A NEW, METAL-STAMPING-BASED SYSTEM TO CONNECT WIRES TO SURFACE MOUNT PRINTED CIRCUIT BOARDS

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THE PROBLEM:

Consumer and industrial electronics manufacturers are constantly miniaturizing Printed Circuit Board (PCB) assemblies. The latest Surface Mount Technology (SMT) has helped, but the following areas of scrutiny remain:

1. Cost of the component(s)
2. The amount of "real estate" the component occupies on the board
3. The cost of integrating the component into other electronics on the board(s).

Actual on-board component attachments are frequently automated. However, wire connections are still needed to bring power/signal to the board, link the board to other boards, and/or attach the board to additional systems. This complexity increases dramatically when the specification requires multiple wire connections to and from multiple boards.

- **The Goal: Simplify, miniaturize, maintain reliability, and minimize cost**

CONVENTIONAL SMT WIRE TERMINATION METHODS

There are many ways to connect a wire to a Printed Circuit Board. A quick review of the existing methods will show the economic value of Zierick's new approach.

Barrier Block

A plastic-based Barrier Block is shown in Figure 1. This is a four-piece construction using a housing, a screw, a clamp and a threaded insert for the screw. In order to connect the wire, the insulation must first be stripped. Blocks are bulky, complicated, and expensive due to the number of pieces.

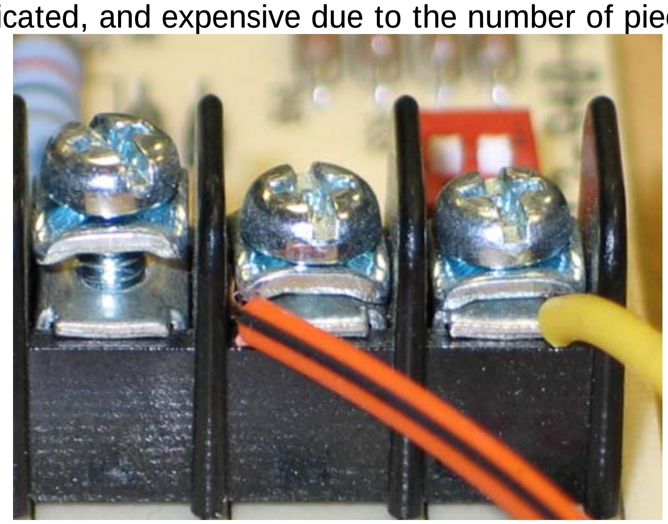


Figure 1: Plastic-based Barrier Block

Pin and Socket (or Tab and Receptacle)

Pin and Socket is a two-piece separable system as shown in Figure 2. The disadvantage to this kind of wire termination is that it requires two connector components (a pin/tab and a receptacle), two separate mountings (one to the PCB and one to the wire), and a final mating connection.

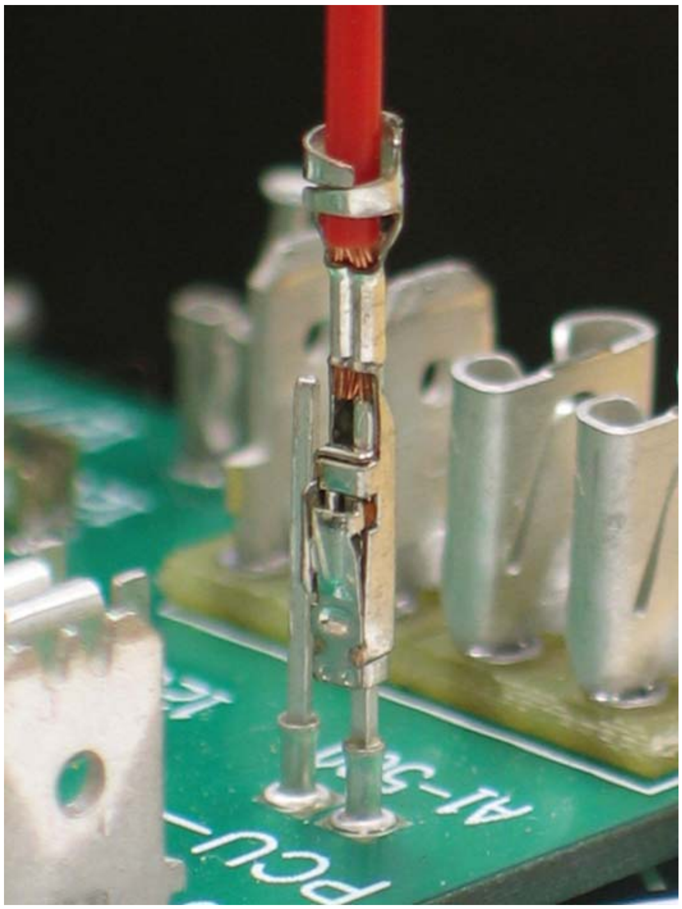


Figure 2: Pin and Socket

Insulation Displacement Connector

Another choice is an IDC, or Insulation Displacement Connector. This is a one-piece terminal that works only with a specific wire size. It requires a bulky plastic housing to hold the blade (not shown in Figure 3), does not provide strain relief for the wire and cannot withstand the harsh conditions of industrial and automotive applications.

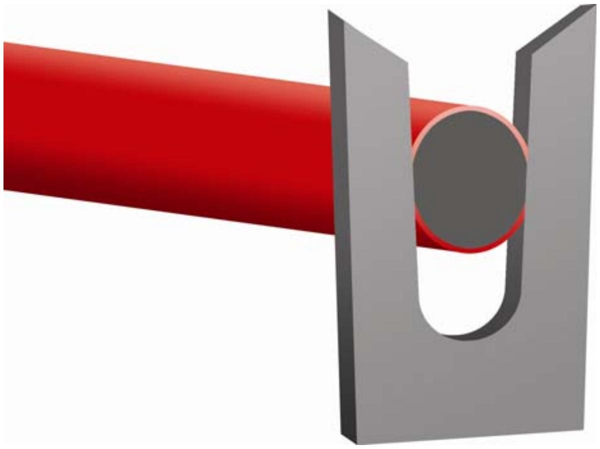


Figure 3: Drawing of a conventional IDC (plastic housing omitted for clarity)

Hand-Solder Wire Directly to the Printed Circuit Board

The most commonly used method in low labor rate countries such as China is to hand-solder the wires directly to the PCB. See Figure 4. The disadvantages include excessive labor time and the fact that the quality of the solder joint is operator-dependent. There can also be serious long-term reliability issues if the wires are under vibration or strain.

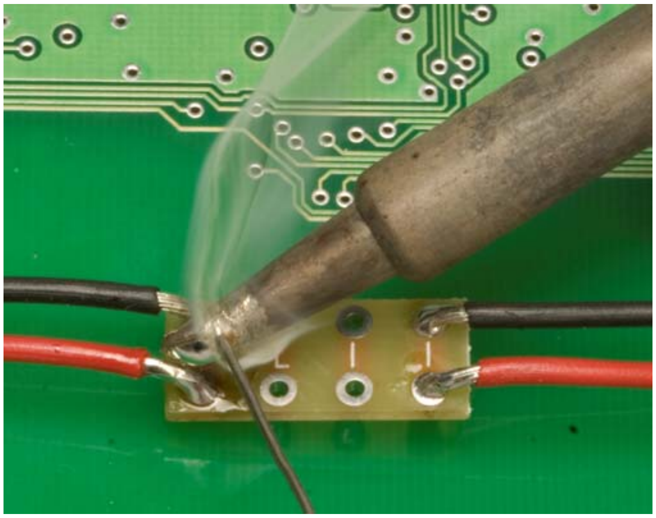


Figure 4: Wire being hand-soldered directly to a PCB

THE SOLUTION:
THE ZIERICK SMT INSULATION PIERCING CRIMP TERMINAL

Engineers in the electronic packaging business know that wire-to-board connection is considered one of the most costly and troublesome steps in the process. The Zierick SMT Insulation Piercing Crimp Terminal (Figure 5) was developed in response to this challenge.

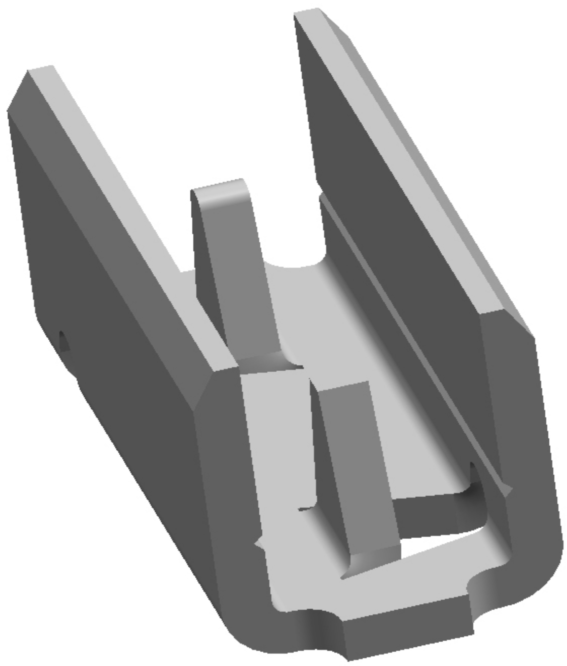


Figure 5: A solid model of The Zierick SMT Insulation Piercing Crimp Terminal

ENGINEERING FEATURES

The ZMC connector consists of a unique flat base for excellent solder adhesion when surface mounting. Two insulation piercing contact spikes protrude from the flat base. The terminal has two sidewalls perpendicular to the base. The connector also features two deep grooves in the transition area between the crimp ears and the terminal base. These insure that when a wire is crimped into the terminal and the crimp ears are formed around the wire, the solder joint on the circuit board is not subject to stress cracking. Inside the terminal, between the two contact spikes, there is a flat area to facilitate vacuum pick-up of the terminal by surface mount placement systems. (Shown in Figure 6.)

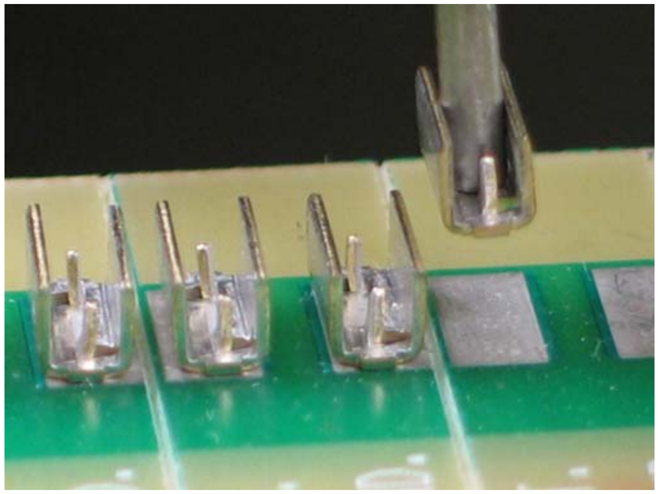


Figure 6: Vacuum pick-up nozzle placing part on SMT PCB

USING ZMC's NEW TERMINAL

The SMT crimp terminal is placed on, and soldered to, the PCB with all the other components, using the same process and the same automated system. Once it is attached to the PCB, the wire can be crimped at any time, either on the assembly line or in the field. No stripping of the wire is required. The wire is simply placed in the terminal between the crimp ears. The terminating tool wraps the crimp ears around the wire, pushing the two spikes into the center of the wire insuring a good electrical connection. Figure 7 shows the crimping process onto a small circuit board.

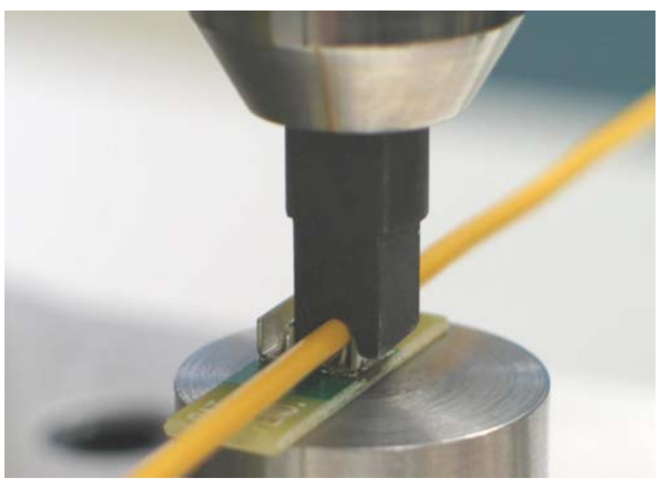


Figure 7: Crimping the new ZMC terminal. A second, uncrimped connector is waiting just to the left. Dual crimp tools and hand crimp tools are also available.

INSULATION PIERCING AND HIGH STRENGTH WIRE CONTACT

Insulation does not need to be stripped from the wire prior to termination since the connection is made when the insulation piercing spikes are forced into the wire strands. The curved terminal "crimp ears" keep the spikes inside the wire and provide strain relief for the conductor. This insulation piercing process requires significantly less force to terminate a wire than conventional crimping, thereby minimizing shock load on the PCB assembly. This process provides a reliable connection through a large range of crimping forces. It is not crimping-force sensitive and can accommodate variations of PCB and solder thickness. Figure 8 shows substantial contact between the wire, crimp ears and the spike.

Figure 8: A cross-section view of a wire inserted into the Crimp Terminal.
Note that the spike solidly penetrates the wire strands.

HOW THE ZMC CRIMP TERMINAL IS MADE

The Crimp Terminal is produced in a high-speed die, similar to the one shown in Figure 9. The die has 14 steps or progressions.

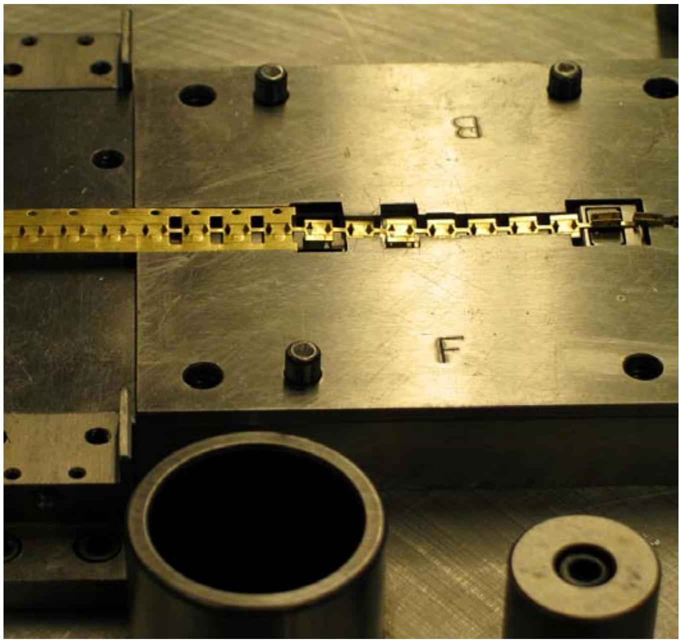


Figure 9: High Speed Die for ZMC Crimp Terminal

The project started with the design of a temporary tool to debug fit and function. It currently runs in a Minster press at 300 strokes per minute (spm) and will be used to produce the first 10 million parts. When the 2-Up “hard tool” comes on line, it will run in a high-speed Bruderer press at 600 spm for a total of 1200 pieces per minute.

The design specifies pre-tinned material to allow Zierick to offer the terminal from the press in any of 3 formats: strip form on a reel, bulk loose piece or continuous tape and reel.

MANUFACTURING OUTPUT

As of the end of 3rd quarter 2008, Zierick has produced and sold 5.2 Million SMT Insulation Piercing Crimp Terminals with ZERO customer returns and ZERO customer complaints. There have been numerous requests for additional Crimp Terminal sizes and current-carrying capacities.

MARKET APPLICATIONS

Zierick is currently rolling out these connectors in high-growth markets such as Light Emitting Diode (LED) lighting and solar energy panels. There are applications in all markets where technology is pushing to place more intelligence onto smaller and smaller circuit boards. Figure 10 shows an application where two wires link a series of small PCB’s, each containing circuitry and a LED.

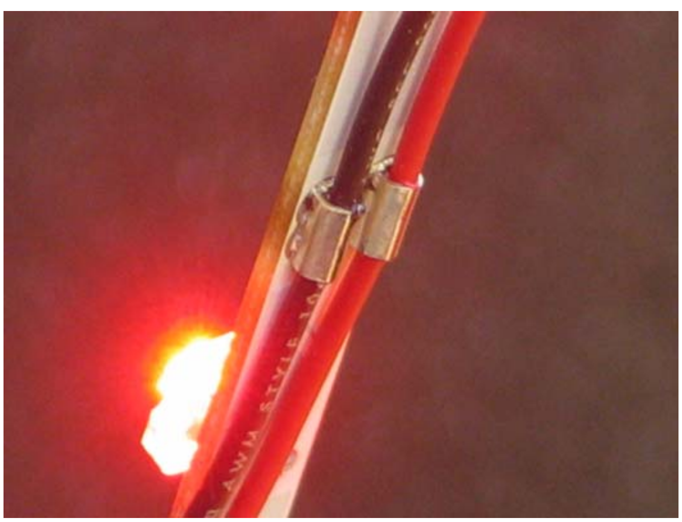


Figure 10: A vertically oriented PCB, two “pass-through” wires, two crimp terminals and a glowing LED

CUSTOMER SAVINGS

Realized savings can be grouped into 3 categories:

1. Price of the connector(s)
2. Value of PCB space saved due to smaller sizes
3. Time savings to install and connect wire

Table 1: Summary SAVINGS Percentages
ZMC SMT Crimp Terminal

Application	Compared to Block or Pin and Socket	Compared to IDC	Compared to Hand Soldering
Price Advantage for ZMC Connector(s)	**50-90%**	**50%**	**N/A**
Board Space Value Saved	**++**	**+**	**+**
Installation LABOR Time Saved			
▪ **Dual wire Pass-through**	**80-88%**		**82%**
▪ **Single Wire Pass-through**	**80%**		**82%**
▪ **Single Wire Termination**	**80%**		**65%**

1. Price of the connector component

Depending on the existing wire termination method, the new 1-piece ZMC terminal is estimated to be anywhere between **2 and 10 times, (50 to 90 Percent) LESS EXPENSIVE** to purchase than other connector-based solutions used to attach a wire to a SMT circuit board.

2. Value of space on the PCB relative to all other connectors

More space on a PCB clearly has value to a manufacturer, although that value is difficult to quantify. The advantages are strongly dependent on the application and the number of wire terminations on the board(s). If market forces are driving products toward size reductions (i.e., mobile consumer electronics), the value to the manufacturer can be significant. The Zierick Crimp Terminal has the smallest footprint available for its designed capabilities. It should also be noted that these size savings translate into weight savings.

3. Time savings to install and connect

The time required to actually connect the wire varies with the method being used. (For comparison purposes below, it is assumed all connectors have already been placed on the board and soldered into place. Data is from extensive studies performed by Zierick Mfg involving the pictured connectors and skilled operators)

- Installing wires to a conventional Barrier Block or Pin and Receptacle connection will take an estimated 5 to 8 times as long as crimping a new ZMC SMT Crimp Terminal. **This translates to an 80 to 88 percent labor time saving per connection.**
- There will not be measurable installation savings over an Insulation Displacement Connector since both the IDC and Crimp Terminal require a similar, yet different tool to fit the wire to the component.
- SUBSTANTIAL LABOR savings will be realized when compared to prevailing hand-solder operations. Studies show that the 4-wire operation shown in Figure 4 will take 80 seconds from wire stripping, through soldering, to cooling and inspection. This would be reduced to 7 seconds per "Crimp", times two crimps, for a total of 14 seconds as shown in Figure 8. **This calculates to an 82% time savings per board**.

  In single wire terminations (non pass-through) to a PCB, each Crimp Terminal will **save an operator approximately 13 seconds or 65%** of hand-solder labor time.

Table 2: LABOR HOURS SAVED per 100,000 Connections
ZMC SMT Crimp Terminal vs. Hand Soldering

Assumptions: 100,000 Connectors, 50-Minute Working Hour

Application	Hand Solder Hrs	ZMC Crimp Terminal Hrs	Labor Hours Saved
1 Wire Pass-through	1,333	233	1,100
2 Wire Pass-through	2,667	467	2,200
1 Wire Termination	667	233	434

FURTHER DEVELOPMENTS

Engineers who have been repeatedly lectured about waste or “muda” realize there is no need for a separate step to place the wire into the terminal. Zierick’s team is working on high-speed automation of the wire/PCB terminating process. The ZMC “Stitching Machine” Crimp Press automatically feeds the wire, presses it onto the insulation-piercing spikes and crimps the terminal. See Figure 11.

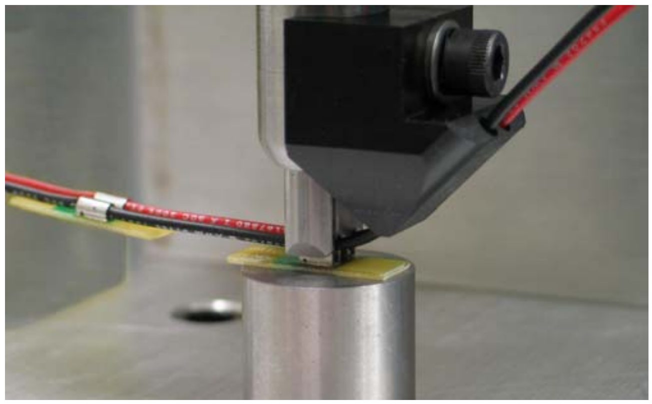


Figure 11: ZMC Stitching Machine

CONCLUSIONS

The Zierick Surface Mount Crimp Terminal is a truly elegant design and an inexpensive way to terminate a wire to a Printed Circuit Board. There is great value in simplicity.

Highlights:

- **The smallest PCB “footprint” of any known wire connector**
- **Designed to provide a high-strength connection to both circuit board and wire along with wire strain relief**
- **One Crimp Terminal can be used in wire pass-through applications where two terminals or solder joints were previously needed**
- **2 to 10 times less expensive than currently available wire/board termination methods**
- **Can be ordered in “tape and reel” for Pick and Place machines**
- **The connectors and wire terminating tools are available to be shipped immediately**

PATENTS

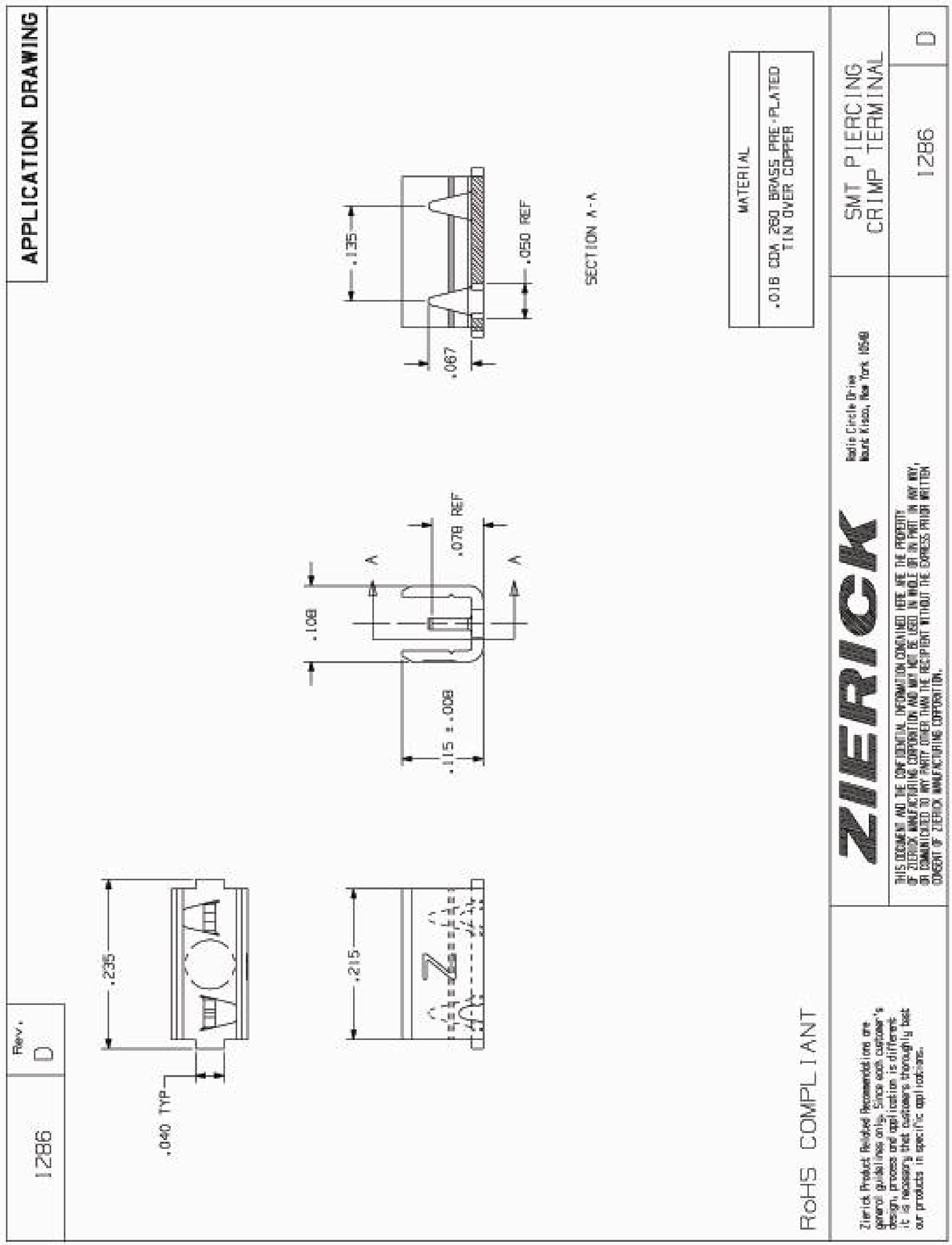
Patent applications are pending in US, Europe and Asia for the Zierick SMT Insulation Piercing Crimp Terminal

APPENDICES

The following pages contain:

- Appendix I: Engineering Print
- Appendix II: Test Data

APPENDIX 1: Engineering Print
(US, European, and Asian Patent applications filed)



APPENDIX II: TEST RESULTS

As part of the validation process the following tests were performed: wire retention to terminal, terminal retention to PCB, current rating/heat rise, thermal cycling and contact resistance.

Wire Retention to Terminal

The terminal was mounted to the PCB on the recommended solder pad using a .006" (0.15 mm) thick stencil and no-clean lead free solder paste. The wire used in the test was 18 AWG 16 strand wire with semi rigid PVC insulation.

a) Pull tests on ten specimens measured the straight axial tension load in pounds.

Force readings were: 16.90 (75 N), 17.70 (79 N), 19.02 (85 N), 21.90 (97 N), 18.70 (83 N), 17.90 (80 N), 20.70 (92 N), 19.30 (86 N), 18.90 (84 N), 20.90 (93 N).

Mode of failure was that the PVC wire and insulation tore while the crimped portion was retained in the connector. See Figure 12.

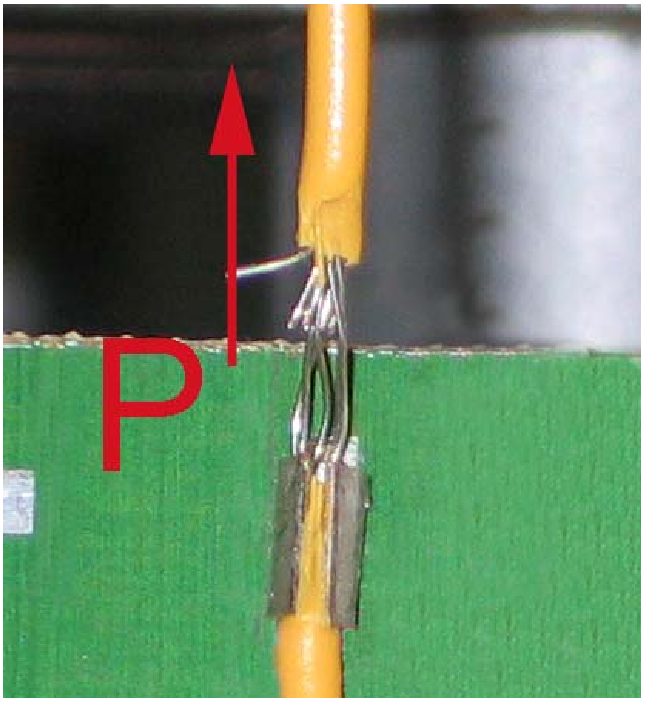


Figure 12: Axial Pull Test

b) Pull tests measured the radial tensile load perpendicular to the axis of the connector pulling away from the surface of the PC board.

Load data recorded was: 15.92 (71 N), 16.09 (72 N), 14.56 (65 N), 16.01 (71 N), 15.48 (69 N), 15.31 (68 N), 14.88 (66 N), 15.93 (71 N), 16.02 (71 N), 14.86 (66 N).

Mode of failure was that the PVC insulation stripped from the wire, and the crimped terminal deformed slightly during wire pullout. See Figure 13.

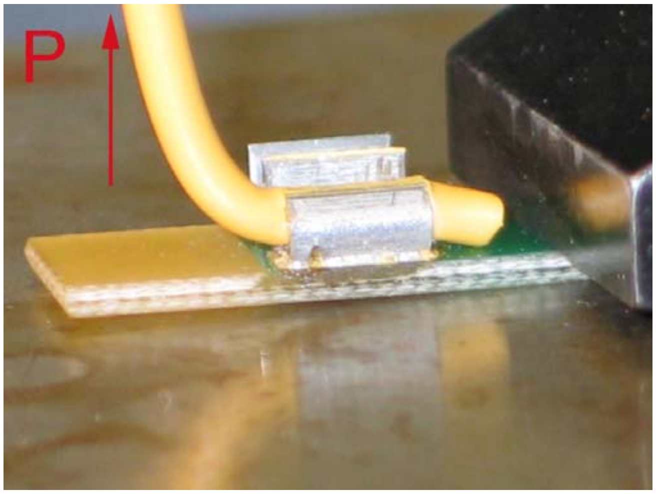


Figure 13: Perpendicular Pull Test

Terminal Retention to PCB

This test was performed two ways: one with the wire crimped in the terminal and the other with no wire crimped in the terminal. There was no difference in retention force of the crimped terminal and the terminal without wire, therefore the crimping had no effect on the terminal retention force.

a) Push load was applied perpendicular to the axis of the terminal along the plane of the PCB while surface mounted to a printed circuit board, as shown in Figure 14.

Load data recorded was: 39.22 (174 N), 49.76 (221 N), 40.09 (178 N), 35.58 (158 N), 39.29 (175 N), 54.09 (241 N), 44.10 (196 N), 41.07 (183 N), 51.22 (228 N), 49.88 (222 N).

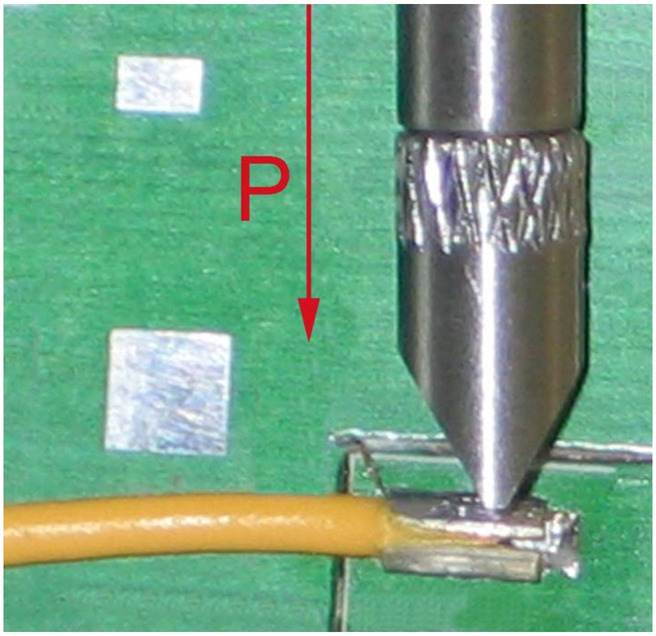


Figure 14: Terminal Retention, Lateral

Mode of failure was that the solder joint failed. The copper pad remained on the board, and the terminal was not deformed.
b) Push load was applied along the axis of the surface mounted connector.

Load data in pounds was 21.56 (96 N), 22.49 (100 N), 32.52 (145 N), 30.19 (134 N), 30.91 (138 N), 38.48 (171 N), 29.99 (133 N), 31.19 (139 N), 29.58 (132 N), 32.11(143 N). See Figure 15.

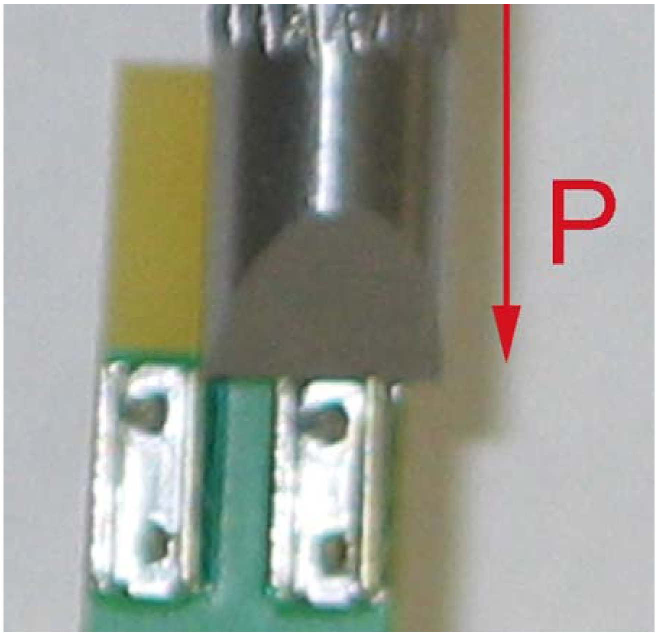


Figure 15: Terminal Retention, Axial

The acceptance requirement is that the terminal to PCB retention force must be at least 50% greater than the wire to terminal retention force. All the results exceeded that requirement.

Ampacity Determination

The heat rise test was performed to determine electrical current limitations, in which similar to UL 310 standard, the current limit is established at 30 degrees Celsius rise above ambient.

Eight crimped terminal specimens were connected in series with 18 AWG stranded wire. The ambient temperature was recorded first at 23.8 degrees Celsius. The specimens were then connected to a power supply. Current was applied in increments, then left for a period of time for terminal temperature to stabilize. The temperature of each terminal was recorded with a thermocouple. Wire temperatures were recorded as a reference.

Table 3: Temperature Rise of each Connector (Increase in Degrees Celsius)

Connector Test Number

Amps	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8
15	16.3	16.5	18.5	16.9	20.1	15.8	19.0	18.1
16	21.6	35.5	36.2	28.7	29.2	26.7	24.8	24.3
18	22.4	37.8	39.1	30.0	31.2	28.7	26.5	31.3

Recorded wire temperature @ 16 amps was 43.1 degrees C
Recorded wire temperature @ 18 amps was 49.7 degrees C

Conclusion: Underwriters Laboratory (UL) specification #310 states the upper limit for temperature rise to be 30 degrees C above ambient. The data above recommend a maximum application of 15 amps to this connector. All recorded temperatures were well below the UL limit at this amperage.

Thermal Cycling and Contact Resistance

Low-level contact resistance measurements were performed on the surface mounted and crimped terminal before and after thermal cycling. Measurement points were near the edge of the solder pad on the PCB and on the wire at 1/4 inch from the terminal. The following are the actual readings in milliohms. No bulk resistance was subtracted from the reading.

Before thermal cycling: 9.0, 10.7, 11.0, 9.0, 10.5, 10.7, 9.5, 11.4, 11.2, 9.3.

Terminals were thermal cycled for 1,000 cycles. Because of the extreme temperatures, the actual test was closer to thermal shock than thermal cycling. The specimens were placed in a +90 degree Celsius hot chamber for one-half hour, then a shuttle mechanism moved them in one minute to the -50 degrees Celsius cold chamber where the specimens were kept for half an hour.

Resistance readings in milliohms after 1,000 cycles: 9.7, 11.5, 12.0, 10.0, 11.4, 11.8, 10.1, 12.5, 12.3, 10.2.

TEST RESULTS SUMMARY

The wire retention to the terminal was so high that the wire broke before the terminal would release the wire. Crimping did not affect the terminal retention force to the PCB, which is at least 50% greater than the wire retention force.

The Heat Rise Test and the Current Rating show that the wire itself gets hotter than the connection, therefore the connection is not the weakest point in the system.

The connector exceeds all requirements set by the industry.