BGA Termination Alternatives

*Planar resistor technology offers
both design flexibility and proven reliability.*

Bruce Mahler, Ohmega Technologies, Inc., Culver City, Calif.

The space constraints of high-density BGA footprints have generated widespread interest in planar resistor technology (PRT). Standard thin film design rules are used to create resistors that are either partial squares, squares or multiple squares of resistive material. Standard series and parallel termination resistors have therefore been mostly rectangular in shape.

The manufacture of both "dogbone" and "elbow" resistors (Fig. 1) for high-density series and parallel termination of BGA devices was allowed by planar resistor technology. PRT resistors can be subtractively printed and etched with very small features and good resistor tolerance. Other design configurations have been investigated as well, and circular resistors were conceived as a method of minimizing required resistor area in the circuit design.

Planar resistor technology has been used in a variety of electronic circuits for more than 22 years. In high-end computer systems, PRT has been used as termination and pull-up resistors, the resistor elements buried on an inner layer of multilayer circuit boards. In consumer electronics applications such as 35 mm cameras, PRT has been designed as potentiometer circuits that replace polymer thick film material on ceramic for better electrical performance (noise-free, low TCR, excellent long-term stability), greater reliability and lower costs.

In millions of circuit boards and trillions of component hours of operation over the past two decades, the reliability of PRT resistors has been excellent. There have been no reported field failures due to inherent resistor film characteristics.

Termination resistor evaluation

Dogbone and elbow resistors have an advantage over circular resistors — they can be incorporated into the BGA footprint itself. In 1995, Ohmega Technologies initiated a test program to evaluate dogbone, elbow, and circular resistor designs for termination resistors, in which a number of circuit board houses participated by building a test board. The board was a four-layer FR-4 multilayer, with the resistors incorporated into the voltage plane (layer 2) in a parallel termination scheme (Fig. 2).
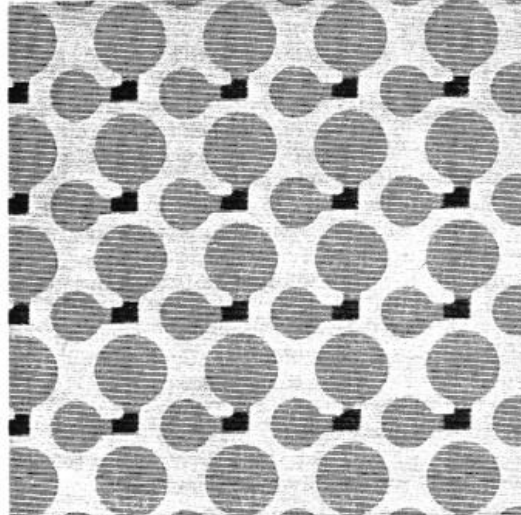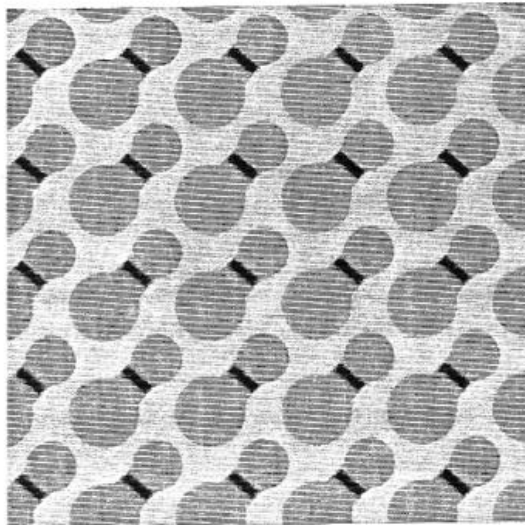

Figure 1.
Dogbone resistors (left) and elbow resistors (right) can be incorporated into the BGA footprint.

A study was conducted to see what tolerances could be achieved without resistor trimming

This was done to aid in the testing of the buried resistors, with one side of each resistor tied to the common voltage plane.

A variety of sheet resistivities were tested, with the focus on termination resistors in the 20 to 100 V range. Twenty-five V/sq sheet resistivity material was used for resistor features typical of both the dogbone and elbow shapes, with a corresponding resistor value of 50 V. Sheet resistivities of 100 V/sq, 250 V/sq and 1,000 (1K) V/sq were tested with corresponding circular resistor values of 11 V, 30 V and 110 V. Some of the test conditions and results of the testing are shown in Table 1.

Rectangular-shaped resistors (indicative of dogbone and elbow resistors) show the greatest stability when subjected to the various environmental conditions listed in the table. Although a number of factors contribute to resistor stability, it is 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 printed circuit board in the X, Y and especially z axis is greatest around the plated through hole. This stress is most pronounced during thermal and humidity excursions where the expansion rates of the dielectric material, inner layer copper planes and electrodeposited through-hole copper via cause mismatched material movements.

Since the tolerance of etched resistors is critical in most applications, a study was conducted to see what tolerances could be achieved without resistor trimming, in both dogbone and elbow resistor designs. Many years of processing rectangular resistors show that excellent tolerances can be obtained with standard subtractive processing. A two square, planar 50 Ω termination resistor, of a standard 20 mil by 40 mil size, can be subtractively etched to a tolerance of 10 percent without trimming.

Figure 2.
A four-layer FR-4 multilayer test board incorporated dogbone and elbow resistors into the voltage plane.

Table 1. Percent Increase in Resistance Value

Test condition	Rectangular 50 Ω	Circular 11 Ω	Circular 30 Ω	Circular 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%	0.3%	0.9%	0.75%
3) Humidity test 240 hrs at 95% RH 40°C.	0.2%	0.3%	0.75%	0.65%
4) Life, operating, 26mW 45°C ambient 1,000 hrs.	0.1%	0.8%	1.25%	1.8%

Data from one volume manufacturer of an 18×24 in. test panel with 700 termination resistors is typical (Fig. 3). The panel was the first panel of planar resistor material that was processed at their facility. Over 30 percent of the resistors were within 1 percent of nominal; over 60 percent were within 2 percent of nominal and over 98 percent were within 5 percent of nominal. Overall tolerance was 6.5 percent of nominal.

Resistor tolerance evaluation

In the case of high-density BGA termination, the dimensions of the resistors would, in most cases, be smaller than the traditional rectangular resistors used in past and current applications of PRT. Therefore, a second test program was undertaken to evaluate the resistor tolerance that could be achieved for both the dogbone and elbow resistor configurations.

Distribution Cure (20 x 40 mils, 2sq)

Avg: 44.01
Max: 46.7
Min: 41.81
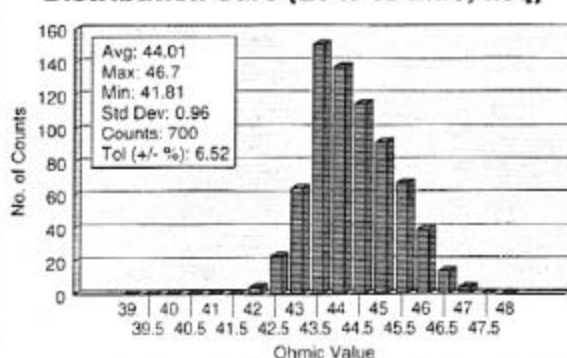Std Dev: 0.96
Counts: 700
Tol (+/- %): 6.52

Figure 3. Typical test results from an 18x24 in. test panel with 700 termination resistors are represented in this data, gathered by one volume manufacturer.

Data showed very good uniformity of resistor values for both dogbone and elbow resistors

A 64 resistor (8×8) array, laid out on 50 mil centers, was created for each resistor design. The arrays were stepped and repeated for a 100 up pattern on a 7×7 in. circuit board area (50 arrays of the dogbone design and 50 arrays of the elbow design). The total number of resistors were 64 times 100, or 6,400. Of this number, 3,200 were dogbones and 3,200 were elbows.

The dogbone resistor was a partial square design, the resistor being defined as 10.5 mils wide and 3.5 mils long (0.33 squares). The elbow resistor was a corner/multiple square design whose width was 5 mils and, when the corner effect of the resistor was considered, defined a 1.3^2 value resistor. To minimize process variations, the resistive material used was of 25 Ω/sq sheet resistivity on a ¼ oz. weight copper foil (9 μm thick copper). The ¼ oz. copper was available on a 2 oz. copper carrier, which was peeled off by the circuit board shop prior to processing.

Manual resistance measurements were made on approximately one-third of the total resistors on the circuit board, or 960 of each resistor shape, for a total of 1,920 readings. Due to probe damage of a few of the resistor elements (accidental scratching during measurement), the total number of readings used in the analysis was 952 of the dogbone and 956 of the elbow.

The data showed very good uniformity of resistor values for both the dogbone and elbow resistors. The fact that the dogbone resistors had a better overall tolerance than the elbow resistors was a surprise, since it was believed that the opposite would be true. This was based on the fact that the dogbone resistors, being only 3.5 mils long, would have the most variation due to imaging and process etch variations. However, it was speculated that since the dogbone resistors were 10.5 mils wide and the elbow resistors were 5 mils wide, the importance of the primary, or first, print and etch in defining the resistors was more critical than the second print and etch. Also, the thin ¼ oz. copper foil tended to minimize under-
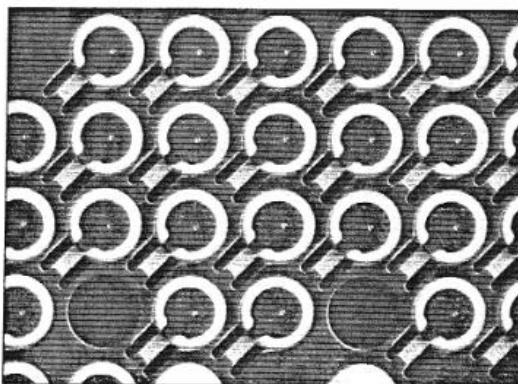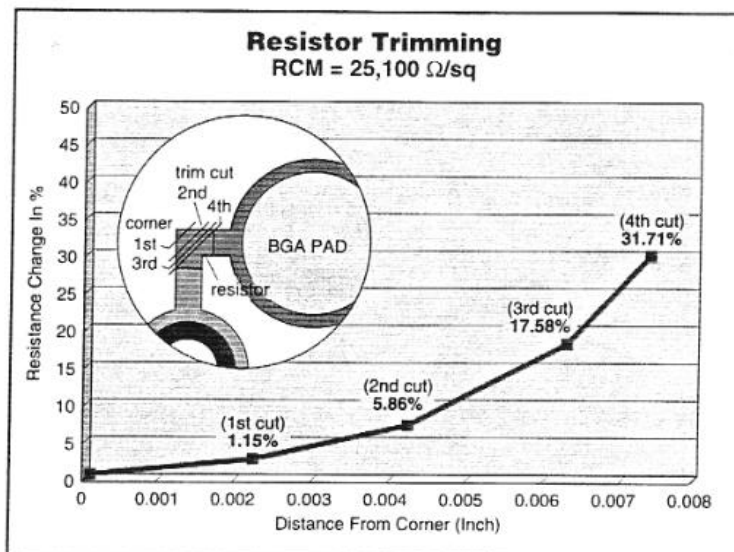

Figure 4.
Tolerances of less than 10 percent as printed and etched can be maintained by this resistor design.

Resistor Trimming
RCM = 25,100 Ω/sq

Figure 5.
A test to determine the effects of trimming on resistor value showed the value increase of the trim to be both predictable and repeatable.

cut variation and tenting of the photoresist during the second photoimaging and etch. A summary of the data obtained from this experiment is shown in Table 2.

There are a number of OEMs currently designing PRT into products that utilize BGA technology. These BGAs are mostly 40 and 50 mil pitch and use PRT technology for either series or parallel (or both) termination requirements. Most of these designs have been able to use either elbow resistors that are much wider than those in the test program, with line widths around 10 mils, or a more traditional rectangular resistor of 10 mil line widths (Fig. 4). Both resistor designs can maintain tolerances of less than 10 percent as printed and etched.

Table 2. Tolerance Evaluation Data	Dogbone resistor	Elbow resistor
Number of resistors:	952	956
Average value:	7.0 Ω	37.2 Ω
Standard deviation:	0.23 Ω	1.46 Ω
Overall tolerance:	9.26%	11.78%
# resistors within 1% of nominal:	229 or 24%*	185 or 19%**
# resistors within 2% of nominal:	454 or 48%	348 or 36%
# resistors within 5% of nominal:	852 or 89%	756 or 79%

*Of total dogbone resistors
**Of total elbow resistors

PRT presents minimal technological risk

Resistor trimming

Another aspect of PRT is its ability to be trimmed using standard thin film trim technologies. That is, the PRT material can be laser, mechanically or abrasively trimmed to tolerances of 1 and 2 percent, if required.

In analog applications, PRT circuits are trimmed to a 1 percent tolerance. Due to the high-volume throughput of analog circuits, the resistor trimming (both mechanical and laser) is highly automated. Being a thin film metal alloy, the PRT material does not have kerf formation after trimming (as is the case with polymer thick film materials), nor does the resistance value drift before becoming stable.

In most digital applications, trimming has not been necessary since most PRT resistor designs can be produced by the circuit board shops with tolerances of less than 10 percent. This has been found to be acceptable for most termination, pull-up and isolation applications to date. Further, trimming of circular and dogbone resistors is either very difficult, or impossible, due to their very small feature size (in the case of dogbone resistors) and the path of current flow (in the case of circular resistors).

The elbow resistor shape, however, is a modi-fied rectangular-shaped resistor and could potentially be trimmed if the resistor footprint was large enough. A test was performed on the elbow resistor design to determine the effects of trimming on resistor value. The trim cuts (Fig. 5) started from the outside corner of the resistor and progressively worked their way "into" the resistor body towards the opposite corner. This was found to be the easiest way to mechanically trim the resistors by hand. The data showed the resistor value increase of the trim to be both predictable and repeatable, regardless of the ohmic value sheet resistivity used.

Overall, the tests demonstrated that PRT is an effective resistor technology for high-density BGA termination requirements. Test results showed that both the dogbone and elbow resistor footprints were superior to the circular resistors from a power and long-term stability standpoint.

The flexibility of resistor design, coupled with the electrical and physical properties of PRT, make it a key technological tool. Furthermore, with over two decades of field use, PRT has both the long-term reliability and breadth of applications that make it a minimal technological risk for the design engineer. **EP&P**