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Insulation Displacement Connections for RoHS Compliance

Marjorie K. Myers
Robert D. Hilty, Ph. D., P.E.

Tyco Electronics
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Marjorie K. Myers* & Robert D. Hilty, Ph.D., P.E.

Tyco Electronics
2901 Fulling Mill Road, Middletown, PA 17057
marjorie.myers@tycoelectronics.com
(1) 717.986.7290

Abstract:

Insulation Displacement Connections (IDC) are used to make separable interconnects between terminals and dielectric coated wires. These connections have traditionally been fabricated using tin/lead and pure tin plating on the IDC connection interface. This report examines the performance similarities between tin plated and tin/lead plated IDC interconnects.

Introduction:

IDC’s are commonly used in electronic connector applications because of their processing ease, flexibility and excellent performance history. They involve no wire stripping, have low insertion forces, discrete or multi stranded cables can be applied, they can be hand or automatically applied, are solder process compatible, and the application process is simple and easily controlled. Figure 1 and 2 illustrate the IDC mating process. The wire insulation within the final contact area(s) is removed during the insertion process to create a semi-permanent metal-to-metal connection between the wire and the IDC connector. IDC designs that are considered reusable (i.e., repairable), allow the reuse of the IDC contact when mated to a virgin section of wire. The keys to designing a reliable IDC connection are to generate a sufficient amount of contact area upon insertion of the wire and maintaining sufficient normal force of that contact interface throughout the lifetime of the IDC.

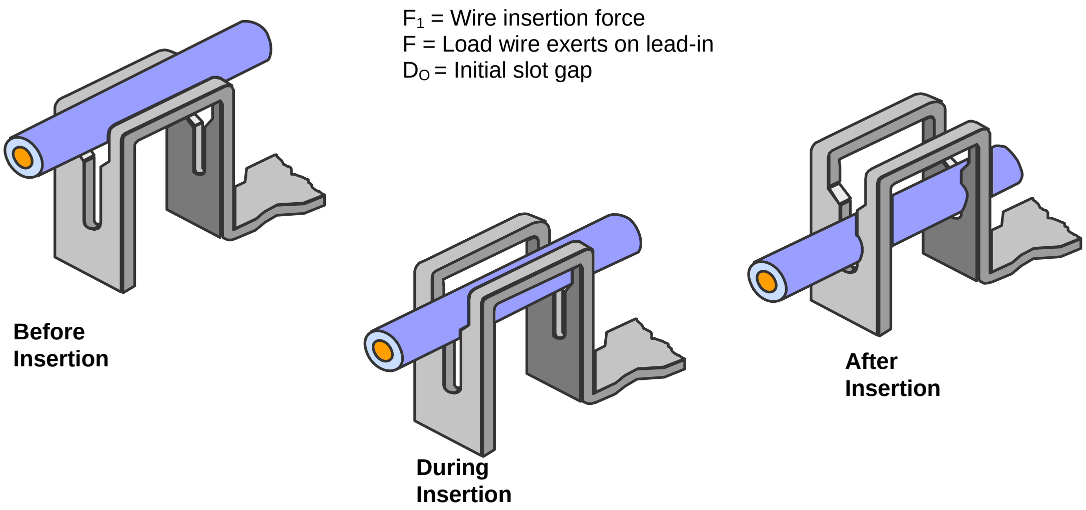

Figure 1. Schematic illustration of a wire being inserted into an IDC slot.

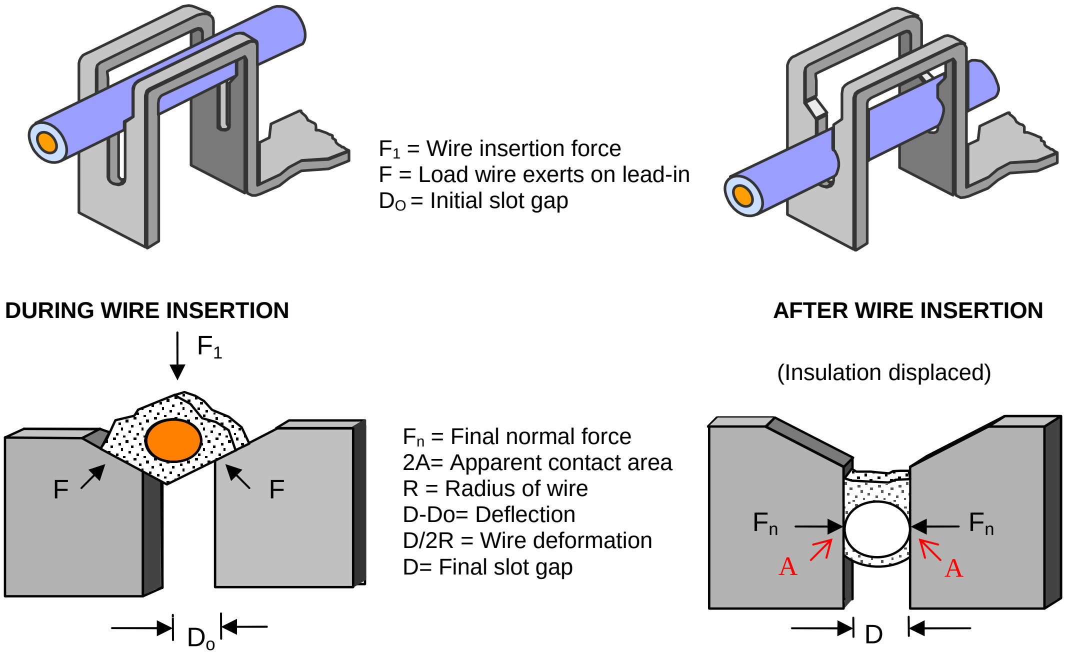

Figure 2: Schematic illustration showing the forces on the insulation and conductor when the IDC connection is created.

IDC design considerations:

Mechanical design guidelines [1]:

Forming a sufficient amount of contact area involves generating enough wire deformation upon insertion of the wire; but not so much as to significantly weaken the wire. The formed apparent area should be equal to or greater than the cross-sectional area of the wire being applied. This corresponds to a wire cross-section deformation on the order of 25 – 35%.

The processing advantages of IDC's (e.g., no wire stripping and low insertion forces) make them potentially susceptible to mechanical disturbances and/or pullout if not properly designed and applied. Therefore, contact interface mechanical stability is achieved by proper IDC beam design and wire strain relief design.

The beam design should be elastic and have a high initial normal force. The beam materials of construction must be selected to retain these forces after any loss of normal force that may occur due to stress relaxation and/or creep of either the wire or the beam materials over the lifetime of the connection.

The strain relief design feature prevents unexpected mechanical disturbance of the contact interface by preventing vibration and motion from being transferred from the cable to the IDC

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[1] Mroczkowski, R., “Insulation Displacement Technology”, AMP engineering note EN133, (1986)

contact area. Strain relief can be incorporated into the terminal, housing and/or cover designs. Common examples of strain relief features used in IDC applications are dual slot terminal design (either two contact slots or one contact slot and one non insulation removing strain relief slot), terminal insulation supports (insulation ‘crimps’), housing slots, wire clamps/ties, housing retention tines, and protective covers.

Dual slot designs are better than single slot designs. Dual slot designs offer better strain relief and are inherently more mechanically stable than single slot designs. If both slots are contact slots, there is more contact area formed and better current path redundancy incorporated into the design. Other wise, the second slot which only grips the insulation without removing it still provides the improved mechanical stability of a dual slot design.

Solid wire single strand wire IDC’s are considered to be more robust than multi stranded wire IDC’s, but if proper precautions in design and application are taken, the difference is minimal. Individual multi-strand wires are smaller and easier to break. If a break occurs during insertion, adequate normal force may not be generated due to the subsequent reduction in cross-sectional area. Also, multi-strand wires in IDC’s can be susceptible to relative motion of the individual strands (i.e., ‘cord wooding’) during insertion. Figure 3 shows the effect of relative motion within the wire bundle as a multi-strand wire goes into an IDC slot. Excessive relative motion of the wires in response to the insertion forces can generate marginal normal force. Proper strand lay (i.e., twist), application tooling features that grip the insulation circumferentially in more than one location, and an adequate amount of extra wire between the cut of wire end and the IDC location, all work to effectively constrain the wire bundle and minimize relative motion of the wires. Using a dual contact slot design also helps by increasing the redundancy of contact spots and constraining the wires upon insertion.

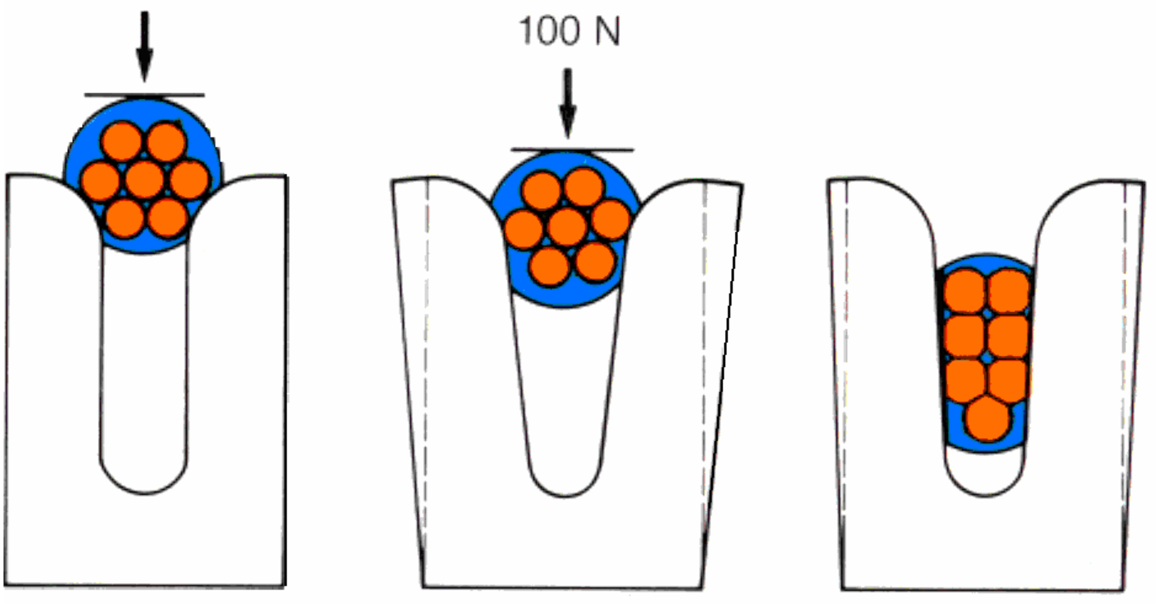

Figure 3: Schematic illustrating the application of a single slot multi-stranded wire IDC

IDC material and IDC surface design guidelines [1, 2]:
The surface coatings used in IDC's act to minimize the initial resistance of the as formed contact interface and help maintain contact resistance stability by protecting the region in and around the formed contact area from excessive environmentally induced corrosion degradation.

The IDC base metal material must resist stress relaxation and/or creep under the IDC application lifetime conditions. IEC has established guidelines for IDC contacts [2]. IEC recommends that IDC be made of bronze, brass or beryllium copper; depending on the design performance and cost requirements. We have found that some newer copper alloys, such as copper-nickel-silicon, are also quite capable of performing well in these applications. The IEC recommended coatings for IDC slots are tin, tin-lead, silver, gold, palladium, or their alloys.

The wires IEC recommends for IDC are either single strand (0.25 to 3.6 mm nominal diameter) or a 7 multi-strand (0.05^2 to 10 mm^2 cross-sectional area) made of annealed copper material with greater than 10% elongation at break. The wires should be plated with tin, tin-lead, or silver. Single strand wires can also be used in the bare unplated state, but not multi-strand wires. Generally, it is better to use plated wire.

One should be careful to specify compatible material combinations within the IDC. Choosing material combinations that are close in the electrogalvanic series [3] helps to minimize the potential for induced electrogalvanic corrosion.

The formed beam lead in and slot surfaces should be sufficiently smooth and burr free to be able to completely remove the insulation material within the formed contact area yet not damage or break the wire(s). The insulation material displaced by the IDC beams around the IDC contact interface should visually cover (physically encapsulate) all areas of bare wire.

Impact of RoHS driven product changes on IDC performance:
Changing IDC's to be RoHS compliant involved removing lead from the IDC and wire coatings (i.e., tin-lead to lead free tin coatings) and the insulation material of the wire – in most cases PVC. Potential IDC failure modes are: excessive wire mating forces, excessive wire unmating forces, high contact resistance at the IDC interface, fretting corrosion susceptibility[4], galvanic corrosion susceptibility, and tin whisker formation. When comparing tin lead to pure tin coatings, the mechanisms driving most of these potential failure modes are similar. Each potential failure mode is addressed below along with their effects.

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[2] EIC 60352, part 3: 'Solderless accessible insulation displacement connections – General requirements, test methods, and practical guidance' and part 4: 'Solderless non-accessible insulation displacement connections – General requirements, test methods, and practical guidance'

[3] Winston, R., *Uhlig's Corrosion Handbook (2nd edition)*, pp 149, 2000.

[4] Bock, E. M. and Whitley, J. H., 'Fretting Corrosion in Electric Contacts', IEEE 20th Holm Conference Proceedings, 1974, pp 129 – 138.

Excessive wire connection/disconnection forces

The force required to connect IDC wire terminations (and disconnect for re-useable IDC designs) is a function three design aspects: 1) insulation cutting and displacement, 2) friction between metallic conductors and 3) degree of wire deformation.

The force it takes to slide and displace the wire insulation is related to the mechanical properties of the wire insulation materials. Non-RoHS compliant compounds (e.g., tribasic lead sulfate) have been historically used as additives in PVC wire insulation materials as heat stabilizers. New formulations have been developed in conjunction with the insulation material suppliers. These have performed as good as or better than the previously used non-RoHS compliant formulations in qualification testing such as flexibility, surface finish, tensile strength and elongation. They have also passed the required UL and CSA specifications. Tyco Electronics (Madison Cable Division) has been supplying wire using these RoHS compliant insulation materials for use in IDC applications for since 2002.

The force it takes to wipe the wire against the IDC beams to form the contact interface is dependant on the friction and durability performance of the surface coatings. Since the coefficient of friction of tin lead and lead free tin surfaces are comparable[5,6], the effect of switching from tin lead to pure tin coatings will not lead to significant changes in friction forces between the metallic conductors.

The degree of wire deformation that occurs as the wire is terminated in the IDC is a function of the relative geometry of the wire and IDC. This is not affected by switching from tin lead to RoHS compliant lead free tin coatings.

Some IDC's are designed to be re-useable meaning the wire can be replaced up to a specified number of times. The disconnection step has to be done in a manner that does not damage to the IDC slot and a fresh section of wire has to be used each time. The durability of the IDC slot being re-used is a function of the durability of the coating of the IDC slot. Whether the coating is tin lead or pure tin, the two metals have comparable coefficient of friction, hardness and oxide layer formation; therefore any differences in wire re-insertion durability are not discernable [4, 5].

Excessive interface contact resistance

Acceptable contact resistance across a traditional tin lead or lead free tin coated IDC contact interface is a function of how that contact is made. When tin based coatings are exposed to the atmosphere they quickly form a stable, thin and brittle oxide layer which protects the underlying metallic tin from further oxidation. Making stable metallic contact between tin interfaces is relatively easy because it takes a minimal amount of normal force and/or wipe to break through this brittle layer of oxide, exposing the relatively soft tin metal underneath. The same contact

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[5] Myers, M. K., 'Coefficient of Friction of Sn Separable Interface Applications', May 2003. http://www.tycoelectronics.com/environment/leadfree/pdf/Coefficient_of_Friction_of_Sn_Separable_Interface_Applications.pdf

[6] Chou, G., Hilty, R., "Effects of Lead Free Surface Finishes on Press-fit Connections", IPC Annual Meeting, 2003. Available at: http://www.tycoelectronics.com/environment/leadfree/pdf/Tyco_IPC_2003_Chou.pdf

physics apply for tin and tin-lead interfaces; thus, switching from tin lead to pure tin coatings has shown no statistically discernable difference in contact resistance performance.[7]

Fretting corrosion susceptibility

The mechanism that makes it easy to make metallic contact to tin or tin lead interfaces is the same one that makes them similarly susceptible to fretting corrosion. Repeated relative motion between the two surfaces (fretting) of a tin metal based contact interface (~ 10 to 100 μm) leads to repeated exposure and oxidation of fresh tin metal which can result in a build up of oxide material within the contact interface. This leads to instability and increases in the contact resistance of the interface. This relative motion can be driven by either mechanical vibration or thermally driven. Strain relief of the wire and mechanical isolation are the best ways to mitigate fretting corrosion in IDC applications. The fretting mechanism for tin and tin-lead interfaces is identical and switching from tin lead to lead free tin coatings has shown no statistically discernable difference in fretting susceptibility.[8]

Galvanic corrosion susceptibility

Galvanic corrosion (dissimilar metal corrosion) occurs when two electrochemically dissimilar metals are in contact in the presence of an electrically conductive path between them which is capable of moving ions from the more anodic metal to the more cathodic metal. If a path by which ions can move is not present, galvanic corrosion of the more anodic metal will not occur. This path can be as minimal as a film of water that can form in the presence of a humid environment. The relative galvanic corrosion susceptibility of two platings (*i.e.*, tin lead and pure tin) in contact with copper alloys is proportional to their relative position on the galvanic series.[3] If two metals are close to each other in the anodic to cathodic galvanic series, they have similar susceptibility to galvanic corrosion when in contact with another material. Tin lead plating contains approximately 7% lead by weight and thus the galvanic potential is equivalent to pure tin. Switching from tin lead to pure tin coatings does not increase the susceptibility of IDC connection to galvanic corrosion. Further, the general risk of galvanic corrosion in IDC terminations is significantly reduced by the sealing effect of the displaced insulation.

Potential for whisker formation

An additional concern with switching from tin lead to pure tin coatings is the potential for an increase in whisker susceptibility. Tyco uses whisker mitigated lead free tin plating baths that have been qualified according to the requirements of iNEMI[9] and the soon to be released JEDEC qualification standard.[10] Further, as a tin whisker mitigation practice, Tyco applies a nickel underplate to our lead free tin product. In the as plated condition, many tin plating will perform well and have limited whisker growth. Since whisker growth is accelerated by compressive

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[7] http://www.tycoelectronics.com/environment/leadfree/pdf/tyco_lf_customer_packet_resistance.pdf

[8] Corman, N., ‘Fretting Performance of Lead Free Finishes’, November 2004, document 503-1002 rev. 0. http://www.tycoelectronics.com/environment/leadfree/pdf/503-1002_LeadFree_Fretting.pdf

[9] iNEMI tin whisker users group acceptance document, can be found at: www.inemi.org

[10] JEDEC JESD201, Tin Whisker Acceptance Procedures, www.jedec.org

stresses, we have found the stress applied to the tin deposits during assembly or in the product application can accelerate whisker growth.[11] In an IDC, the compression region is inside the region of the as-formed contact interface. When the IDC is created, any whiskers that may form in a compressively deformed tin deposit around the formed contact interfaces would be encapsulated within the displaced insulation, preventing growth of the whiskers and any associated failures. To further examine the role of stress in whisker growth, we can compare the performance to that found in press-fit applications where the compressive stress state is very high. This product is easier to analyze since there is not dielectric material in the region of high stresses. Our testing has shown that press-fit products that use whisker mitigated tin plating over a nickel barrier can meet the requirements of the iNEMI tin whisker acceptance document; that is to say, the maximum whisker length does not exceed 40um after 6 months of accelerated aging.[12]

Results:

The test methods used to verify performance of product designed with IDC terminations are unaffected by the RoHS changes. This is reflected in by the allowance of pure tin coating in the IEC testing standards 60352 part 3 and part 4. These methods do not differentiate testing for tin lead vs. pure tin coated product.

A typical product level testing procedure used at Tyco Electronics for product qualification can be found in the Tyco Electronics product specification 108-60016 [13]. This testing procedure is designed to test whole connectors which include IDC and pure tin coatings. The IEC test standards related to IDC (60352 part 3: accessible, part 4: non-accessible) are designed to test IDC only. Correspondingly, there are a greater number of test methods specified in the Tyco Electronics product specification. Table 1 illustrates the results of testing based on the 108-60016 product specification. The table includes the potential failure modes accelerated by each test condition and results pertaining to IDC. Testing that was not related to IDC is not included in the table. All pure tin coated product tested to this specification passed all of the product requirements.

An outline of the testing procedures for the IEC 60352-3 can be found in Appendix 1 (60352-3). This can be compared to the testing that has been reported in Table 1. While the test conditions are not identical, the test methods and the acceleration of failure modes are similar in each test protocol.

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[11] Hilty, R. D. and Corman, N., “Tin Whisker Reliability Assessment Using Monte Carlo Simulation”, IPC/JEDEC 8th International Lead Free Conference, San Jose, CA, April 2005.

[12] Hilty, R. D., Chou, G.C., Myers, M. K., “Tin Whisker Qualification Testing – Eye of the Needle Compliant Pin Products”, Tyco Electronics Document 503-1006, Rev O, 11MAR05. http://www.tycoelectronics.com/environment/leadfree/pdf/503-1006_Tin_Whisker_Qualification_Testing_CompliantPin.pdf

[13] 108-60016, “AMP Common Termination (CT), Connector 2mm Pitch, M/T Type, Lead Free Version” and Qualification Test Report 501-60003 rev. A

Table 1: 501-60003 rev. A Qualification test report (testing details) based on product specification 108-60016: AMP Common Termination (CT), Connector 2mm pitch, M/T Type, Lead Free Version

Test	Test exposure	Parameter ranges	IDC specific failure modes tested	result
Mechanical Requirements				
Axial tensile strength of wire termination	Head operation speed: 50 mm/minute	AWG #24# and 26: 19.6 N (2.0 kg force) AWG #28: 14.7 N (1.5 kg force)	mechanical robustness	acceptable
Lateral tensile strength of wire termination		AWG #24# and 26: 14.7 N (1.5 kg force) AWG #28: 11.76 N (1.2 kg force)	mechanical robustness	acceptable
Vibration sinusoidal low frequency	10-55-10 Hz, 1 minute, 98 m/s^2 (10 G), amplitude 1.5mm, X, Y, and Z axis, 2 hours each	No electrical discontinuity greater than 1 µs	contact resistance stability fretting resistance	acceptable
Physical shock	490 m/s^2 (50 G), halfsine wave, 11msec, XYZ drops, total of 18 drops	No electrical discontinuity greater than 1µs	contact resistance stability	acceptable
Resistance to soldering heat	Flow soldering Reflow soldering	No evidence of physical damage	---	acceptable

Table 1 (continued): 501-60003 rev. A Qualification test report (testing details) based on product specification 108-60016: AMP Common Termination (CT), Connector 2mm pitch, M/T Type, Lead Free Version

Test	Test exposure	Parameter ranges	IDC specific failure modes tested	result
Environmental Requirements				
Thermal shock	-55°C - 85°C, 5 cycles	Final 20mΩ maximum Termination R (low level)	contact resistance stability	acceptable
Temperature humidity cycling	40 to 60°C, 90~95%RH, 96 hours	Final 20mΩ maximum Termination R (low level)	contact resistance stability fretting resistance galvanic corrosion resistance	acceptable
Humidity (steady state)	40°C, 90~95%RH, 240 hours	Final 20mΩ maximum Termination R (low level)	contact resistance stability galvanic corrosion resistance	acceptable
Salt spray	5% salt concentration, 48 hours	Final 20mΩ maximum Termination R (low level)	contact resistance stability galvanic corrosion resistance	acceptable
Industrial SO_2 gas	3 ppm, 240 hours	Final 20mΩ maximum Termination R (low level)	contact resistance stability	acceptable
Temperature life	85 ± 2°C, 96 hours	Final 20mΩ maximum Termination R (low level)	contact resistance stability	acceptable
Resistance to Cold	-25°C, 48 hours	Final Termination Resistance (low level) 20mΩ maximum	contact resistance stability	acceptable
Sequence testing	30 cycles mating cycles@ 10 cycles/min Measure LL Term. R 25°C to 65°C, 95%RH, 10 cycles Measure LL Term. R	20mΩ maximum Termination R (low level) Final 20mΩ maximum Termination R (low level)	contact resistance stability	acceptable

Table 1 (continued): 501-60003 rev. A Qualification test report (testing details) based on product specification 108-60016: AMP Common Termination (CT), Connector 2mm pitch, M/T Type, Lead Free Version				
Test	**Test exposure**	**Parameter ranges**	**IDC specific failure modes tested**	**result**
Electrical Requirements				
Termination Resistance (low level)	Initial/final 10mA @ 20mV	Initial: 10 mΩ maximum Final: 20 mΩ maximum	---	acceptable
Dielectric strength	Intial/final 1kV, AC (50 Hz), 1 minute	No abnormality allowed	Insulation degradation	acceptable
Insulation resistance		Initial: 1000 MΩ Final: 500 MΩ	Insulation degradation	acceptable
Temperature rising vs. current	Test current: 3A for #24 AWG 2 A for #26 AWG 1 A for #28 AWG	30°C maximum T-rise	---	acceptable

Conclusions:

1. IDC terminations are a low cost method of fabricating a separable interconnect.
2. Pure tin plating has been used on IDC connections for decades and is an IEC recommended coating.
3. Pure tin plating is a “drop-in” replacement for tin/lead plating in IDC interconnects. Products will retain all of the original functionality and performance.

Appendix 1: Outline of information related to testing of IDC in 60352-3

TableA1.1: Testing criteria as per 60352-3 section 8 related to the design of the IDC		
• If the IDC design meets all the requirements in the 13.2 column, the Basic test schedule applies • If not, the 13.3 Full test schedule applies • If the IDC design deviates from specified qualities in both the 13.2 or 13.3 columns, this specification does not apply		
	13.2 Basic test schedule applies	**13.3 Full test schedule applies**
Single stranded wire		
Wire material	Annealed copper (10% elongation at break)	other
Surface finish	tin, tin-lead, or silver, bare unplated	other
Wire dimension range	0.25 – 0.8 mm diameter [AWG# 30-20]	> 0.8 – 3.6 mm diameter [AWG# 20 -7]
Multi-stranded wire		
Base metal	7 stranded annealed copper (10% elongation at break)	other
Surface finish	tin, tin-lead, or silver	
Wire dimension range	0.075 – 0.5 mm^2 cross-sectional area [AWG# 28 – 20]	0.05 mm to >0.075 mm^2 and > 0.5 mm^2 to 10 mm^2 cross-sectional area [AWG# 30, 29, 19 – 7]
IDC Beams		
Base material	bronze, brass or beryllium copper	other
Surface finish	tin, tin-lead silver, gold, palladium, or their alloys	other

Table A1.2: **60352-3 13.2 Basic test schedule outline**		*** unless otherwise specified**
Initial Visual examination - ~5x magnification - dimension and quality of all samples		
First sample set		
Test phase	**Test exposure**	**measurement**
IDC Contact Resistance		1-5 mΩ delta permitted depending on wire type and coating
Bending of the wire	axial load on wire 5 - 10 % breaking strength of wire both directions 30, 60, 90° from vertical 90 as specified 10 cycles Visual inspection	no electrical discontinuity > 1 µsecond no wire damage
Rapid change in temperature	-55°C to 100°C 30 minute 5 cycles *	
Damp heat, cyclic	55°C 6 cycles, 2 variants *	
IDC Contact Resistance		1-5 mΩ delta permitted depending on wire type and coating
Second sample set		
Test phase	**Test exposure**	**measurement**
Transverse (wire) extraction force	25 - 50 mm/min	2-12 N minimum force depending on wire type and size
Additional testing for re-uesable IDC's only		
Test phase	**Test exposure**	**measurement**
Repeated Connection and Disconnection	specified # of cycles Fresh wire per cycle Largest wire for cycling, smallest wire for final	Check for damage
Transverse (wire) extraction force	25 - 50 mm/minute	2-12 N minimum force depending on wire type and size

Table A1.3: **60352-3 13.3 Full test schedule outline** *** unless otherwise specified**		
Initial examination ~5X mag. Visual evalution of dimension and quality of all samples		
Test sample Group A		
Test phase	**Test exposure**	**measurement**
Transverse (wire) extraction force	Head operation speed: 25 - 50 mm/minute	2-12 N minimum force depending on wire type and size
Test sample Group B		
Test phase	**Test exposure**	**measurement**
IDC contact resistance		1-5 mΩ delta permitted depending on wire type and coating
Bending of the wire	axial load on wire 5 - 10 % breaking strength of wire both directions 30, 60, 90° from vertical 90 as specified 10 cycles Visual inspection	no electrical discontinuity > 1 µsecond no wire damage
Electric Load and Temperature	100°C, 1000 hours, @ specified current *	
IDC contact resistance		1-5 mΩ delta permitted depending on wire type and coating
Test sample Group C		
Test phase	**Test exposure**	**measurement**
IDC contact resistance		1-5 mΩ delta permitted depending on wire type and coating
Vibration	Depending on design: 10 – 2000 Hz 50 – 200 m/s^2 (5 – 20 G) 0.35 to 1.5 mm amplitude Depending on design 3 axis 5 cycles per direction	no electrical discontinuity > 1 µsecond
Rapid change in temperature	-55°C to 100°C 30 minute 5 cycles *	
Climatic sequence		

Dry heat	100°C *	
Damp heat, cyclic, 1st cycle	55°C, 2 variants *	
Cold	-55°C *	
Damp heat, remaining cycles	55°C, 2 variants *	
IDC contact resistance		1-5 mΩ delta permitted depending on wire type and coating
Test sample Group D		
Test phase	**Test exposure**	**measurement**
IDC contact resistance		1-5 mΩ delta permitted depending on wire type and coating
Corrosion, industrial atmosphere	SO$_2$: 0.5 +/- 0.1 10-6 (vol/vol) H$_2$S: 0.1 +/- 0.02 10-6 (vol/vol) 25°C +/- 2°C 75 +/- 3% RH 10 days (240 hours) *	
IDC contact resistance		1-5 mΩ delta permitted depending on wire type and coating
Additional testing for re-useable IDC's only		
Initial examination ~5X mag. Visual evalution of dimension and quality of all samples		
Test phase	**Test exposure**	**measurement**
Repeated connection and Disconnection	specified # of cycles Fresh wire per cycle Largest wire for cycling, smallest wire for final	Check for damage
Test sample Group A (reuse-able repeat)		
Test sample Group C (reuse-able repeat)		
Test sample Group D (reuse-able repeat)		