Thin-Film NiP Embedded Resistor Reliability in Military/Aerospace Applications

By

Bruce P. Mahler, Ohmega Technologies, Inc.

And

Brigitte Lawrence, Brigitflex, Inc.

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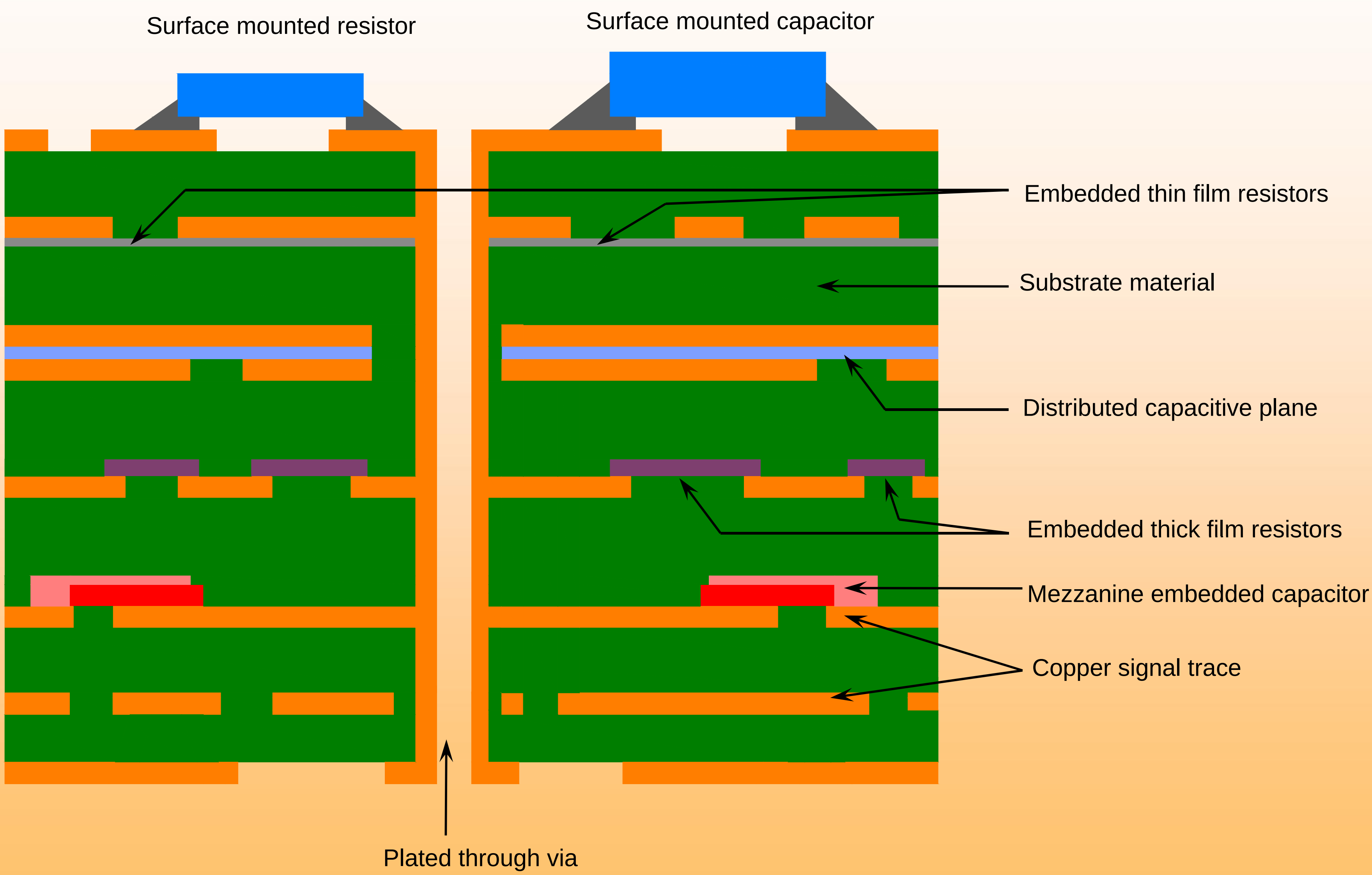
Embedded Passives (Resistors/Capacitors) in PCB's



Advantages of Embedded Resistors

Electrical Advantages

Improved line impedance matching
Shorter signal paths and reduced series inductance
Reduced cross talk, noise and EMI

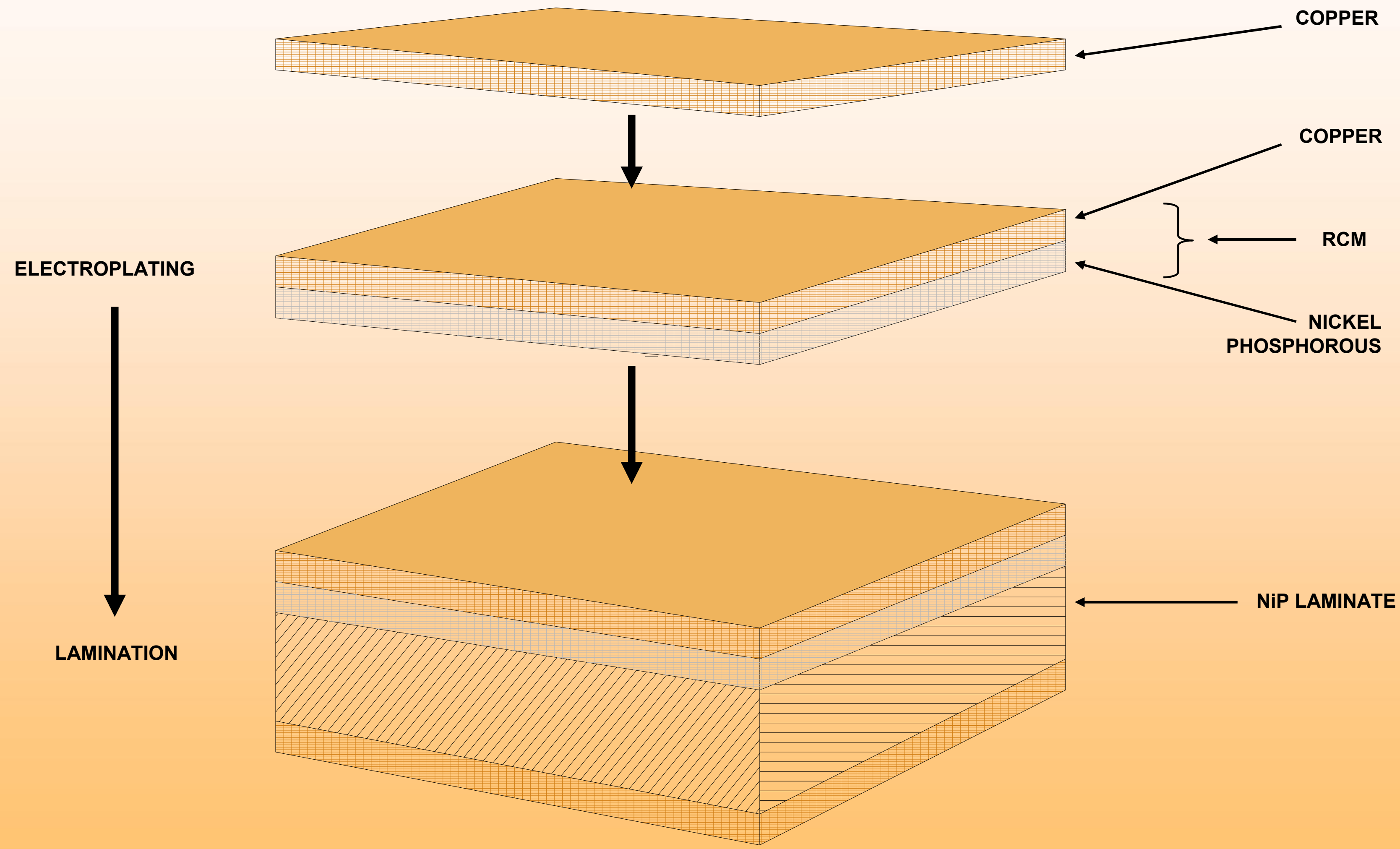
PCB Design Advantages

Increase active component density and reduced form factors
Improved routing due to elimination of vias
Board simplification, size reduction and/or densification

Improved Reliability

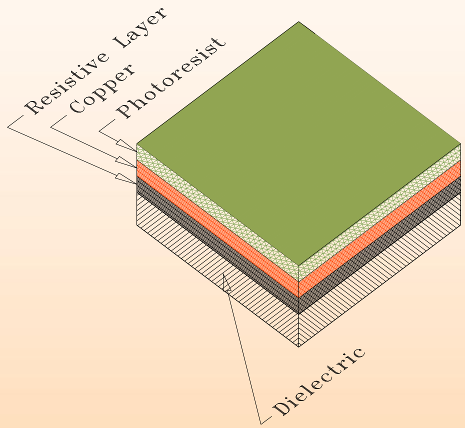
Low RTC of < 50 PPM
Life testing: 100,000 hours < 2% drift at 110°C
Stable over wide frequencies: tested beyond 40 GHz
Elimination of solder joints
Testing at inner layer and bare board stage

NiP Resistive Material

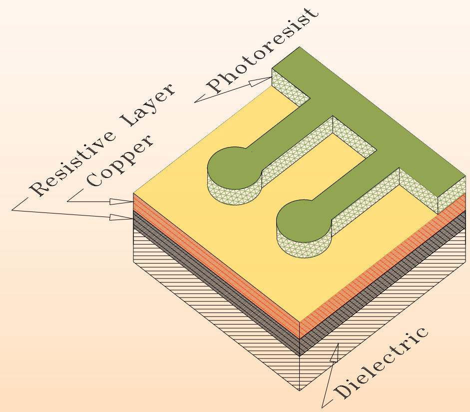


PCB Processing of the NiP Resistor Alloy

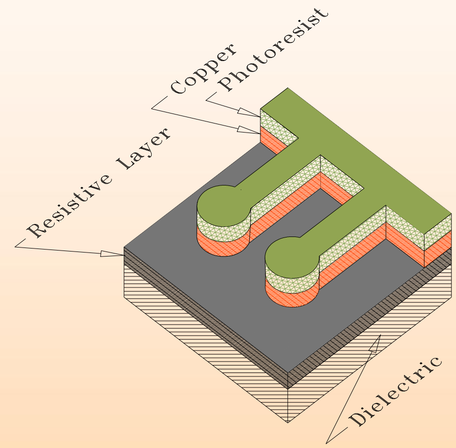
- **STEP 1**: Apply Photoresist to Laminate



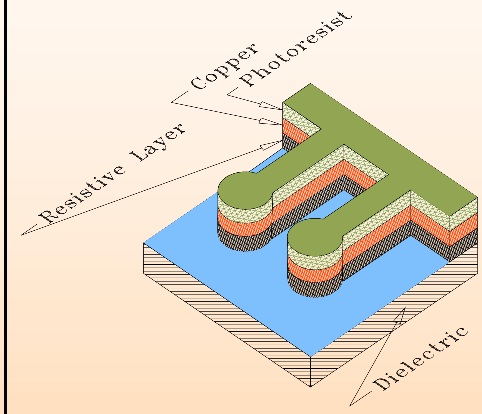
- **STEP 2**: Print and Develop Composite Image



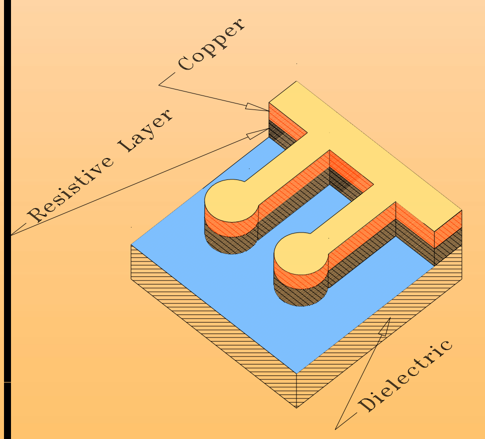
- **STEP 3**: Etch Unwanted Copper Using Any Conventional Etchant (1st etch)



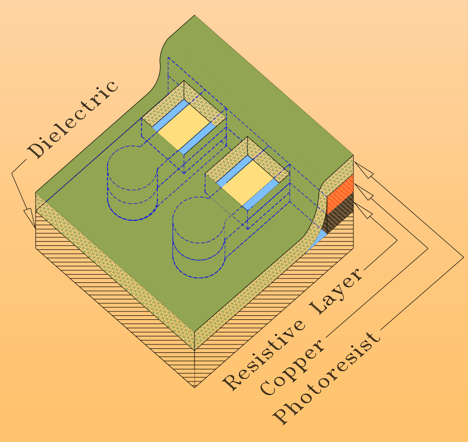
- **STEP 4**: Etch Unwanted Resistive Material with Copper Sulfate Solution (2nd etching process)



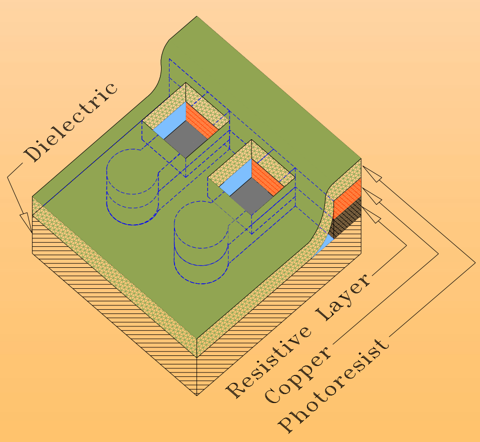
- **STEP 5**: Strip Photoresist



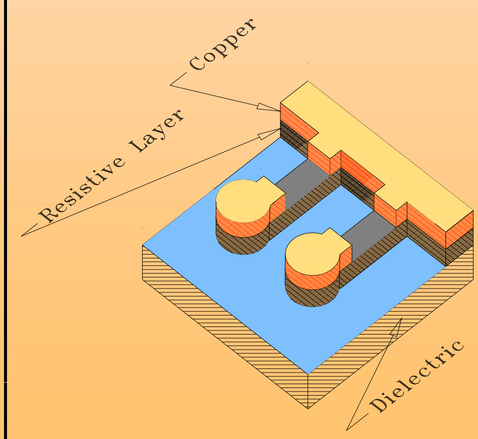
- **STEP 6**: Apply Photoresist, Print and Develop Conductor Protect Image (2nd print)



- **STEP 7**: Etch Away Copper Over the Designed Resistor Using a Selective Alkaline Etchant (3rd etch)



- **STEP 8**: Strip Photoresist



Embedded Resistor Testing

- Electrical testing is required to verify correct resistor values and identify out-of-tolerance resistors
- All resistors should undergo electrical testing at the inner layer and bare board stage to assure resistor tolerances and facilitate failure analysis.
- AOI is not a substitute for inner layer electrical test
- Standard electrical test equipment is utilized
  - Universal bare board tester (bed-of-nails with fixture)
  - Flying probe tester (fixtureless)

Embedded versus SMT Processes

NiP embedded resistors are created using standard print-and etch Processes and eliminate the need for discrete resistor placement and attachment.

Standard PCB print and etch process controls and IPC Specs apply to embedded resistors. Soldering process controls and specifications due not apply to embedded resistors.

In Military/Aerospace and other critical applications, elimination of the discrete resistor solder joints improves reliability and yields.

NiP Resistor Reliability

PROPERTIES AND SPECIFICATIONS						Remark and Condition
Sheet Resistivities	10	25	50	100	250	
Material Tolerance	+/-3	+/-5	+/-5	+/-5	+/-10	
Load Life Cycling Test (Δ R%)	<0.3 (after 1087 hrs)	<5	<5	<5	0.5 (after 1000 hrs)	Ambient Temp: 70C On Cycle: 1.5 hrs Off Cycle: 1.5 hrs Length Of Test: 10000 hrs
Current Noise Index in dB	<-16	<-15	<-15	<-15	<-15	Voltage Applied: 10 ohm/sq.: 53.2V 25 ohm/sq.: 5.6V, 100 ohm/sq.: 7.9V
Short Time Overload (Δ R%)	0	0	0	0	0	Power:2.5 X Rated Time: 5 sec
Resistance Temperature Characteristic(RTC) PPM/°C	20	50	60	100	100	Hot Cycle: 25°, 50°,75° 125°C Cold Cycle: 25°, 0°,-25°, -55°C

NiP Resistor Reliability

PROPERTIES AND SPECIFICATIONS						Remark and Condition
Sheet Resistivities	10	25	50	100	250	
Humidity Test (Δ R%)	0.3	0.5	0.75	1	2	MIL-STD-202-103A Temp: 40 °C Relative Humidity: 95% Time: 240 hrs
Thermal Shock (Δ R%)	0.1	-0.5	1.0	1.0	1.0	MIL-STD-202-107B No of Cycles: 25 Hot Cycle Temp: 125 °C Cold Cycle Temp: -65 °C
Hot Oil (Δ R%)	--	0.1	0.25	0.5	0.75	IPC-TM-650 METHOD 2.4.6 Temp: 260°C Immersion: 20°C
Solder Float (Δ R%)	0.2	0.5	0.75	1.0	0.5	MIL-STD-202-210D Temp: 260°C Immersion: 20 Second
Resistance to Solvent (Δ R%) Toluence 1-1-1: Trichloroethan: Acetone: Freon:	N/A	 0.2 0.0 0.2 0.0	N/A	N/A	N/A	MIL-STD-202-215A Immersion: 15 mins
Capacitance(pF) (at 5 Hz)	~0	~1	~1	~1	~1	
Inductance (nH) (at 5 Hz)	< ~0.6	< ~0.6	< ~0.6	< ~0.6	< ~0.6	

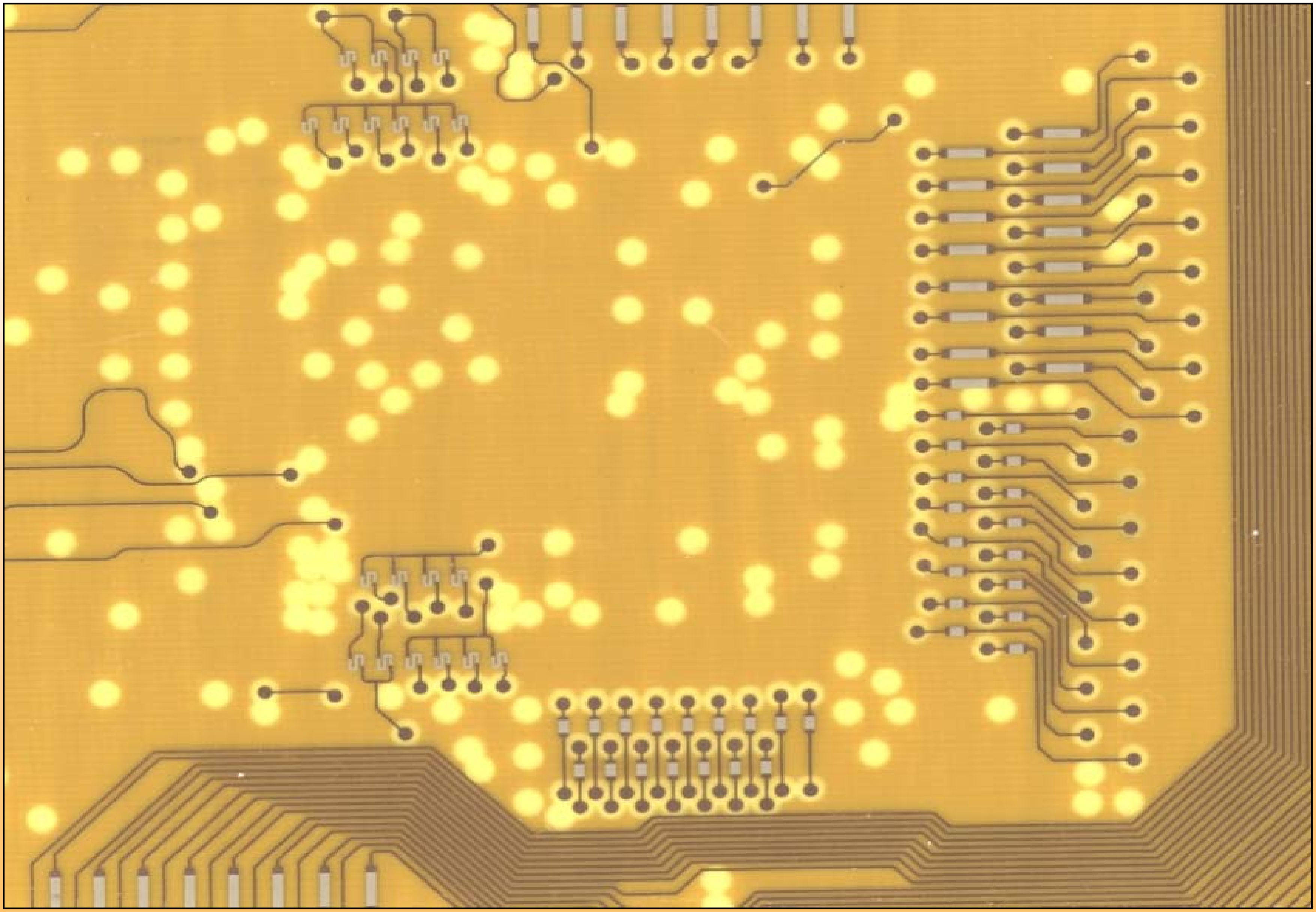
NiP Resistor Reliability

Alcatel

Researchers at Alcatel tested NiP resistors for broadband (45 MHz-5 GHz) telecom applications to compare the reliability of NiP resistors to 0805 discrete chip resistors rated at 125 mW. The NiP resistors were as good as, or better than, the chip resistors in all performed tests.

Type of Test	Measured max./min. ΔR (Alcatel Tested)	Ohmega Specifications	Thick film chip R (0805)
Humidity Test **Temp: 40 °C** **Relative Humidity: 93%**	**After 21 days:** 0.22% for 25 Ohm/sq. 0.07% for 100 Ohm/sq. 0.10% for 250 Ohm/sq. **After 56 days:** 0.74% for 25 Ohm/sq. 0.14% for 100 Ohm/sq. 0.22% for 250 Ohm/sq.	**After 10 days:** 0.5% for 25 Ohm/sq. 1.0% for 100 Ohm/sq.	**After 56 days:** ≤ ± 1.5%
Thermal Cycling **Hot Cycle Temp: 125 °C** **Cold Cycle Temp: -25 °C**	**After 100 Cycles** - 0.03 % for 25 Ohm/sq. 0.03 % for 100 Ohm/sq. - 0.08 % for 250 Ohm/sq.	**After 25 Cyles** - 0.5% for 25 Ohm/sq. 1% for 100 Ohm/sq	≤ ± 25%
Aging Wihout Load **Temp: 125 °C**	**After 100 Hrs.** 0.10% for 25 Ohm/sq 0.08% for 100 Ohm/sq - 0.13% for 250 Ohm/sq	Not specified	Not specified
Solder Heat/Float **Temp: 260 °C** **Immersion: 20 sec**	- 0.02% for 25 Ohm/sq 0.01% for 100 Ohm/sq - 0.01% for 250 Ohm/sq	0.5% for 25 Ohm/sq 1% for 100 Ohm/sq	≤ ± 25%

Alcatel Design-Inner Layer of an MLB



Termination and pull-up resistors in an ATM switching card.

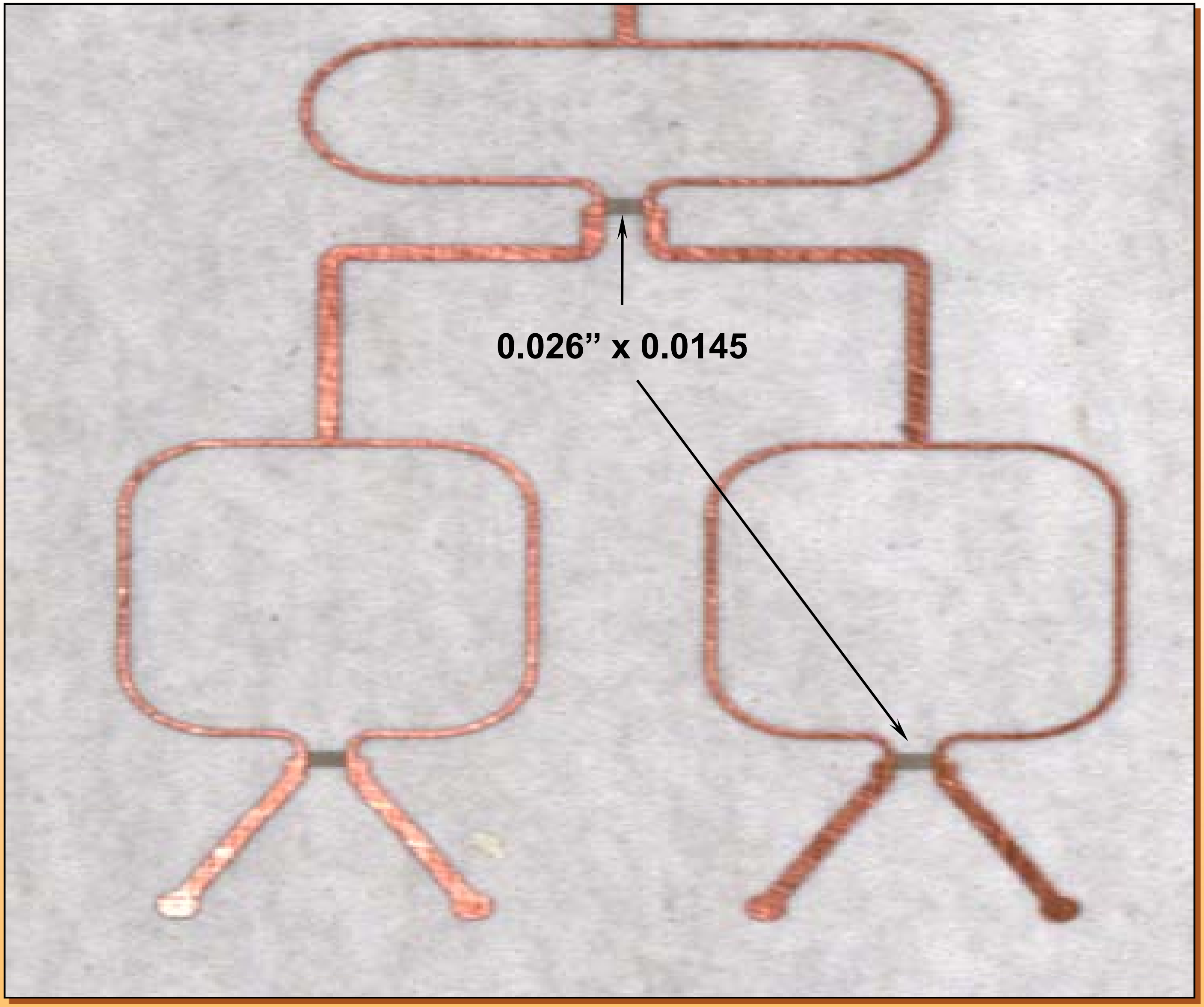
NiP Resistor Reliability

Dassault (Thales)

Dassault Electronique did a 2 year study of the NiP resistive material for an active phased array antenna (X-band). The resistors were used in a stripline configuration on a PTFE substrate. The NiP material was compared to chip resistors and screen printed polymer inks. The NiP material was selected for use due to superior tolerance and stability (compared to printed polymer inks) and space saving, parasitic reduction, and solder joint removal (compared to chip resistors). The results of testing are as follows:

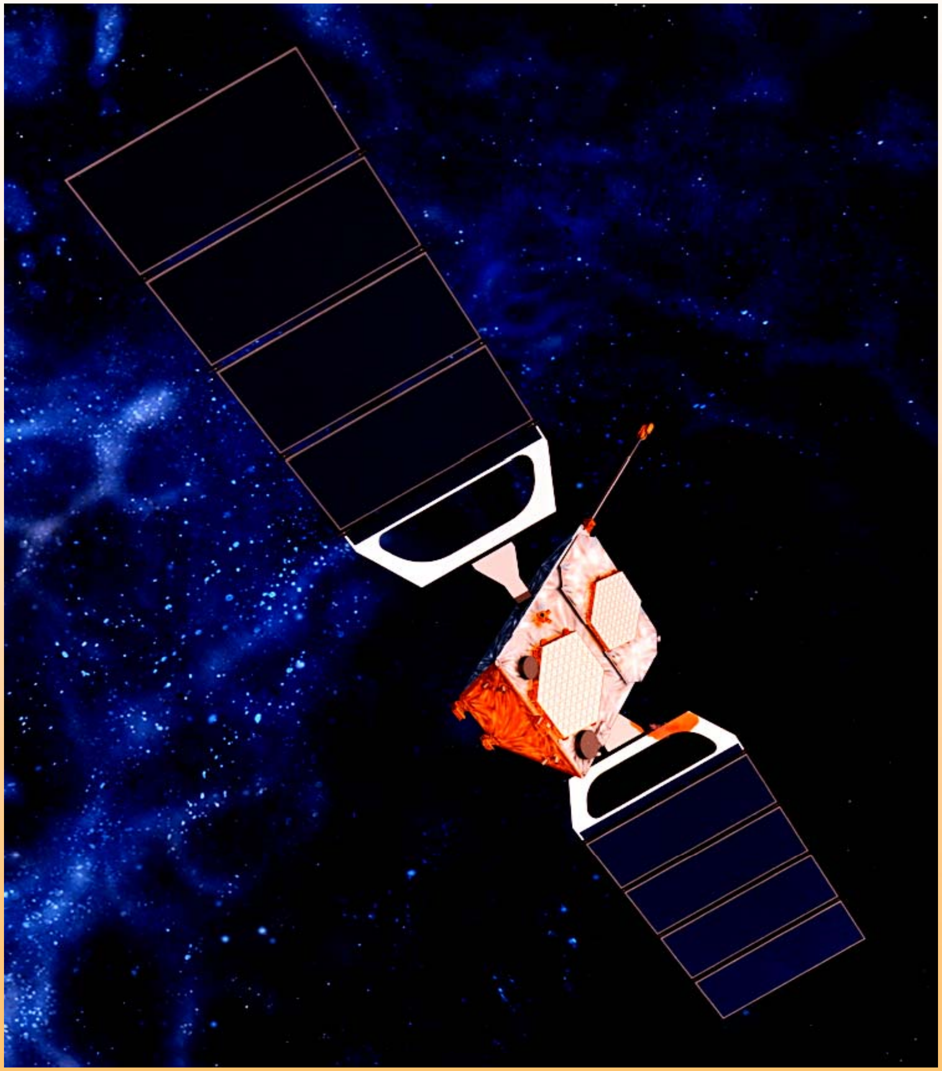
Etching Tolerance	Minimum Resistor Width	Tolerance After Fusion Bonding	Influence of Ohmega-Ply Foil Layer on Microwave Properties	Shift of Resistor Values After 500 Thermal Cyles (-55° C,+125° C)	Thermal Coefficient of Resistance Within the Range (-55°C, +125°C)	Power Handling	No shift in microwave performance of two ports power divider, when Ohmega Foil Technology is tested under the following conditions:
5%	200 µm	7%	NO	Microstrip: +2% Stripline: +3%	Microstrip: ± 6% Stripline: ± 7%	300 mW	• 500 thermal cycles (- 55° C, +125° C) • 500 hours at 125° C • 40 days 40° C, 95% RH • 48 hours salt spray

NiP Resistor Reliability

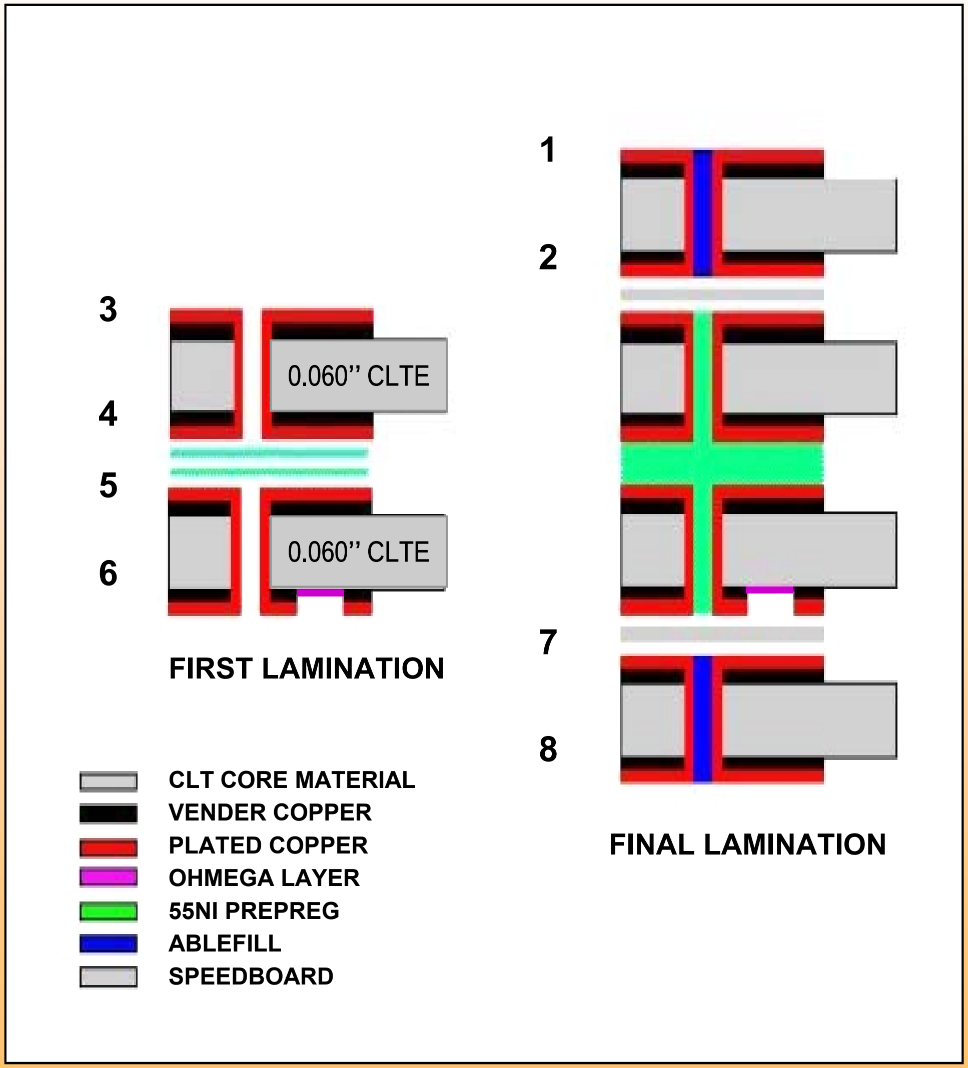


Enlargement of a four-up array 16-way power divider with 50 Ω/□ OhmegaPly® resistors

NiP Resistor Reliability



OhmegaPly® resistor in microwave application for Globalstar antenna.



Layer stack up.

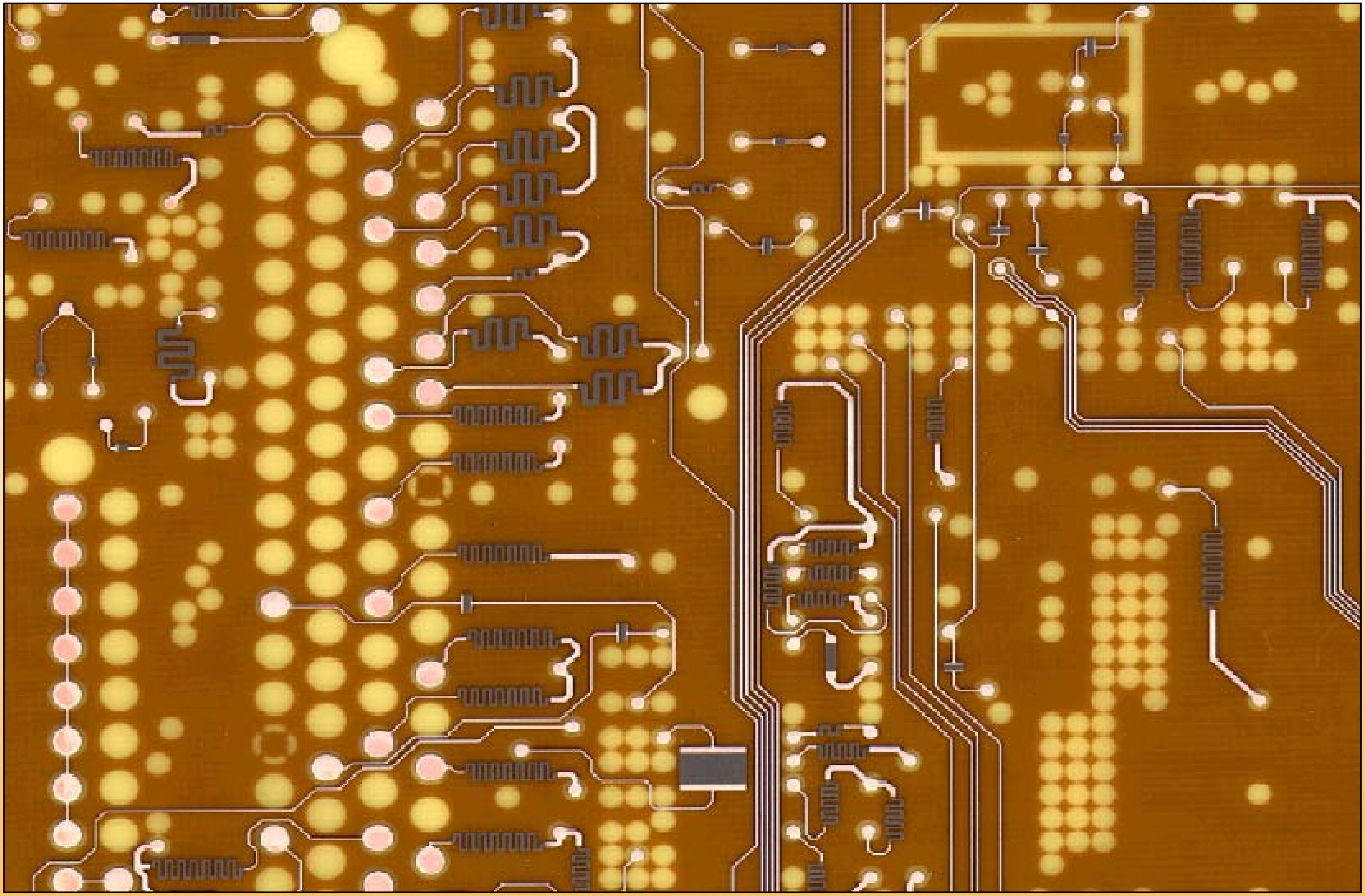
NiP Resistor Reliability

Military/Aerospace Organization

Highly Accelerated Thermal Shock Test (HATS)

	CHANGE IN RESISTANCE AFTER 1000 CYCLES		
Resistor Network	**% change in Resistance**	**Test Result**	**Test Condiltion**
1	0.20	Pass	15 Coupons Per Resistor Network
2	0.15	Pass	Total Cycle Time: 10.85 minutes
3	0.20	Pass	High Temperature: +145 C
4	0.17	Pass	Low Temperature: -40 C
			High Temperature Extended Dwell Time: 0.25 minutes
			Low Temperature Extended Dwell Time: 0.25 minutes

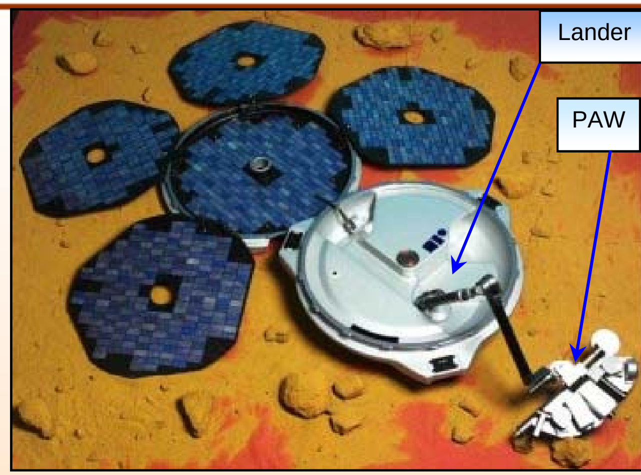
NiP Resistor Reliability



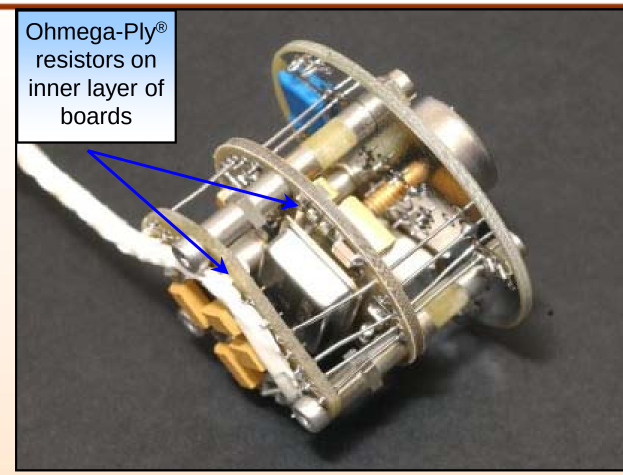
Pull-Up/Pull-Down resistors in a missile control circuit board

NiP Resistor Reliability

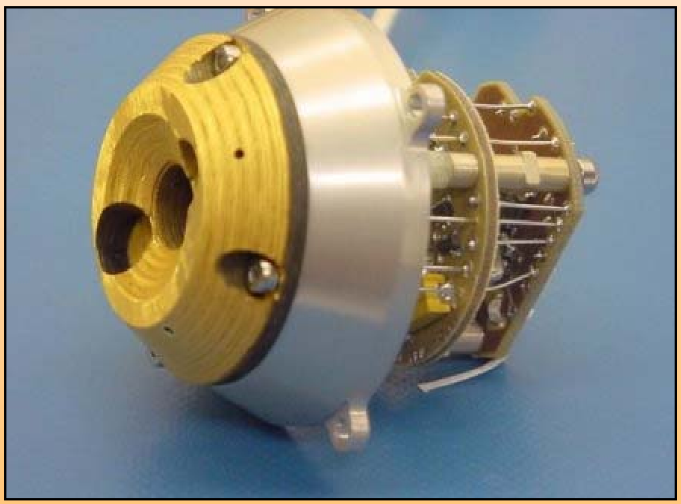
▲ *Mars Express orbiter*



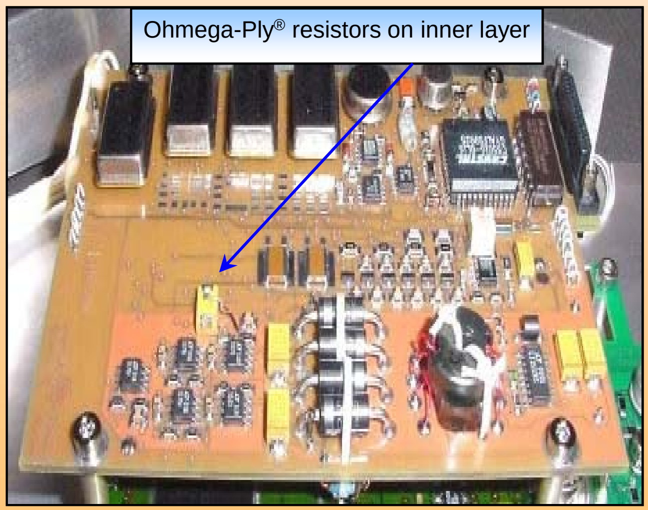
▲ *Beagle 2 Lander with instruments on its robotic arm*



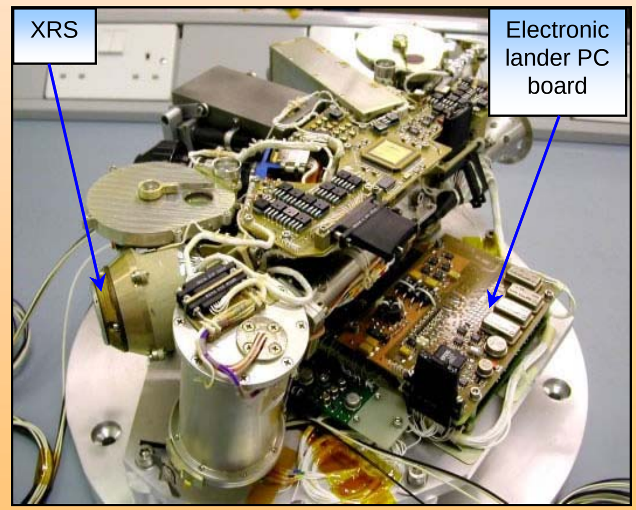
▲ *X-Ray Spectrometer (XRS) with Ohmega-Ply® resistors*



▲ *X-Ray Spectrometer with cover to measure the elements in rocks*



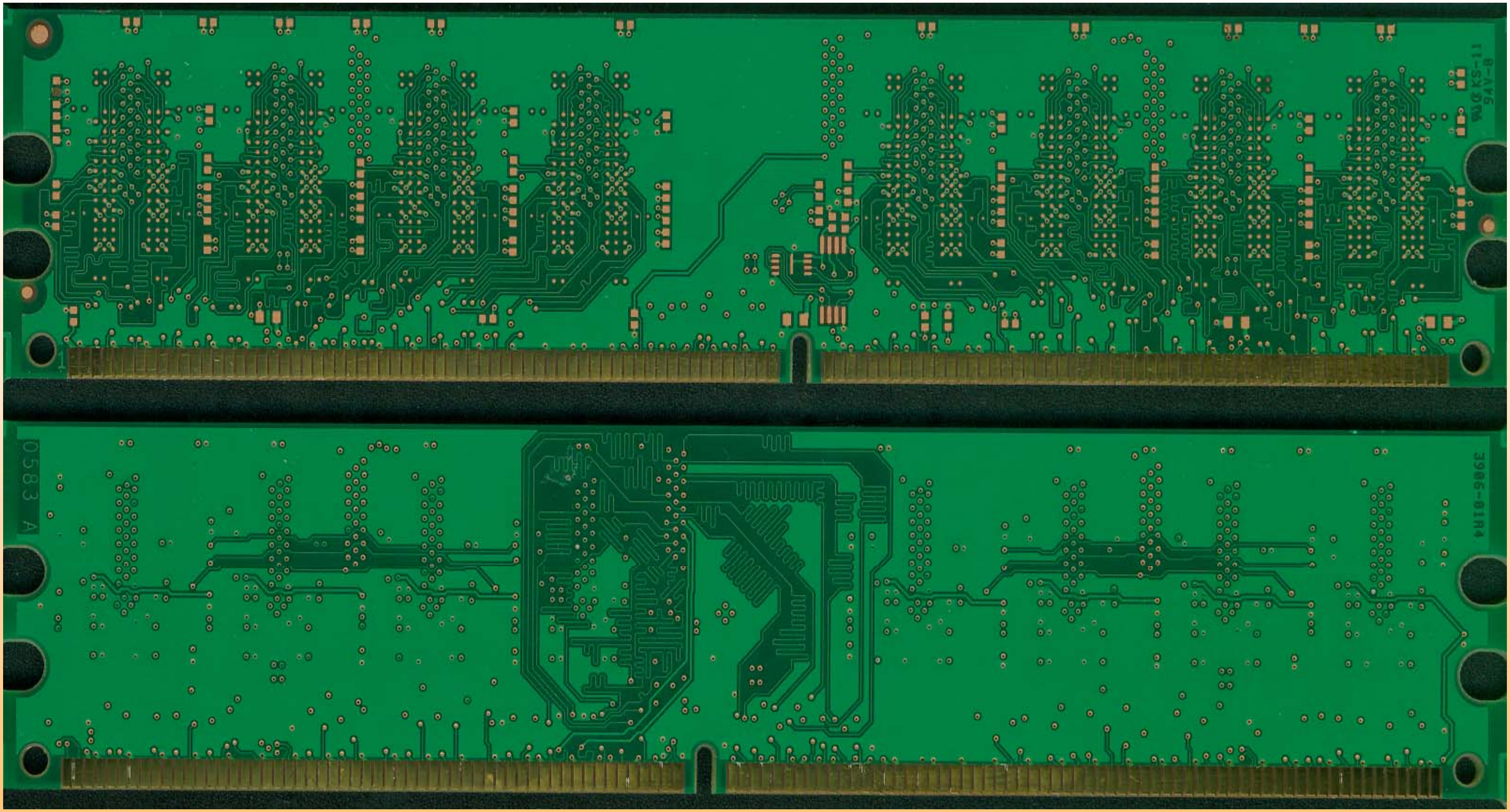
▲ *Ohmega-Ply® resistors in electronic lander PC board*



▲ *Top view of PAW (position adjustable workbench)*

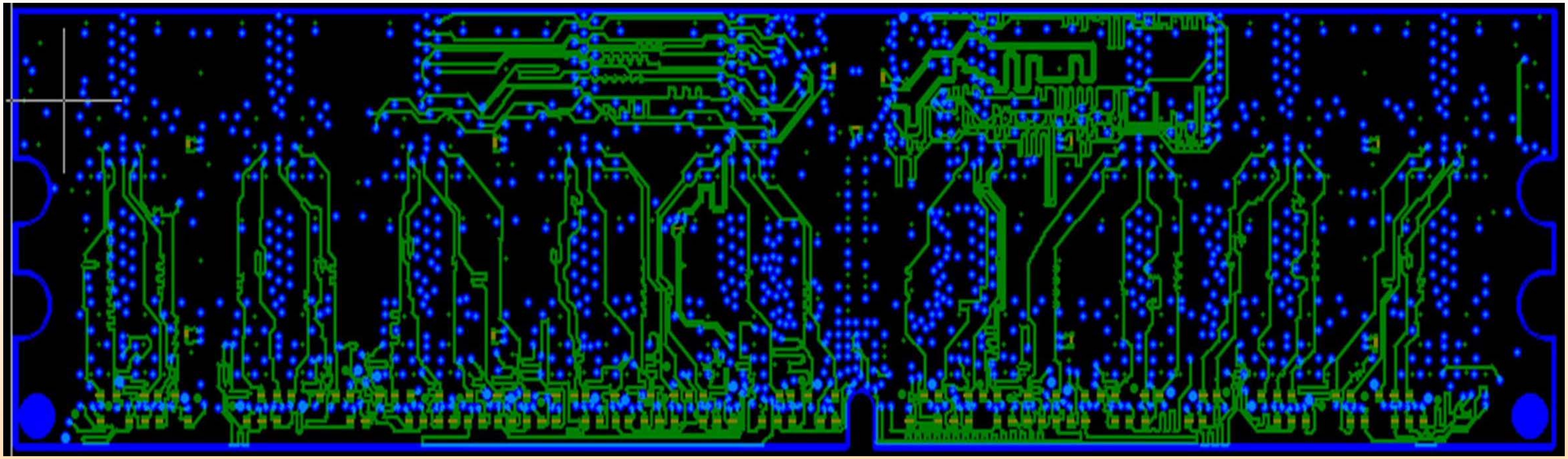
Embedded NiP Resistors in ESA Mars Express Beagle 2 Lander

NiP Resistor Reliability

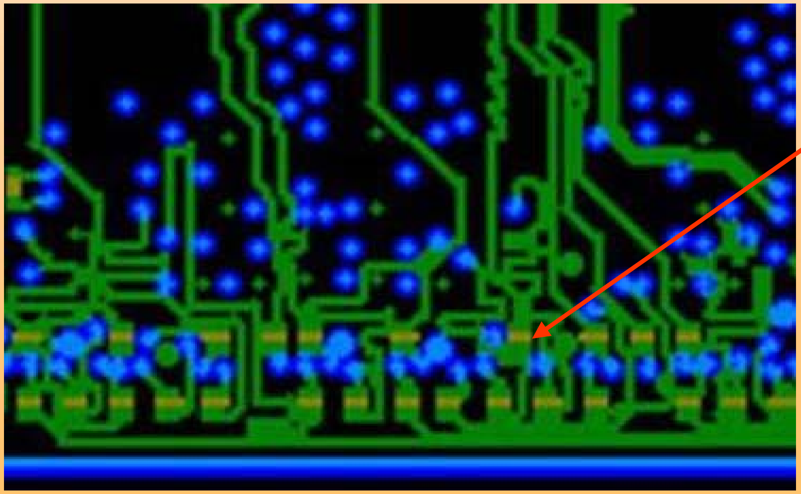


▲ *NiP Resistors Embedded in DRAM PCB – FR4 Dielectric for Lead-Free Assembly*

NiP Resistor Reliability



▲ *NiP Resistors on Inner Layer of DRAM Design*



▲ *Enlargement of Above Design*

NiP Resistor Reliability

Application of NiP Resistors on a Lead-Free Substrate

- Resistive stability after solder float (%ΔR)
- Thermal stress test-to-failure.
- Compare FR4 to a “Lead-Free” laminate.
- Test at T260 20 seconds versus T288 10 seconds.
- Preconditioning; baking versus no-baking
- Failure means resistor becomes unstable or open.
- The result was that the lead-free laminate was clearly superior at T288. Surviving 25 cycles.

NiP Resistor Reliability

SUBSTRATE	% ΔR AT 1 CYCLE	% ΔR AT 2 CYCLE	% ΔR AT 5 CYCLE	% ΔR AT 10 CYCLE	% ΔR AT 15 CYCLE	% ΔR AT 20 CYCLE	% ΔR AT 25 CYCLE	TEST METHOD	CONDITION
FR-4	-0.36	-0.47	-0.47					T260. 20 sec	no bake
Lead Free	-0.57	-0.58	-0.62	-0.54	-0.24	-0.13	-0.08	T288, 10 sec	5 hr bake
Lead Free	-0.27	-0.37	-0.46	-0.27	-0.16	0.17	0.26	T288, 10 sec	no bake
FR-4	-1.39	open						T288, 10 sec	5 hr bake
FR-4	-1.25	open						T288, 10 sec	no bake

Memory board, 10 layers with one layer of 22 ohm resistors, 23 mils x 10 mils.
Built using Double Treat 1/2A50ohm NiP resistive material.
The FR-4 PCB used a standard multifunctional epoxy laminate.
The "lead-free" PCB used a phenolic-cured laminate.
Testing per IPC-TM-650, Method 2.4.13.1, baking was performed at 125 dC.

Embedded Resistor stability is an indicator of the PCB structural integrity

IPC Standards Development for Embedded Passives

IPC specifications for embedded passives has been in development for a number of years. These are:

•IPC-4902, Specifications for Materials for Embedded Passive Devices for Printed Boards

•IPC-2227, Sectional Design Standards for Boards Utilizing Embedded Passive Devices

•IPC-4821 Specification for Embedded Passive Device Capacitor Materials for Rigid and Multilayer Printed Boards

•IPC-4811 Specifications for Embedded Passive Device Resistor Materials for Rigid and Multilayer Printed Boards

Conclusion

- Thin-Film NiP resistors have been successfully used in Military/Aerospace applications for over 35 years
- Extensive testing has been performed to prove the reliability of NiP resistors in Military/Aerospace applications
- Design and Test Standards for embedded passives are currently under development by IPC