Embedded Passives in Laminated PCB(Organic)

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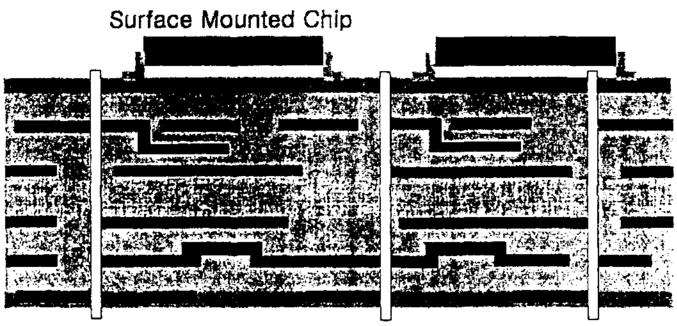
R&D Center
SIMMTECH Co., Ltd.

What is Embedded Passives?

Embedded passives : passive component placed in PCB



: Singulated Embedded Capacitor

: Singulated Embedded Resistor

Major passive component in electronic circuit
: Capacitor, Resistor, Inductor...

Background

- Ratio of Discrete Passive Compnent and IC number inside Portable Electronic Application → About 15:1 ~ 30:1
  - ❑ 30% of Solder Joint
  - ❑ 40% of Board Surface Area
  - ❑ 90% of Component Placement

System	Passives	IC	Ratio
Motorola StarTAC Cellular Phone	993	45	22:1
NTT DoCoMo Cellular Phone	492	30	16:1
Casio QV10 Digital Camera	489	17	29:1
Sony Handy Cam DCR-PC7	1329	43	31:1

Nomber of Passive Components

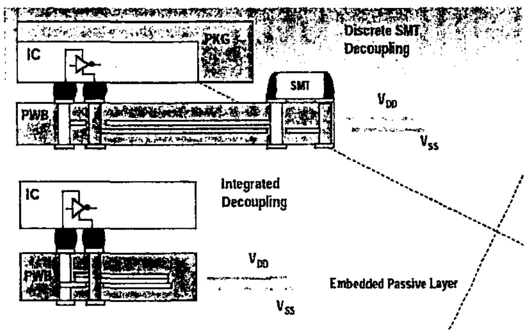
	Motherboard :	486	Pentium 120	Pentium 200 MMX	Pentium II 333MHz	Pentium III
Capacitors	Leaded MLC	58	·	·	·	·
	SMT MLC	·	151	190	300	600
	Cap Arrays (4)	·	·	32	140	200
	Leaded Tantalum	15	1	·	·	·
	SMT Tantalum	·	·	·	37	80
	Aluminum	·	7	32	11	15
	Feedthrough	·	·	3	·	·
	Disks	·	·	·	4	·
Total capacitors		73	159	257	485	895
Resistors	Leaded Resistors	92	·	·	·	·
	SMT Resistors	·	146	188	635	1,000
	Resistors Arrays (2)	·	·	·	10	·
	Resistors Arrays (4)	·	64	148	336	300
Total resistors		92	210	336	981	1,300
Total passives		165	369	593	1,473	2,195

Number and type of passive component in PC Motherboards

Why Embedded(Advantages)

▶ Minimum 5% of the Surface Area can be saved
☞ Board Size Reduction

▶ The cost of conversion to place SMT components can be reduced
☞ Cost Reduction



▶ The parasitics should be reduced or eliminated(surface mount resistor and capacitors have inherent parasitic functionalities)
☞ Improved Electrical Performance

▶ Improved wireability, higher reliability, reduction in part numbers, higher throughput in manufacturing assembly and increased yield in manufacturing assembly
☞ Improve Productivity

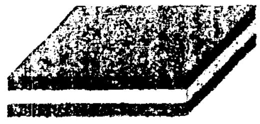
Disadvantages(Barriers)

- Risk associated with new technologies
- Reduced design flexibility
- Cannot provide wide range of resistor values
- Cannot provide tight absolute tolerances
(tolerances of 10-20% compared to 1% for discrete components)
- Sometimes unstable to hold their values over time and temperature
- Perceptiopn that embedded passives is a higher cost solution

Embedded Capacitor

Capacitor

The capacitor is a device for storing electric energy



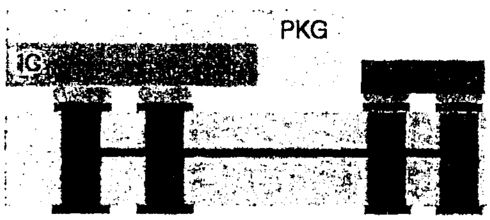
Material

Paraelectrics : Low Dielectric constant (Dk < 100)
Organic base system (FR-4, Epoxy)
Very stable with respect to frequency and normal temp range
Variation in properties when high humidity

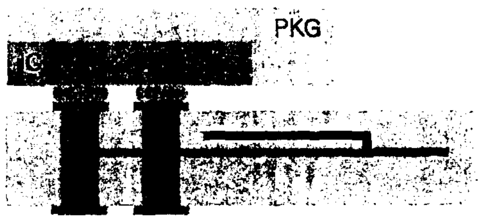
Ferrroelectric : High Dielectric constant (Dk > 1000)
Barium titanate, glass ceramic
Very stable to environmental condition
Variation in properties with regard to frequency

Application (capacitor value : 1pF ~ 1μF)
Lower value : filtering, timing, A/D functions – tight tolerance, high stability
Upper value : Decoupling, energy storage – loose tolerance

Decoupling Capacitor



Discrete SMT Decoupling



Embedded Decoupling

High frequency and parasitic inductance induce Switching noise
Switching noise is origin of system delay and EMI

Decoupling Capacitors → decreasing switching noise

Requirement of decoupling capacitors

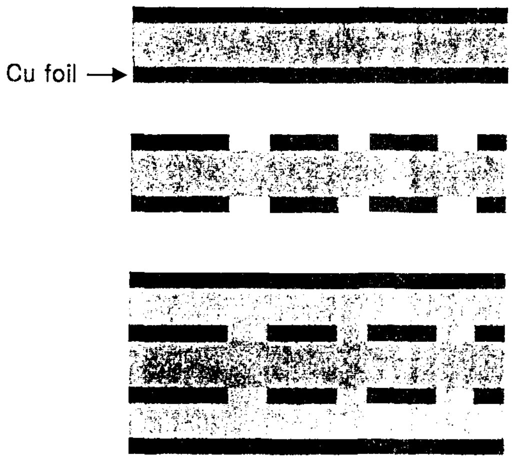
- high frequency properties
- high capacitance
- closer distance with Chip

Organic Laminate Type E/C

Organic Laminates type

- Dielectric material : FR-4 epoxy, Barium titanate filled polyimide or epoxy
- Electrode material : Copper foil

Process



◀ Laminate capacitor

◀ capacitor formed
by etching process

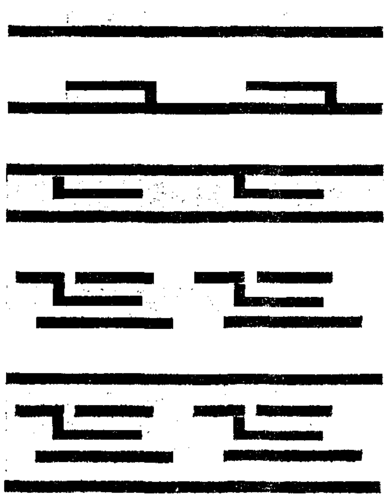
◀ Continue to build PCB
using standard process

Screen Printable Type E/C

Screen Printable type

- Dielectric material : Barium titanate or glass ceramic dispersed in polymer
- Electrode material : Copper foil, Silver paste

Process



◀ Screen printing and curing

◀ Electrode paste printing

◀ Laminate to FR-4 core

◀ Singulated
by patterning process

◀ Continue to build PCB
using standard process

Embedded Capacitor Materials

	Organic Laminates			Screen Printable Composition	
Maker	Sanmina	DuPont	3M	DuPont	Sanmina
Trademark	BC-2000	Hik	C-Ply		EmCap
Materials	FR-4 Impregnated With $BaTiO_3$ in epoxy resin	$BaTiO_3$ in Polyimide Cast on Copper foil	$BaTiO_3$ Dispersed In epoxy resin	Glass powder and BaTi (Ferroelectric) in Polymer	$BaTiO_3$ Dispersed In epoxy resin
Dielectric Const. (1GHz)	4	12~20	22		36
Capacitance	0.5 nF/in²	1.5 nF/in²	10~30 nF/in²	100 ~ 180 nF/in²	2.1 nF/in²
Thickness	50 ㎛	8~25 ㎛	5 ~ 25 ㎛	50 ~ 70 ㎛	100 ㎛
Loss tangent % (1GHz)	0.021	0.01	0.10		0.06
Remark	Commercially available technology Tolerance : ± 0.015 nF	More process than Laminate film type Low breakdown Voltage	High capacitive Density Low breakdown Voltage	More process than Laminate film type Higher capacitance density * On developing	

Embedded Resistor

Resistor

Material

- Conductive Carbon/Silver filled polymer pastes, ceramic paste Epoxy/metal resistive composite
- Resistivity value : 1 ~ 1MΩ/ square

Application (resistor value : a few to million Ω)

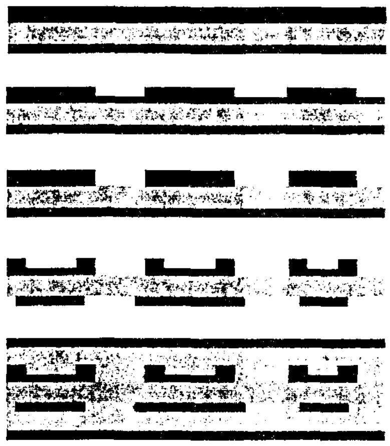
- Many circuit have low and high value on the same substrate
- Basic transfer Voltage/Current
- Voltage reducer
- Pull up/down in digital circuit...etc

Thin Film Type E/R

Thin film Laminates type

- Trademark product : Omega-Ply
- Cu foil / Resistor/ FR-4 /Cu foil laminate film,
- Resister material : Metal alloy- NiP

Process



◀ Laminates resistor

◀ Selective etching copper layer

◀ Chemically strip resistor film

◀ Selective etching both copper layer

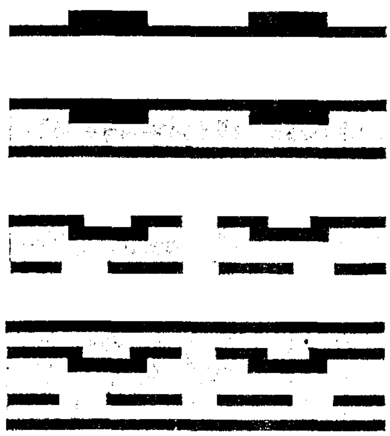
◀ Continue to build PCB using standard process

Screen Printable Type E/R

Screen Printable type(Inner Layer)

- Material : Conductive Carbon/Silver filled polymer pastes, conductive polyimide, ceramic paste

Process



◀ Screen printing and curing

◀ Laminate to FR-4 core

◀ Patterning copper layer

◀ Continue to build PCB using standard process

Resistance Formula

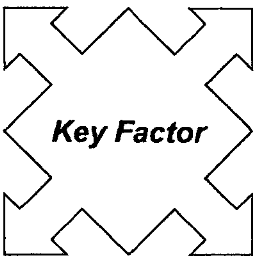
$$R = P \times \frac{L}{W \times \frac{Tn}{Tp}}$$

P = Ink Resistance
L = Distance between Copper Pad on the Resistor Printed
W = Printed Resistor Width
Tn = Nominal Printed Thickness(Cured)
Tp = Printed Thickness(Wet Film)

Key Factor

Distance between Copper Contacts(Conductor Space)

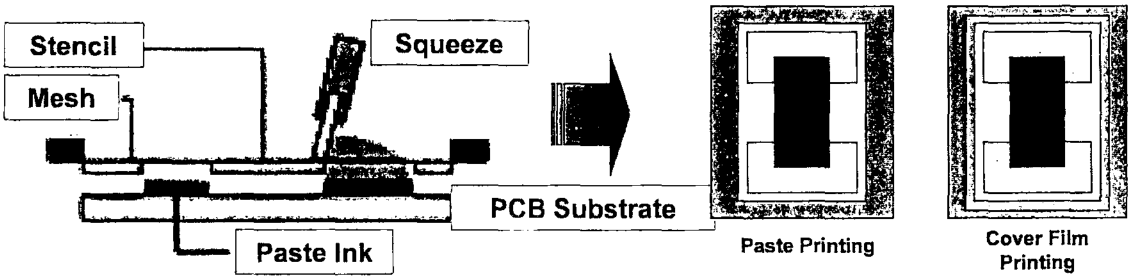
Area of Resistor Paste(Ink)



Thickness & Width of Resistor Paste(Ink)

Cure Temp. & Time

Screen Printable Type E/R

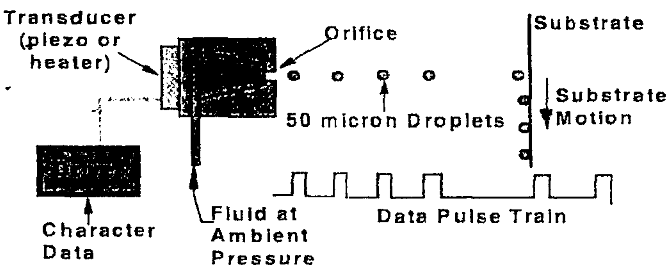


< Normal Screen Printing Method >

Ink-Jet Printing(Microfab)

Technology

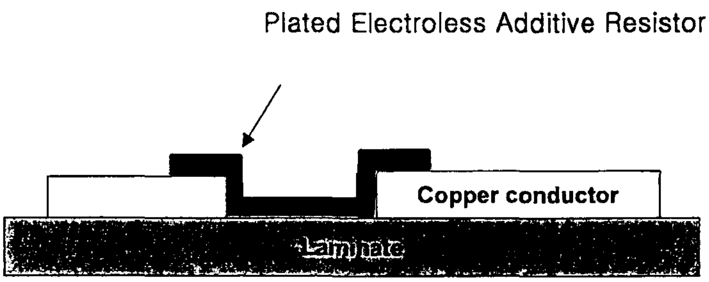
Drop-on-Demand Ink-Jet Printing



- Polymeric resistor
- Fluid viscosity, dispensing temp., number & size of dispensed droplets

Plated Additive Resistor(MacDermid)

Technology

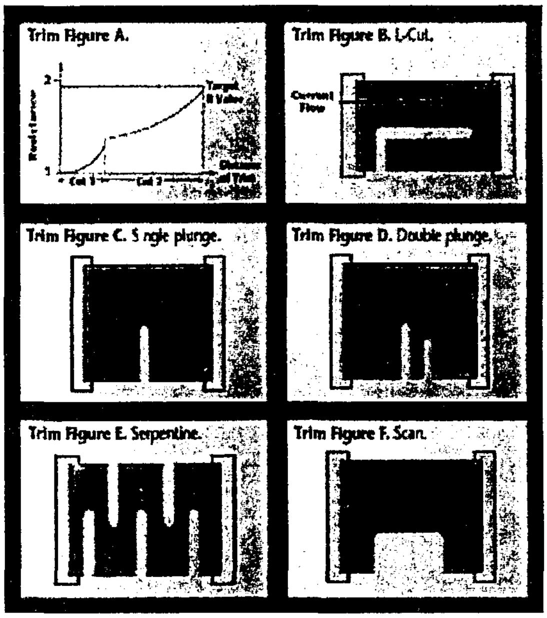


- Electroless plating
- Use relatively standard Plating processes and substitutes

Embedded Resistor Materials

	Screen Printable type				Thin film Laminates type
Maker	Electra Polymer & Chemical Ltd.	Ormet	DuPont	DuPont	Omega-Ply
Materials	Conductive Carbon/Silver filled polymer pastes	Epoxy/metal resistive composite	LaB_6 based film (ceramic paste)	Conductive Polyimide -blend material	Resistor/conductor laminate film (Metal alloy- NiP)
Resistance	1~ 1MΩ/square	10 ~ 150Ω/square	10~ 10kΩ/square	10 ~ 1MΩ/square	25, 50, 100, 250 Ω/square
Remark	Disadvantage : low resistivity Limited use under High temp/humidity	TCR < 300 ppm Tolerance < 20 % Low temp curing (200℃) * On developing	TCR < 150 ppm Stability of thermal cycling and aging is excellent * On developing		TCR = 50 ~100 ppm Tolerance : ± 10 %

Trimming



Statistical Parameter	R1	R2
N =	1137	1137
Target =	70.0 Ω	3900.0 Ω
Average Initial Value =	57.2 Ω	3346 Ω
Average Funal Value =	70.1 Ω	3888.8 Ω
Initial Error =	18.3 %	14.2%
Final Error =	0.19 %	-0.29 %
Final 3 σ =	0.3 %	0.2 %
Final Cpk 1 % =	2.416	3.045
Final Cpk 1 % =	14.338	20.164

Table : Pre-Test and Post-Trim Data for Carbon Loaded Poly Epoxy Thick Film Resistors.

Future of Embedded Passives

Area of concern	2000	2003	2005 ~
Material	Demonstrable	Acceptable properties	
Manufacturing	Low yield	Acceptable Yield	Cost-effective Infrastructure
Design & test	Demonstrable		Widespread Common price
Cost	High	Competitive	Cost saving
Available	Few Supplies No standard	Available from A few sources	Standard parts available From multiple sources