Method for Evaluating ICT Probe Penetrability of Flux Residues

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Abstract

As printed wiring boards become increasingly densely populated, more ICT probing is being done on SMT soldered connections that may be covered with flux residues. These flux residues will physically block the ICT probe from making electrical contact unless the probe can penetrate the residue. The ease of ICT probe penetrability depends on several factors, including the probe pin force and tip shape; the size and shape of soldered pad contacted; the solder paste used; and solder reflow conditions. A methodology has been developed to evaluate ICT probe penetrability for a variety of conditions. An automated dispensing machine was modified to provide an accurate x-y table with a z-axis head and vision system for a “flying probe” penetrability tester capable of making thousands of ICT probes in under 20 minutes. The resistance of each probe the ICT pin makes is measured using a computer data acquisition system. After the testing, the ICT probe is examined microscopically to determine if flux residue adheres to the pin after making thousands of probes.

ICT pin probe-ability was studied for various solder pastes, reflow conditions, solder pad shapes, and ICT probe tip shape and pin force. This new methodology effectively differentiates between conditions that are difficult to pin test in practice and those that are easy. Newer no-clean solder pastes with soft flux residues are easier to probe than older, high-residue RMA-type solder pastes, as expected. Hotter and longer reflow profiles make flux residues harder and more difficult to probe. ICT probes with high pin forces probe tough flux residues better than probes with low pin forces, and some tip shapes probe flux residues better than others do. Pads with vias, where flux residue gets trapped, are much more difficult to probe than flat pads. By using this test method, solder pastes can be evaluated for ICT probe penetrability during product development and electronics manufacturers can evaluate solder paste, reflow conditions and ICT probe combinations to optimize pin testing.

Introduction

Electronic devises, such as hand-held mobile phones, portable computers and personal organizers, continually get smaller, and, hence their printed wiring boards are also smaller and increasingly densely populated with components and soldered connections. With little board space available, In-Circuit Test, (ICT) pin probing is sometimes done on surface mount technology (SMT) soldered connections that may be covered with solder paste flux residue. Additionally, increasing interest in Pin-In-Paste reflow of through hole connectors has created a need for probing through-hole pins through flux residue. This flux residue may form a brittle or tough film on the soldered joint, preventing the ICT probe pin from penetrating it to make a good electrical contact with the solder. If this occurs, the ICT measurement will indicate a lack of circuit continuity, even if the tested circuit board is good. The ICT measurement may need to be repeated, which is costly if large fraction of the circuits tested have bad ICT contacts owing to impenetrable flux residue. A soldered joint with a pliable flux residue will be easier to penetrate and allow more effective ICT testing. However, if the flux residue is sticky as well as soft, flux residue will build up on the pin tip, requiring more frequent cleaning of the ICT probes. The quality of the flux residues on soldered joints depends on the materials used in the solder paste flux and the temperature vs. time conditions (reflow profile) the solder paste was exposed to during the reflow process. The quantity of flux residue on a soldered connection will also affect the ability of an ICT pin to penetrate it to the solder below. The shape and size of a soldered pad will affect the amount and/or thickness of flux residue that covers it. The effectiveness of ICT testing also depends on the tip shape and force of the probe pins used. Some pin tip shapes cut through flux residues better than others. Probes with higher pin forces penetrate flux residues better than those with lower pin forces. For the reasons given above, it is desirable to evaluate the ICT penetrability of a particular combination of solder paste, reflow conditions, and ICT probe pin shape and force using a test methodology that allows thousands of pin contacts per individual probe, as is the case in actual ICT testing.

Engineering studies of ICT probe penetrability have been made in the recent past. Mackie[1], then later Guo et al. [2], evaluated ICT probe penetrability of solder paste flux residues by measuring the "force to contact." This method gave a rough indication of the relative penetrability of various flux residues. However, a relatively small number of contacts were measured, so the effect of thousands of pin probes was not examined. Later Seelig and Suraski[3] looked at the effect of several styles of ICT probe and different solder pastes by measuring the contact resistance of the probes to a single type of flat SMT pad. They also found that certain solder paste flux residues built up rapidly on probe tips, while other flux residues do not.

The method described in this paper uses an automated dispensing machine, modified to allow thousands of accurate ICT probes on different kinds of soldered pads. The current method measures the resistance of pin-soldered pad contacts and is an enhancement of an initial method developed at Motorola[4], which used an electronic relay to determine if electrical continuity is established for any pin-soldered pad contact. Using this test method, ICT pin probe-ability was studied for various solder pastes, reflow conditions, solder pad shapes, and ICT probe tip shape and pin force.

Description of test method.

In this test method, a modified Camalot 3800 Dispensing System is used as a high-speed, accurate x-y table with a z-axis head for "flying probe" pin probe-ability evaluation of solder paste flux residues/ICT probe combinations. A small metal ICT probe socket was fabricated to fit securely into the dispenser's cartridge holder and hold a QA type-100 spring-loaded ICT pin probe, as shown in Figure 1. Because the dispenser has an excellent vision system, the dispenser was programmed to allow the ICT pin to accurately and sequentially hit thousands of soldered pads. The z-axis control of the dispenser is set so that the pin is depressed in accordance with the pin specification and thus the force exerted by the spring-loaded pin probe is essentially the same for all sequential contacts.

Figure 1. ICT probe holder for Camalot 3800 Dispensing System pin testing.

In the first version of this method, an electrical test circuit was only used to evaluate circuit continuity; i.e. that the test pin is making electrical contact with the soldered pad being probed. A schematic diagram of the original relay-type circuit is given in Figure 2. This test indicates continuity by activating a 5V relay switch when the test pin electrically contacts the pad being probed. No contact resistance was measured, and no predetermined maximum threshold resistance was designed into the circuit.

Later, the continuity threshold resistance was determined by replacing the probe test pin and the pin test coupon with a 10 kΩ variable resistor, or “trim-pot”. The trim-pot was set at 10 kΩ, where the output of the continuity-indicating relay was 0 V, or no contact. The resistance of the trim-pot was slowly reduced from its maximum value until the output of the relay just switched open, indicating contact. This occurred when the trim-pot was set at 2 kΩ. However, it is useful to know the actual pin pad contact resistance, because a contact resistance of 20 – 2000 Ω might give erroneous results rather than a simple open circuit during ICT evaluation.

The continuity portion of the relay-type pin probe test was modified to allow measurement of the resistance from the probe pin contacting a soldered pad to a connector on the top right corner of the pin test coupon. A schematic diagram is given in Figure 3. The voltage drop across this resistance is measured, and the resistance is calculated using the simple equation given in the diagram. By using a data acquisition system (National Instruments PC-516 DAQ card programmed with LabView software), voltage, and hence resistance, can be measured for each sequential pin-pad contact and stored in an ASCII file for further analysis.

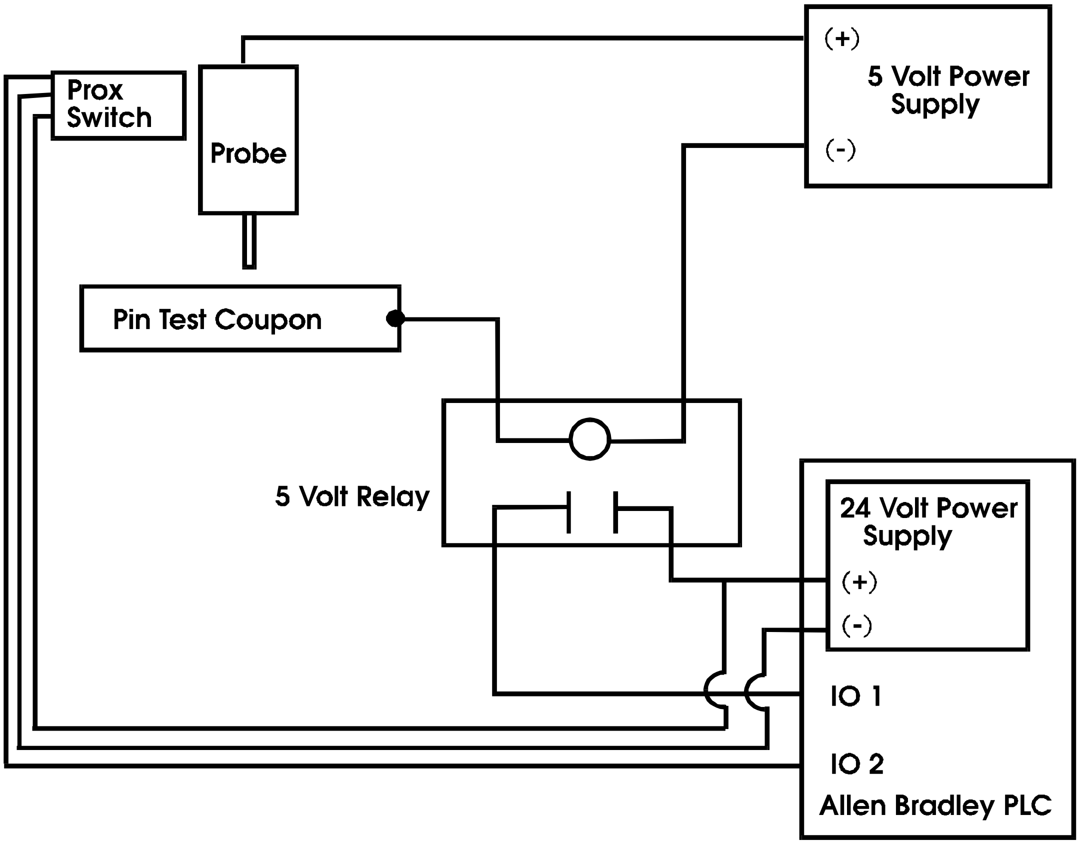


Figure 2. Schematic diagram of relay-type ICT probe penetrability circuit.

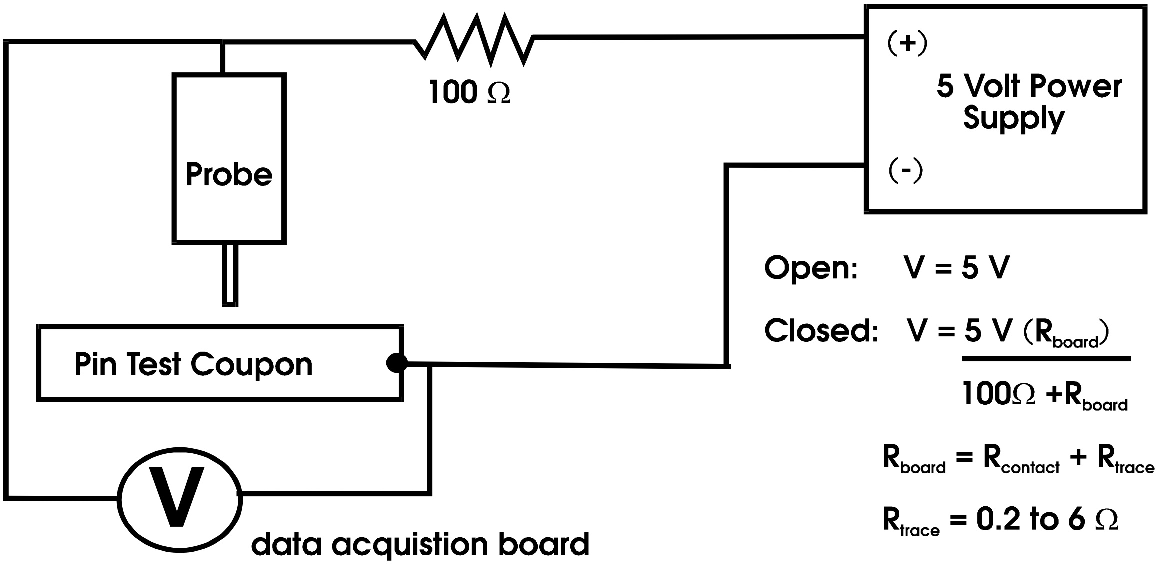


Figure 3. Schematic diagram of contact resistance ICT probe penetrability circuit.

The pin test coupon consists of 4032 SMT soldered pad contacts, 1008 contacts each of four types: A. 40 mil square pads, B. 40 mil square pads with 13 mil plated drill holes (vias), C. 28 mil square pads, and D. 28 mil square pads with 13 mil vias. The contact pads are connected in series by a single copper trace, so that the coupon itself has an intrinsic resistance of about 5 – 6 Ω from the board contact to the last contact pad on the trace. Hence, a small board resistance correction had to be subtracted from the measured resistance to obtain probe-pad contact resistance to an accuracy of about ± 0.5 ohms.

The effect of solder paste type and probe tip shape on ICT probe penetrability

Using the contact resistance measurement method, three kinds of solder paste were evaluated for ICT pin probe penetrability: 1. an old-style, full-bodied RMA paste (paste 1), 2. an experimental paste designed for good pin probe-ability (paste 2), and 3. an older no-clean paste (paste 3). Two pin test coupons were printed for each paste, using a 6 mil stencil. The coupons were reflowed in air with an Atmos 2000 oven using the reflow profile given in Figure 4.

The 1008 pattern B pads (40 mil squares with 13 mil vias) on each of the soldered coupons were probed, one coupon for each paste with a 6.5 oz sharp chisel pin (QA part 100-PRP2563H) and the other coupon with a 6.5 oz blade pin (QA part 100-PRP2555H). Pictures of these probe tips are given in Figure 5. The pattern B pads were chosen because the via provides a little well in the center of the pad that traps flux residue, making the pad relatively difficult to probe, as will be discussed in detail in the next section of the paper. In addition, an unsoldered pin test coupon was probed with a 6.5 oz sharp chisel pin as a control. Probe-pad resistance results are given Table 1 and shown graphically in the Figure 6.

All 1008 test pads on the bare board had measured resistances < 5Ω. For paste 2, the chisel-tipped pin and the blade-tipped pins gave 86% and 99.5% of the pads with measured resistances < 5Ω, respectively. For paste 1, the chisel-tipped pin and the blade-tipped pin gave 4.6% and 25% of the pads with measured resistances < 5Ω, respectively. This shows that blade-tipped pins pierce flux residues more effectively than chisel-tipped pins. With the blade-tipped pin, paste 1, paste 2, and paste 3 gave 25%, 99.5%, and 35% of the pads with measured resistances < 5Ω, respectively. This roughly matches the relative pin-probabilities of these pastes in practice.

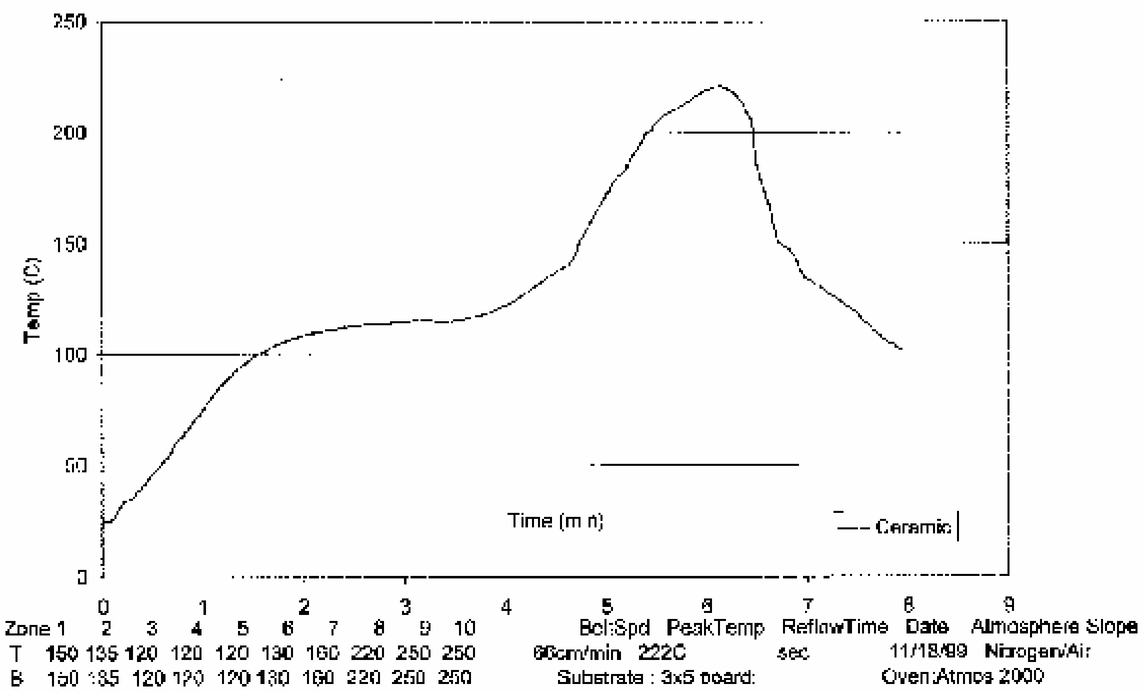


Figure 4. Reflow profile used to reflow the three different pastes.

Figure 5. Probe tips used; **a.** sharp chisel (QA part 100-PRP2563H) **b.** blade (QA part 100-PRP2555H).

Table 1. ICT probe-pad resistances for three types of solder paste and two types of probe tips.

Range of Resistances	Number of probe-pad contacts						
		Chisel-Tipped Pin			Blade-Tipped Pin		
	Bare Board	Paste 1	Paste 2	Paste 3	Paste 1	Paste 2	Paste 3
<5	1008	47	863	322	255	1003	356
5-10	0	6	14	39	1	2	9
10-20	0	1	6	15	0	0	0
20-50	0	2	4	13	0	1	3
50-100	0	0	2	3	0	0	1
100-200	0	0	0	0	0	0	0
200-500	0	0	1	8	0	0	3
500-1000	0	0	2	1	0	0	0
1000-2000	0	1	0	0	0	0	1
>2000	0	951	116	607	752	2	635

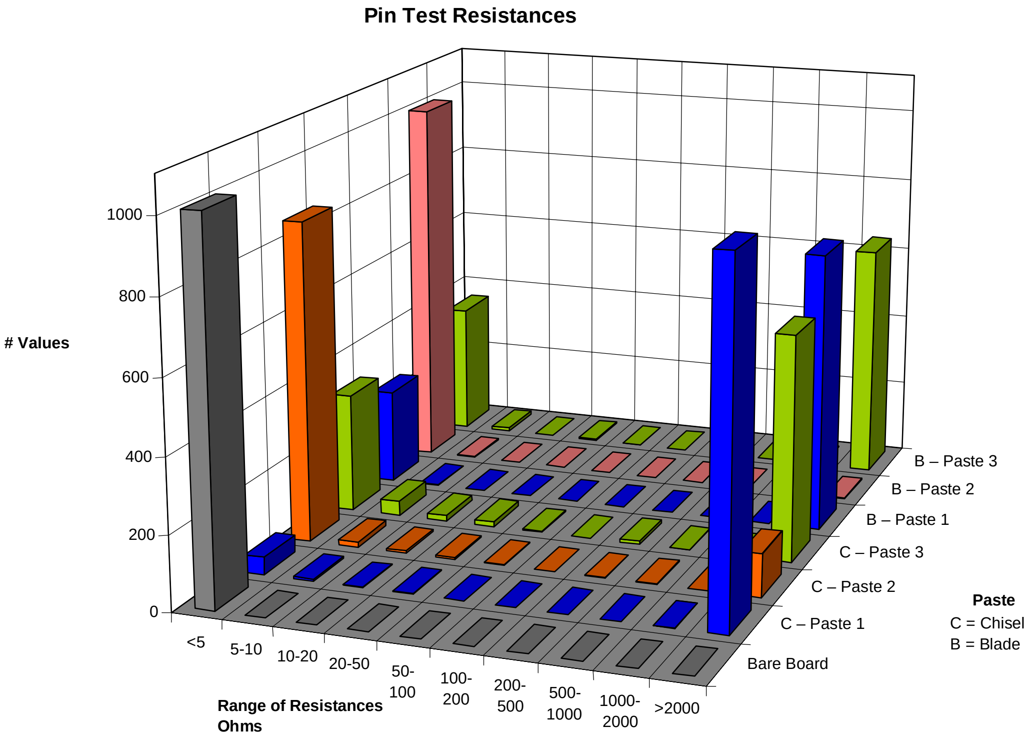


Figure 6. ICT probe-pad resistances for three types of solder paste and two types of probe tips.

In summary, this part of the study showed:

- The contact resistance test method can differentiate between solder pastes that are easy to pin test and those that are difficult. Paste 2 is easy to pin-probe, paste 3 is moderately difficult to pin-probe and paste 1 is very difficult to pin-probe.
- The contact resistance test method can differentiate between the penetrability of different ICT pins. A probe with a chisel-shaped tip pierced flux residue moderately poorly, while one with a blade-shaped tip pierced flux residues relatively well.

The effect of reflow profile and soldered pad shape on the ICT probe penetrability

A relatively pin-testable no-clean paste, experimental paste A, was printed on to pin-test coupons with a 5 mil stencil. One coupon, each, was reflowed at one of four different reflow conditions given in Table 2:

Table 2.

Reflow condition	Peak Temperature	Soak Time	Time above Liquidus
1	215°C	90 s	60 s
2	215°C	90 s	90 s
3	230°C	90 s	60 s
4	230°C	90 s	90 s

The B patterns (40 mil pads with vias) of each coupon were probed with a 6.5 oz sharp chisel tipped ICT pin, and examined microscopically after 5, 20, 100, and 1008 ICT probes. Additionally, the probe contact resistances were measured for all four patterns on each coupon.

The contact resistance measurements and micrographs are given for the coolest reflow conditions, 215°C with a 90 s. soak and a 60 s time above liquidus in table 3 and figure7. This paste had somewhat limited pin penetrability and considerable flux residue build-up, suggesting that the flux residue was sticky and its build-up prevented good probe-pad electrical contacts. This flux build up was observed after as little as 5 physical contacts, and continues to increase with increasing number of physical contacts. For this solder paste, the ICT probe testability of the A and C patterns without via holes were nearly perfect, and very little flux residue was accumulated for these solder pad shapes. The B and D pads with via holes were harder to probe, and flux residue built on the probe tips. The build up of residue was slightly greater for the larger B pads than the smaller D pads.

Contact resistance measurements for the B patterns (40 mil square pads with vias) for all the reflow profiles studied are given in table 4, and flux residue pick up after 1008 probe contacts for paste A are given in figure 8. The penetrability of the pattern B pads soldered with paste A improved by increasing the time above liquidus from 60 s in reflow condition 1 to 90 s in reflow condition 2. Also, much less paste flux residue was picked up with condition 2 than with condition 1. However, in reflow conditions 3 and 4, where the peak temperature was increased from 215°C to 230°C, the pin probe-ability of the flux residues got slightly worse. This suggests that there is an optimum reflow condition for probe penetrability of the solder paste flux residue which provided just enough heat to prevent the residues from being sticky, but not too much heat or too high a peak temperature, which may cause the flux residue to become tougher or harder and more difficult to probe.

The number of contact resistance measurements for paste A less than 5 Ω for all the pad shapes and all the reflow profiles studied are given in table 5. This table clearly shows that the A and C pads without vias are nearly completely penetrable for all the reflow profiles studied. These pads without vias to trap flux residue are so easily probed with a 6.5oz chisel that no discrimination was found between the probe-ability of the reflow profile studied. However, the B and D pads with vias were not completely probed, so the number of contacts made that were less than 5 ohms did discriminate between the reflow profiles examined.

In summary, this part of the study showed:

- Soldered pads with vias that trap flux residues are harder to probe with ICT pins than flat pads. This allows the pads with vias to discriminate more sensitively between relatively probe-penetrable solder paste residues than flat pads.
- Some solder paste residues are stickier than other residues, allowing the residue to be picked up by the probe tip. The built-up flux residues may prevent effective probe-pin electrical contacts if not cleaned with sufficient frequency.
- The reflow conditions used affect the hardness of flux residues. Hotter reflow profiles will make flux residues less sticky and possibly more pin penetrable. However, too hot a reflow profile may render flux residues too hard or tough and less penetrable. There may be an optimum reflow condition for solder pastes that will provide the most penetrable residues.

Table 3

Paste: Pin Testable No-Clean Paste A
Alloy: 63/37

Reflow Profile: 215°C/ 90 soak / 60 liq
Pin Tip: Chisel
Pin Force (oz.) = 6.5

	# of contacts in range					Average
Resistance	**A**	**B**	**C**	**D**		**all sections**
< 5	1008	508	1008	706		807.5
5 - 10	0	1	0	10		2.75
10 - 20	0	0	0	0		0
20 - 50	0	0	0	0		0
50 - 100	0	0	0	0		0
100 - 200	0	0	0	0		0
200 - 500	0	0	0	0		0
500 - 1000	0	0	0	0		0
1000 - 2000	0	0	0	0		0
> 2000	0	499	0	292		197.8
Average (only <2000)	0.88	1.22	0.82	1.34	Ω	
Standard Dev.	0.357	0.550	0.417	0.995	Ω	

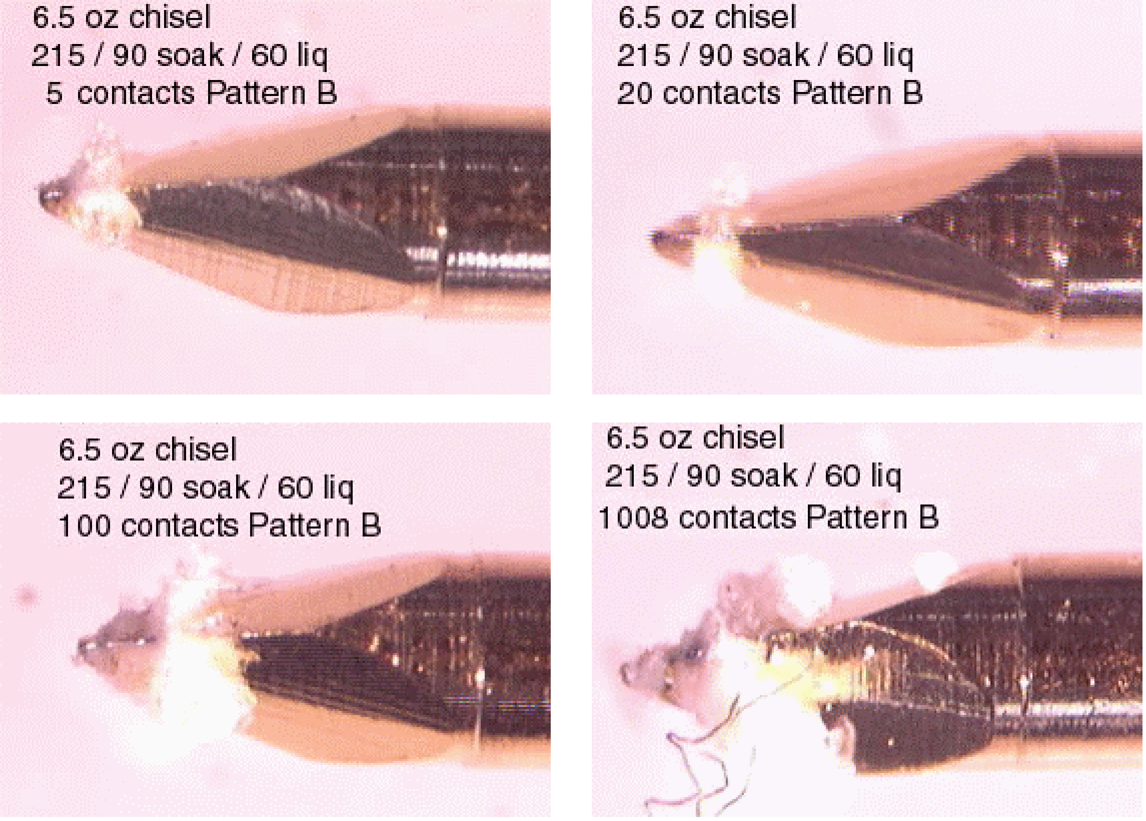


Figure 7. Flux residue pick-up for paste A with increasing probe contacts.

Table 4. ICT probe penetrability vs. reflow profile

B patterns (40 mil pads with vias)

Pin Tip:	Chisel			
Pin Force (oz.) =	6.5			
	Paste A			
	# of contacts in range			
Reflow condition	1	2	3	4
Peak Temperature	215ºC	215ºC	230ºC	230ºC
Soak Time	90 s	90 s	90 s	90 s
Time above liquidus	60 s	90 s	60 s	90 s
Resistance				
< 5	508	882	869	821
5 – 10	1	1	3	0
10 – 20	0	0	0	0
20 – 50	0	0	0	0
50 – 100	0	0	0	0
100 – 200	0	0	0	0
200 – 500	0	0	0	0
500 – 1000	0	0	0	0
1000 – 2000	0	0	0	0
> 2000	499	125	136	187
Average (only <2000)	1.22	1.86	1.79	2.04
Standard Dev.	0.550	0.439	0.474	0.370

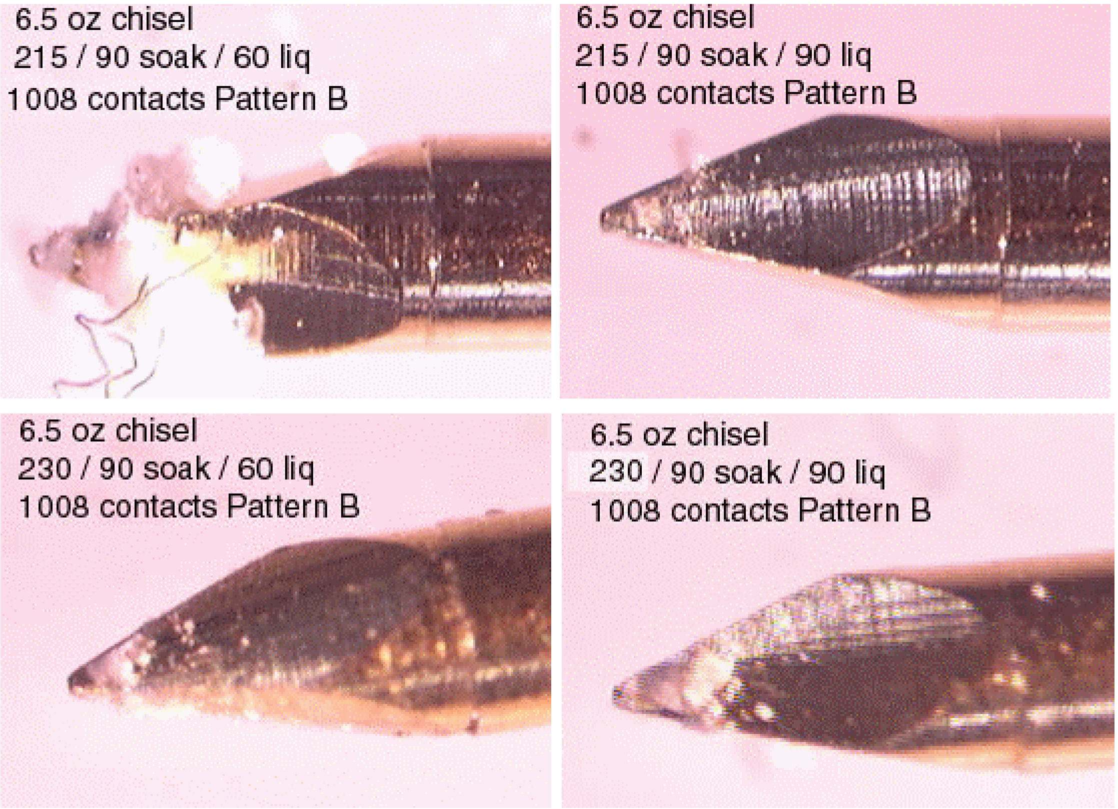


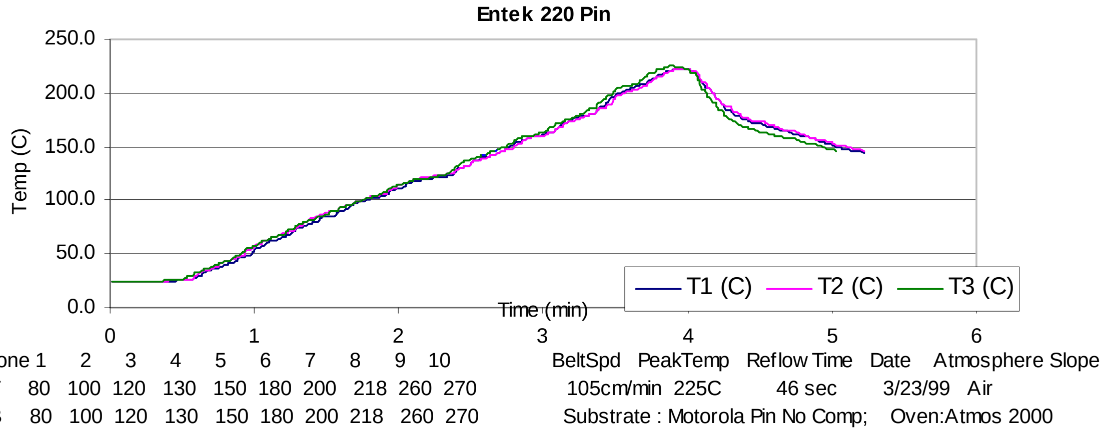
Figure 8. Flux residue pick-up for paste A with respect to reflow profile.

Table 5. ICT probe penetrability vs. solder pad shape for paste A.

Reflow Profile	Number of Contacts < 5 Ω A	B	C	D
215°C/ 90 s soak / 60 s liq	1008	508	1008	706
215°C/ 90 s soak / 90 s liq	1008	882	1008	630
230°C/ 90 s soak / 60 s liq	1008	869	1008	437
230°C/ 90 s soak / 90 s liq	1008	821	1008	511

The effect of pin force and number of reflow profiles on ICT probe penetrability

An experimental pin-testable solder paste was reflowed using the profile given in figure 9, either one or two times, six coupons for each reflow condition. Three coupons for each reflow condition were pin tested with 6.5 oz sharp chisel ICT probes and the other three were pin tested with 10.8 oz sharp chisel probes. The distribution of contact resistance measurements for pattern B probe-pad contacts, averaged for the three coupons tested, for one and two exposures to reflow and the two different pin forces is given in table 6.



Zone	1	2	3	4	5	6	7	8	9	10
T	80	100	120	130	150	180	200	218	260	270
B	80	100	120	130	150	180	200	218	260	270

BeltSpd	PeakTemp	Reflow Time	Date	Atmosphere	Slope
105cm/min	225C	46 sec	3/23/99	Air	

Substrate : Motorola Pin No Comp; Oven:Atmos 2000

Figure 9. Reflow profile used to reflow no-clean paste

As expected, the probes with the higher pin force pierced the flux residues slightly more effectively than those with the lower pin force. Exposing the solder paste to two reflow profiles rendered the flux residue more difficult to probe. The reflow conditions had a somewhat greater effect on probe penetrability than the pin force did.

Flux residue build up on the probe tips after 12096 physical probe-pad contacts for one and two reflows is shown in figure 10. A greater volume of flux residue was picked up for the coupons exposed to one reflow, and the residue was soft and sticky. The residue picked up after two reflows was harder, drier and more crumbly.

Table 6. ICT probe penetrability vs. probe force and number of reflow profiles

Pin force, oz.	**6.5**	**10.8**	**6.5**	**10.8**
# of reflows	**1**	**1**	**2**	**2**
Resistance	**# B pattern contacts (average of three boards)**			
< 5	989.7	1004	831	877.7
5 - 10	1.7	2.3	1.7	5
10 - 20	0.3	0	0	0.7
20 - 50	0.7	0	0	0
50 - 100	0	0	0	0
100 - 200	0	0	0	0
200 - 500	0	0	0	0
500 - 1000	0	0	0	0
1000 - 2000	0	0	0	0
> 2000	15.7	1.7	175.3	124.7

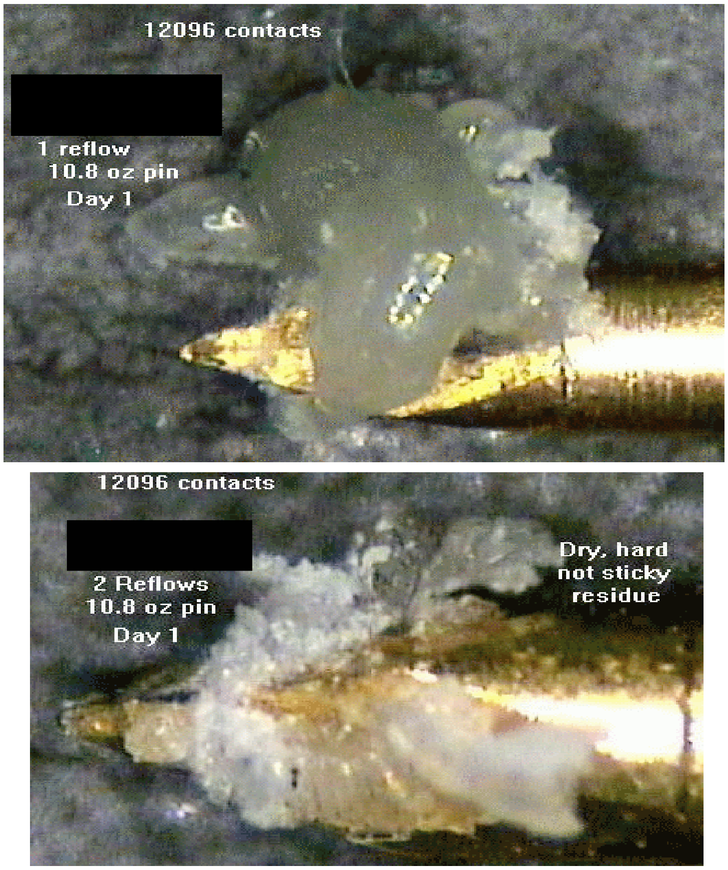


Figure 10. Flux residue pick-up for a no-clean solder paste with 1 and 2 reflow

In summary, this part of the study showed:

- Probe penetrability increases slightly with pin force.
- Probe penetrability decreases with the number of reflows the solder paste was exposed to.
- Flux residues of this solder paste were soft and sticky after one reflow, but harder and drier after two reflows.

Conclusions

The original relay-style test was intended to provide a way to compare the pin probe-ability of various solder paste residues processed under various conditions. To this purpose, it provides useful information; i.e. it indicates which solder paste residues are easier to pin test than others. The new test circuit provides a measure of contact resistance. The contact resistances can be grouped into ranges of resistances for data analysis. However most of the probes that make actual electrical contact have resistances less than 5 ohms, which indicate that the relay-type test does provide useful information.

The contact resistance measurement method is able to differentiate between the ICT probe penetrability of different solder pastes. It is able to differentiate between the pin-testability of different kinds of SMT soldered pad types; pads with vias are more difficult to probe than flat pads. It can determine differences in the penetrability of the residues of solder pastes processed with diverse reflow conditions, including multiple reflows. Finally, the test can differentiate between the penetrability of ICT probe with various tip shapes and pin forces.

By using this test method, solder pastes can be evaluated for ICT probe penetrability during product development and electronics manufacturers can evaluate solder paste, reflow conditions and ICT probe combinations to optimize pin testing.

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References

1. Mackie, A., "ATE Probe-Testing of Flux Residues", IPCWorks'96 Proceedings (1996) pp. A2-1 – A2-7
2. Guo, D., Kamin, S., and Ong, T., "A New Test Method to Predict ICT Performance of Solder Pastes", Proceedings NEPCON West '99 (1999) pp. 194-201
3. Seelig, K. and Suraski, D., "The Development of a Pin Probe Testable Solder Paste", Circuits Assembly, May 2000, pp. 64 – 70
4. Weiss, M, Motorola Computer Group, Manufacturing Center Of Excellence., unpublished work