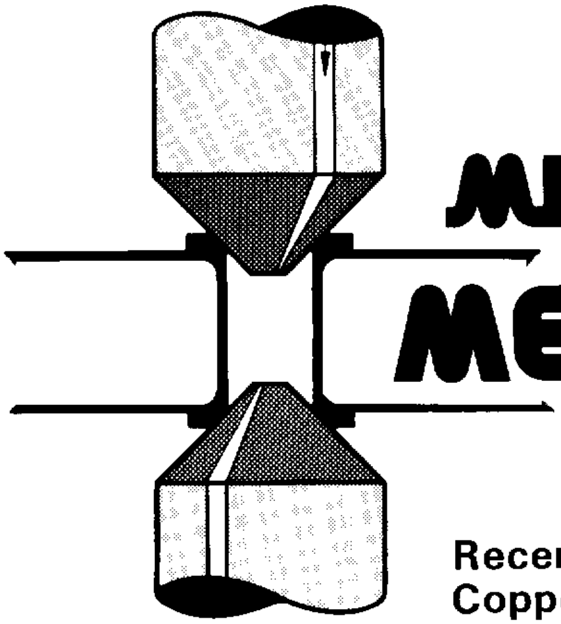

MICRORESISTANCE MEASUREMENT TECHNIQUES

Recent Advancements In PWB Through-hole Copper Thickness Measurement Technology

Michael D. Stebel, UPA Technology, Inc.

With today's high-density electronic packaging, the failure of even a single printed wiring board through-hole can be catastrophic. For this reason the need to test through-hole copper for proper thickness and integrity has become widely recognized by manufacturers and users of printed wiring boards.

Fast and accurate nondestructive techniques are preferred over time consuming and wasteful destructive methods, especially since it is important to test as many plated through-holes as possible without adversely affecting productivity.

Microresistance Method

The most widely used and respected nondestructive technique for through-hole copper thickness measurement is the microresistance measurement technique.

This technique is based on the principle that once one has accurately measured the precise resistance of the cylinder of copper that lines a through-hole of known dimensions, then the average thickness of the copper may be accurately determined from the following relationship:

$$R = \frac{K\rho T}{\pi t(D+t)}$$

where R = measured resistance in microhms
ρ = specific copper resistivity (1.69 microhm-cm)
T = thickness of PWB laminate
K = units conversion constant
D = ID of hole
t = copper plating thickness

The 4-point method for measuring through-hole copper resistance of such small magnitude has been known for some time. Explained in general terms, a precisely controlled current is applied through the cylinder of copper with one set of electrodes. The potential difference or voltage drop that develops across the hole is then picked up by another set of electrodes, electrically isolated from the others, and sent to the electronic unit where it is translated into resistance by Ohm's Law:

$$R = \frac{E}{I}$$

where R = resistance
E = voltage drop
I = current

Advances in 4-point Probe Design

In order for through-hole copper thickness to be accurately determined from the equation in Fig. 1, the microresistance measurement must correspond to the theoretical resistance of the copper cylinder. Because of this consideration, probe design is critical. The probe must be designed in such a way so as to distribute the current uniformly through the copper cylinder and detect the voltage drop which results.

Early probe designs utilized current-injection contacts which made essentially only point contact with the copper plated through-hole. This resulted in a nonuniform distribution of current, producing current and voltage gradients which not only flowed through the copper cylinder but also through the copper pads. Resistance measurements obtained from these probes did not correspond to the theoretical resistance of the copper cylinder, and conversions of microresistance to copper thickness could only be accomplished using empirically derived tables or charts. In addition, corrections for pad size were often necessary.

An important advancement was the introduction of conical probe contacts, that are still the basis of current probe design. As shown in Fig. 4, the cones are divided into two sections. The larger of these sections injects current around approximately 315°, or 85% of the copper cylinder. The remaining sector contains the electrically isolated voltage pickup contacts which actually need only make point contact with the edges of the through-hole. These sector electrodes are located 180° apart from each other. The result of this configuration is the uniform distribution of current and accurate resistance measurements which are not affected by pad size and correspond to the theoretical resistance of the copper cylinder. Copper thickness may be determined using the equation in Fig. 1 and excellent correlation with microscopic cross section measurements is experienced.

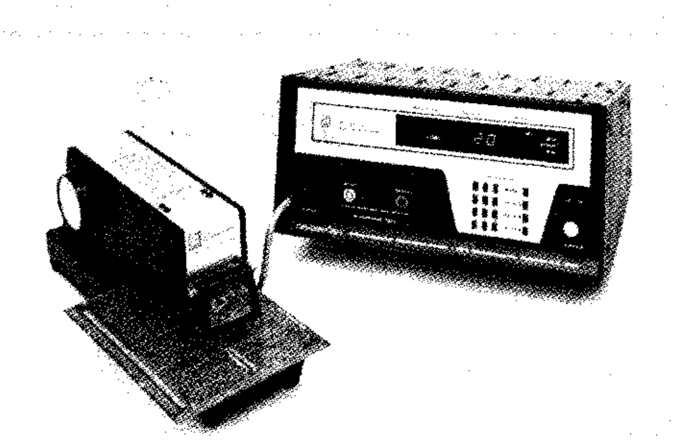

FIGURE 3. Advanced, computerized measurement system.

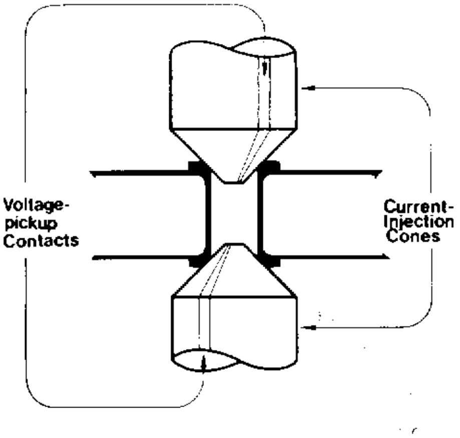

FIGURE 4. Conical probe configuration showing current injection and voltage pickup contacts.

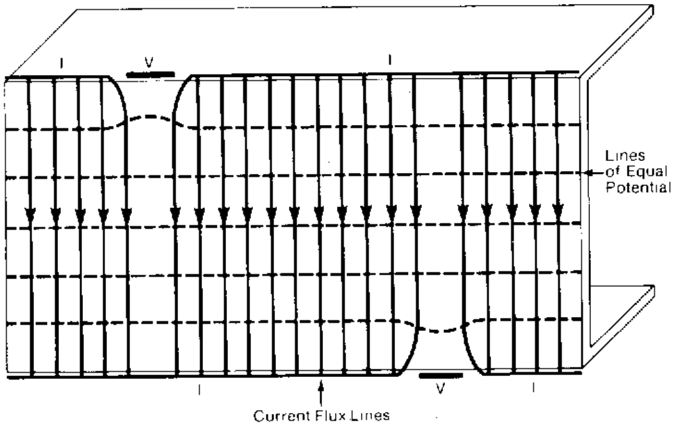

FIGURE 5. Flattened-out representation of through-hole plating showing the uniform current distribution with advanced conical probes.
I = areas of probe current injection
V = areas of probe voltage pickup

Fig. 5 is a flattened-out representation of a copper-plated through-hole showing the areas of current injection (I) and voltage pickup (V). Current flow and direction is represented by the vertical lines and the resulting lines of equal potential are represented by the dashed horizontal lines (which are always perpendicular to the lines of current they cross). The uniform current distribution realized with conical probes is graphically demonstrated in this diagram.

The original probes of this configuration were subject to rotational variations caused by probe tip misalignment or holes not perpendicular with respect to the plane of the printed wiring board. In these circumstances it was necessary to obtain the average of several measurements taken on each hole before converting to copper thickness. This problem has been eliminated with the introduction of "floating" contacts which essentially self-align with respect to the edges of the hole and ensure uniform current injection. This advancement eliminated significant rotational variations, as well as eliminating the need for frequent probe tip alignment and thereby reducing maintenance costs. The need for several measurements per hole was eliminated and testing time was reduced.

Because of the fixed 6 inch (15, 2cm) throat depth with these tabletop probe systems which limits the width of PWB's that can be tested to 12 inch (30, 5cm), and because of the industry's need for a low-cost alternative to these sophisticated probe systems, hand-held probes have been developed. Such probes are low in cost and allow measurements to be made on very large boards such as those used in the computer industry; however, they are somewhat more operator-dependent with respect to positioning. These probes can be very accurate providing that they are positioned properly and that they satisfy the same current distribution requirements as set forth above. There are presently two hand-held probe designs currently on the market.

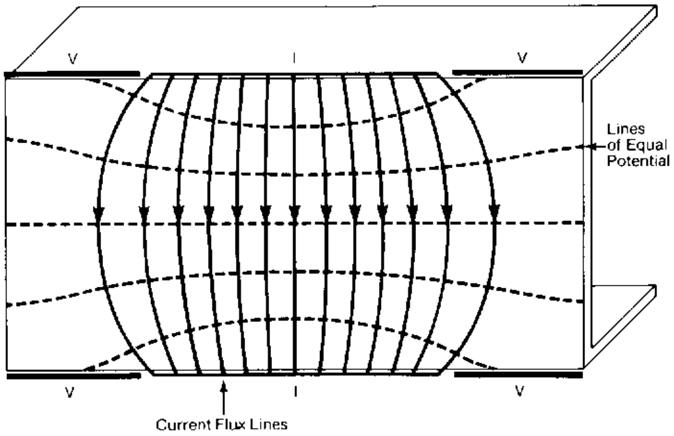

FIGURE 6. Flattened-out representation of through-hole plating showing the nonuniform distribution of current with "split-cone" type probes.
I = areas of probe current injection
V = areas of probe voltage pickup

One such design utilizes conical probe tips split into two equal halves. This "split-cone" probe design provides current injection only around 180° of the hole's perimeter. The voltage drop is sensed by the other half of each cone.

As shown in Fig. 6, the current distribution is nonuniform. There is an appreciable fanout of current around the circumference of the hole and into the pad areas; thus, the measurements obtained with this probe must be corrected for pad size. Due to the current gradients induced in the through-hole, the voltage drop varies considerably around the hole. This probe design, therefore, suffers from poor accuracy, and correlation with microscopic cross section measurements is not regularly experienced.

Recently, a greatly improved hand-held probe design was introduced which provides extremely accurate measurements. As shown in Fig. 7, this probe also features split cones. However, both cone halves perform the current injection function. An electrically-isolated voltage "spear"

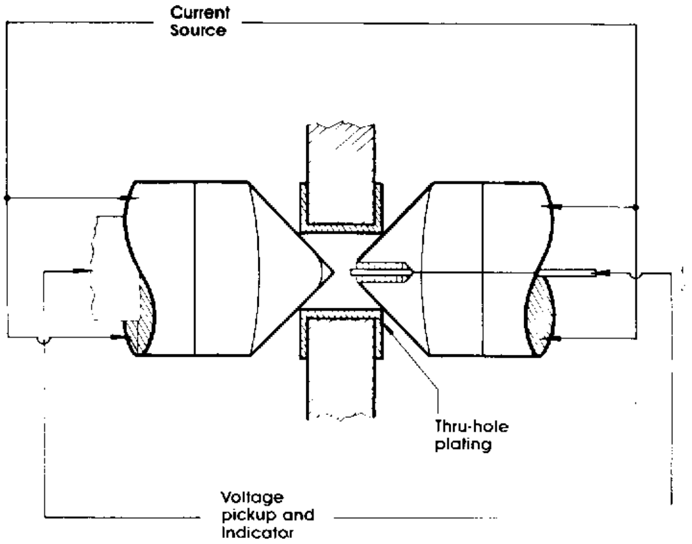

FIGURE 7. Advanced hand-held probe configuration showing current injection and voltage pickup contacts.

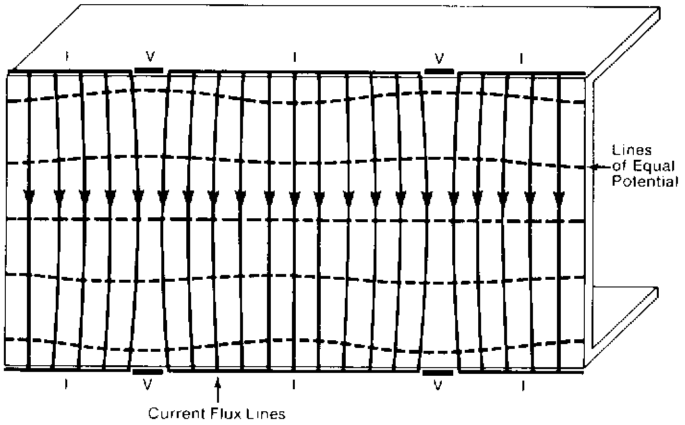

FIGURE 8. Flattened-out representation of through-hole plating showing the uniform distribution of current with advanced hand-held probes.

I = areas of probe current injection
V = areas of probe voltage pickup

contact sandwiched between the two cone halves detects the voltage drop across the through-hole at two opposite points on each side of the hole. Thus, the average potential difference is accurately detected. As shown in Fig. 8, current distribution is extremely uniform and measurements are completely independent of pad size. With these probes, as with the table-top probe shown in Fig. 3, the resistance measurements correspond to the theoretical resistance of the copper cylinder and the micro-resistance-to-copper-thickness conversions can be accomplished using the theoretical formula in Fig. 1. Excellent correlation with microscopic cross section is once again realized. Fig 9 shows these hand-held probes in position on a printed wiring board.

Advances in Instrument Design

The design of the basic electronic unit is also critical to the accuracy, reliability and simplicity of this measurement technique.

One such consideration is the influence of extraneous electromagnetic interference on the resistance measurements. The instrument must also be calibrated to a known reference resistance standard and supply a precisely controlled current to the probe system.

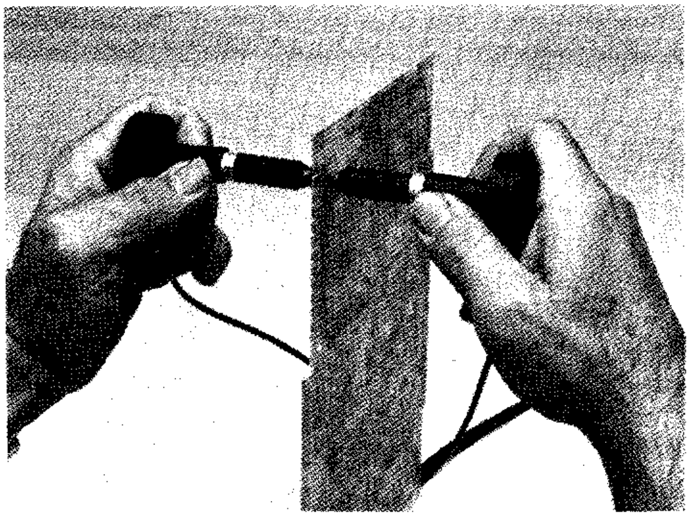

FIGURE 9. Advanced hand-held probes in position in a PWB through-hole.

Instruments of older design are still being used with acceptable results. These instruments supplied a small constant AC current (approximately 250 milliamps) to the probe. As the magnitude of the currents and voltages involved was very small, the accuracy of the measurements was often affected by inductive pickup from local electromagnetic fields caused by nearby power supplies, lights and other electrical equipment. Additionally, the inherent noise in the 60Hz signal made accurate measurements impossible under 70-80 microhms. While this is a minor limitation for most through-hole copper measurements, it does present problems when testing through-holes in very thin flex circuits where resistances may range from 10-50 microhms.

To eliminate these problems, advanced instruments such as the one shown in Fig. 3 use pulsed DC current rather than alternating current to eliminate the effects of electromagnetic interference. Using short-duration pulses of relatively large current (5 amps), accuracy is enhanced and since the average current in the through-hole is only 20 milliamps, no damage is done to the copper. These instruments are self-calibrating, requiring no user calibration and provide high-precision measurements to the nearest microhm unit. These instruments are, therefore, readily used by unskilled personnel.

Resistance-to-copper-thickness conversion with these units must be accomplished using a special slide rule. To use the slide rule the hole's inside diameter, board thickness and measured microresistance are entered. The slide rule, based upon the relationship of Fig. 1, then provides the through-hole copper thickness.

Very recently, a microprocessor-based instrument was introduced as shown in Fig. 3. This instrument automatically computes and displays the copper thickness from its resistance measurements and user-entered inside hole diameter and board thickness.

The user enters the above data through a data entry keyboard on the instrument's front panel. After the PWB under test has been properly positioned in the probe, the instrument instantly displays the computed copper thickness. This instrument features a nonvolatile memory for retaining the most recently entered through-hole dimensional data.

An additional feature is an ACCEPT/REJECT audio-visual indicator system. The user enters, through the data entry unit the minimum copper thickness which will meet his specification. The instrument then provides a green ACCEPT light on good holes and a red REJECT light along with an audio signal on holes which are under specification. This further reduces testing time and significantly increases productivity.

Applications and the Meaning of the Measurements

The microresistance technique is particularly suited for the measurement of through-hole copper thickness in finished or tin-lead-coated PWBs. The intrinsic capability of this technique to effectively "see through" tin-lead can be explained by noting that tin-lead has approximately one-tenth the electrical conductivity of copper. Therefore, the tin-lead appears to be only one-tenth of its actual thickness in the copper thickness measurements - an influence which is generally small enough to be ignored.

Only electrically-parallel holes cannot be tested with this technique. Such holes are defined as being electrically connected on both sides of the board, thus giving the probe current an alternate path. Such a condition is found on in-process PWBs. The microresistance technique can still be employed; however, the holes to be tested must first be electrically isolated.

With the advanced probe and instrument designs described above, the nondestructive copper thickness measurements consistently correlate with those of microscopic cross section. The limitation of microsectioning technique, in addition to the time required, its destructive nature, etc., is its inability to indicate the over-all condition of the hole. Only the copper in one plane of view can be observed. By contrast, as microresistance measurements correspond to the average copper available to carry current, the over-all condition of the copper plating is, indeed, indicated. In addition, as voids or cracks reduce the plating's current-carrying capability and increase its resistance, the microresistance technique is capable of detecting the presence of such defects. Significant defects will be indicated by unusually low copper thickness readings.

Conclusion

Recent technological advances have greatly enhanced the accuracy and reliability of the 4-point microresistance technique for through-hole copper thickness measurement. The development of microprocessor-based instruments coupled with improved probe design, makes this technique an ideal alternative to costly microscopic cross section analysis. □

UPA Technology, Inc.
60 Oak Drive · Syosset New York 11791 · (516) 364-1080 · Telex 14-3115

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