The Design and Use of OhmegaPly[®]

Embedded Resistors for Series and Parallel Termination

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Introduction

The OhmegaPly[®] Embedded Thin-Film Resistor Material has been used since the early 1970's as terminating resistors in a variety of electronic systems. Through generations of digital designs, the shape, size and layout of the terminating resistors has evolved to meet the demands of increased IC density and the changing packaging architectures. This paper will review some of the earlier applications of OhmegaPly terminating resistors and describe the improvements made in the material to meet today's demanding requirements for high density PCB termination.

Proper signal-line termination reduces signal reflection, increases speed and performance and improves signal integrity. This is critical for high speed digital signals as it reduces trace, pad and via impedance and via stubs. (1)

OhmegaPly embedded terminating resistors can be placed very close to the end of the driveline, improving impedance matching and reducing line delay. Fig 1 and Fig 2 show typical design layouts for both series and parallel termination using OhmegaPly as embedded resistors in multilayer circuit boards. Unterminated drivelines and stubs are also reduced or eliminated and the inductive reactance is lowered when compared to discrete resistors. This is critical as the inductance of chip resistors combined with via inductance can seriously impact cross-talk as well as the leading edge of the high speed signal (2).



Figure 1. Parallel terminating resistors



Figure 2. Series terminating resistors

Design and Use of OhmegaPly Termination Resistors

OhmegaPly was used for terminating resistors in 1973 in the Tektronix 21 and Tektronix 31 desk top programmable calculators. The terminating resistor network was used at the end of a connecting cable that tied peripherals to the calculator. The resistor network consisted of fortyfour 120 ohm value resistors. Twenty-two resistors were on each side of a rigid double-sided FR4 substrate. OhmegaPly 25 ohm per square sheet resistivity product was used and the resistor dimensions were approximately 60 mils wide and 290 mils long (3).

A more sophisticated use of OhmegaPly for terminating resistors occurred a year later in 1974. Control Data's Aerospace (Military) group designed 100 ohm per square OhmegaPly into a multilayer board as parallel terminating resistors for ECL logic devices (Fig 3). The resistor design (Fig 4) had two elements in parallel extending from a common via. A 50 ohm value resistor was created by paralleling two-100 ohm value resistors and a 75 ohm value resistor was





Figure 3. Control Data PCB Board

Figure 4. A 75 ohm value made using 2- 150 ohm parallel resistors

created by paralleling two-150 ohm value resistors. Although this basic design was used on a number of part numbers, ultimately the design was changed to one resistor element using 25 ohm per square material in order to use less area for the terminating resistor footprint. Further generations of Cyber systems continued to use OhmegaPly for ECL logic termination. The use of OhmegaPly for ECL terminating resistors migrated to Control Data's commercial mainframe group and was designed into the Cyber 203 and Cyber 205 (4).

In 1980, Cray Research began to use OhmegaPly for parallel termination of the ECL logic used in the Cray 1 Supercomputer. Cray chose to incorporate the planar resistors on the voltage plane of an existing design using the same lead hole configuration used by discrete components. This enabled them to implement the use of OhmegaPly quickly and at minimum cost as only the 2.5V layer needed replotting. The initial 68 ohm value resistor design was 16.5 mils wide and 45 mils long using 25 ohm per square sheet resistivity product (Fig 5).

During the wave solder assembly process some resistors shifted up in value by a few ohms. This occurred sporadically. Although no apparent cause for this instability was seen, it was theorized that the resistor's closeness to the via (in some cases the end of the resistor element was only 2-3 mils from the edge of the via) resulted in the ohmic value shift due to the thermal/mechanical stress induced on the via during the wave solder operation. The resistor layout was redesigned to incorporate a thermal/mechanical isolation area between the resistor and the plated through hole (Fig 6).



Figure 5.

Figure 6.

A test was performed to evaluate the modified design. One hundred sixty-six resistors were subjected to six wave-soldering cycles. It was found that the average drift for the entire test was



only +0.3 ohm with a maximum drift of +1 ohm. (Table 1) (5).

Table 1.

Following generations of Cray Supercomputers (Cray XMP, Cray YMP, Cray 2) used OhmegaPly resistors with a thermal/mechanical connection of about 10-20 mils between the termination resistor and the via. With the advent of HDI and microvia technology, current recommendations are to use an approximately 10 mil connection of copper for mechanically drilled via's and approximately 5 mils for laser drilled microvias for thermal/mechanical stability. (Fig 7)



Figure 7.

In the 1990's, the basic design of the OhmegaPly terminating resistors remained the same while

application of the Technology began to grow, especially by Computer and Telecommunications companies. Some of the users were Harris (6), Sun Microsystems, Prime Computer, Data General, Wang, Sequent, IBM and Alcatel (7).

Greater I/O densities and the use of BGA packages became common within the Electronics Packaging Industry. The space constraints of these packages generated growing interest in embedded termination resistors. Standard thin film design rules created resistors that were either partial squares, squares or multiple squares of resistive material.

A study was done in 1995 to evaluate the stability of various alternative resistor footprints for BGA termination (8). A four layer FR4 test board was built with these designs incorporated into the voltage plane (layer 2) in a parallel termination scheme (Fig 8). This was done to aid in the testing of the embedded resistors, with one side of each resistor tied to the common voltage plane.



Figure 8.

The resistor designs included rectangular (Fig 9) and circular resistors (Fig 10).



Figure 9.

Figure 10.

Subsequent testing of the resistors showed that the rectangular-shaped resistors had better

stability than circular resistors when subjected to a variety of environmental conditions (Table 2).

Test condition	Rectangular	Circular	Circular	Circular
	50 Ω	11Ω	30 Ω	110 Ω
1) Short term load testing	700 mW	500 mW	350 mW	350 mW
2) Solder float 260 °C , 20 sec per cycle.4 cycles	0.15%	0.30%	0.90%	0.75%
3) Humidity test 240 hrs. at 95% RH 40 °C	0.20%	0.30%	0.75%	0.65%
4) Life operating, 26mW, 45 °C ambient 1,000 hrs.	0.10%	0.80%	1.25%	1.80%

Table 2. Percent increase in resistance value

Although a number of factors contribute to resistor stability, it was speculated that circular resistors are subject to greater physical stress than rectangular resistors due to their proximity to

the interconnect via. The dynamic movement, or stress, of the PCB in the X, Y and especially Z axis is greatest around the plated through via. This stress is most pronounced during thermal and humidity excursions where the expansion rates of the dielectric material, inner layer copper planes and plated through copper vias cause mismatched material movements. Further, the heat distribution (and power density) of a circular resistor under load is not uniform as the heat is concentrated in the inner area of the resistor, near the via.

As the embedded resistor footprints became smaller and more narrow it was important to determine how much the smaller size and narrower width limited the current carrying capacity as well as their susceptibility to electrostatic discharge (ESD). In 2001, Delphi Delco Electronics Systems tested a number of new and developmental thin and thick film resistive materials for susceptibility to ESD. OhmegaPly was selected for use as the benchmark material because of its history of reliability and thermal and electrical stability. OhmegaPly was found to be ESD stable throughout the voltage range from 2 kV to 8 kV and resistors widths as narrow as 10 mils. It was the only thin film resistive material to pass this test. OhmegaPly is typically 4-10 times thicker than other thin film resistive alloys of similar sheet resistivities. This results in greater power carrying capability and a greater stability in ESD testing (9).

A study was done in 2001 to determine the effect of miniaturization on embedded terminating resistors relative to their rated power. It found that 16 mil wide resistors were able to dissipate between 200 and 300 milliwatts at 40C. Since terminating resistors operated well below this

power, it was determined that much narrower resistor widths could be used. Resistor widths of 10 mils became a common Industry practice (10).

The evolution to greater I/O densities and routing constrictions made it very difficult, if not impossible, to embed termination resistors in the logic plane of the PCB under the BGA package. Clearly another strategy needed to be employed.

In 2004 Ohmega Technologies, Inc. developed a new product, ORBIT[®], specifically to meet this challenge. ORBIT was a ten ohm per square sheet resistivity thin film material which allowed termination resistors to be built within traces and eliminated the requirement for designing a resistor footprint and placing them within the circuit layout (11) (Fig 11).



Figure 11.

Because ORBIT was much thicker than other OhmegaPly sheet resistivites, its power dissipation was greater, about 25% more than 25 ohm per square material (Table 3).



Table 3.

ORBIT also had a tighter material tolerance than the higher sheet resistivity products--3% versus 5% for 25 – 100 ohm per square sheet resistivities. These were critical parameters for the formation of very small resistor elements that could handle the rated power and tolerances required for termination resistors. The ORBIT product was processed like the other OhmegaPly sheet resistivity products. Since the resistors were built within the trace, any board shop with the capability of building controlled impedance traces could build ORBIT termination resistors.

Currently, the ORBIT technology for series termination resistors is used by a number of computer, medical and telecommunications equipment manufacturers. Other applications for ORBIT have also become popular, especially as heater elements in flexible circuits (OhmegaFlex[®] heaters) and in R-Card arrays for military/aerospace applications.

Greater circuit densities and smaller feature sizes have driven ORBIT termination resistors to even smaller dimensions. Resistor widths of 3 mils and less are not unheard of. In order to maintain acceptable resistor tolerances, state of the art imaging and etching has become more popular, in particular with the use of LDI (Laser Direct Imaging). LDI has the advantage of allowing for near perfect registration for the second imaging that defines the resistor length. This means that the overlap of photoresist can be smaller and resistors can be placed closer to other circuit layer features (Fig 12).



Figure 12.

One current application for OhmegaPly ORBIT requires small element sizes (6 mil wide x 10 mil long) on an inner layer of a relatively large circuit board (14" x 15"). These resistors have a rated power of 125 mW. The unique design requires 3 resistor elements in series (Fig. 13).



Figure 13.

The board shop manufacturing these boards is achieving close to a 100% OhmegaPly resistor layer production yield for this application with a resistor tolerance requirement of +/- 10%. Both the first image (defining the resistor width) and second image (defining the resistor length) are done using LDI.

<u>Summary</u>

After decades of excellent performance within critical military/aerospace applications (satellites, fighter aircraft, missiles, control circuits) OhmegaPly remains the embedded material of choice for most termination requirements. Currently OhmegaPly is being used for termination requirements in a broad and diverse number of applications including space exploration, telecommunications, cellular, medical and industrial electronics.

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