Ka-Band RF MEMS Phase Shifters for Energy Starved Millimetre-Wave Radar Sensors

R. Malmqvist[1,2], C. Samuelsson[1], B. Carlegrim[1], Rantakari[3], T. Vähä-Heikkilä[3], A. Rydberg[2] and J. Varis[3]

[1]FOI, Swedish Defence Research Agency, Linköping, Sweden
[2]Uppsala University, Uppsala University, Sweden
[3]VTT, Technical research centre of Finland, Espoo, Finland

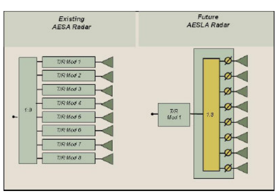
2010 Int. Semiconductor Conference (CAS2010), Sinaia, Romania, Oct. 11-13, 2010

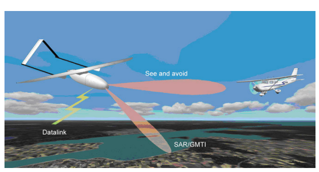
November 18, 2010

Outline

- **Introduction**
  - Background, target application (low-power multifunctional radar sensor)
- **Ka-band RF MEMS phase shifters made on quartz**
  - Loaded line and switched line phase shifter circuits
- **System level impact of using low-loss RF MEMS phase shifters**
  - Phased array front-end architectures (AESA/PESA)
- **Conclusion**
  - Summary

Energy starved mm-wave radar sensors

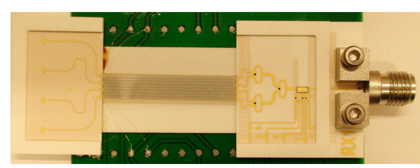




- Increasingly important to achieve low cost, size, weight and DC power for the radar hardware on small sensor platforms such as UAVs. The passive electronically scanned array (PESA) antenna architecture may for certain applications result in compact, power-efficient and affordable systems
- Compared with using COTS, a use of multi-bit phase shifters realised using RF MEMS technology could result in significantly improved RF properties at microwave/millimetre-wave frequencies

RF MEMS phased arrays (MOSART project)

- MEMS based reconfigurable RF systems for software radio, wireless sensors, and MMID technology (MOSART project)
- Funded and supported within the NORDITE program (Sweden, Finland, Norway)
- Adaptive RF front-ends (incl. low-loss phased arrays) using RF MEMS and LTCC based technologies
- Project time: 2008-2010

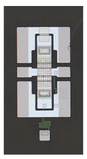


- Prototypes of 35 GHz active phased array modules (PESA front-end architecture using low-loss RF MEMS phase shifters, LNA together with antennas and feed networks made on LTCC) have been realised within the MOSART project carried out by the research partners VTT, Uppsala University and FOI
- An RF MEMS loaded line phase shifter circuit with 3.5 dB of average loss @ 35 GHz were used (VTT design)
- Various phase shifter circuits implemented on quartz using a capacitive RF MEMS switch process at VTT

RF MEMS phase shifter (quartz)

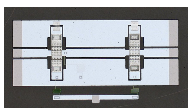
35 GHz loaded line phase shifters (22.5° and 45° bits)

1-switch phase shifter (22.5° bit)

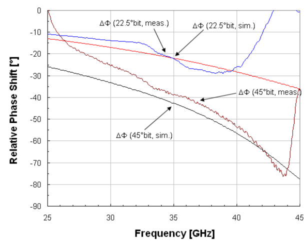


0.3 mm²

2-switch phase shifter (45° bit)



1.3 mm²

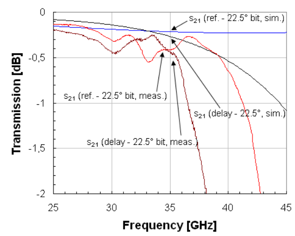


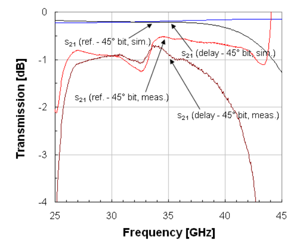
- 1-switch phase shifter circuit ➡ a relative phase shift of 22° @ 35 GHz (22° simulated)
- 2-switch phase shifter circuit ➡ a relative phase shift of 38° @ 35 GHz (45° simulated)

R. Malmqvist
FOI Swedish Defence Research Agency

RF MEMS phase shifter (quartz)

35 GHz loaded line phase shifters (22.5° and 45° bits)





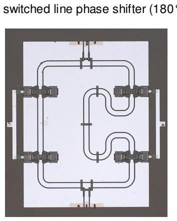
- 1-switch phase shifter circuit (22.5° bit) ➡ 0.4 dB of insertion loss @ 35 GHz (0.2-0.3 dB simulated)
- 2-switch phase shifter circuit (45° bit) ➡ 0.5-0.9 dB of insertion losses @ 35 GHz (0.4-0.7 dB sim.)

R. Malmqvist
FOI Swedish Defence Research Agency

RF MEMS phase shifter (quartz)

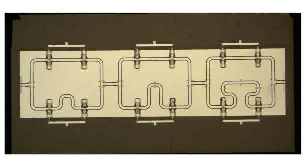
35 GHz switched line phase shifters (180° bit and 3-bit)

1-bit switched line phase shifter (180° bit)



9 mm²

3-bit switched line phase shifter (45° + 90° + 180°)



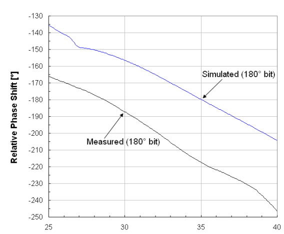
28 mm²

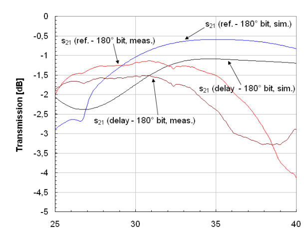
- 1-bit and 3-bit RF MEMS phase shifter circuits implemented using switched line (SL) topologies
- SL phase shifter functionality will depend on that all the RF MEMS switches used are functioning as intended

R. Malmqvist
FOI Swedish Defence Research Agency

RF MEMS phase shifter (quartz)

35 GHz switched line phase shifter (180° bit)





- 1.2-1.5 dB of insertion loss and 187° dB of relative phase shift @ 30 GHz ➡ FoM = 122°/dB
- Discrepancies may be explained by a higher capacitive loading for the air bridges used in this design

R. Malmqvist
FOI Swedish Defence Research Agency

RF MEMS phase shifters results

Measured and estimated data (summary)

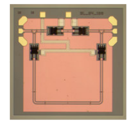
Phase shifter - state	Loss (22° bit)	Loss (45° bit)	Loss (180° bit)	Loss (3-bit)	Loss (5-bit)
Min (ref.)	0.4 dB @ 35 GHz (0.2 dB sim.)	0.5 dB @ 35 GHz (0.4 dB sim.)	1.2 dB @ 30 GHz (0.6 dB sim.)	2.1 (est.)	3.5 (est.)
Max (delay)	0.4 dB @ 35 GHz (0.3 dB sim.)	0.9 dB @ 35 GHz (0.7 dB sim.)	1.5 dB @ 30 GHz (1.1 dB sim.)	2.8 (est.)	4.5 (est.)
Average	0.4 dB @ 35 GHz (0.3 dB sim.)	0.7 dB @ 35 GHz (0.6 dB sim.)	1.4 dB @ 30 GHz (0.9 dB sim.)	2.5 (est.)	4.0 (est.)

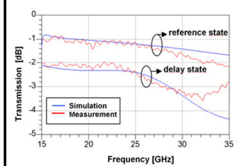
- Phase shifter bits (22.5°, 45° and 180°) realized with 0.4 dB, 0.7 dB and 1.4 dB of average losses, respectively
- 3-bit and 5-bit MEMS phase shifter circuits are estimated with average losses of 2.5 dB and 4 dB, respectively

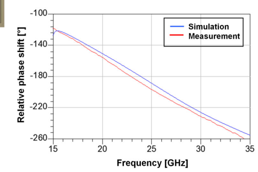
R. Malmqvist
FOI Swedish Defence Research Agency

RF MEMS phase shifter (GaAs MMIC)

24 GHz (1-bit) switched-line phase shifter (180°)


3 mm²



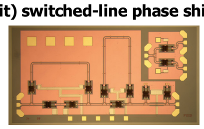


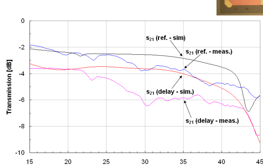
- 1.2-2.3 dB of insertion loss (1.8 dB average) and 180° dB of relative phase shift @ 23 GHz
- A relatively good agreement was found in this case between measured and simulated results

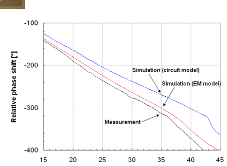
R. Malmqvist
FOI Swedish Defence Research Agency

RF MEMS phase shifter (GaAs MMIC)

35 GHz (3-bit) switched-line phase shifter (315°)


7 mm²



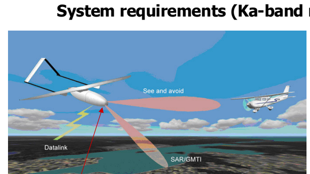


- 3.7-5.8 dB of insertion loss (for the 000 and 110 states) and 270° dB of relative phase shift @ 29.5 GHz
- A μ-strip based MEMS-MMIC 3-bit phase shifter design has 3 dB of simulated average loss @ 35 GHz

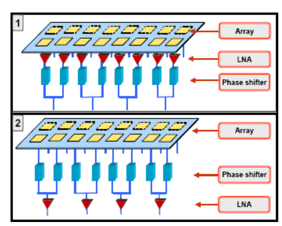
R. Malmqvist
FOI Swedish Defence Research Agency

Impact of using RF MEMS phase shifters

System requirements (Ka-band multifunctional radar system)




Ku-band conformal array antenna aperture developed at FOI
(L. Pettersson et al., *5th Europ. Workshop on Conformal Antennas*, Bristol, UK, Sept. 2007)

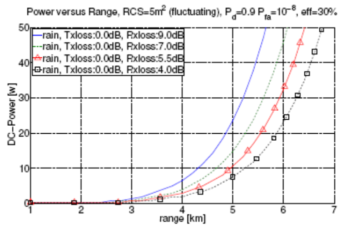


- Conformal antennas may be integrated in the fuselage of a small sensor platform such as e.g. an UAV
- Critical aspects w.r.t. feasible sensor hardware cost, weight and DC power (max 50 W for the radar: RF & Dig.)
- A use of a PESA front-end architecture on the Rx side (e.g. 1:8) can drastically reduce the no. LNAs needed

R. Malmqvist
FOI Swedish Defence Research Agency

Impact of using RF MEMS phase shifters

System analysis (See-and-Avoid Radar)



- Estimated required P_{dc} (Tx) for a See-and-Avoid (PESA Rx) phased array radar sensor in heavy rain when assuming different phase shifter losses (assuming also 2 dB of feed network losses) – 5.5 km of $R_{detection}$

- Low phase shifter losses (2-4 dB) needed for all-weather radar capability (max 20-25 W of P_{dc})

R. Malmqvist
FOI Swedish Defence Research Agency

Impact of using RF MEMS phase shifters

System analysis (Synthetic Aperture Radar)

Phase shifter loss (@ Ka-band) (Technology)	DC power consumption (P_{DC}) - Tx
7 dB (5 bit) (COTS) [11]	33 W
4 dB (5 bit) (Estimated) [17]	17 W
2 dB (3 bit) (RF MEMS) [10]	10 W

- Estimated values of required P_{dc} (Tx) for a Ka-band multifunctional SAR sensor (using a PESA Rx front-end)

- Low-loss MEMS phase shifters may reduce P_{dc} (Tx) with a factor 2-3 (compared with using COTS)

R. Malmqvist
FOI Swedish Defence Research Agency

Conclusions

- We have presented an assessment study of fabricated millimetre-wave RF MEMS phase shifters for a Ka-band low-power (energy starved) multifunctional radar sensor application

- Two loaded line phase shifter bits result in a phase shift of 22.3° and 38° together with 0.4 dB and 0.9 dB of losses @ 35 GHz, respectively. A switched line phase shifter achieve 187° of phase shift and 1.5 dB of loss @ 30 GHz (corresponding to FoM = 122°/dB)

- The realised RF MEMS phase shifter circuits may be used to implement low-loss multi-bit (e.g. 3-bit and 5-bit) phase shifters for certain mm-wave applications

- We estimate that a use of such high performance RF MEMS phase shifters can reduce by a factor 2-3 the required transmit DC power level in a Ka-band phased array radar system

R. Malmqvist
FOI Swedish Defence Research Agency

Acknowledgements

- VINNOVA and TEKES (in Sweden and Finland, respectively) for the funding and continuous support of the NORDITE project MOSART

- European Union for the funding and continuous support of the FP7 ICT project MEMS-4-MMIC

- The work was carried out in the framework of COST Action IC0803 - RF/Microwave Communication Subsystems for Emerging Wireless Technologies

R. Malmqvist
FOI Swedish Defence Research Agency