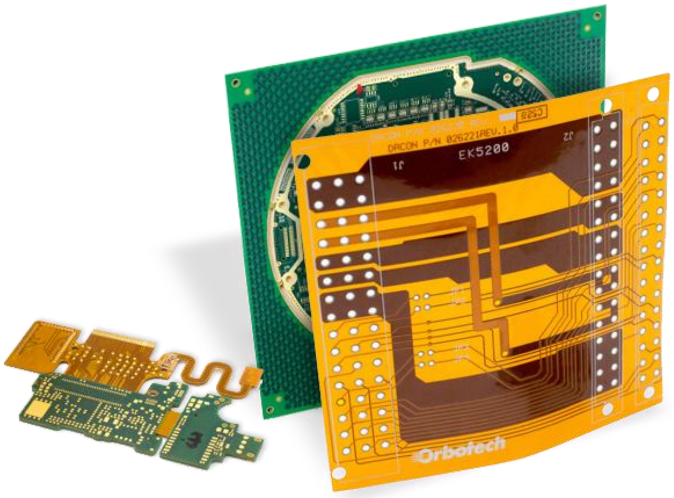


The Technology of Embedded Components for PCB

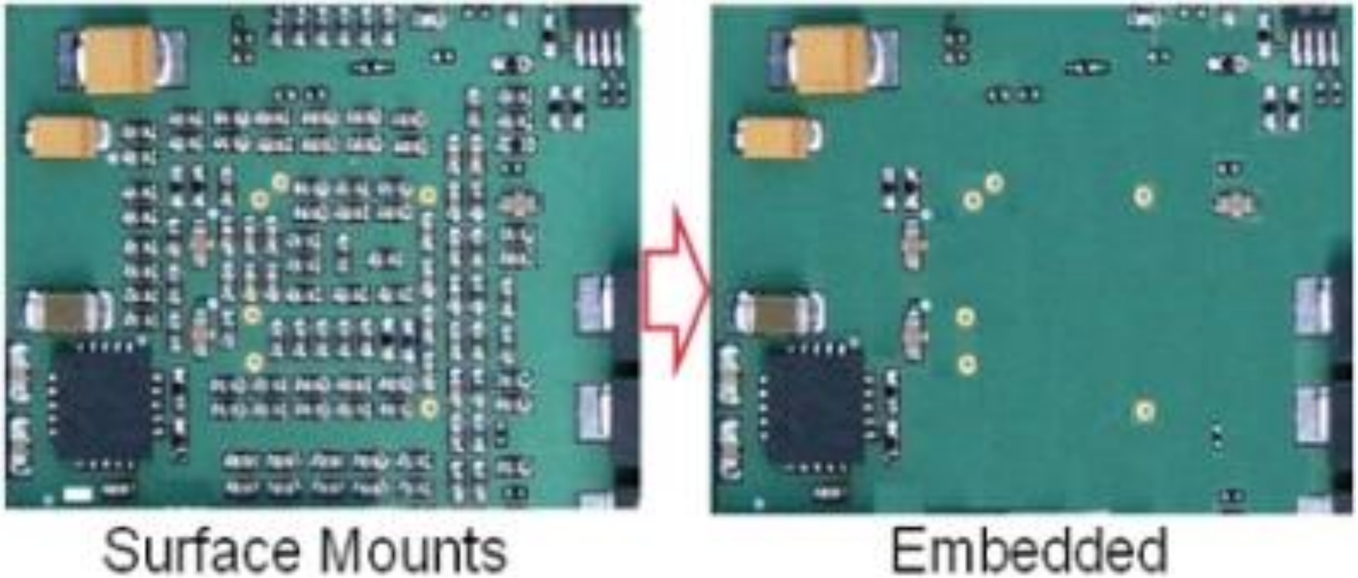
Vitaly Bensman

Senior Process Engineer at Eltek Ltd.

June 2021

Ver.2

Productivity- Functionality- Reliability



Today, the generic single board computer is generally composed of 5% integrated circuits, 4% connectors, 40% capacitors, 33% resistors and 18% miscellaneous parts. Clearly resistors and capacitors are the majority of components on any generic PCB. The target is to reduce the number of SMT resistors from 33% of the total components to 10% or less, increase the yield, while allowing designers better signals and more surface real estate [6].

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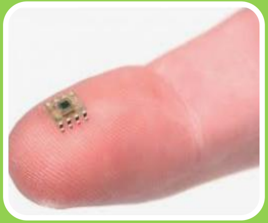
Advantages of Embedded Components



Miniaturization

- Package replacement
- Space sampling on external surface

Functionality

- Integrated shielding
- Short signal path

Reliability

- Protected against external environment impact
- Secure fixing- less solder joints
- Thermal management

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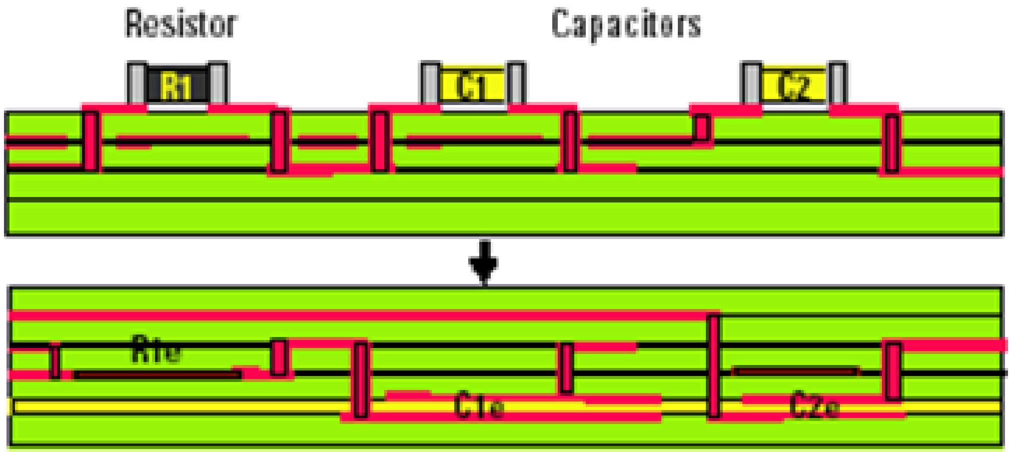
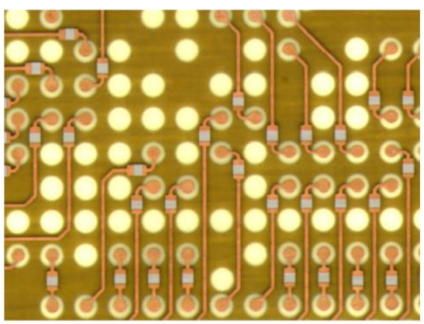
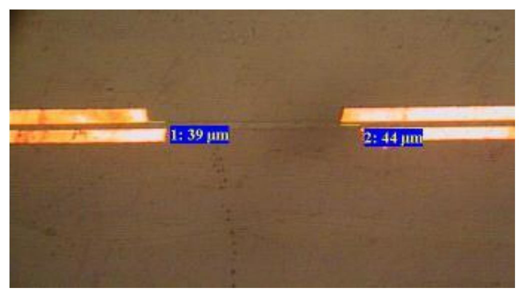
Types of Embedded Elements

Resistors | **Capacitors** | **Inductors**







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Applications of Embedded Elements

Computers

- Supercomputers
- Mainframes
- Parallel Processors
- Servers
- Workstations
- Add-on and peripheral cards
- PC cards
- IC cards

Telecommunications

- Cellular bay stations
- ATM switching systems
- Portable communications equipment
- Sonet Multiplexers

Instrumentation & Test Equipment

- Loaded board testers
- Logic analyzers
- IC probe cards
- Burn-in boards
- Interface cards

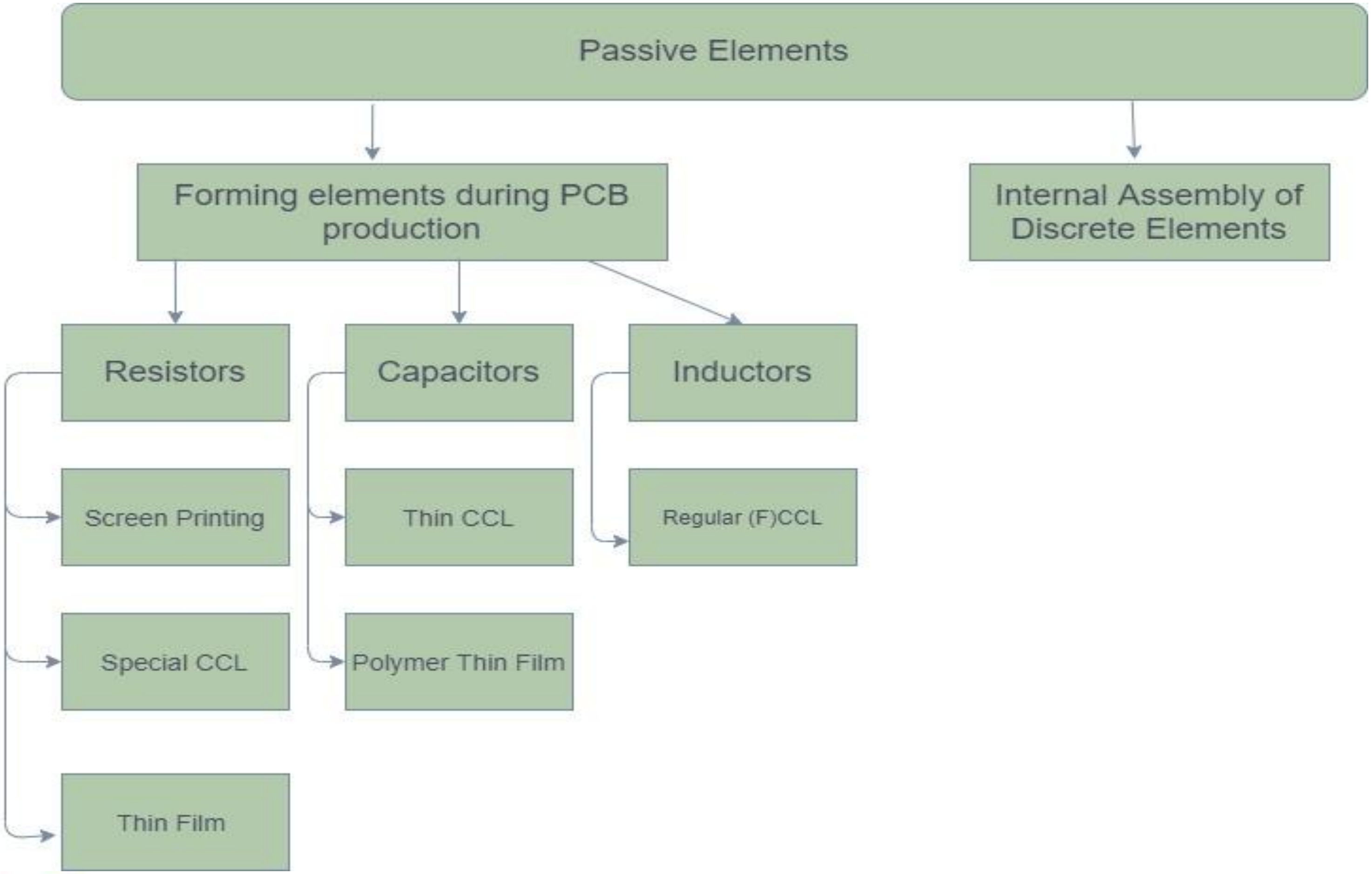
Military & Aerospace

- Satellites
- Antennas
- Radar systems
- Mil-spec computers
- Radomes

Consumer & Automotive

- Potentiometers
- Actuator circuits
- Heater elements

Processes of Embedding Passive Elements in PCB



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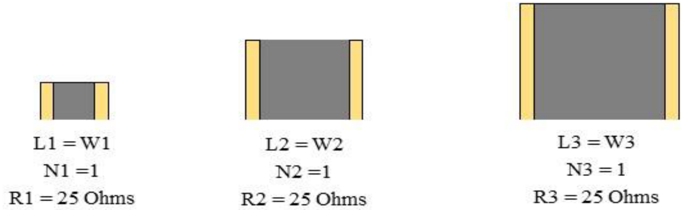
Basic Calculating for Sheet Resistivity

- Sheet resistivity, stated in Ohms per square and is dimensionless
- A square area of resistive material equals the sheet resistivity of material

25 ohms per square (Ω/■) sheet resistance

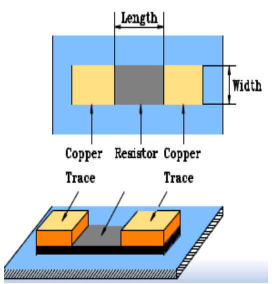


Resistor value = Sheet Resistivity X Ratio of Element Length to Width

R=Rs * (L/W); where L/W= number of squares N

For Example:

- **Sheet Resistivity (Rs)= 50 Ω/■**
- **Length= 0.025" (25 mil)**
- **Width= 0.010"(10mil)**
- **R=50 Ω/■ X(25mils/10mils) ■**
- **R=125 Ω**



Equivalent Resistance - Req

- Equivalent Resistance is the **TOTAL** resistance of a circuit
  - Symbol: Req
  - Units: Ω Ohms
- Formula:

Series:	**Parallel:**
Req = $R_1 + R_2 + R_3 + \ldots$	$\frac{1}{Req} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \ldots$

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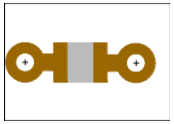
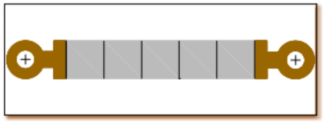
Basic Resistors Patterns Calculating for Sheet Resistivity

1. Bar Type



N<1



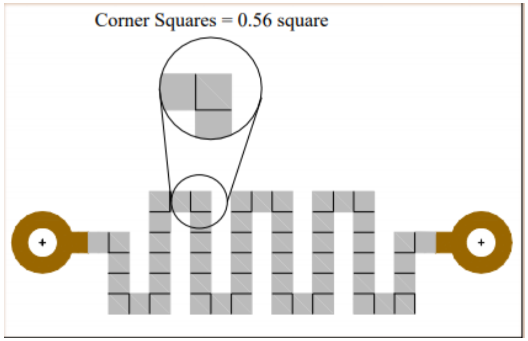
N>1

$R=R_s*N$

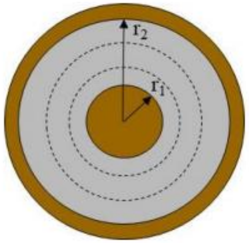
2. Serpentine Type

N-regular square; N_c – Corner Square

$R=R_s*(N+0.56*N_c)$

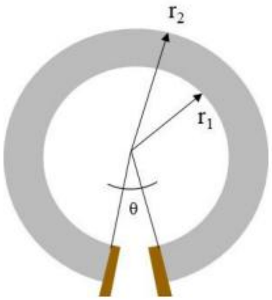


3. Circular Resistor



$$R=\frac{R_s}{2\pi}\ln\frac{r_2}{r_1}$$

4. Arc Resistor



$$R=R_s\frac{\pi(r_2+r_1)}{(r_2-r_1)}\left(\frac{360-\theta}{360}\right)$$

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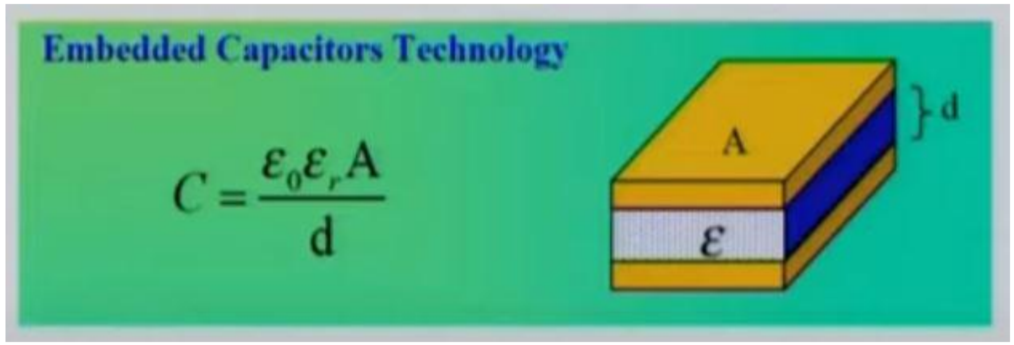
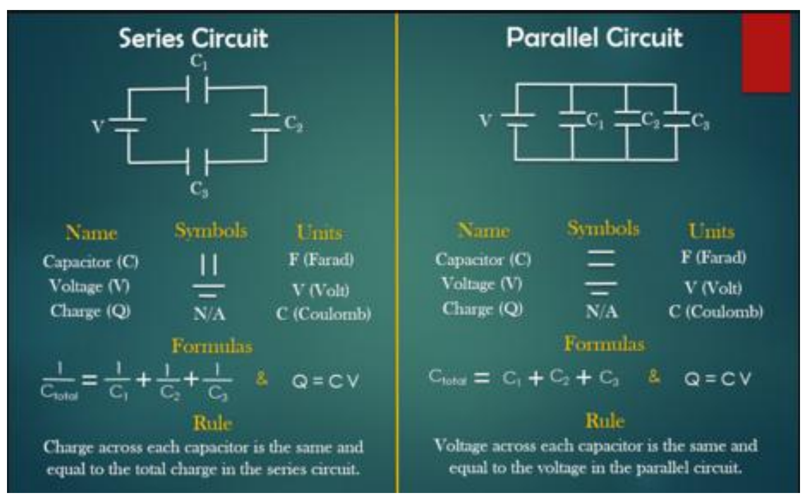
Basic Calculating for Capacity



Permittivity of air: $\varepsilon_0 = 8.8541878176 \times 10^{-12}$ F/m



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CCL Materials for Embedded Resistors

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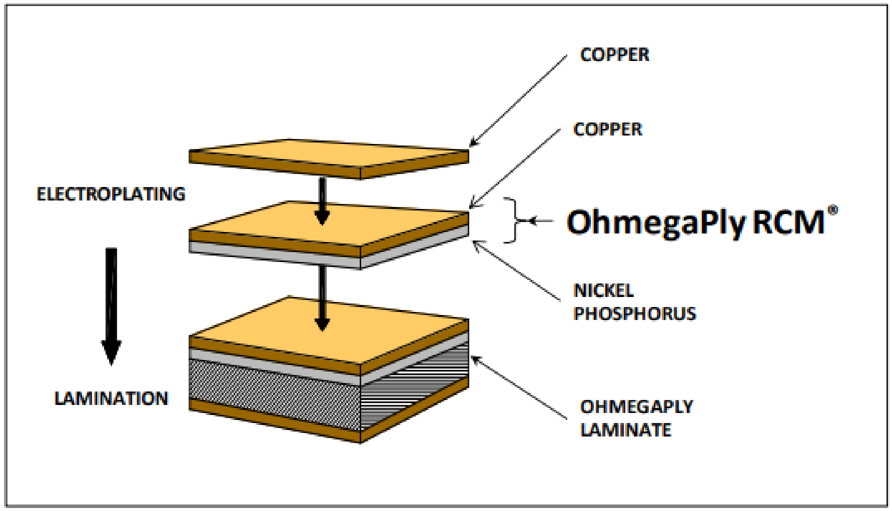
Choosing CCL Materials for Embedded Resistors

OhmegaPly®

Ohmega
Ohmega Technologies, Inc.

OhmegaPly is a **Nickel Phosphorous (NiP)** metal alloy that is electrodeposited on to copper foil. The thin film NiP metal alloy/copper foil combination is called OhmegaPly **RCM** (**Resistor-Conductor Material**).
The RCM is laminated to a dielectric material, like any other copper foil, and subtractively processed to produce copper circuitry and planar resistors.



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Choosing CCL Materials for Embedded Resistors

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Ohmega Technologies, Inc.

OHMEGAPLY® RCM TECHNICAL SPECIFICATION									
Sheet Resistivity	Unit	**10 Ω/□**	**25 Ω/□**	**40 Ω/□**	**50 Ω/□**	**100 Ω/□**	**250 Ω/□**	**377 Ω/□**	Remark and Condition
Material Tolerance	%	±5	±5	±5	±5	±5	±10	±15	Sheet Resistivity
Resistance Temperature Characteristic (RTC)	PPM/ °C	20	50	75	75	100	100	150	MIL-STD-202-304 -55°C to 125°C
Maximum Power	W	0.175	0.100	0.090	0.085	0.070	0.060	0.050	Values shown for 20 mil x 10 mil (LxW) resistors
Load Life Cycling Test	Δ R%	<0.3	<5	--	<5	<5	<0.5	<5	MIL-STD-202-108I 70C, 1.5 hours On/Off Cycle, 10000 hours
Solder Float	Δ R%	0.2	0.5	0.8	0.8	1.0	0.5	0.7	MIL-STD-202-210D 260°C, 20 sec

Available copper foil: 3/8 Oz (12µm), ½ Oz (18µm), 1.0Oz (35µm)

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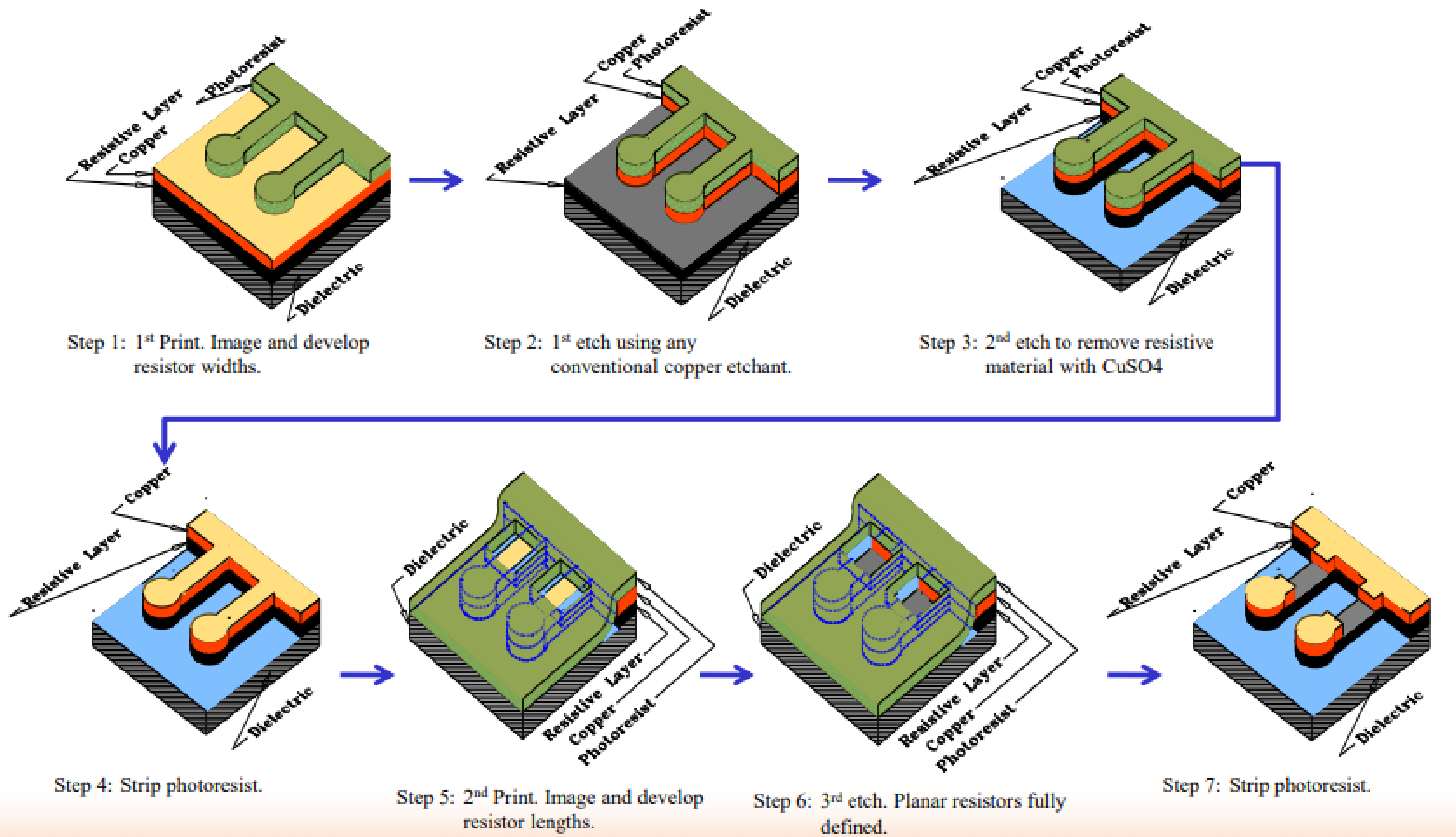
OhmegaPly® Process

Ohmega
Ohmega Technologies, Inc.



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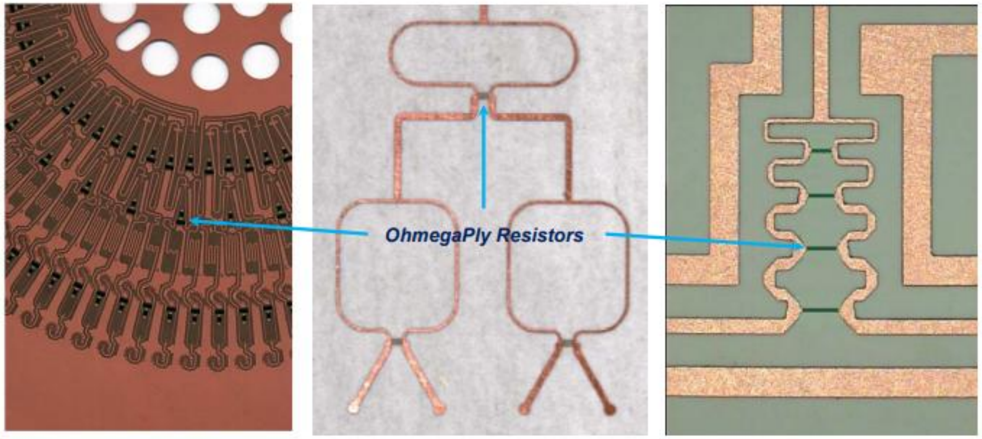
OhmegaPly® Material Combination

- OhmegaPly® RF

  OhmegaPly® foil laminated on Low Dk base materials. Available From Rogers (RO3850, RO4003, RO6002, CLTE-XT) and Taconic (TSM-DS).



▲ OhmegaPly® power dividers in Globalstar antenna

▲ 16-way power divider with 50 Ω/sq OhmegaPly® resistors

▲ Power divider with 25 Ω/sq OhmegaPly®

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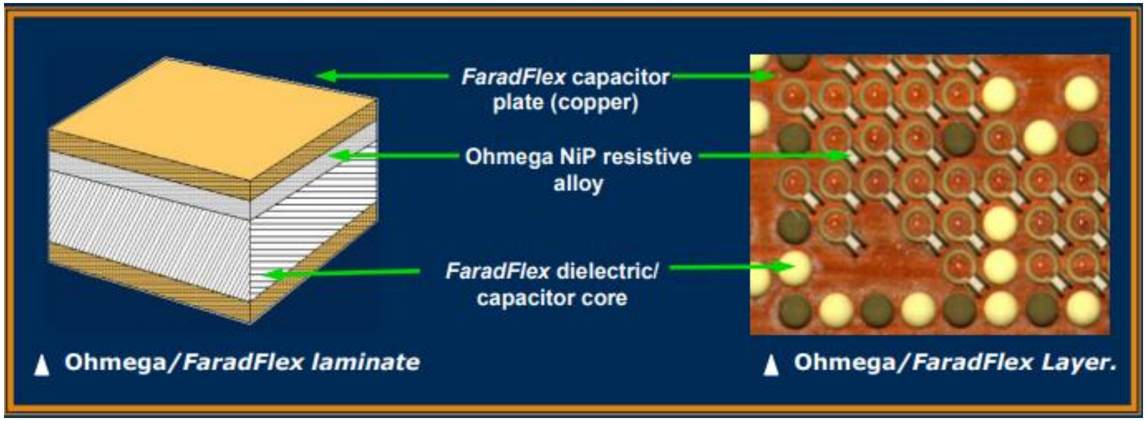
OhmegaPly® Material Combination

- OhmegaPly® / FaradFlex ® Resistance-Capacitance CCL

  Ohmega® /FaradFlex® is a combined product of the OhmegaPly® thin film resistive-conductive material (RCM) laminated to a FaradFlex® dielectric material and subtractively processed to produce embedded RC Networks.



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Choosing CCL Materials for Embedded Resistors

Ticer TCR® Resistor Foil

TCR® Integrated Thin Film Resistor Foil is supplied in a variety of foil widths and thicknesses using Grade 3 copper foil.

The are three (3) resistivity alloys are available with TCR ® foil:

- ✓ NiCr, Nickel Chromium
- ✓ NCAS, Aluminum Silicon
- ✓ CrSiO, Chromium Silicon Monoxide

TCR ® with Nickel Chromium (NiCr) resistor alloy reduces fabrication steps by eliminating the need for a separate resistive layer etch.

All three resistivity alloys can be subjected to multiple thermal excursions, such as lead-free reflow, with minimal resistance change and ensured long-term reliability.

Choosing CCL Materials for Embedded Resistors

Ticer TCR® TECHNICAL SPECIFICATION								
Resistivity Material		**NiCr**			**NCAS**				**CrSiO**
Sheet Resistivity	Unit	**25 Ω/□**	**50 Ω/□**	**100 Ω/□**	**25 Ω/□**	**50 Ω/□**	**100 Ω/□**	**250 Ω/□**	**1000 Ω/□**
Material Tolerance	%	±5	±5	±5	±5	±5	±5	±5	±7
Resistance Temperature Characteristic (RTC)	PPM/°C	< 110	< 110	< 110	-20	-20	-20	-20	-300
Maximum recommended power dissipation at 40° C	W/in^2	250	200	150	250	200	150	75	250
Base copper foil thickness		18 and 35			18 and 35				18 and 35
Recommended etching solutions	Step 1 Step 2 Step 3	Cupric chloride Ammoniacal ------			Ammoniacal Acidic permanganate Ammoniacal				Ammoniacal Alk. Permanganate Ammoniacal

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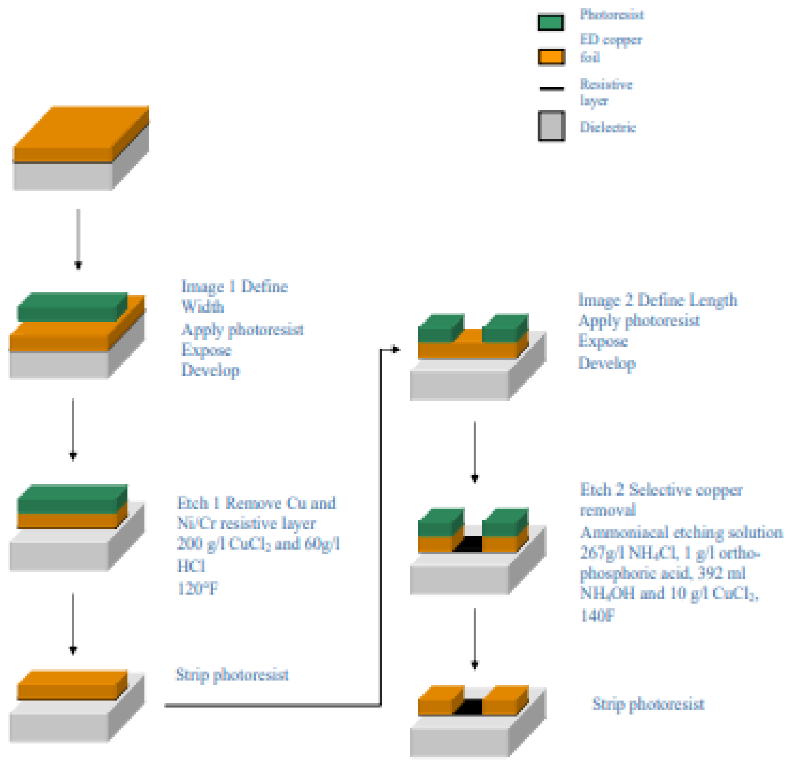
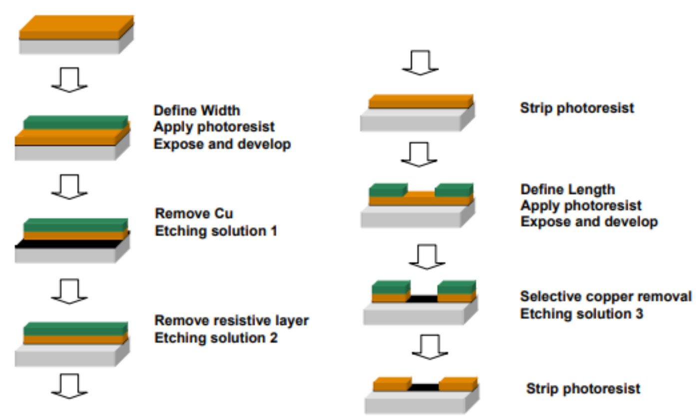
Choosing CCL Materials for Embedded Resistors

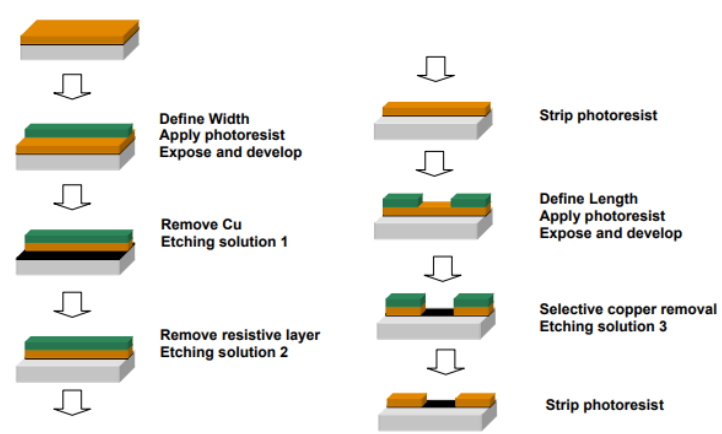
Etching Sequence of Nickel Chromium (NiCr) Resistive Materials



Etching Sequence of Nickel Chromium Aluminum Silicon (NCAS) Resistive Materials



Etching Sequence of Chromium Silicon Monoxide (CrSiO) Resistive Materials



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Ticer® Material Combination

DuPont™ **Pyralux® APR** double-sided, copper-clad resistor laminate is an all-polyimide composite of polyimide film bonded to copper foil, similar to Pyralux® AP, but including Ticer Technologies TCR® thin film copper resistor foil as one or both of the clad foils.

Note: Embedded resistors should be applied in rigid portions of PCBs and should **not be placed in areas where dynamic flex will occur**. Locating embedded resistors in flex-to-install locations is possible, but should be thoroughly tested and confirmed. Resistance values may be altered.

Resistive Alloy	NiCr	NiCrAlSi
Sheet Resistance (Ohms/sq.)	25, 50, 100	25, 50, 100, 250
Material Tolerance (%)	+/- 5	+/- 5
Temperature Coefficient of Resistance (max ppm/C)	110	-20
Base Copper Foil thickness (um)	18, 35	18, 35
Recommended Etch Solution 1st Etch 2nd Etch 3rd Etch	 Cupric Chloride Ammoniacal N/A	 Ammoniacal* Acidic Permanganate Ammoniacal* *Cupric Chloride alternatively
Resistor Tolerances (%) Feature size 10 mil or greater Laser Trimmed	 +/- 10 +/- 1.0	 +/- 10 +/- 1.0
Minimum Feature Sizes* "In trace" resistors Trace width Trace spacing Termination overlap Resistor "keep out" * Power and resistance heating must also be considered.	 5 mils Fabricator capability Fabricator capability 2.5 mils 10 mils	 5 mils Fabricator capability Fabricator capability 2.5 mils 10 mils
Resistor Patterns	Fractional to high multiple squares. Serpentine and Others	Fractional to high multiple squares. Serpentine and Others
Maximum recommended power dissipation at 40C (watts/sqin) OPS = ohm/sq.	25 OPS: 250 50 OPS: 200 100 OPS: 150	25 OPS: 250 50 OPS: 200 100 OPS: 150 250 OPS: 75

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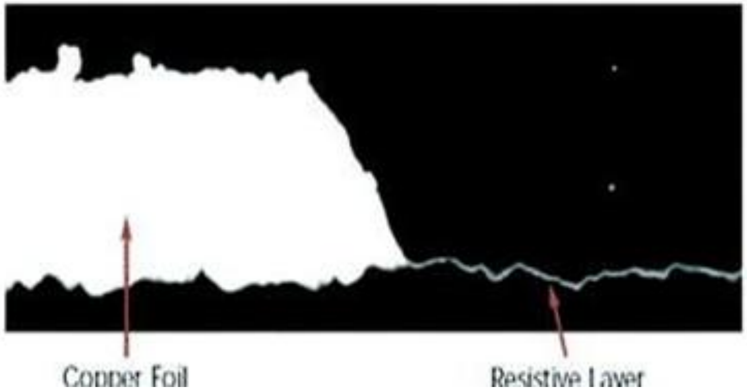
Ticer® Material Combination

- Ticer® RF

  Ticer® foil laminated on Low Dk base materials.
  Available From Rogers (RO4003, RO4350B)



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Choosing CCL Materials for Embedded Resistors

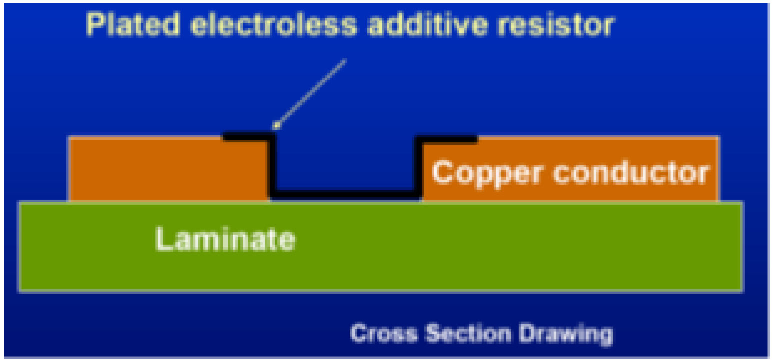
MacDermid

MacDermid M-Pass™

MacDermid has a thin-film plated resistor that can be selectively applied directly to inner layers.

The M-Pass process is similar to "Ohmega-Ply" in that it uses nickel phosphorous (**NiP**) as the resistive element.

The outcome of this effort is a unique, patent-pending technology designed to replace discrete surface mount resistors. Using the deposition of resistive metals, this innovative technology is designed to meet a wide range of ohms-per-square resistor requirements.



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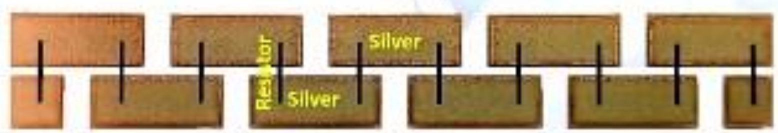
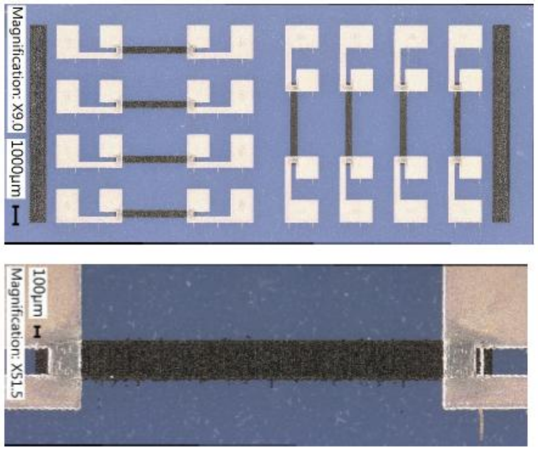
Choosing CCL Materials for Embedded Resistors

Printed Embedded Resistor

- Resistance: 1.4 KΩ
- Thickness: 3.5 μm
- Width: 300 μm
- Length: 540 μm
- Pads: Sicrys™ Silver Ink
- Substrate: Glass
- Printing method: Inkjet



Sicrys™ RI-6DM-3 and **RI-20DM-1** a resistive ink based on carbon black nanoparticles and diethylene glycol monomethyl ether , designed for digital inkjet printing.



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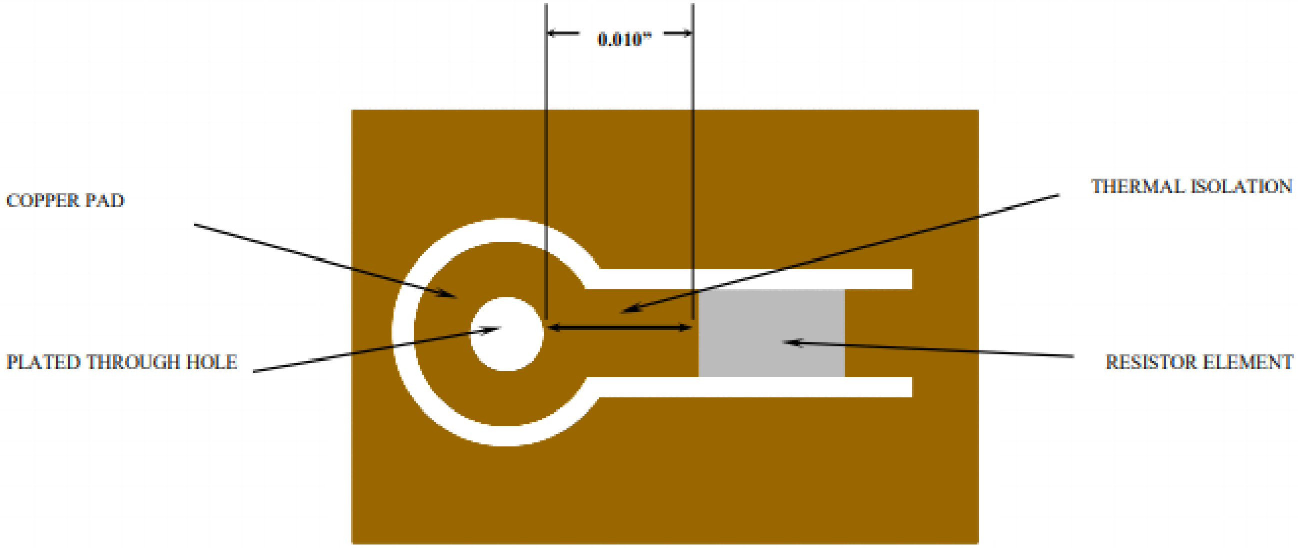
Basic Design Rule for Embedded Resistors

The recommended offset is 0.010" and 0.005" for laser drilled microvias.



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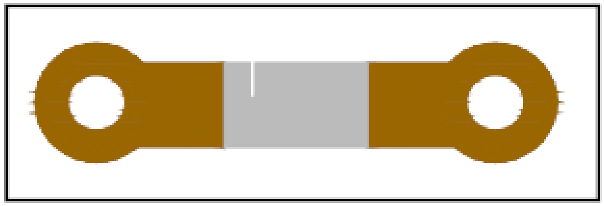
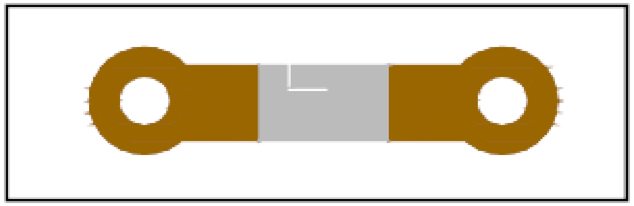
Resistor Trimming

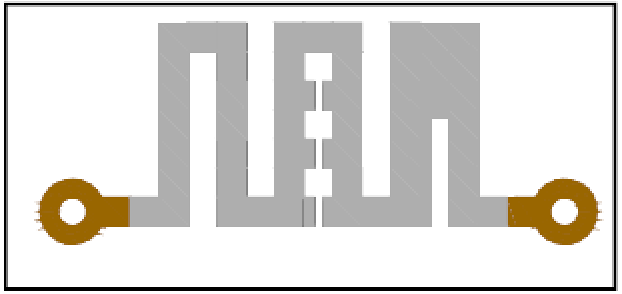


▲ *Plunge Trim*



▲ *L-cut trim*

▲ *Trimmable resistor Ladder network*



▲ *Trimmed multiple square resistor*

The top figures are designed without special modification for trimming except to provide enough area to handle power dissipation and current if cross-section is reduced by a conventional trim cut.
The bottom figures are designed with segments for adjust without reducing cross-section of primary current path.

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Resistor Electrical Test Recommendations

Input the test voltages on most other standard systems,

- ✓ Continuity {opens} 10 volts (20mA limiting current).
- ✓ Isolation {shorts} 40 volts (10 Mega ohm failure).

Special probes enable innerlayer testing through double treat or black oxide coatings.

For extremely low value resistors (i.e. less than 15 ohms), contact, probe and lead resistance becomes a critical factor in determining measurement accuracy.

Coupons electrically tested to monitor material, process variation, but coupons are not a substitute for 100% electrical testing read boards.

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CCL Materials for Embedded Capacitors

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Choosing CCL Materials for Embedded Capacitors

3M™ Embedded Capacitance Material (ECM)

Consists of a very thin layer of ceramic-filled epoxy sandwiched between two layers of copper foil

Property	Test Method	C0614	C1012	C2006
Capacitance/Unit Area (1 kHz)	Supplier Method	6.4 nF/in^2 (1.0 nF/cm^2)	10.0 nF/in^2 (1.6 nF/cm^2)	20.0 nF/in^2 (3.1 nF/cm^2)
Dielectric Thickness	Cross-section	14 µm (0.55 mils)	12 µm (0.47 mils)	6 µm (0.24 mils)
Copper Type	Supplier Method	RA	ED or RA	RA
Copper Thickness	Cross-section	35 µm	35 µm (ED/RA) or 17 µm (ED)	35 µm RA
Capacitance Tolerance	Supplier Method	+/- 10%	+/- 10%	+/- 10%
Dielectric Constant (1 kHz)	Supplier Method	16	22	22
Dissipation Factor (1 kHz)	Supplier Method	0.005	0.010	0.010
Temperature Coefficient of Capacitance (TCC)	Supplier Method	Meets X7R requirements		
Dielectric Strength (Volts/Mil)	ASTM D149	3300	3000	3000
HiPOT Voltage	IPC-TM-650 2.5.7.2	100 V	100 V	50 V
UL Flammability Rating	UL 94	94 V-0		
UL Relative Thermal Index (RTI)	UL 796	130°C	90°C[4]	90°C[4]
UL Solderability Limits	UL 796	288°C/30 sec.	288°C/20 sec.	288°C/20 sec.
Glass Transition Temperature	Supplier Method (DSC)	120°C		
Moisture Absorption (wt %)	ASTM D570	0.11	0.10	0.10
CTE (ppm/C)	Supplier Method (TMA)	32 (x,y,z)	31 (x,y,z)	31 (x,y,z)
Degradation Temperature	IPC-TM-650 2.3.40	345°C	375°C	375°C
Peel Strength (pli)	IPC-TM-650 2.4.9 modified	4.0	6.0 (ED)/4.0 (RA)	4.0 (RA)
Thermal Conductivity (W/m*K)	ASTM F433 modified	0.5		
Halogen Content (ppm)	BS EN 14582:2007	<400	None Detected	

Choosing CCL Materials for Embedded Capacitors

FaradFlex®

FaradFlex® MC8M, MC12M and MC24M are advanced lm based laminate materials designed for ultra thin, low impedance, low inductance, buried capacitance, or reduced thickness applications.

Copper Availability:

- ✓ 0.5 oz /0.5 oz
- ✓ 1 oz / 1 oz
- ✓ 2 oz / 2 oz
- ✓ 2 oz / 1 oz

Typical Dielectric Nominal Thicknesses:

- ✓ MC8M 8 µm (1/3 mil)
- ✓ MC12M 13 µm (½ mil)
- ✓ MC24M 22 µm (1 mil)

Electrical Properties	Tested	Method	Units	MC8M	MC12M	MC24M
Capacitance Density (Cp)	1 MHz	IPC TM-650 2.5.5.3	nF/in^2 (pF/cm^2)	3.1 (480)	1.9 (300)	1.2 (180)
	1 GHz			2.5 (390)	1.6 (250)	0.9 (140)
	3 GHz			2.5 (390)	1.5 (240)	0.9 (140)
	10 GHz			2.45 (380)	1.48 (230)	0.8 (340)
Dielectric Constant(Dk)	1 MHz	IPC TM-650 2.5.5.3		4.4	4.4	4.4
	1 GHz			3.48	3.5	3.48
	3 GHz			3.45	3.5	3.45
	10 GHz			3.37	3.4	3.37
Dissipation Factor (Df)	1 MHz	IPC TM-650 2.5.5.3		0.016	0.015	0.015
	1 GHz			0.021	0.02	0.016
	3 GHz			0.021	0.02	0.017
	10 GHz			0.021	0.02	0.017
Dielectric Strength		IPC TM-650 2.5.6.2	VDC/ micron	>400	>415	>208
Volume Resistivity		IPC TM-650 2.5.17	Ohm/ cm	2.59E+16	5.93E+15	1.10E+15
Surface Resistance		IPC TM-650 2.5.17	Ohm	3.02E+13	3.50E+13	7.20E+13
Working Voltage		-	Volts	1280	1600	>2000
Migration (85C/85%RH)	35V/50V	-		>1000(35V)	>1000(50V)	>1000(50V)

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Choosing CCL Materials for Embedded Capacitors

DUPONT™ INTERRA™ HK 04J

PLANAR CAPACITOR LAMINATE

DuPont™ Interra™ HK 04J is a thin laminate with a polyimide dielectric designed to function as a power and ground plane in printed wiring boards.

Available Materials:

Product Code	Dielectric Constant	Dielectric Thickness	Copper Thickness (side 1)	Copper Thickness (side 2)
HK 04J2518E	3.5	25µm	18µm	18µm
HK 04J2536E	3.5	25µm	36µm	36µm
HK 04J2572E	3.5	25µm	72µm	72µm
HK 04J7423E	3.5	12µm	36µm	36µm
HK 04J7420E	3.5	12µm	72µm	72µm
HK 04J7341E	3.5	25µm	18µm	36µm
HK 04J7403E	3.5	25µm	36µm	72µm

Properties	HK04J25	HK04J12
Dielectric Thickness µm	25	12
Dielectric Type	Polyimide	Polyimide
Capacitance Density, pF/cm^2	125	260
Dielectric Constant at 1 MHz	3.5	3.5
Loss Tangent at 1 MHz	0.005	0.005
Dielectric Strength, kV/mil	6-7	8
Adhesion to Cu (Peel strength) N/mm (pli)	1.8 (10)	1.4 (8)
Surface Resistivity, ohm	$>10^{14}$	$>10^{14}$
Volume Resistivity, ohm-cm	$>10^{16}$	$>10^{16}$
Elongation, %	>50	>50
CTE 50-200C, ppm/^{0}C	21	18
Water Absorption, %	0.8	0.8
Tg, °C	225	225

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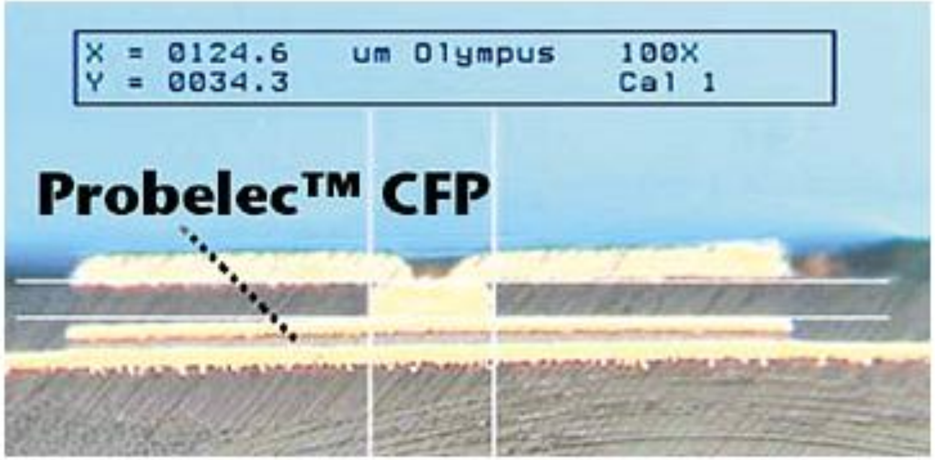
motorola

VANTICO

Motorola, in partnership with Vantico AG, developed “ProbelecT CFP” (ceramic-filled photodielectric) mezzanine structure for embedded capacitance. The term mezzanine is used to emphasize the fact these capacitors are formed in an intermediate layer between a core layer of a PWB and an HDI layer of a PWB. The capacitor, therefore, does not consume any real estate on the HDI layer except for a microvia that is dropped to access the top capacitor electrode.

These capacitors are formed by a fairly conventional process of coating, laminating, printing, etching, and developing, followed by the application of a microvia to connect the capacitor to layer 1. Key to this process is **the photosensitive dielectric** and the ability to apply it in controlled thickness to the smooth solid-copper surface of the sub-core .**The capacitance density of this process is about 10 nF/in^2**



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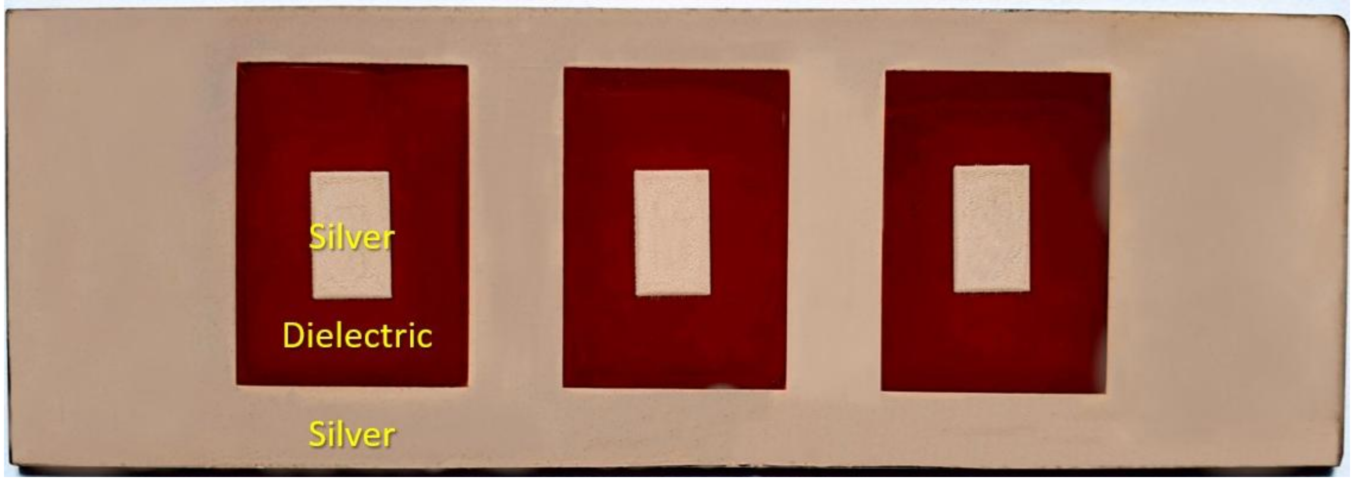
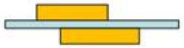
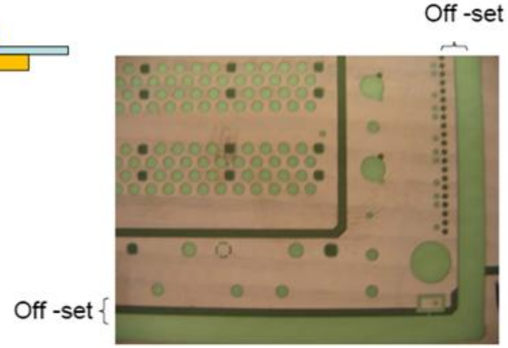


The inkjet-based conductive digital printing solutions and producer of conductive digital inks including silver capacitors.

Basic Design Rule for Embedded Capacitors Layers

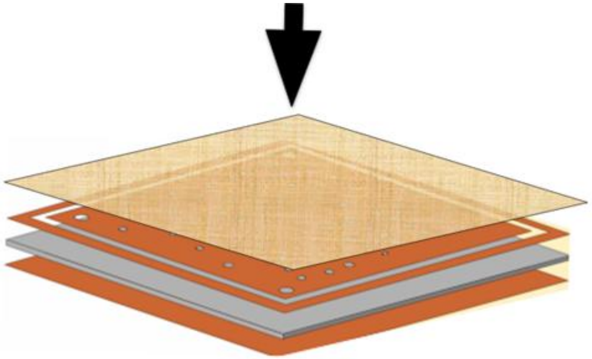
1. Offset Back to Front Pattern





2. Use thin and density prepreg for preventing layer movements.

   The best prepreg choice next to the Capacitor layer is normally 1078 but 1067 works well too. The 106 and 1080 tend to be less dimensionally stable.



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IPC Standards for Embedded Passive Device Printed Boards

IPC-2316 — Design Guide for Embedded Passive Device Printed Boards

IPC-4811 — Specification for Embedded Passive Device **Resistor** Material for Rigid and Multilayer Printed Boards

IPC-4821 — Specification for Embedded Passive Device **Capacitor** Material for Rigid and Multilayer Printed Boards

IPC-7092 — Design and Assembly Process Implementation for Embedded Components

Questions

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