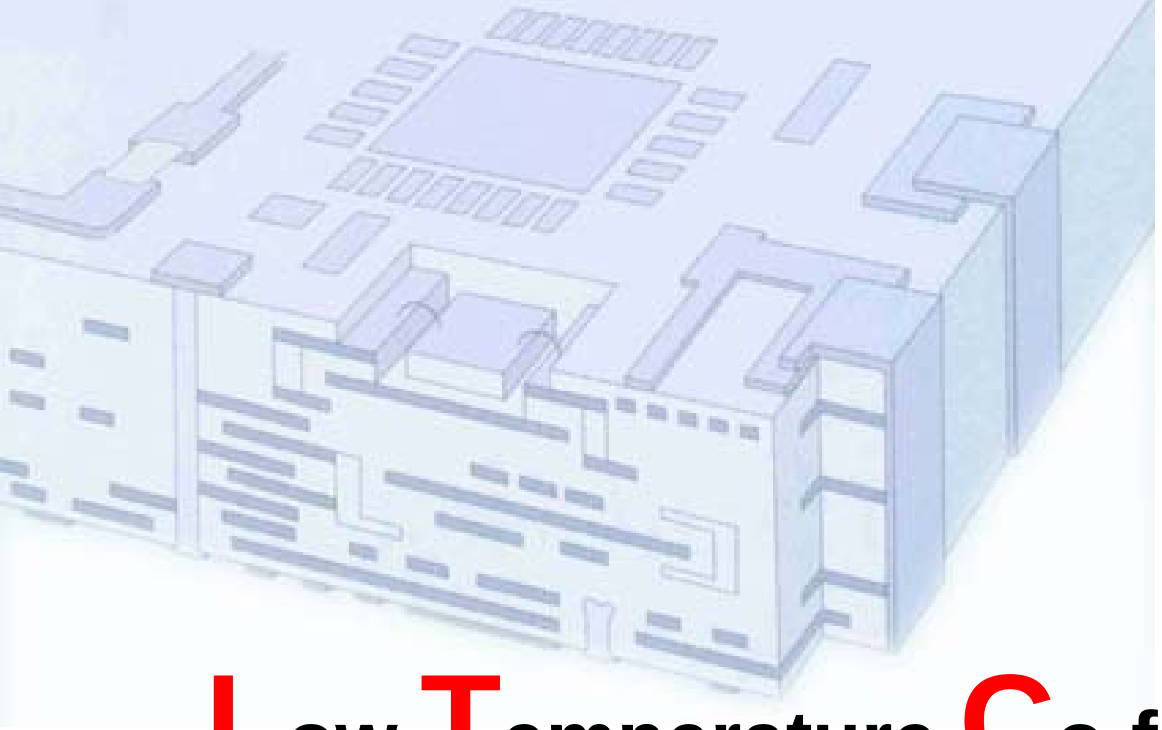


Low Temperature Co-fired Ceramic

授課教師： 江簡富 教授

台大電信 電波組 碩一 R92942051 楊錫明
R92942054 郭宗男

Outline

- What is LTCC?
- Advantages
- Process of LTCC
- Applications of LTCC
- Future developments
- Case study
- Conclusion

What is LTCC? (1/1)

Low **T**emperature **C**ofired **C**eramics

<1000 °C

One fire

Ceramic base

- Multilayer
- Size and cost reduction for many applications
- Frequency range from 100 MHz to 40 GHz
- Use of buried components: resistors, capacitors, and inductors
- High density of interconnections with three-dimensional design

What is LTCC? (2/2)

- Optimized transitions (from planar circuitry to rectangular <or circular> waveguides.)
- Packaging solutions
- Thermal management for heat dissipation in power applications
- In-house LTCC prototype manufacturing design and characterization of modules and antennas

LTCC Transition

The transition between microstrip line and the laminated waveguide of LTCC

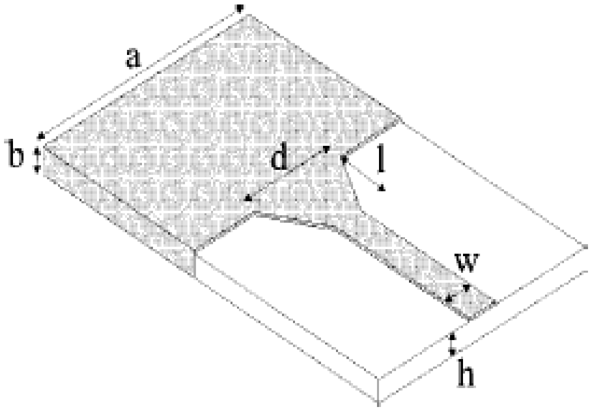
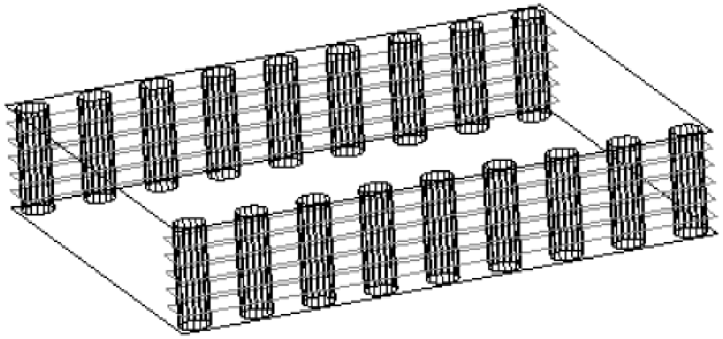
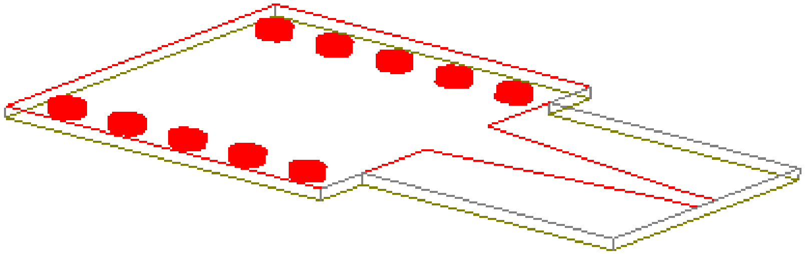


Fig. 1. Configuration of the proposed transition of microstrip line to rectangular waveguide on the same substrate.

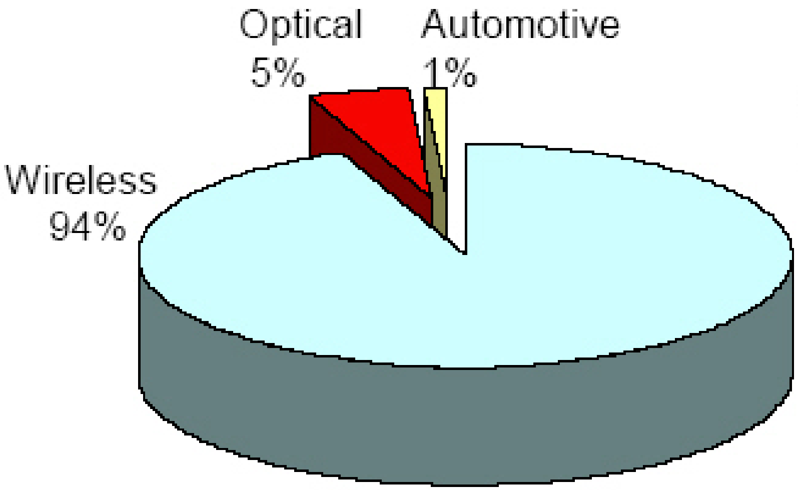


The laminated waveguide of LTCC

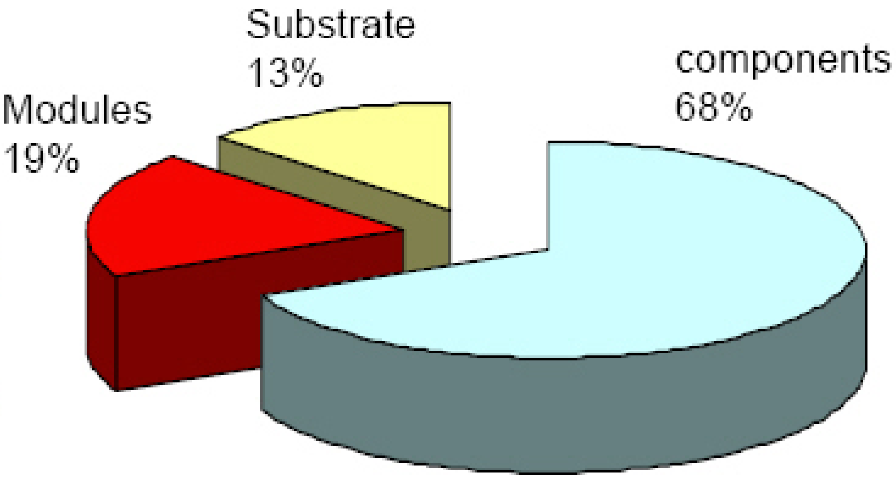


Ref: 10.

LTCC product market



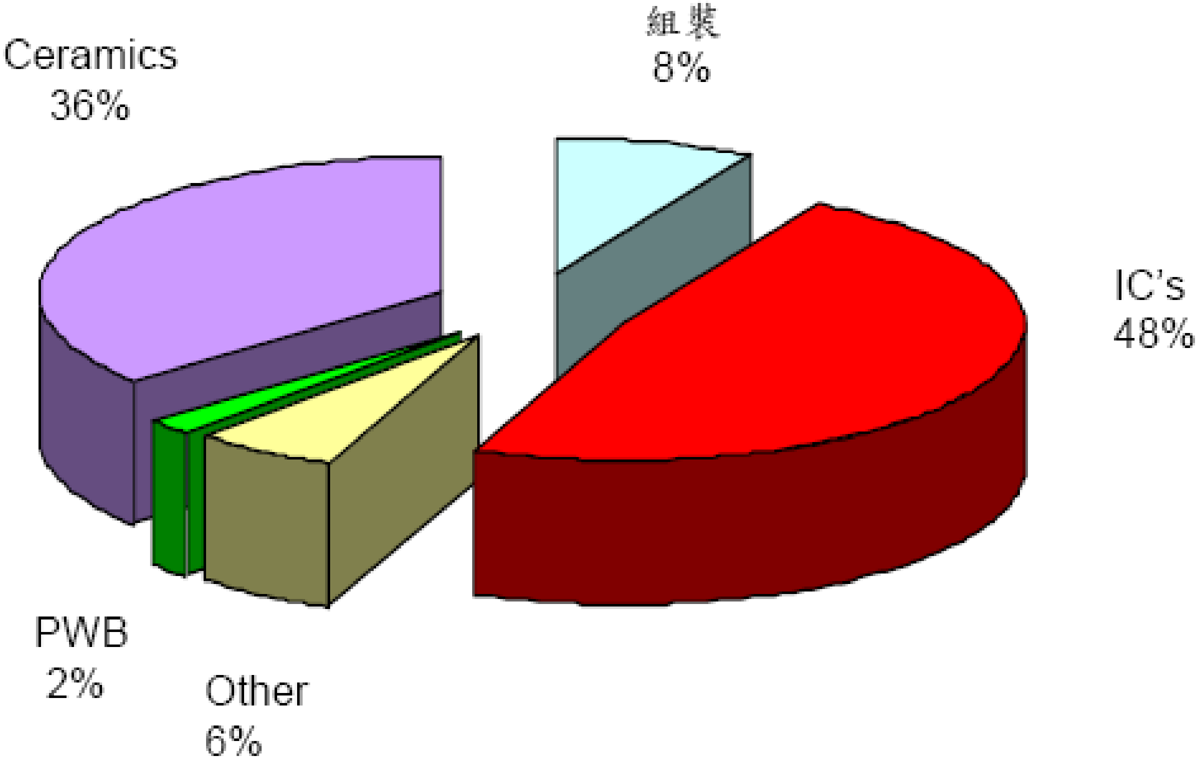
用途數量規模



分類數量規模

Ref: 1.

Cost Distribution for Typical Wireless Transceiver



PWB (Printed Wiring Board)

Source:1997 MCM Conference

Ref: 1.

Outline

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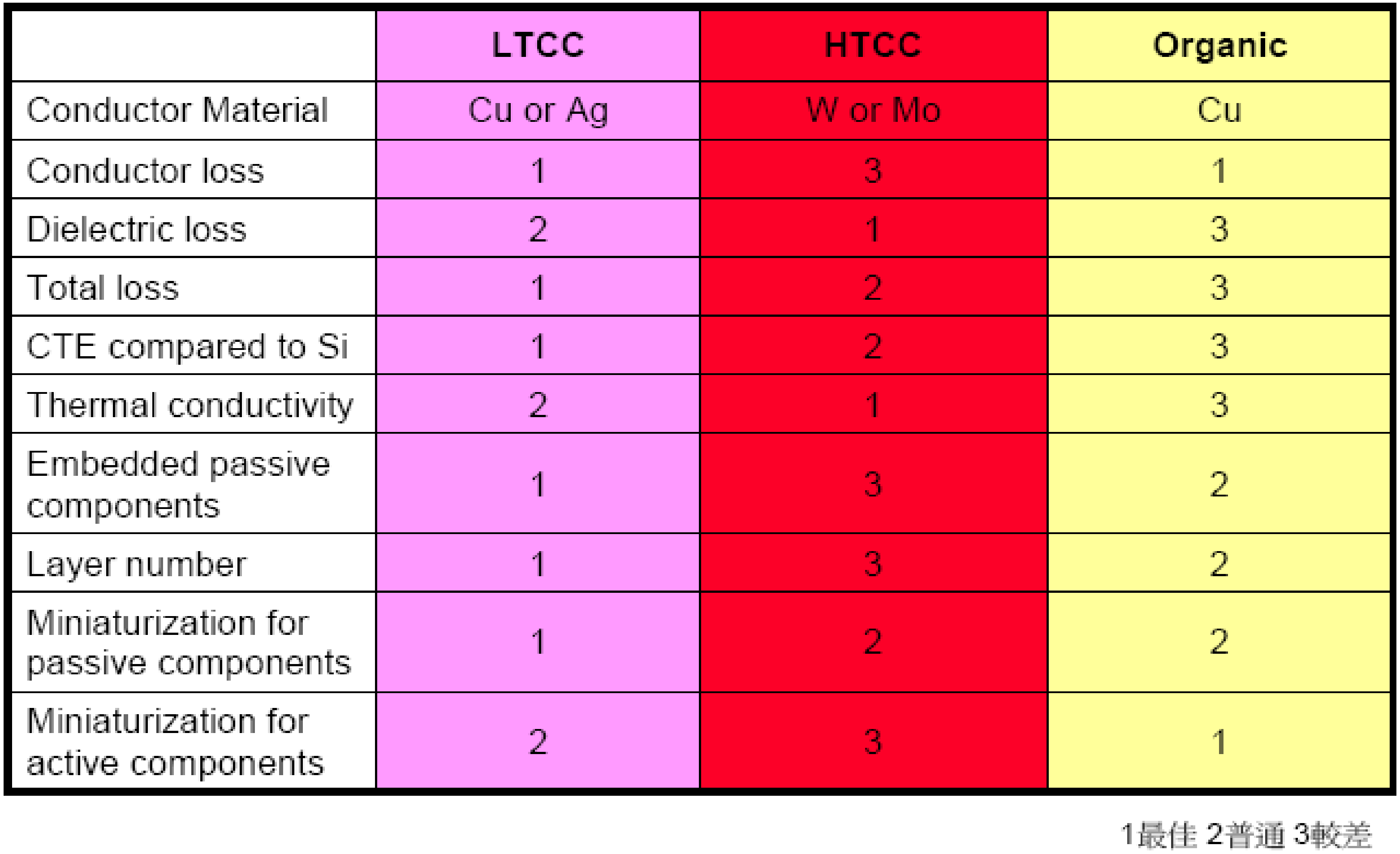
Difference between HTCC and LTCC

	LTCC	HTCC
Co-fired temperature	850℃	1950℃
metal	a lower fusion point metal	a higher fusion point metal
Quality	High	low

Why use LTCC?



	LTCC	HTCC	Organic
Conductor Material	Cu or Ag	W or Mo	Cu
Conductor loss	1	3	1
Dielectric loss	2	1	3
Total loss	1	2	3
CTE compared to Si	1	2	3
Thermal conductivity	2	1	3
Embedded passive components	1	3	2
Layer number	1	3	2
Miniaturization for passive components	1	2	2
Miniaturization for active components	2	3	1

1最佳 2普通 3較差

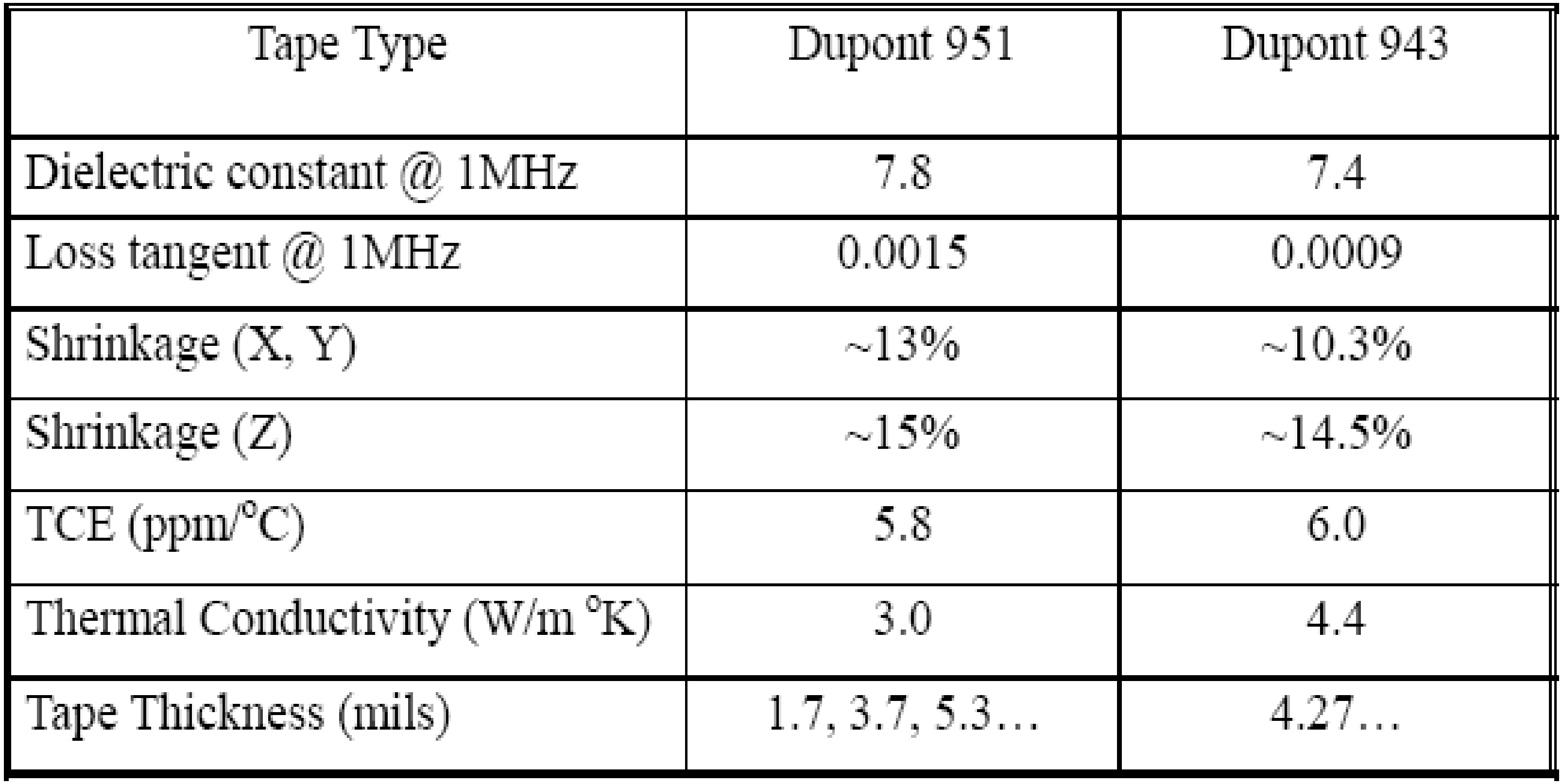
CTE : Co-efficient of Thermal Expansion

Ref: 1.

Conductor Properties

Material	Resistivity(mΩ/cm)	Melting Point(℃)
Silver (Ag)	1.63	961
Copper (Cu)	1.72	1083
Gold (Au)	2.44	1063
Wolfram (W)	5.51	3370

Material Properties

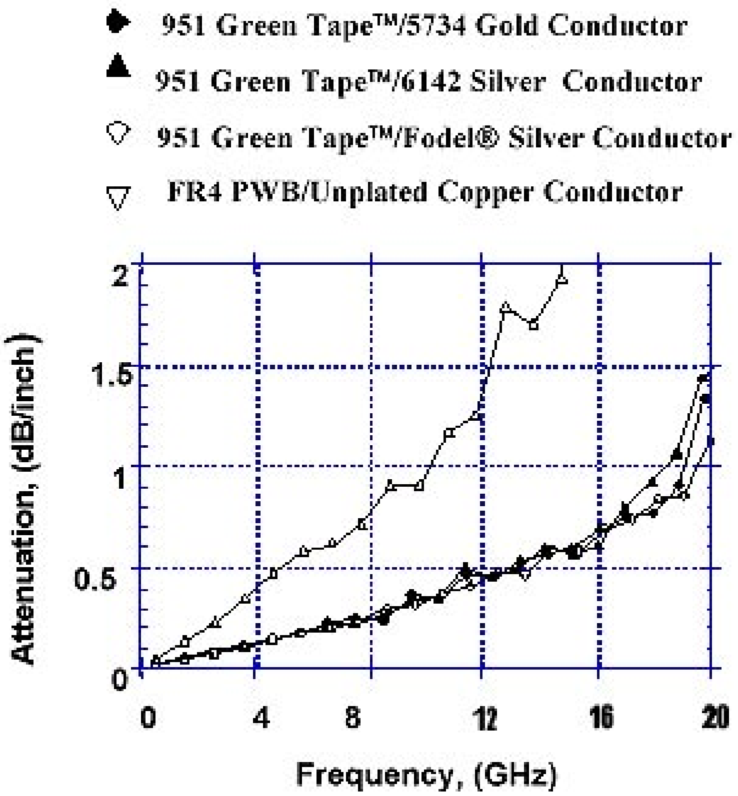


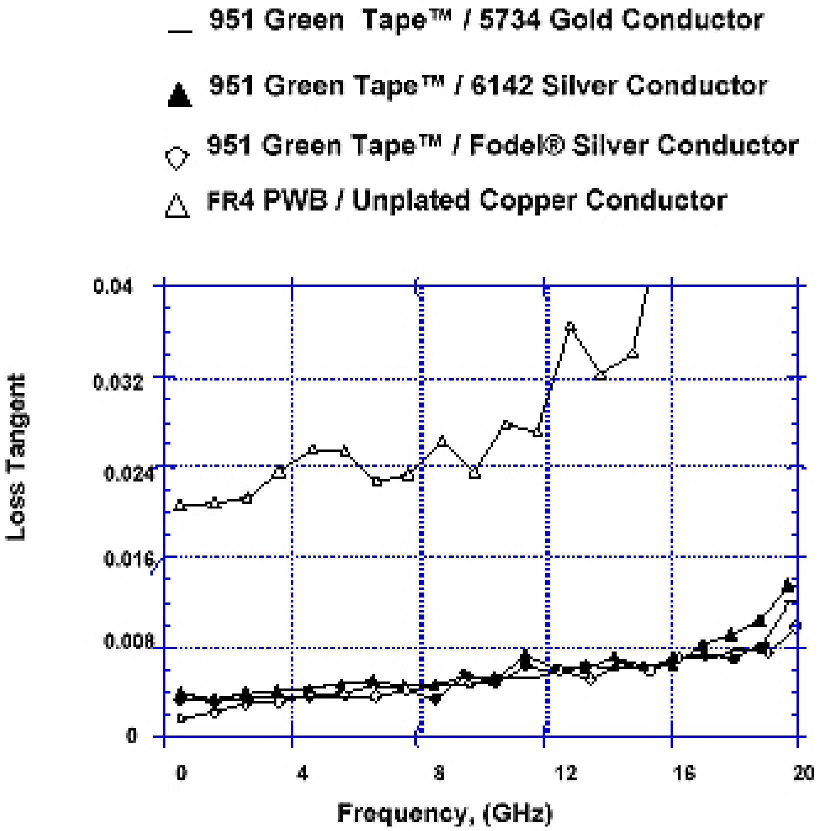
Tape Type	Dupont 951	Dupont 943
Dielectric constant @ 1MHz	7.8	7.4
Loss tangent @ 1MHz	0.0015	0.0009
Shrinkage (X, Y)	~13%	~10.3%
Shrinkage (Z)	~15%	~14.5%
TCE (ppm/°C)	5.8	6.0
Thermal Conductivity (W/m °K)	3.0	4.4
Tape Thickness (mils)	1.7, 3.7, 5.3…	4.27…

TCE : Temperature Coefficient of Expansion

Ref: 1.

High Frequency Characterization





Ref: 4.

Benefits (1 / 3)

- Integrated passives --- reliability, size reduction
- High Q, low loss
- Outstanding reliability
- 3-D design
- Controlled impedance(內部接線的阻抗)
- Environmental stability(熱膨脹係數低)

Benefits (2 / 3)

- Direct chip attach---TCE matching to Si and GaAs
- Rapid prototyping
- Volume manufacturing capacity
- every single layer can be inspected (and in the case of inaccuracy or damage) replaced before firing; this prevents the need of manufacturing a whole new circuit.

Benefits (3 / 3)

- integrating components is Cost reduction
- A clear advantage over other multichip module (MCM) technologies in integrating passive components

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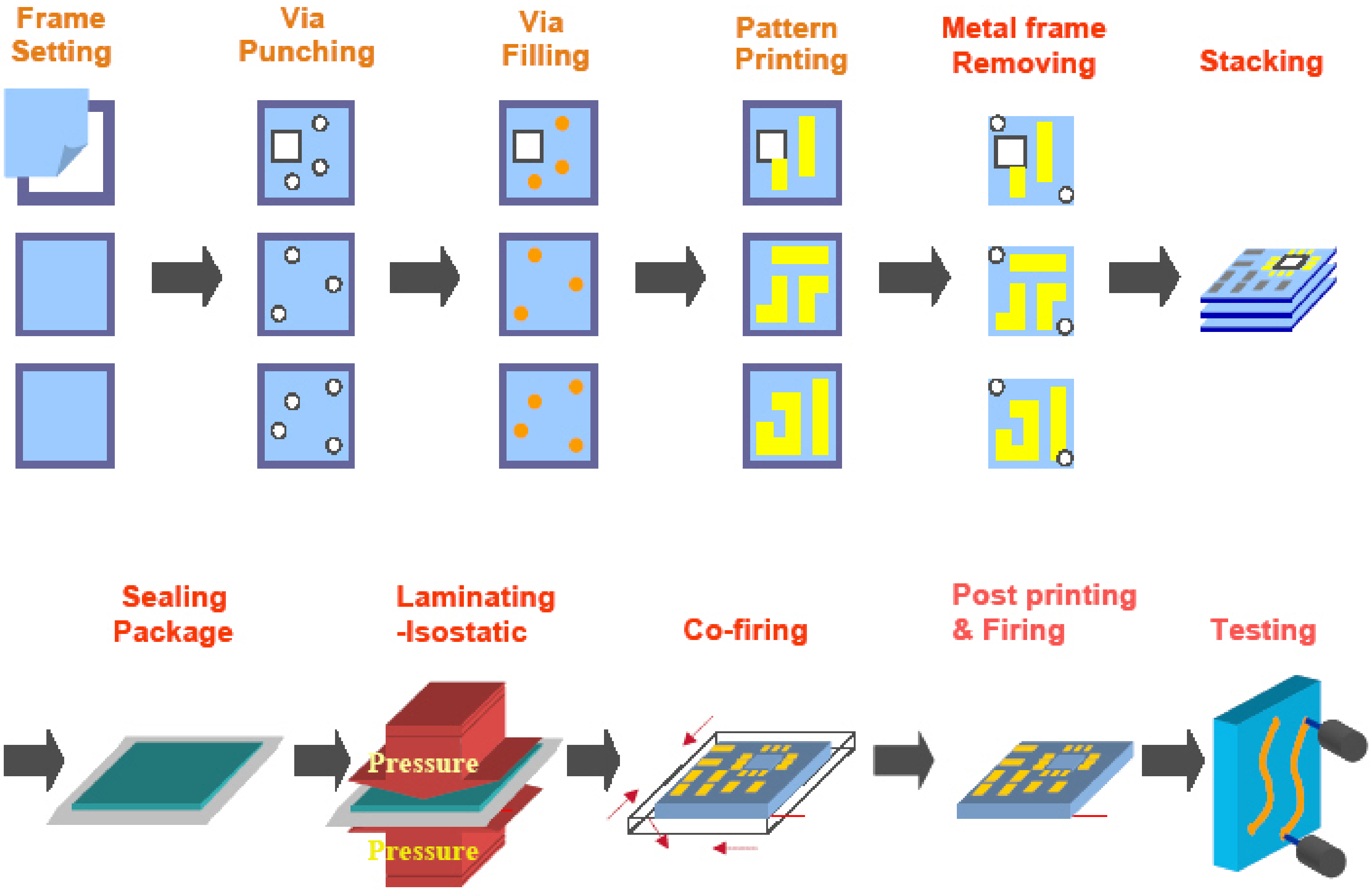
Process of LTCC



Frame Setting

Via Punching

Via Filling

Pattern Printing

Metal frame Removing

Stacking

Sealing Package

Laminating -Isostatic

Co-firing

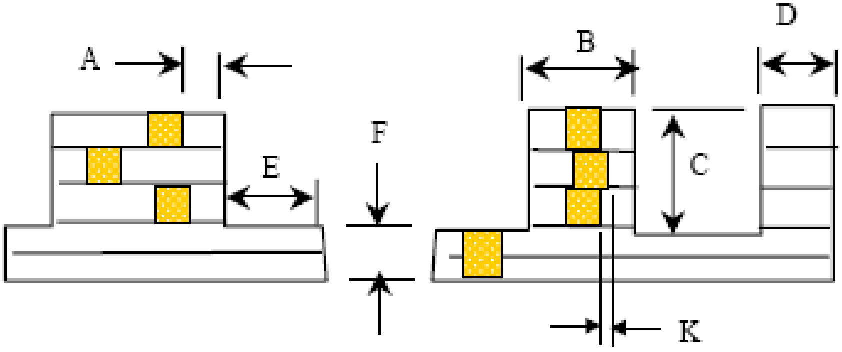
Post printing & Firing

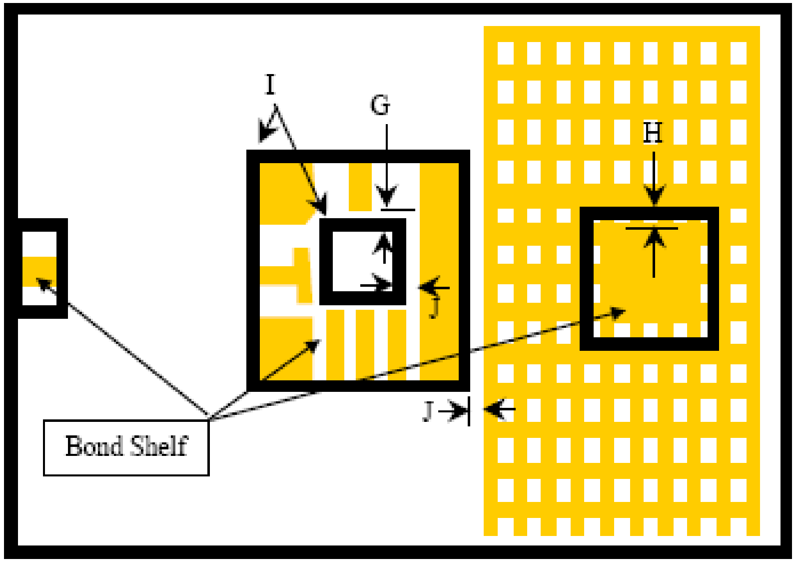
Testing

Ref: 2.

CAVITIES

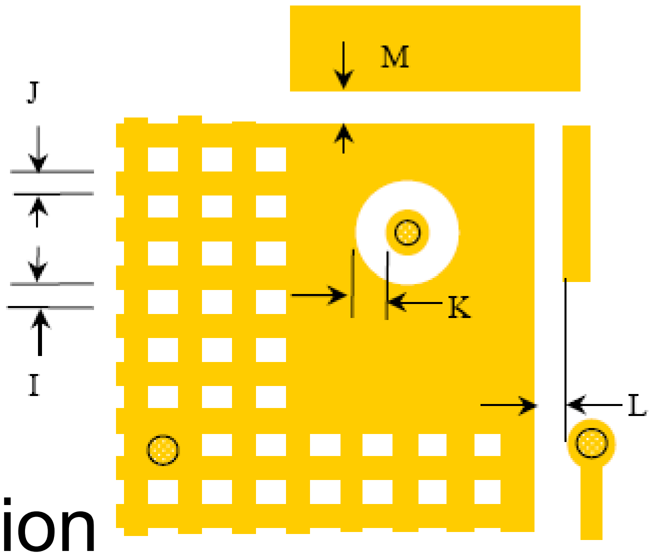
- Cavity design is complicated by concerns of deformation during lamination and firing, particularly of thin or deep walls.





Ref: 5.

GROUND PLANES

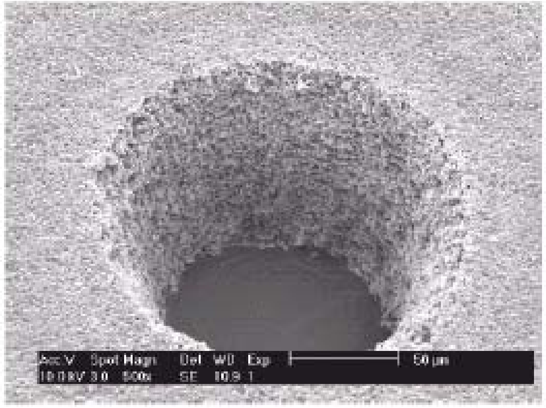


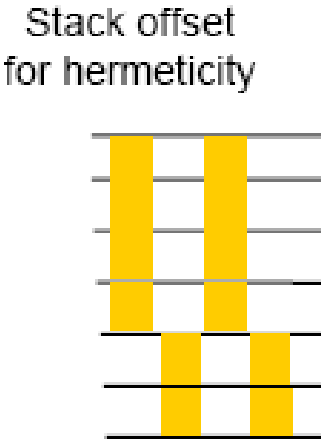
- Gridded ground planes
  - ☐ use less precious metal
  - ☐ create less ceramic distortion
  - ☐ Lines half as wide as spaces result in 55% metal coverage, and are recommended.
  - ☐ Solid areas are required at via landings and may be added at other locations.

Ref: 5.

Three general types of Vias(1/3)

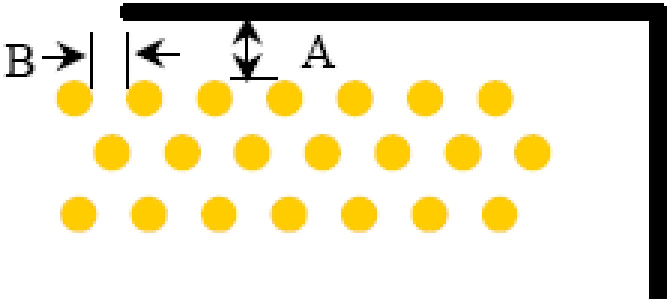
- RF shield vias –
  - cover pads optional





RF Shield Vias

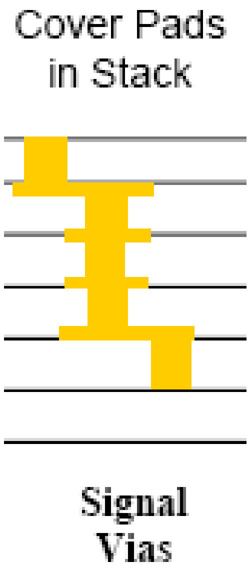
RF Shield Vias

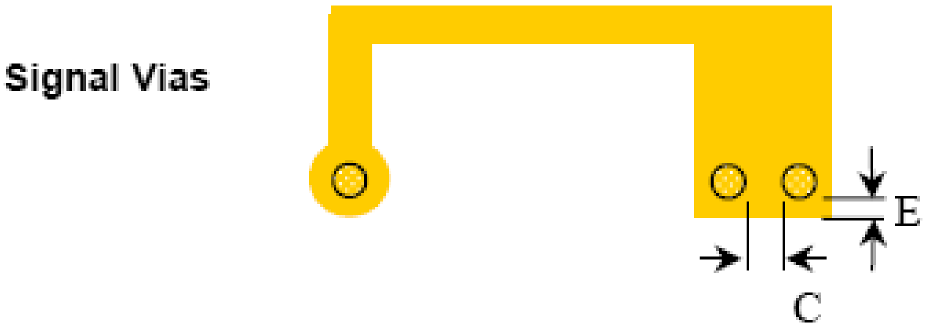


Ref: 5.

Three general types of Vias(2/3)

- signal vias –
  - cover pads recommend



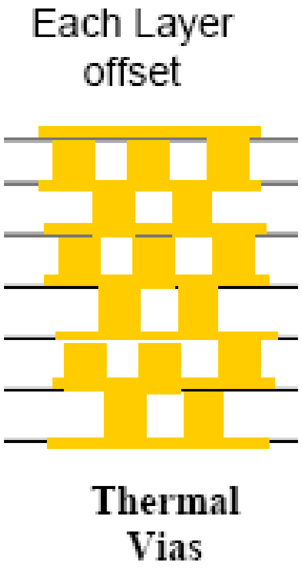


Via sizes are limited by tape thickness, due to aspect ratio of filling the vias. Keeping aspect ratio of via to tape close to 1 is optimum for manufacturability.

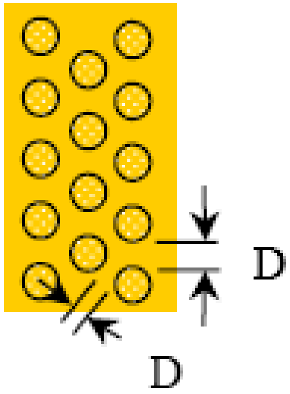
Ref: 5.

Three general types of Vias(3/3)

- thermal vias –
  - connected by planes
  - staggered with planes at each layer



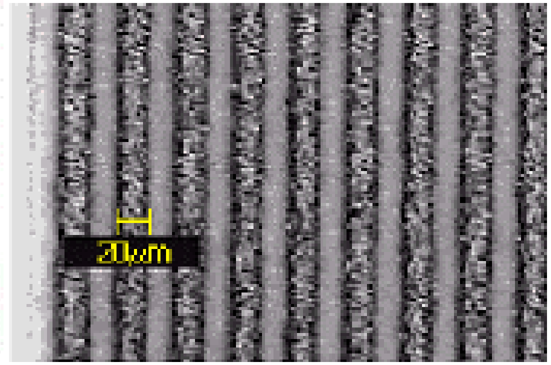
Thermal Vias

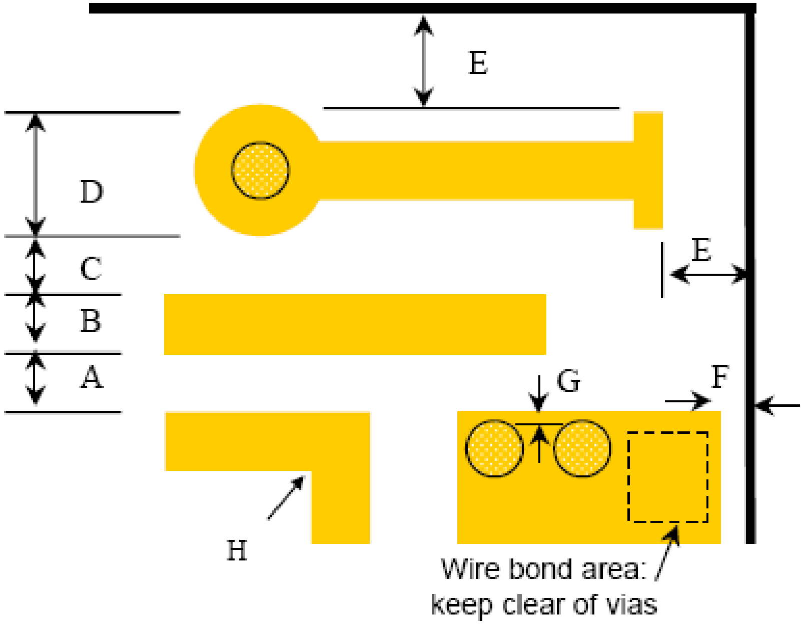


Ref: 5.

CONDUCTORS

- Conductors are typically printed on the green tape
- Placement close to cut edges must be carefully



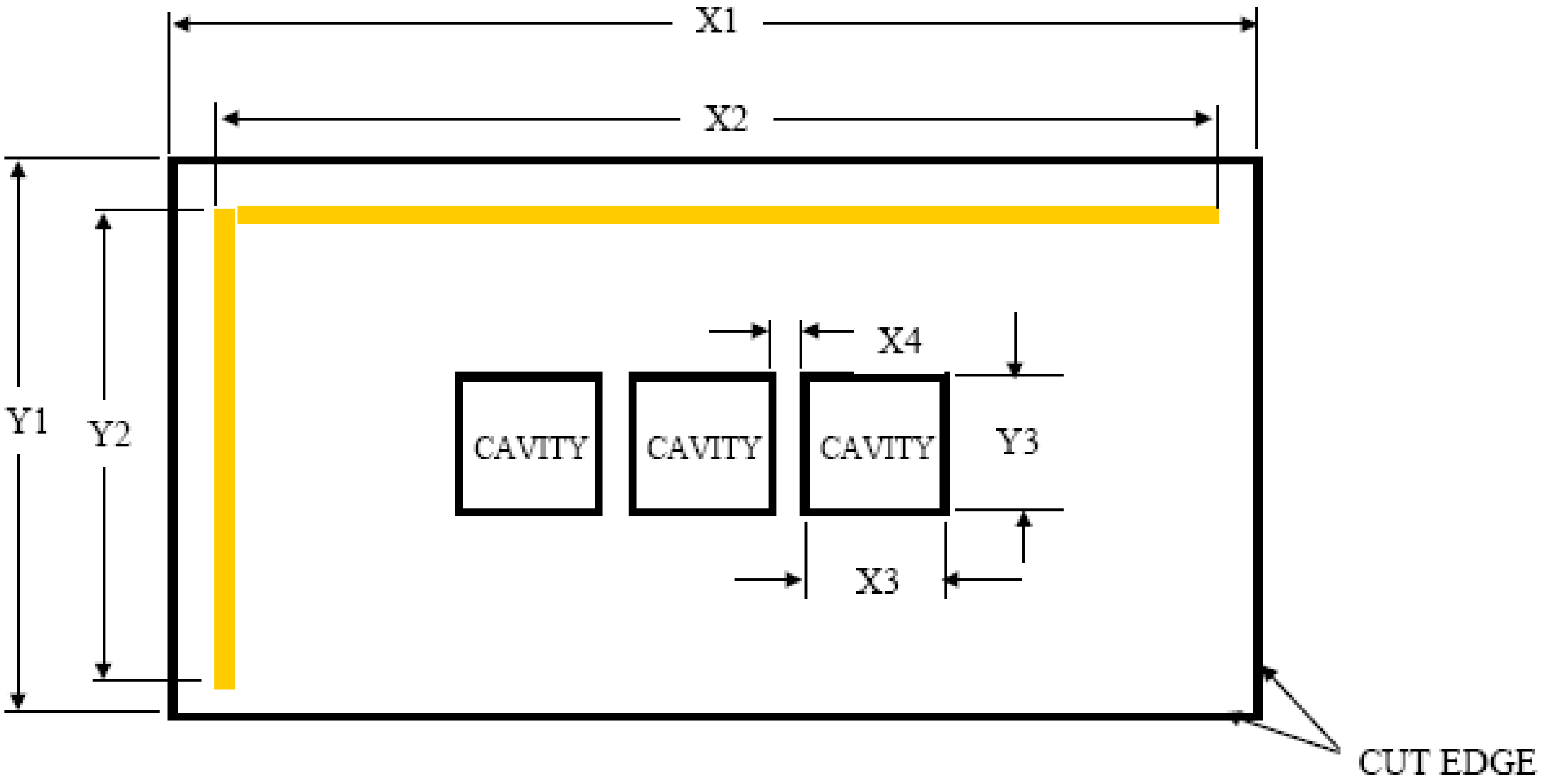


Ref: 5.

CUTTING PROCESSES

- Hot Knife
- Saw Cut
- Laser Cut
- Laser Scribe
- Hot Knife Scribe

PACKAGE DESIGN

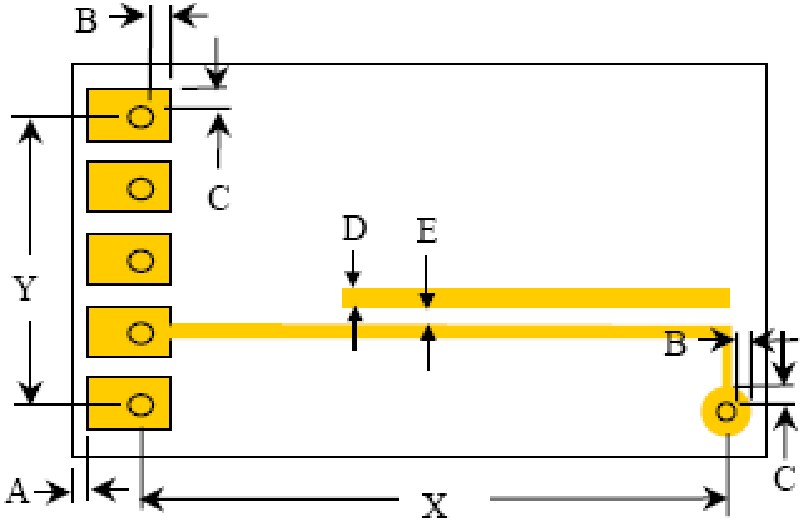


Ref: 5.

POST PRINT

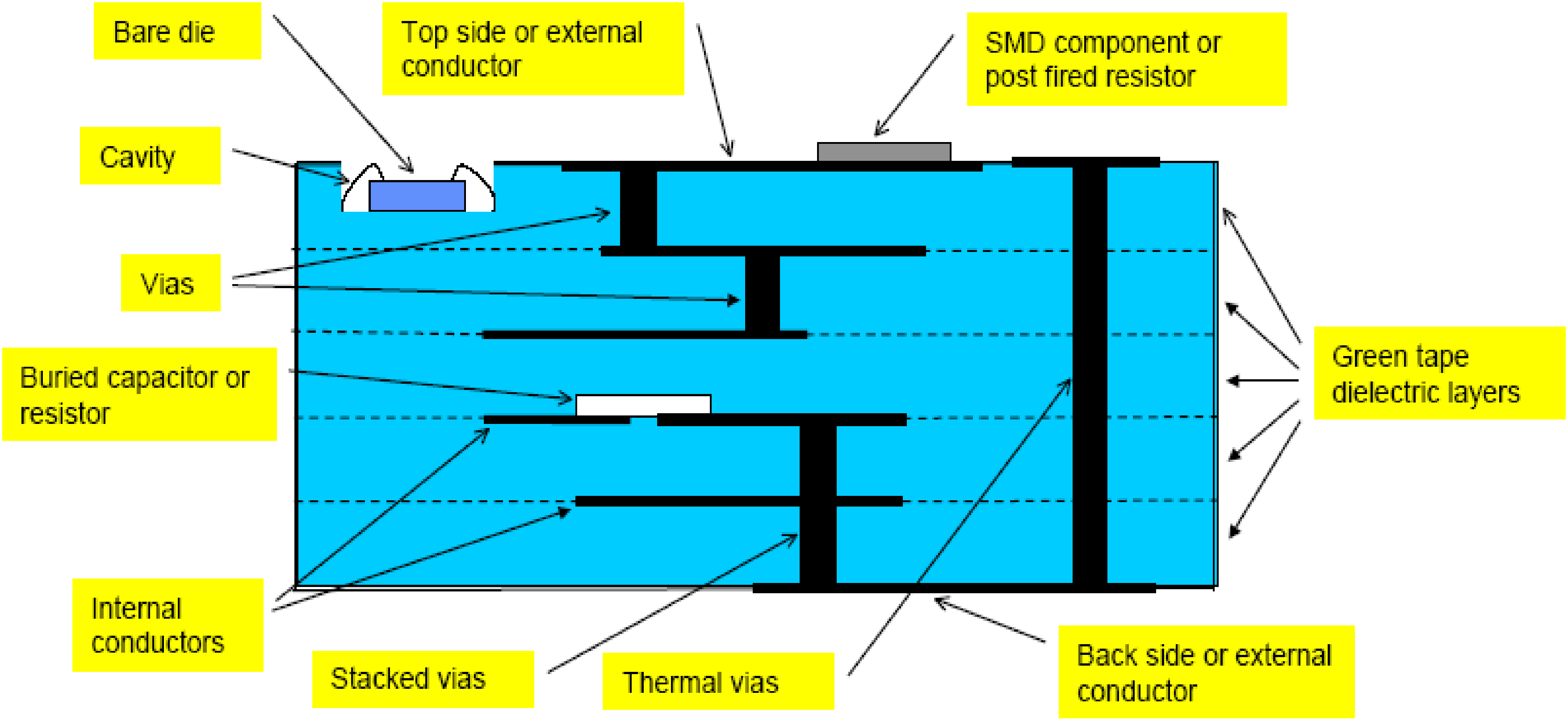
- Post printing refers to the process of printing conductors after firing the package, usually after cutting to size.
- Post printing will also be required if grinding is necessary.
- the catch pad sizes

  must besufficiently large



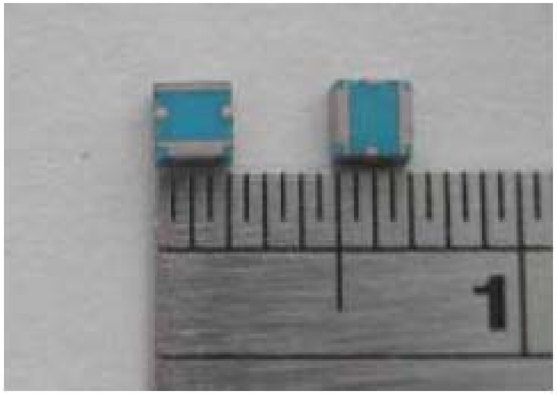
Ref: 5.

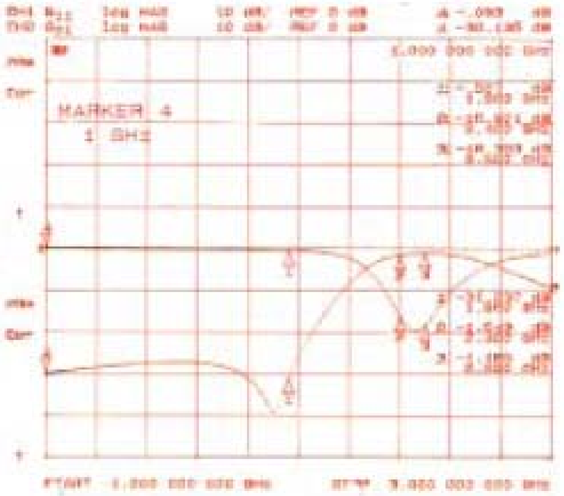
Cross Section of LTCC Modules



Ref: 3.

2.4 GHz LTCC Filter

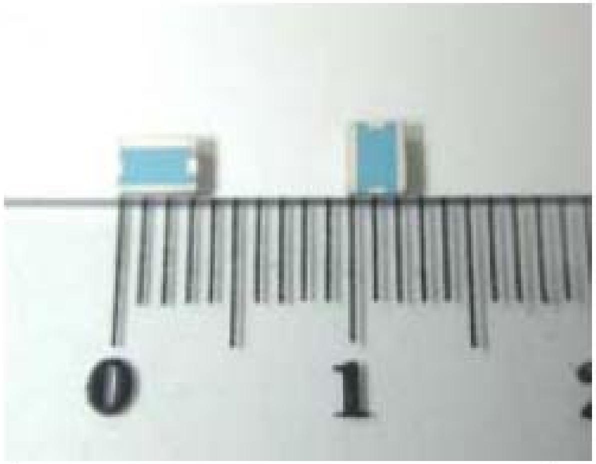


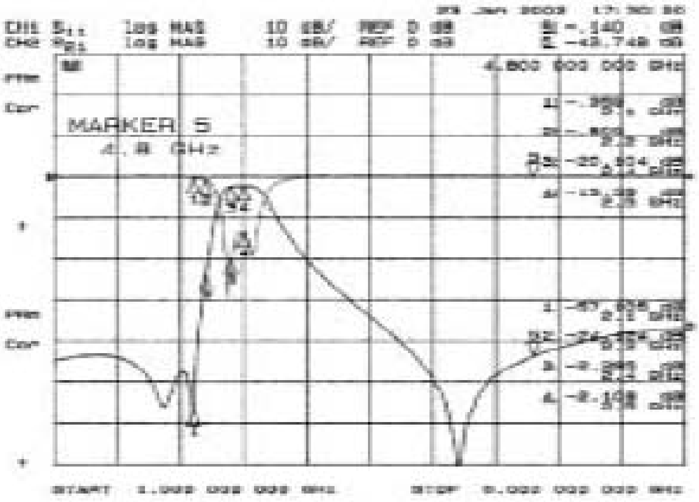


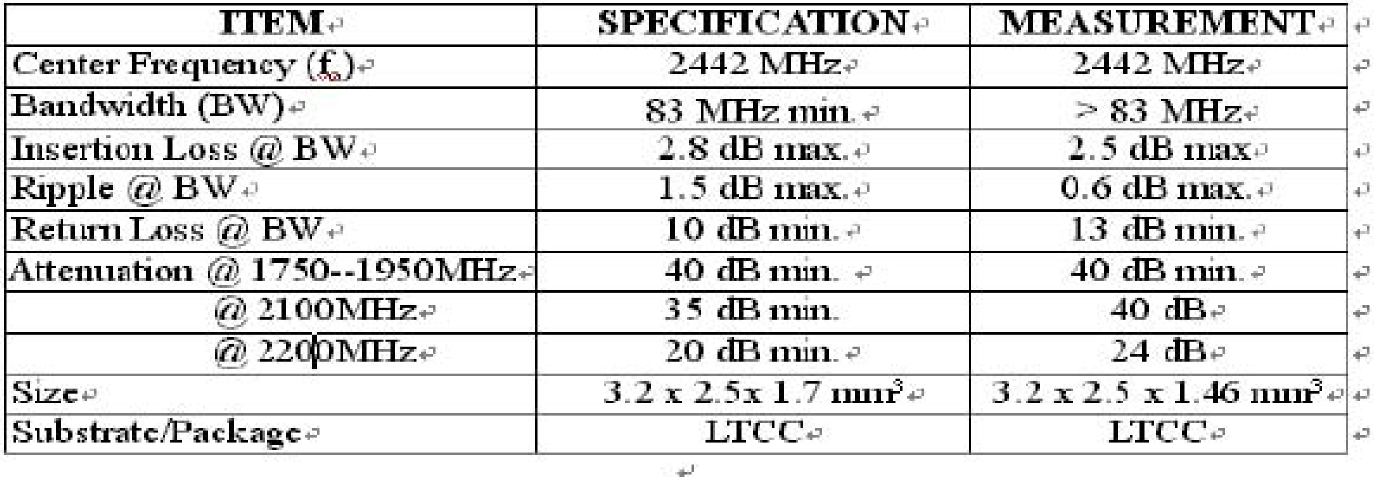
Item	Spec.
Center Freq.(f_0)	2.45GHz
Bandwidth	f_0 +/- 50MHz
Insertion Loss	2 dB max.
Attenuation	30 dB min. @ 1.96GHz
Size(mm³)	2 x 2 x 1.5

Ref: 1.

2.4 GHz LTCC High-Rejection-Rate Filter



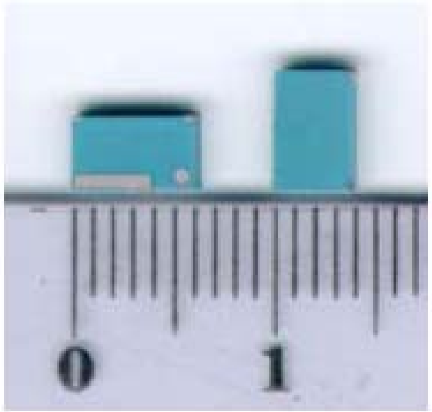


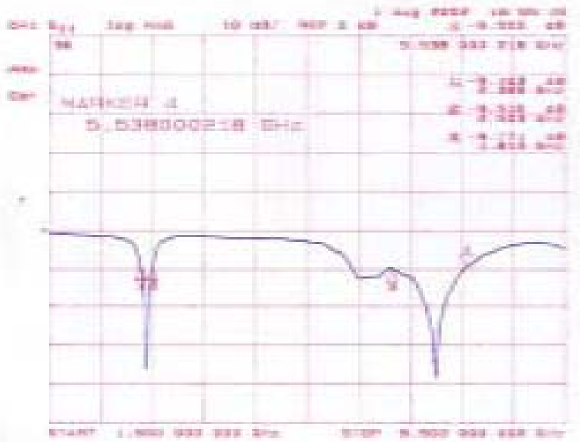


ITEM	SPECIFICATION	MEASUREMENT
Center Frequency (f_o)	2442 MHz	2442 MHz
Bandwidth (BW)	83 MHz min.	> 83 MHz
Insertion Loss @ BW	2.8 dB max.	2.5 dB max
Ripple @ BW	1.5 dB max.	0.6 dB max.
Return Loss @ BW	10 dB min.	13 dB min.
Attenuation @ 1750--1950MHz	40 dB min.	40 dB min.
@ 2100MHz	35 dB min.	40 dB
@ 2200MHz	20 dB min.	24 dB
Size	3.2 x 2.5x 1.7 mm^3	3.2 x 2.5 x 1.46 mm^3
Substrate/Package	LTCC	LTCC

Ref: 1.

MLC/LTCC Embedded Antenna





Items	Measurement	
	ISM 2.4 GHz	ISM 5 GHz
Bandwidth	110 MHz	1100 MHz
VSWR	2.0	2.0
Gain	1.0 dBi	1.8 dBi
Polarization	Linear	Linear
Azimuth beam width	Omni-directional	Omni-directional
Impedance	50 Ω	50 Ω
Size	$6.0 \times 4.0 \times 1.5$ mm^3	

Ref: 1.

Outline

- What is LTCC?
- Advantages
- Process of LTCC
- Applications of LTCC
- Future developments
- Case study
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LTCC Applications

- Monolithic , Three-dimensional , Cost-effective
- Firing Temperature < 1000 ℃
- Benefits :

  flexibility , density , reliability , reduced weight , low-loss

- Better than thick-film process (single-step)
- High performance in commercial and military use

LTCC for Wireless Applications

- Base Station Amplifier Modules
- Transmitters and Receivers
- Handset Power Amplifiers
- Low Noise Amplifiers
- Voltage Control Oscillators
- Mixers
- Filters
- Power Splitters and Combiners
- Matching Networks

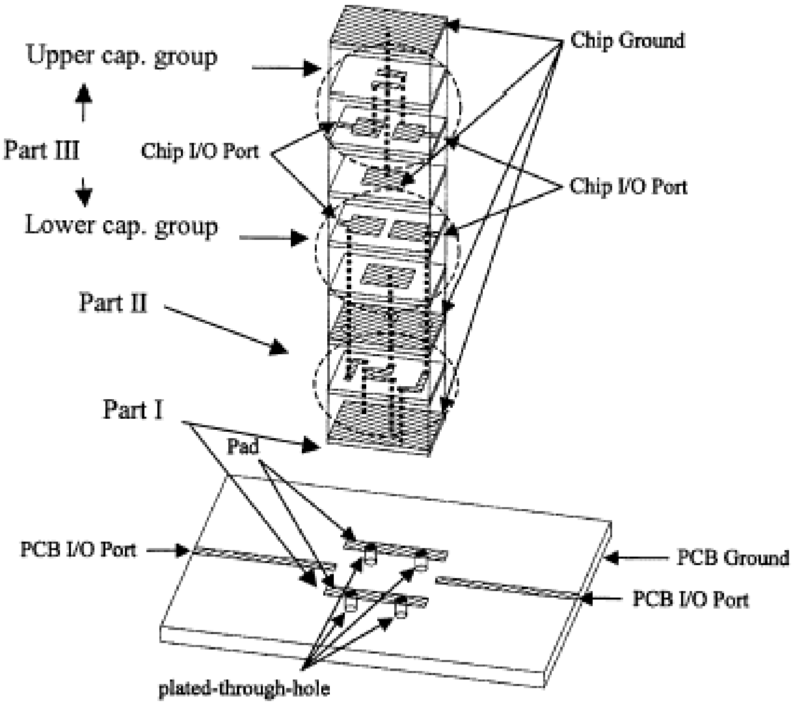
LTCC in Military & Space Environments

- Transmitters/Receivers
- Phased Array Radar
- Amplifiers
- Filters
- Converters
- Power Drivers
- Sensors

LTCC in the Automotive Industry

- Engine Management Systems
- Gearbox Management Systems
- Anti-Lock Braking Systems
- Global Positioning Systems
- Gas Discharge Lamp Controllers
- Ignition Modules
- Sensor Modules

Miniaturized LTCC Filters



(a)

- Reserve all the design advantage of strip line
- Can be use in portable telephone and other device

Miniaturized RF Modules(1/3)

- Have a lower cost than conventional thick-film process
- Allow innovative implementation of circuit
- The ability to integrate L , R , C
- Incorporation with IC technology further opens a wide range of functionalities and modularization

Miniaturized RF Modules(2/3)

Material properties

- Layer thickness : 25μm~250μm
- Layer count : 80 layers
- ε_r : 5~300
- tanδ : 0.001~0.005
- Silver has been extensively used as conductors
- Surface material : platinum , palladium , silver , gold

Miniaturized RF Modules(3/3)

Advantages

- Reduced size (1/2)
- Reduced cost (1/4)
- Key improvement :

impedance matching between circuits or module

⇨improve the performance and power efficiency of PA

⇨**longer battery life or smaller battery size**

LTCC Module

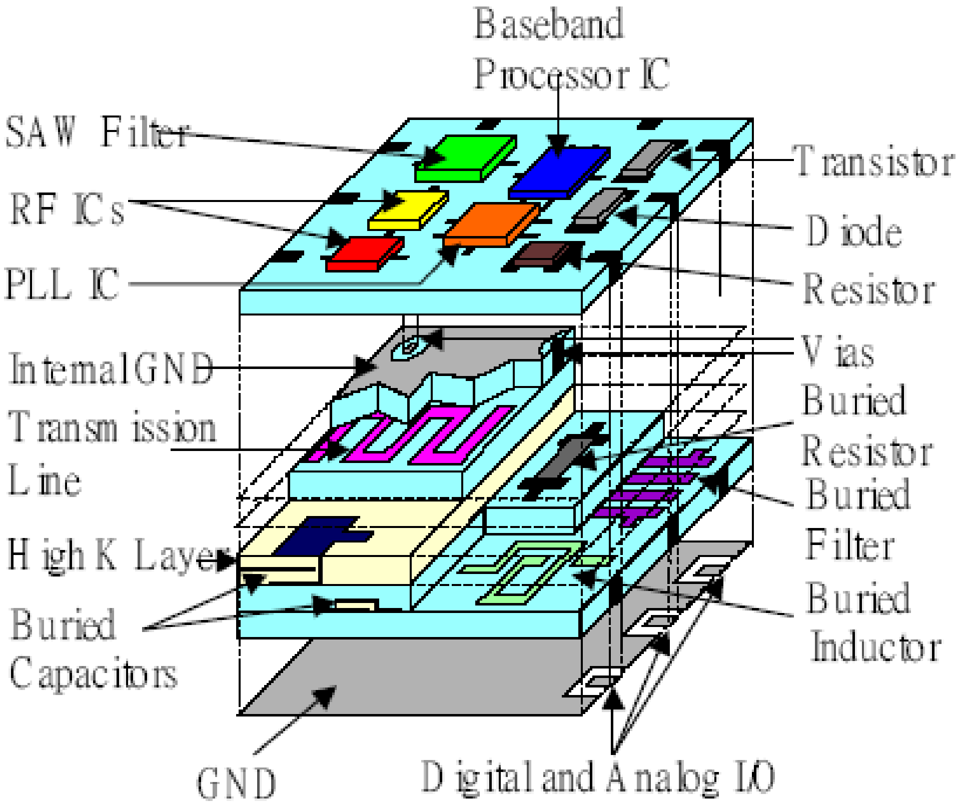
*Buried passive components

*Substrate as package (cavity…)

*Lower TCE (match to Si
and GaAs)

*Smaller module volume

*Packaging capability (BGA, FC…)



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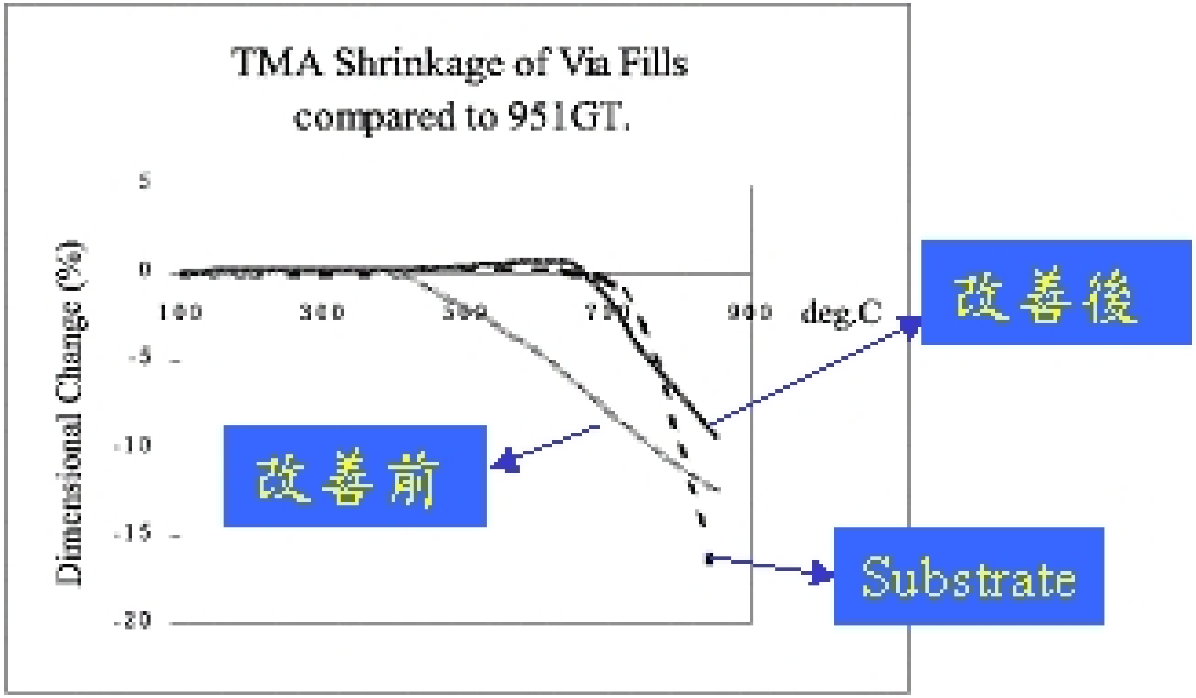
Future developments

- Zero shrinking
- High-permittivity dielectric pastes
- Buried (active) components
- TB-BGA
- Optical components
- Liquid and gas interfaces / conductors
- Brick box system

Zero shrinking

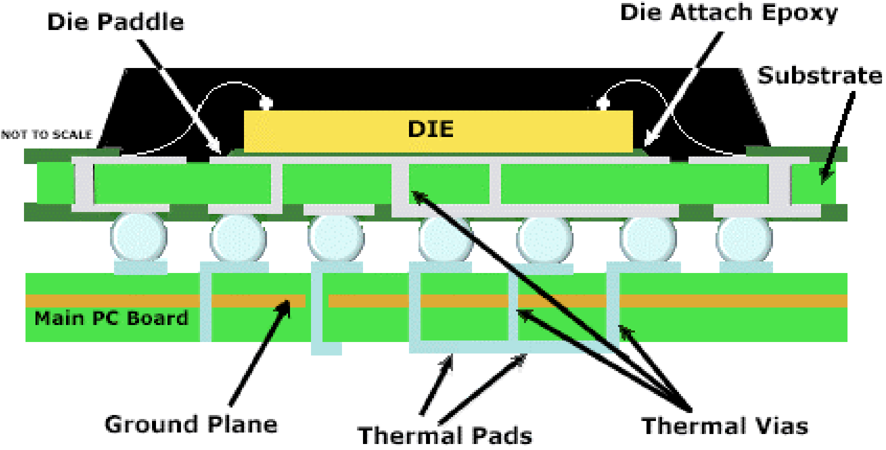
共燒收縮匹配(延遲燒結)



Ref.:2001 IMAPS proceeding

不同塡孔膠之燒結收縮曲線
改善前：添加塡孔膠爲收縮製程使用
改善後：添加塡孔膠爲不收縮製程使用

TB-BGA



© 1995-2004 Analog Devices, Inc.

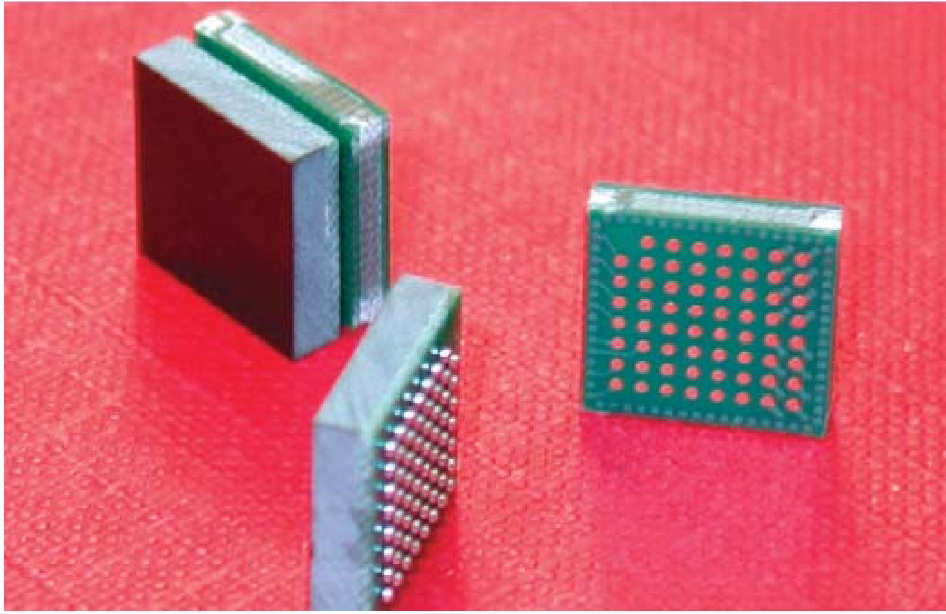
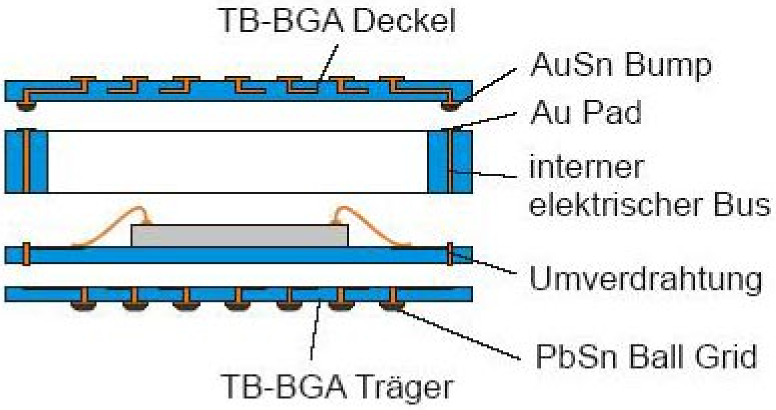


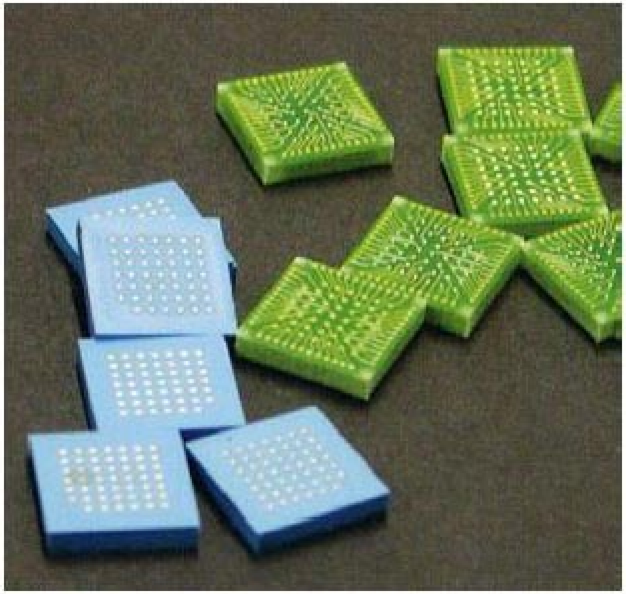
Bild 1: Match-X-Stromsensor- und Signalkonditionierungsbaustein; jeweils einzeln und als Stack (links oben)

http://www.mstonline.de/publikationen/infoboerse/ib_2003/ib42.pdf

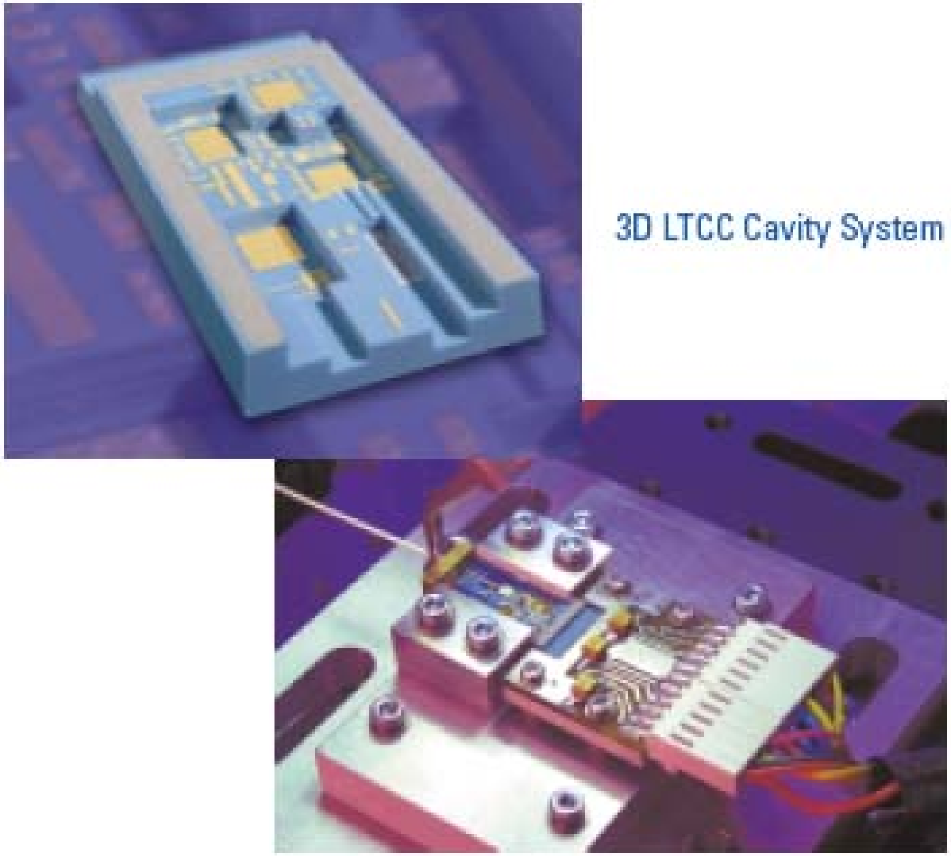
- Low Temperature Cofired Ceramics (LTCC) (siehe Photo, links)
- FR4-Platinenwerkstoff (siehe Photo, rechts)



http://www.imtek.uni-freiburg.de/mikroelektronik/content/upload/system_04.pdf



Optical components



3D LTCC Cavity System

Precision Fibre Alignment

When formulating a new optical product, one of the most critical decisions is the choice of package.

www.cmac.com/mt/

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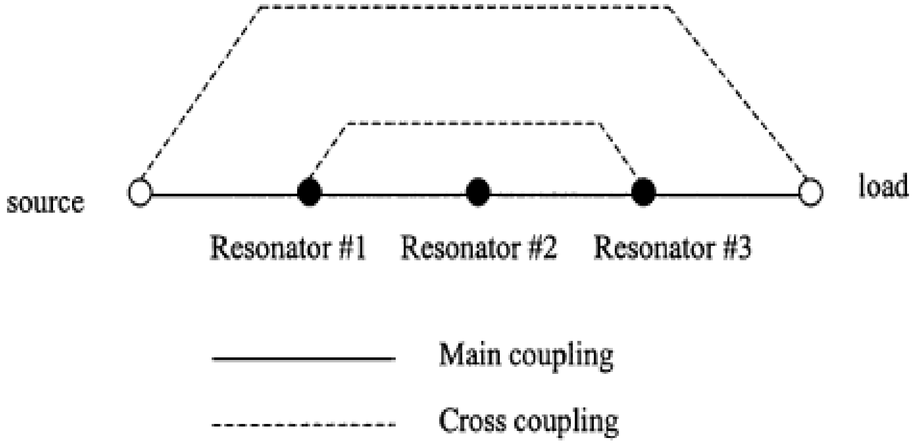
Realization of Transmission Zeros in Combline Filters Using an Auxiliary Inductively Coupled Ground Plane

Ching-Wen Tang,
Yin-Ching Lin,
Chi-Yang Chang

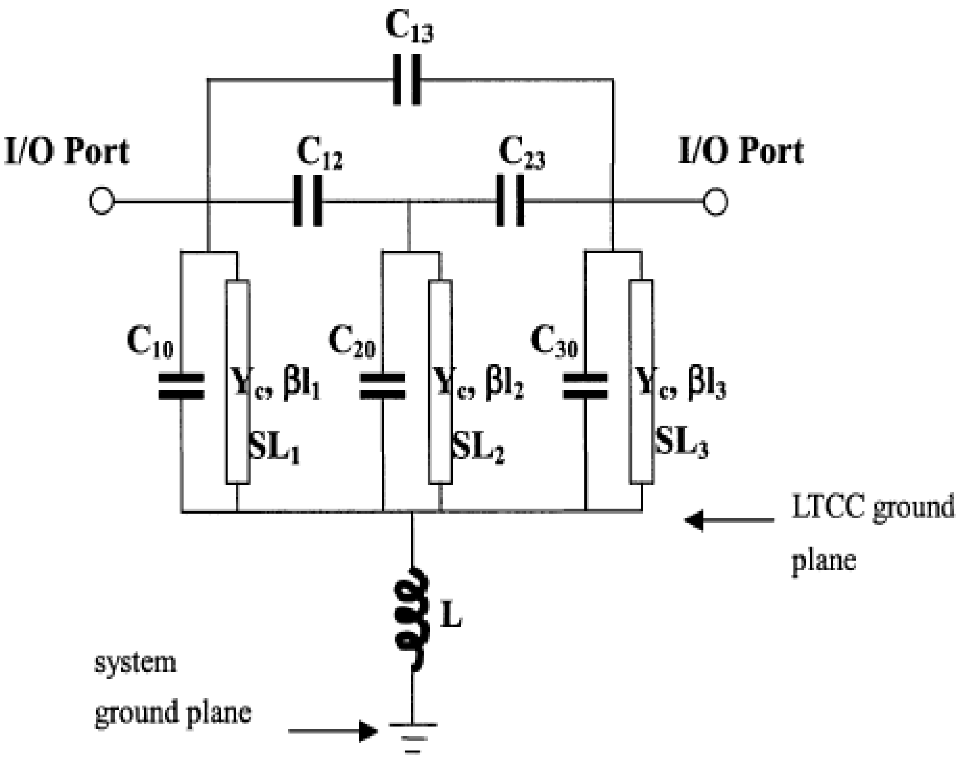
IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,
VOL. 51, NO. 10, OCTOBER 2003

Introduction

- Inductive coupling among three resonator
- Three pole combline filter with capacitive cross-coupling between I/O ports
- Generate two transmission zeros at a low-side skirt to reject local and image signals.
- For the high-side skirt , the inductance generates an extra transmission zero to suppress the harmonic frequency.
- By tuning the L and C_{13} properly, three transmission zeros appeared at proper places.

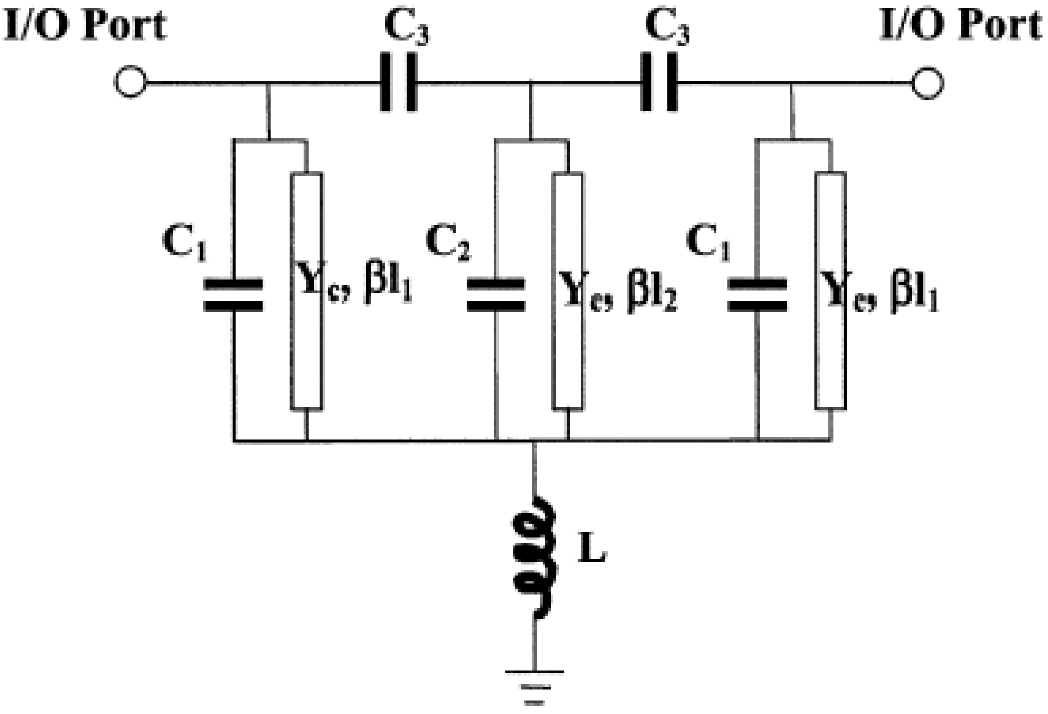


(a)

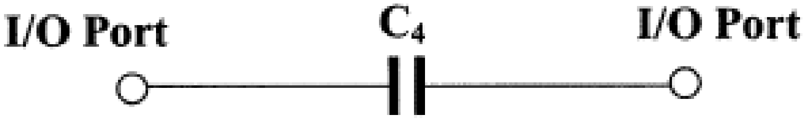


(b)

Derivation of The Y Matrix



(a)



(b)

$l_1 = l_3$

$C_{10} = C_{30} = C_1 = 4.48\text{pF}$

$C_{20} = C_2 = 2.16\text{pF}$

$C_{12} = C_{23} = C_3 = 0.77\text{pF}$

$C_{13} = C_4 = 0.36\text{pF}$

Size of $SL_{1,3}$

$= 74\text{mil} * 8\text{mil}$

Size of SL_2

$= 115\text{mil} * 8\text{mil}$

$L = 0.04\text{nH}$

$\varepsilon_r = 7.8$

Derivation of The Y Matrix

$$
\begin{aligned}
Y_{11} &= Y_{22} \\
&= Y_{C4} \\
&\quad + \frac{Y_{C3}^2 + (1 + Y_{C3} Z_L + Y_1 Z_L) \cdot [Y_2 Y_{C3} + Y_1 (Y_2 + 2 Y_{C3})]}{2 Y_{C3} + 4 Y_1 Y_{C3} Z_L + Y_2 (1 + 2 Y_{C3} Z_L + 2 Y_1 Z_L)} \\
&= \frac{Y_{N1}}{Y_D} \qquad (1)
\end{aligned}
$$

$$
\begin{aligned}
Y_{12} &= Y_{21} \\
&= -Y_{C4} - \frac{Y_{C3}^2 + Z_L (Y_1 + Y_{C3}) \cdot [Y_2 Y_{C3} + Y_1 (Y_2 + 2 Y_{C3})]}{2 Y_{C3} + 4 Y_1 Y_{C3} Z_L + Y_2 (1 + 2 Y_{C3} Z_L + 2 Y_1 Z_L)} \\
&= \frac{Y_{N2}}{Y_D} \qquad (2)
\end{aligned}
$$

$Y_1 = j(\omega C_1 - Y_C \cot(\beta l_1))$

$Y_2 = j(\omega C_2 - Y_C \cot(\beta l_2))$

$Y_3 = j(\omega C_3 - Y_C \cot(\beta l_3)) = Y_1$

Z_L is the impedance of inductor

Y_{C3} is the admittance of capacitor C_3

Y_{C4} is the admittance of capacitor C_4

Prediction of The Transmission Zeros by Y Matrix

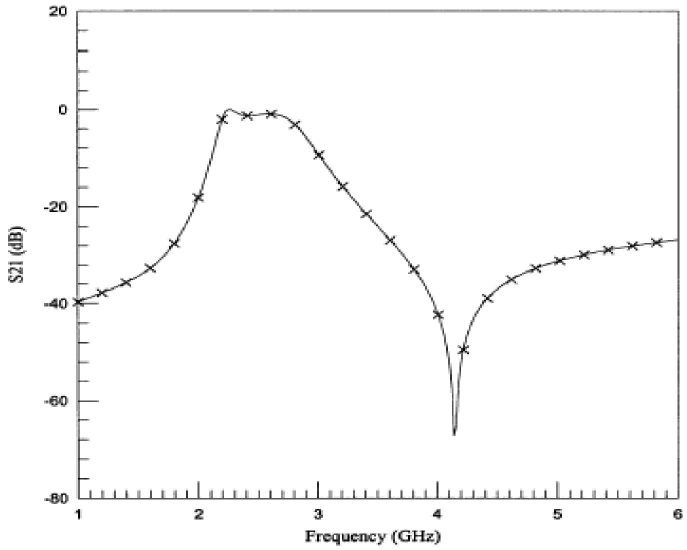
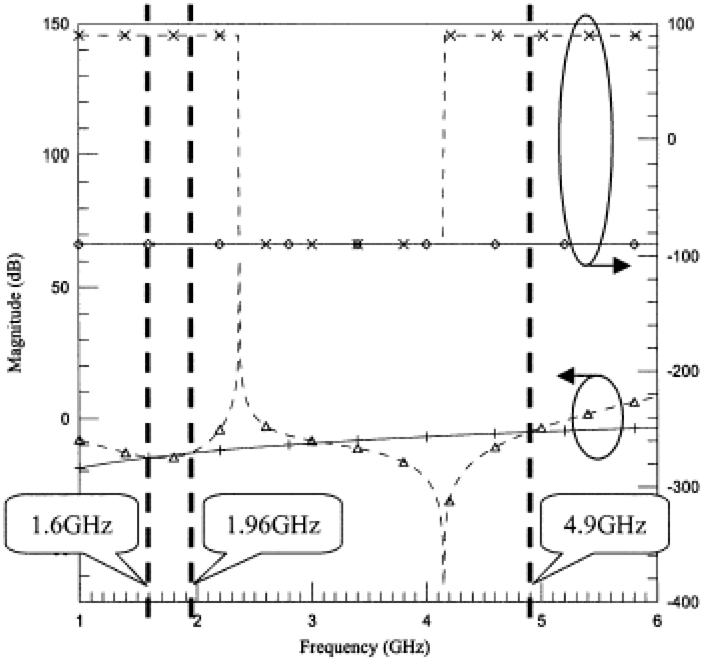


Fig. 3. Response of the filter in Fig. 2(a) with the transmission zero located at



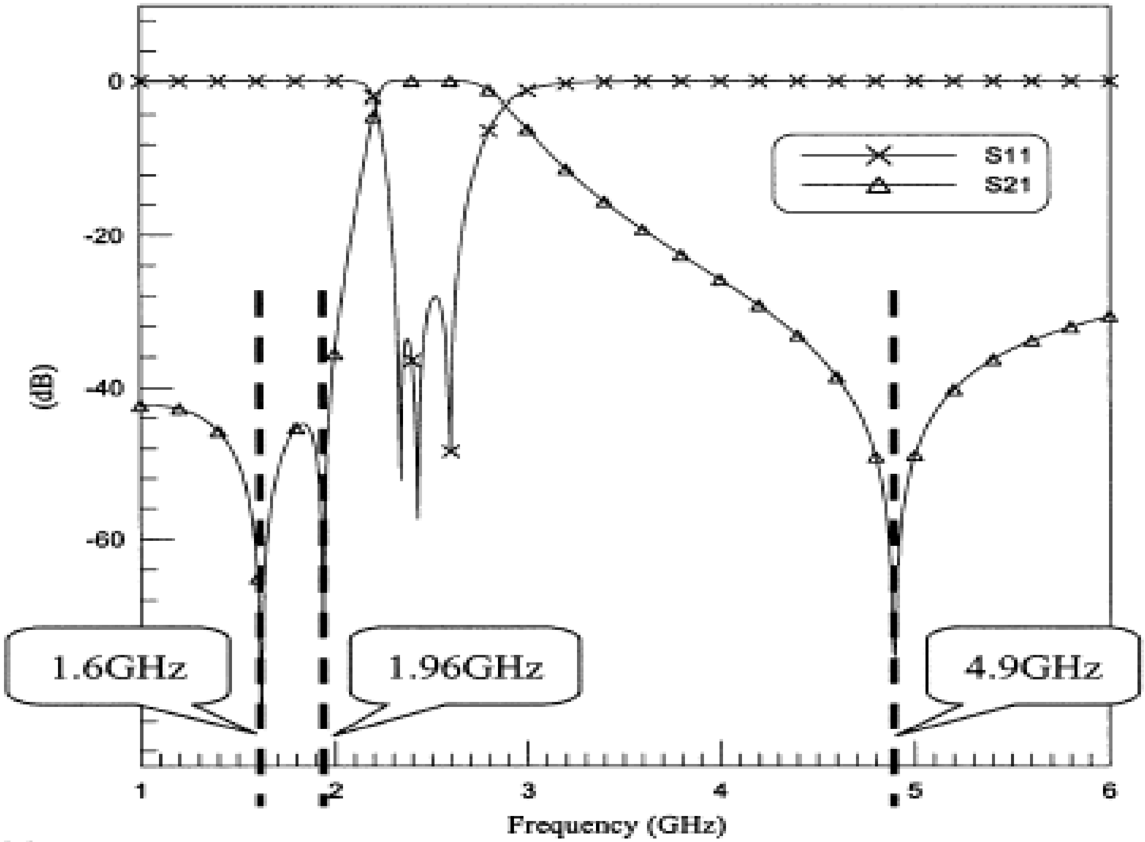
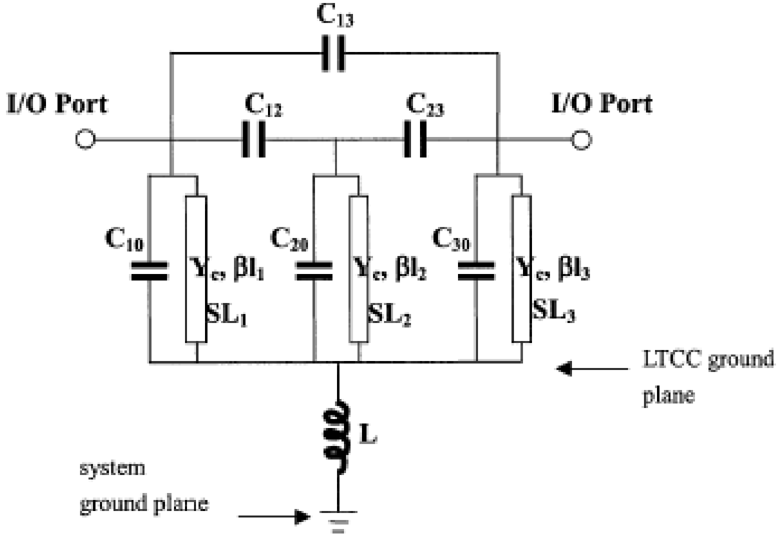
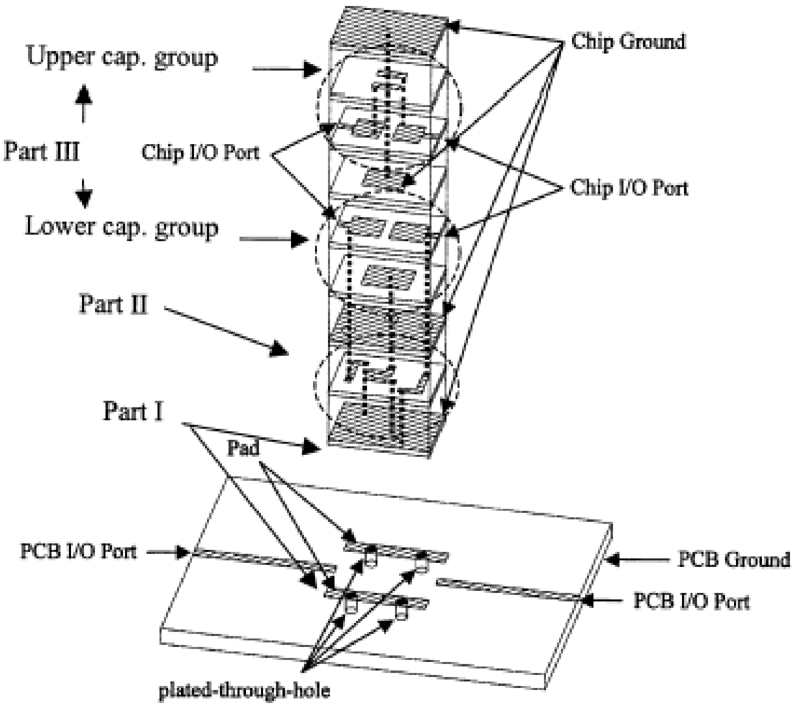


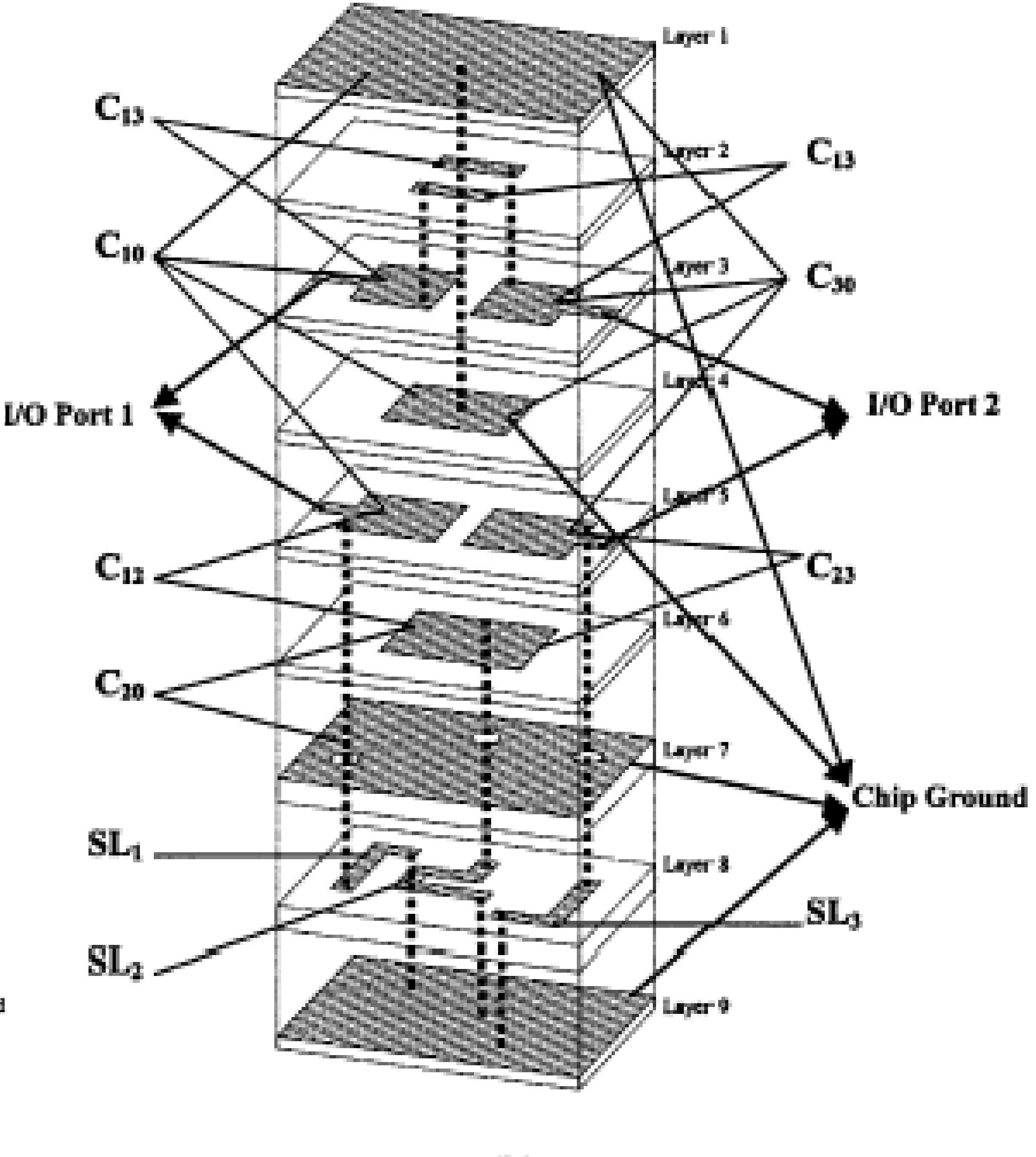
Fig. 5. Simulated result of the multilayer LTCC bandpass filter.


C13
I/O Port
C12
C23
I/O Port
C10
Yc, βl1
SL1
C20
Yc, βl2
SL2
C30
Yc, βl3
SL3
LTCC ground plane
L
system ground plane

(b)

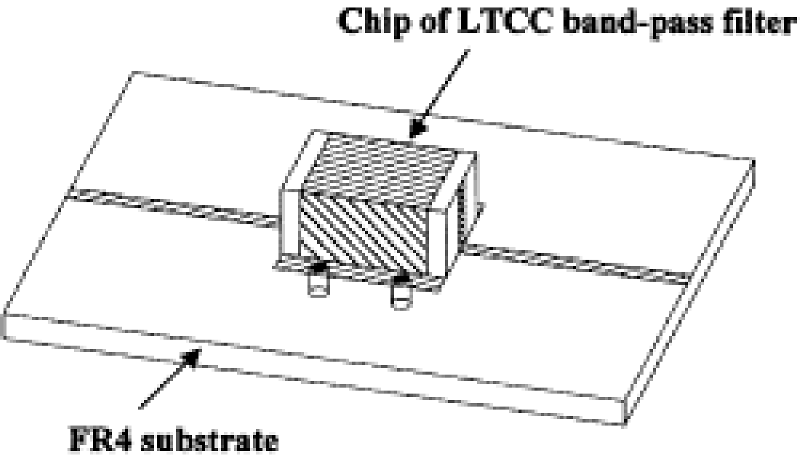

Chip Ground
Upper cap. group
Part III
Chip I/O Port
Chip I/O Port
Lower cap. group
Part II
Part I
Pad
PCB I/O Port
PCB Ground
PCB I/O Port
plated-through-hole

(a)


Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
C13
C10
I/O Port 1
C12
C20
SL1
SL2
C13
C30
I/O Port 2
C23
Chip Ground
SL3

(b)

EM simulation by HFSS



(c)

FR4 PCB
t = 0.4 mm
$\varepsilon_r = 4.47$

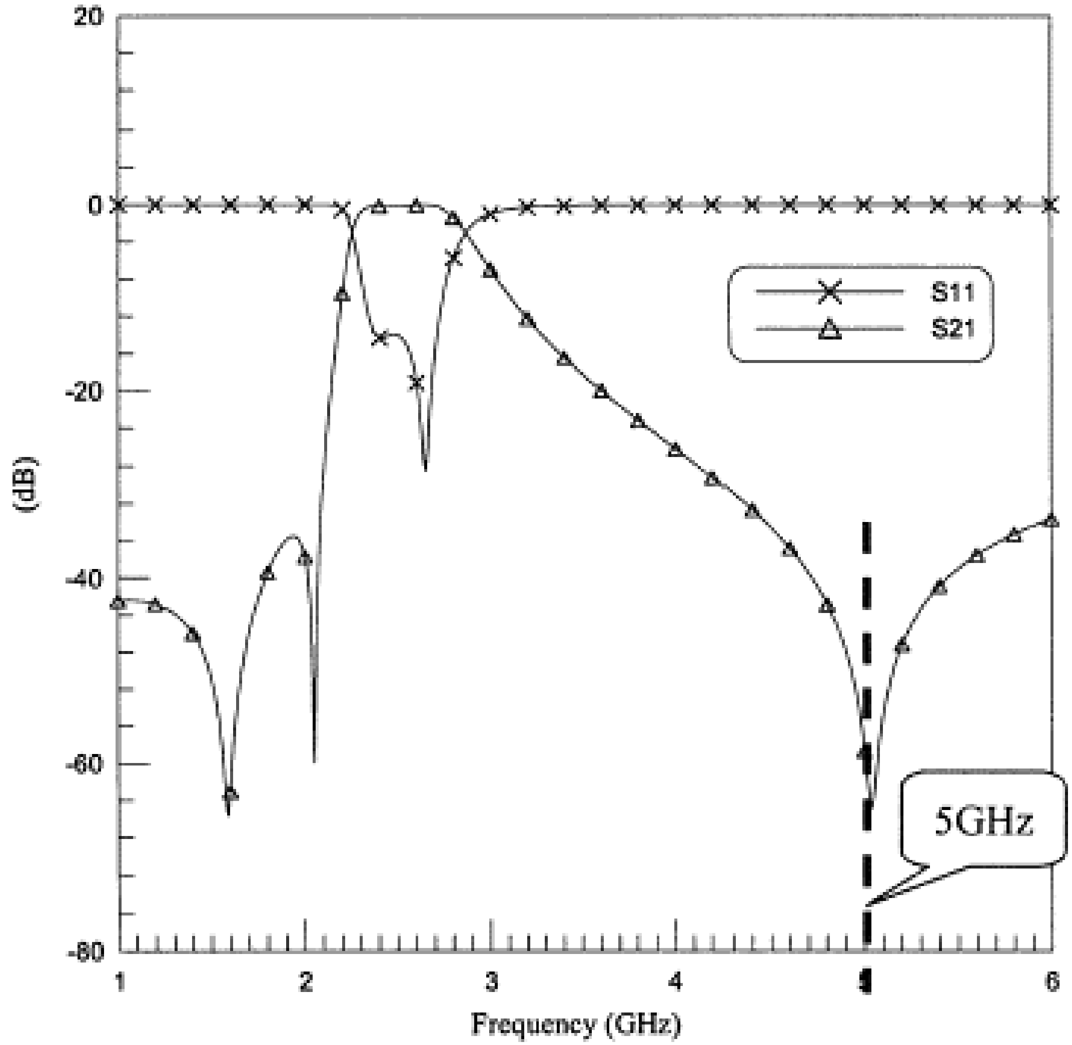
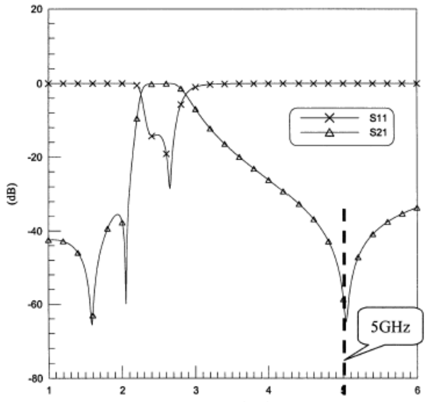
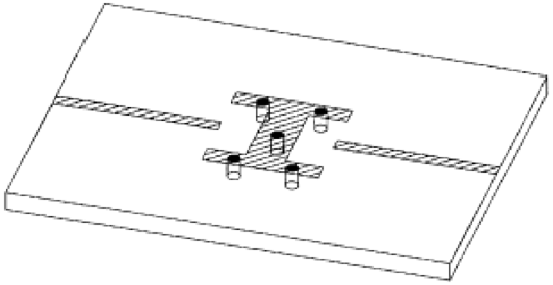


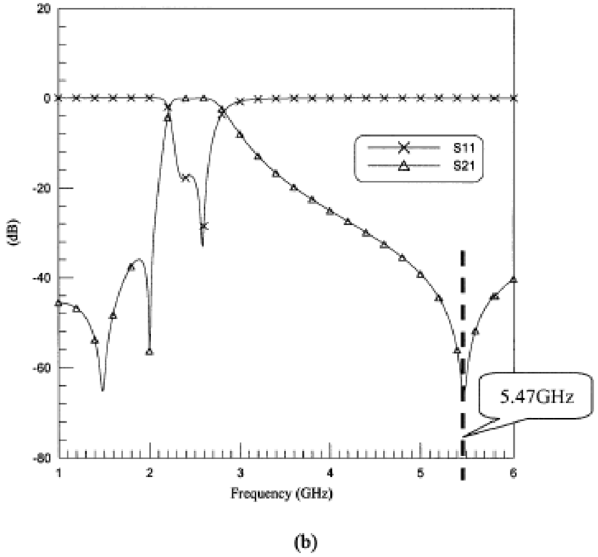
Fig. 7. Simulated response of an LTCC filter mounted on a PCB, as shown in Fig. 6(c).

Analysis of Three Parasitic

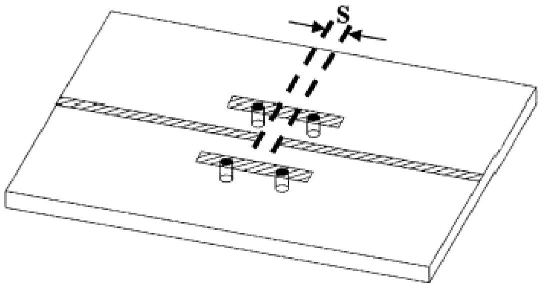


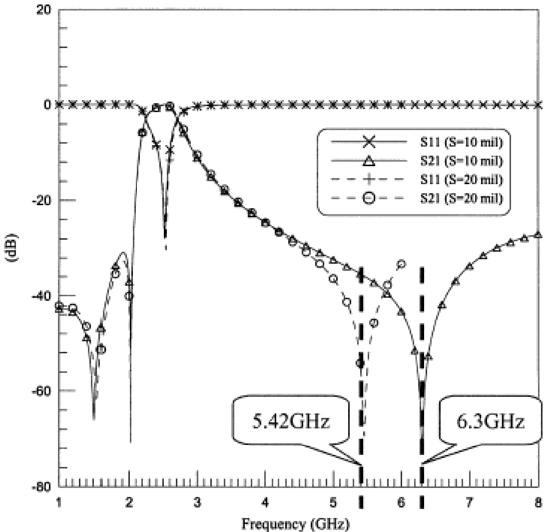
1) Through-hole inductance



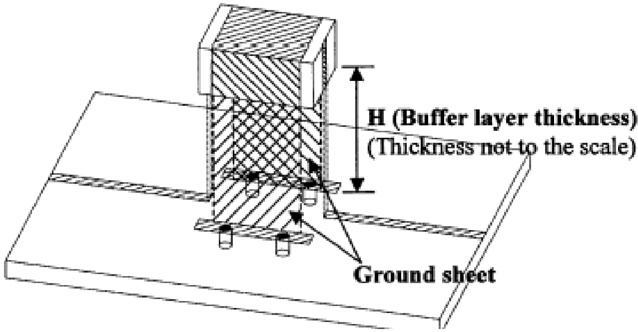


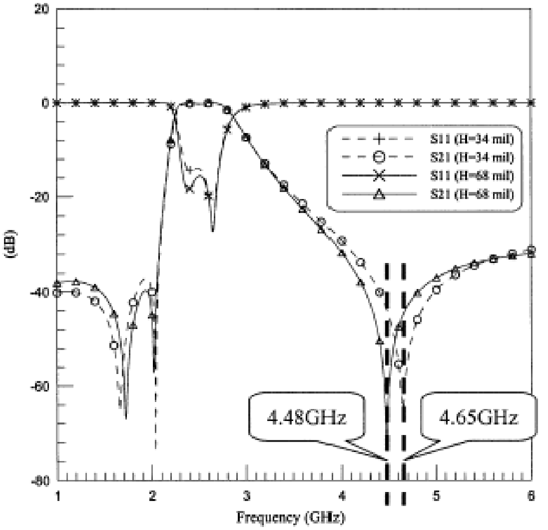
2) Microstrip gap





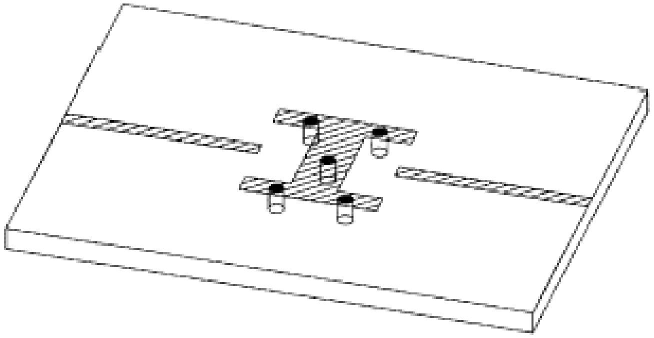
3) Buffer layer thickness





Analysis of Three Parasitic Effects- *Through-hole inductance*

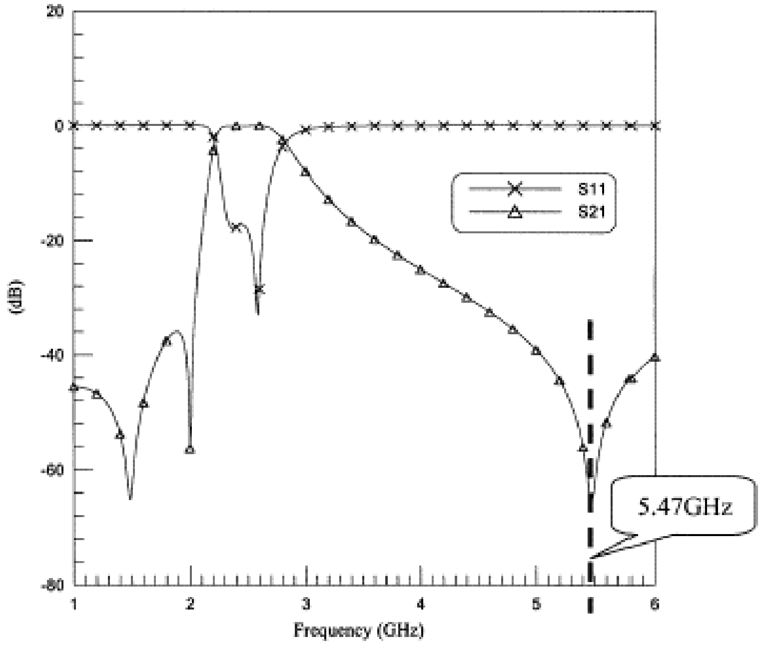
- 4 holes : 5.00 GHz
- 5 holes : 5.47 GHz



$$holes \propto \frac{1}{L}$$

$$L \propto \frac{1}{f_{zero}}$$

$$\color{red}{holes \propto f_{zero}}$$



(b)

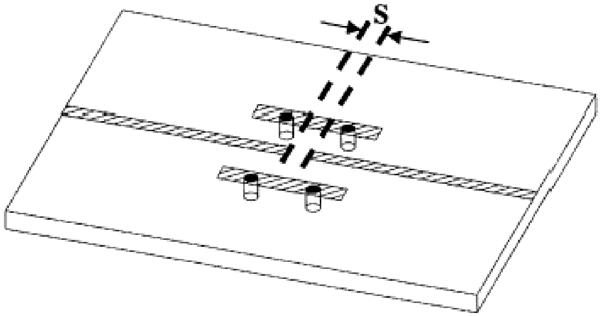
Analysis of Three Parasitic Effects- *Microstrip gap*

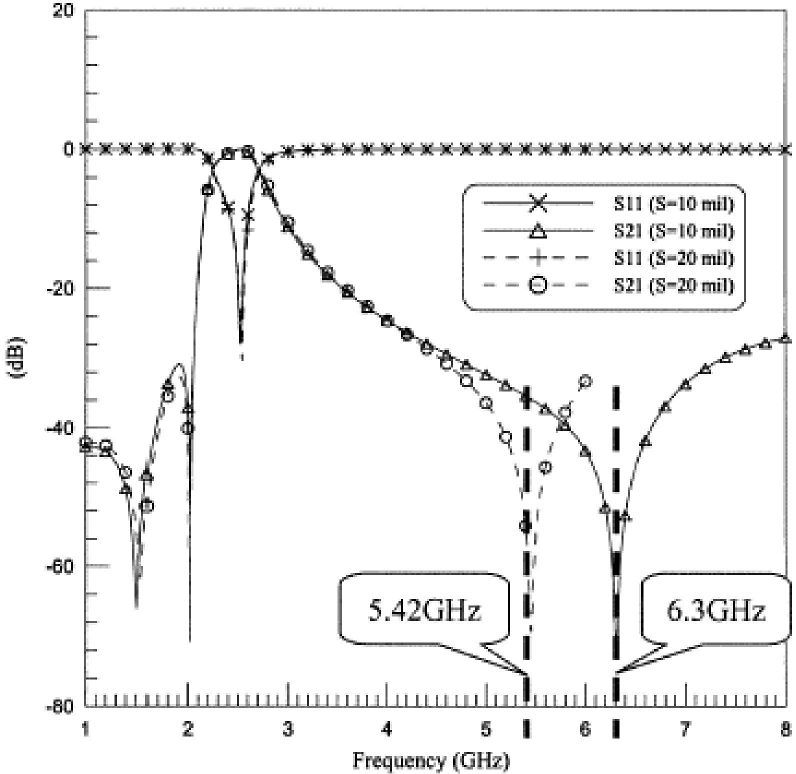
- 20 mil : 5.42 GHz
- 10 mil : 6.30 GHz

$$S \propto \frac{1}{C}$$

$$C \propto f_{zero}$$

$$S \propto \frac{1}{f_{zero}}$$





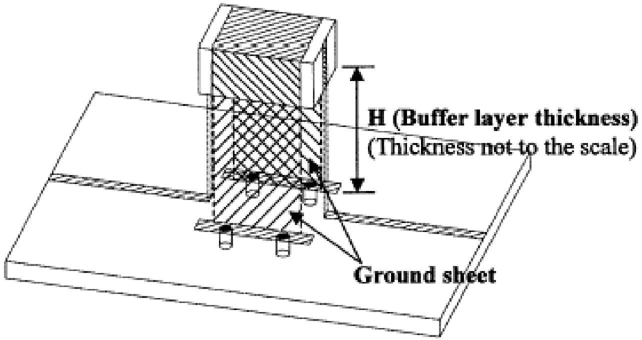
Analysis of Three Parasitic Effects- *Buffer layer thickness*

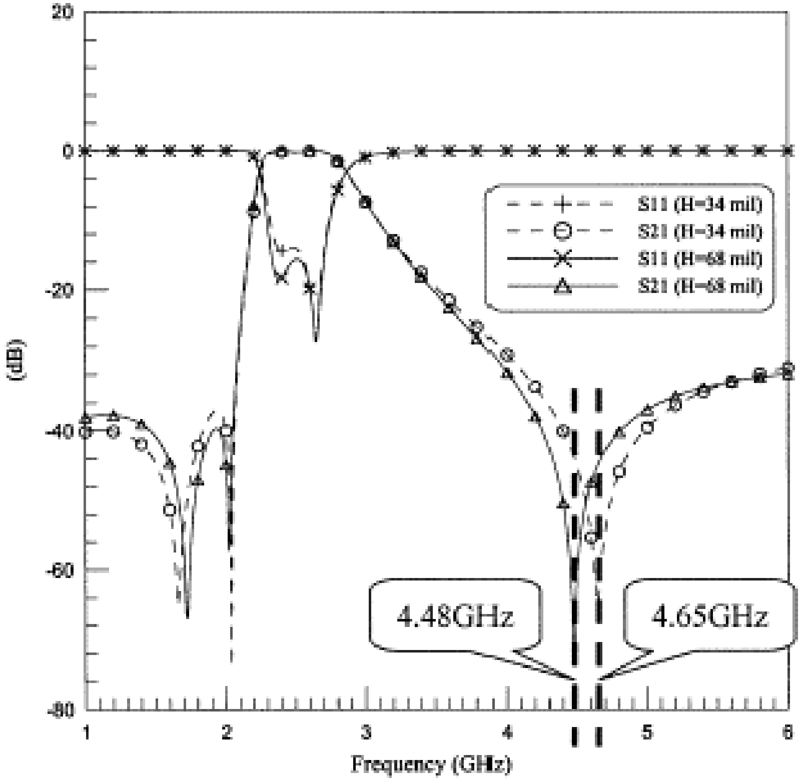
- H=34 mil : 4.65 GHz
- H=68 mil : 4.48 GHz

$$H \propto L$$

$$L \propto \frac{1}{f_{zero}}$$

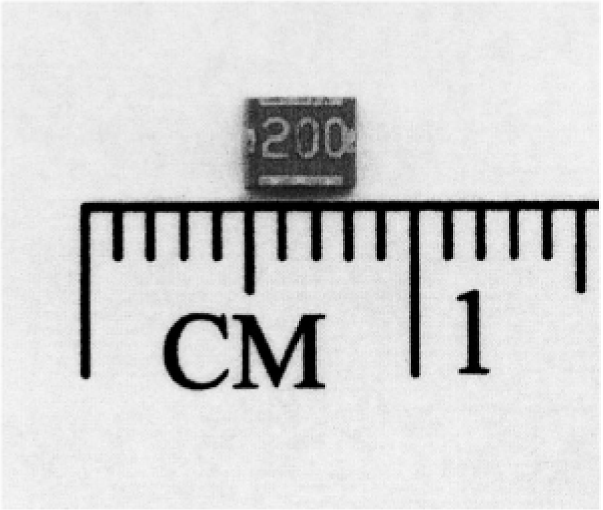
$$H \propto \frac{1}{f_{zero}}$$

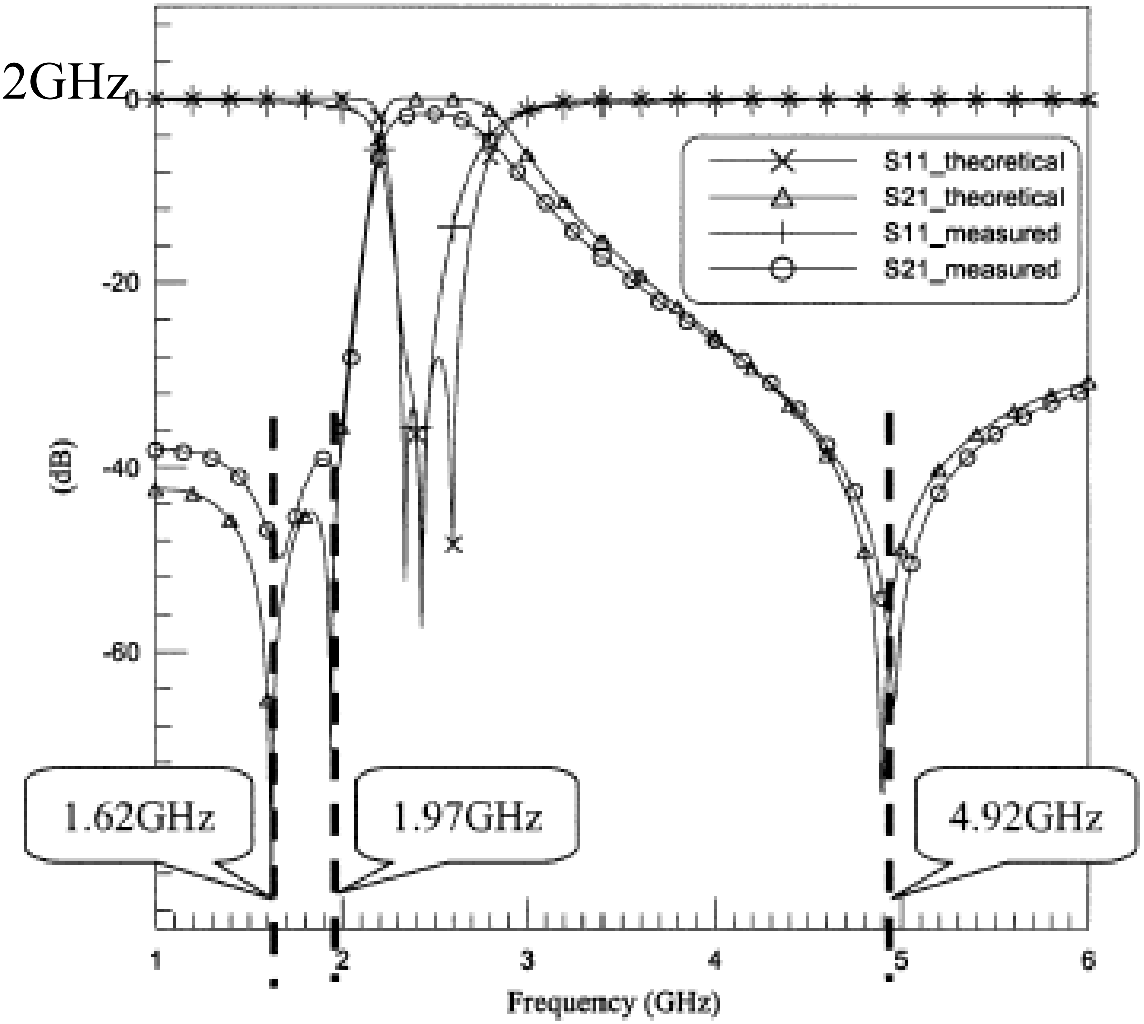




MEASURED RESULTS

- Dupont951ε_r=7.8 ; tanθ=0.0045
- Buffer layer thickness = 3.6 mil
- Chip size = 3.2mm*2.5mm*1.2mm
- IL<1.67dB
- Zeros = 1.62GHz;1.97GHz;4.92GHz
- Metal thickness=5μm





Design of a 2-Pole LTCC Filter for Wireless Communications

Vadim Piatnitsa ,
Eino Jakku ,
Seppo Leppaevuori

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS,
VOL. 3, NO. 2, MARCH 2004

FILTER DESIGN

Filter Specification

- Pass Band : 1.9 GHz~ 2.0 GHz
- f_o : 1950 MHz
- BW : 5 %
- IL : < 2 dB
- OBR $_{low}$: >20 dB (1.58~1.64 GHz)
- OBR $_{up}$: >10 dB (1.75~1.81 GHz)

FILTER DESIGN

Filter Synthesis

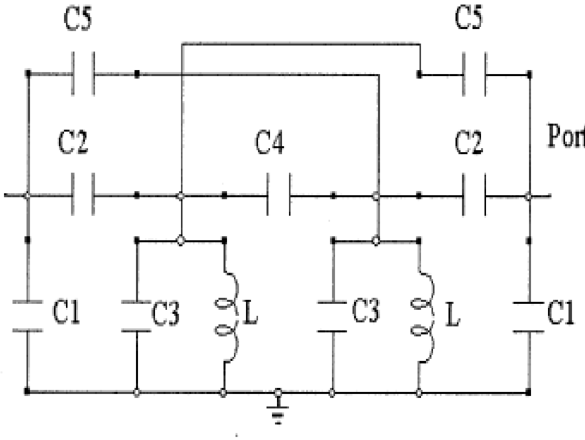


Fig. 1. The equivalent scheme of the second- order filter with cross coupling.

TABLE I
KEY PARAMETERS OF THE EQUIVALENT SCHEME

C1, pF	C2, pF	C3, pF	C4, pF	C5, pF	L, nH
0.2	0.5	1	0.1	0.1	4.2

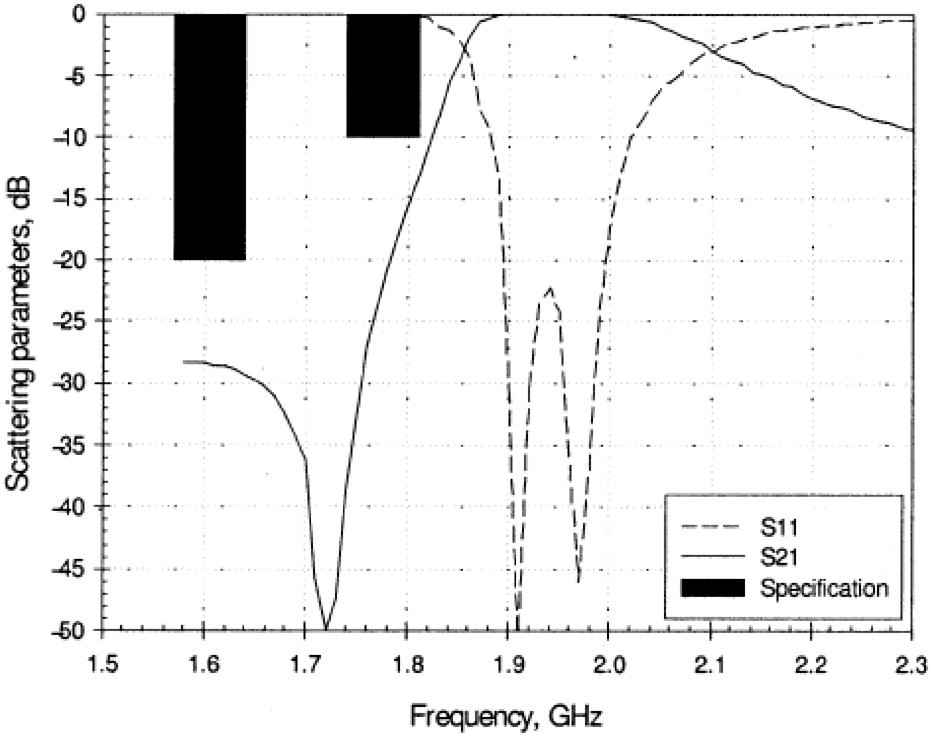


Fig. 2. The frequency response of the equivalent circuit.

2-pole filter Chebyshev prototype

FILTER DESIGN

Physical Realization of the Filter

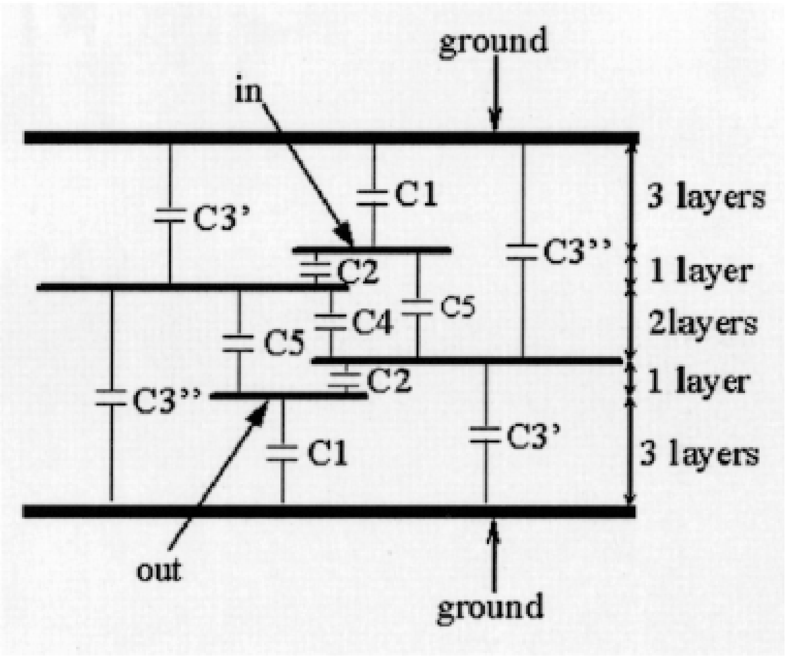


Fig. 3. The physical realization of capacitances.

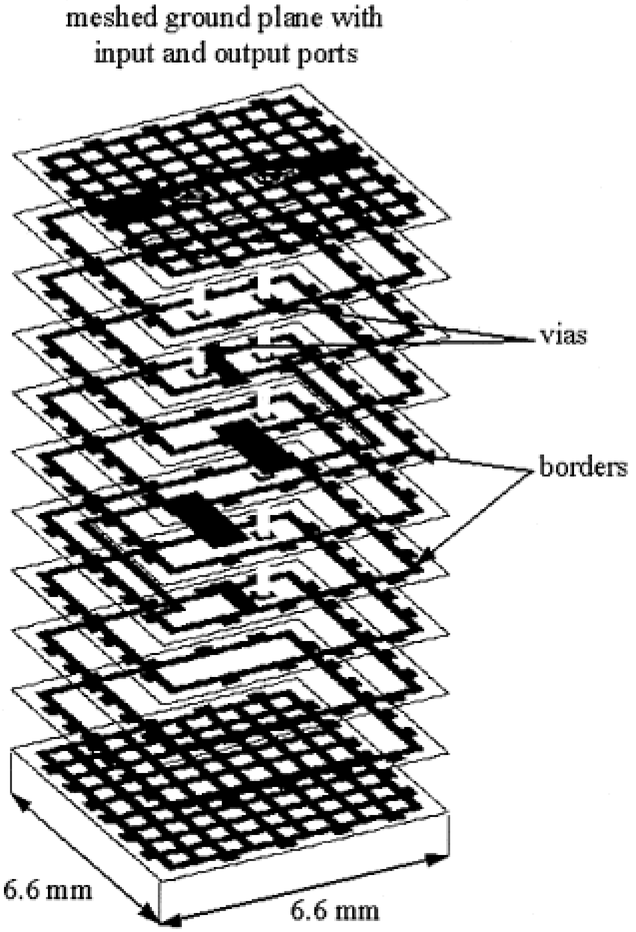


Fig. 4. The 3-D filter structure without vias between ground planes.

FILTER DESIGN

Simulation

- ε_r = 9.2 ± 0.1
- tan θ = 0.002
- t = 99.1 ± 2.5 μm
- t_c = 10μm
- shrinkage at x,y = 12.3%
- shrinkage at z = 15.6%

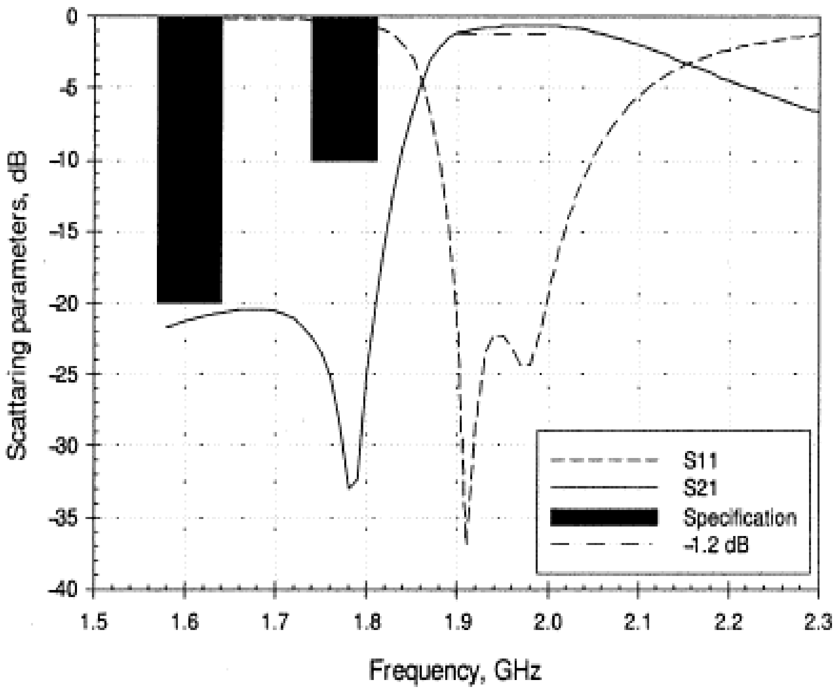


Fig. 5. The simulated filter.

FILTER DESIGN

Measurement

- RL : >13 dB
- IL : < 1.9 dB
- OBR_{low} : > 23 dB
- OBR_{up} : > 10 dB
- Size : 6.6x6.6x0.836 mm^3

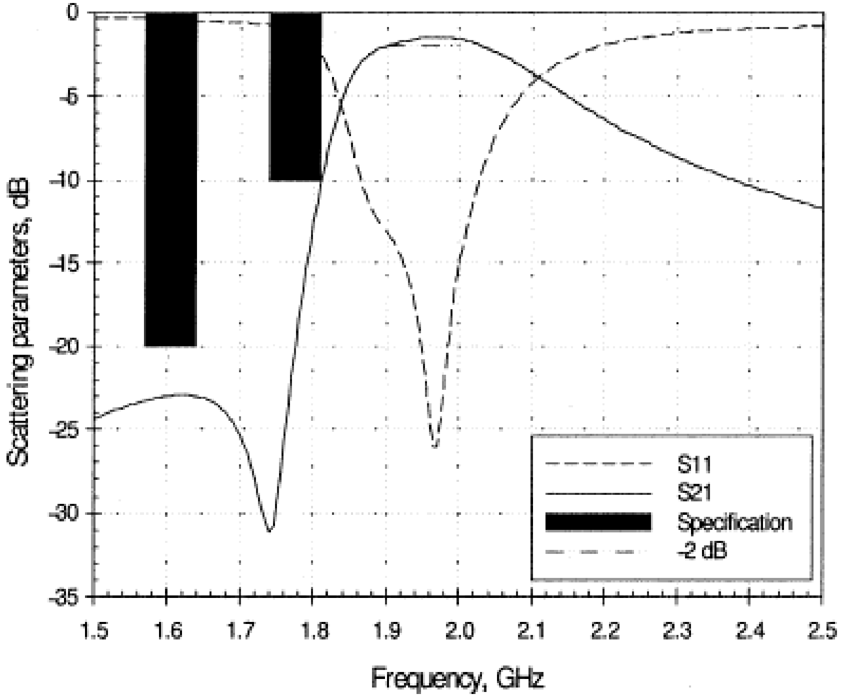
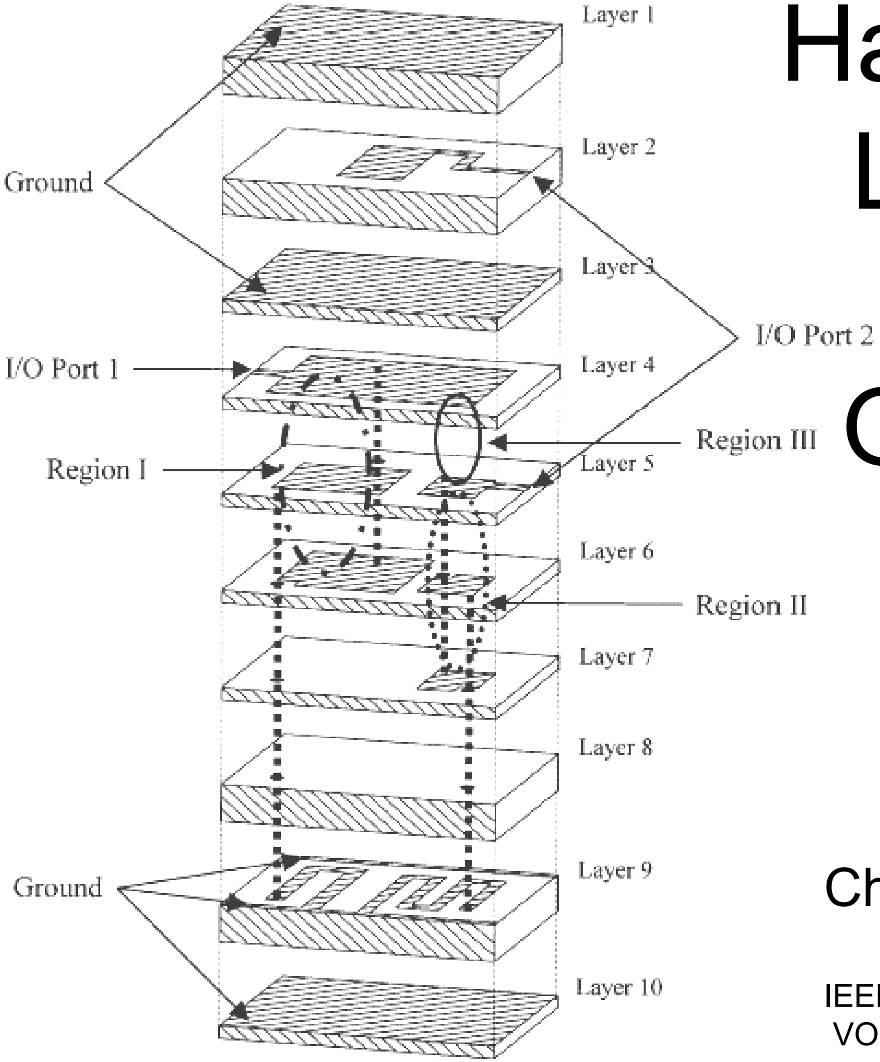


Fig. 6. The measured performance of a designed multilayered LTCC filter.



Harmonic-Suppression LTCC Filter with the Step-Impedance Quarter-Wavelength Open Stub

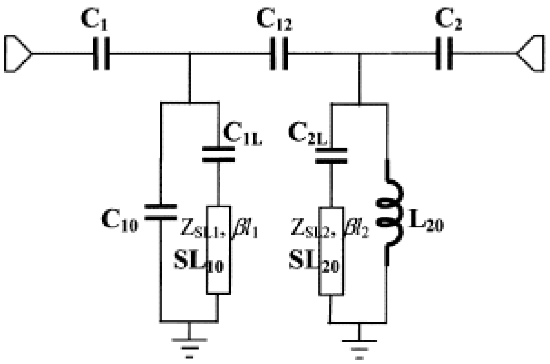
Ching-Wen Tang

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,
VOL. 52, NO. 2, FEBRUARY 2004

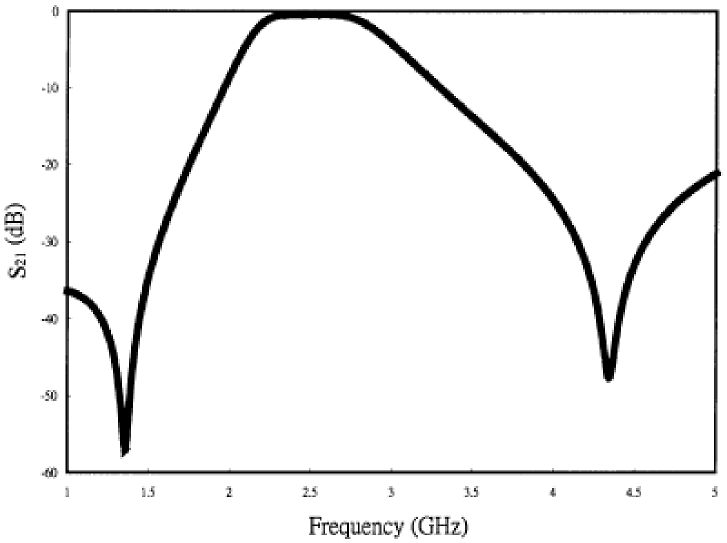
Filter desired specifications

- Pass Band : 2.4 ~ 2.483 GHz
- IL : < 2 dB
- $\text{Zero}_{\text{lower}}$: 1.96 and 2.1 GHz
- $\text{Zero}_{\text{upper}}$: 4.8–5 GHz

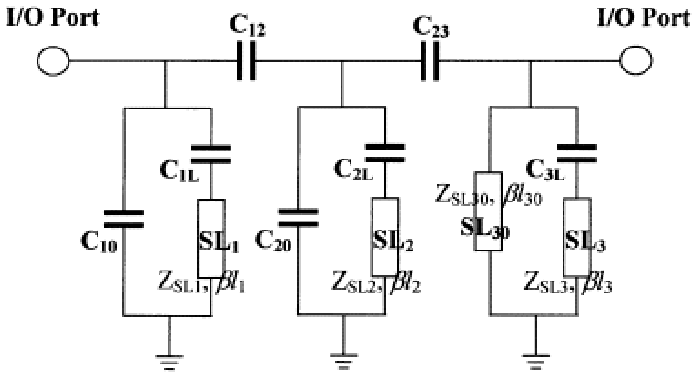
Filter constructions



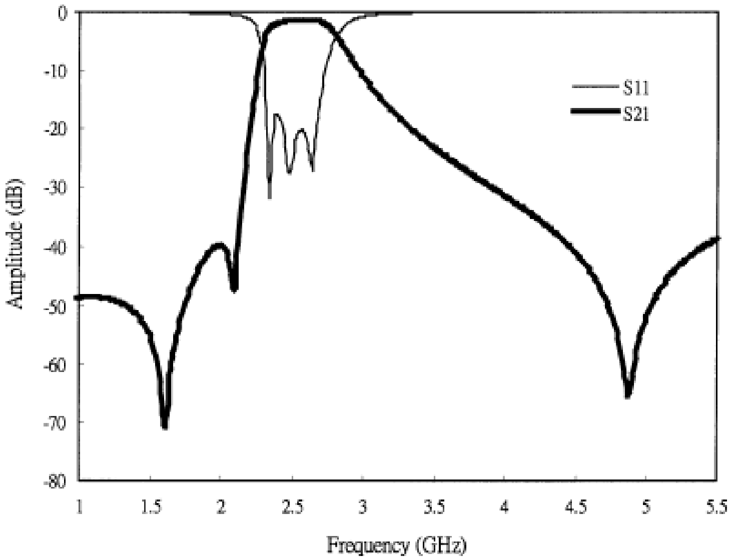
(a)



(b)

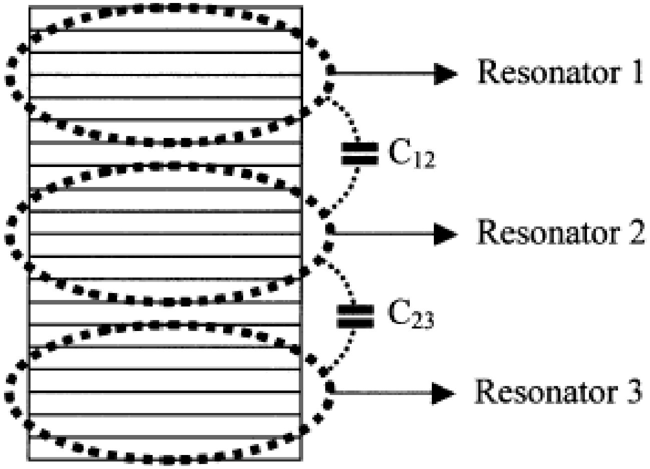


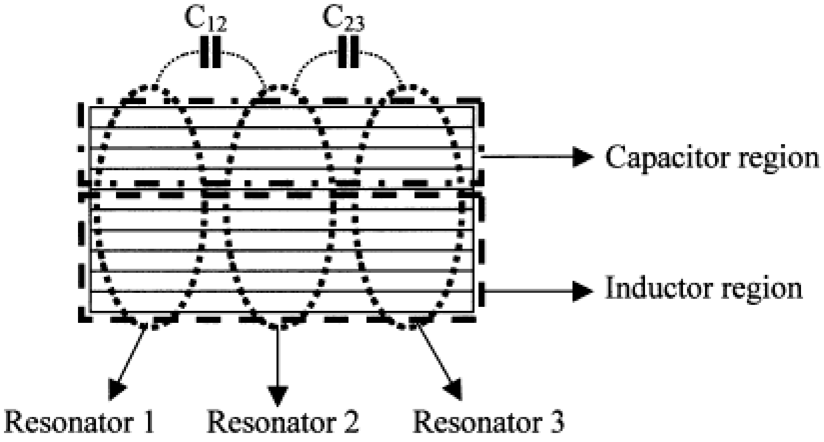
(a)

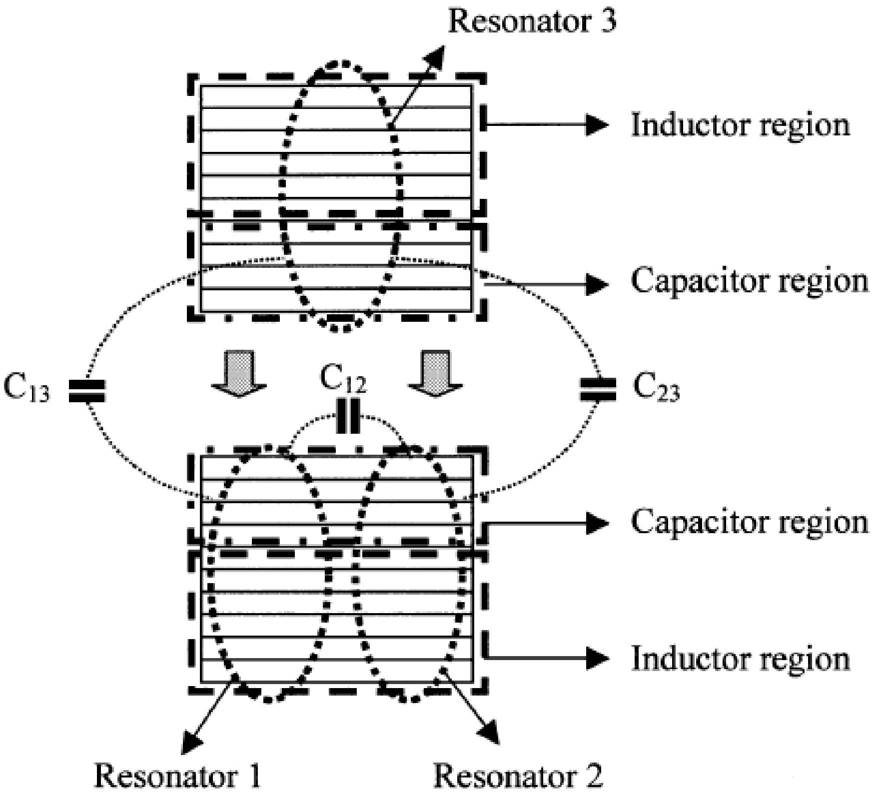


(b)

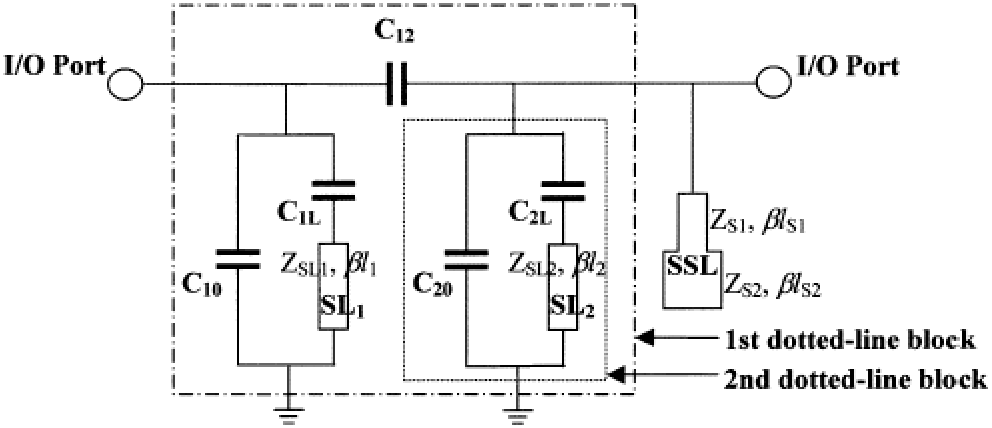
Concept of multilayer filter (1/2)

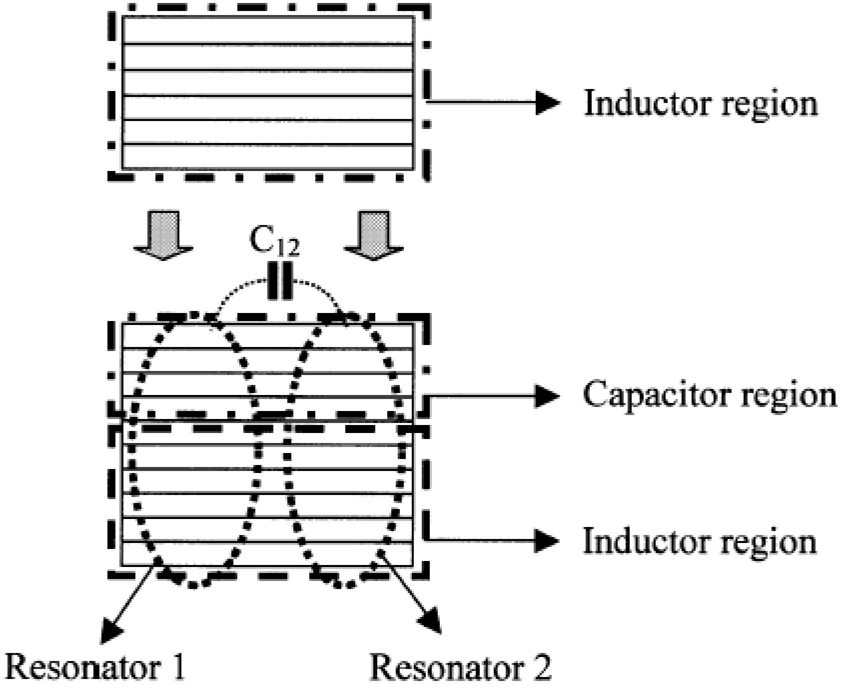




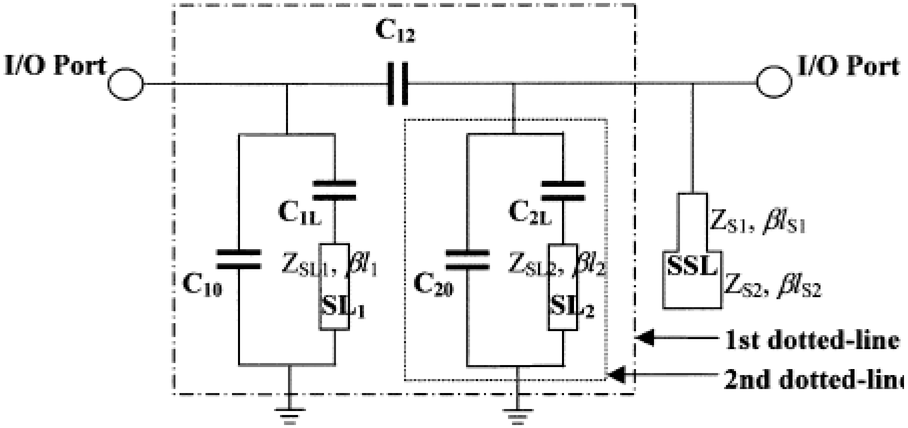


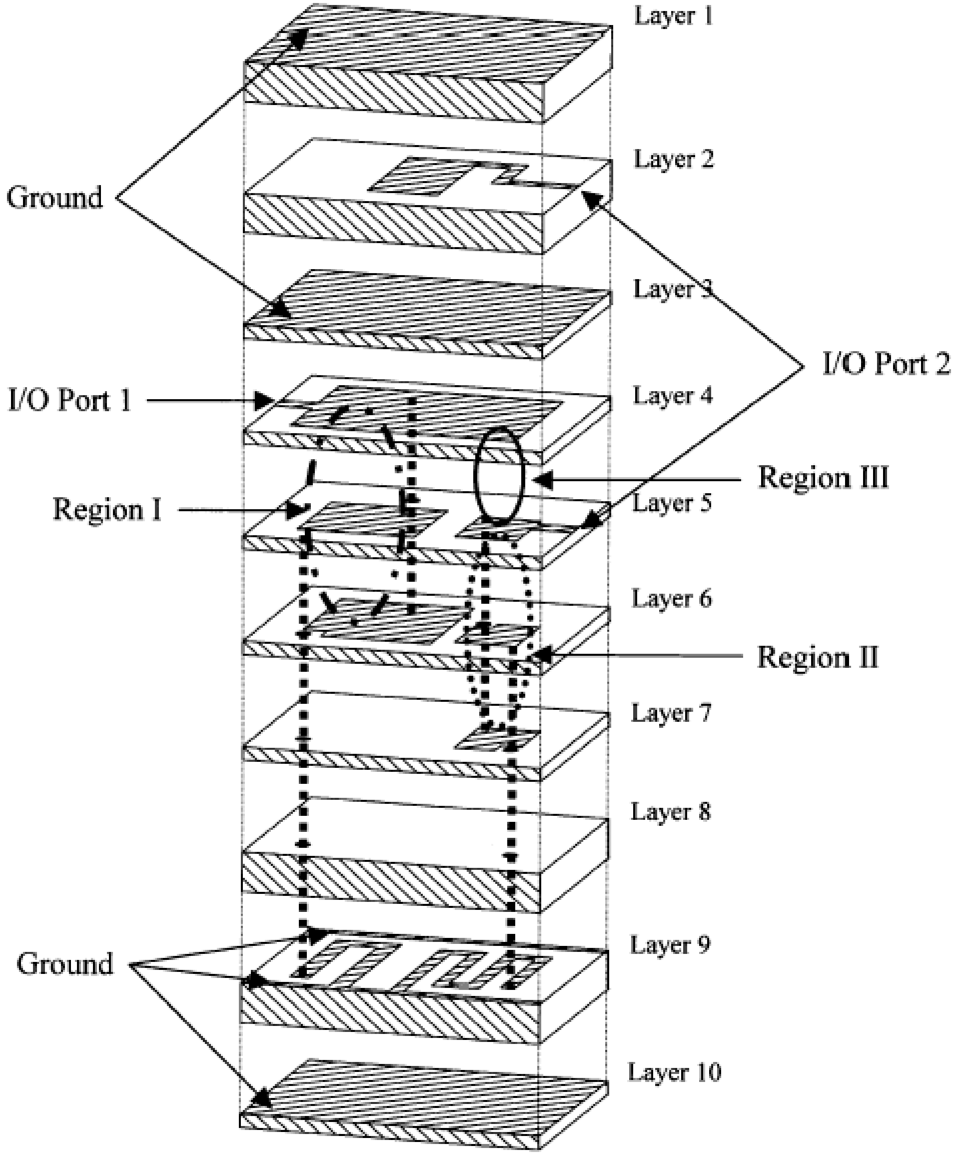
Concept of multilayer filter (2/2)



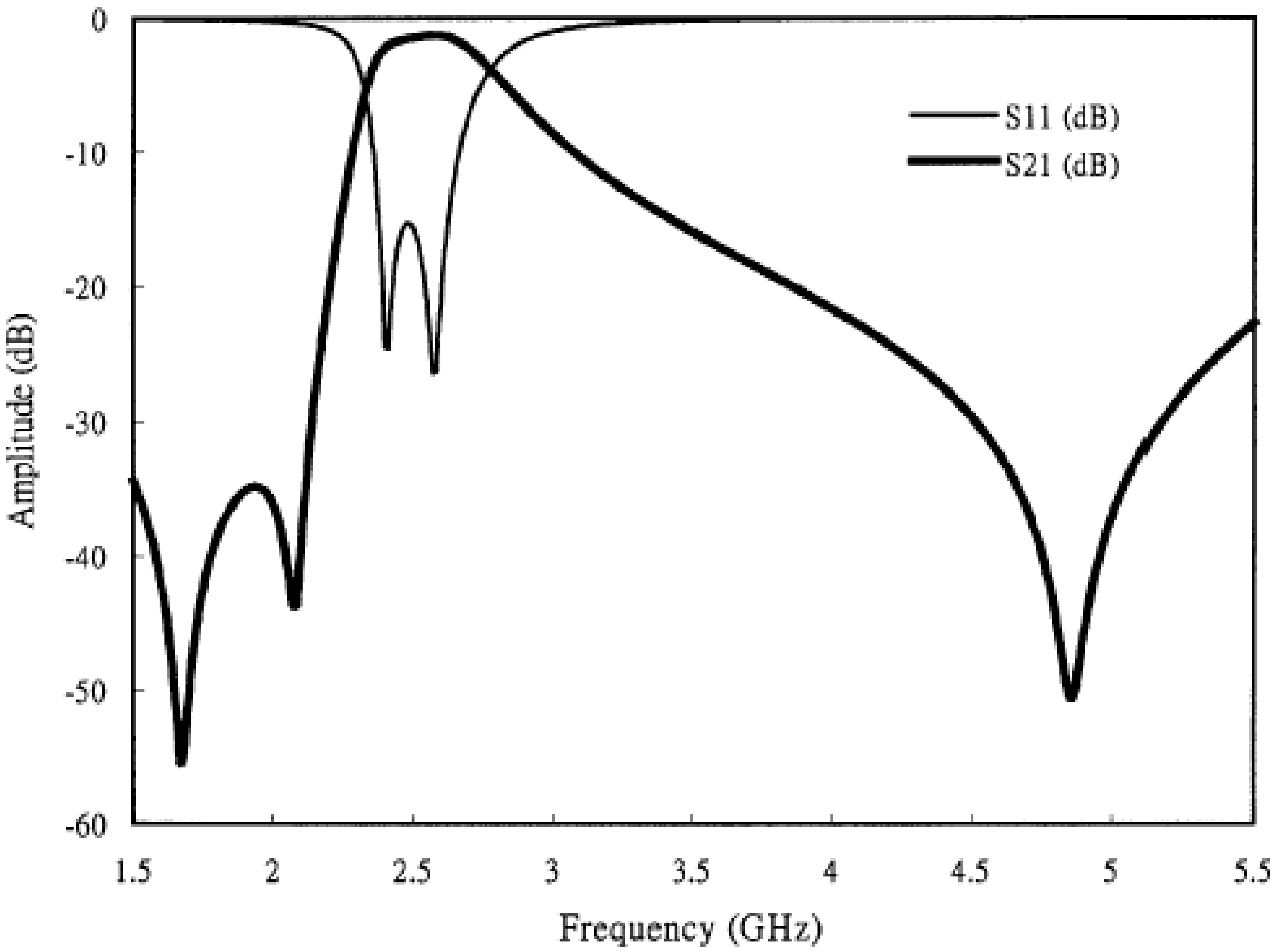


LTCC structure

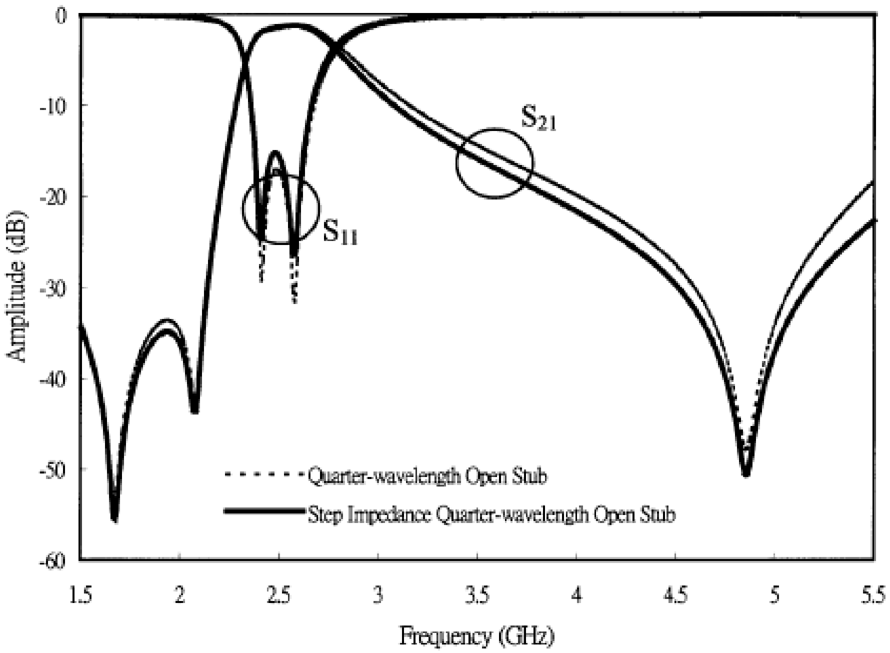


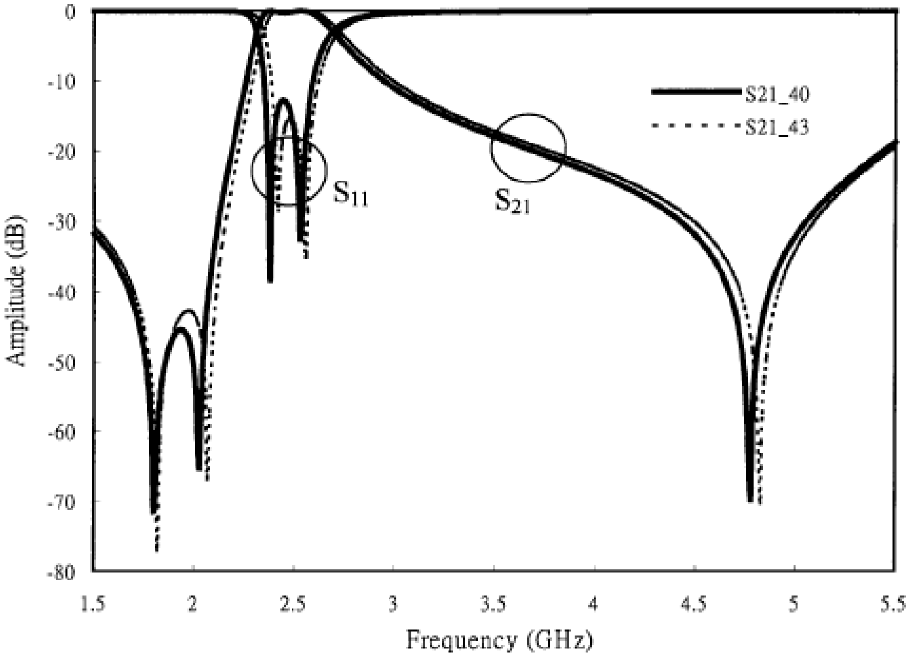


Simulated result of the LTCC BPF

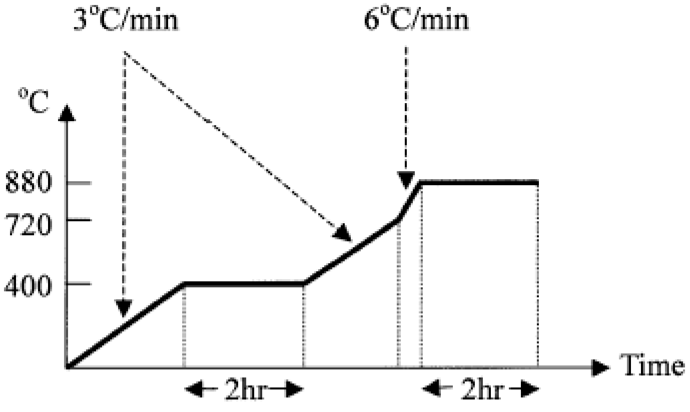


Differences of stub and layer thicknesses

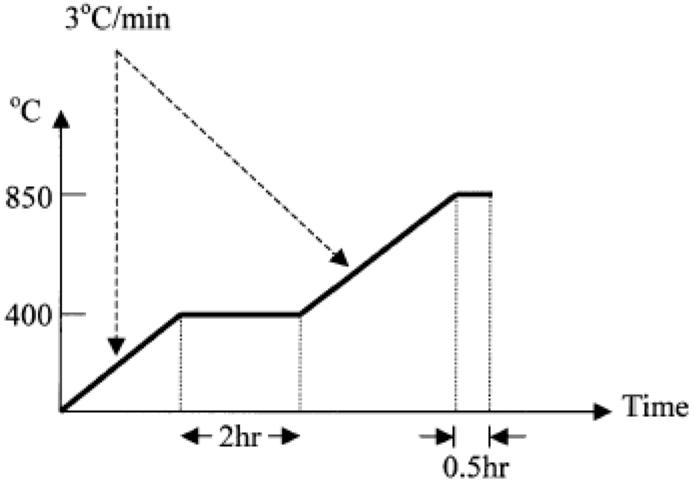




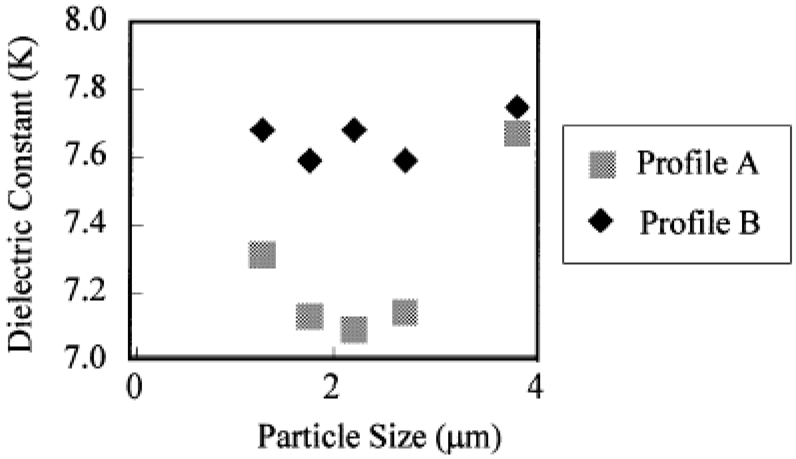
Two different sintering profiles



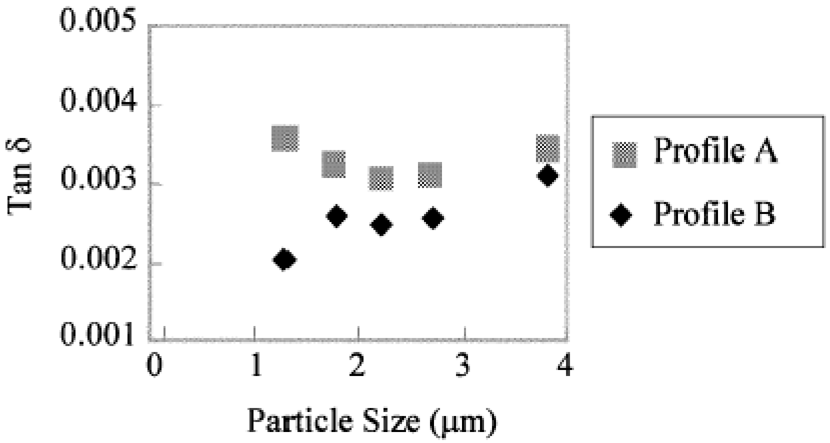
(a)



(b)

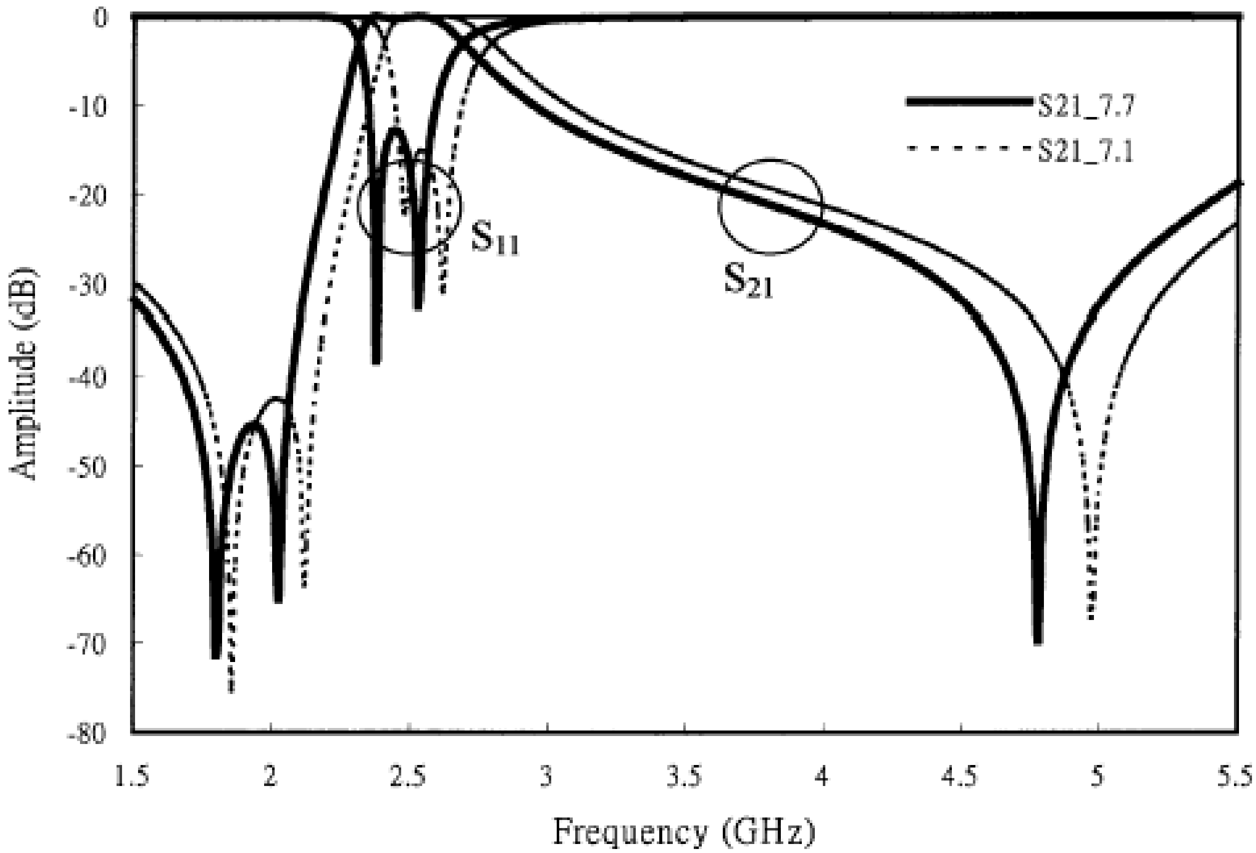


(a)

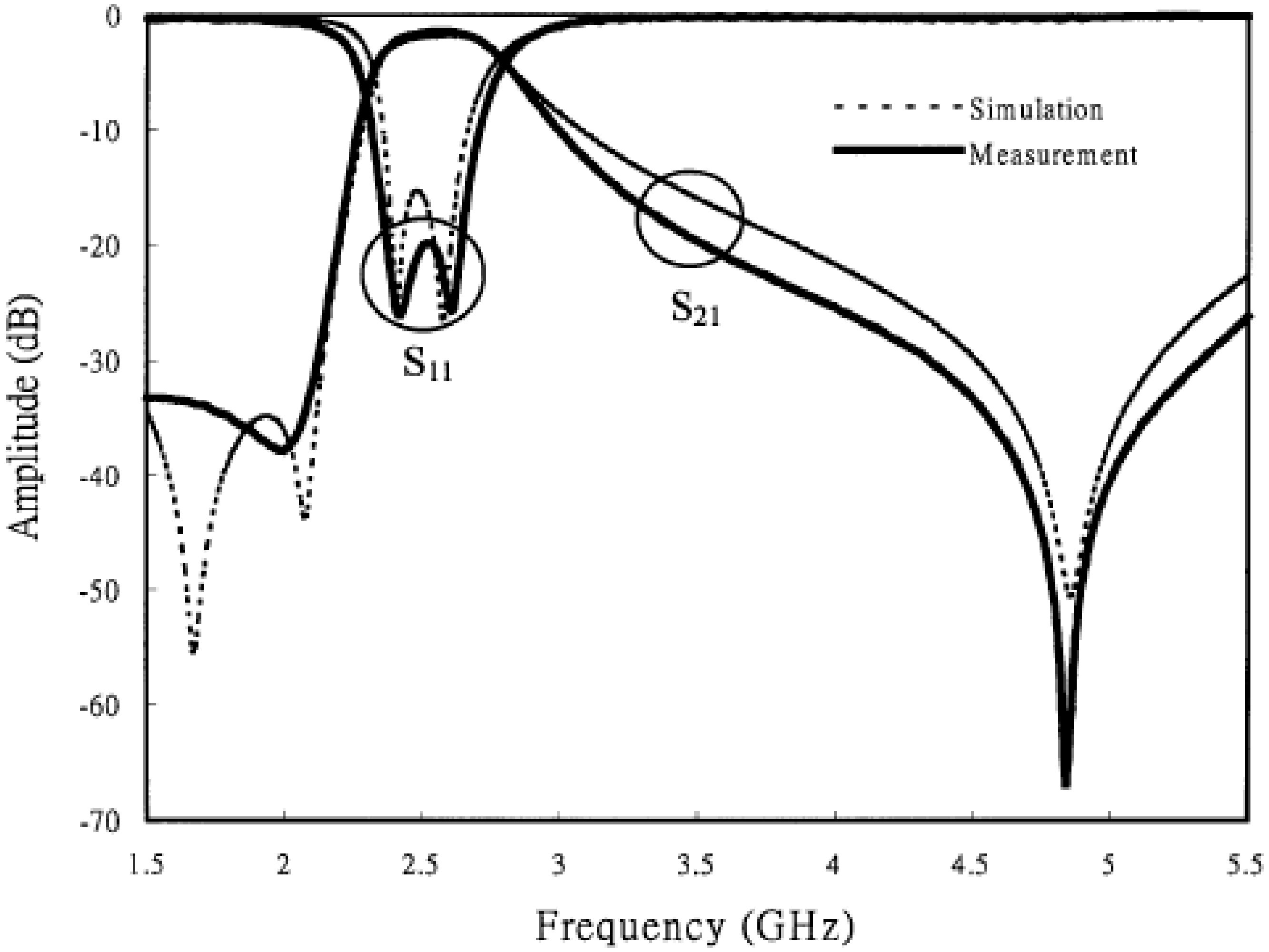


(b)

Simulated with two different dielectric constants



Measurement



Outline

- What is LTCC?
- Advantages
- Process of LTCC
- Applications of LTCC
- Future developments
- Case study
- Conclusion

Conclusion

- Size and weight reduction is the trend of wireless or mobile communication, and LTCC seems to be the most efficient method.
- Zero shrink variation is the important future work of LTCC.

Reference

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