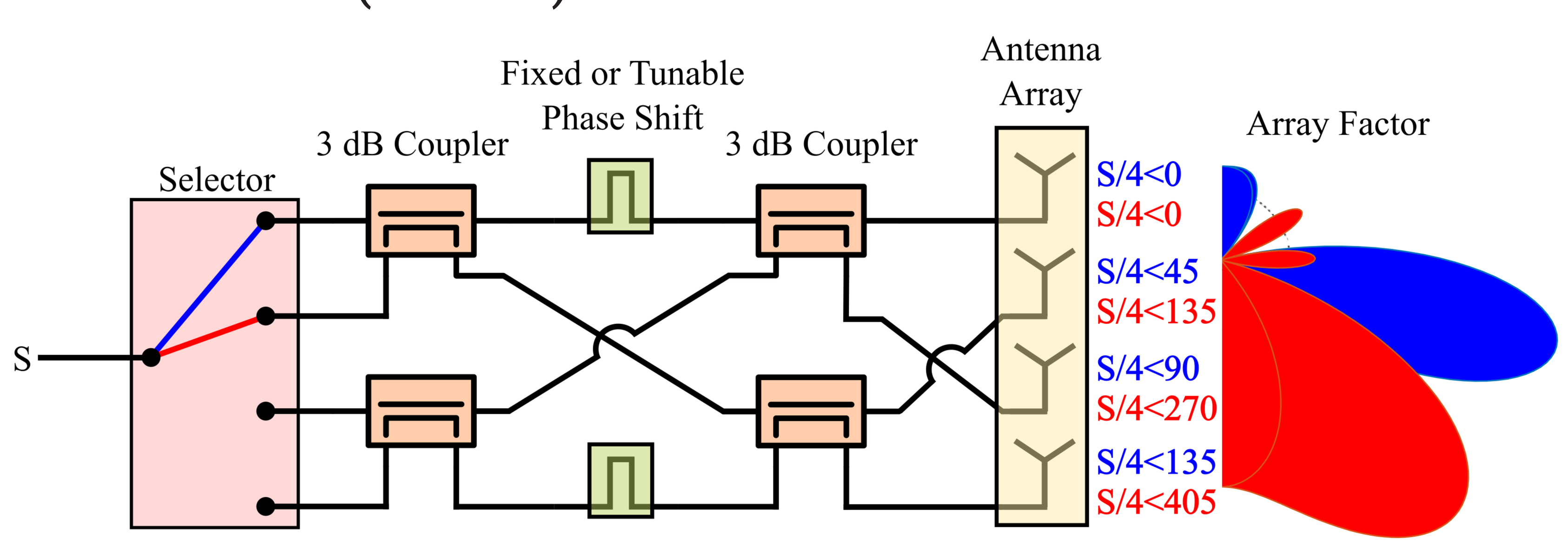


Fig. 1: Block diagram of a 4×4 Butler matrix, input selector, and antenna array. The outputs corresponding to two inputs are shown as well as the generated array factor.

RESEARCH OBJECTIVE

Design an on-chip low loss feed network that can be easily integrated with other actives of a millimeter wave front-end.

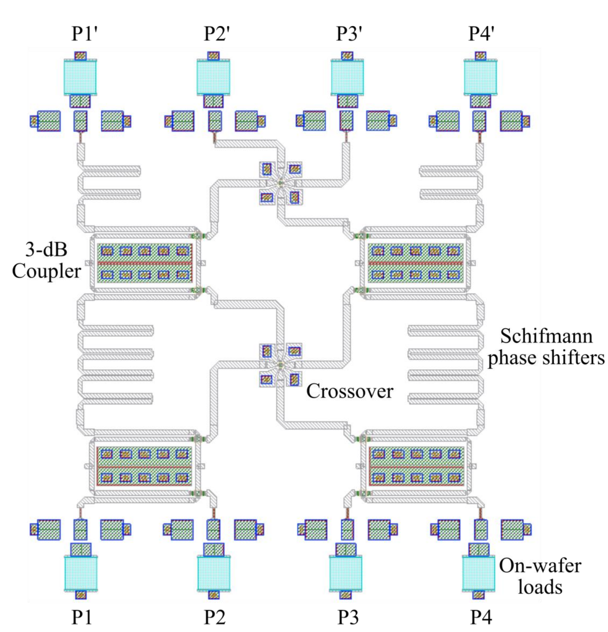
METHODS AND MATERIALS

- Designed in WIN Semiconductors' 2 mil PP10-20 process, with 0.1µm-gate depletion pHEMTs with f_t of 160GHz and 4V operation.
- This platform offers two interconnect metals with air bridge crossovers, precision thin film resistors, and MIM capacitors.
- Simulations done using Cadence AWR Microwave Office with foundry provided PDK models.

Results

Static Butler Matrix

- Centered at 44 GHz
- 2 GHz bandwidth



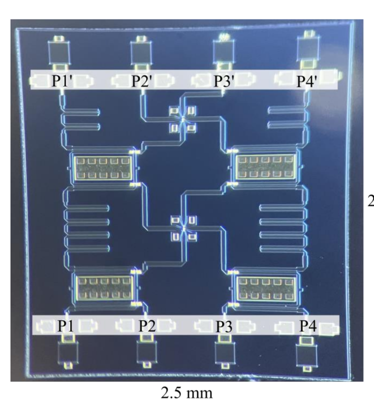


Fig. 2: Layout (left) and photograph (right) of the static Butler matrix.

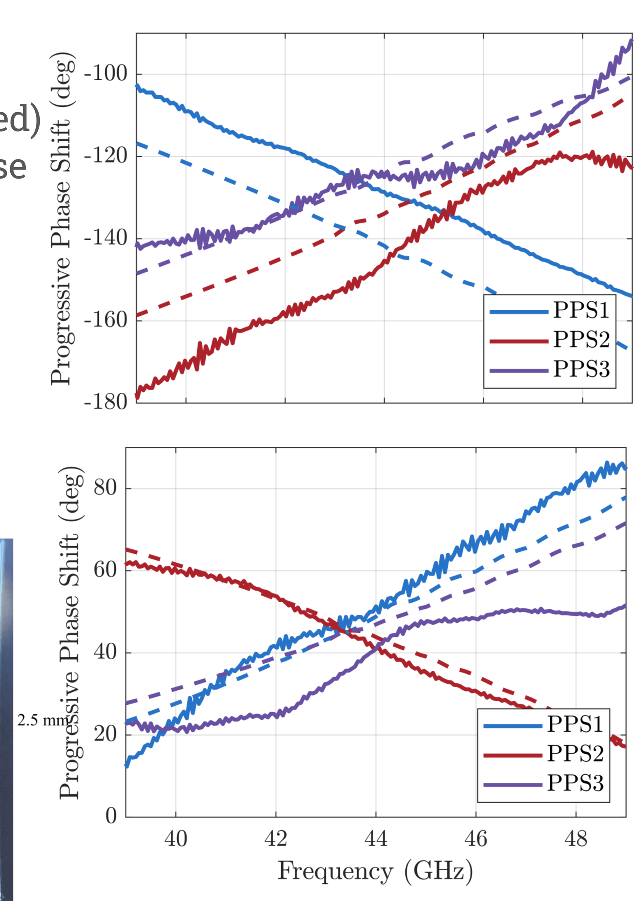
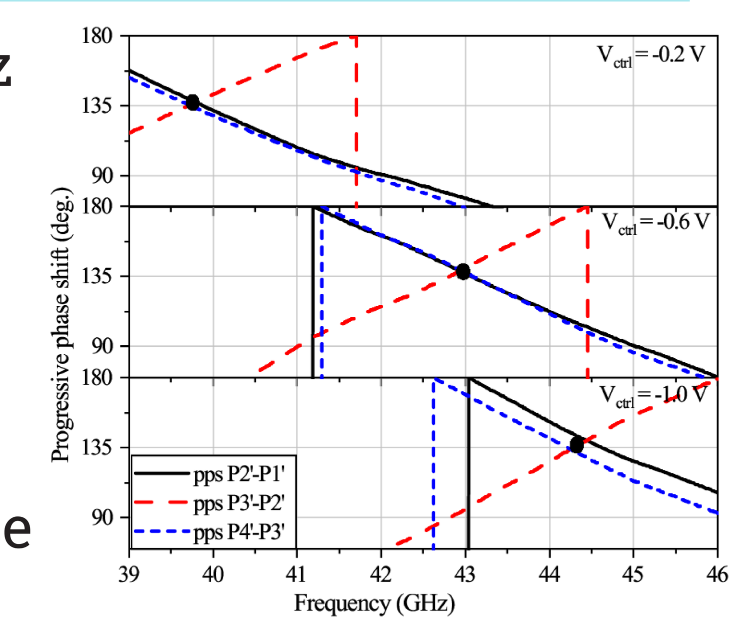
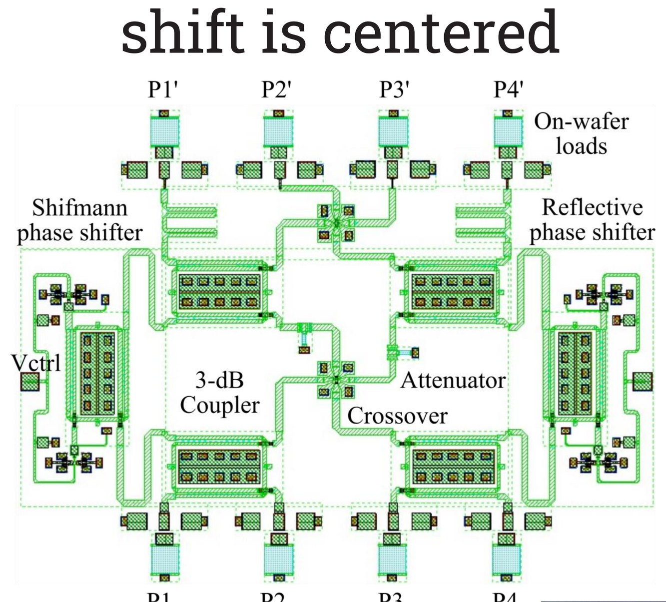


Fig. 3: Measured (solid) and simulated (dashed) progression phase shift (PPS) for exciting P1 (top) and P2 (bottom).

Tunable Butler Matrix

- Operates from 39.8-44.5 GHz
- Constant phase shifter in middle section is replaced by a reflective phase shifter
- One control voltage, V_{ctrl}, at both phase shifters tunes where the progression phase shift is centered





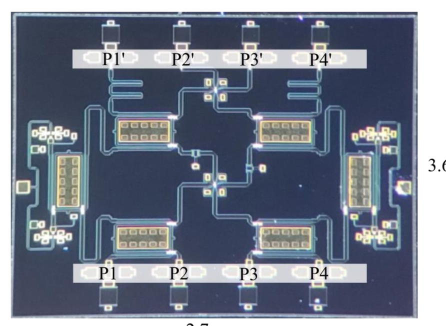


Fig. 4: Layout (left) and photograph (right) of the tunable Butler matrix.

Fig. 5: Simulated (top) and measured (bottom) progressive phase shift (PPS) for V_{ctrl} = -0.2 V(top), -0.6 V (middle), and -1.0 V (bottom when exciting P1.

CONCLUSION

These Butler matrices can be used to feed 4 element antennas with minimal deviation from the expected beam steering direction.

Performance is competitive compared to discrete chip phase shifters around 40 GHz.

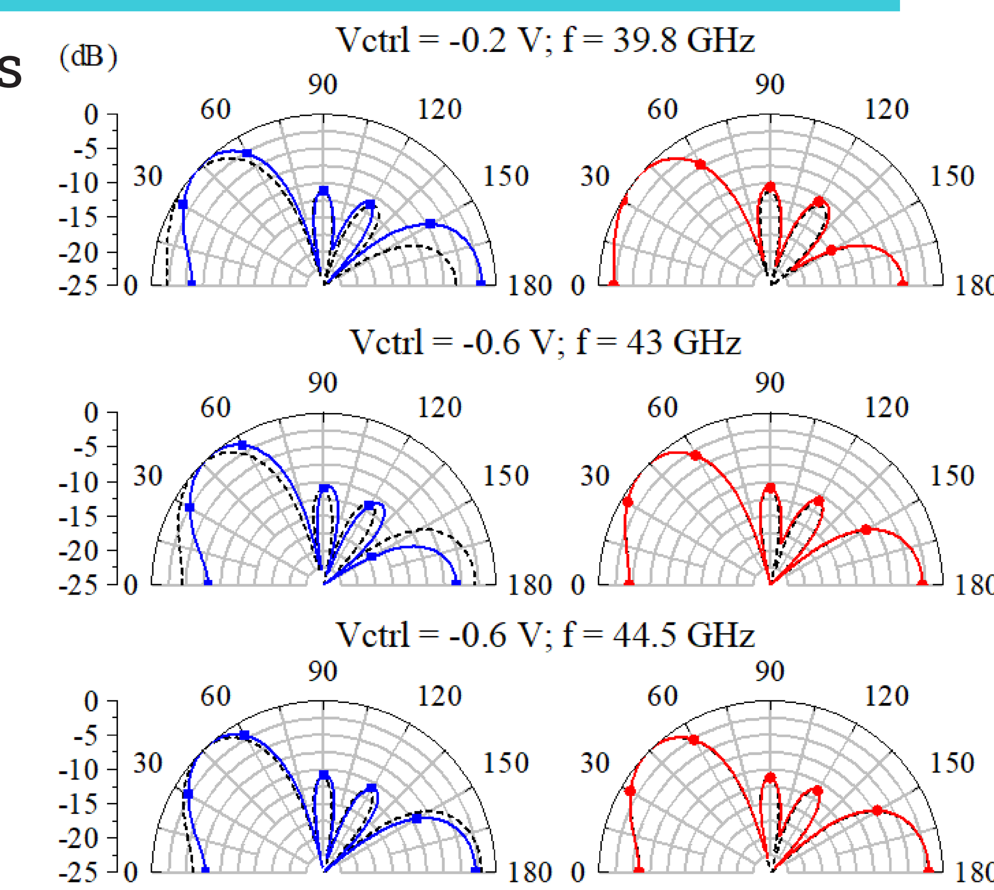


Fig. 6: Array patterns from the tunable Butler matrix using ideal phase progression (black), simulated (blue) and measured data (red) at different V_{ctrl}.

Table 1: Performance of Discrete Millimeter-Wave Phase Shifters

Ref.	Process	Freq. (GHz)	Phase Shift (°)	IL(dB)	Δ°	ΔA (dB)
[2]	CMOS	36-40	360	20.2	2.6	2.6
[3]	CMOS	37-40	360	9.3	8	0.6
[4]	CMOS	37-40	202	11	4.1	0.3
[5]	InGaAs	31-40	360	8.8	4.7	0.6
This	**InGaAs**	**43-45**	**405**	**2.4**	**19**	**0.6**
This	**InGaAs**	**39.8-44.5**	**405**	**5.2**	**5.6**	**1.7**

ACKNOWLEDGEMENTS

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