Friedrich-Alexander-Universität
Erlangen-Nürnberg

Reconfigurable Front-End Modules Based on Ferroelectric Varactors

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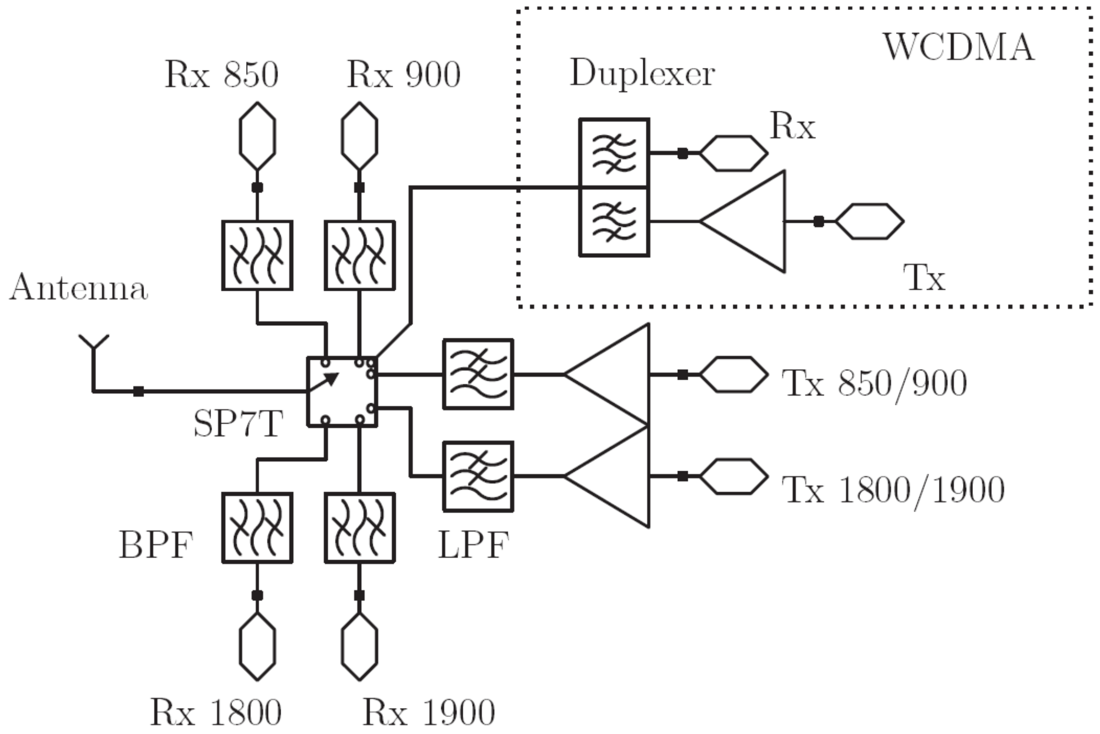
Outline

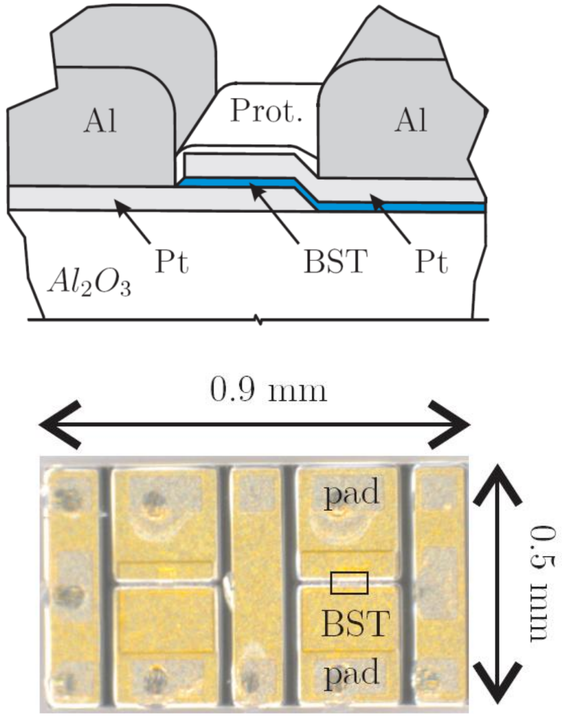
- Motivation
- Tunable Passive Components
- Part 1
  - Frequency Agile Filters
  - Frequency Agile Power Dividers & Couplers
  - Prototype Implementation & Results
- Part 2
  - Impedance Matching Networks
  - L, Pi, T, and reflection type
  - Prototype Implementation & Results
- Conclusion

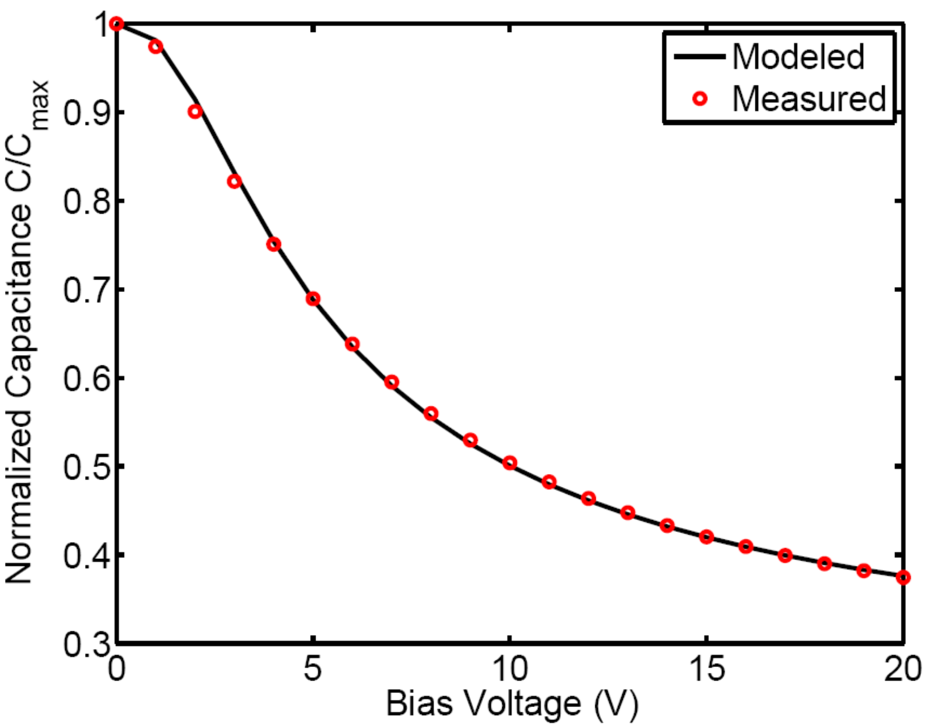
Motivation



- Increasing number of communication bands
- Additional wireless services, e.g. GPS, WiMAX
- Demand for reconfigurable front-end solutions

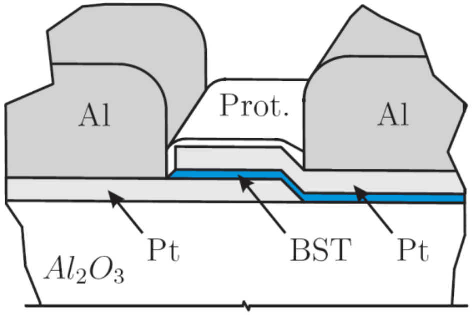
Ferroelectric Thin-Film Varactors

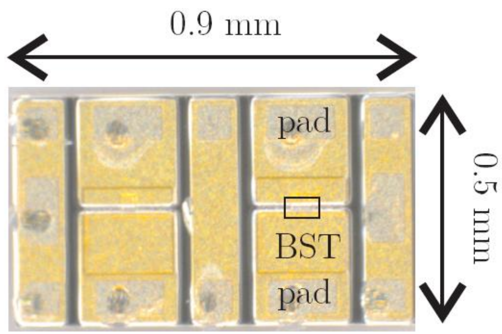


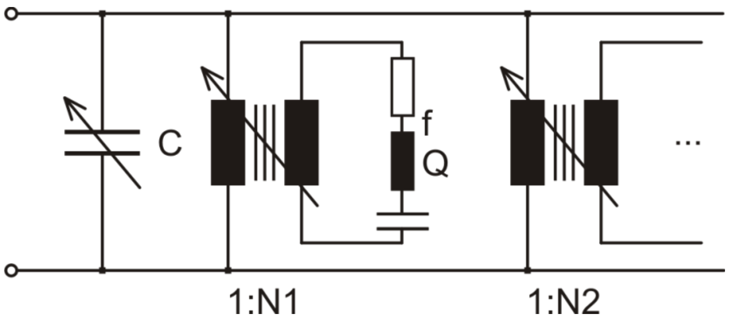


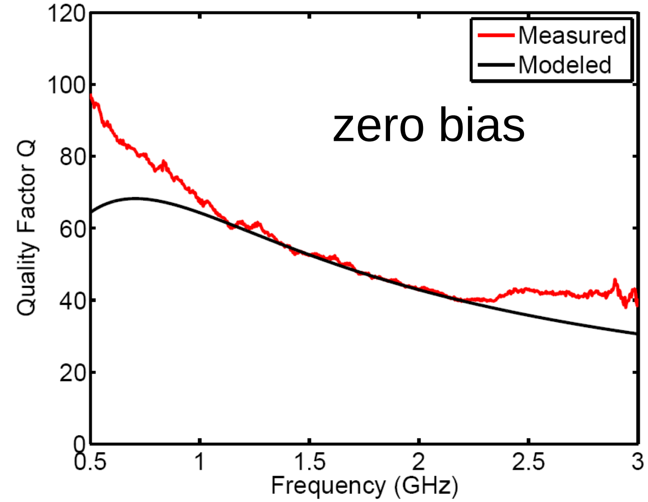
- Nonlinear component
- Compact dimensions
- Induced acoustic resonance

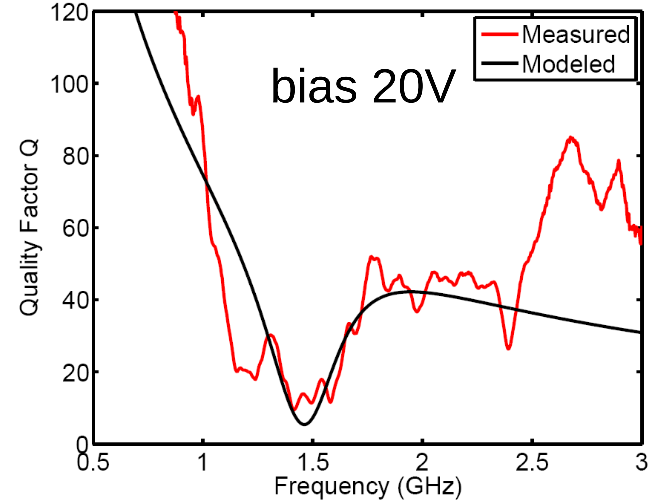
Ferroelectric Thin-Film Varactors





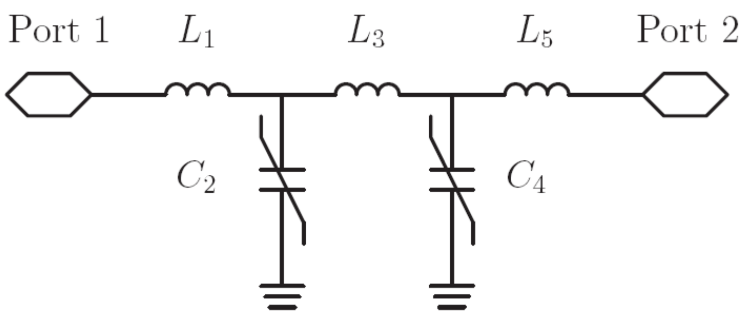


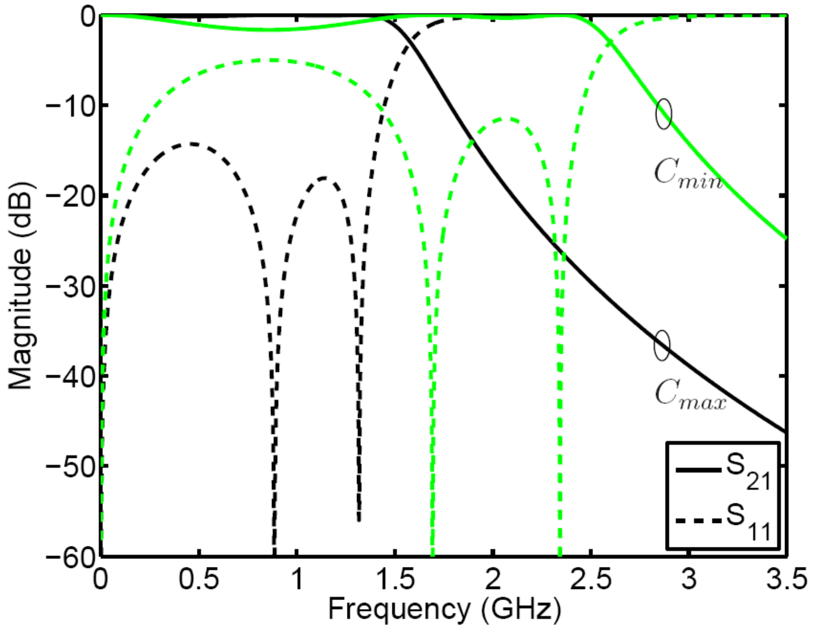




- Metal-Insulator-Metal (MIM)
- Compact dimensions
- Q around 40 @ 2 GHz
- ADS model available

Filter Design – Lowpass





$$M_{i=1,3,5} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z_i \\ 0 & 1 \end{bmatrix}$$

$$M_{j=2,4} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_j & 1 \end{bmatrix}$$

$$M_{total} = M_1 \cdot M_2 \cdot M_3 \cdot M_4 \cdot M_5$$

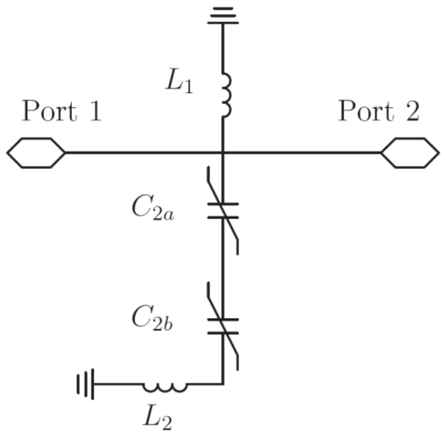
$$z_2 = j\omega_2 = \pm \frac{\sqrt{2CL_3(-2L_1L_3 - 2L_1^2 + Z_0^2CL_3 + \alpha)}}{2CL_1L_3}$$

$$z_3 = j\omega_3 = \pm \frac{\sqrt{2CL_3(-2L_1L_3 - 2L_1^2 + Z_0^2CL_3 - \alpha)}}{2CL_1L_3}$$

$$\alpha = \sqrt{-4L_1L_3^2Z_0^2C + 4L_1^4 + 4L_1^2L_3Z_0^2C + L_3^2Z_0^4C^2}$$

- Chebyshev lowpass filter
- Analytical formulas for zero locations

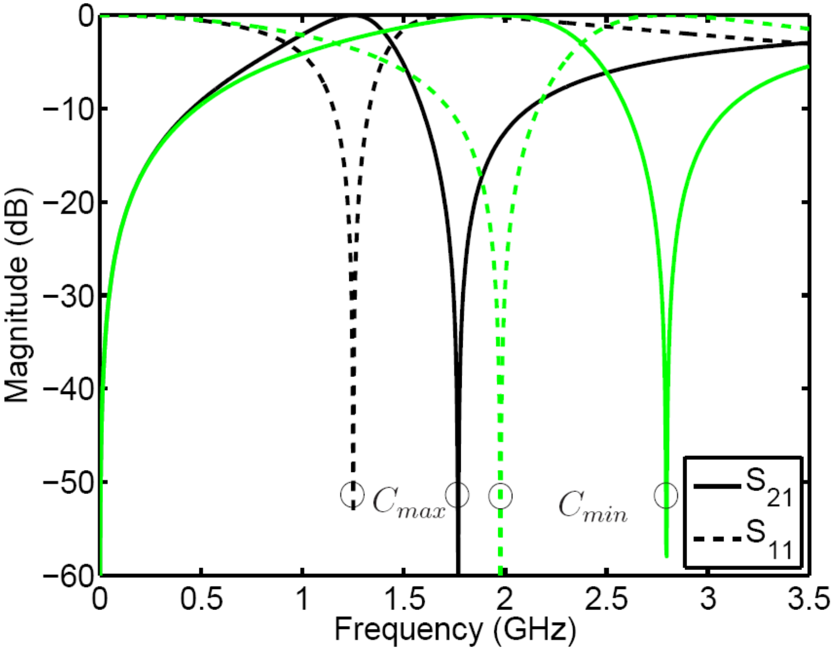
Filter Design – Notch Filter



$$M_1 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_1 & 1 \end{bmatrix}$$

$$M_2 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_2 & 1 \end{bmatrix}$$

$$Y_2 = 1/[2/(pC) + pL_2]$$

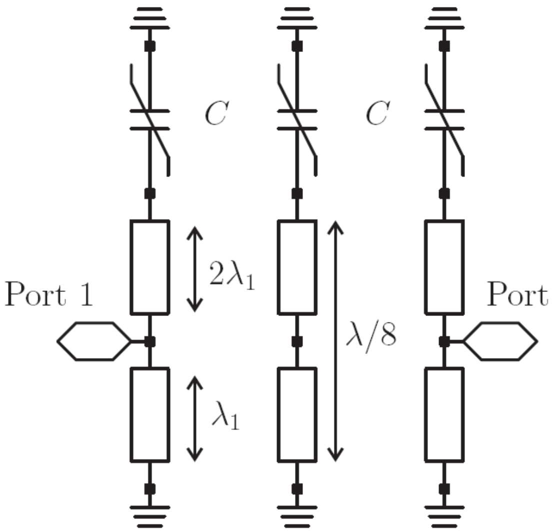


- Notch filter
- Analytical formulas for zero and pole locations

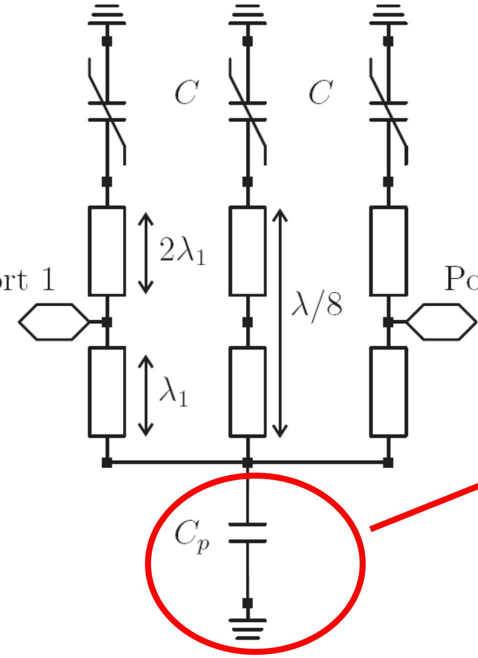
zero $z_1 = j\omega_1 = \pm\sqrt{-2/[(L_1+L_2)C]}$

pole $p_2 = j\omega_2 = \pm\sqrt{-2/(L_2C)}$

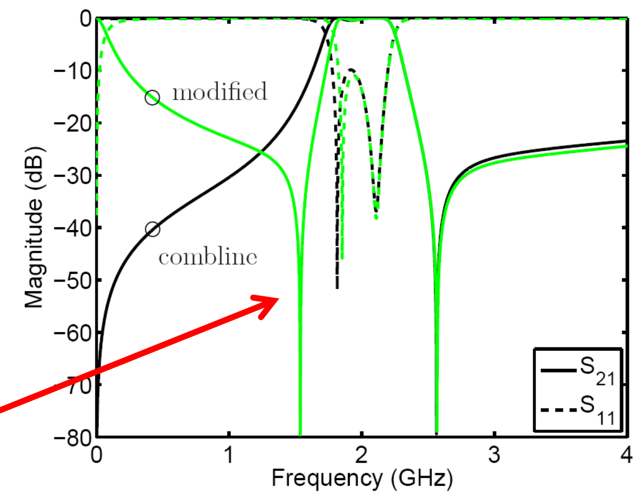
Modified Combline Filter

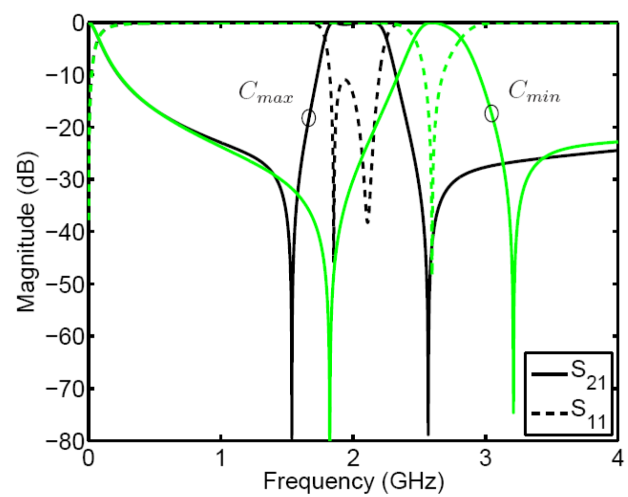


Combline



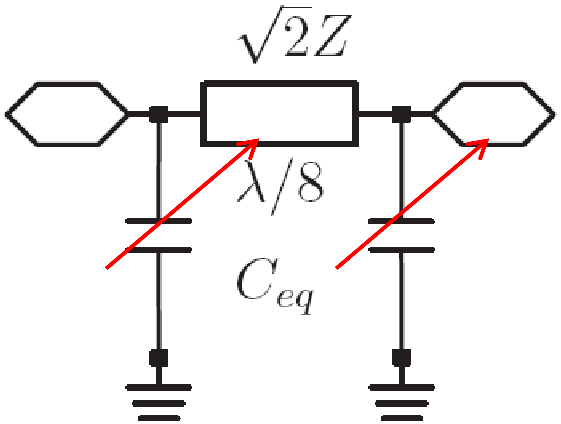
Modified





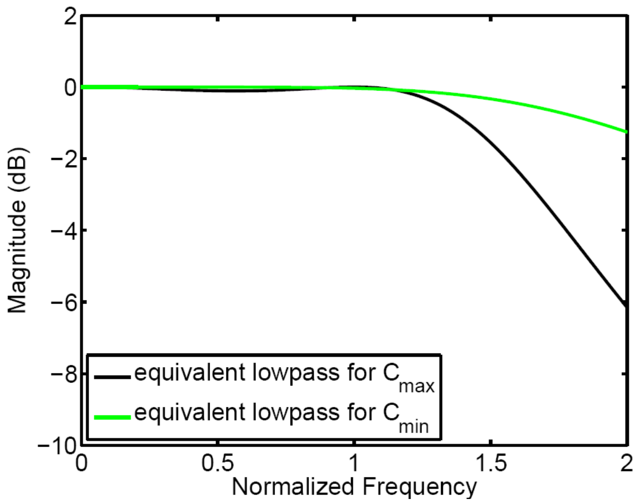
- Second attenuation pole is shifted from DC to lower stopband

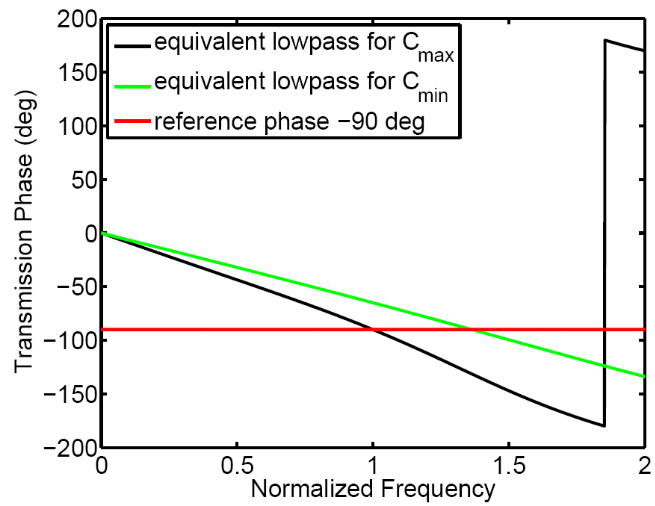
Frequency Agile λ/4 Segments



Tuning of C_{eq} → shifts resonance

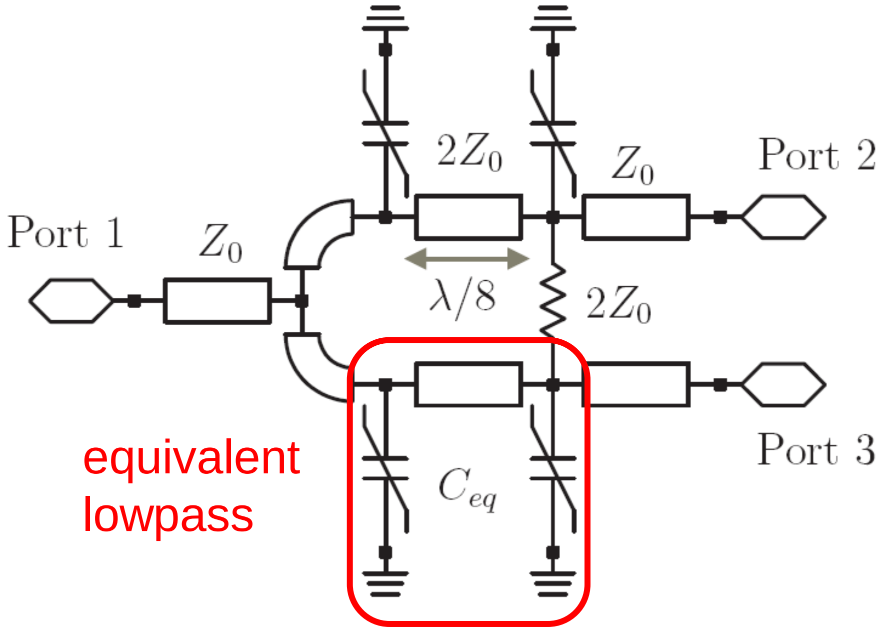
$$C_{eq} = \frac{1}{\omega\sqrt{2}Z} = \frac{1}{2\pi f\sqrt{2}Z}$$

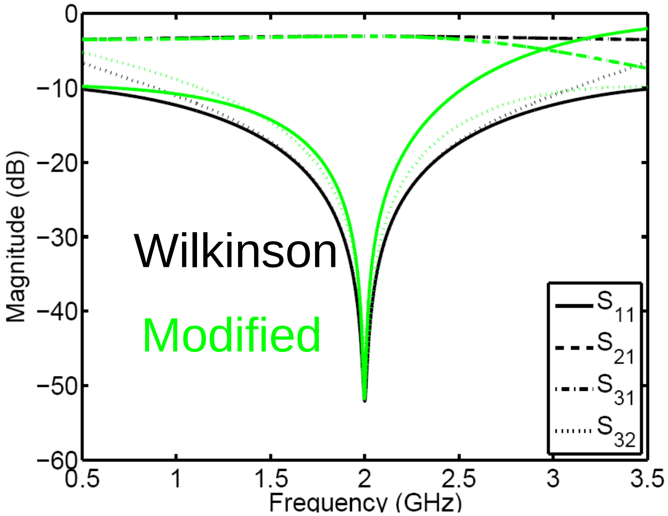


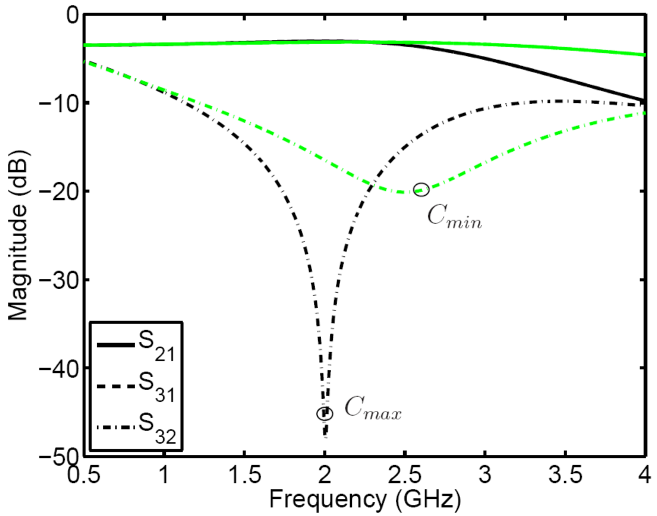


- Scalable network
- Slightly detuned Z
- Perfect phase shift

Tunable Wilkinson Divider

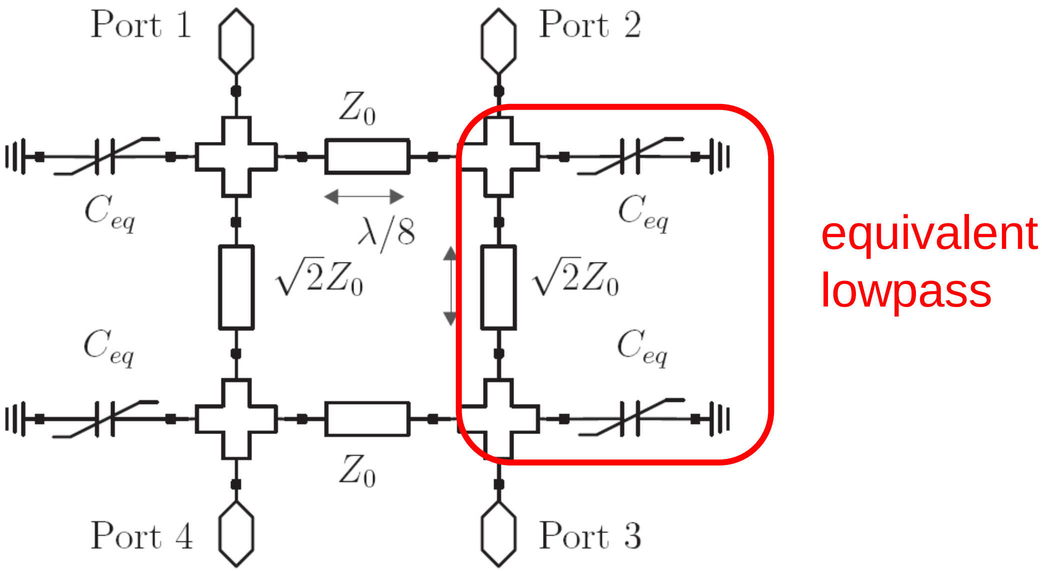


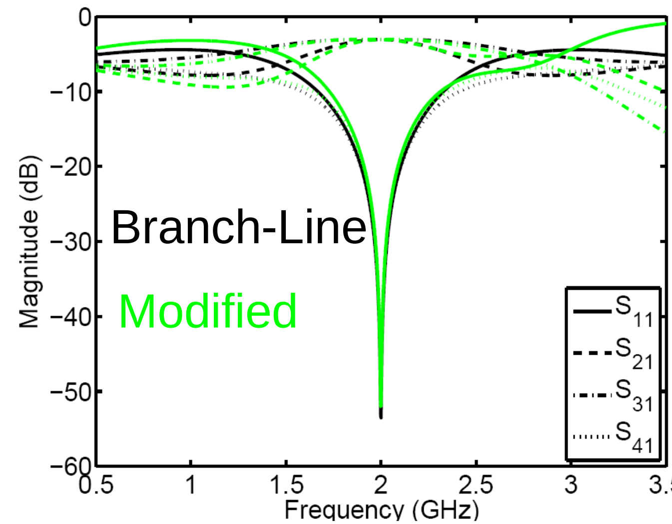


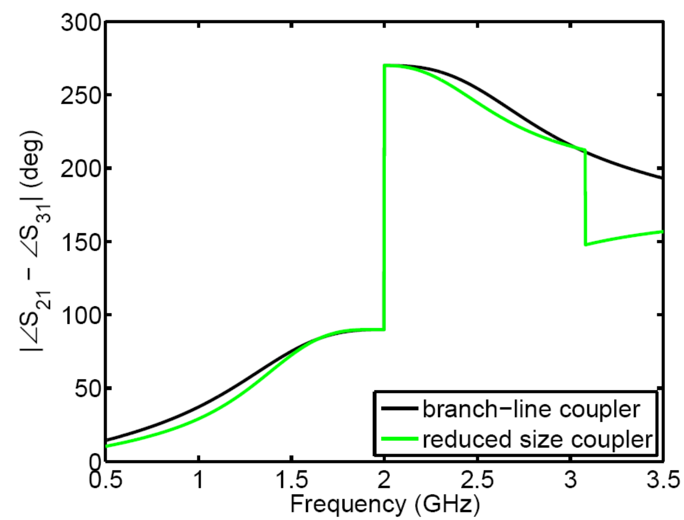


- Size reduction 50%
- Multiband tuning
- Assumed tunability 60%

Tunable Branch-Line Coupler

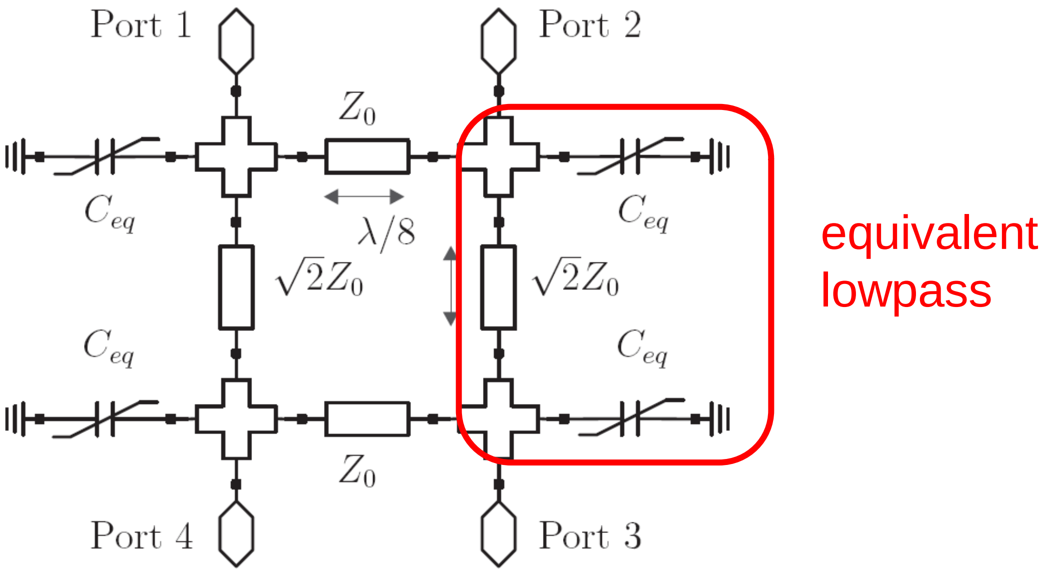


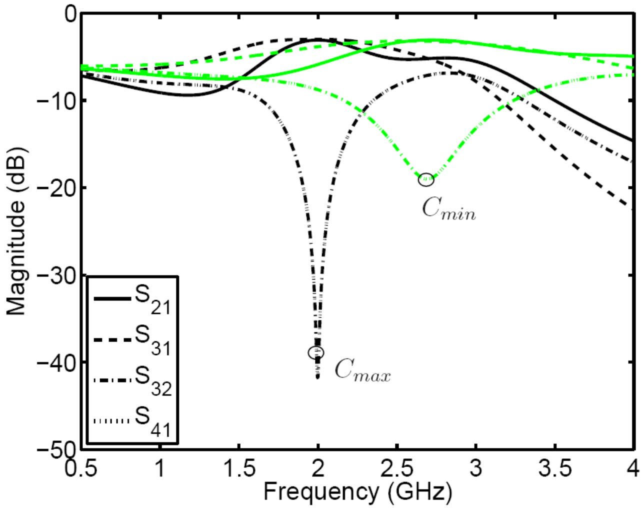


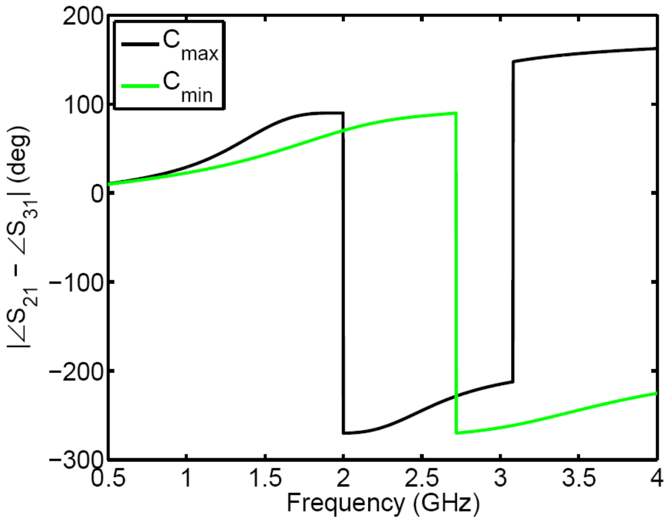


- Size reduction 50%
- Perfect phase match
- C_{eq} serves as shunt element for both segments

Tunable Branch-Line Coupler

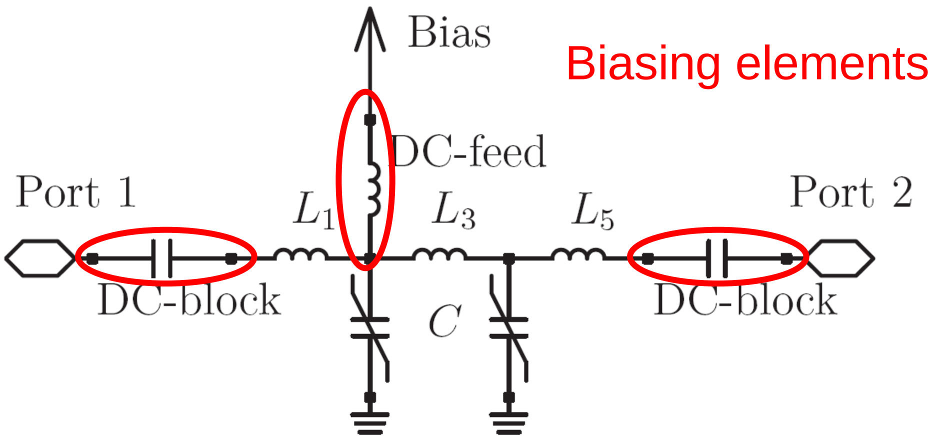


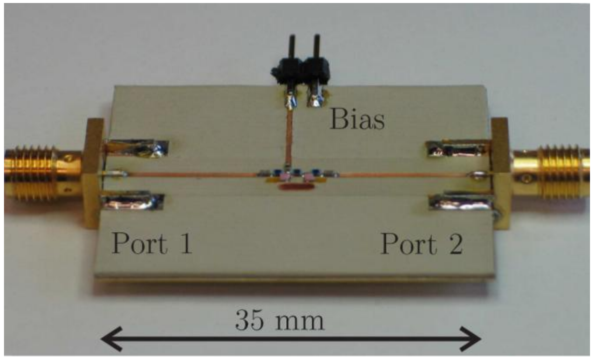




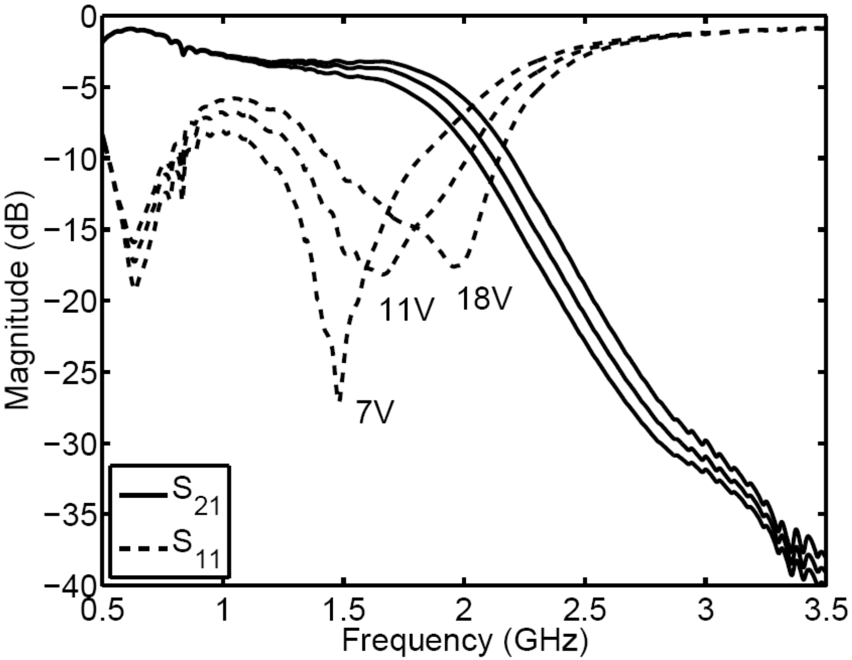
- Size reduction 50%
- Perfect phase shift
- Multiband operation with tunability of 60% for C_{eq}

Tunable Lowpass (1)

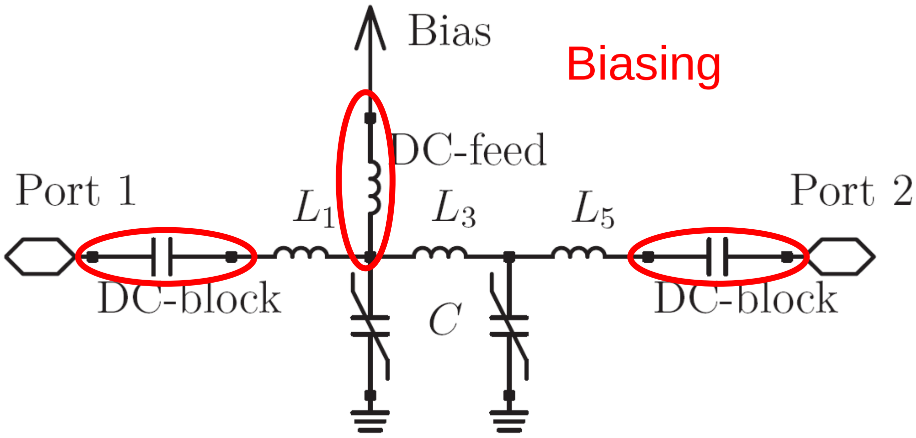




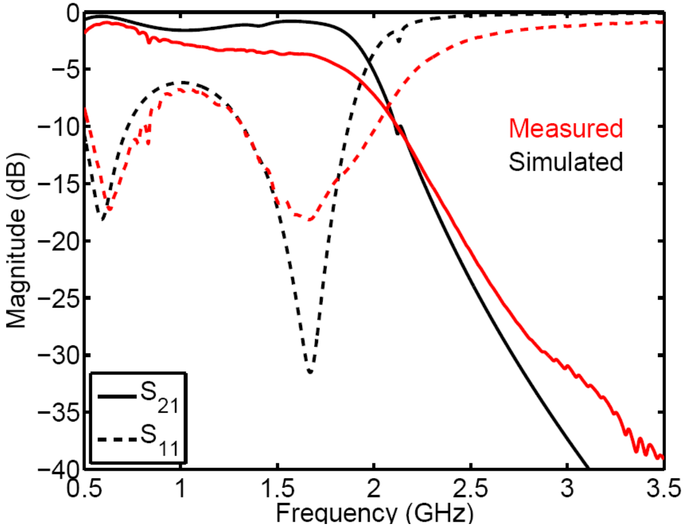
- Tuning range of 30%
- 1.5-2GHz multiband
- High losses due to moderate Q and RF isolation

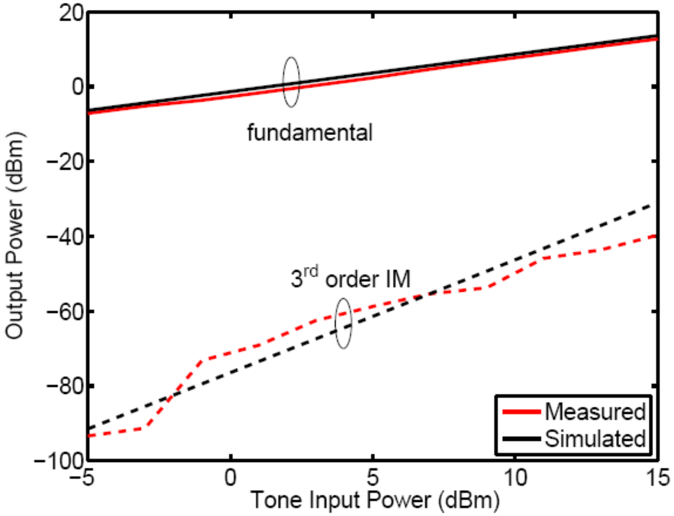


Tunable Lowpass (2)

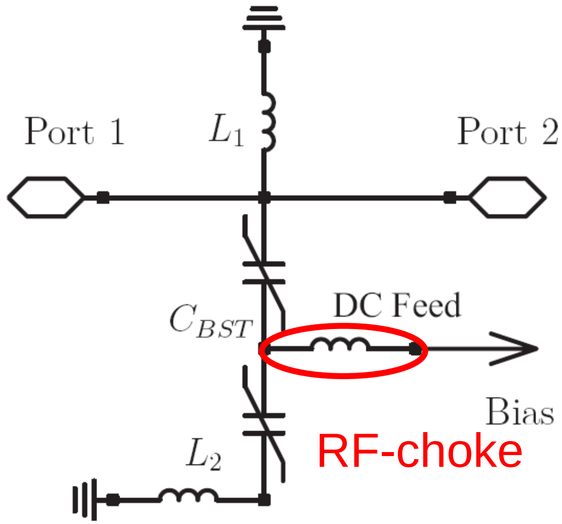


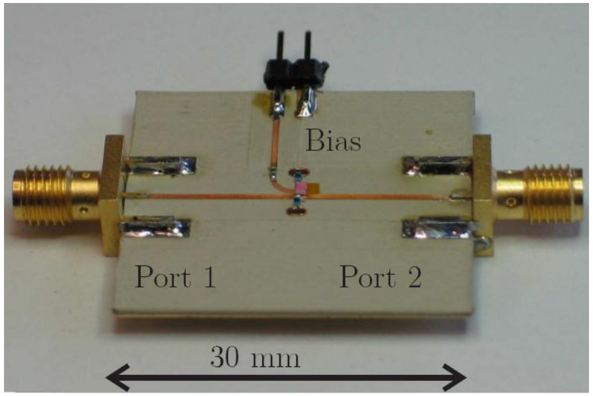
- Good agreement
- Loss due to varactor imbalances and prototype assembly
- Two-tone test @ 1.95GHz with Δf=5MHz and Bias=20V

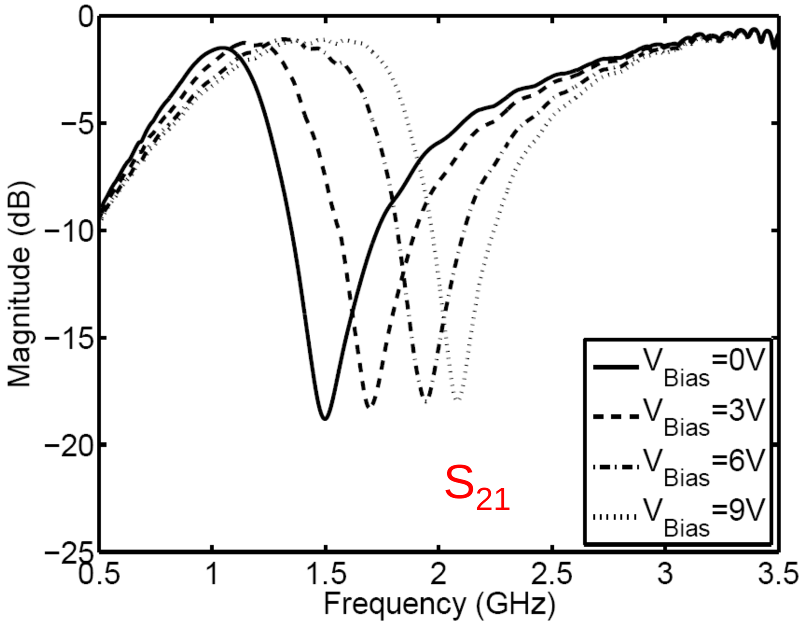




Tunable Notch Filter (1)

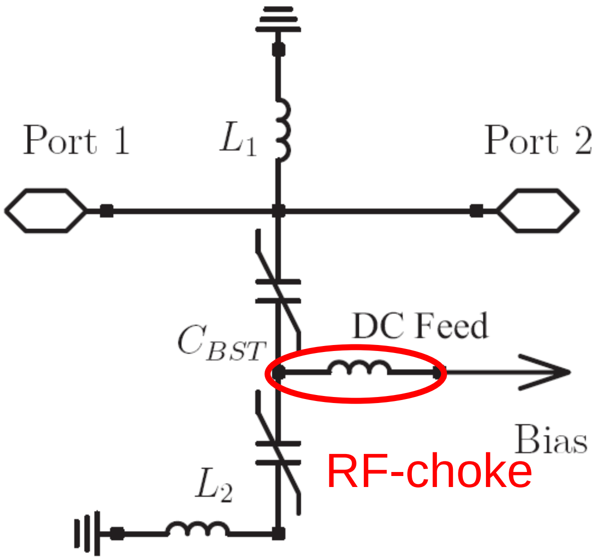


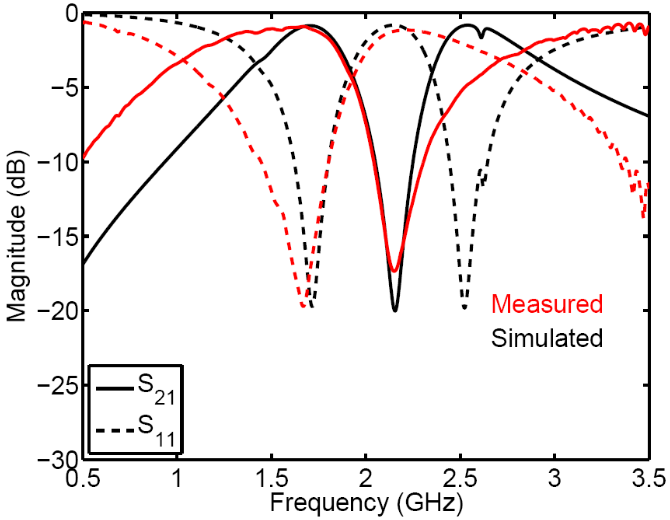


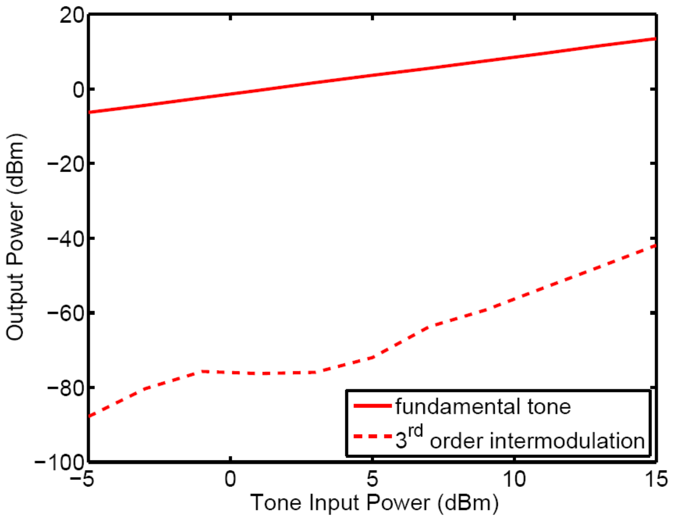


- Cascaded varactors simplify biasing
- Notch tuning 1.5-2.1GHz
- Multiband operation
- Low losses

Tunable Notch Filter (2)

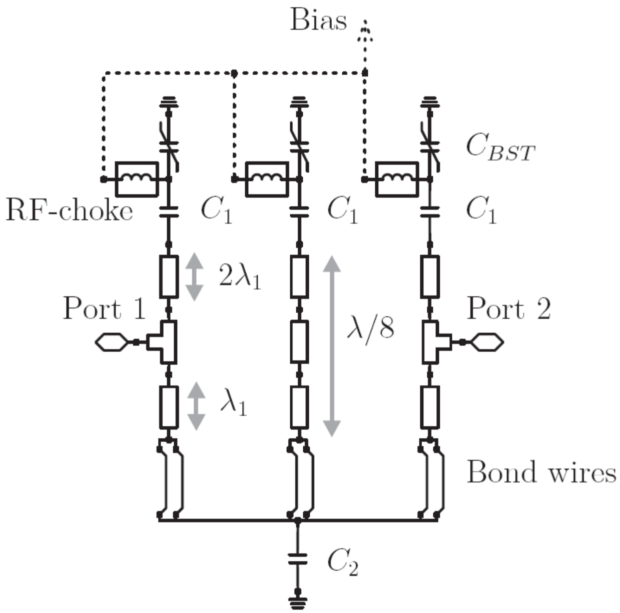


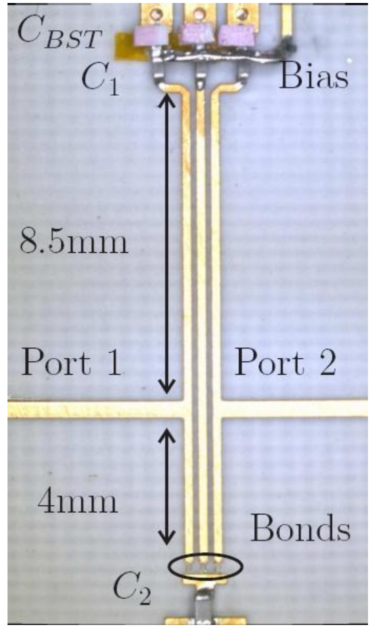


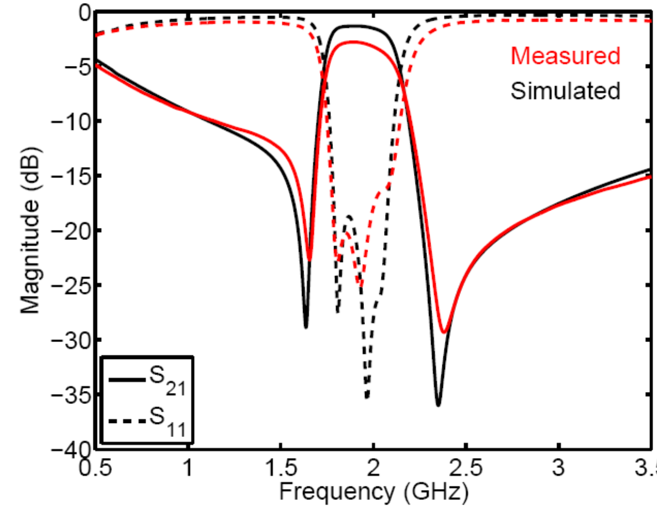


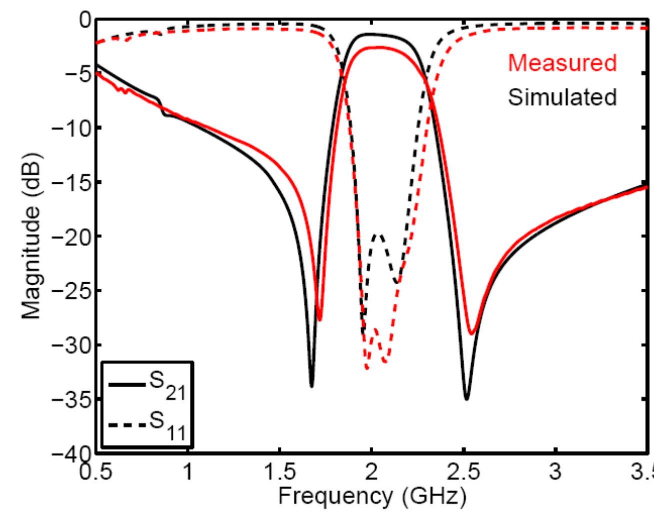
- Good agreement between simulation and measurement
- Two-tone test @ 1.95GHz with Δf=5MHz and Bias=20V

Tunable Combline Filter (1)



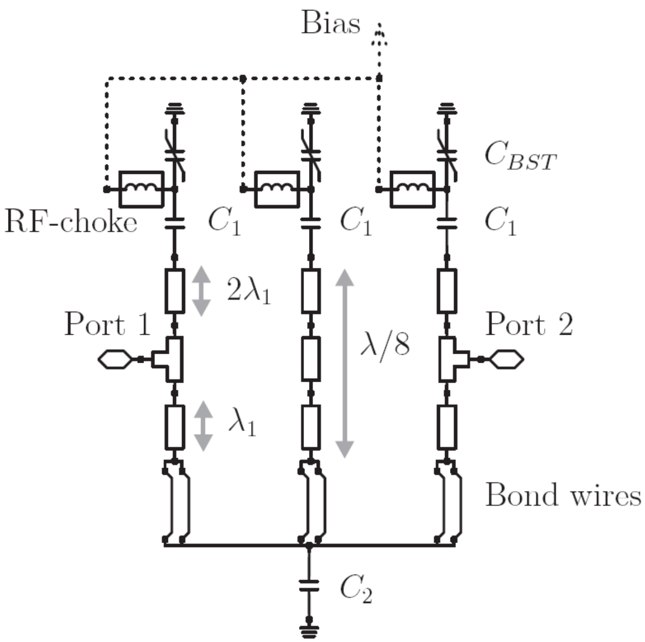


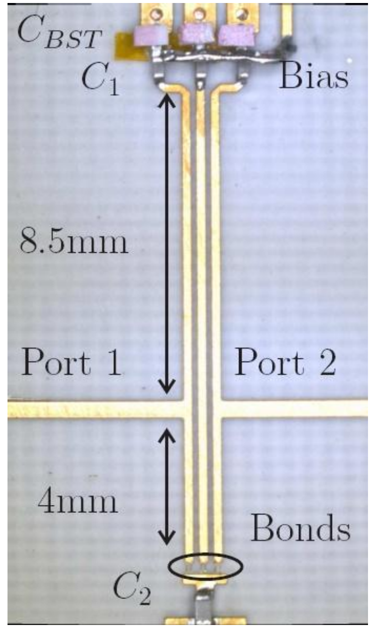




- Good agreement
- Compact dimensions
- IL < 3dB and RL > 20dB
- Tuning 1.8-2GHz

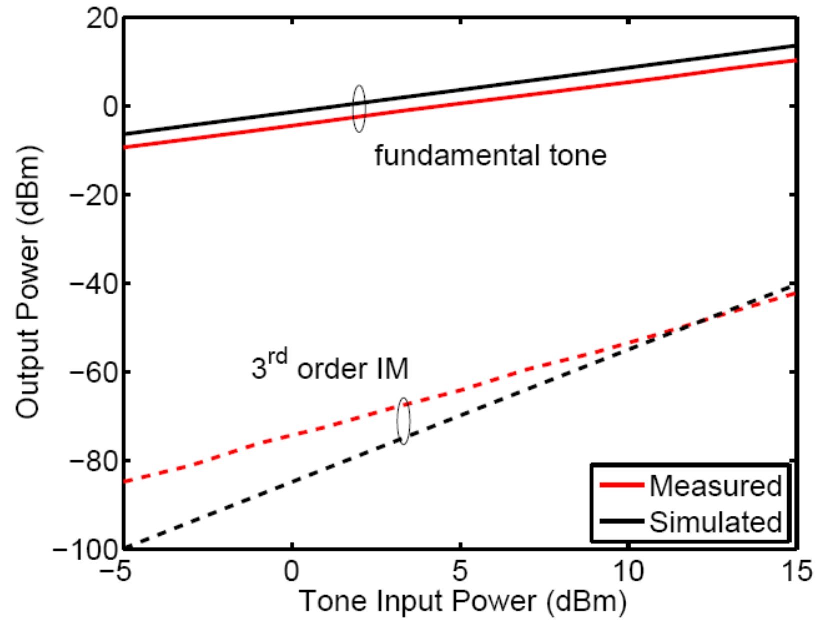
Tunable Combline Filter (2)



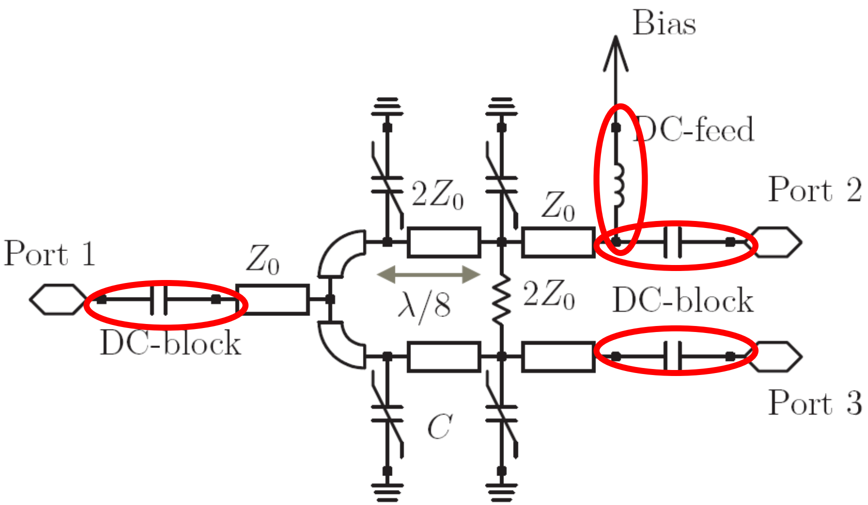


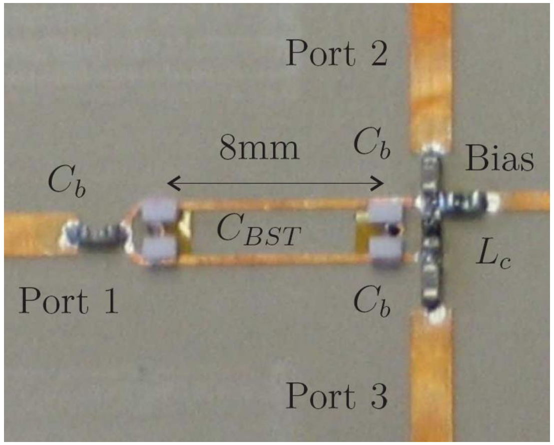
Bias (V)	f_0 (GHz)	IL (dB)	RL (dB)
0	1.85	2.8	20
5	1.90	2.7	22
10	1.97	2.6	26
15	2.02	2.6	28

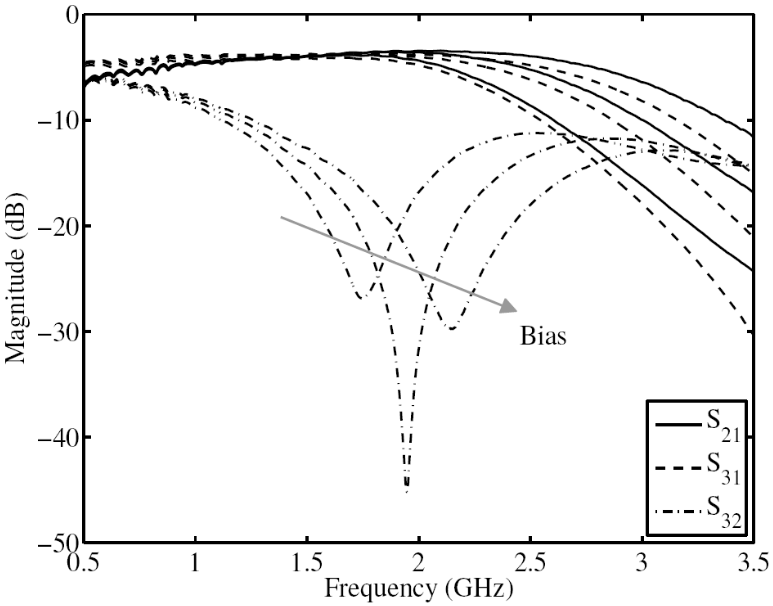
- Two-tone test @1.95GHz with Δf=5MHz and Bias=5V
- OIP3=36.5dBm

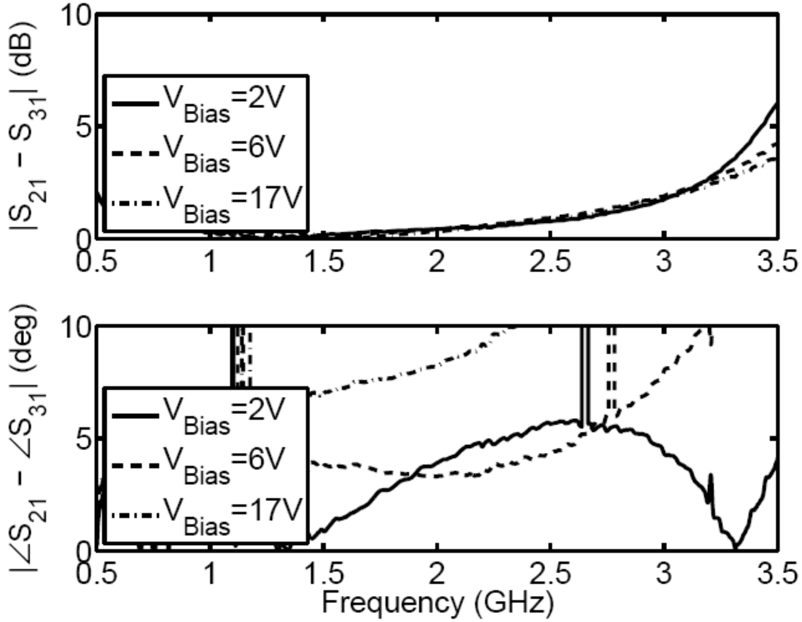


Tunable Wilkinson Divider (1)

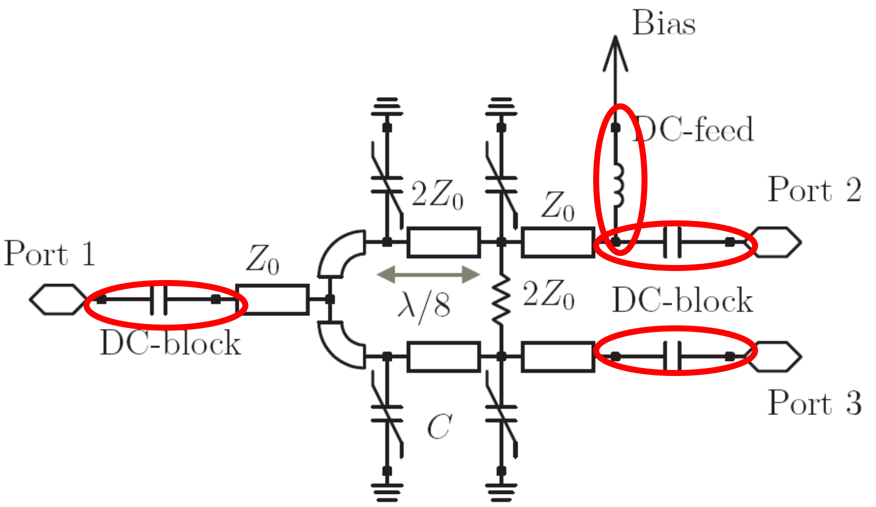


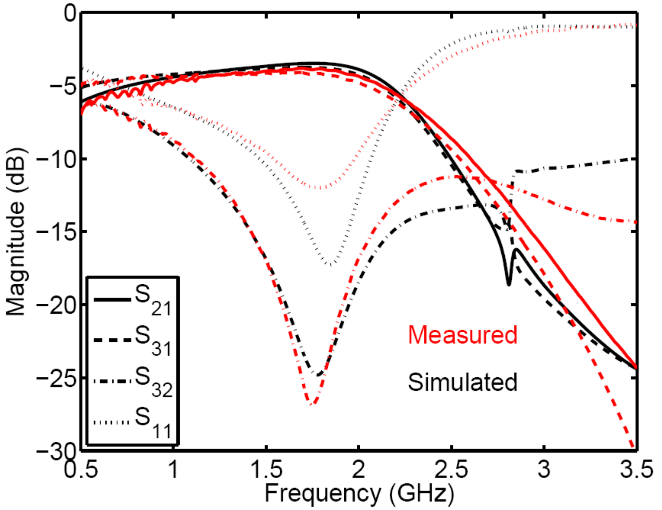




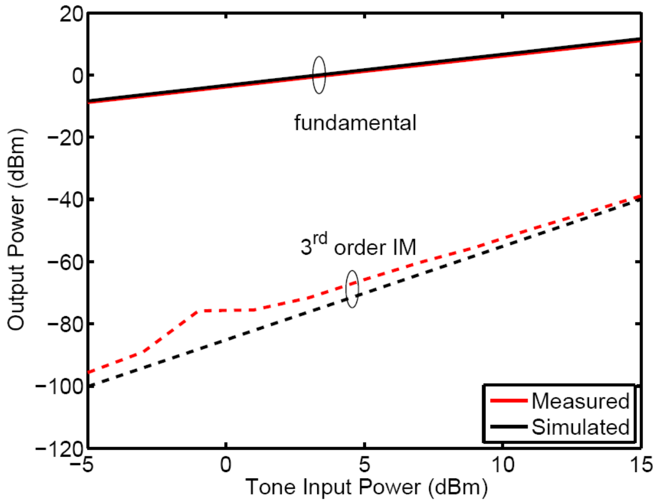


Tunable Wilkinson Divider (2)

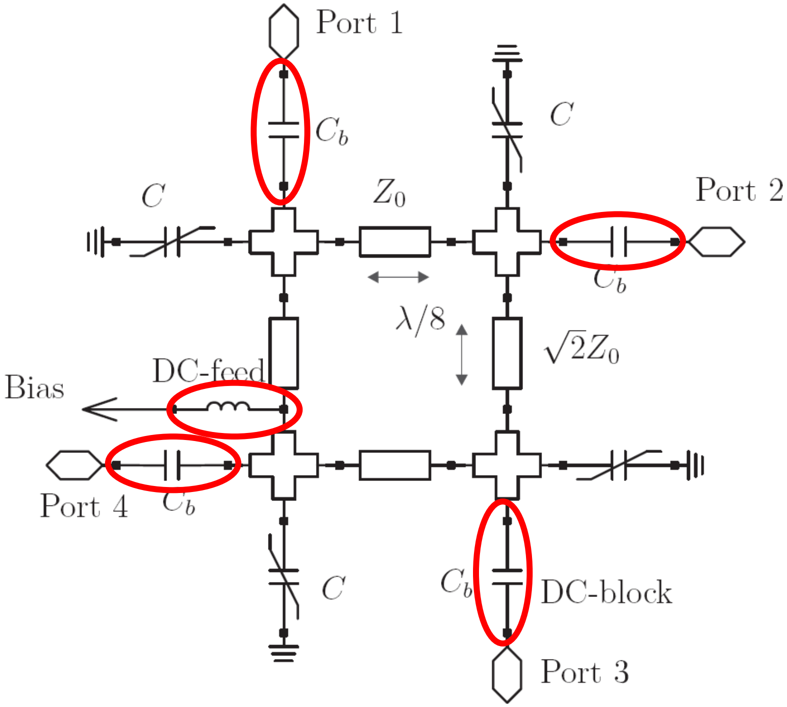


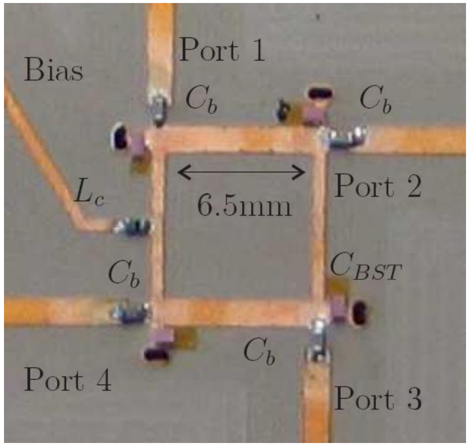


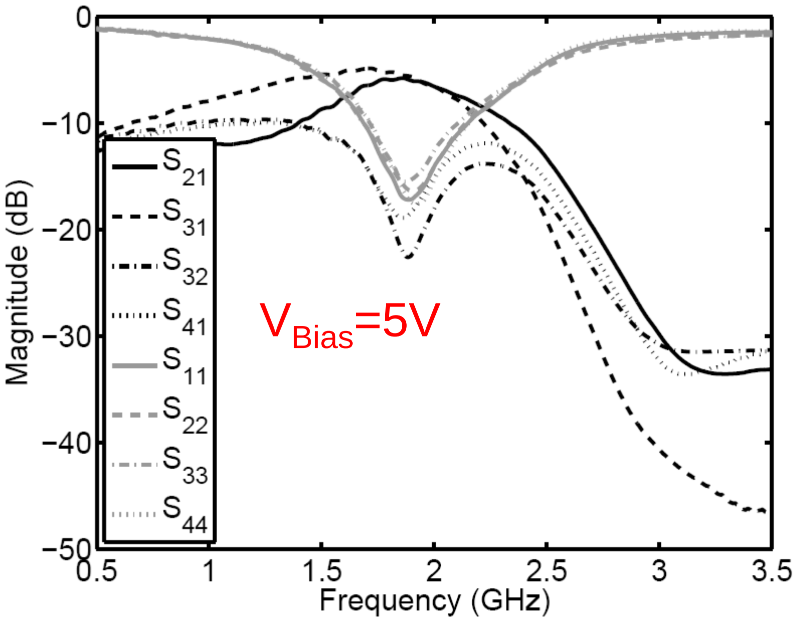
- IL < 1.2dB, Isolation > 25dB
- Lowpass filtering S_{21},S_{31}
- Attenuation > 20dB at $2f_0$
- Tuning range 1.7-2.1GHz



Tunable Branch-Line (1)







- Size reduction 50%
- Lowpass filtering
- Attenuation > 30dB at second harmonic

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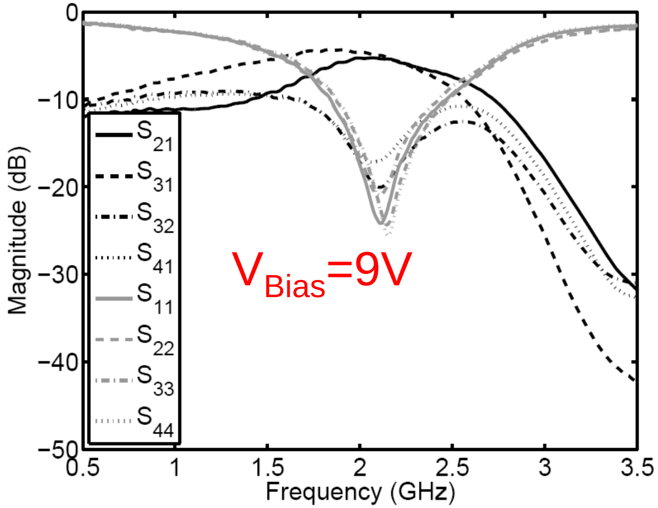
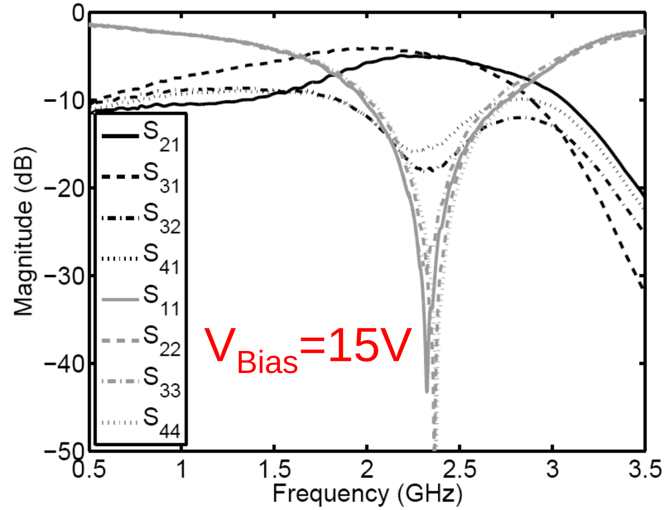
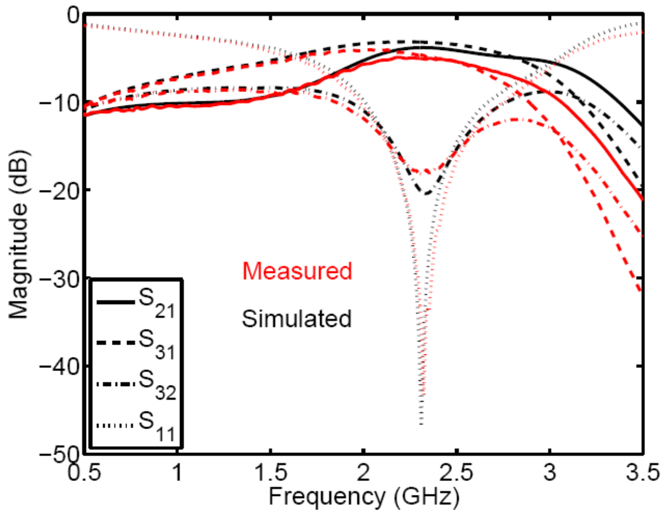
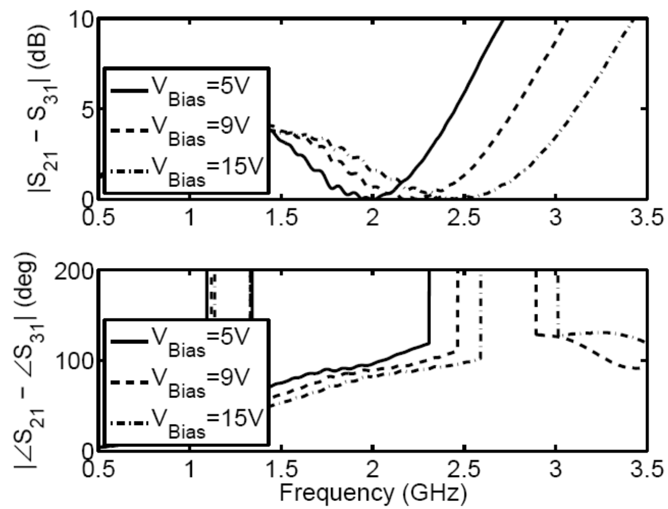
Tunable Branch-Line (2)

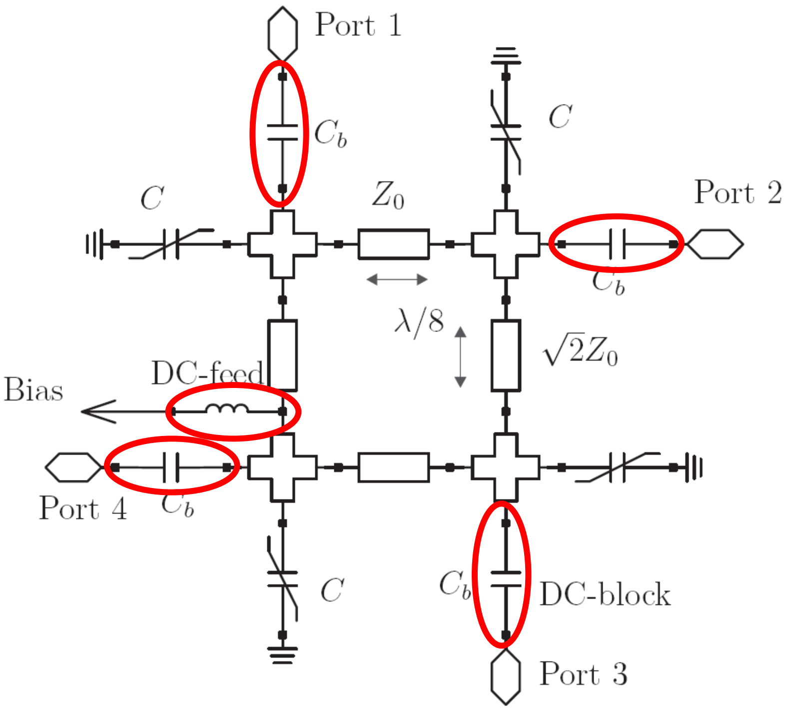


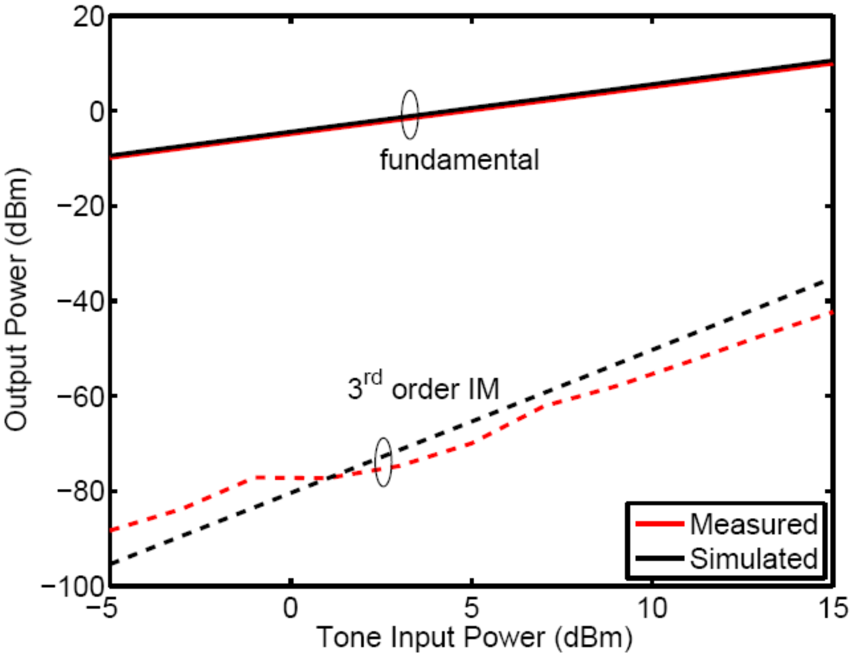






Tunable Branch-Line (3)



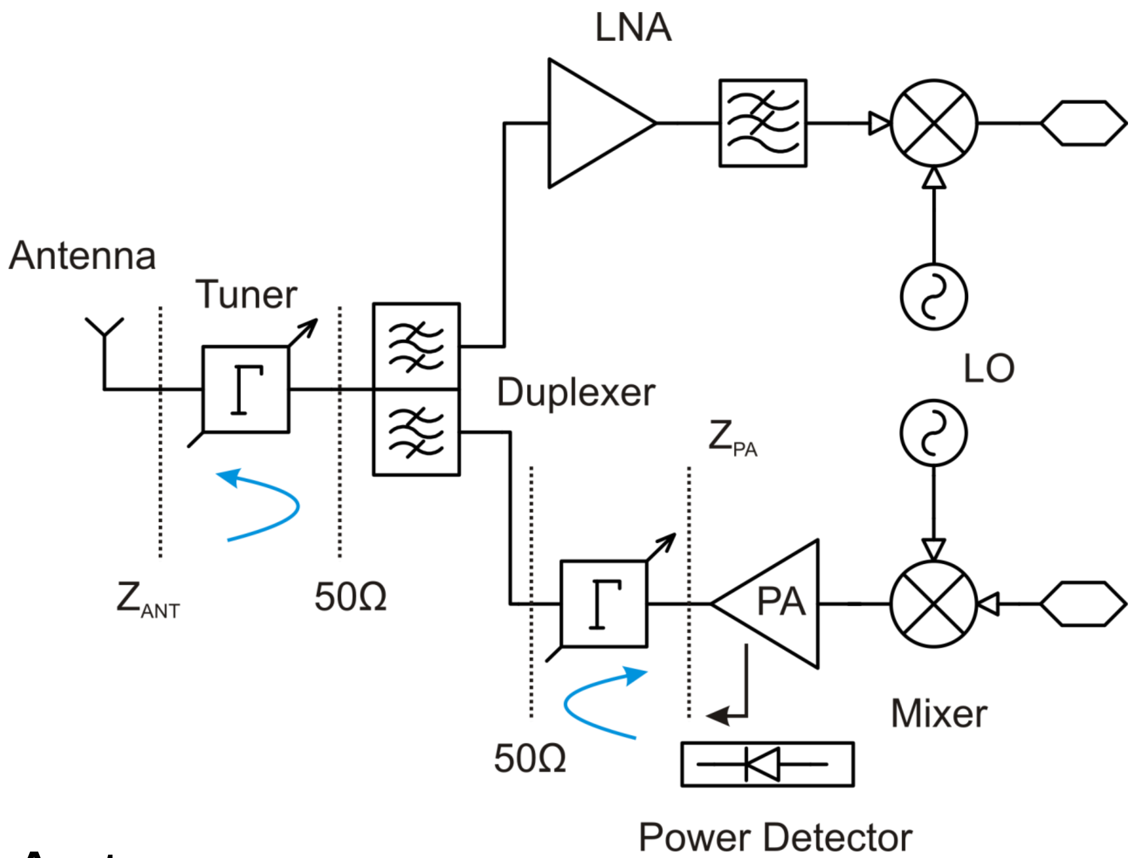


- Tuning range 1.8-2.3GHz
- IL < 2.7dB, RL > 15dB
- Amplitude error < 0.4dB, phase error < 5deg

Part 2 – Impedance Matching

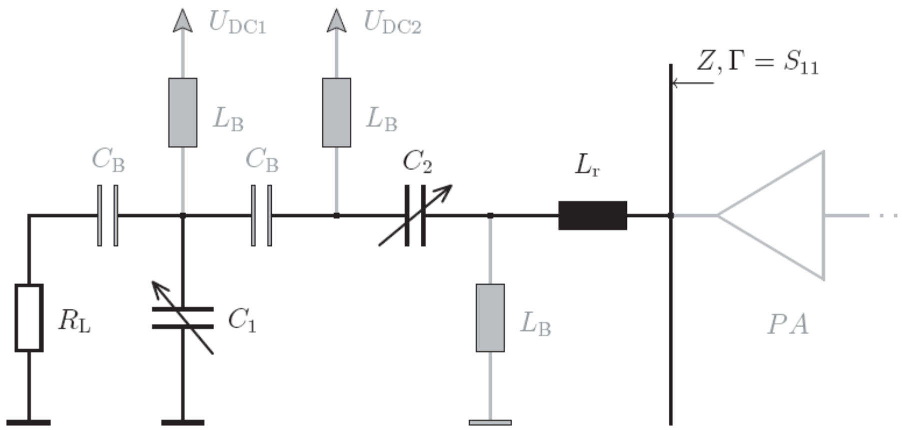
- Motivation - Missmatch Conditions
- L Matching Network
- Pi Matching Network
- T Matching Network
- Reflection Type Matching Network

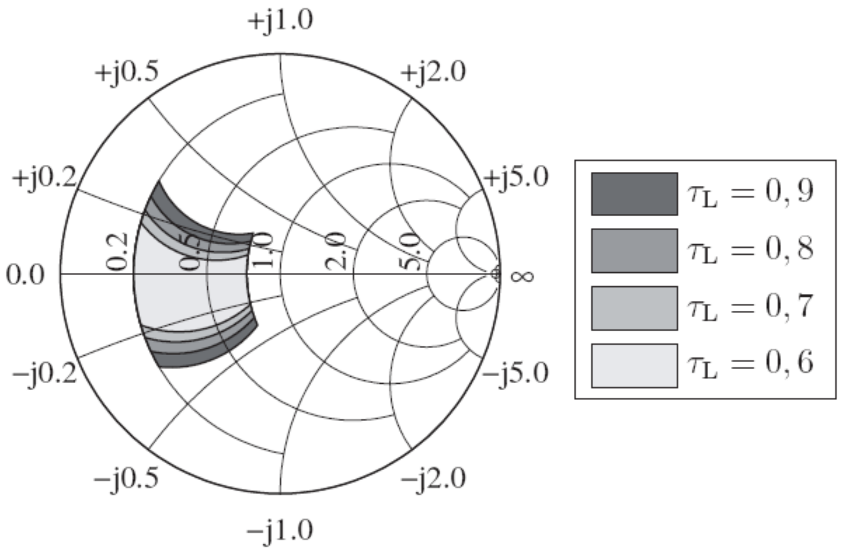
Mismatch Conditions



- Antenna
- Power amplifier

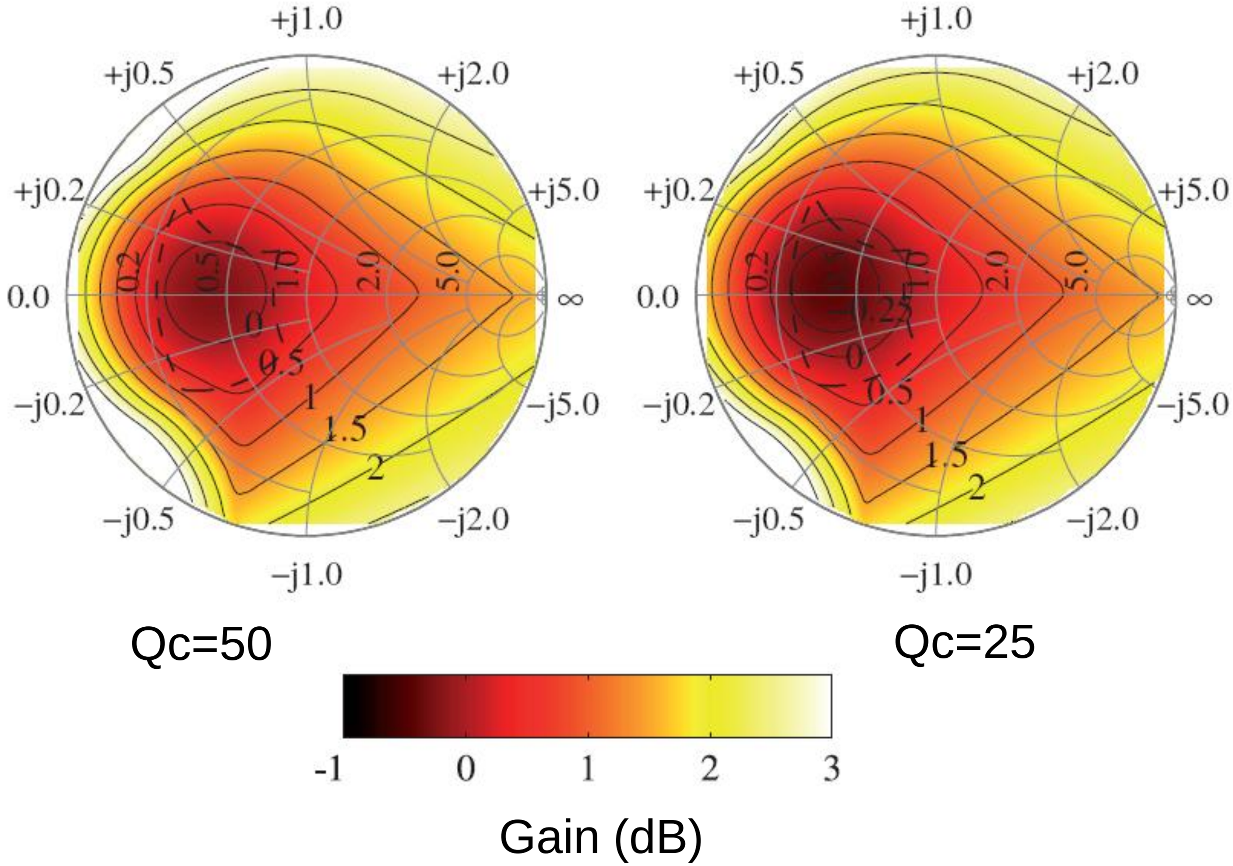
L - Matching Network





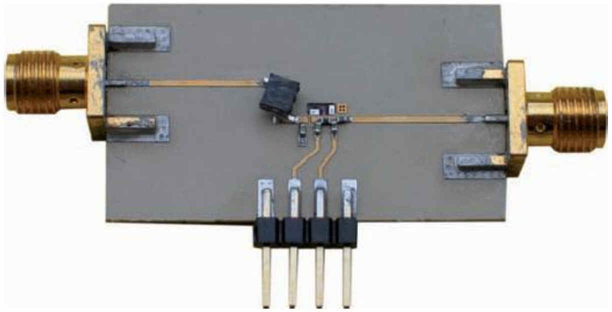
- PA Matching
- Tunable L is series LC
- Small matching area

L - Network Gain

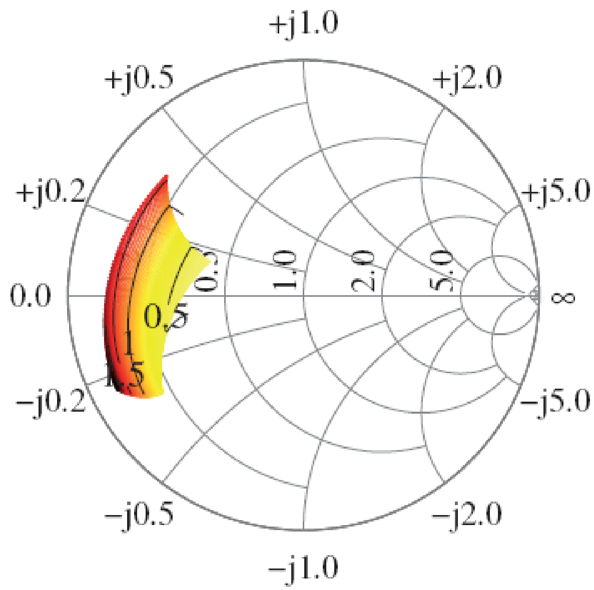


- Fixed MN with Zin=25Ω SMD 0402 components
- Losses for minor impedance variations

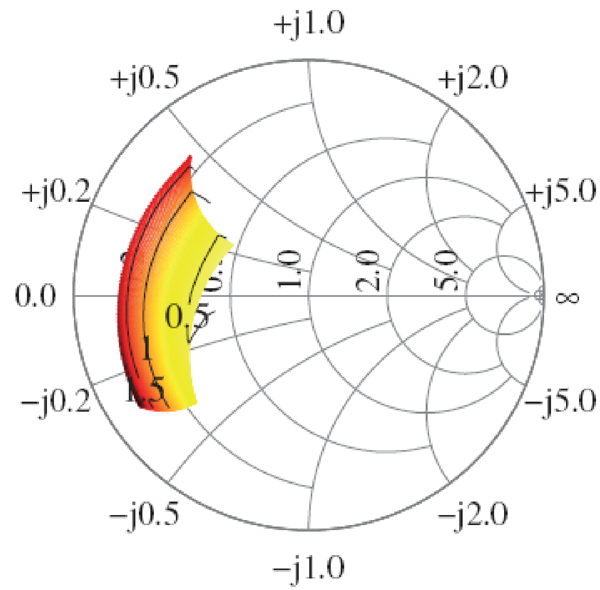
L - Matching Area



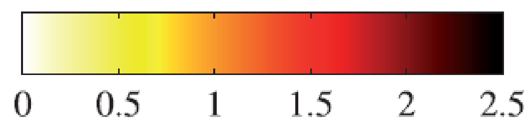
Bias



Simulated



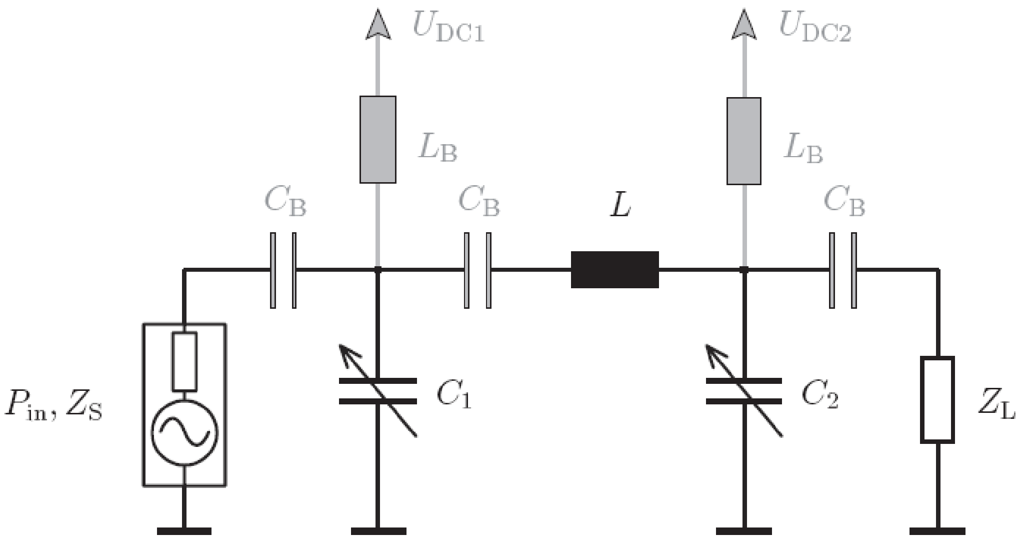
Measured

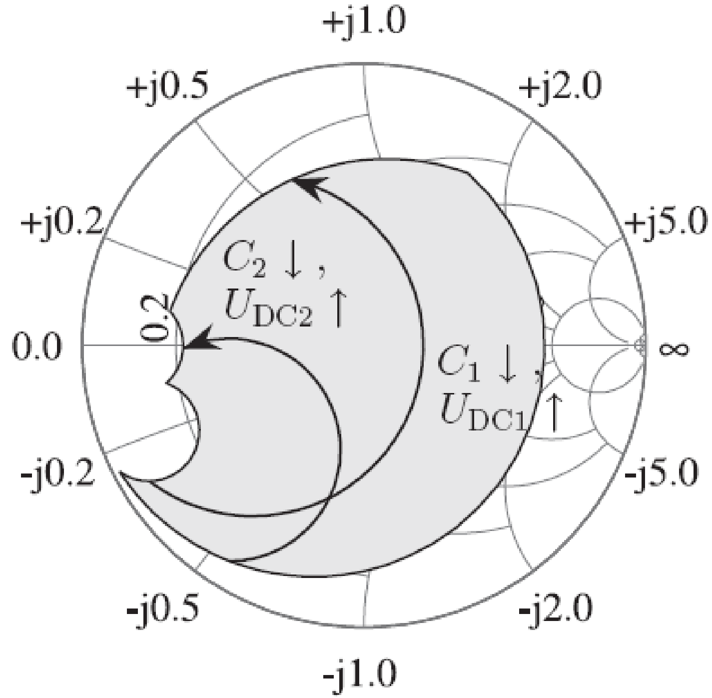


Transducer Power Loss (dB)

- Excellent agreement
- Dynamically adjustable PA impedance

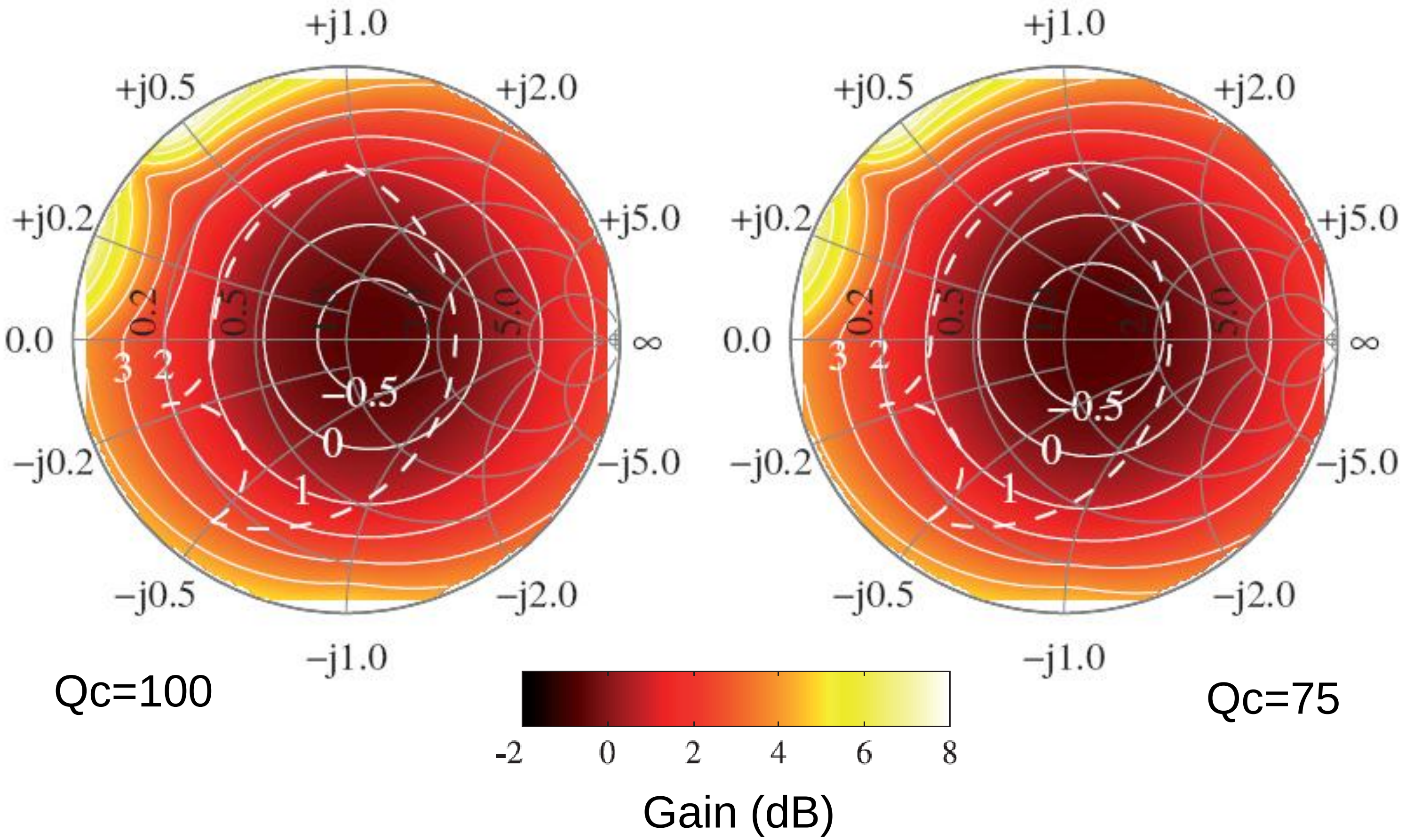
Π - Matching Network





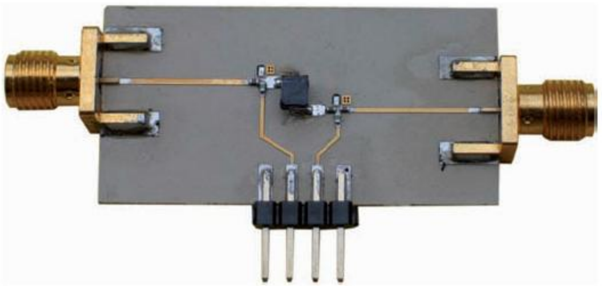
- High C value
- Suitable for low impedances
- Low IMD

Π – Network Gain

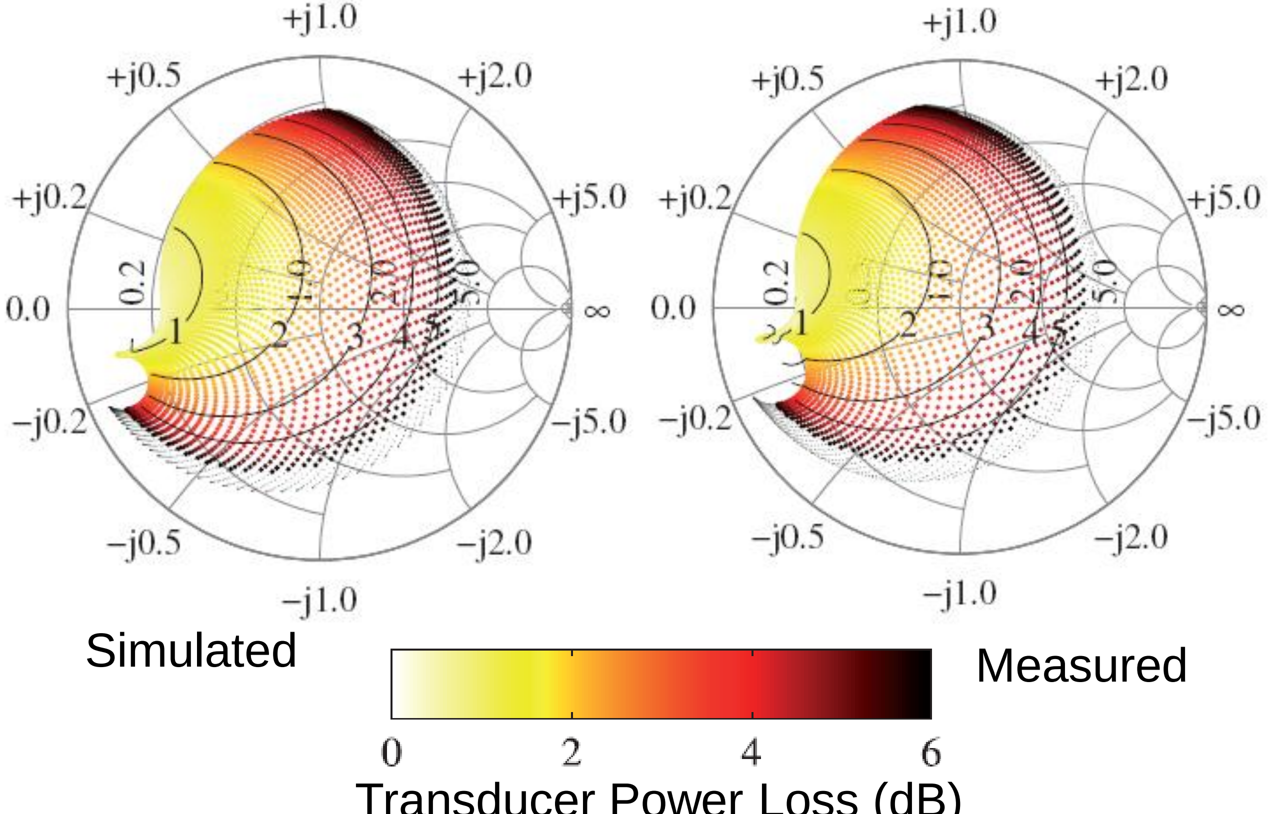


- Gain for significant impedance variations

Π – Matching Area



Bias

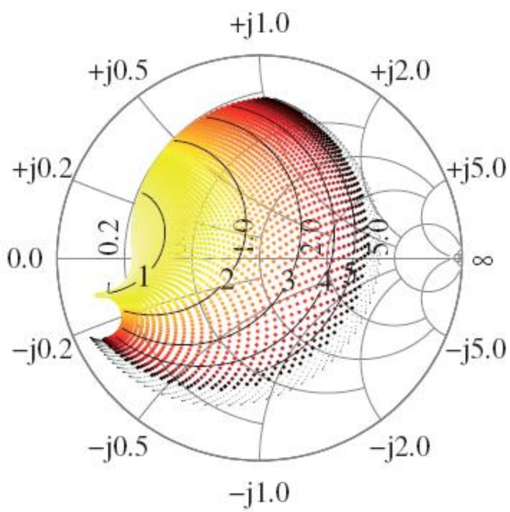


Simulated

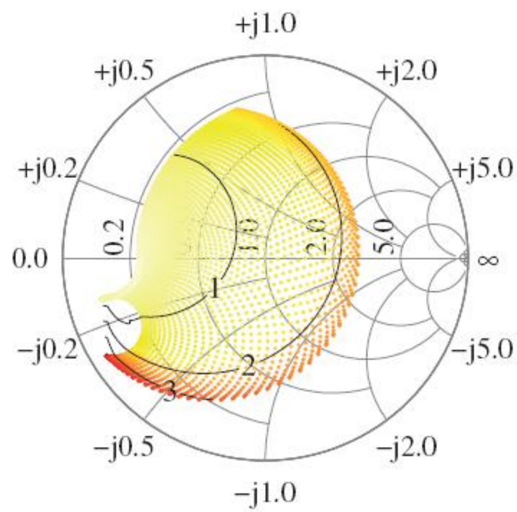
Measured

- Excellent agreement
- Losses increase for higher impedances

Assembly Parasitics

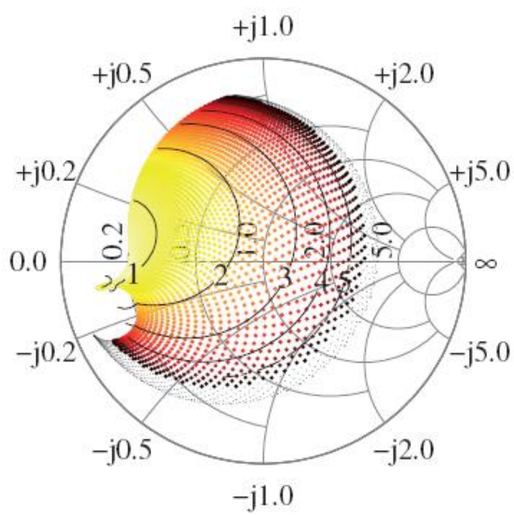


Simulated with bond wires



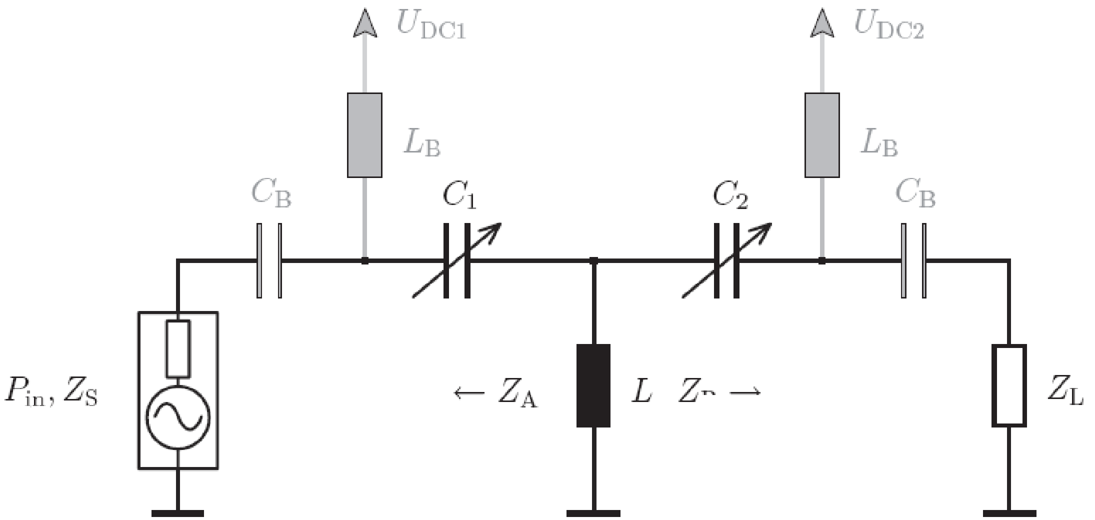
Simulated without bond wires

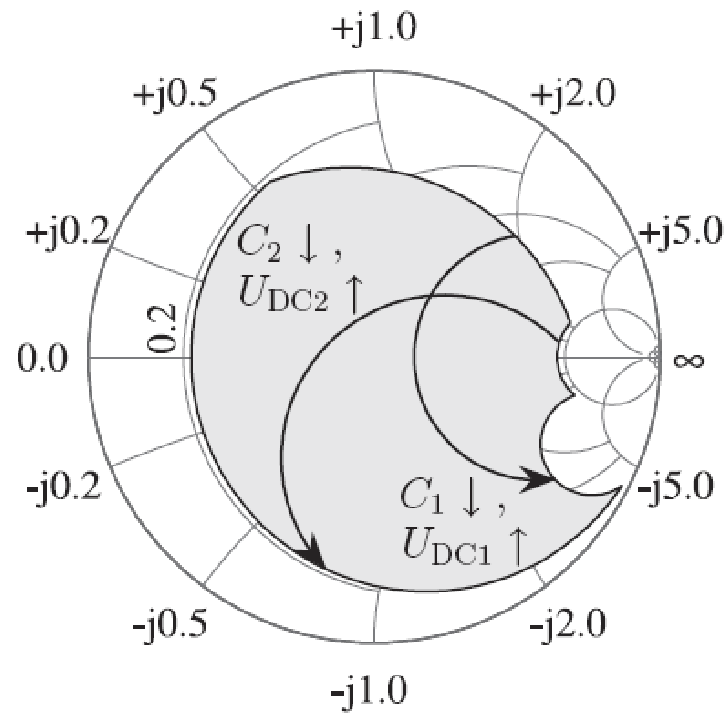
Measured



Transducer Power Loss (dB)

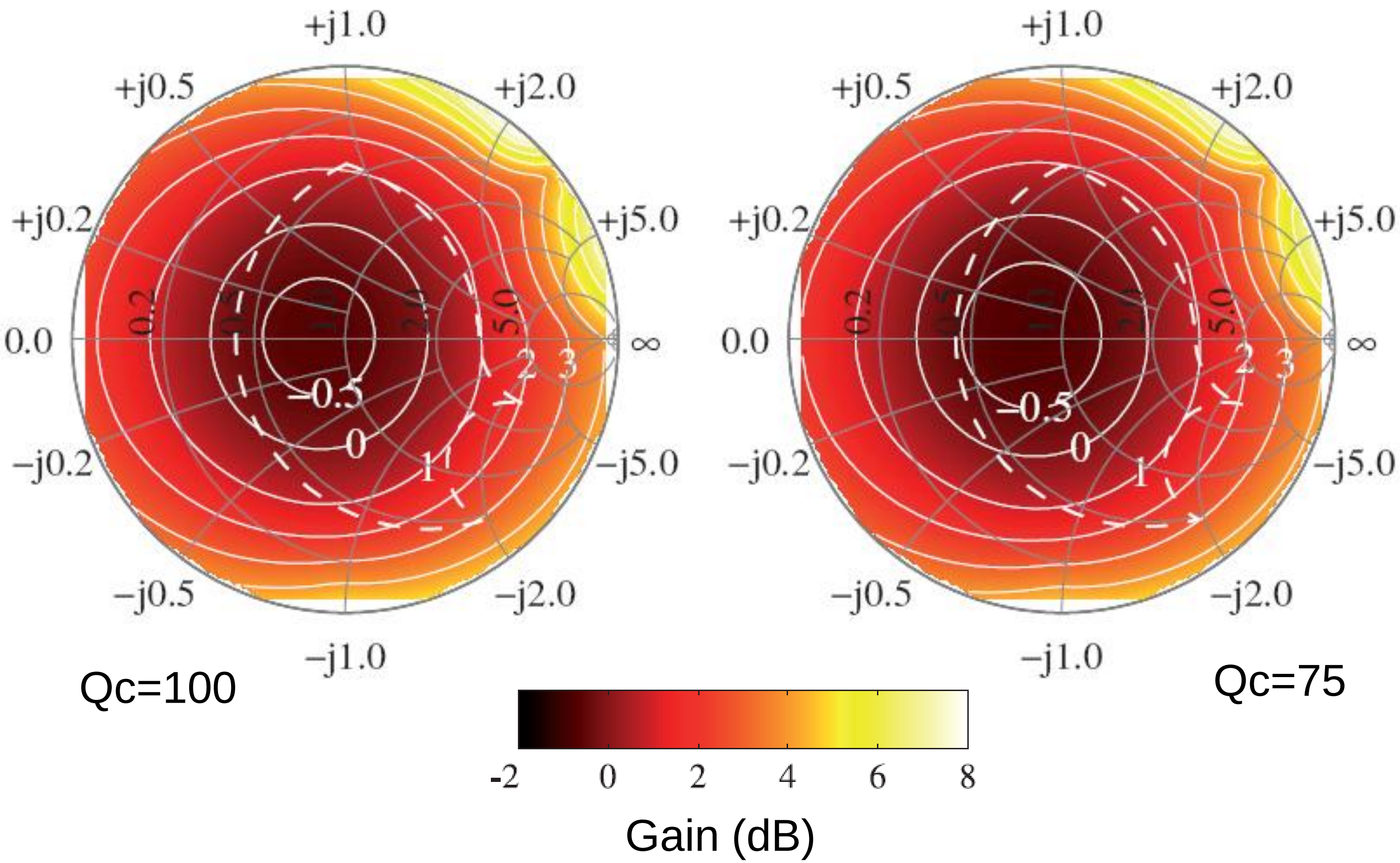
T – Matching Network





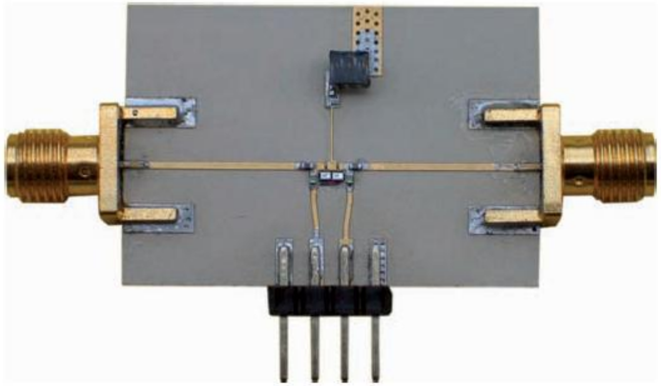
- Low C values
- Suitable for high impedances
- High IMD

T – Network Gain

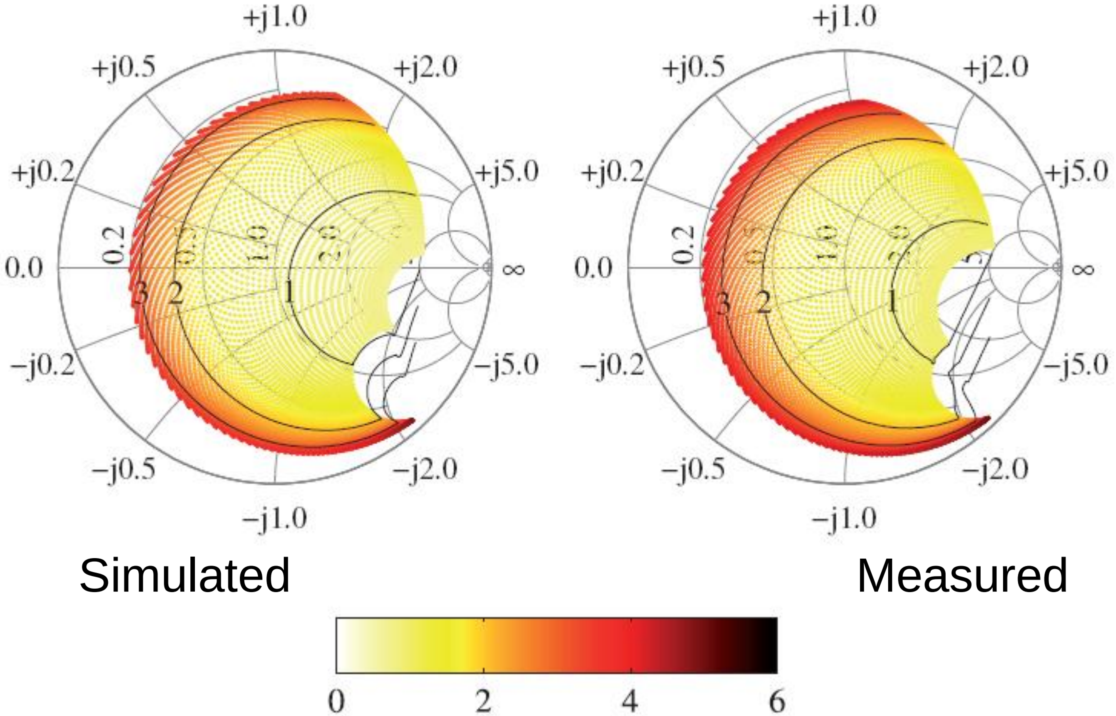


- Gain for signifficant impedance variation

T – Matching Area



Bias



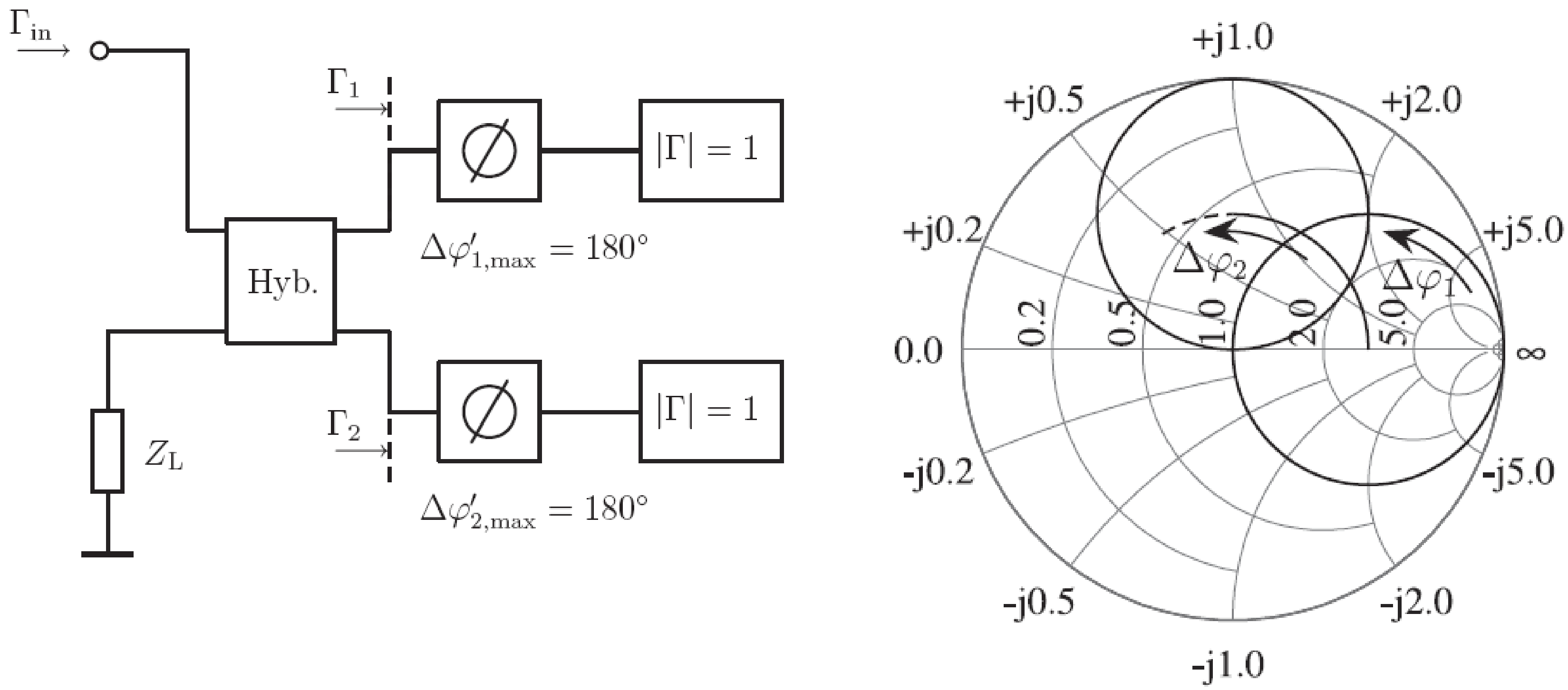
Simulated

Measured

Transducer Power Loss (dB)

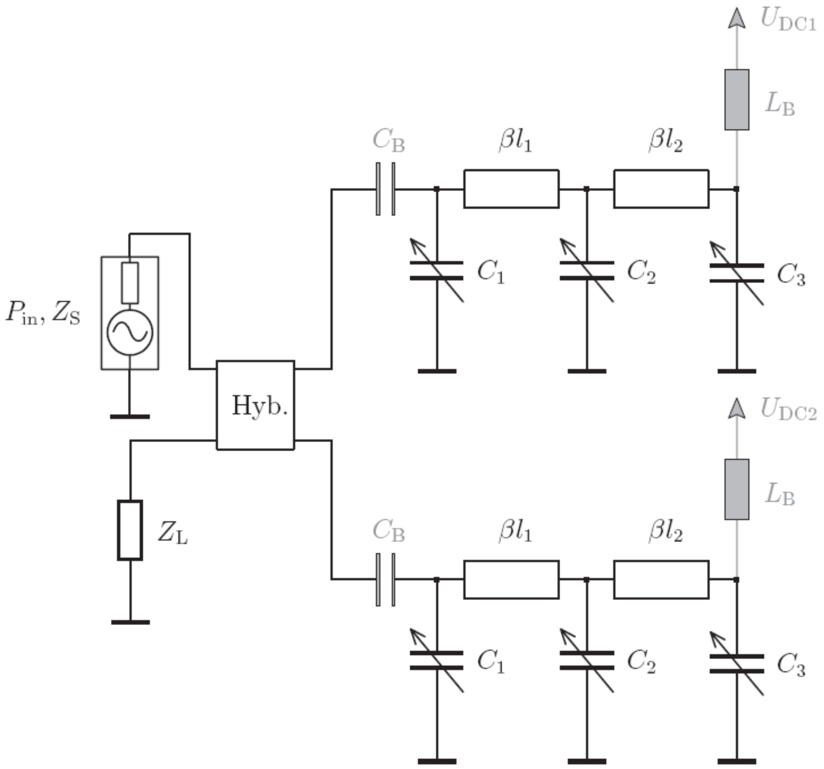
- Excellent agreement
- Higher losses for low impedances

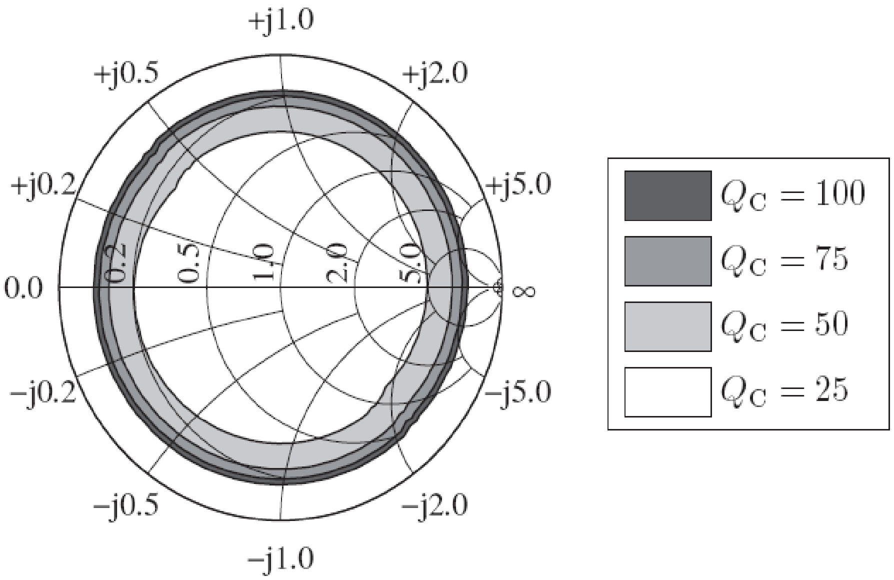
Reflection – Matching Network



- Total Smith chart area coverage
- Hybrid coupler and phase shifters
- Large circuit dimension

Reflection Type Circuit

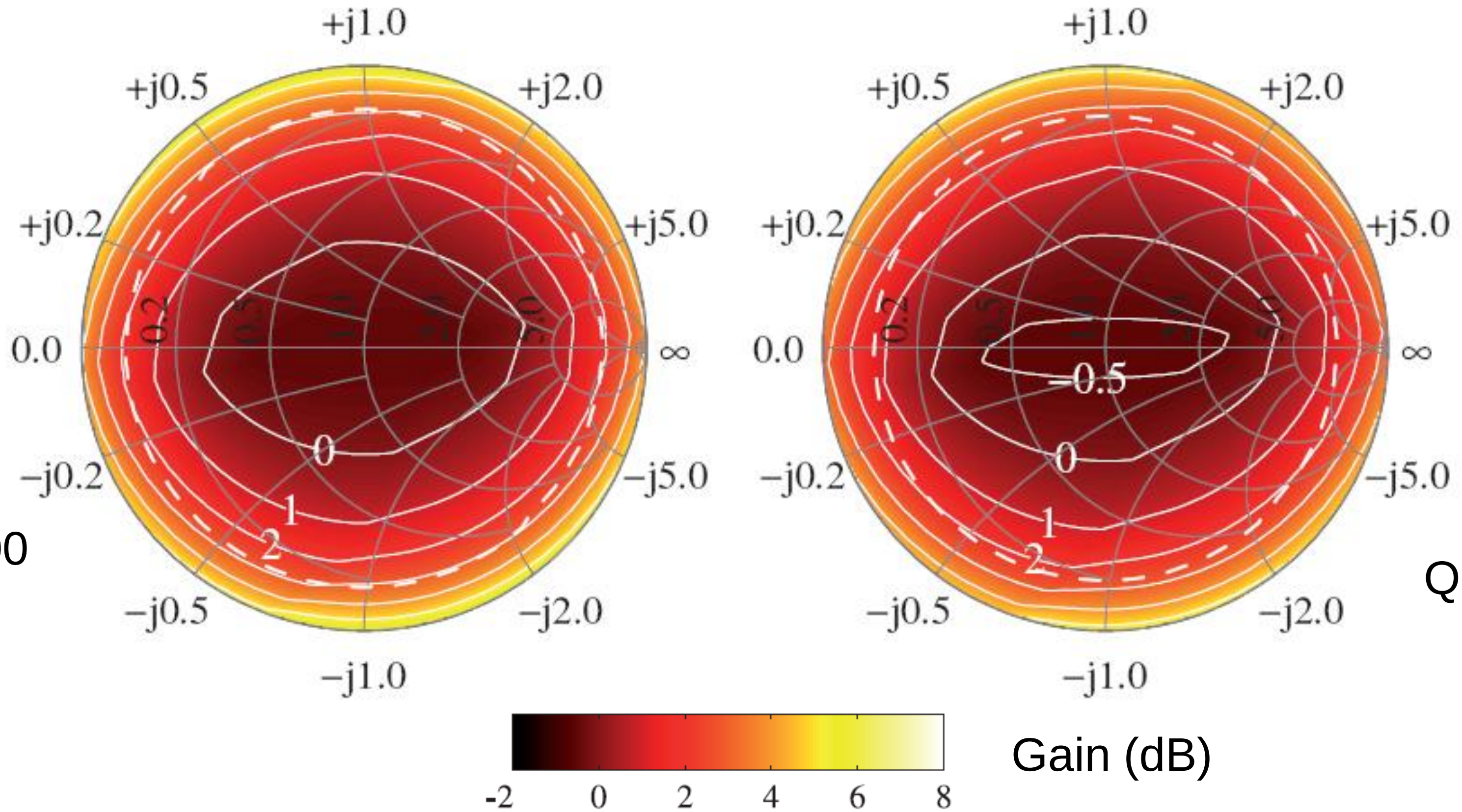




- High Q values for varactors lead to large matching area

Reflection – Network Gain

Qc=100

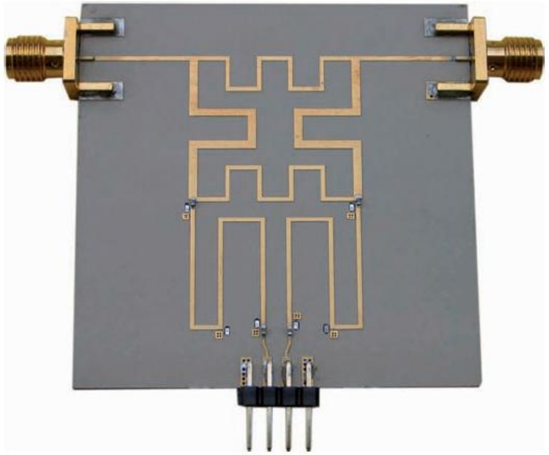


Qc=75

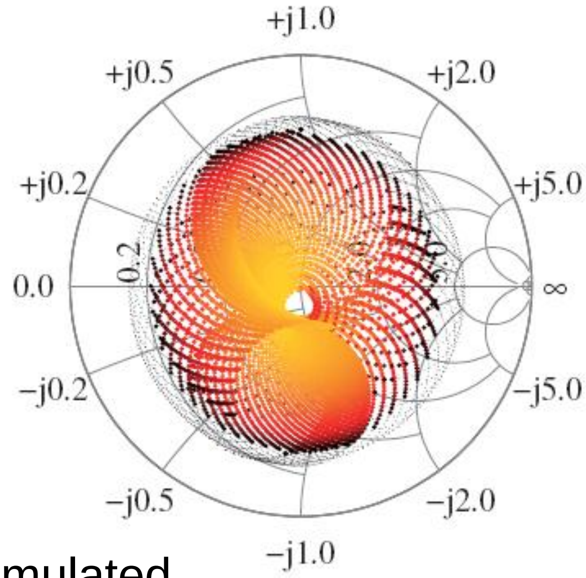
Gain (dB)

- Gain for signifficant impedance variation

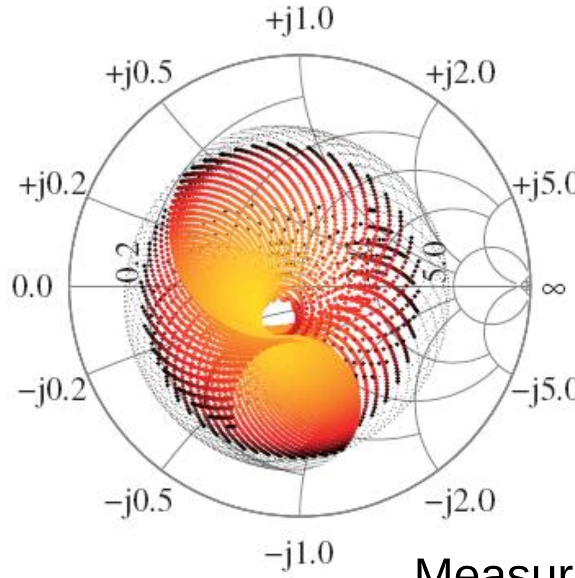
Reflection – Matching Area



Bias



Simulated



Measured

Transducer Power Loss (dB)

- Excellent agreement
- Symmetric matching area

Conclusion

Conclusion

- Potential of ferroelectrics in tunable front-end
- Tunable microwave circuits
- Prototype implementation & results

Outlook

- Integration of tunable microwave subsystems in front-end architectures