Ohmega-Ply® Resistor Tolerance

When 15% Is Better Than 1%

Printed Circuit designers have begun to increasingly use Ohmega-Ply Planar Resistor Technology in their multilayer circuit designs, especially for termination and pull-up resistors. In most cases, Ohmega-Ply replaces chip resistors that have tolerances of 1-2%. In most cases, the Ohmega-Ply resistors have a final tolerance of 10-15%. While this tolerance difference is a concern to many designers, it does not accurately compare the ACTUAL tolerance of using chip resistors vs. Ohmega-Ply buried resistors.

Surface-mount, or thru-hole, resistors normally come only in specific set values, which from the onset may not provide a perfect termination value. For example, if the line termination requirement is 50 ohms, and the available discrete resistors initial tolerance was 2%, then the actual tolerance for the line termination would be 8%.

In contrast, Ohmega-Ply resistor nominal values are determined by a simple ratio of the length of the resistor to its width times the sheet resistivity used. This allows for creation of any nominal resistor value. For example, if the line termination requirement is 48 ohms, and the Ohmega-Ply sheet resistivity used is 25 ohms per square, then 48 ohms/25 ohms per square = 1.92 squares. A resistor that is 1.92 squares would therefore equal a nominal value of 48 ohms. For instance, a resistor that is a 15 mils wide by 28.8 mils long rectangle would be the optimum 48 ohm value.

However, for termination of high speed digital signals, other factors are much more important than just the DC resistive tolerance. The two main ones are the thermal, overload and humidity effects on resistors (DC) and the inductance and capacitance of the resistive circuit (AC).

A comparison of typical resistor characteristics (DC) is as follows:

Resistor Type	**RTC**	**TS**	**HTE**	**STO**	**HUMIDITY**
	(ppm)	**%**	**%**	**%**	**%**
Ohmega-Ply (25ohm/square)	50	-0.5	0.1	0.0	0.5
Chip Resistor	100	+/-0.25	0.2	0.1	+/-0.4
Resistor Network	100	+/-0.25	+/-0.25	+/-0.25	+/-0.5

Note: RTC = Resistance Temperature Characteristics PPM/C
TS = Thermal shock -65 to +125 C
HTE = High temperature exposure (soldering)
STO = Short term overload
Humidity = 40 C at 95% RH, 240 hours

As can be seen in the above chart, the Ohmega-Ply resistors during normal exposure to soldering, use and storage conditions, tend to change their value much less than do discrete resistors. Long term changes tend not to be factored into many product designs.

The other factor is the inductance and capacitance of the resistive circuit (AC). This is the most critical factor when comparing Ohmega-Ply resistors to chip or discrete resistors.

A comparison of resistor characteristics (AC) for a 100 ohm value is as follows:

Resistor Type	**Series Inductance (nH)**
Ohmega-Ply	line impedance matching
Chip R (0603)	-25% of DC value
Chip R (0805)	-35% of DC value

Large discontinuities may exist when using discrete parts for termination of high speed digital circuits. This discontinuity will seriously impact cross-talk as well as the leading edge of the high speed signal.
Over the past few years there has been an evolution to chip resistors from thru-hole to discrete resistors for line termination. During this transition, the increasing frequency of the signals as well as the shorter rise times associated with these faster signals, has made the use of the thru-hole parts- as well as surface mount devices- an effective way of providing termination. This is due to the high inductance associated with the standard leaded and surface mount resistor packages. Listed below is a comparison of series inductance in a few resistor packages:

Typical Series Inductance of Resistors	
Resistor Type	**Series Inductance (nH)**
1/4W axial	2.5
1/8W axial	1.0
1/8W 1206 chip	0.9
Ohmega-Ply	<0.4

The inductance is reduced by using smaller packages. The least inductance is found in the Ohmega-Ply thin film metal alloy material.

In addition, the inductive reactance increases as the signal rise time increases. The chart below indicates the reactance change as the rise time decreases for a 1206 chip resistor:

Rise Time (ns)	**Inductive Reactance (ohms)**
1	2.82
.5	5.65
.25	11.3

Inductive Reactance was calculated using the formula: X(Tr) = 3.14 (LnH)/Rt
Reflection due to this inductance, if used on a 50 ohm line, will be 2X the above inductive reactance, or as much as 22.6 ohms with a .25 ns rise time. This assume as single pull-up resistor. If a split terminator is used, then the reflection will be cut in half to 11.3 ohms. Still a very significant value.

Vias required to connect both surface mount and thru-hole resistors are another source of inductance. Ohmega-Ply buried resistors require fewer interconnect vias than discrete parts and therefore reduce overall via inductance. The via inductance is in series with the component and adds inductance to the equivalent circuit. Via inductance is approximated by the use of the following formula:

L = 5.08h[ln(4h/d) + 1]
where L = inductance of via, nH
h = length of via, in.
d = diameter of via, in.

Since the equation involves a logarithm, changing the via diameter does little to influence the inductance. A large change may be effected by changing the via length. Via length is taken to be the effective length from the surface to the inner connection. Blind vias provide a low inductance path if the multilayer stack-up supports a short via length. Most high density designs involving BGA package termination that use buried Ohmega-Ply resistors use a blind via interconnect from the solder pad on the surface to the buried resistor on the signal or voltage plane in layer 2 or 3 below.

Normal vias with a diameter of .010" to .016" diameter and with a length of .012" provides an inductance in the 1 nH range. This inductance times 2 (for 2 vias) is added to the inductance of the resistor, giving about 3 nH per

connection. The inductive reactance of this combination of device and vias, using the equation $X_L = 3.14/T_{10-90}$ for a .3 ns rise time would be 31.4 ohms. A very significant number, especially in high speed digital designs.
In addition, resistor networks tend to have increased inductance due to their internal interconnect and external leads. Semiconductor packages with "built-in" termination have the disadvantage of having series inductance to contend with both inside of the package and in the lead inductance resulting in termination tolerances of 20 to 25%.
In conclusion, buried resistors can eliminate almost all of the inductance, and thus the reactance, normally associated with discrete resistors and their vias. An Ohmega-Ply buried resistor of 10%-15% will thus exhibit significant signal integrity improvements over chip and discrete resistors of a 1 to 2% tolerance.

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