Array Sockets and Connectors Using MicroSpring™ Technology

Nathan L. Tracy, Richard Rothenberger,
Charles Copper, Ned Corman, Gary Biddle,
Alexandra Matthews, Sean McCarthy

Tyco Electronics Corporation
Harrisburg, PA
ntracy@tycoelectronics.com

Biography

Nathan Tracy received his BS in Electrical Engineering from the University of Massachusetts, Dartmouth in 1982. The first 16 years of his career were spent in the RF and microwave industry, working at Tyco Electronics M/A-COM division. For the past two years he has worked in Tyco Electronics Technology Group, where he is an Applications Development Manager.

Richard Rothenberger received his Bachelor's in Mechanical Engineering from Rochester Institute of Technology in 1985, and his Juris Doctorate from Widener University in 1998. The first 12 years of his career included engineering and management experience in the machine design, product development and product management areas. For the past 3 years he has worked in the Tyco Electronics' Technology and Business Development Group as a Chief Technologist.

Charles Copper received his Ph.D. in mechanical engineering in 1993 from the University of Virginia. He has spent 7 years in the electrical connector industry working with the development engineering community. For the past year he has been with the Tyco Electronics Technology Group.

N. E. Corman holds a BS in Physics from Elizabethtown College and a Masters Degree in Engineering from Pennsylvania State University. He joined AMP in 1979 and has continued to work in contact physics related areas. Ned is a member of the technical staff in the Technology Group of Tyco Electronics.

Gary Biddle received his BS in Physics from the University of Florida and MS in Physics from Pennsylvania State University in 1986. He has worked 12 years in the RF and microwave department of AMP Tyco Electronics. He currently is a development engineer with the company.

Alexandra Matthews is currently a Product Development Engineer in the Tyco Electronics Technology group working on design and process innovation of new connector technologies. She received her B.S. degree in Mechanical Engineering from Lafayette College in 1996. That same year, she joined the Tyco Electronics M/A-COM division in Lowell, Massachusetts, where she worked with a team of engineers to establish a manufacturing line for RF and Microwave multi-chip assemblies.

Sean McCarthy received his BS, MS, and Ph.D. degrees in Electrical Engineering from Pennsylvania State University. He has served as a Development Engineer in Tyco Electronics' Technology Group since 1997.

Abstract

In the electronics industry there are a number of market factors driving the development of separable high density array connections for socketing components and interconnecting printed circuit boards. Many of the existing socket and connector technologies do not ideally address these needs. Finer pitch, lower height, improved electrical performance, lower mating force, higher durability, and industry standard manufacturing processes are required, to name a few. In addition, quick to market, economical prototyping and competitive production costs are

necessary. To meet this diverse set of requirements, a revolutionary, bondwire scale contact technology has been developed and applied to several types of interconnection products. This technology, as well as its associated fabrication process is easily customized for each application and is capable of contact pitches down to 0.5mm (0.019in) at 10 to 15 grams of normal (mating) force.

This paper will describe the process used to create reliable contact structures, including examples of process variables that can be altered to meet application specific mechanical and electrical performance requirements. The results of electrical and mechanical modeling of several contact geometries will be presented and discussed, as well as reliability test results and contact interface mechanics analysis. A concluding section will be devoted to a discussion of the practical application of this technology to interconnection products with examples of current applications and products in development.

Market Drivers

The electronics packaging industry is continuously evolving to meet higher and higher performance levels with more economical product costs. This drives a number of aspects of what many current and future interconnections will need to meet. Below are a few of the areas affected:

- **Pin count:** Higher levels of integration and greater bandwidth increase the number of signal and power connections that are required for a given device. There are devices on the market today that routinely have pin counts greater than 1000.
- **Finer pitch:** As pin count increases, there is a requirement to decrease pitch to minimize package size and reduce the amount of area required on the motherboard.
- **Lower mating force:** Increasing pin counts require that mating forces be reduced to minimize cost, size and complexity of the clamping hardware, and to minimize warpage as well as ensure the survivability of the printed circuit board that is being mated.
- **Reduce height:** To improve packaging of systems, such as notebook computers, the height of the interconnection must be minimized. In addition, reduced height helps to meet more demanding performance requirements by shortening the electrical connection.
- **Optimize electrical performance:** Due to increasing signal speeds from packaged device to motherboard, and faster power supply load transients, it is critical to improve/optimize the electrical performance of the contacts within the interconnect.
- **Optimize installation:** Tool-less installation, preferably ‘industry standard’ automation, decreases cost and improves throughput. Additionally, the surface finish of the motherboard should be a low cost industry standard such as tin-lead, or in the future, a lead free tin alloy.
- **Improve availability:** The interconnection technology should have a short design cycle and a ‘quick to deliver’ capability. This dictates that special manufacturing tooling must be eliminated or minimized so it does not impose unreasonable tolerances or special requirements. A software tooled technology would address this need. The production process must have high throughput capacity.

MicroSpring Technology

To meet these demands, Tyco Electronics is developing and evaluating several LGA (Land Grid Array) interconnect technologies because we believe that LGA is one of the most promising packaging styles to meet all of the aforementioned industry trends. One of the LGA concepts being developed for socketing is MicroSpring technology. MicroSpring technology is a revolutionary bondwire scale method of fabricating a metal contact that differs in several ways from conventional stamped and formed contacts. MicroSpring sockets and connectors offer a number of features that benefit each of the market drivers mentioned above. Some of these features include the following:

- Reduced normal forces: 10 to 15 grams per contact
- Fine pitch: Down to 0.5 mm
- Low profile: Down to 0.7 mm
- High pin counts: Greater than 2500 contacts per array
- Ease of use: Pick and place, SMT (Surface Mount Technology) attach
- Availability: Significantly software tooled

Details on how these features are achieved are discussed below.

Background

FormFactor, Inc. in Livermore, CA, initially invented the patented MicroSpring technology for use on semiconductor wafer probe cards[1]. The needs of wafer probing (dense contact array, pitch below 0.25mm (.01in), etc.) drove FormFactor to create a contact fabrication technique that is wirebonder based. This enables them to leverage an existing manufacturing infrastructure, and achieve all the objectives necessary for wafer probing. FormFactor has provided MicroSpring probe cards to the semiconductor industry for over four years, with some of the probe cards seeing over 2 million touchdowns (mating cycles). To date there has been no identified wear-out mechanism, and FormFactor now provides MicroSpring probe cards with a lifetime warranty[2].

Fabrication Process

A Tyco Electronics MicroSpring LGA socket is shown in Figure 1. Figure 2 shows a drawing of a typical socket cross-section, and Figure 3 shows an electron microscope image of an array of individual MicroSpring contacts. Note that the socket provides a LGA interface to the component to be socketed and a conventional SMT BGA (Ball Grid Array) interface to the system motherboard.

Figure 1

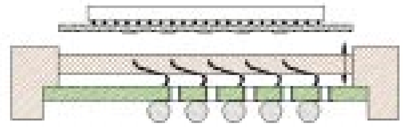

Figure 2

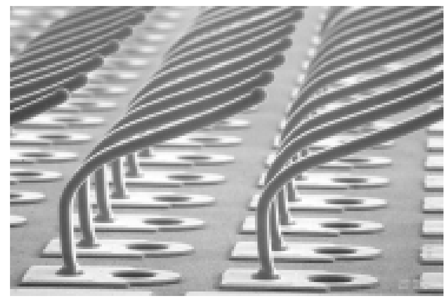

Figure 3

The process of creating a MicroSpring array is as follows:

1. A printed circuit board is fabricated with the appropriate array pattern of pads on the top and bottom. Each top pad is connected to its corresponding bottom pad with a plated via. The pads are configured according to the desired array pattern (example: 19 rows by 25 columns, 475 positions, 1.27mm pitch). Several of these arrays can be fabricated on a single printed circuit board panel.
2. The printed circuit board panel is loaded into a specially configured wire bonder, which creates a wire bond on a top side pad. Using software, it creates a spring shape in free space, and then cuts the wire at a precisely controlled height. It then indexes to the next pad location and repeats. When the wire bonder is finished, an entire panel of array spring shapes has been created. The wire bond material currently being used is gold in either rectangular or round cross-section, but could be any wirebondable material. The wire bond process is fully automatic and runs at speeds of 2 to 12 bonds per second, depending on wire-shape and bonder.
3. The fully populated panel moves to the plating process, where the wire bond spring

shapes are heavily plated with a nickel alloy, which provides the mechanical spring properties. This plating thickness can be varied depending on the contact's cross section and its desired characteristics. After the nickel alloy, gold is plated as the top surface metal.

4. The next process is solder ball placement and attach. This is performed using existing high volume, automated equipment.
5. Following ball attach, the panel of MicroSpring arrays is singulated into individual arrays, and a molded contact protector is attached to each array. The contact protector functions to protect the contact array during packaging, shipping, pick and place, etc. and also acts to align the component to be mated (example: a microprocessor) to the array contacts. When the component to be mated with the array is installed, the contact protector 'floats' downward to allow the contact tips to mate with the component. The contact protector also acts as a positive compression stop.
6. The final process step is test and inspection, where we test the arrays for short and open circuits, and inspect for coplanarity.

It is important to note that the majority of the fabrication process is software tooled and easily modified on a requirement by requirement basis. The spring shape is controlled by a software program that loads a spring profile into the wirebonder. By modifying this profile, we can easily tailor both mechanical and electrical performance of the contact using well-known connector design procedures. The mechanical properties are also significantly affected by the plating process and can be altered by increasing or decreasing the plating thickness. Also, plating multiple layers of multiple materials can achieve customized electrical properties.

The same wire bonders are used for bonding both round and rectangular cross-section wire, regardless of contact pitch. This process is controlled by programming so that entirely different contact arrays can easily be produced with software changes.

The contact protector is a simple molded polymer component that does not require extremely tight tolerances. For quick prototypes there are various existing rapid prototyping methods from which to choose, and for low volume requirements, we have successfully used 'soft' metal molds that are quickly machined.

Analysis of MicroSpring Contacts

Since MicroSpring Technology differs in fabrication, materials, and interface mechanics from traditional connectors, an in-depth analysis to validate its application in production sockets and connectors has been performed. The following are a series of discussions on that analysis.

Mechanical Analysis of MicroSpring Contacts

MicroSpring contacts provide substantially lower contact forces than traditional designs and use an electroplated Ni-alloy as the primary spring material. These differences require analysis of the mechanical stability of the electrical interface and an understanding of the structural performance of an electroplated alloy. This analysis pertains to a contact beam of rectangular cross-section, although many cross-sections are possible.

Z-axis Deflection

Figure 4 shows the rectangular cross-section geometry that was analyzed and modeled, while Figure 5 shows the force vs. deflection behavior of the design. The contact spring is a cantilever structure that is fixed at the base and free at the tip.

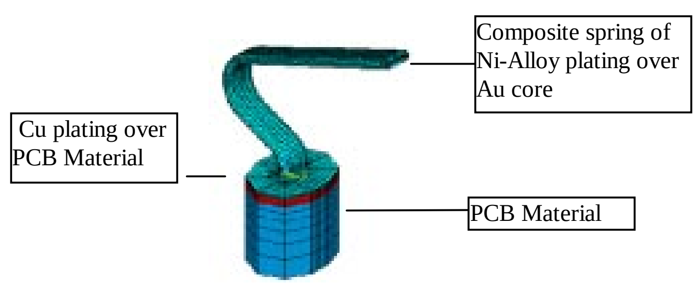

Figure 4

The variation in Ni-alloy plating thickness has the largest impact on spring force behavior. To investigate this variation, numerical models of the spring were used to predict the spring behavior for the minimum 22µm (micrometer) (866.14µin), average 23.5µm (925.2µin) and maximum 25µm (984.25µin) plating thickness.

In the figure below, measurements from a typical spring are included with the numerical predictions. The correlation between model and actual testing is reasonable, which validates the model for connector design purposes.

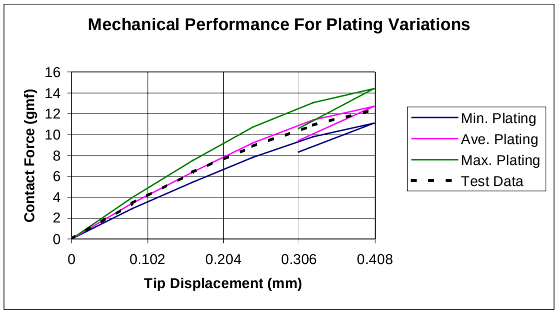

Figure 5

Figures 6A and 6B indicate the relationship between contact vertical deflection and contact wipe. At approximately 0.4mm (0.016in) of vertical contact tip deflection the contact tip will wipe the interface area about 0.2mm (0.008in). As will be discussed later in this paper, at least 0.025mm (0.001in) of wipe is important for displacing contaminants and films that may be present on the contact surface of the chip carrier. As Figure 6B indicates, 0.025mm (0.001in) of wipe is readily obtained.

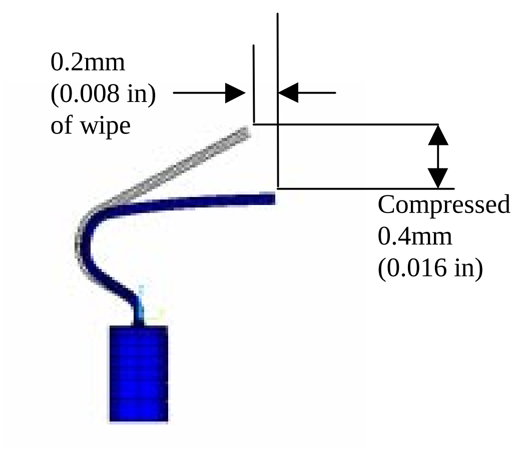

Figure 6A

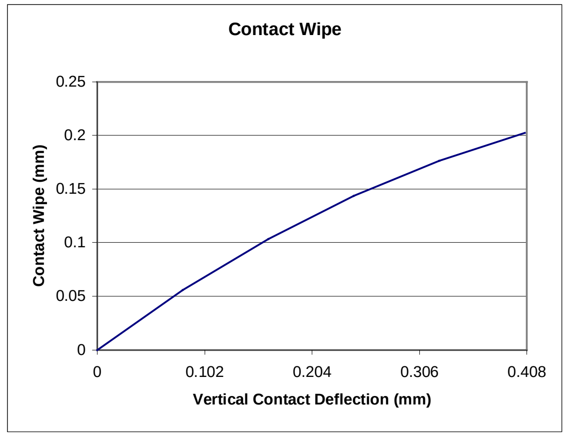

Figure 6B

Mechanical Stress Analysis

As shown in Figure 7, mechanical finite element modeling indicates that the contact spring exhibits generally elastic behavior, with the exception of a small region of plasticity in the "knee" area of the contact. This design minimizes the plastic strain present at the printed circuit board interface.

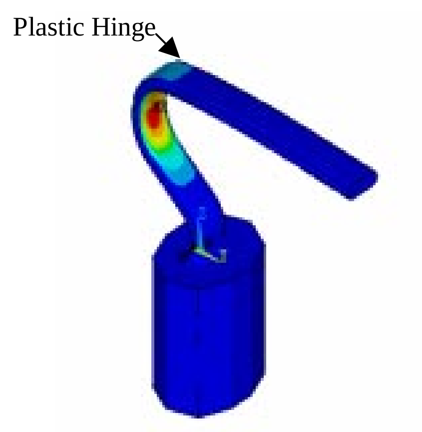

Figure 7: Contour plot of plastic strain

Low Force Contact Resistance Analysis of MicroSpring Contacts

Traditionally, 100g normal force has been recommended as a design requirement for gold contacts. This normal force reasonably assured reliable contact even to contaminated gold surfaces and mechanical robustness of the contact/connector system. As connector size and contact density requirements have changed, this design requirement has been challenged.

Presently, successful designs are available with normal forces from 50 to 100g. Thirty grams normal force is sufficient to establish electrical contact for reasonably clean gold surfaces.[3] This analysis will explore the contact resistance of a 10g normal force system.

Examples of a Socket and a MicroSpring contact array were previously shown in Figures 1 and 2. The contact normal force is a minimum of 10g/spring. Mechanical clamping of the system is provided by the socket housing and mounting hardware.

Validation Tests:

Typical qualification tests were run using a 475 position, 1.27mm pitch MicroSpring socket which daisy chained the contacts into 4 sections of the socket. Voltage leads on the test board allowed resistance readings to be made for contacts grouped in pairs. The tests consisted of Temperature Life (1000 hr. @ 105 C), Thermal Cycling (1000 cycles from –55 C to 125 C), Vibration and Physical Shock and MFG (Mixed Flowing Gas) Exposure (ClassIIa for 14 days). The result of this testing is summarized in Figures 8A and B. Plot 8A shows the range of measured resistances for the contact pairs before and after testing. Plot 8B shows the range of resistance changes per pair after the testing. There were 780 contacts measured for each Physical Shock/Vibration and Temperature Life, 312 contacts for MFG, and 1500 contacts measured during Thermal Cycling.

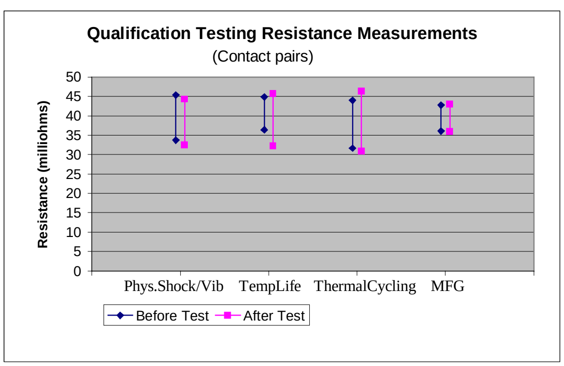

Figure 8A

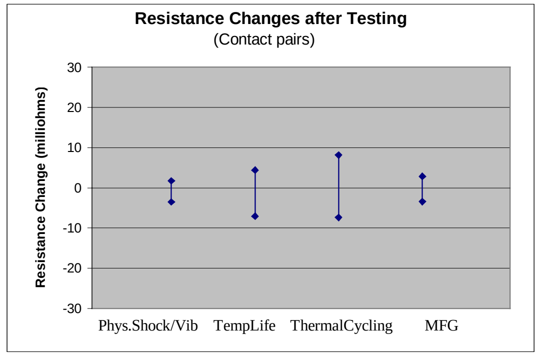

Figure 8B

Film Penetration:

In the ideal world of clean gold surfaces, 10g normal force is sufficient to produce low and repeatable contact resistance regardless of contact geometry. However, it is not realistic to expect clean surfaces in actual use. A series of tests were run to evaluate the effectiveness of the MicroSpring tip geometry for film penetration.

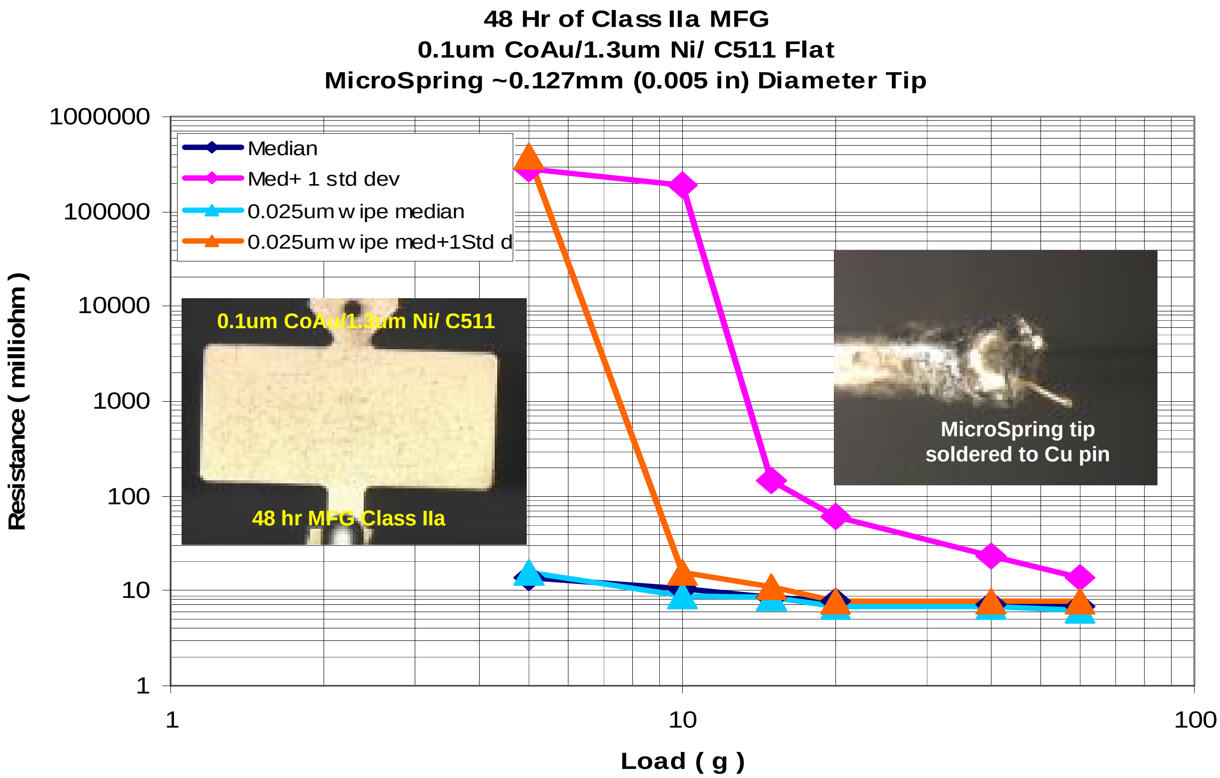

Figure 9

MicroSpring tip geometry consists of an approximate 0.127mm (0.005in) diameter with an average roughness (r_a) of 0.2µm (8µin) or less. A flat coupon plated with 0.1µm (4µin) hard gold was exposed to 48hr of MFG ClassIIa. This exposure is known to produce pore corrosion films on the surface of the flat which cause an increase in the measured contact resistance. MicroSpring contacts were removed from their array and soldered to the tip of a copper pin. The pin was in turn mounted in an automated contact resistance probe. This arrangement allowed electrical connection to the MicroSpring contact with a minimum of bulk resistance. It also shortened the MicroSpring length, which made it possible to measure resistance up to 60g normal force. A series of measurements were made at normal force levels of 5, 10, 15, 20, 40 and 60 grams. At each force level, the contact was wiped 0.025mm (0.001in), and then from 0.05mm (0.002in) to 0.254mm (0.010in) in 0.05mm (0.002in) increments. Each measurement utilized a new contact and a new location on the flat. Six measurements were made at each force level. The results are shown in Figure 9.

Figure 9 shows an inset picture of the corrosion on the gold flat and the Cu pin with a MicroSpring tip soldered to the end. The first set of data curves shows the median and the median plus one standard deviation with no wipe. The median shows the basic trend while the median plus one standard deviation shows the spread in the data. As one would expect for a film-covered surface, a significant level of variability is evident even at the 60g level. The second set of data curves is the median and the median plus one standard deviation with 0.025mm (0.001in) of wipe. In this case the resistance drops significantly at 10g normal force. Additional wipe distance had only a marginal effect and is not included in the figure. Therefore penetration of these films at 10g normal force is the result of the combination of the sharp tip geometry and at least 0.025mm (0.001in) wipe.

Friction Coefficient:

The mechanical stability of the contact interface will be influenced by the normal force and the friction coefficient. The friction coefficient was measured using a MicroSpring contact against three different gold plated pads. The pads were 0.76µm (30µin) CoAu with an average surface roughness of 0.66µm (26µin) over Ni on a BT (bismaleimide triazine) substrate, 0.22µm (9µin) Soft Au with an average surface area roughness of 0.48μm (19μin) over Ni on a BT substrate and 0.76μm (30μin) Au with an average surface area roughness of 1.5μm (59μin) over Ni on a ceramic substrate. The tests were done with 10g normal force. Each test was run with a fresh contact and pad. The sliding distance was approximately .5mm (0.020in). It took 6 seconds to complete one full cycle. The friction coefficient for the hard gold pad ranged from 0.2 to 0.25 and was relatively constant over 10 sliding cycles. The friction coefficient for the soft gold was approximately 0.4 and also was relatively constant over 10 sliding cycles. For the ceramic substrate gold pad, the coefficient ranged initially between 0.35 and 0.5, and decreased to a value between 0.2 to 0.3 after 5 to 8 sliding cycles. There was no visible track on the hard or soft gold pads on the BT substrate after the friction tests. The ceramic substrate gold pad had a distinct wear track. This wear track and corresponding high initial friction coefficient are most likely the result of the surface roughness on these pads.

Summary of Low Force Contact Resistance Testing:

- Validation tests have demonstrated the viability of this system.
- The MicroSpring contact with its approximate 0.127mm (0.005in) diameter tip has film penetration ability with 10g of normal force and at least 0.025mm (0.001in) wipe.
- Friction coefficients for the MicroSpring contact tip at 10g load levels are similar to friction coefficients measured for other gold plated contact systems

Electrical Performance Modeling Analysis of MicroSpring Contacts

With today's system designers looking at faster speeds and tighter line to line spacing, board level interconnections are becoming more critical. No longer can the interconnection be ignored; it must be factored into the performance of the entire system. One must consider impedance profiles and mutual coupling factors within the interconnections to control crosstalk, skew, and signal transmission. The MicroSpring contact design offers a new contact technology to ensure signal integrity in this ever-changing and demanding world.

MicroSpring contacts allow greater flexibility than ever before for tuning the electrical performance of an interconnection device. Flexibility is achieved by utilizing software tooled fabrication methods, allowing maximum design optimization. As an example of this flexibility, 4 contact geometries were evaluated for electrical performance by generating models. The four geometries are shown in Figure 10.

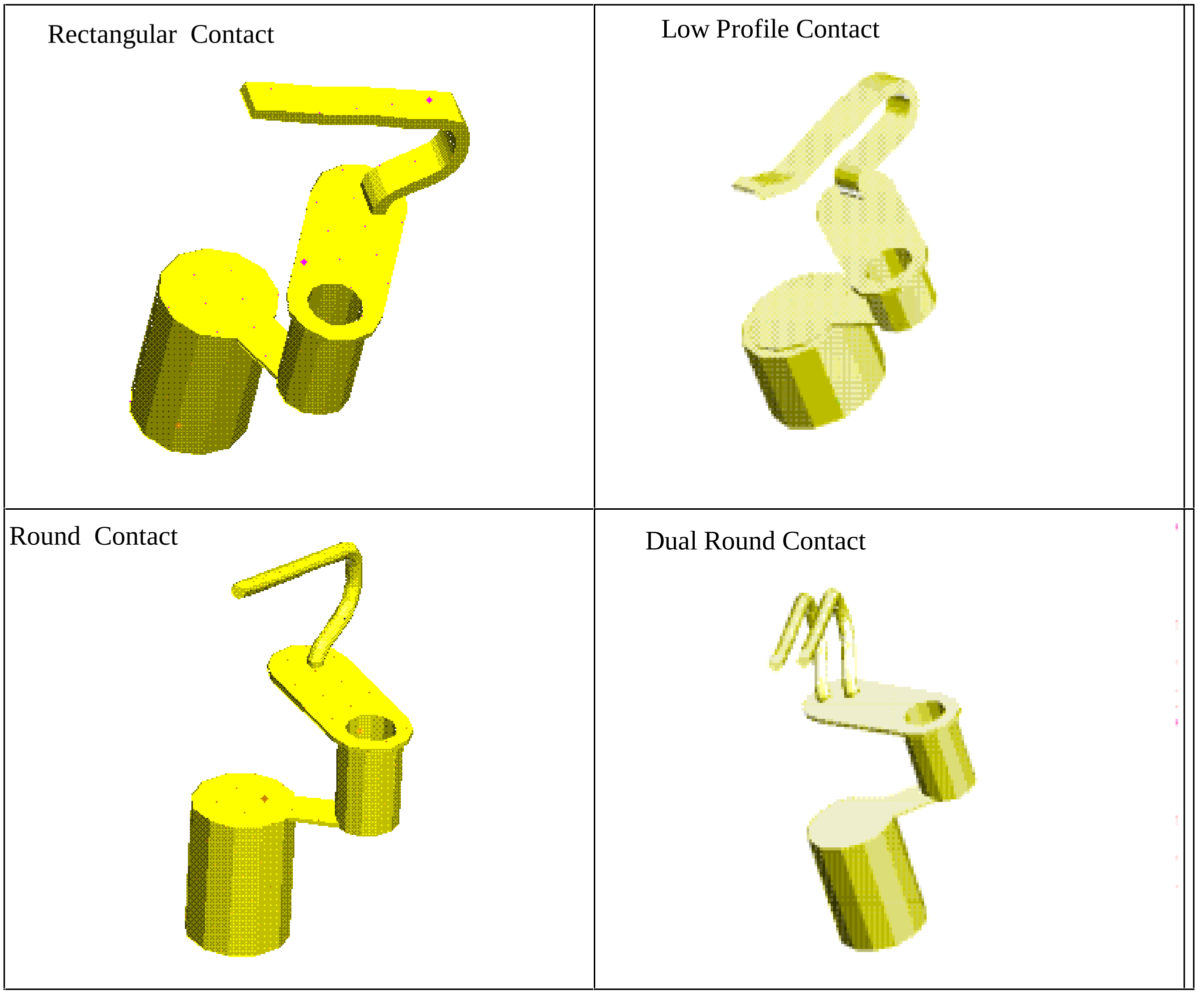

Figure 10

MicroSpring Interconnection Simulation Methodology

Simulation of the interconnection begins with the construction of a physical model. The physical model must contain the electrical path for each contact and the connector body. The contacts are fabricated on a printed circuit board containing a via hole. The electrical path for the MicroSpring contact, such as Figure 11, has the spring member attached to a pad which utilizes a via to access the bottom of the board.

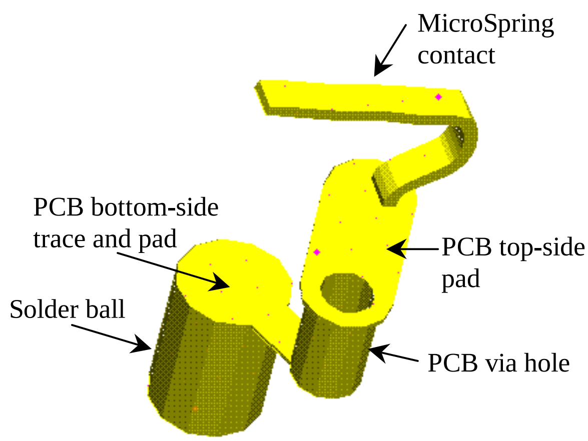

Figure 11 MicroSpring Contact Application

The lower side of the board contains a short strip and pad to which a solder ball is attached (0.9mm (0.035in) height, in this example). The circuit path is the tip of the spring member to the bottom of the solder ball. The physical model is imported into an electromagnetic field solver to determine the inductance and capacitance matrices.

Figure 12 below illustrates nine MicroSpring contacts assembled into a 3 x 3 matrix body on a 1.27 mm pitch.

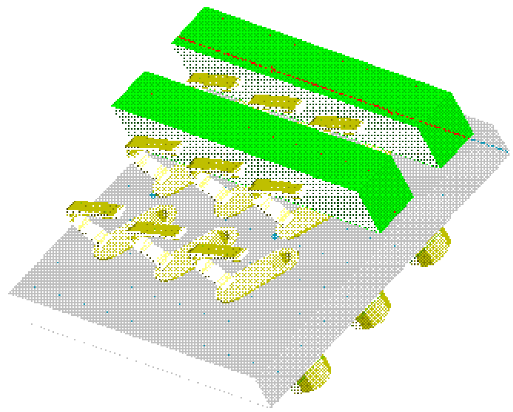

Figure 12 3x3 MicroSpring matrix

Two of the contact protector bars have been removed for illustrative purpose, as four bars exist in the model. It is necessary to include all geometrical dimensions and material properties to yield the correct matrices. The field solver computes all of the self and mutual terms for the matrix. When possible, capacitance and inductance matrices are validated with experimental results. Fixtures were created for the rectangular contacts and inductance measurements have been made that validate the model.

The system designer community will incorporate the inductance and capacitance matrices in their own system circuit simulations to evaluate signal integrity performance. The interconnection will become an integral part of the system simulation. The designer will determine how the matrices will be used, which contacts will be active, which contacts will be quiet, which contacts will be grounded, and the signal characteristics. The performance of the interconnection can be quantified in terms of impedance, crosstalk, skew, propagation delay, and signal transmission.

This simulation methodology was used to develop the physical model and inductance and capacitance matrices for all four MicroSpring contact geometries shown previously in Figure 10.

Discussion of Results

As mentioned above, the complete inductance and capacitance matrices are of prime importance to system designers. However, the component level parameters can be viewed separately to indicate their merit.

One may extract self-inductance and loop inductance from the inductance matrix. The self-inductance for an individual MicroSpring contact segment only is shown in Figure 13 as "Self Ind. Contact." This would be from the contact's tip to where it is bonded to the board pad. In contrast, the self-inductance for the entire contact path, as shown in Figure 11, is labeled in Figure 13 as "Self Ind. Complete."

The loop inductance and mutual inductance terms for two contacts using the center contact and an adjacent contact are also shown in Figure 13. The loop and mutual values include the entire contact path (which includes the solder ball height).

With regard to capacitance, similar terms can be extracted from the capacitance matrix. The capacitance of the center contact as well as the mutual capacitance terms between the center contact and adjacent 1.27mm (0.05 in) neighbors are shown in Figure 13. Two values are provided for mutual capacitance, one for the side adjacent contact and one for the vertical adjacent contact.

Contact Type	Self Ind. Contact	Self Ind. Complete	Loop Inductance	Mutual Inductance	Capacitance	Mutual Capacitance
Rectangular	0.83 nH	1.68 nH	2.60 nH	0.38 nH	0.245 pF	0.041 & 0.051 pF
Low Profile	0.65 nH	1.05 nH	1.80 nH	0.15 nH	0.25 pF	0.038 & 0.042 pF
Round	0.95 nH	1.88 nH	2.98 nH	0.39 nH	0.23 pF	0.039 & 0.049 pF
Dual Round	0.7 nH	1.62 nH	2.47 nH	0.38 nH	0.25 pF	0.052 & 0.044 pF

Figure 13

The modeled performance in Table 13 is not meant to represent the performance limits of MicroSpring contact technology, but merely to show typical variation that can be achieved with four representative contact configurations. Currently, new contact shapes have been modeled with loop inductance of less than 1nH.

Technology Applications

Due to its ease of configuration and lack of required tooling, the MicroSpring contact is versatile and has many potential applications. One of the first areas being pursued with product design and hardware is LGA sockets, although many other areas have been identified such as test sockets and contacts for PCBs, IC packages, packaged ICs, Burn In sockets for packaged ICs, Engineering Bring-up sockets, high density board to board array connectors, etc.

Tyco Electronics is currently using MicroSpring technology to produce sockets that have heights varying from 2.36 to 1.73 mm (0.093 to 0.068in) tall (height from the top of the motherboard to the bottom of the LGA component being socketed).

Height is dependent on the size of the solder ball being used and the MicroSpring contact geometry. Currently there are several versions of LGA sockets going into production this year.

In addition, there are specific efforts being made to develop low profile versions of MicroSpring sockets. A technology demonstration was completed at FormFactor with a 0.7mm (0.027in) socket height, and Tyco Electronics is continuing a similar effort with the objective of a 0.7mm (0.027in) height production version later this year. The low height version offers two advantages, one being lower profile for applications such as notebook computers, and the second being improved electrical performance due to the shorter electrical path. Low profile techniques include unconventional spring geometries and alternative printed circuit board materials.

Another concept being developed to leverage MicroSpring sockets is that of pitch spreading in the socket. This concept utilizes the printed circuit board that is already present in the socket, except more layers are added to perform some degree of routing within the socket. The semiconductor packaging industry has the production capability today to economically work at much finer pitches than the motherboard industry. The MicroSpring contact array also has the ability to be produced at very fine pitches. By leveraging the routing within the socket, we can produce sockets that have very fine pitches on the top side (LGA) to interface with the semiconductor packaging, and conventional pitches on the bottom (BGA) to interface with the motherboard. This concept has the potential to reduce semiconductor package costs (smaller size), and minimize motherboard costs (less layers). In addition, passive components can be mounted on the socket or even embedded into it. Figure 14 illustrates this concept. In the case of a very high pin count ASIC going onto a large printed circuit board panel in the communication industry's routers and switches, this motherboard layer count reduction can be significant.

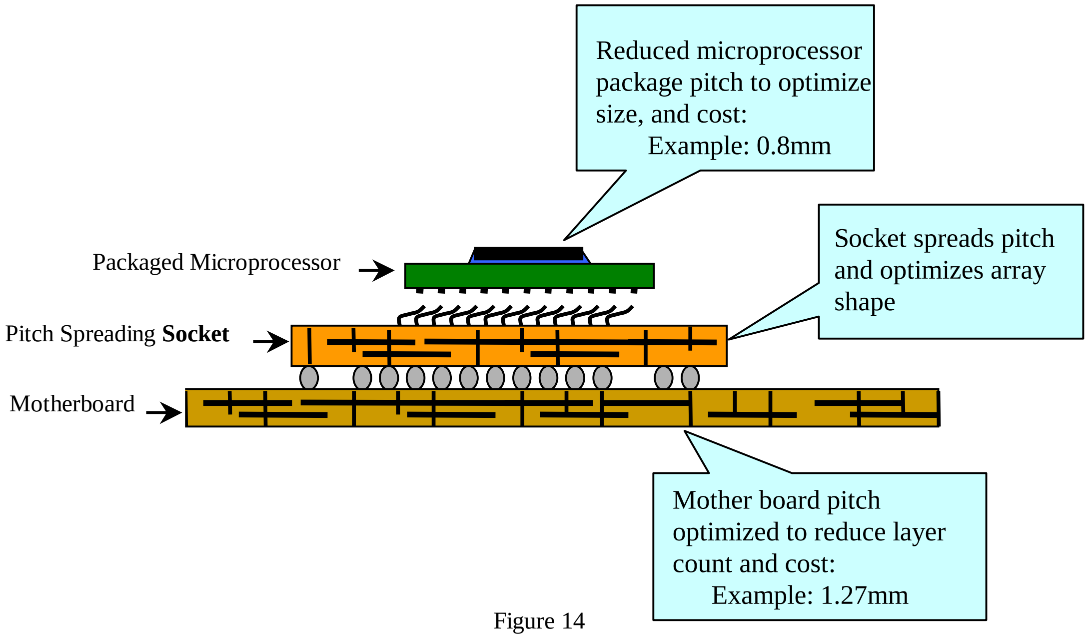

Figure 14

This same concept can be applied to achieve a socket that could accept multiple chips and perform the high speed chip to chip routing in the socket, so the larger motherboard is not affected by routing high speed signals and the associated costs (lower yields, unfamiliar design rules, etc.).

Summary

MicroSpring technology has been extensively analyzed and tested at Tyco Electronics to prove its applicability to high reliability production sockets. The manufacturing steps leverage existing high volume processes that are proven to be economical. The technology is flexible enough to meet custom requirements, and to be quick to market. It offers low normal force, fine pitch, high pin count arrays, all of which are needed for current and future microelectronic packages. These attributes also promise to provide creative solutions to other packaging dilemmas where performance, size, cost, and time to market all stretch traditional approaches beyond their limits.

The authors wish to acknowledge the efforts of Kim Beach, Terry Shingara, David Rickert, Keith Murr, Steven Jarrett, Jerry Bogar, Billie Beauregard and Kelly Yingst of Tyco Electronics for their contributions in completing this paper and John Novitsky, Tom Dozier, and John Eiman of FormFactor, Inc. for their assistance with test samples, and duplication of the MicroSpring contact fabrication process at Tyco Electronics.

---

[1] FormFactor Patent numbers: 5,917,707, 5,772,451 et al.
[2] Yield Enhancing Probe Cards, FormFactor, Inc. Sales Literature
[3] Gold vs. Tin on Connector Contacts, J.H. Whitley, AMP Inc. P140-74