Chapter 8

Bended Differential Transmission Line Using Compensation Inductance and Capacitance

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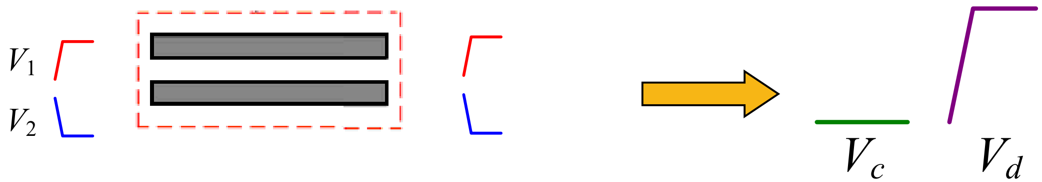
Outline

- Motivation
- Literature Survey
- Bended Differential Transmission Line Using Right-Angled Bend
- Bended Differential Transmission Line Using Compensation Inductance and Capacitance
- Conclusions

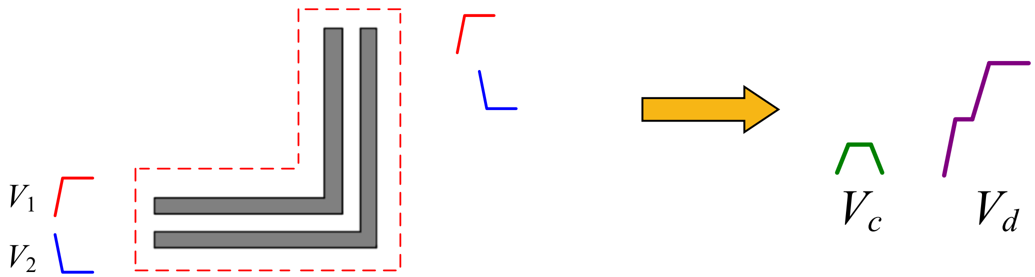
Motivation

- Straight Differential Line
  - No path difference → No common-mode noise induced

$$\begin{bmatrix} V_c \\ V_d \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ 1 & -1 \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

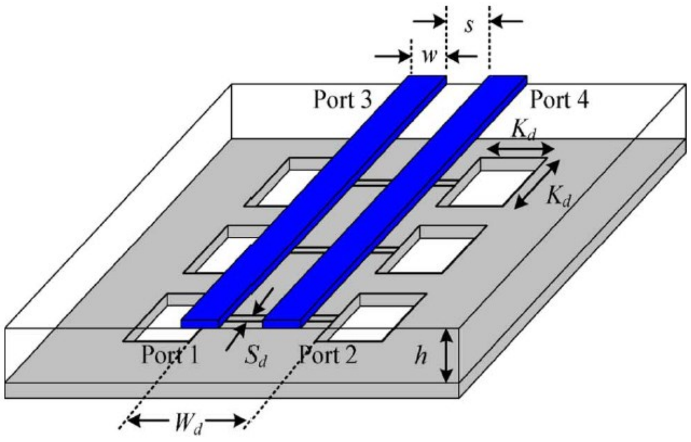


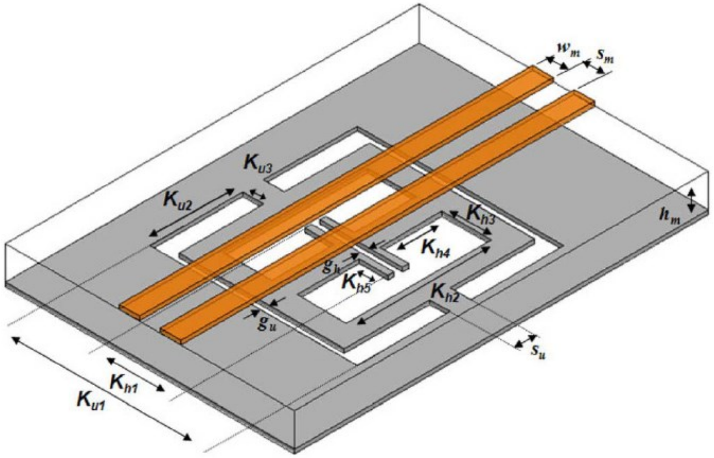
- Right-Angled Differential Line
  - With path difference → Common-mode noise induced



Literature Survey

- Common-Mode Noise Filter [1], [2]
  - Advantage: PCB process compatibility
  - Disadvantage: Limited bandwidth, interlayer interference, large size



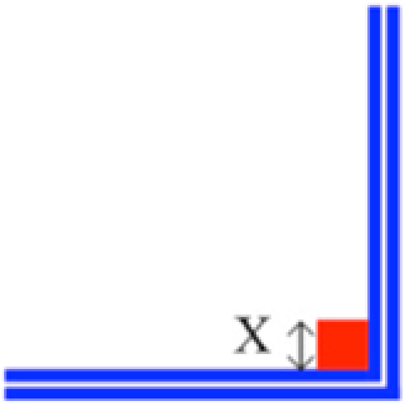


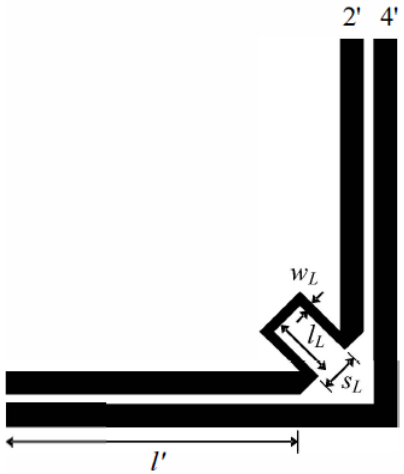
[1] W.-T. Liu, C.-H. Tsai, T.-W. Han, and T.-L. Wu, "An embedded common-mode suppression filter for GHz differential signals using periodic defected ground plane," *IEEE Microw. Wireless Compon. Lett.*, vol. 18, no. 4, pp. 248–250, Apr. 2008.

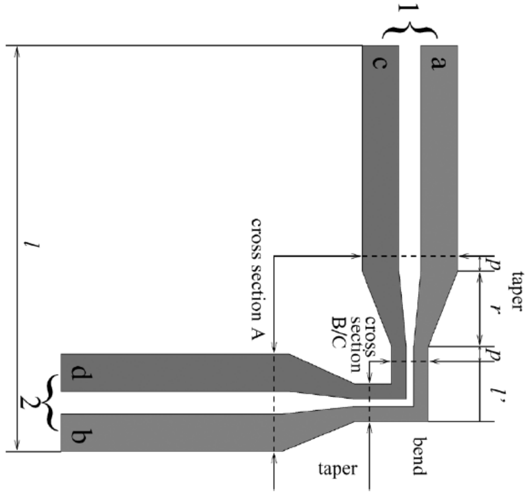
[2] S. J. Wu, C. H, Tsai, T. L. Wu, and T. Itoh, "A novel wideband common-mode suppression filter for gigahertz differential signals using coupled patterned ground structure," *IEEE Trans. Microw. Theory Tech.*, vol. 57, no.4, pp. 848-855, Apr. 2009.

Literature Survey

- Compensated Differential Line [3]-[5]
  - Advantage: No interlayer interference, broadband, compact
  - Disadvantage: Differential-mode reflection





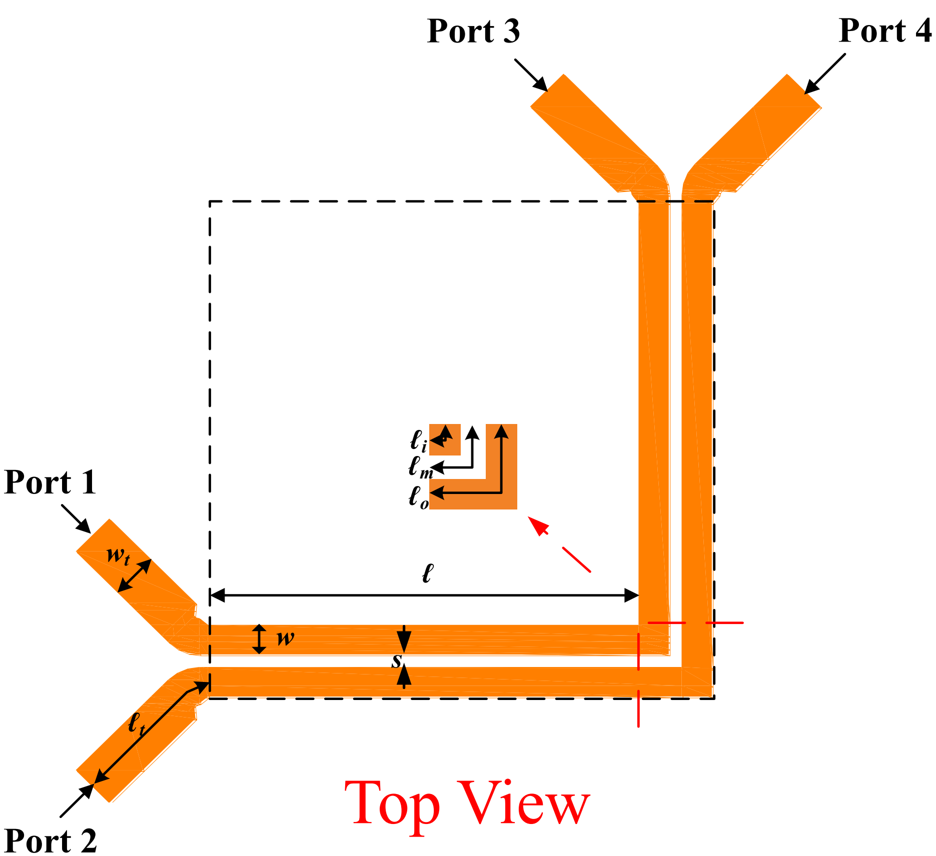


[3] G. H. Shiue, W. D. Guo, C. M. Lin, and R. B. Wu, "Noise reduction using compensation capacitance for bend discontinuities of differential transmission lines," *IEEE Trans. Adv. Packag.*, vol. 29, pp. 560–569, Aug. 2006.
[4] C. H. Chang, R. Y. Fang, and C. L. Wang, "Bended differential transmission line using compensation inductance for common-mode noise suppression," *IEEE Trans. Compo. Packag. Manu. Tech.*, vol. 2, pp. 1518–1525, Sep. 2012.
[5] C. Gazda, D. V. Ginste , H. Rogier, R. B. Wu, and D. D. Zutter, "A wideband common-mode suppression filter for bend discontinuities in differential signaling using tightly coupled microstrips," *IEEE Trans. Adv. Packag.*, vol. 33, pp. 969–978, Nov. 2010.

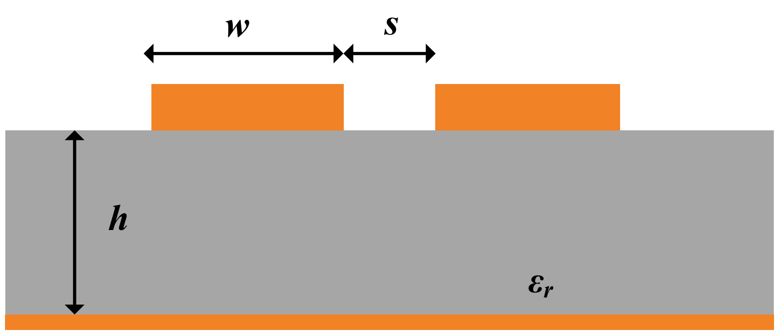
Bended Differential Transmission Line Using Right-Angled Bend

- Structure and Dimensions
  - FR4 substrate with εr=4.4 and tanδ=0.02

w (mm)	s (mm)	h (mm)
1.75	0.75	1.6
ℓ_i (mm)	ℓ_o (mm)	ℓ_m (mm)
1.75	6.75	4.25
ℓ (mm)	w_t (mm)	ℓ_t (mm)
25	2.9	9.22



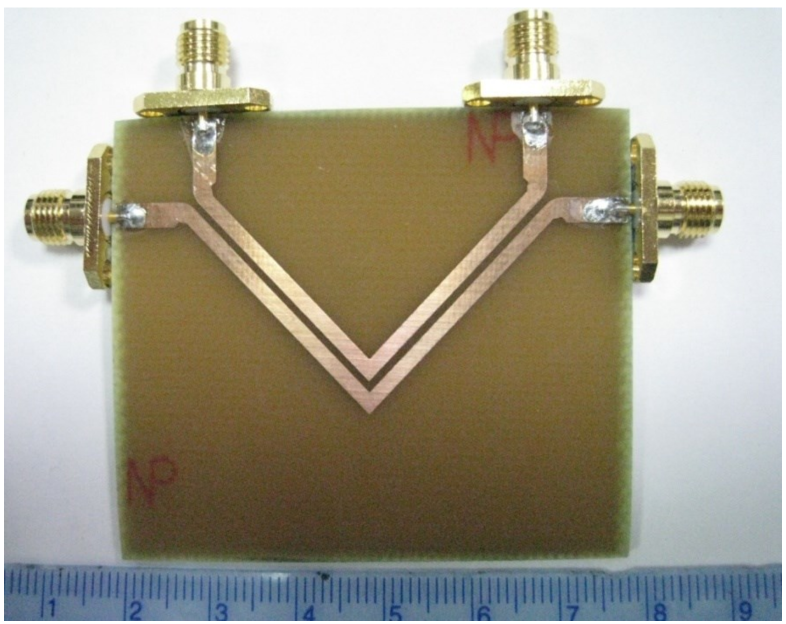
Top View



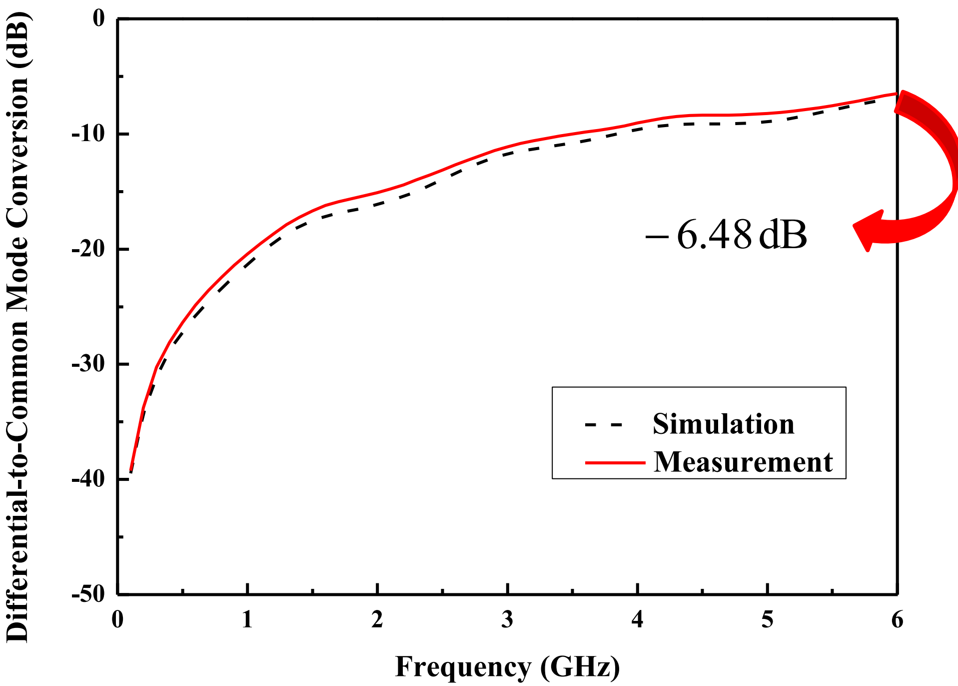
Cross-sectional View

Bended Differential Transmission Line Using Right-Angled Bend

- Differential-to-Common Mode Conversion
  - Maximum value of -6.48 dB



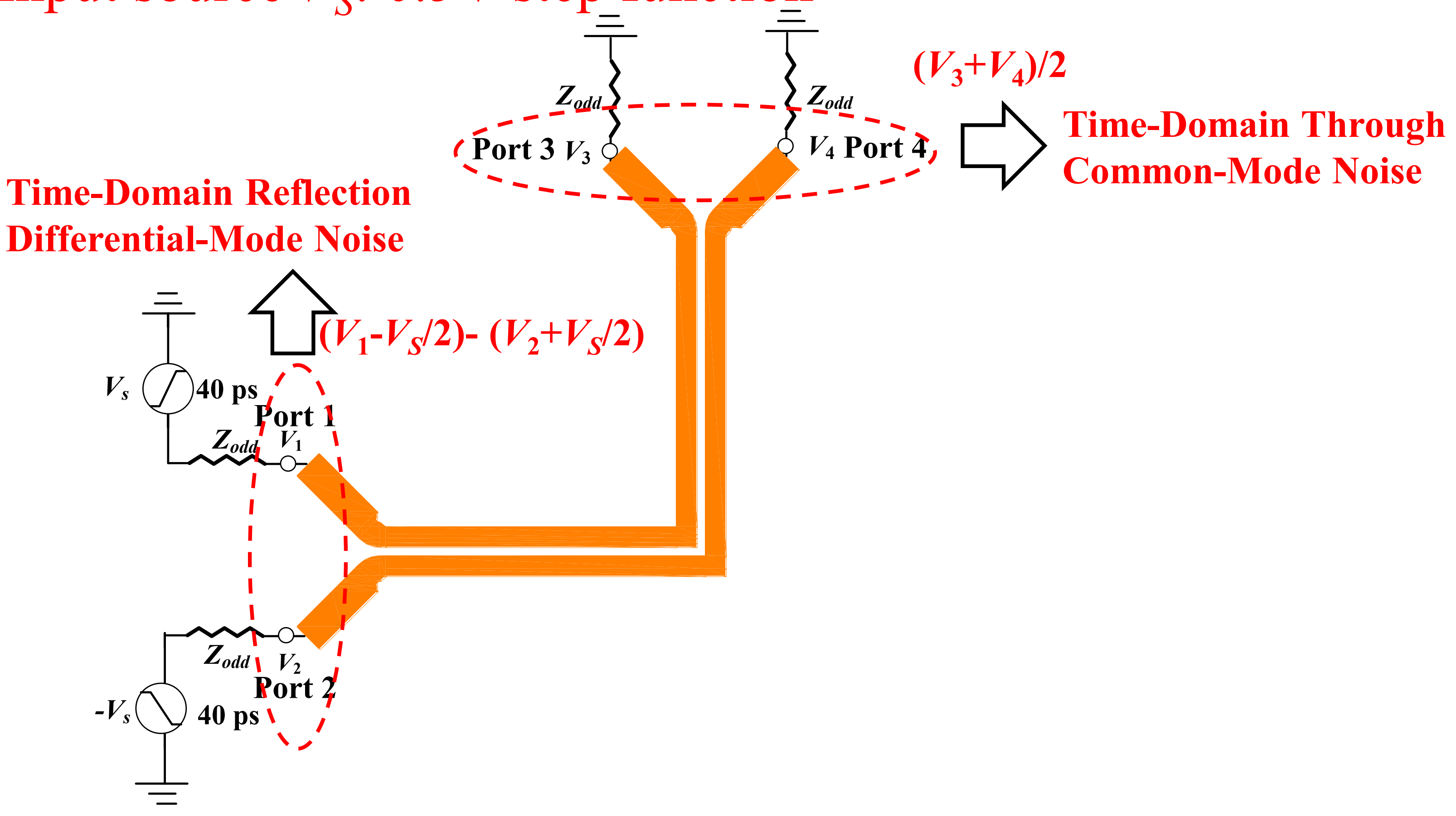
Fabricated Circuit



Mode Conversion

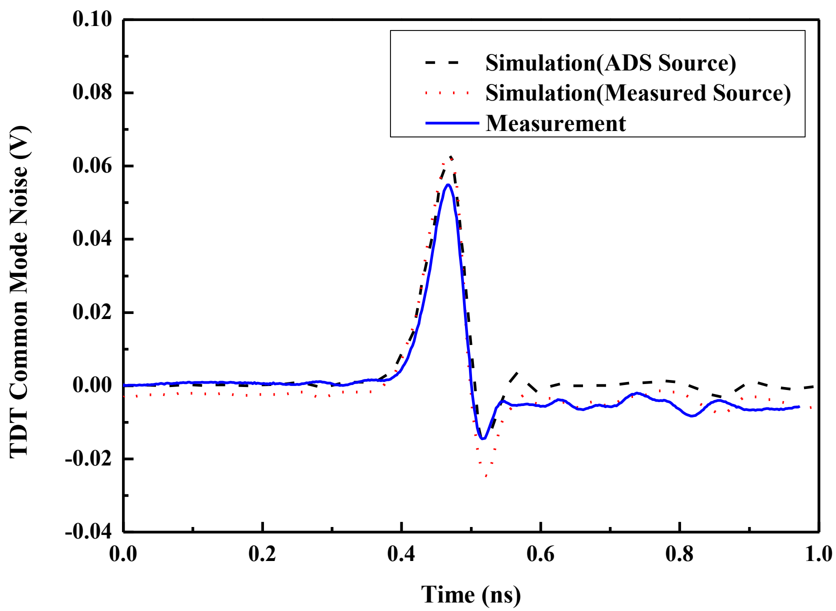
Bended Differential Transmission Line Using Right-Angled Bend

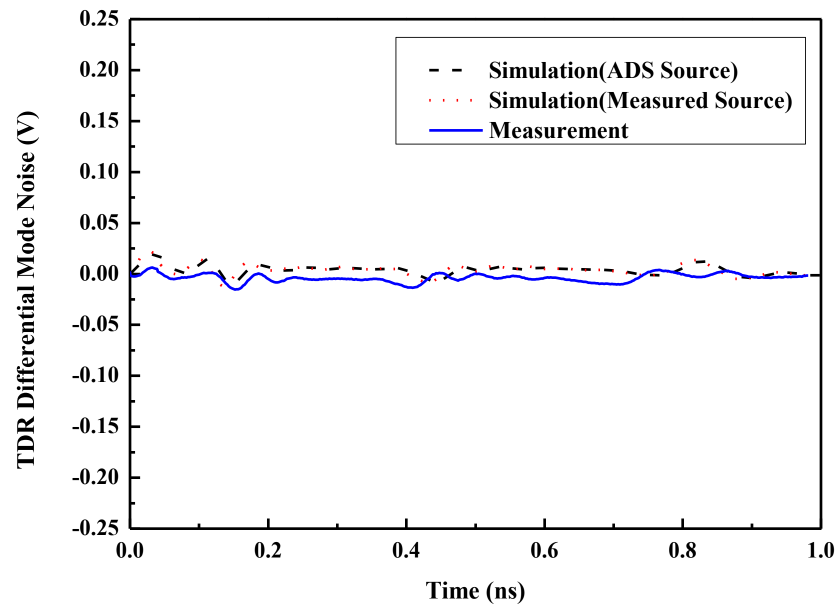
- Time-Domain Simulation Setup
  - Input source V_S: 0.5V step function



Bended Differential Transmission Line Using Right-Angled Bend

- TDT Common-Mode and TDR Differential-Mode Noises

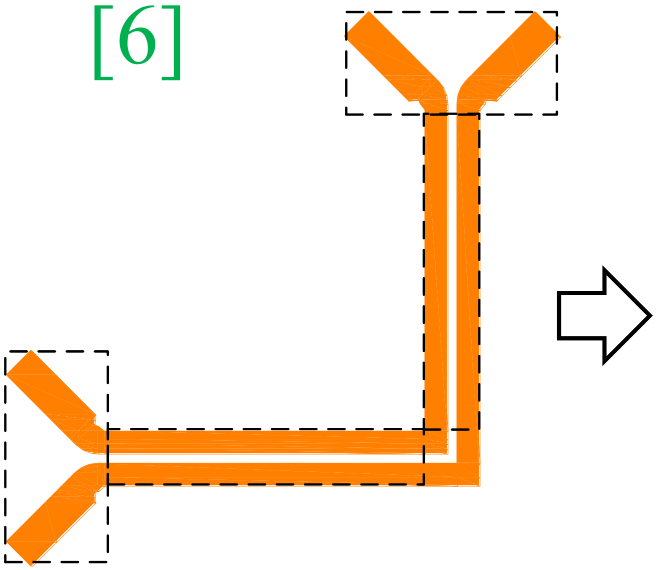




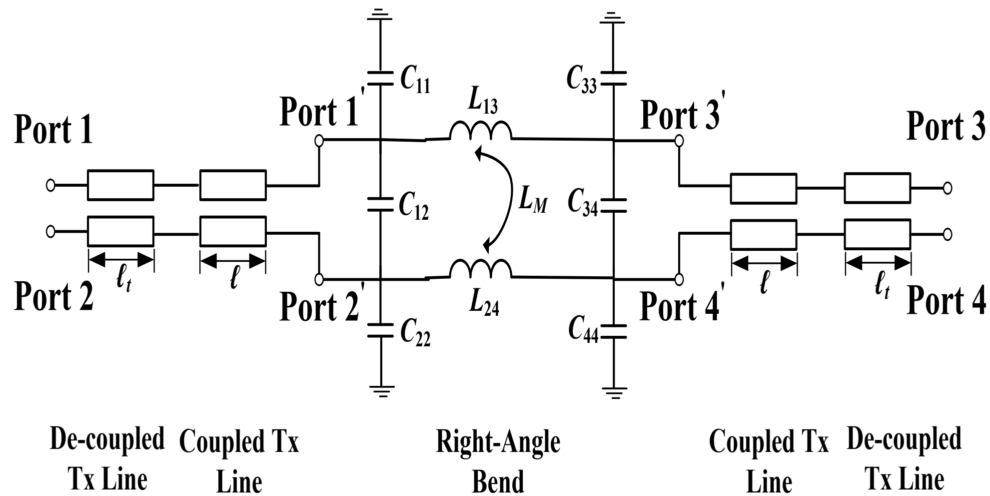
TDT Common-Mode Noise (Volt)	Simulation	0.064
	Measurement	0.056
TDR Differential-Mode Noise (Volt)	Simulation	0.020
	Measurement	0.017

Bended Differential Transmission Line Using Right-Angled Bend

- Equivalent Circuit of Right-Angled Bend [3], [6]



Right-Angled Differential Line



Equivalent Circuit

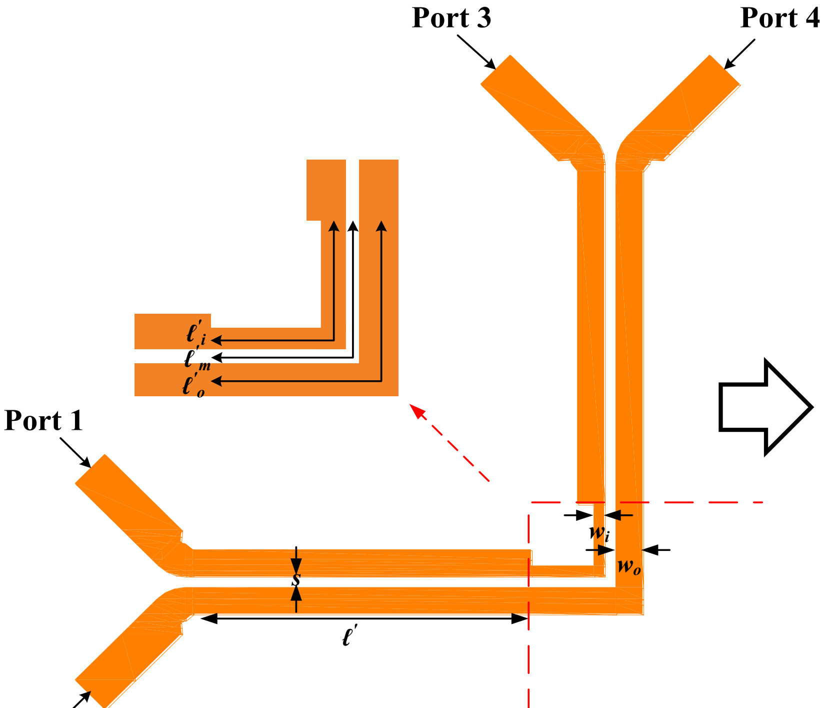
L_{13} (nH)	L_{24} (nH)	L_M (nH)	$C_{11}(C_{33})$ (pF)	$C_{22}(C_{44})$ (pF)	C_{12} (C_{34}) (pF)
0.6727	2.5949	0.4993	0.0676	0.2609	0.0397

[6] K. C. Gupta, R. Garg, I. Bahl, P. Bhartia, *Microstrip Lines and Slotlines*. Artech House on Demand, pp. 458—486, 1996.

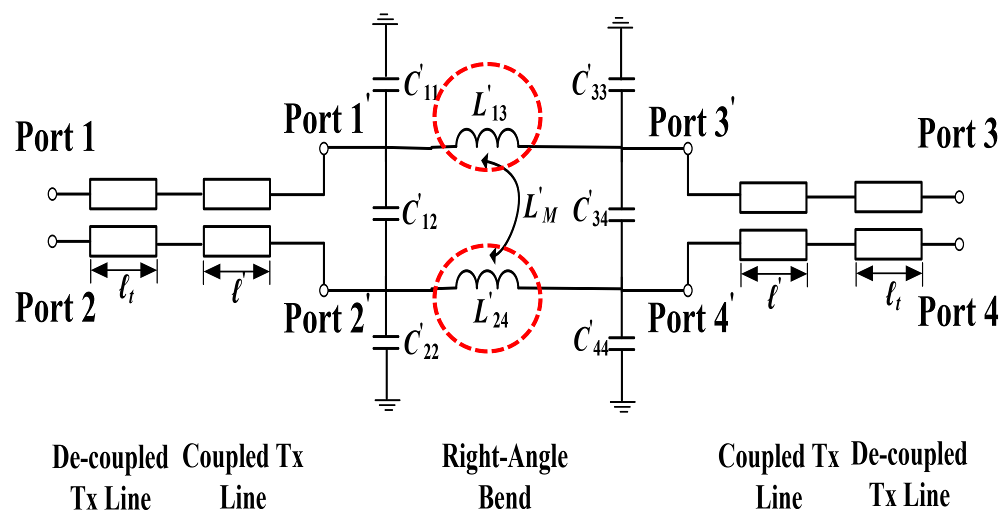
Bended Differential Transmission Line Using Compensation *L* and *C*

- Inductance Compensation
  - Using asymmetric coupled line

ℓ' (mm)	w_o (mm)	ℓ'_o (mm)
21.9948	1.75	12.76
s (mm)	w_i (mm)	ℓ'_i (mm)
0.75	0.68	8.83



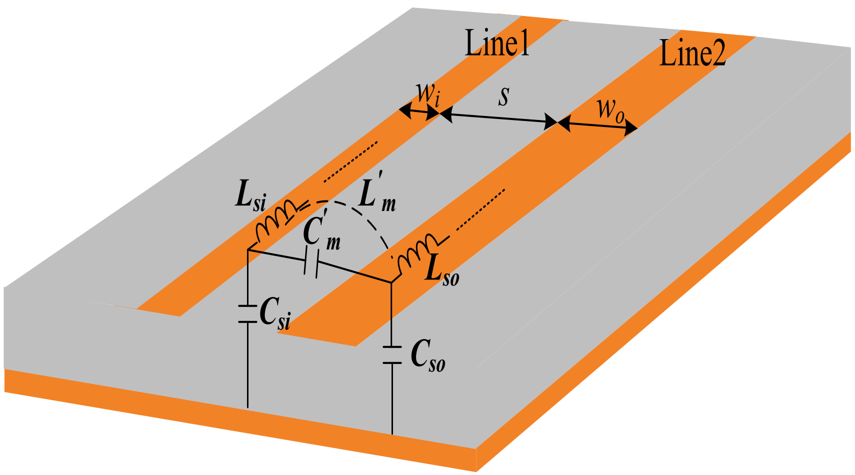
Inductance-Compensated Differential Line



Equivalent Circuit

Bended Differential Transmission Line Using Compensation *L* and *C*

- Inductance Compensation
  - Equivalent circuit values of the asymmetric coupled line



Asymmetric Coupled Line

$$L'_{13} = L_{si} \times \ell'_i$$

$$L'_{24} = L_{so} \times \ell'_o$$

$$L'_M = L'_m \times \ell'_m$$

$$C'_{11} = C'_{33} = C_{si} \times \frac{\ell'_i}{2}$$

$$C'_{22} = C'_{44} = C_{so} \times \frac{\ell'_o}{2}$$

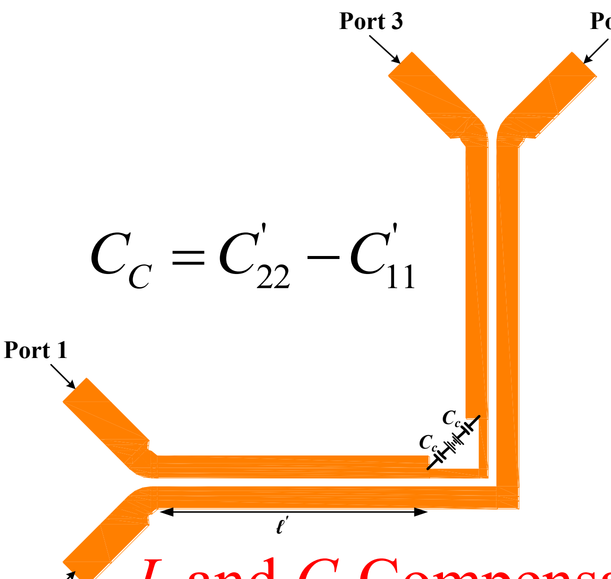
$$C'_{12} = C'_{34} = C'_m \times \frac{\ell'_m}{2}$$

L'_{13} (nH)	L'_{24} (nH)	L'_M (nH)	$C'_{11}(C'_{33})$ (pF)	$C'_{22}(C'_{44})$ (pF)	$C'_{12}(C'_{34})$ (pF)
4.9035	4.9055	1.5096	0.2124	0.4932	0.0907

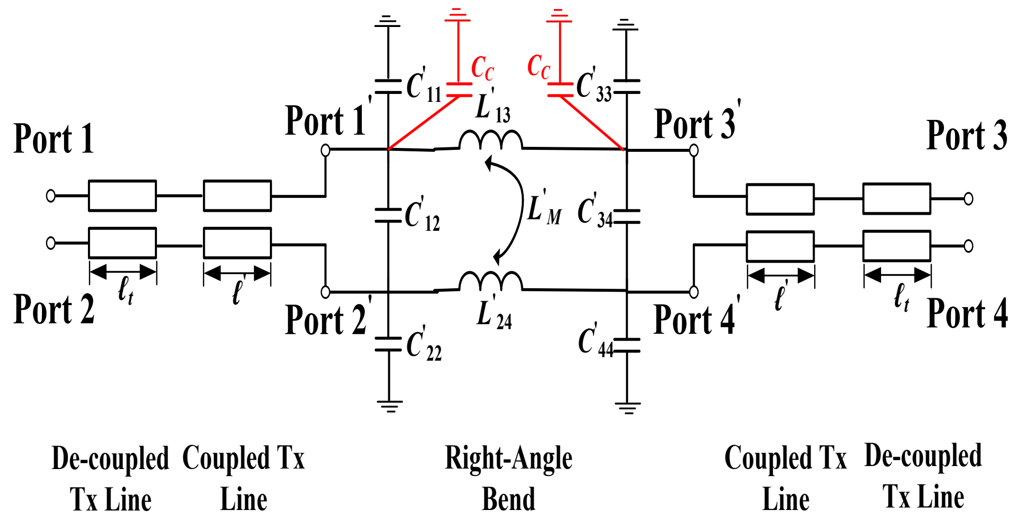
Bended Differential Transmission Line Using Compensation *L* and *C*

- Capacitance Compensation
  - Using SMD capacitor

$$C_C = C'_{22} - C'_{11}$$



L and *C*-Compensated Differential Line

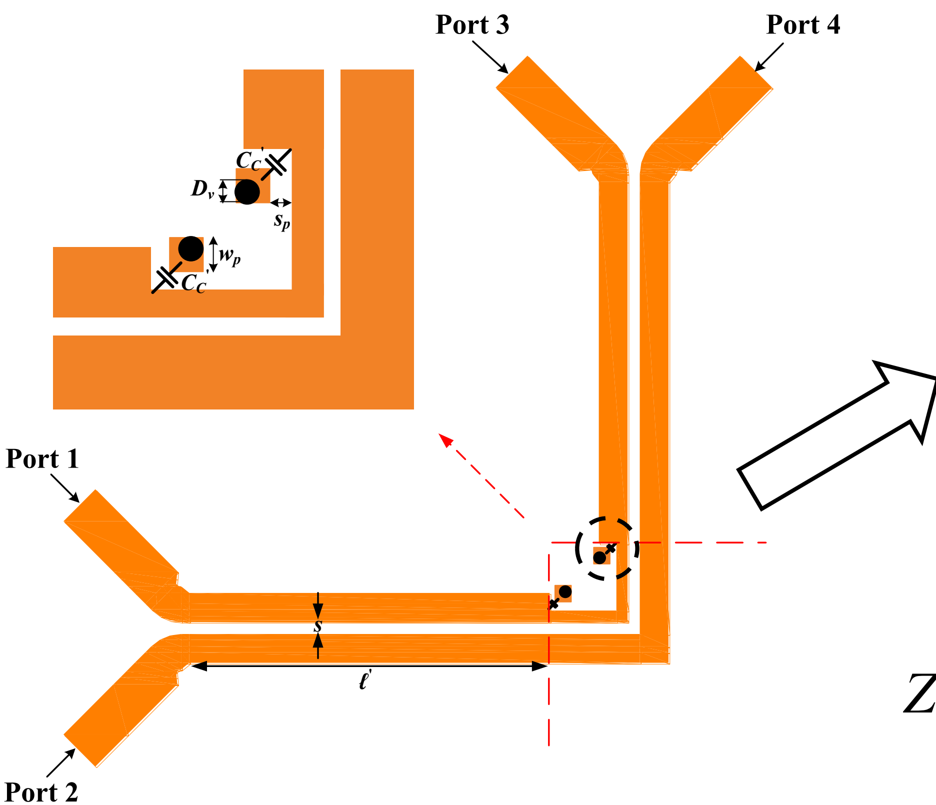


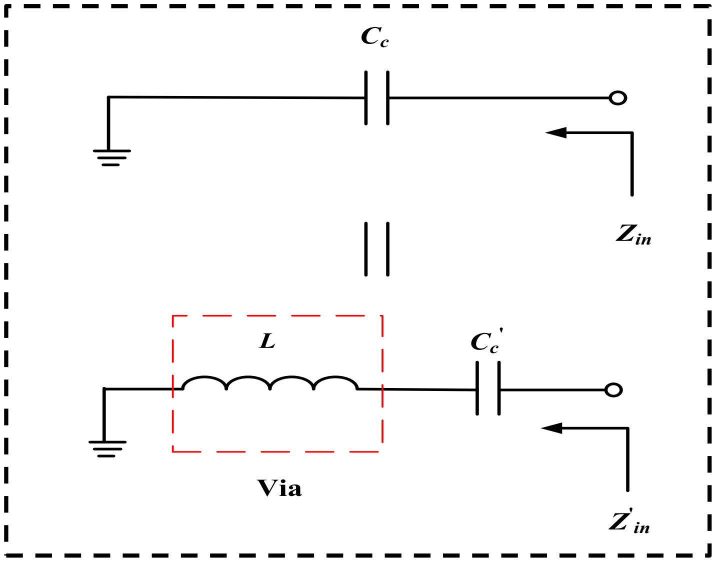
Equivalent Circuit

L'_{13} (nH)	L'_{24} (nH)	L'_M (nH)	$C'_{11}+C_C$ ($C'_{33}+C_C$) (pF)	C'_{22}(C'_{44}) (pF)	C'_{12} (C'_{34}) (pF)
4.9035	4.9055	1.5096	0.4932	0.4932	0.09067

Bended Differential Transmission Line Using Compensation *L* and *C*

- Capacitance Compensation
  - Implementation with grounded via



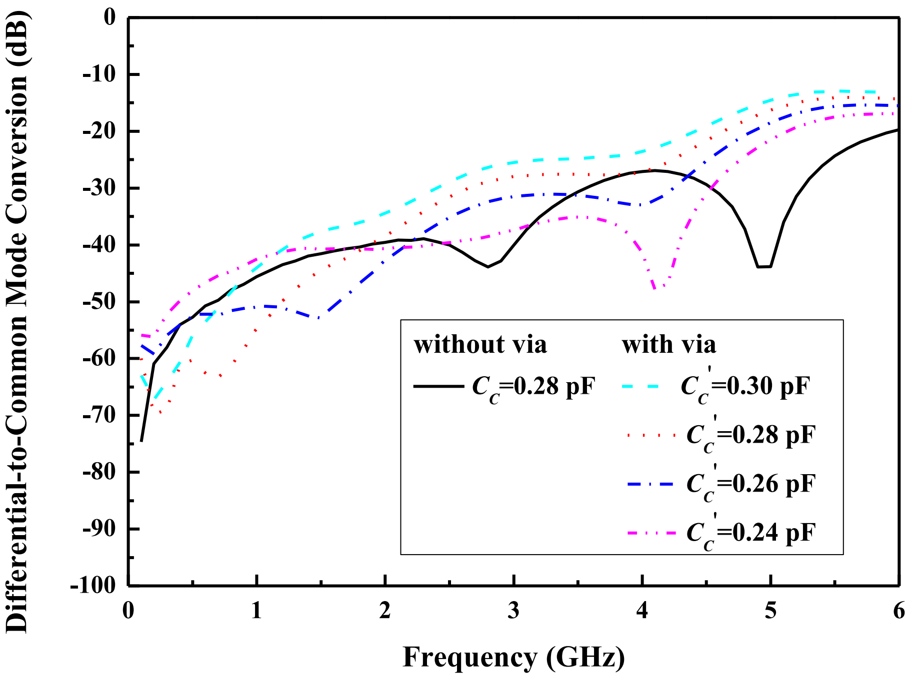


Equivalent Circuit

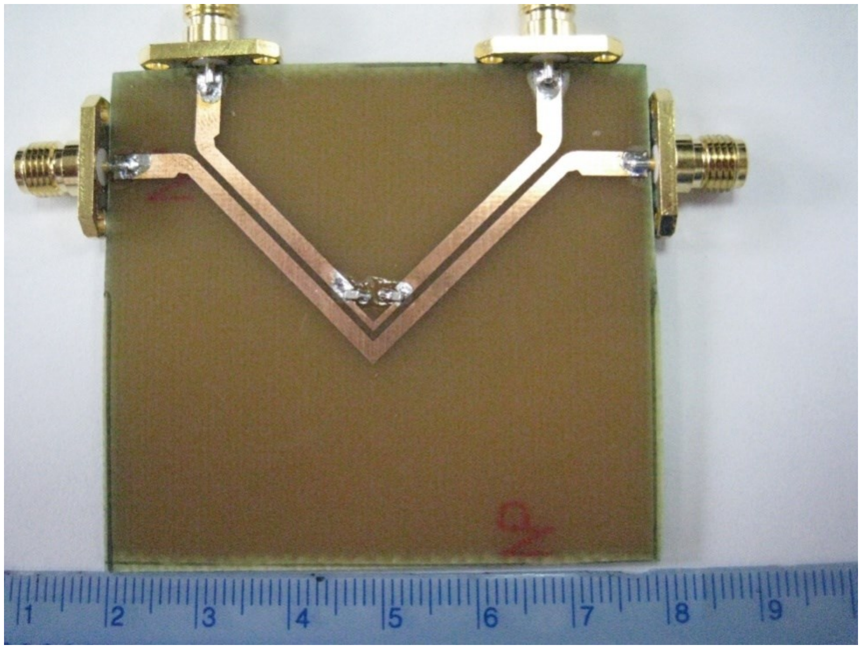
$$Z_{in} = Z'_{in} \quad \Longrightarrow \quad C_C' = \frac{1}{\omega^2 L + \frac{1}{C_C}}$$

Bended Differential Transmission Line Using Compensation *L* and *C*

- Differential-to-Common Mode Conversion
  - With and without vias



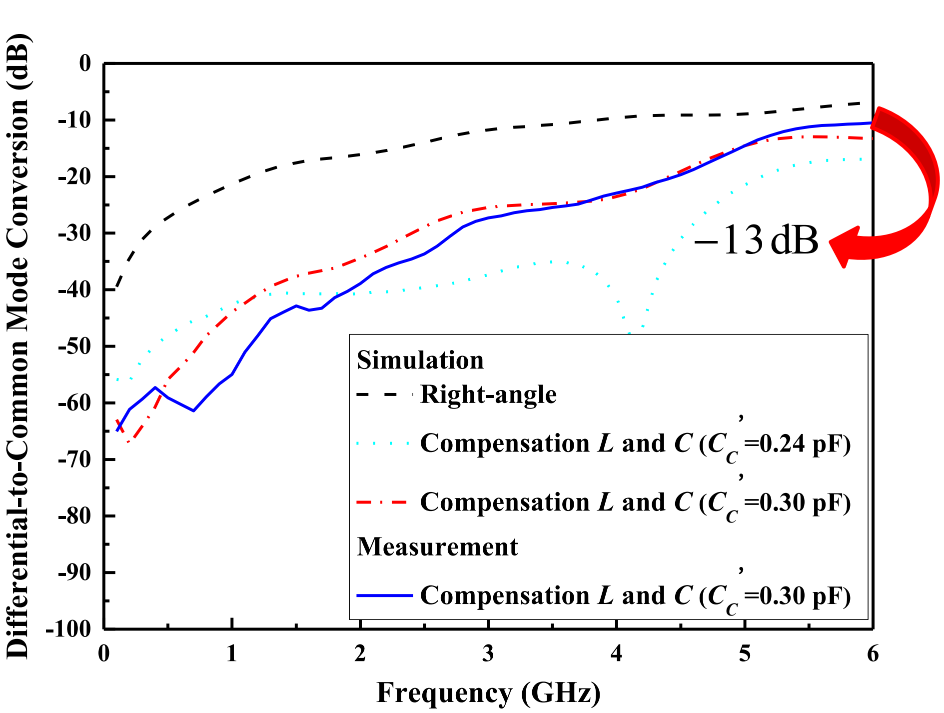
Mode Conversion



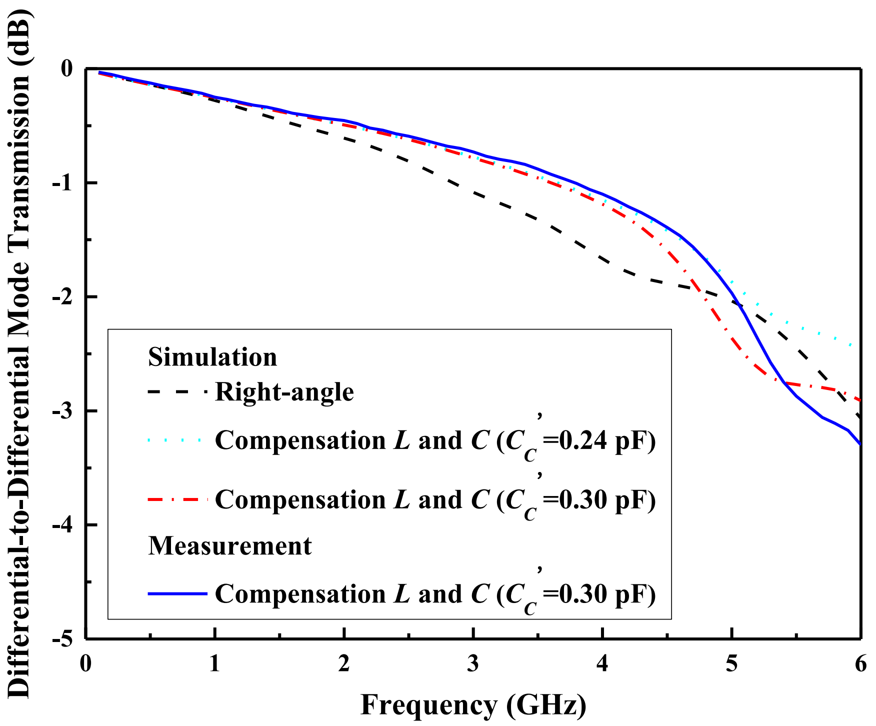
Fabricated Circuit

Bended Differential Transmission Line Using Compensation *L* and *C*

- Mixed-Mode *S*-Parameters
  - Diff.-to-comm. mode conversion and diff. mode transmission



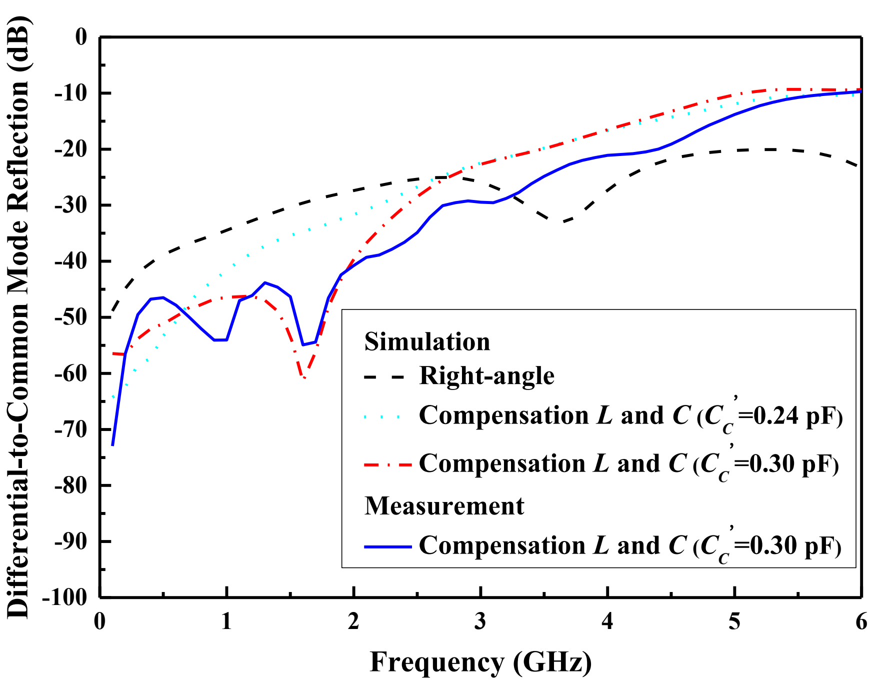
S_{c2d1}



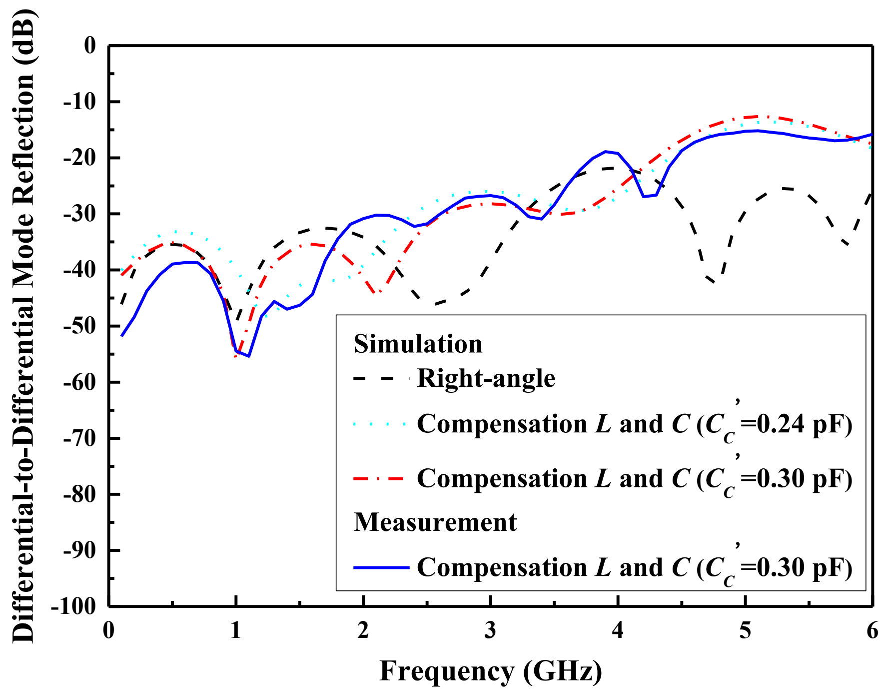
S_{d2d1}

Bended Differential Transmission Line Using Compensation *L* and *C*

- Mixed-Mode *S*-Parameters
  - Diff.-to-comm. mode reflection and diff. mode reflection



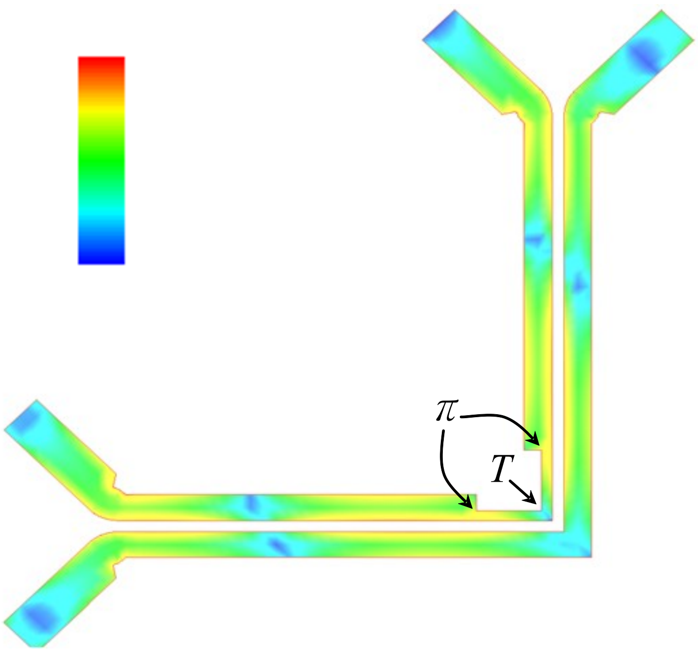
S_{c1d1}



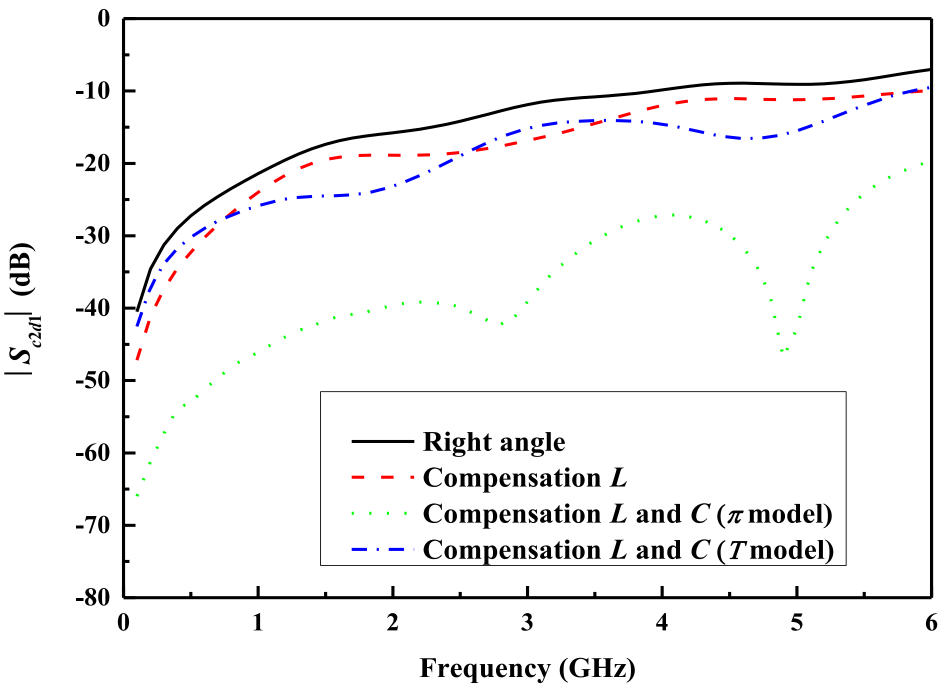
S_{d1d1}

Bended Differential Transmission Line Using Compensation *L* and *C*

- Differential-to-Common Mode Conversion
  - Various SMD capacitor placement



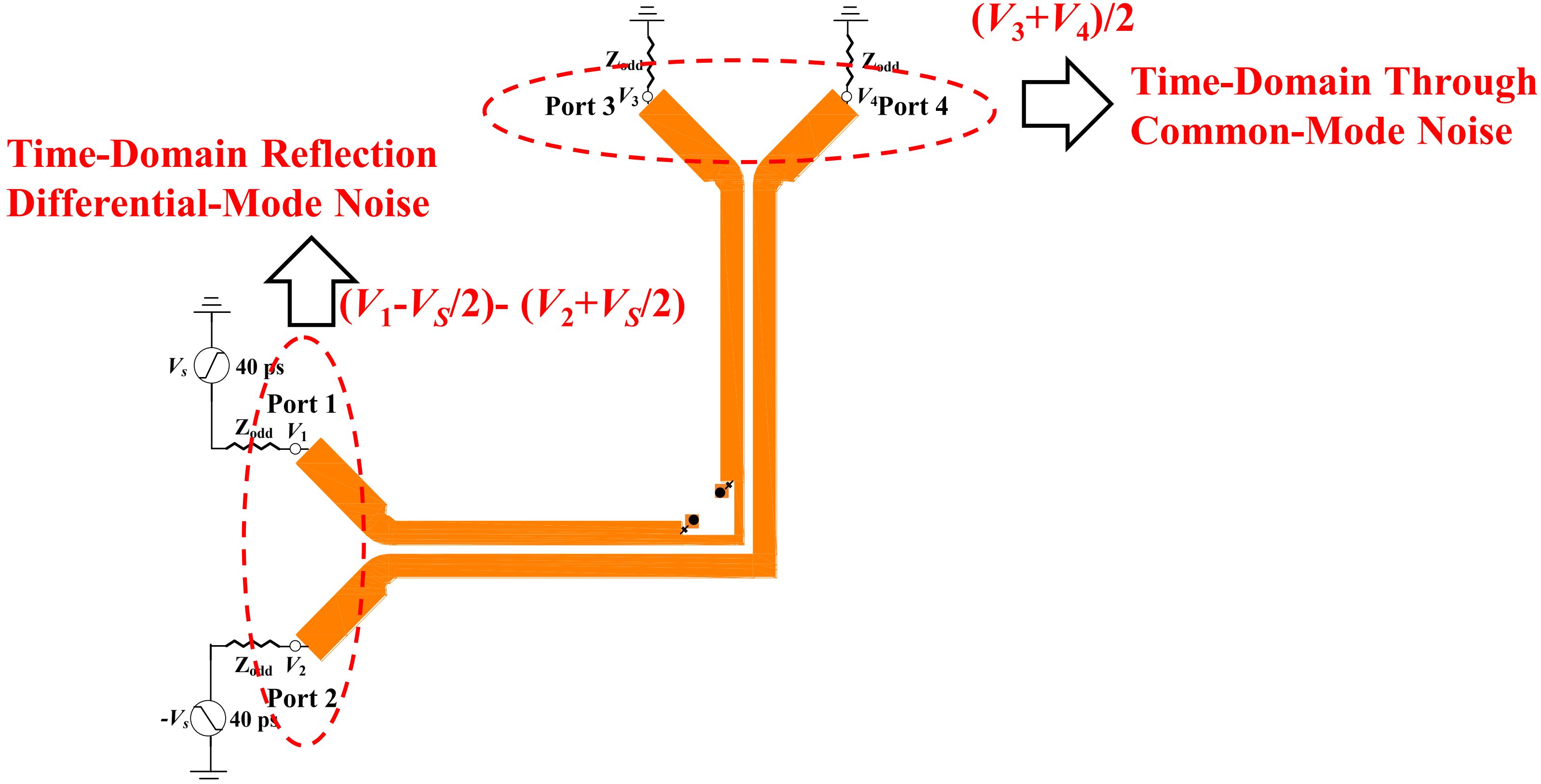
Current Distribution



Mode Conversion

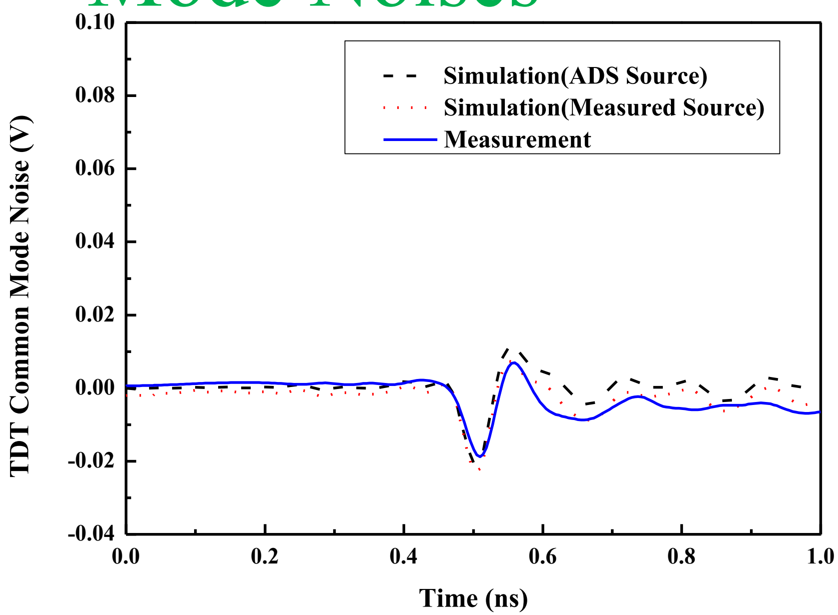
Bended Differential Transmission Line Using Compensation *L* and *C*

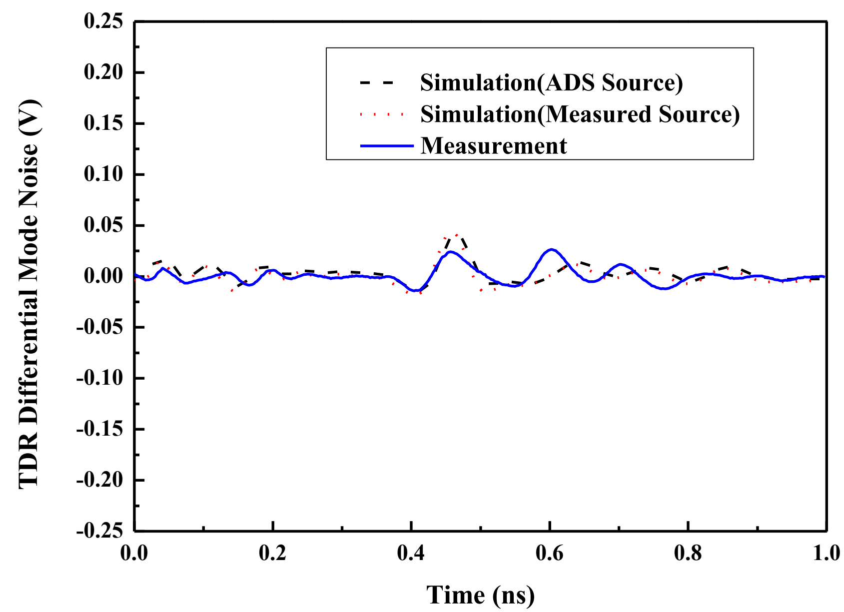
- Time-Domain Simulation Setup
  - Input source V_S: 0.5V step function



Bended Differential Transmission Line Using Compensation *L* and *C*

- TDT Common-Mode and TDR Differential-Mode Noises





TDT Common-Mode Noise (Volt)	Simulation	0.021
	Measurement	0.019
TDR Differential-Mode Noise (Volt)	Simulation	0.040
	Measurement	0.030

Conclusions

- Mixed-Mode *S*-Parameters
  - Differential-to-common mode conversion is greatly reduced from -6.48 to -13 dB.
  - Differential-mode transmission is maintained.
  - Differential- and common-modes reflections are kept small.
- TDT Common-Mode and TDR Differential-Mode Noises

	TDT Common-Mode Noise (Volt)		TDR Differential-Mode Noise (Volt)	
	Measurement	Simulation	Measurement	Simulation
Right-Angled Bend	0.056	0.064	0.017	0.02
Compensation *L* and *C*	0.019	0.021	0.030	0.04