A Novel Embedded Common-mode Filter for above GHz differential signals based on Metamaterial concept

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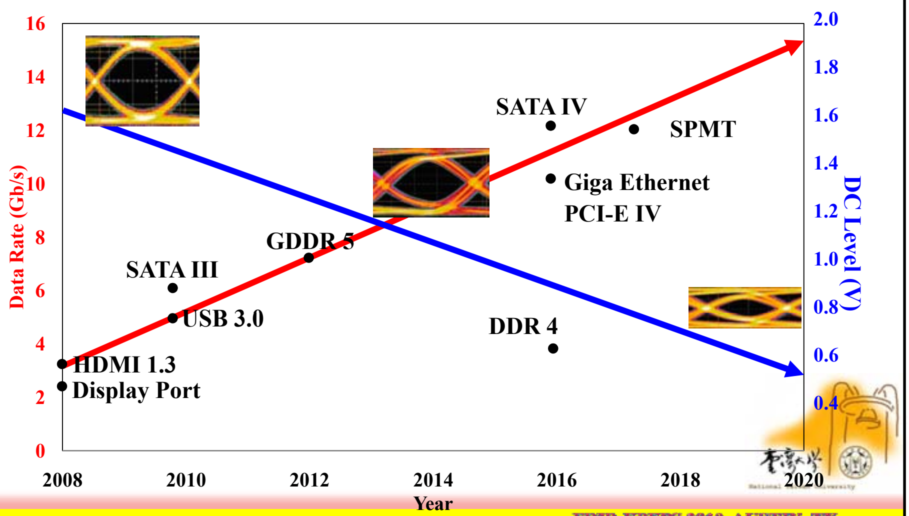
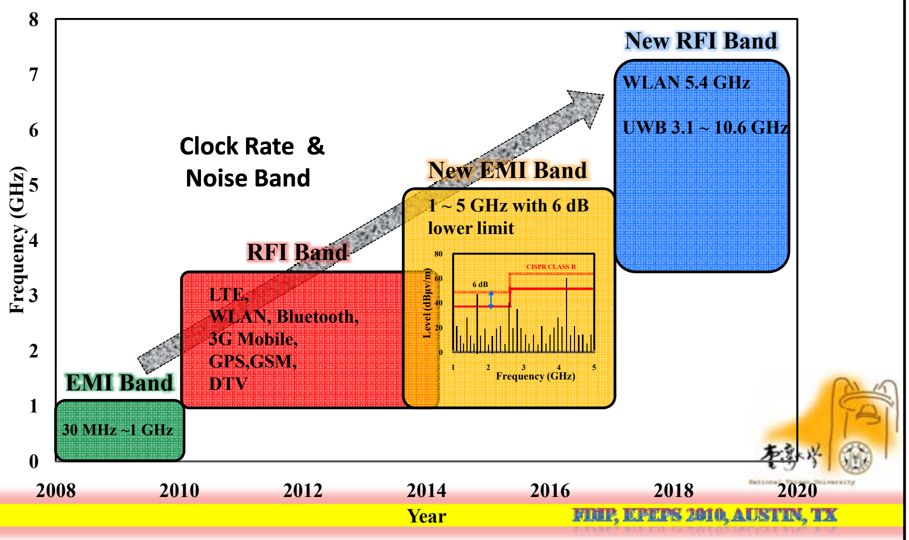
Outline

- ✓ Introduction
- ✓ Problems and conventional solution
- ✓ Proposed solution and concept
  - DGS
  - Metamaterial Transmission line
- ✓ Case study：component
  - RFI
  - EMI
- ✓ Conclusion

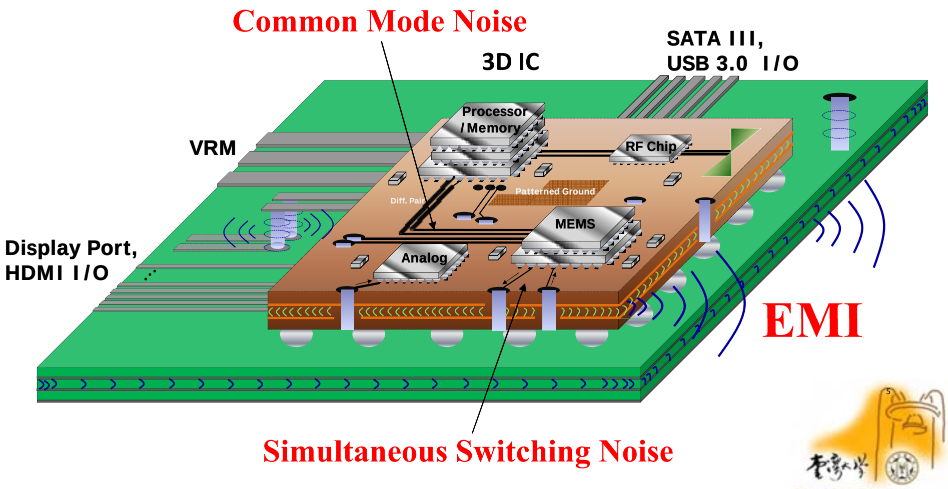
Trend of Differential Signaling



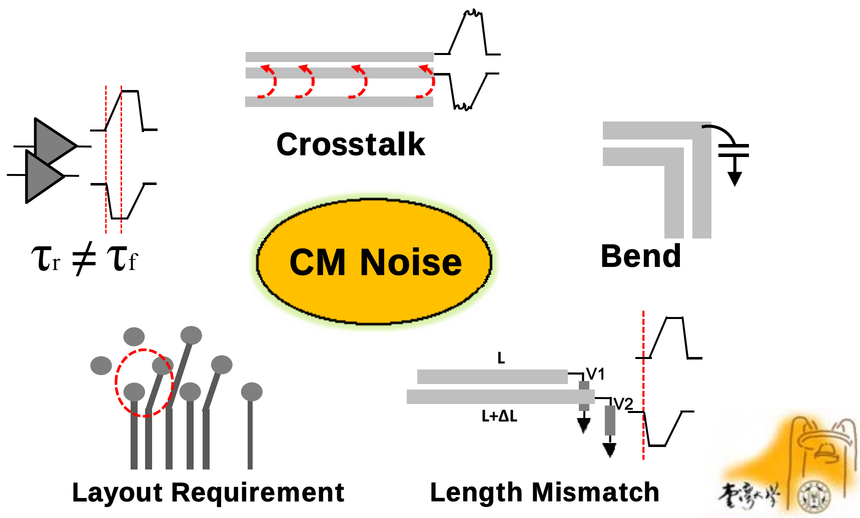
EMI / RFI Trend



Electronic System

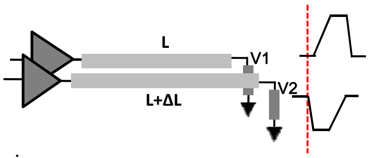


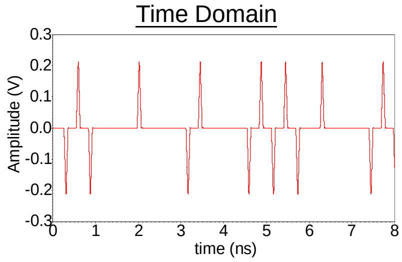
Common Mode Noise

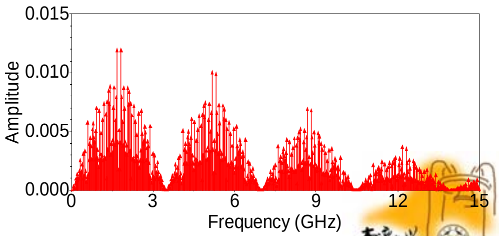


Example

- A 3.5 Gbps differential PRBS passing through a differential pair with length mismatch (PRBS : Pseudorandom Binary Sequence)

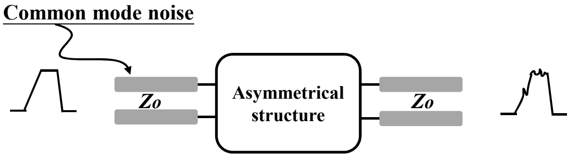




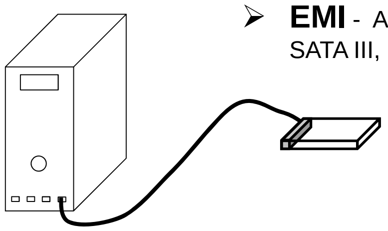


Problems

- **SI** - Mode Conversion : Common mode to Differential mode.

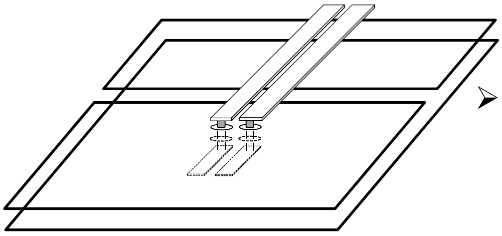


- **EMI** - Attached I/O cables (HDMI, SATA III, USB 3.0…) .

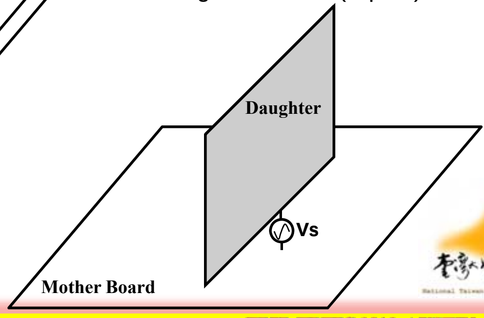


Problems

- **PI** - Via transition, crossing slots (plate cavity).



- **RFI** - Shielding metals, heat sink, daughter boards (Dipole).



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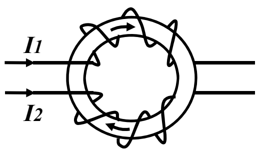
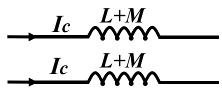
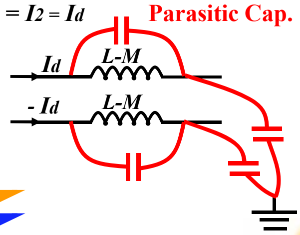
Conventional Solution



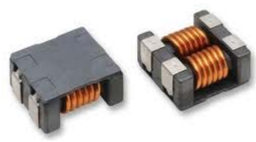
<u>CM mode</u> $I_1 = I_2 = I_c$



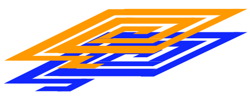
<u>DM mode</u> $I_1 = I_2 = I_d$



Ferrite：



Thin Film：



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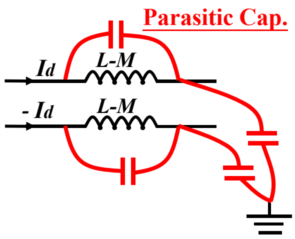
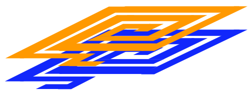
Bottleneck



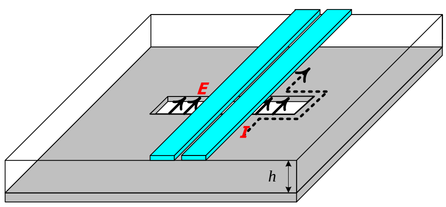
Asymmetrical geometry



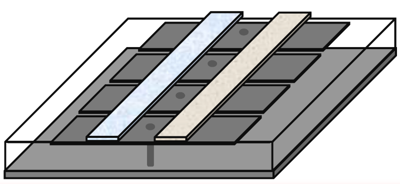
- ***L ≠ M***, parasitic ***C***, **and** asymmetrical geometry **degrade** the differential signal quality.

Proposed embedded structures

1. Defected Ground Structure (DGS)

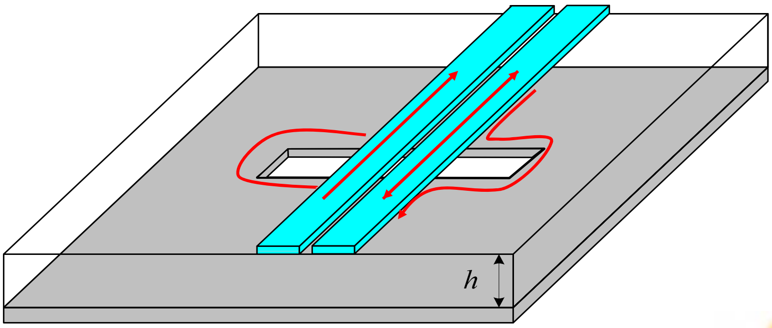


2. Transmission Line Metamaterial

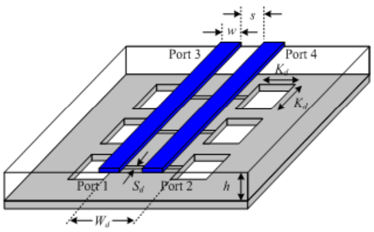


Defectd Ground Structure(DGS)

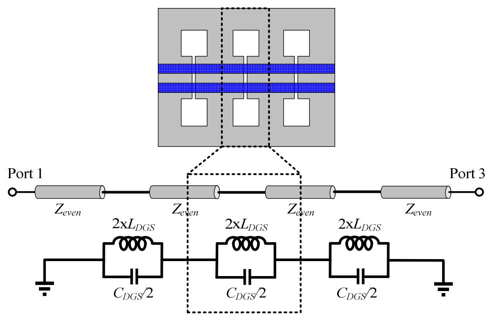
Differential Mode Excite(Signal)
Common Mode Excite(Noise)



DGS-1



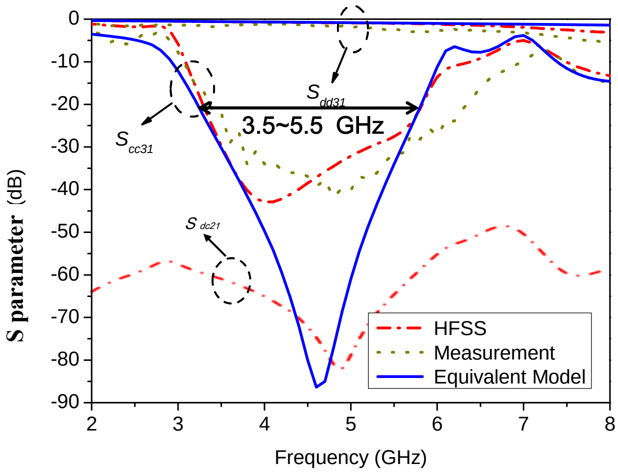
0.47 λg × 0.76 λg



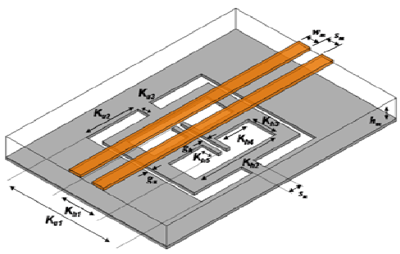
- Use Periodic DGS to produce electromagnetic bandgap for common mode

[1] W. T. Liu, C. H. Tsai, T. W. Han, T. L. Wu, "An embedded common mode suppression filter for GHz differential signals Using Periodic Defected Ground Plane", *IEEE Microwave and Wireless Components Letters*, vol. 18, no4, pp. 248-250, Apr, 2008.

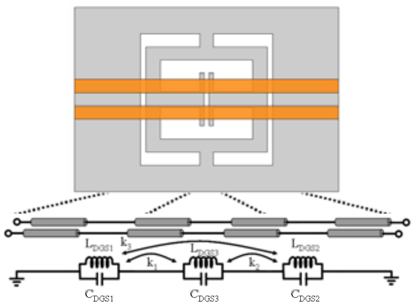
Performance



DGS-2



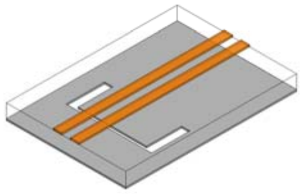
0.44 λg × 0.44 λg

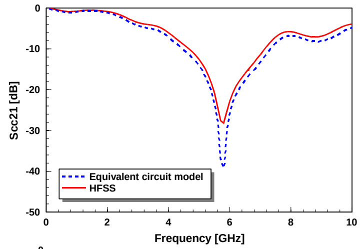


- Apply mutual coupling to enhance the bandwidth of common mode suppression.

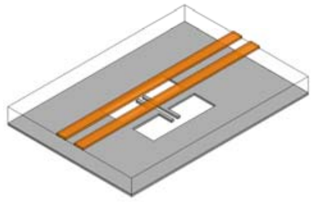
[2] S. J. Wu, C. H, Tsai, and T. L. Wu "A novel wideband common-mode suppression filter for GHz differential signals using coupled patterned ground structure," *IEEE Trans. Microwave Theory Tech.*, vol. 57, no.4, pp. 848-855, Apr. 2009.

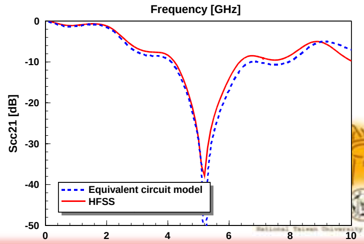
Design Concept (1/3)





- L_{DGS1}=2.36nH, C_{DGS1}=0.324pF.

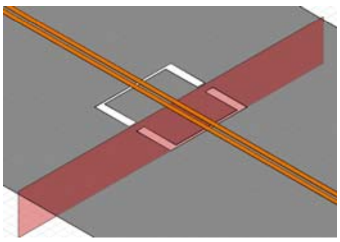


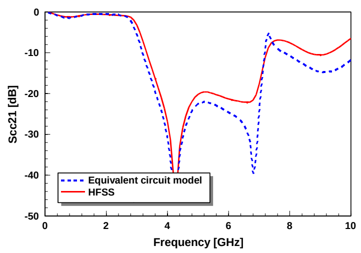


- L_{DGS3}=3.39nH, C_{DGS3}=0.276pF.

Design Concept (2/3)

Magnetic Coupling Coefficient

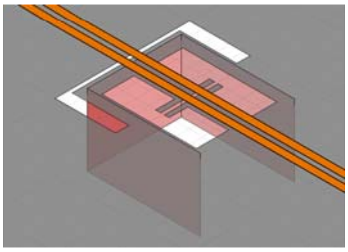


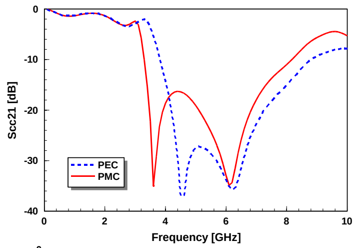


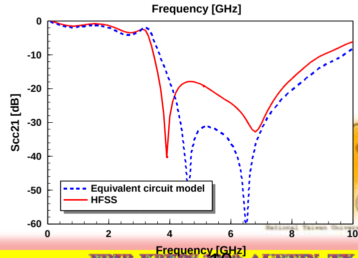
$$k_m = \frac{L_m}{L} = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2}$$

$$k_m = 0.11$$

Asynchronous Tuned Magnetic Coupling



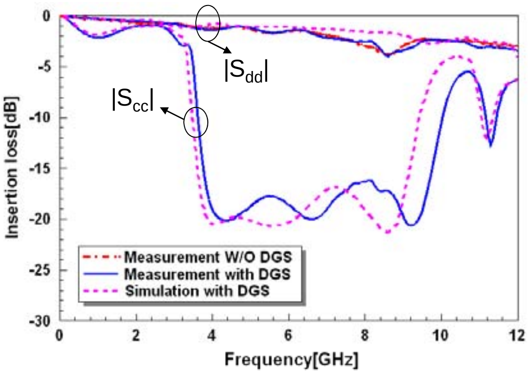


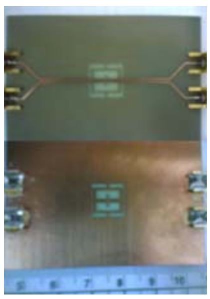


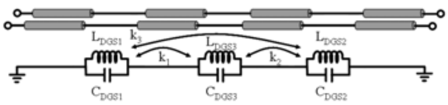
$$k_M = \sqrt{\left(\frac{f_{e1}^{\ 2} - f_{m1}^{\ 2}}{f_{m1}^{\ 2} + f_{e1}^{\ 2}}\right)\left(\frac{f_{e2}^{\ 2} - f_{m2}^{\ 2}}{f_{m2}^{\ 2} + f_{e2}^{\ 2}}\right)}$$

$$k_M = \pm 0.043$$

Performance

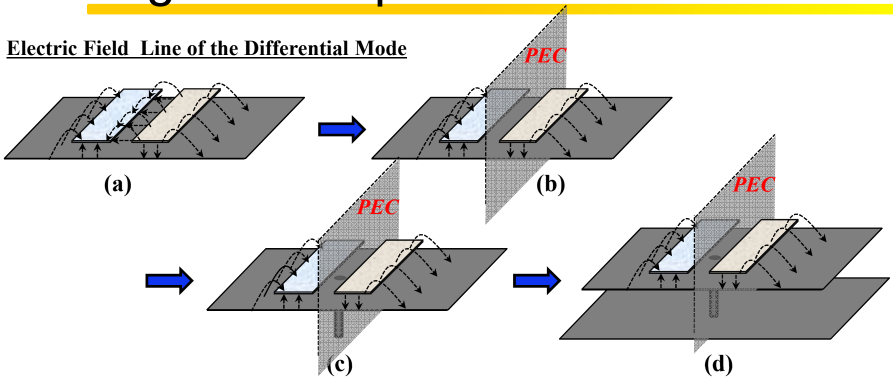




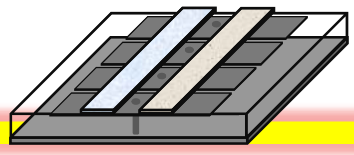


Design Concept-TL Metamaterial

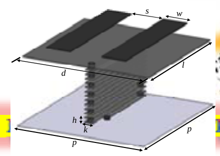
Electric Field Line of the Differential Mode



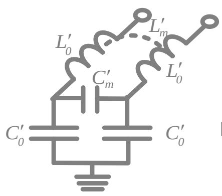
Type1：PCB/SiP



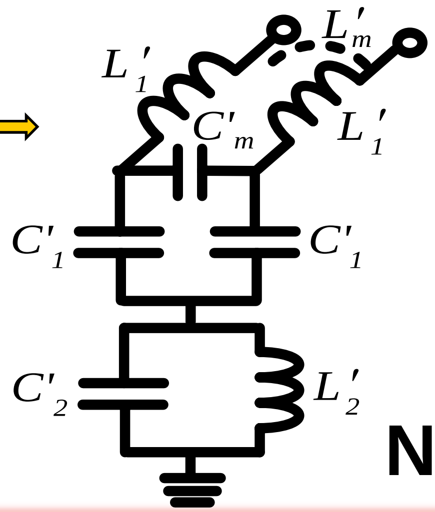
Type2：Component



New Equivalent circuit

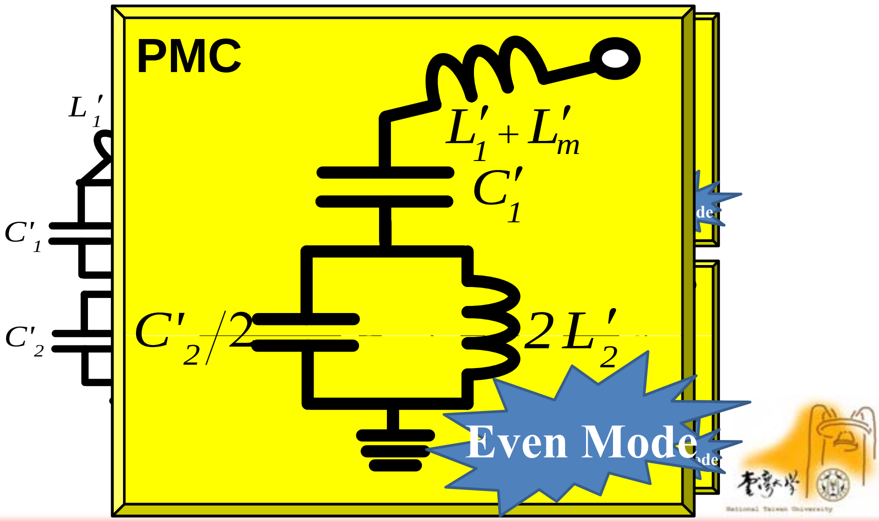


Conventional



New

New Equivalent circuit



Metamaterial Differential Line

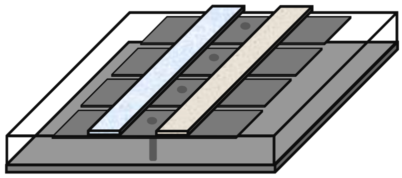
Assume $p \ll \lambda$ and lossless

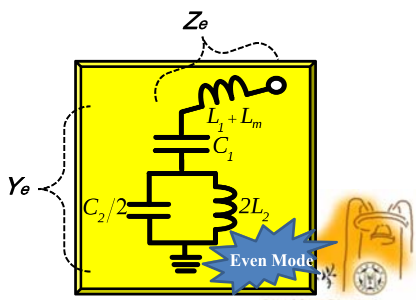
$$\gamma_e = \alpha + j\beta = \frac{1}{p}\sqrt{Z_e Y_e}$$

$$= \frac{j\omega}{p}\sqrt{(L_1 + L_m)\frac{C_1(1-\omega^2/\omega_0^2)}{(1-\omega^2/\omega_c^2)}}$$

$$= \alpha \ , \ \ \omega_c < \omega < \omega_0$$

$$\omega_c = \frac{1}{\sqrt{L_2(2C_1 + C_2)}} \ , \quad \omega_0 = \frac{1}{\sqrt{L_2 C_2}}$$

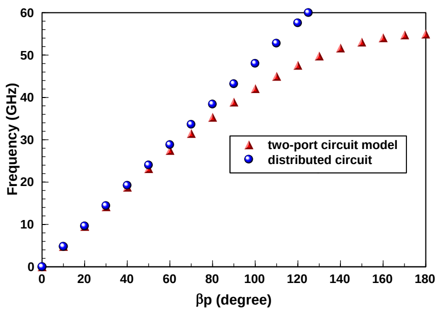


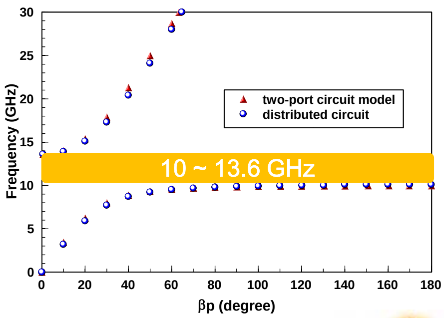


Effective material parameter :

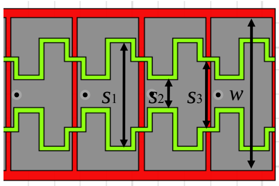
$$\varepsilon(\omega) = Y_e / j\omega = \frac{C_1(1-\omega^2/\omega_0^2)}{(1-\omega^2/\omega_c^2)} < 0 \ , \quad \omega_c < \omega < \omega_0$$

Dispersion Diagram

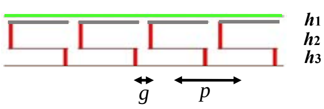




Example I: Embedded CMF in LTCC



Top view



Side view

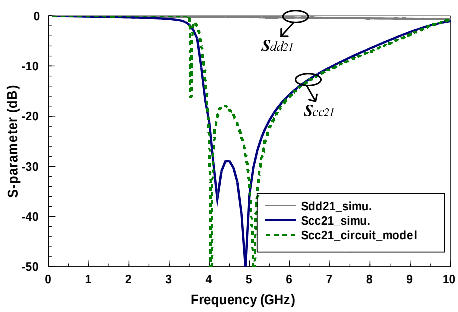
$w_1 = 0.1$ mm
$s_1 = 1.38$ mm
$s_2 = 2.18$ mm
$s_3 = 0.58$ mm
$w = 3.2$ mm
$h_1 = 0.115$ mm
$h_2 = 0.468$ mm
$h_3 = 0.312$ mm
$g = 0.18$ mm
$p = 1.28$ mm

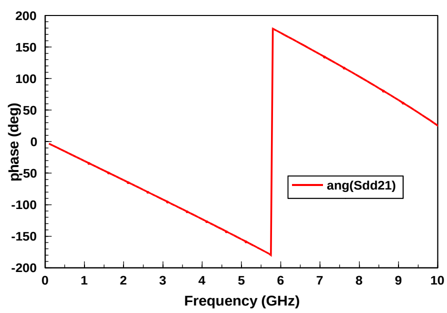
$$\omega_c = \frac{1}{\sqrt{L_2(2C_1 + C_2)}}$$

$$\omega_0 = \frac{1}{\sqrt{L_2 C_2}}$$

DK=7.8
4 Cells
Size：0.3 $\lambda g \times$ 0.2 λg

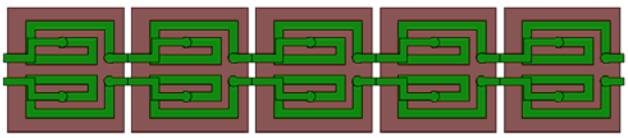
Performance



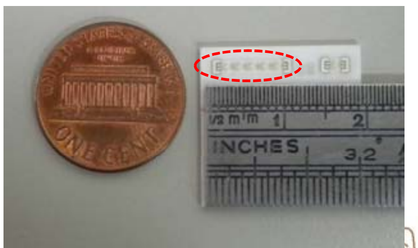


A designed stop-band (3.8-7.1 GHz) for common mode is seen both in simulation and measurement

Example II: wideband CMF



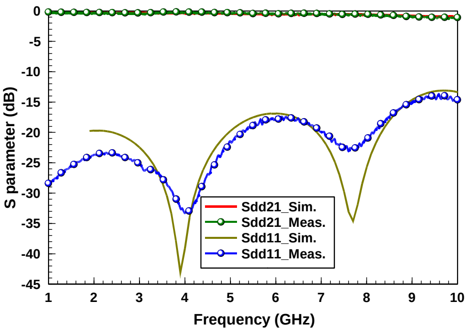
Low Temperature Co-fired Ceramic (LTCC)：
# of Layer：11 (Ag)
DK = 3.9
# of Cell：5
Size --- **0.05** λ_g x **0.26** λ_g (1.6 x 8 mm^2)



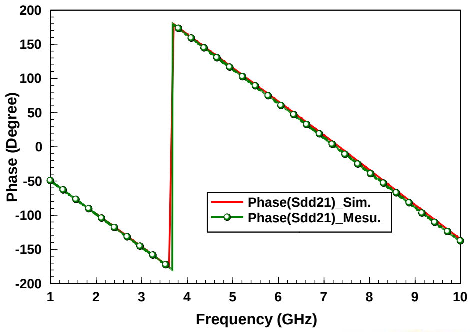
Photograph

Performance-Diff.

Amplitude

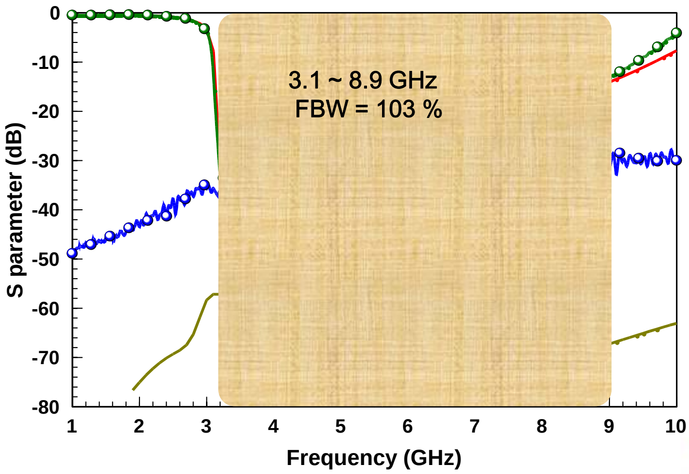


Phase



A good differential mode transmission is seen both in simulation and measurement

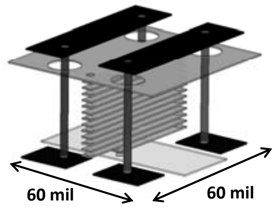
Performance-CM

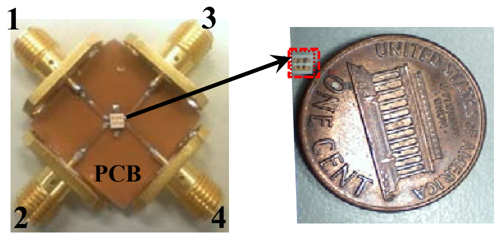


Example III: Compact CMF

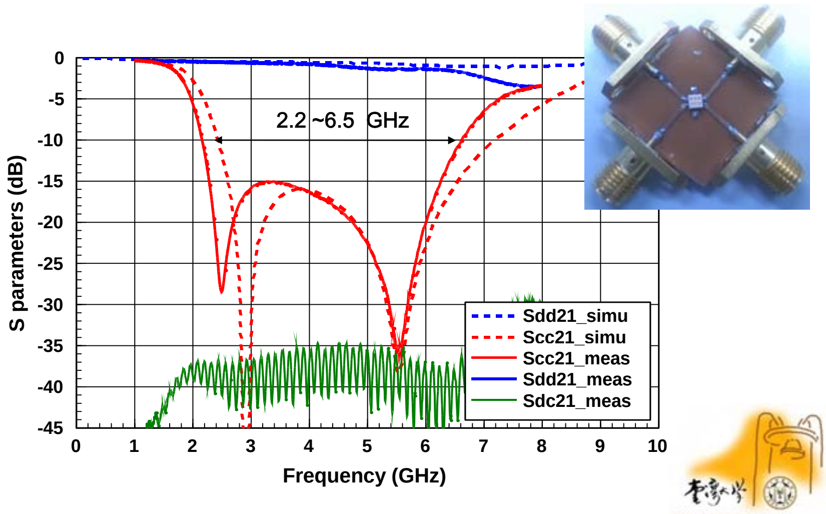
Low Temperature Co-fired Ceramic (LTCC) :
# of Layer : 17 (Ag)
DK = 7.8

Goal :
Size ---0606 (60 mil x 60 mil)
Case 1 --- 2.5 ~ 8 GHz





Performance



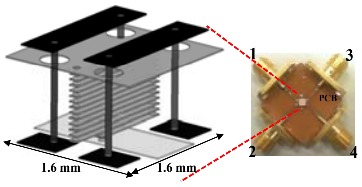
Example IV: CMF for EMI/RFI Suppression

Low Temperature Co-fired Ceramic (LTCC)：
\# of Layer：17 (Ag)
DK = 7.8

Goal：
Frequency---@ 2.1 G for UMTS
Size ---0606 (60 mil x 60 mil)

L_1	0.86 nH
L_2	2.02 nH
L_m	0.05 nH
C_1	1.5 pF
C_m	0.07 pF

$$\omega_0 = \frac{1}{\sqrt{L_2 C_1}} = 2.1\ \text{GHz}$$



RFI for 3G UMTS

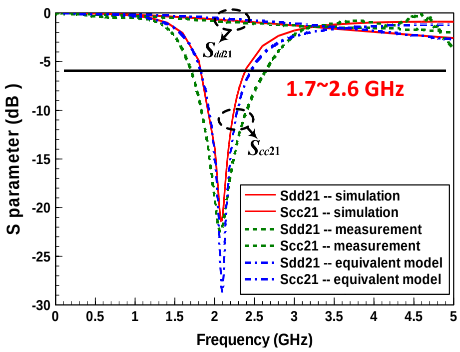
UMTS：Universal Mobile Telecommunications System is one of the third-generation (3G) mobile telecommunication technologies.

Frequency band	Frequency (MHz)	Region
2100	1920-1980, 2110-2170	Europe, Asia, Oceania, Brazil
1900	1850-1910, 1930-1900	North America , Latin America
1700	1710-1755, 2110-2155	USA, Canada
900	880-915, 925-960	Europe, Asia, Oceania
850	824-849, 869-894	USA
800	830-840, 875-885	Japan

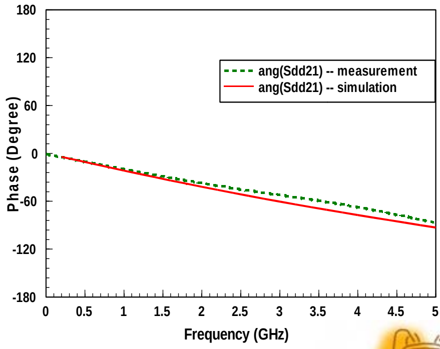
[1] http://www.umtsworld.com/technology/frequencies.htm

S parameter

Magnitude

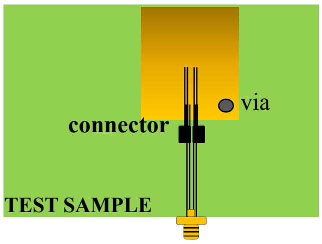


Phase

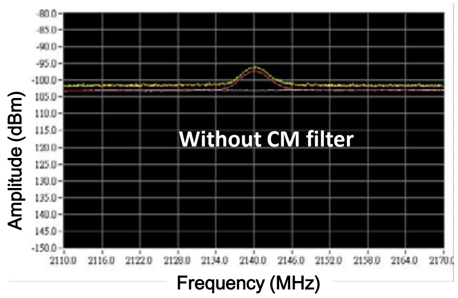


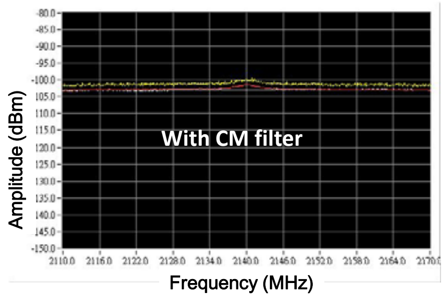
RFI-Measurement setup

Frequency @ 2.1 GHz UMTS
Input Power : -30 dBmW



RFI-Performance

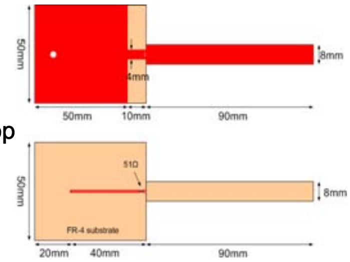


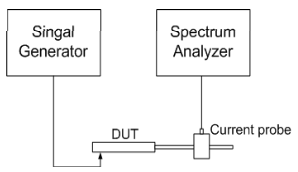


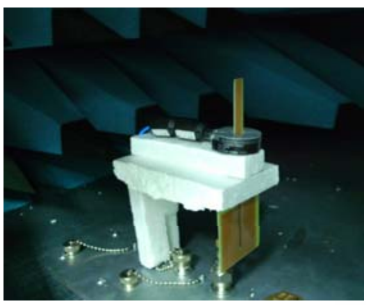
EMI-Measurement setup

Bottom

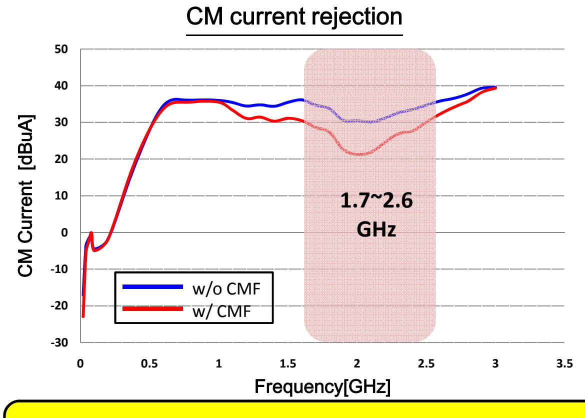
Top







EMI-Performance



About 6-8 dB suppression for CM current is observed from 1.7 GHz to 2.6 GHz

Conclusion

- DGSs and Metamaterial concept are proposed to design the embedded common-mode filter.
- Good diff. mode transmission with low mode conversion.
- Wideband common mode suppression.
- Realized on PCB and LTCC substrate (SiP).

Thank you for your attention

Q & A