Resistive transmission line terminators: The good, the bad, and the ugly

Operation to 20 GHz and beyond is possible with the new breed of chip and BGA packages

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With the explosive growth in high-speed digital applications, design engineers are increasingly faced with the critical challenge of maintaining signal integrity. Rise times, lossy conductors, dielectric constants, and ground planes are all important considerations in the design of fast digital circuits, but if the shape of the digital signal deteriorates, the other factors are moot.

The most widespread culprit in false triggering of digital thresholds occurs when the signal is distorted by reflections from improperly terminated transmission lines. Transmission line termination comes in two basic flavors—series and parallel—but both require that simple device—the resistor. So, let's determine resistor suitability for high-frequency transmission line termination by taking a look at some good, some bad, and some downright ugly resistor packages.

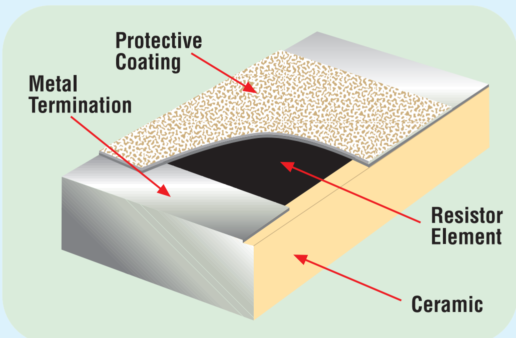

Fig. 1. The chip resistor is basically a planar device with metal wraparound terminations on the vertical chip ends.

The good: Chip resistors and BGAs

Surface-mount chip resistors are the most popular resistor packages today. Typical chip resistor construction is shown in *Fig. 1*. The chip resistor is basically a planar device with metal wraparound terminations on the vertical chip ends.

The chip resistor looks like a pretty simple package at first glance. But at gigahertz frequencies, the package begins to take on the personality of an inductor or capacitor. *Figure 2a* is a diagram of a chip resistor mounted on a pc board, much like a termination resistor would be mounted when terminating a microstrip transmission line on a pc board.

The series inductance associated with the wraparound terminations of the chip makes the chip behave as a large impedance at high frequencies. A shunt capacitor also exists across the resistor element between the two chip terminations, tending to lower the chip's impedance at high frequencies.

Either the parasitic capacitance or the parasitic inductance of a chip will dominate at high frequencies. In larger chips with higher-resistance values, the parasitic capacitance dominates. In smaller chip resistors using termination values in the range of 50 to 75 Ω, the device is typically inductive—the parasitic inductance is dominant.

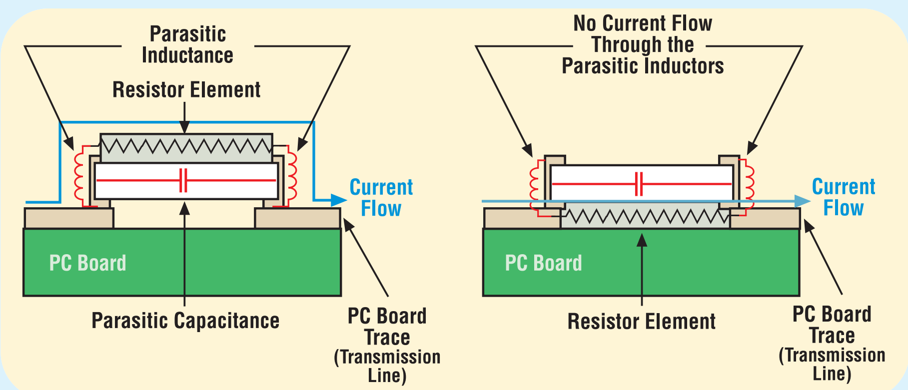

Fig. 2. Parasitic inductance and capacitance can create problems at gigahertz frequencies for a chip resistor mounted normally to a pc board (a). Mounting the part resistor-side down eliminates the bulk of the series inductance (b).

At first glance, it may appear that a design engineer can do nothing to reduce the parasitics of a resistor chip terminator. But recall that most of the chip inductance is due to the chip's wraparound terminations. If the wraparounds can be taken out of the current path, the inductance will be reduced.

A simple technique used to eliminate the bulk of the series inductance of the chip is to simply flip it over when mounting it on the pc board. When mounted resistor side down, the series inductance in the current path is eliminated as shown in *Fig. 2b*. When a chip resistor such as IRC's PFC series is mounted resistor side down, it functions well as a terminator to beyond 6 GHz.

For high-density applications such as high-speed switch backplanes, arrays or networks of resistors are used for termination of multiple high data rate digital lines. The elimination of wraparound terminations enables excellent frequency performance up to 20 GHz and beyond in high-speed termination applications (see *Fig. 3*).

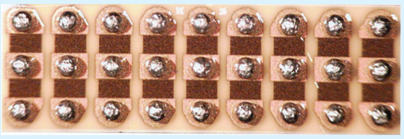

Fig. 3. The elimination of wraparound terminations—as in this BGA resistive termination array—enables excellent frequency performance up to 20 GHz and beyond in high-speed applications.

The bad: Wire-bonded packages

Wire-bonded plastic packages prevail for use with resistor arrays and networks. These packages typically use very-small-diameter (0.001-in.) gold wire to connect the resistor die to the lead frame inside the package. The inductance of a length of wire is inversely related to the diameter and is higher for a small diameter wire of given length than for the same length wire of larger diameter.

Inductances of 1 to 2 nH are common for bond wires. The bond wire inductor looks like an open circuit at high frequencies. As the frequency increases, the resistor rises in impedance. Wire-bonded resistor packages are generally limited to use below 500 MHz, although with careful attention to the design of the die, and keeping the wire lengths as short as possible, it is possible to extend the usable range of these packages for termination applications to 1 GHz.

The ugly: Wirewound and spiral trimmed axial resistors

Axial resistors may be through-hole and have lead wires attached to the end terminations as shown in *Fig. 4* or they may be the nonleaded MELF style. Axial thin-film resistor packages are constructed using a cylindrical ceramic onto which the thin film resistor material is deposited and then laser trimmed to the desired resistance value.

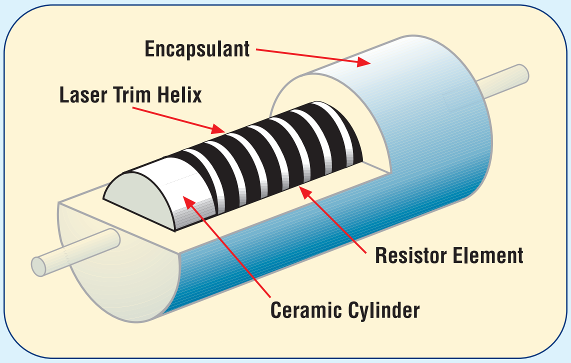

Fig. 4. Constructed using a cylindrical ceramic onto which the thin-film resistor material is deposited and then laser trimmed, axial thin-film resistors can have a parasitic inductance of more than 0.1 µH and an impedance of more than 600 Ω at 1 GHz.

Axial wirewound resistors are similar in construction to *Fig. 4* except that the spiral current path is wound on the ceramic cylinder using wire instead of resistive film. These resistors look and act like inductors at high frequencies. In fact, depending on the sheet resistance of the resistor film, a typical 50-Ω axial, laser-spiraled film resistor can have a parasitic inductance value of more than 0.1 µH and an impedance of more than 600 Ω at 1 GHz. Of course, an impedance mismatch of this magnitude would create serious signal integrity problems for most high-frequency wave shapes. EP