IDEC Chip Design Contest

13-15 GHz Passive Variable-Gain Switched Phase Shifter with X-Attenuator using 28-nm Bulk CMOS

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I. Introduction

- Driven by high-speed data demands, the Ku-band (13.75–14.6 GHz uplink) has become a key spectrum for SATCOM.
- In SATCOM phased arrays, phase shifters enable precise beam steering by dynamically controlling signal direction, allowing flexible link optimization in mobile or multi-beam scenarios.
- ✓ In this work, a Ku-band variable-gain phase shifter is implemented using an X-attenuator structure that enables 180° phase control and attenuation tuning, optimized for compact beam steering systems.

II. Circuit Design

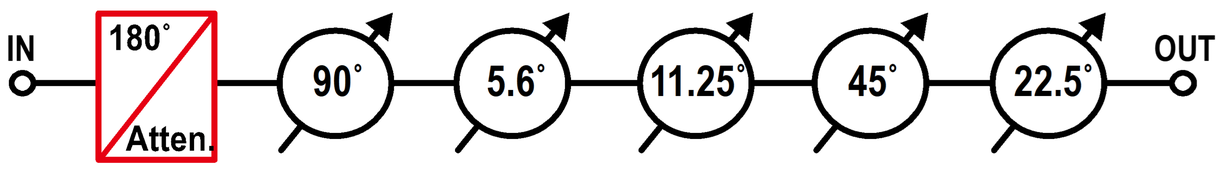

Fig. 1. Block Diagram of Variable-Gain Phase Shifter

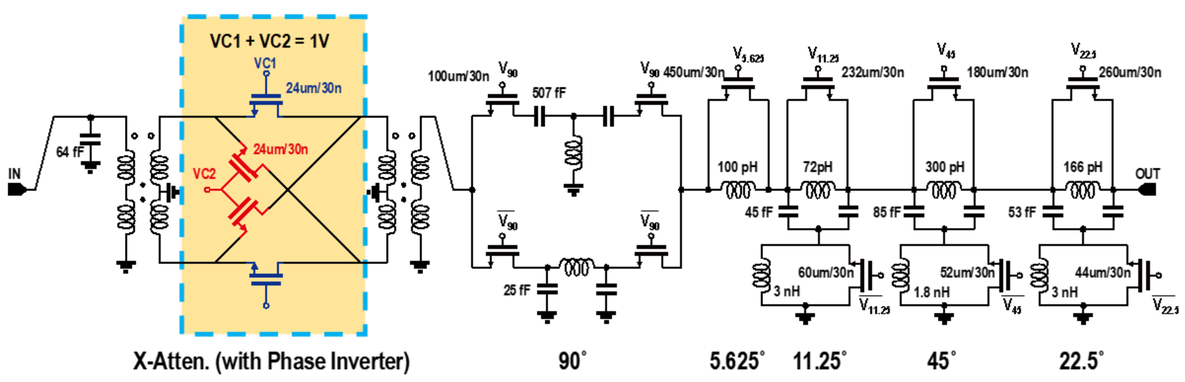

Fig. 2. Full Schematic of Variable-Gain Phase Shifter

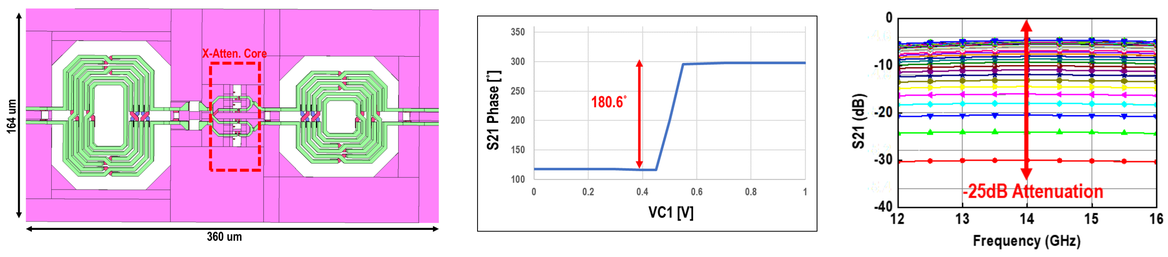

Fig. 3. Phase/gain response with voltage variation in the X-atten.

- Frequency: 13-15 GHz
- Topology: Passive Variable-Gain Switched Phase Shifter
- Applied Technique:
  - ✓ X-attenuator integrates a phase inverter, enabling a continuous 180° phase control range.
  - ✓ Gain tuning is achieved through a voltage-controlled passive attenuation path with high linearity.
  - ✓ A passive 5-bit switched-type phase shifter provides discrete phase control with no power consumption.
  - ✓ The 90° phase bit adopts a hybrid high-pass/low-pass filter design for wideband phase flatness.
  - ✓ Transistor sizes are optimized to balance insertion loss and phase slope sensitivity.
  - ✓ Top-layer metal (M9) is utilized in inductors and transmission lines to minimize parasitic loss.

III. Simulation Result

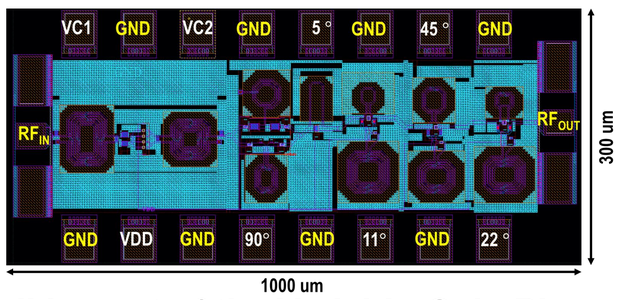

Fig. 4. Full Layout of the Variable-Gain Phase Shifter

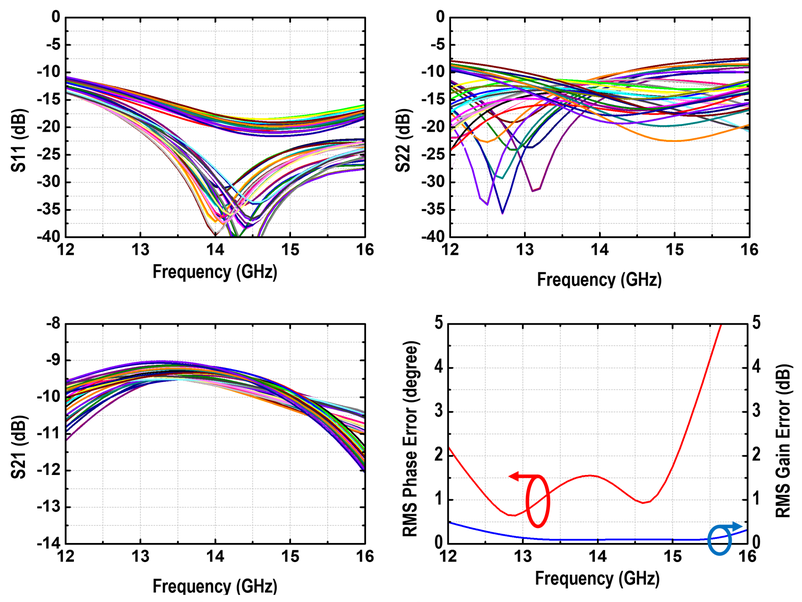

Fig. 5. S-parameter Simulated results

- Simulation Result:
  - ✓ Frequency: 13-15 GHz
  - ✓ Phase Resolution: 0~360° (LSB=5.625°)
  - ✓ Attenuation Range: 25 dB

IV. Conclusion

Ref.	This Work (Sim.)	[1] IMS'24	[2] ICMMT'19	[3] ACCESS'22
Process	28-nm CMOS	0.13-um SiGe	0.13-um CMOS	65-nm CMOS
Technique	X-atten. with STPS	STPS+ RTPS	High Pass / Low Pass	Low Pass LC
Freq. (GHz)	13 - 15	14 - 15	8.5 – 10.5	5-11
RL (dB)	> 9	> 8.4	> 13	> 10
IL (dB)	9.08 – 10.8	4.3 - 8.1	14	< 41
RMS PE (°)	0.7 – 1.75	< 12	4	< 5.2
RMS GE (dB)	0.17 - 0.27	< 1.1	0.4	-
Power (mW)	0	0	0	0
Core Area (mm^2)	0.3	0.17	3.52	2.46

The proposed variable-gain PS was designed using a 28-nm Bulk CMOS process. The PS demonstrates superior performance compared to other literature in the field.

[1] S. Kim, K. W. Choi, B. Yoon, J. Kim and I. Ju, "Compact, Low Loss 4-Bit Ku-Band Hybrid Passive Phase Shifter Realized in 0.13-μm SiGe HBT BiCMOS for LEO SATCOM," 2024 IEEE/MTT-S International Microwave Symposium - IMS 2024, Washington, DC, USA, 2024, pp. 760-763.
[2] S. Wu and D. Pang, "A 6-bit CMOS Passive Phase Shifter for X-Band Phased Arrays," 2019 International Conference on Microwave and Millimeter Wave Technology (ICMMT), Guangzhou, China, 2019.
[3] J. -M. Song and J. -D. Park, "A 5–11 GHz 8-bit Precision Passive True-Time Delay in 65-nm CMOS Technology," in IEEE Access, vol. 10, pp. 18456-18462, 2022.

Acknowledgement

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