TECHNISCHE UNIVERSITÄT DARMSTADT

TH2H-6

Fully Printed Tunable Phase Shifter for L/S-Band Phased Array Application

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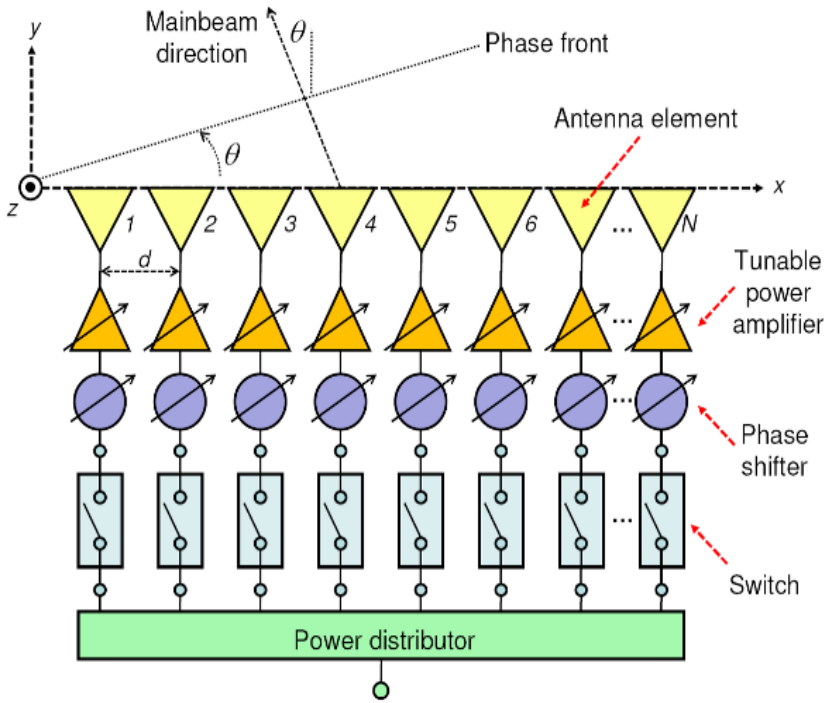
Outline

- Motivation
- Development of Low Temperature Sintered BST Thick-films
- MIM Varactor Fabrication and Measurement
- Phase Shifter Design and Simulation
- Phase Shifter Fabrication And Measurement
- Conclusion
- Outlook

Motivation

- Multi frequency functionality:
  - Tunable phase shifters
  - Tunable antennas
  - Tunable filters

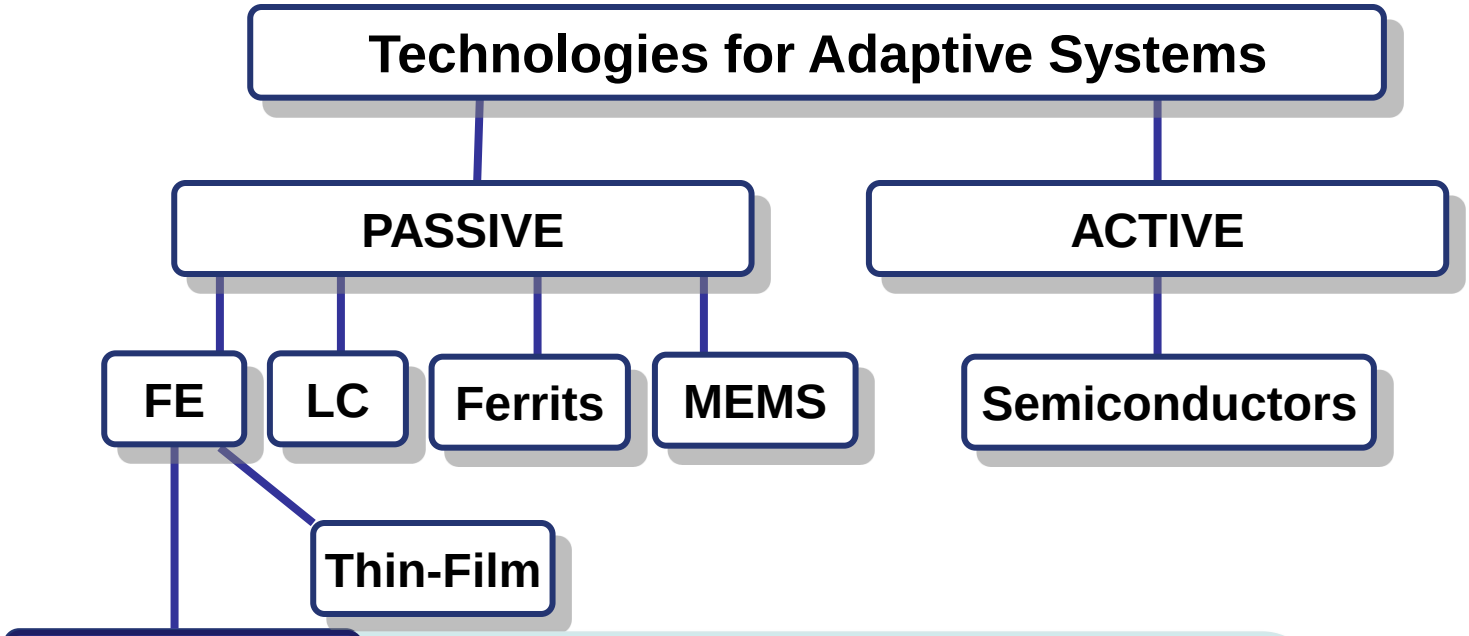


- A tunable component can reduce
  - Size
  - Complexity
  - power consumption

- The functional components in a tunable circuit are tunable varactors

Motivation

Why BST Thick-Film?



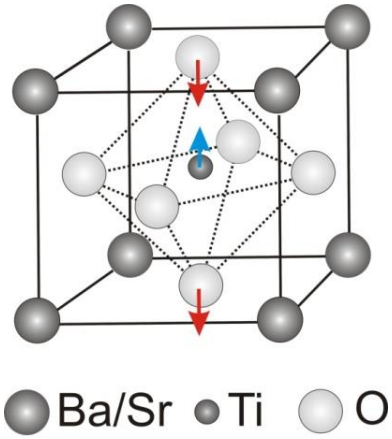
Motivation

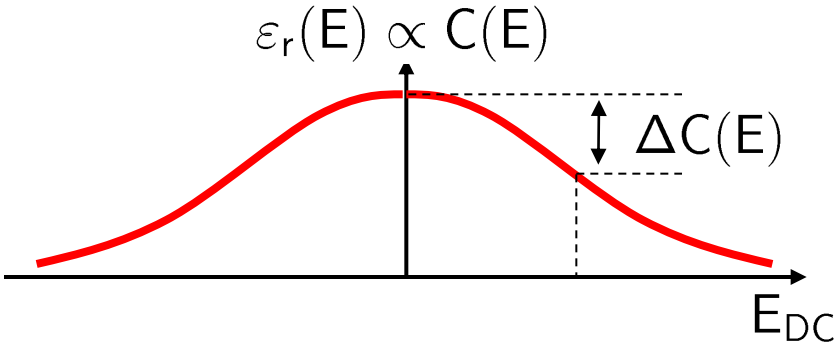
- **Tunable Dielectric** : Barium-Strontium-Titanate (BST)

➢ Permittivity changes by applying an electrostatic field

➢ Basic tunable component

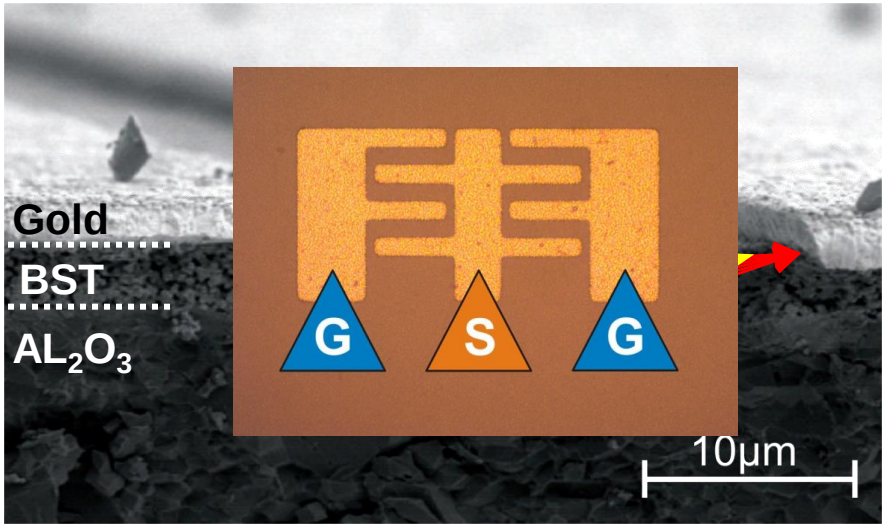
  - Tunable Interdigital Capacitor (IDC)





Tunability

$$\tau_C(E) = \frac{C(0)-C(E)}{C(0)}$$



Motivation

- IDC Limitations:
  - Minimum gap is restricted → Reduce maximum electric field per µm
  - Delicate fabrication process
  - Low FoM
  - Geometry efficiency

Material Tunability

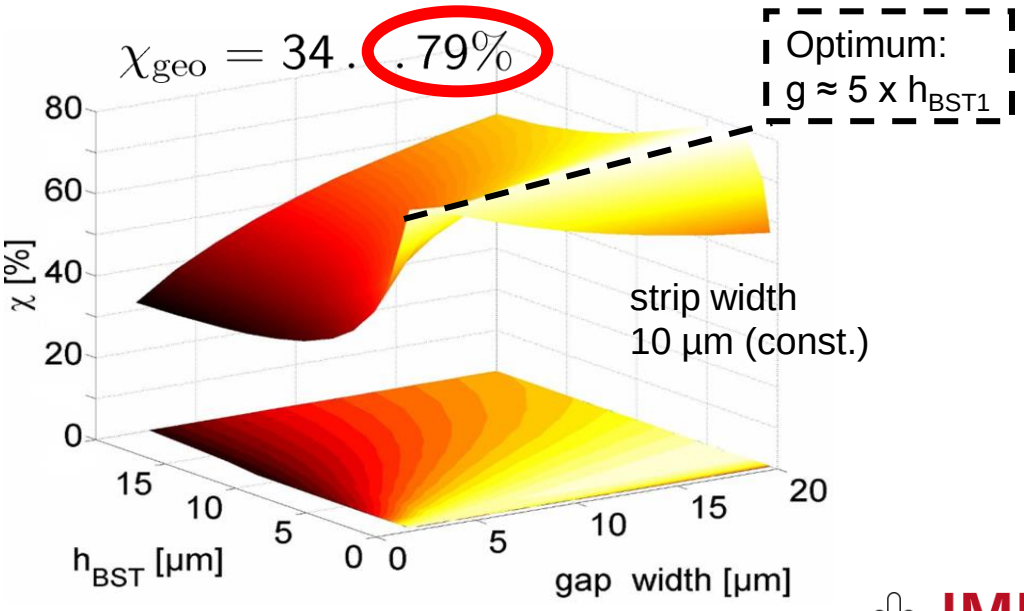
$$\tau_\varepsilon(E) = \frac{\Delta\varepsilon_r(E)}{\varepsilon_r(0)}$$

Component Tunability

$$\tau_C(E_{eff}) = \frac{\Delta C(E_{eff})}{C(0)}$$

Geometry Efficiency

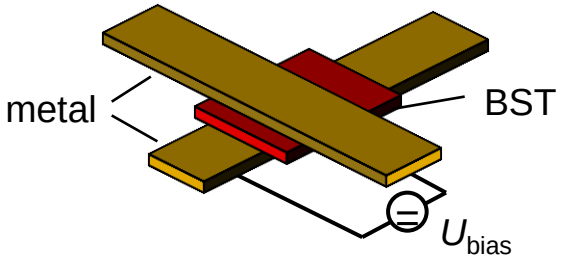
$$\chi_{geo}(E_{eff}) = \frac{\tau_C(E_{eff})}{\tau_\varepsilon(E_{eff})}$$



MIM Varactor

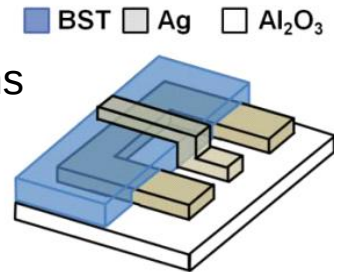
- Metal Isolator Metal Capacitors (MIM):

  - ✓ Reduce biasing voltage
  - ✓ Increase breaking voltage
  - ✓ Increase maximum tunablity
  - ✓ Improver Insertion Loss
  - ✓ Decrease number of tunable units

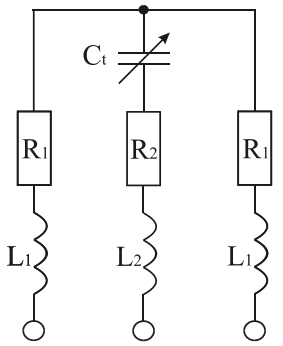


- MIM Varactor Layers:

  - ➢ MIM Varactor fabricated by selective printed BST and Silver film
  - ➢ The bottom and top layers are metallic electrodes
  - ➢ The middle layer is the BST thick-film
  - ➢ Three inductances represent the electrode executions



Layout of the MIM varactor

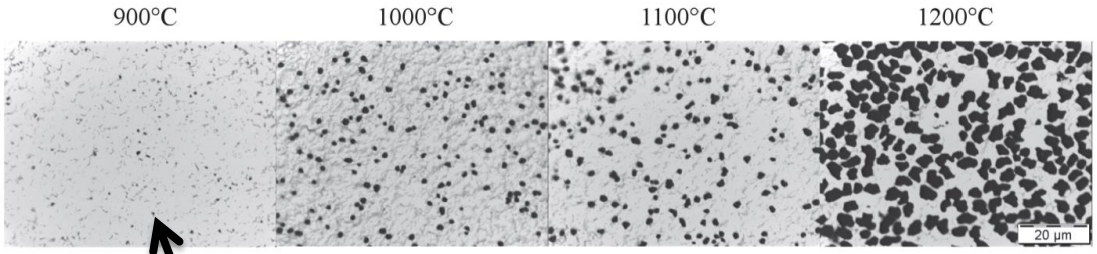


Equivalent circuit of the MIM varactor

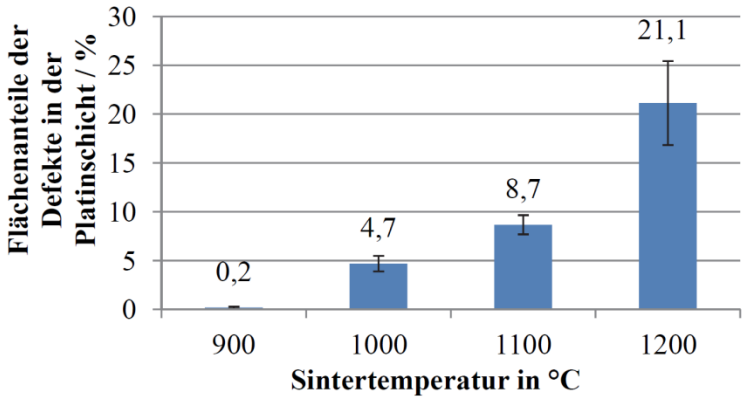
Screen Printing

- Printing Process:
  - Fast
  - Cost effective
  - Low fabrication tolerances

- Degradation of the platinum layers
  - The increase in the number of defects in the platinum layer (200nm) on top of Al2O3 substrates (sintered 1h) at different sintering temperatures.



Taken with light microscope at 1000 × magnification



- Goal:
  Reducing BST sintering temperature below 900°C

Screen Printing

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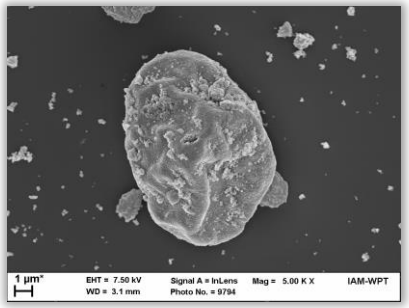
➢The Screen printing technology:

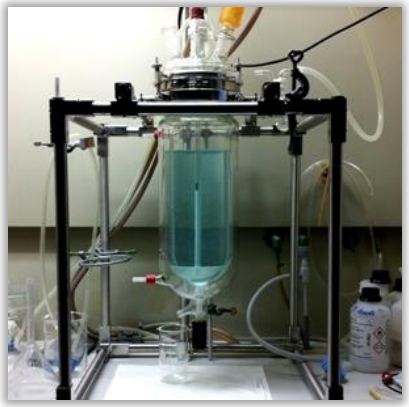
BST-P

- **BST–ZnO-**
  - ➢ L
  - ➢ H
  - ➢ Ad

Reactants:
(Ba / Sr / Cu)-Acetates
Ti(IV)- Isopropoxide
in **Acetic acid + water**



SOL
↓ *Spray-drying*
Precursor
↓ *Calcination (900°C)*
Calcined Powder
↓ *Addition of ZnO-H_3BO_3, Co-milling*
Powder Mixtures
↓ *Dispersing*
Paste



IMP

Screen Printing

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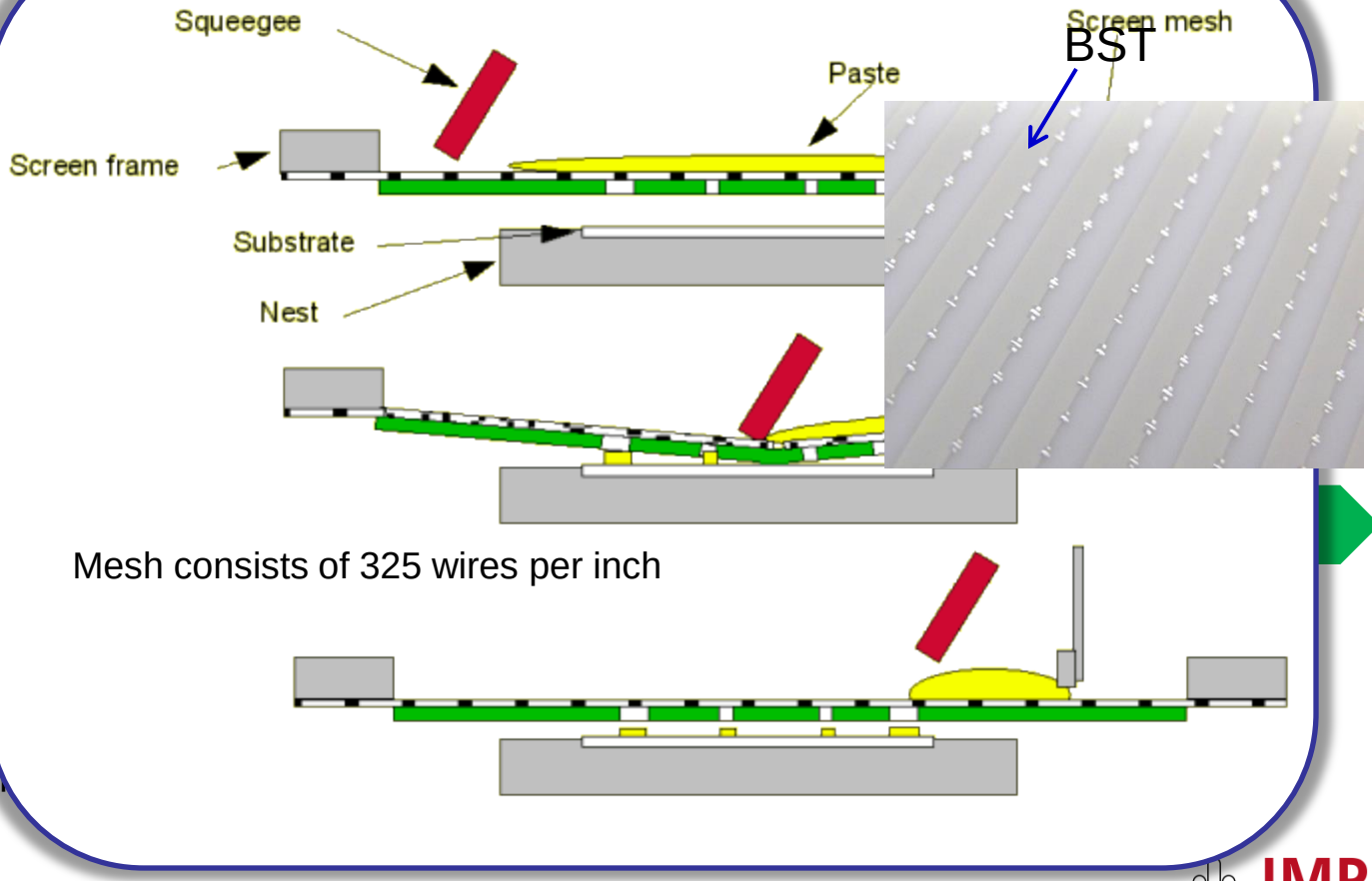
➢The Screen printing technology:

BST-Powder

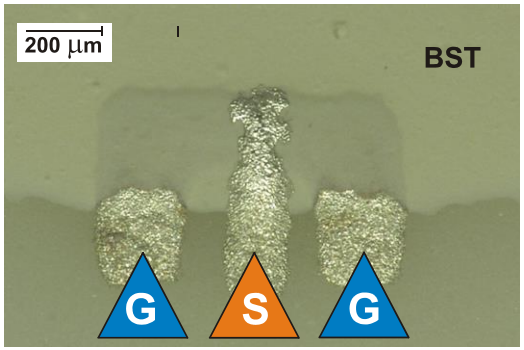
- **BST–ZnO–B_2O_3 composite**
  - ➢ Low porosity
  - ➢ High sintering activ
  - ➢ Adequate dielectric

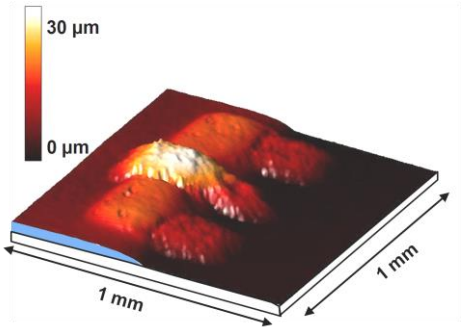


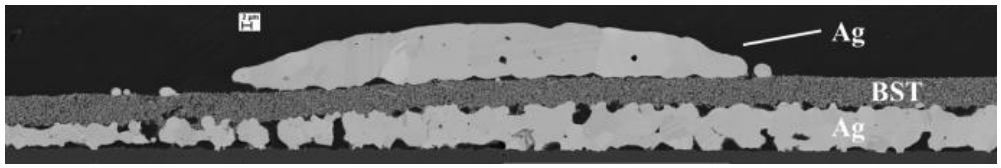
IMP

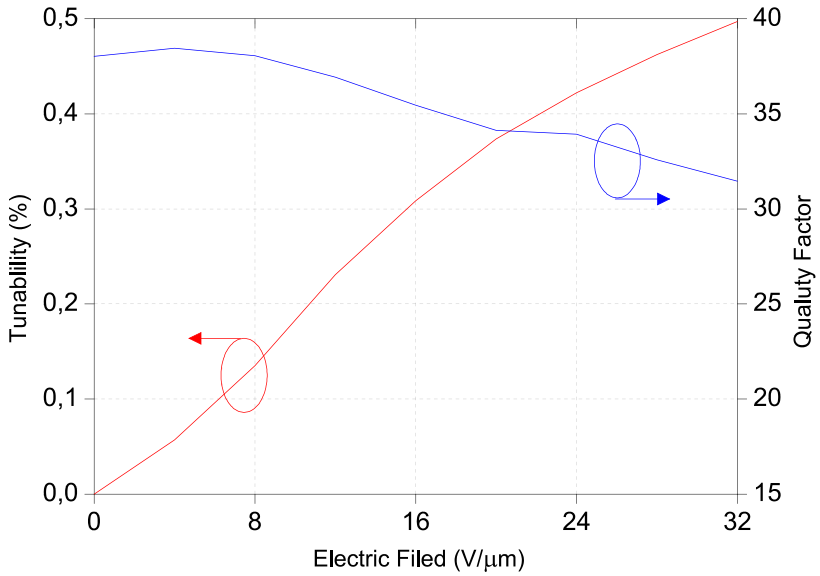
MIM Varactor

- MIM Varactor Protoype:
  - The fabrication is done by subsequent screen-printing and drying of each layer
  - Samples were co-fired in purified dried air at a temperature of 850°C for 1h
  - Measurement results of the fully printed MIM varactor over the tuning voltage at 1.7 GHz
  - By applying a maximum voltage of 160 V, a tunability of 50% is achieved
  - Relative permittivity = 210 and capacitance of 3.8 pF





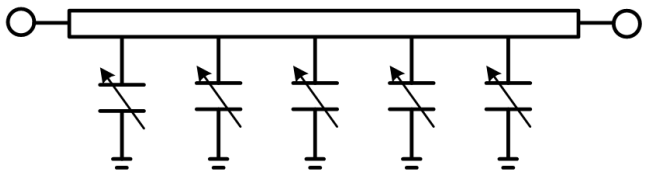




Phase Shifter

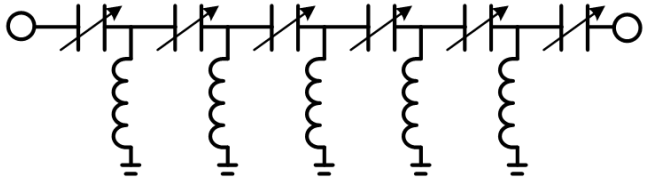
- Comparison between loaded transmission line and metamaterial delay line phase shifters

Loaded transmission line phase shifter (LL)



It is a broadband transmission line with shunted varactor loadings. Its positive propagation constant is controlled by tuning varactors.

Metamaterial delay line phase shifter (MM-DL)

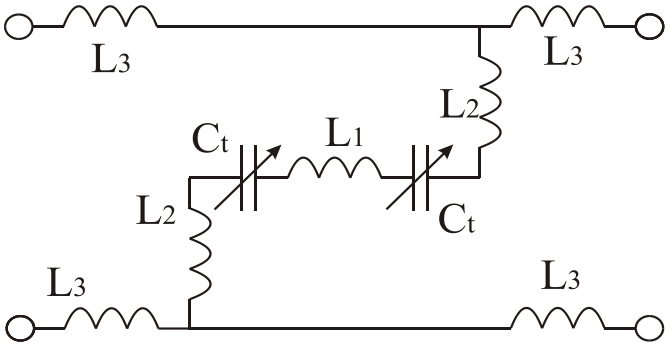


It is a chain of cascaded band pass unit cells. It can achieve equivalently zero or negative propagation constant. Ferroelectric varactors are serial connected in the line.

$$\beta_{RH} = -\frac{1}{\omega\sqrt{L \times C_t}} \qquad Z_{RH} = \sqrt{\frac{L}{C_t}}$$

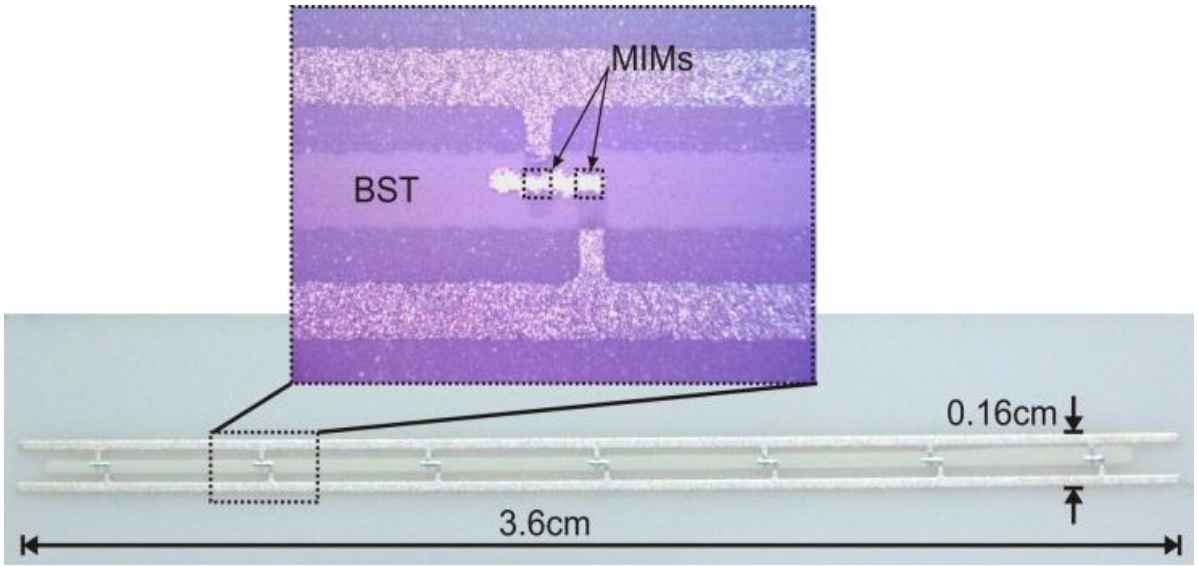
Simulation

- The unit cell equivalent circuit and layout of the loaded line phase shifter



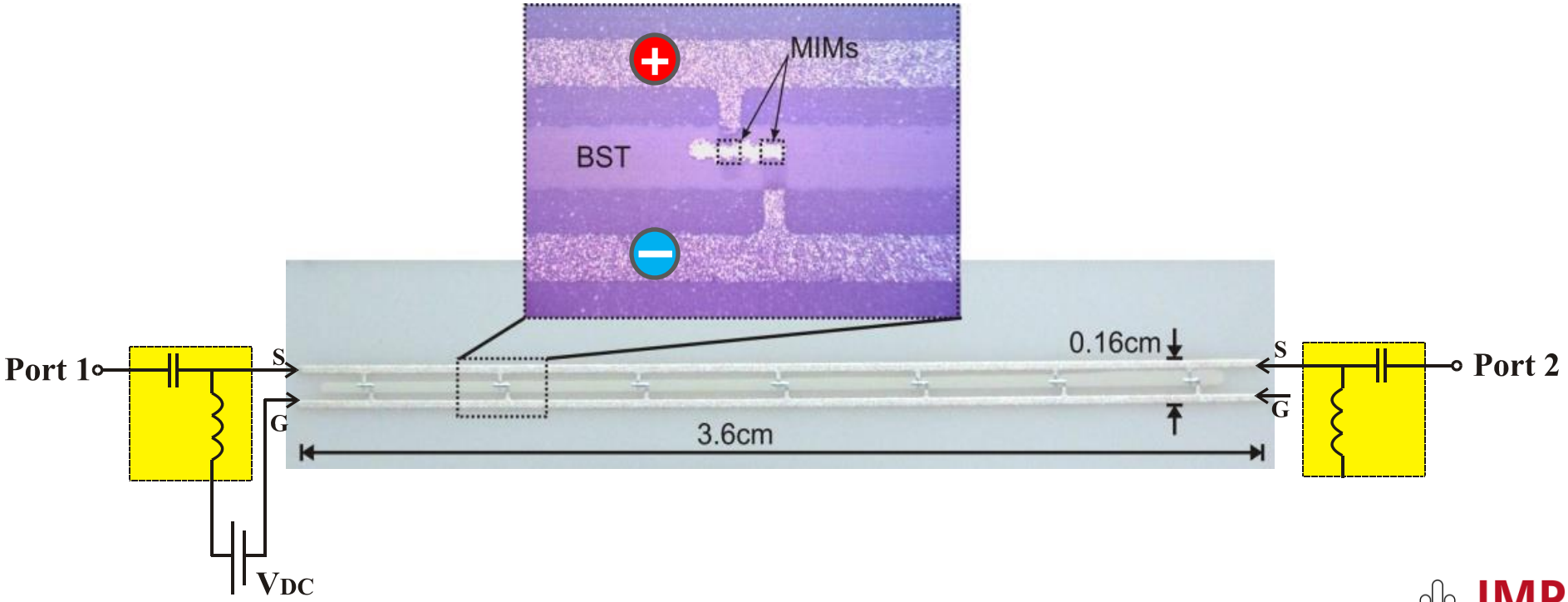
Phase Shifter Prototype

- Tunable phase shifter prototype:
  - Center frequency at 1.7GHz
  - Simulation software ADS
  - BST line thickness 5.9μm
  - The intersection of the top and bottom layer of each MIM varactor is 160×100μm²
  - Conductor layer thickness 13μm
  - Number of unit cells 7 unit cells



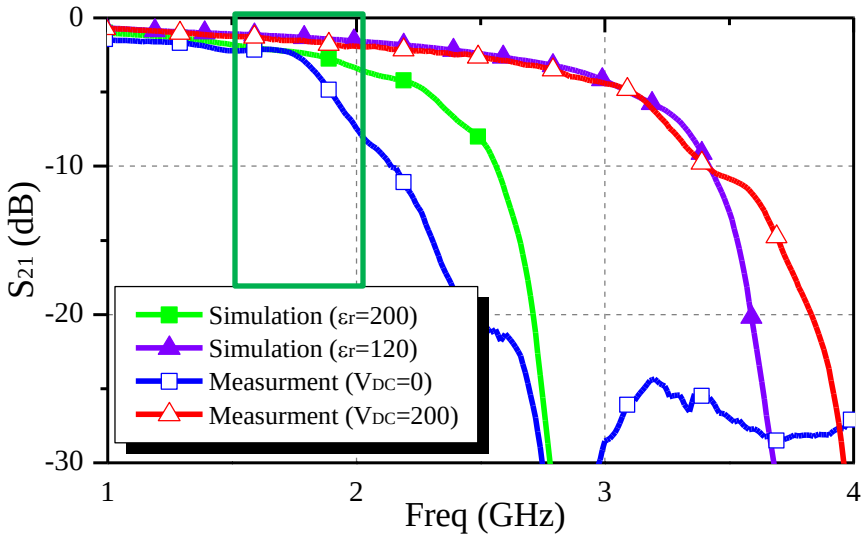
Phase Shifter Prototype

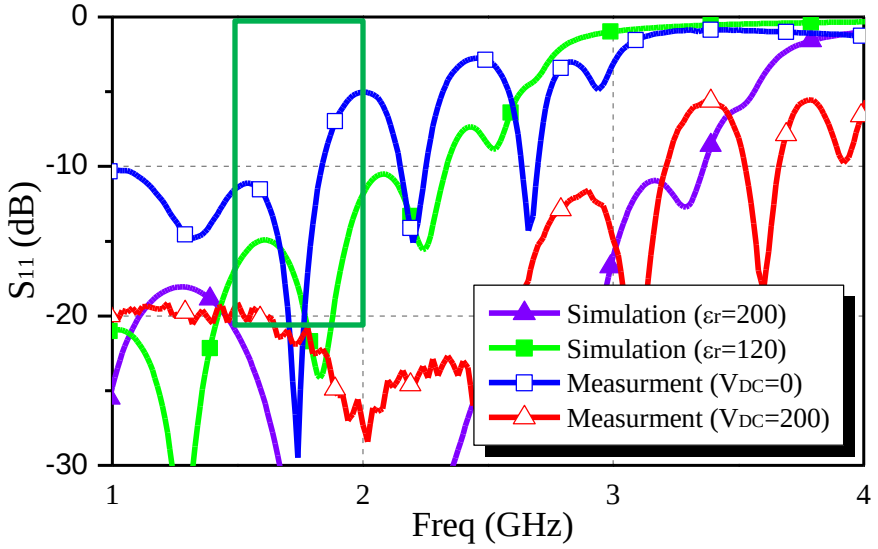
- On-Wafer measurement :
  - Measurement in a 50 Ω system
  - Tuning voltage applied by using Bias-T
  - Tuning Voltage changed between 0 to 200 V
  - Simple biasing concept



Measurement results

- S-Parameter Measurement Results:



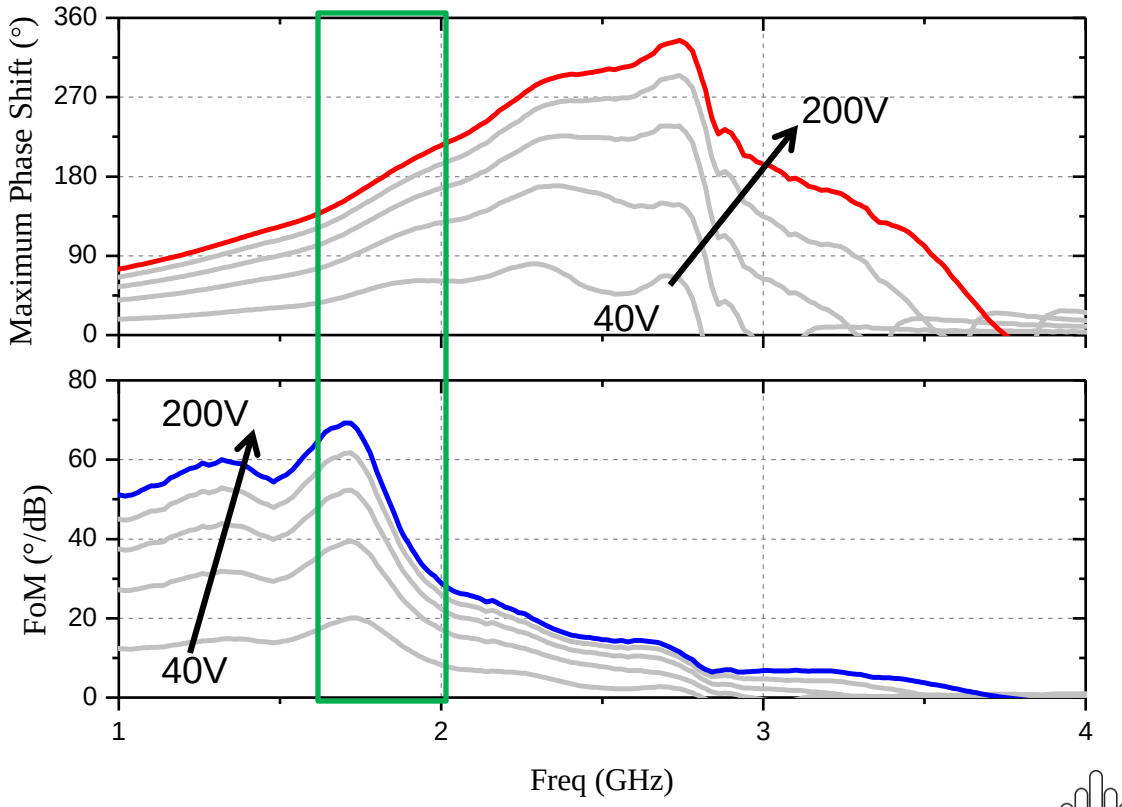


- Simulation and measurement comparison:
  - The fabrication tolerance
  - Parasitic microstrip propagation mode
  - The alignment accuracy

Measurement results

- Phase Shift and Figure of merit (FoM):
  - A phase shift of 158° is achieved at 1.72GHz with a FoM of 70°/dB

$$FoM = \frac{\Delta\varphi}{IL_{max}} \ (°/dB)$$



Summary

• Conclusion

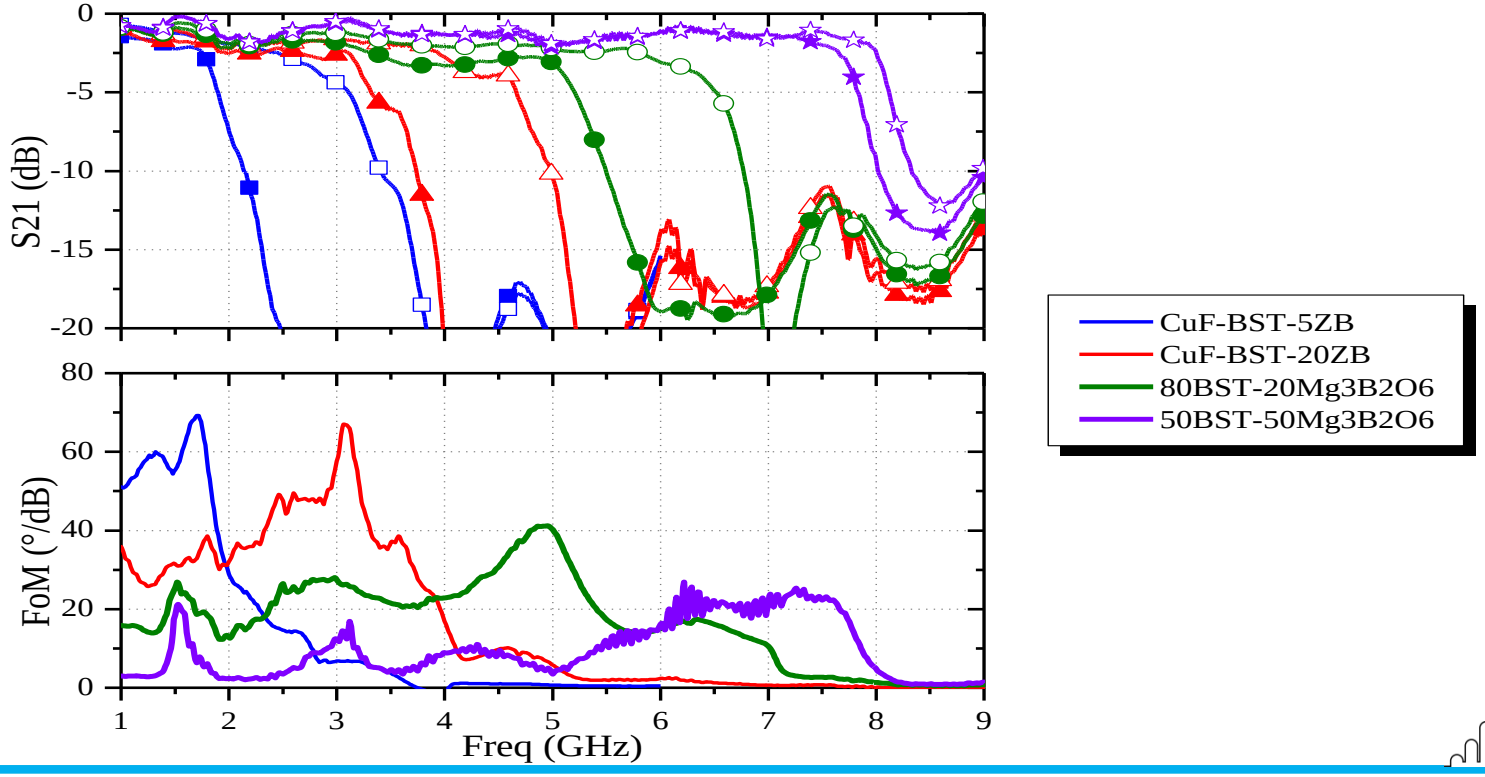
- The Fully screen printed technology is implemented as simple, fast and low-cost process
- Fully printed MIM varactor gives a maximum tunability of 50% by applying 160V
- A fully screen-printed load line phase shifter is fabricated and measured at L-band
- A phase shift of 158° is achieved at 1.72GHz with a FoM of 70°/dB

Freq (GHz)	Δφ (°)	FoM (°/dB)	Vmax (V)	Varactor	Sintering Temp	Ref
3	20	14.6	200	MIM*	850	[4]
2.5	4.5	6.55	250	MIM*	850	[5]
2	70	58	100	MIM/IDC	-	[6]
2.5	48	20	100	Planar	-	[13]
2.5	63	21	100	MIM *	1200	[6]
2.8	65	29	100	IDC	-	[14]
1.75	158	70	200	MIM*	850	This Work

*Fabricated in fully screen printed technology

Summary

- **Outlook**
  - The fabricated MIM capacitor demonstrates a simple and flexible preparation
  - For phased array applications, it is necessary to have 360° phase shift (16 unit cells)
  - Higher operation frequencies are targeted, which can be reached by higher printing accuracy and reduced line width



Thank you for your attention

Cooperation Partners

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