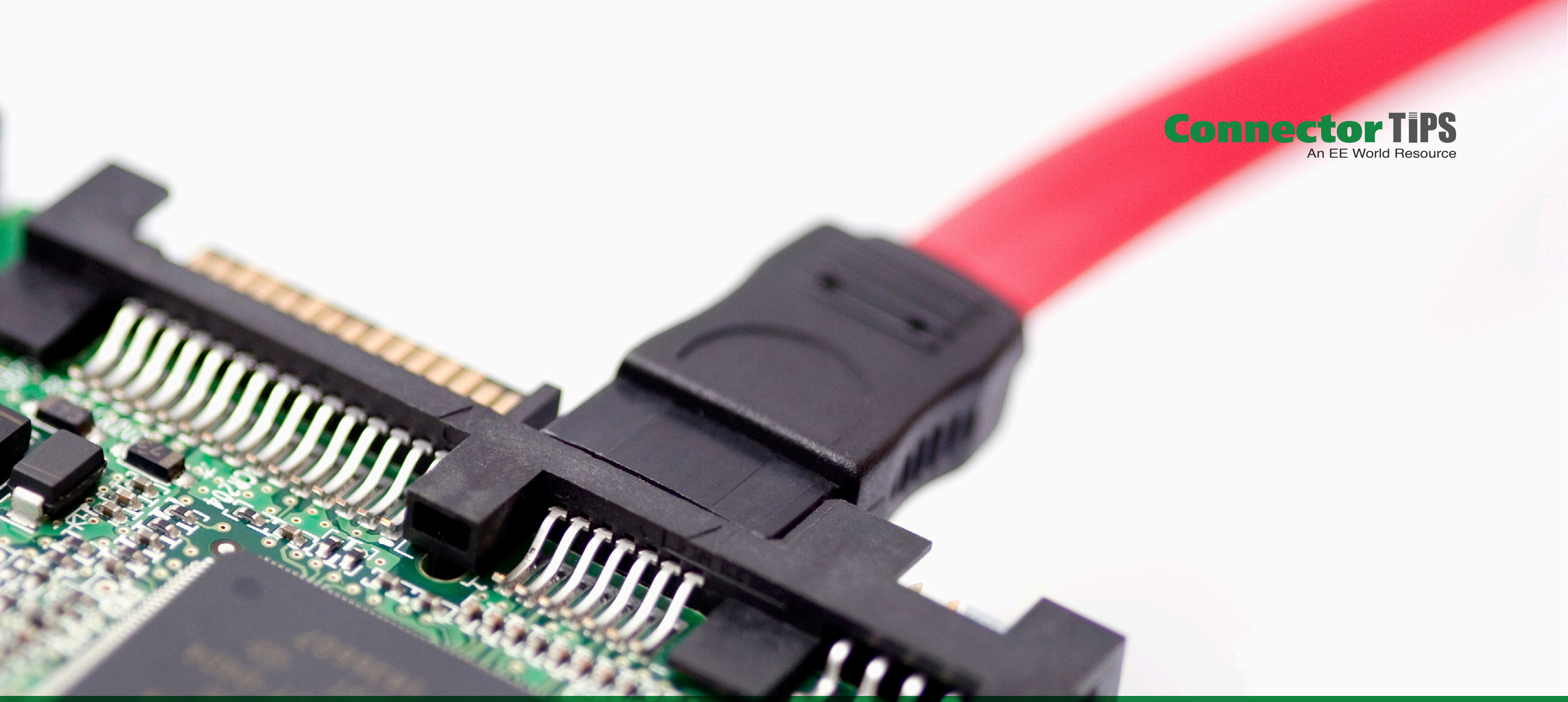


CONNECTOR TIPS DESIGN GUIDE

CONNECTOR BASICS

Design engineers tasked with specifying interconnect components, including wire-to-wire, board-to-board and wire-to-board designs must understand the many types of components available. The editors of *Design World* & EE World Online present some of the most commonly asked questions in this exclusive white paper–from the different mating options to contact types and materials down to the dangers of using counterfeit designs.

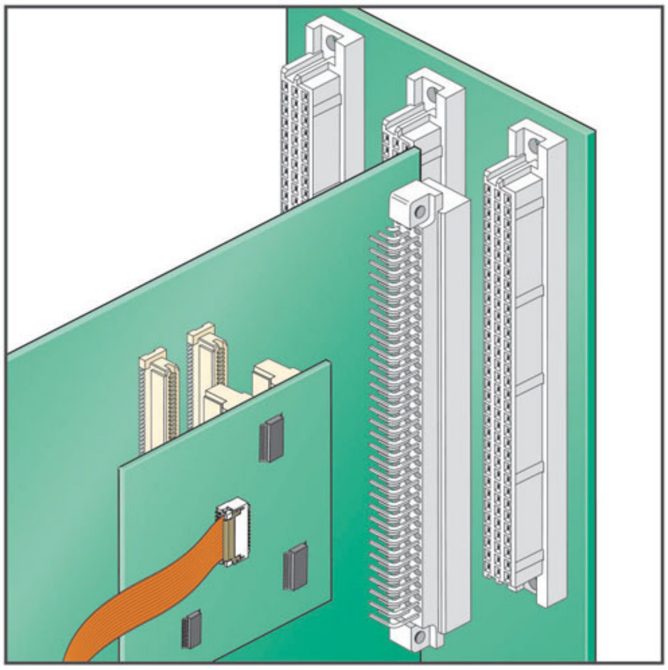
TABLE OF CONTENTS

Why have connectors at all? 2
Wave Solder vs. Press Fit vs. SMT........................ 4
What makes contact beams work in connector designs? 6
Why use compliant pins in connector designs? 8
What are the benefits of spring-loaded contacts? 10
What are horizontal mount interconnects? 12
When should you use floating pin technology? 14
How much gold is enough in connector designs 15
Gold alternatives in connector designs 17
Are tin-plated connectors OK for my application? 19

Why have connectors at all?

Wouldn't system design be a lot easier if everything were in one box, on one board? The schematic becomes the board design and the world can be much simpler. One pass through the SMT line, test the box, and ship. Connectors seem to only complicate the situation because they:

- Add a point of failure in the system
- Complicate system design and can lengthen design cycles
- Cost money
- Need to be applied to the board or cables, adding additional cost and complexity
- Add to the bill of materials to be procured, stored, and potentially scrapped if a design is changed



An illustration showing a FFC/FPC connector on a mezzanine board. *Illustration courtesy of Cleaver Brinkerhoff.*

A very wise man, Don Wilson, formerly of Bellcore, the organization that for many years wrote standards for telecom connectors, gave me the best answer to this question I have ever heard:

It is desirable to partition systems into pluggable units because it allows:

- Board manufacturers to sell their boards into many different systems.
- The systems engineer to specify boards with the functionality he needs
- The purchasing department can source boards from multiple suppliers, assuring competitive pricing and continuity of supply

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The system can be offered in configurations that best match the needs of the end user, such as:

- Processors
- IO (Input Output) configurations
- Cabinet size and configuration
- Memory and hard drive options

Having pluggable units also facilitates system trouble-shooting, repair and spare inventory because:

- Most users can remove and replace a pluggable unit. If it works, it is fixed. If not, you move on to the next step on the troubleshooting list.
- A few processor spares or memory cards can support an entire Google size data center, minimizing down time and cost.

The pluggable units can have dramatically different manufacturing processes, such as:

- Some boards are high layer count with complex functions
- Others are very simple and cheap to make—maybe even an off-the-shelf commodity
- Cables come from different sources than boards
- Cables can be copper or fiber
- Cable lengths can be selected for proper fit

It often happens that a design is optimized for semiconductors that are still in development. Having these chips on pluggable units allows the OEM to plug in boards with current technology now, upgrading to the latest and greatest semiconductors when they are released and proven to work.

Fear of failure is a major driver for any designer. By designing with pluggable modules, risk is greatly reduced, ensuring that you meet time-to-market targets while still having the advantage of plugging in the latest and greatest technology as it becomes available.

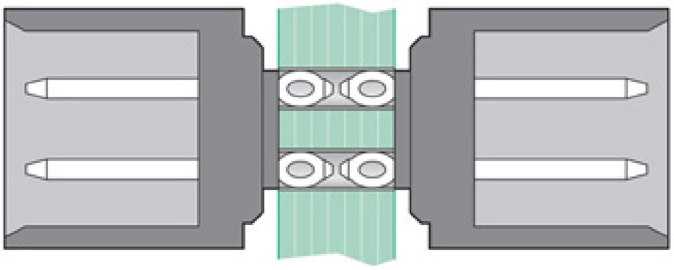
Don described connectors as "Disconnectors" that allow for optimizing system design to best match the needs of the end application. Without disconnectors, there would be a lot more design time, risk for time-to-market, quality, and cost. I guess connectors will be around for a while longer.

Wave Solder vs. Press Fit vs. SMT

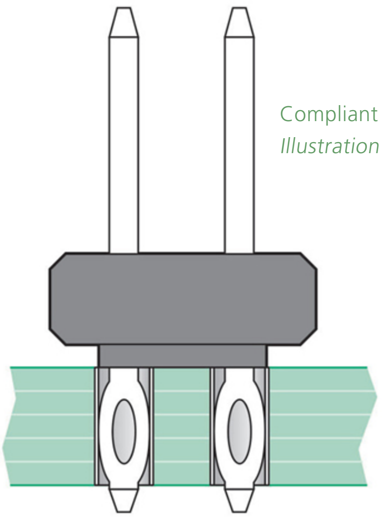
Many board-to-board connectors are available in three different versions to meet the needs of a broad range of system designs. This article will discuss some of the considerations that are important to making the right connector technology choice for your design.

First, let's address the obvious:

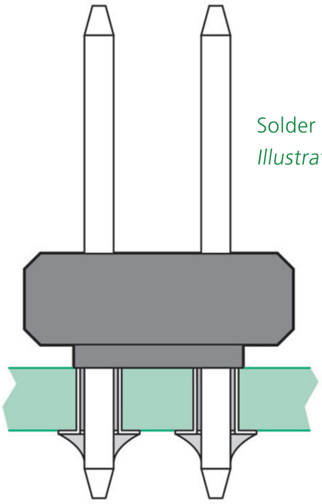
Backplanes nearly always use press fit connectors because:
• Thick backplanes can be damaged by the thermal excursion during either wave or SMT processes that can cause the layers in the board to heat unevenly, potentially breaking plated through holes.
• To avoid thermal exposure nearly every connector you might use on your backplane is available with compliant press fit pins.
• Compliant press fit pins have formed features that create gas-tight joints by acting as springs pressing outward against the barrel of the plated through hole. The plated through holes used in backplanes must be tightly controlled with greater diametric precision than other boards. In addition, the aspect ratios (length of the plated through hole relative to the diameter of the drilled hole) tend to be high. Backplanes are generally procured from a specialized supplier.
• Connectors can be pressed into the front of a backplane, into the rear, or both, with short compliant pins sharing a common hole. Because printed circuit boards (PCBs) in general have a ±10% thicknes dimension, pressing short compliant pins into both sides eases system complexity by decoupling the tolerance set in front of the backplane from the tolerance set for boards or cables in the rear.



Compliant pins share plated through holes in a mid plane.
Illustration courtesy of Cleaver Brinkerhoff.



Compliant press fit pins.
Illustration courtesy of Cleaver Brinkerhoff.



Solder tail PCB joint showing solder fillets.
Illustration courtesy of Cleaver Brinkerhoff.

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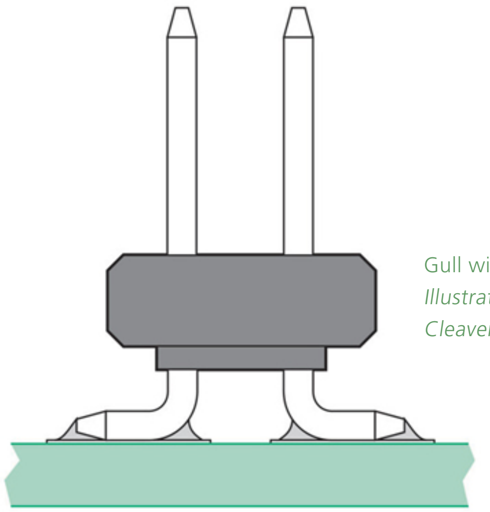


Gull wing SMT tails.
Illustration courtesy of Cleaver Brinkerhoff.

Boards that only see a wave solder process should use wave soldered connectors:

- Wave soldered joints remain the strongest possible solder joints.
- You do need to take care, however, that the portion of the tail protruding from the bottom of the board is the right length. Therefore, connector companies offer many different solder tail options for solder tail connectors. In general terms, choose a lead length that protrudes from the board at the maximum thickness range, and does not solder bridge to the adjacent lead on a board at the minimum thickness range. Do the math. Solder filets generally create a tent at 45° from the pin tip. Adjacent tents cannot touch.

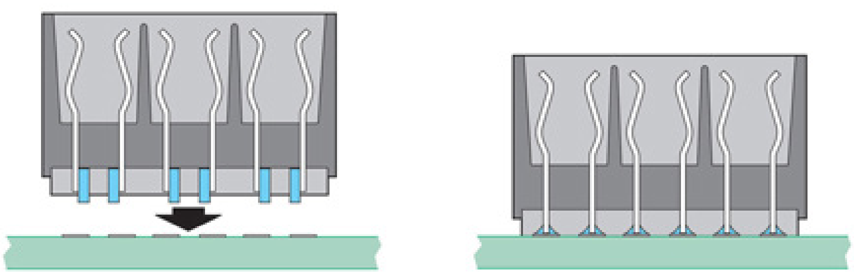
Boards that are totally SMT:

- SMT connectors on SMT boards eliminte the need for additional operations, either press fit or wave.
- One- or two-row SMT connectors are normally quite production-friendly, with the solder tails exposed for easy soldering and inspection. Connectors with more than two rows have concealed solder joints that are difficult to inspect and repair. Multi-row SMT connectors will need a solder ball or solder charge combined with very well controlled solder profile to achieve high production yields. X-ray inspection may be required.
- Signal integrity can be excellent for both SMT connectors and press fit connectors using very small plated through holes.
- Sometimes it is possible to populate SMT components in the connector shadow on the other side of the board. Using a press fit connector usually wastes the space on the other side.

Press fit connectors on SMT boards also have their place:

- Solder_Charge-images-combined
- Press fit connectors can be placed in the middle of an SMT board.
- Feed-through pins can enable stacking of multiple boards.
- Avoid issues with thermal mismatch for very large connectors.
- Create a strong right-angle connector interface that is less vulnerable to abuse during mating and unmating.

When choosing a connector technology, consider the production consequences of your choice as well as the signal integrity and mechanical robustness of your design.



SMT connectors soldered to surface pads on boards.
Illustration courtesy of Cleaver Brinkerhoff.

What makes contact beams work in connector designs

Beam design is a very important part of the job of any connector design engineer. Not being an engineer myself, I will grossly oversimplify, but I hope you will find the conclusions to be helpful and satisfying.

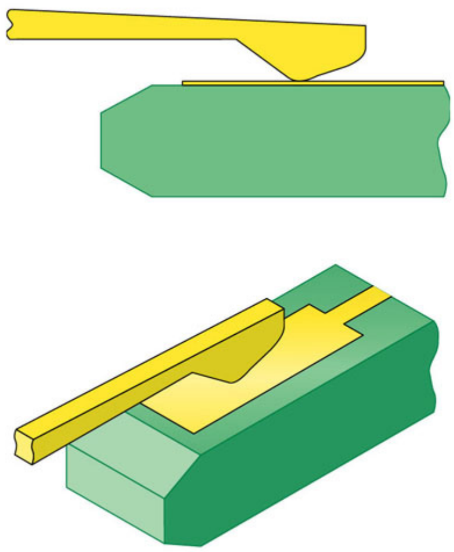
Beams need to perform a couple of functions, including:

- Contact must have lead-in to ensure the parts mate smoothly and completely
- Deflection of the beam when mated creates contact normal force that is sufficient to ensure good electrical contact under all mating conditions.
- This beam deflection also provides added mating tolerance

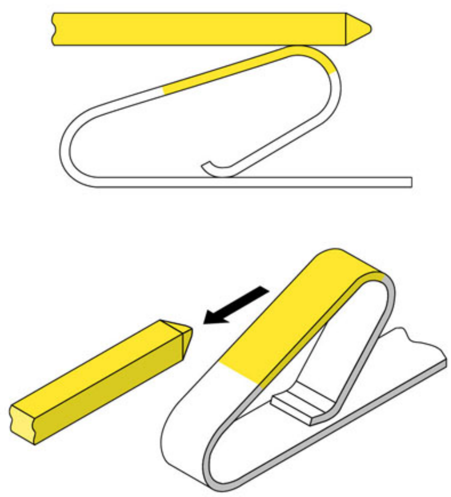
I told you I would oversimplify. Achieving these functions under all conditions throughout the life of the connector is far from trivial. Design engineers first need to choose an appropriate contact material that has the right spring properties. There are hundreds of copper alloy formulations in the metals catalogs, each having different compromises for machine ability, formability, conductivity, spring characteristics, and corrosion resistance. Connector contacts must not degrade during their life when exposed to heat.

For example, automotive engine compartment connectors need to withstand continuous exposure to temperatures up to 140°C. The designer must also choose contact materials that are safe during manufacturing, normal use, and disposal.

Other characteristics of the strip material also come into play, like purity and surface smoothness. The raw material must be consistent in thickness and how it performs during the stamping operation. One of the reasons that you will find that specifications in catalogs call out



Typical edge card single beam contact. *Illustration courtesy of Cleaver Brinkerhoff.*



Beam folded back to provide support and increase normal force. *Illustration courtesy of Cleaver Brinkerhoff.*

"Copper Alloy" rather than a more detailed material specification is to give the connector manufacturer the flexibility to use different alloys from different suppliers that offer comparable performance. This flexibility ensures competitive pricing and continuity of supply.

Connector designers then use a lot of creativity to meet the prime functions while dealing with other constraints,

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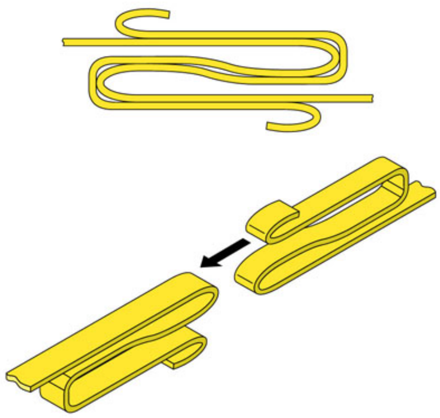
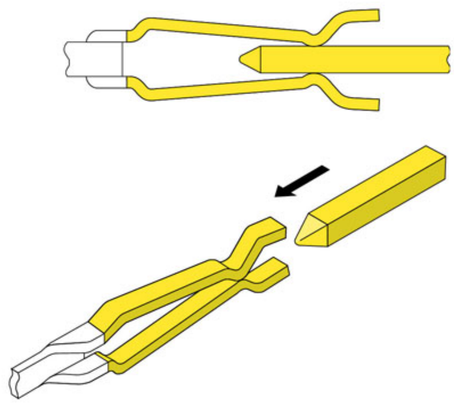
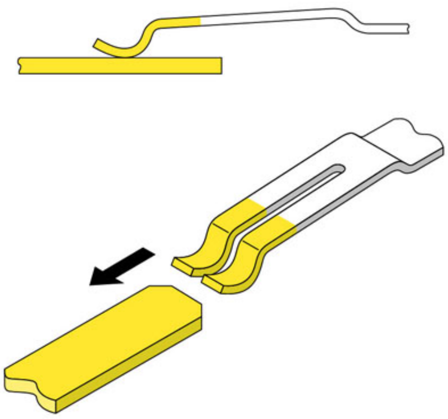


The IBM Serpent contact used in cables mating main frame computers together was probably the ultimate in reliable mating performance. *Illustration courtesy of Cleaver Brinkerhoff.*



Typical dual beam contact mates with both sides of mating pin. *Illustration courtesy of Cleaver Brinkerhoff.*



Bifurcated beams are used in many high speed connectors to improve signal integrity while maintaining the reliability of redundant mating points. *Illustration courtesy of Cleaver Brinkerhoff.*

like size, electrical performance, signal integrity, and system reliability. Here are some examples:

Single beam contacts provide the simplest and least expensive contact form. You will find these frequently in edge card connectors and memory card contacts.

Single beams can be improved with shapes like this where the wrap-around contact provides a better lead-in, more gentle mating force, and better long term reliability. Longer springs are a good thing, but they require more room and cost more than simple beams. You will most often find these in the kinds of connectors used in the appliance industry, office equipment, and a multitude of wire-to-wire and wire-to-board connections.

The apex of using long beams with redundant contacts was the Serpent contact used up until the 1990s to connect IBM mainframes together. These connectors could tolerate thousands of mating cycles without degradation. I suspect they are still in computer rooms around the world today.

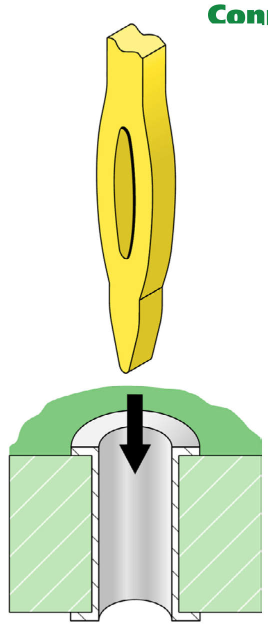
A typical dual beam contact provides better reliability by having two mating points on opposite sides of the mating pin. Balanced forces from both sides are good and perform very well in high vibration environments.

Bifurcated beams mating on one side of a mating blade allow for higher density while ensuring excellent reliability. These designs are preferred for higher speed electrical performance because the contact geometry causes less of an impedance discontinuity.

Signal integrity considerations are driving modern high speed—greater than 25 Gbps connector beam designs. Traditional contacts where the contact mates to a pin or blade typically have the pin extend 2+ mm beyond the mating point. At speeds greater than 25 Gbps, this creates an electrical stub causing electrical reflections that are quite disruptive to optimized signal integrity. One design uses two hermaphroditic beams that mate with each other in a way that minimizes this stub.

Connector designers continue to use their knowledge of contact physics and material properties to optimize connectors to assure long mating life, optimized signal integrity, and competitive cost.

Why use compliant pins in connector designs



The C compliant section has excellent contact with the plated through hole in both maximum and minimum hole sizes. *Illustrations courtesy of Cleaver Brinkerhoff.*

You may well ask: What are the alternatives?

First, I should explain that a compliant pin is one that when inserted into a plated-through hole, creates a spring force against the barrel of the hole that creates a gas-tight joint that is just as good electrically as a solder joint. It has the additional advantage of not exposing the printed circuit board to a heat cycle, especially important on high layer count backplanes.

Compliant pin technology first started to appear in the 1970s. This technology was developed by and for the telecom industry, notably ATT, or Western Electric at the time.

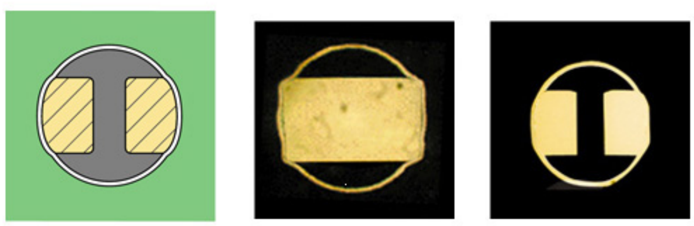
Prior to compliant pins, the choices were solder and rigid square pins with no compliant section. Both were problematic. Wave soldering was not possible for pins with long tails. Vapor phase reflow was possible, but exposed the board to very high temperatures. The rigid square pins required a very tight diametric tolerance (±002) that is difficult to hold and increased board cost.

One of the first compliant pins that came from Western Electric was the C-pin. It has a coined C shaped portion that when pushed into the hole, compressed in a very controlled way, creating a gas-tight joint around about 70% of the plated hole surface area. This kind of compliant pin could withstand even the rigors of wire wrapping, not uncommon at that time, where a machine would wrap a small wire around the square part of the pin, also creating a gas-tight joint with the wire. This put a lot of torsional force on the pins and the compliant joint. With 0.025 in. square into 0.040 in. plated through holes, and pins on a 0.100 or 0.125 in. pitch, this was a practical solution for making backplanes.

Compliant press fit pins had other advantages as well:

- They are repairable. One can extract or punch out a pin easily and replace it with a new pin.
- The pin can extend well beyond the rear surface of the backplane, to allow mating to connectors on both ends. For example, you can pass circuits through a backplane to mate with a cable connector
- Compliant pins can be wire wrapped, making it very quick to produce a prototype backplane for a low speed less than 622 Mbps. It is also a low cost way to make a small batch of backplanes rather than pay for the design and tooling needed for multilayer boards.

In the beginning, there was a lot of skepticism that such a pin termination would survive environmental conditions in the field, so a lot of testing was done to assure that these pins would work well in the field 40 years in the future in Alaska or Panama. Customers were worried about many failure modes from corrosion to creepage of the board over time and temperature extremes. Out of this effort came Bellcore (Now Telcordia) specifications for testing. The best way to evaluate the integrity of the compliant



Comparison cross sections showing a rigid pin compared to a compliant pin. Note how much more gentle on the hole a compliant pin can be.

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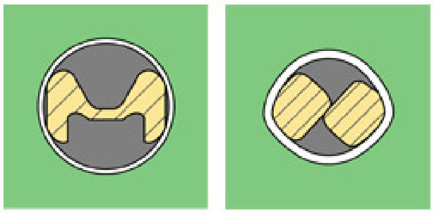
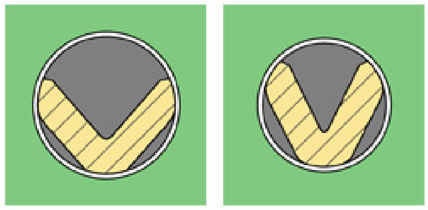
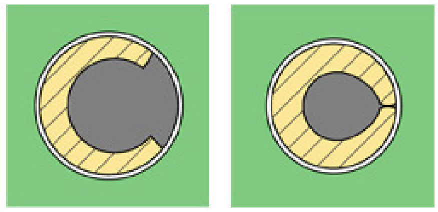


Over the years, many shapes have been invented for compliant pins, including S, M, Sigma, and many more. *Illustration courtesy of Cleaver Brinkerhoff.*



The V pin is optimized for thinner materials common on right angle daughter card connectors. This view shows how the tips comply in the largest and smallest plated through holes

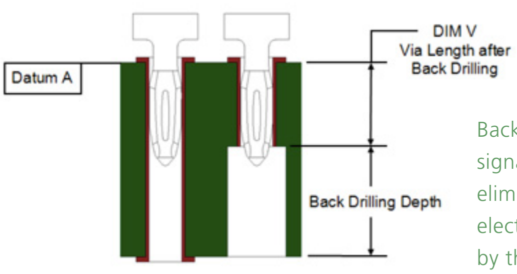


The C compliant section has excellent contact with the plated through hole in both maximum and minimum hole sizes. *Illustration courtesy of Cleaver Brinkerhoff.*

pin-to-board connection in production is by pulling a pin and measuring the force required to pull it out. In the beginning, it was common to specify retention of 30 N (6.7 lb) per pin. Today, with the smaller pins that never see wire wrap torque or other forces that will break the joint, it is common to specify retention forces as low as 2.5 N, about half a pound. This is possible because the pins are tightly locked into the connector and not subject to the abuse that the pins were in the early days. Telcordia GR 1217 Core specification requires that compliant pins can be removed and replaced at least twice without compromising retention force or deforming the holes.

Each connector manufacturer tried to differentiate their compliant design to avoid paying royalties on existing patents. A variety of shapes emerged: Eye of the needle, Action pin, Sigma, S pin, and a few more all were developed to serve the market.

The advantages of compliant pins quickly won over the skeptics and by the early 80s, nearly all backplane connectors used press fit tails.



Back drilling enhances signal integrity by eliminating the electrical stub created by through vias. *Image courtesy of FCI Electronics.*

Over the years, plated through hole diameters have dropped dramatically from 0.040 in. down to 0.032 in., on down to 0.022 in., then 0.018 in. and now as low as 0.016 in. and even 0.012 in. as a result of higher pin density and the signal integrity advantages of small holes. Today, the vast majority of connector manufacturers have adopted the eye of the needle, especially after the patent ran out for this pin. The major advantage of the eye of the needle is that it is able to scale down as the size of the pin and the size of the hole has decreased. In addition the eye of the needle is relatively easy to stamp, especially compared to more complex designs.

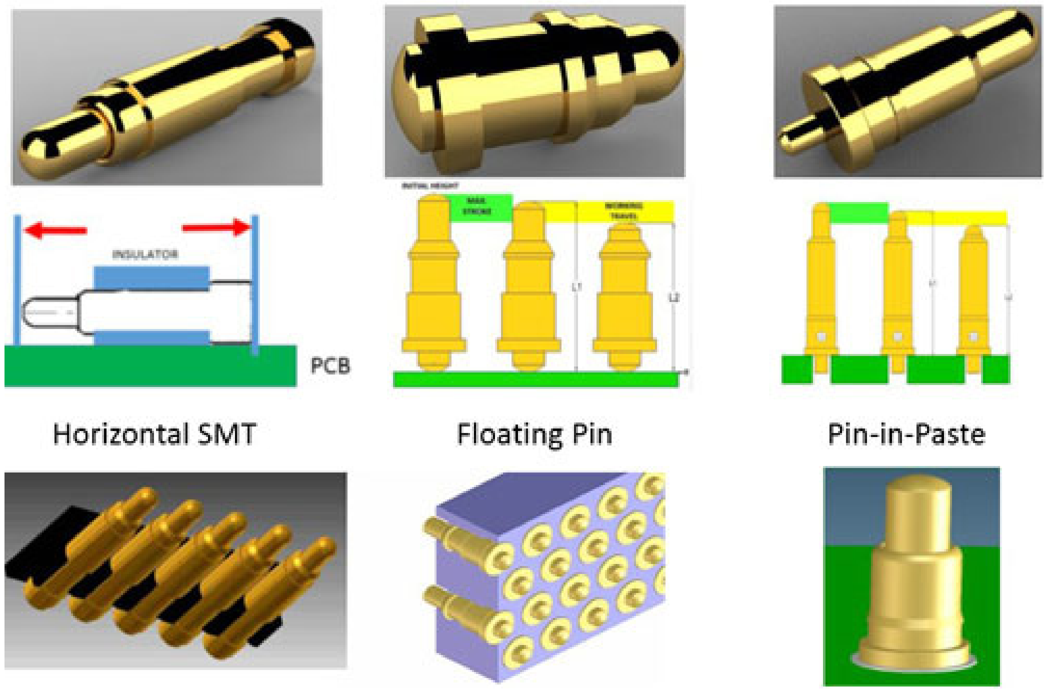
Press fit has signal integrity advantages as well. It is now practical to back drill the plated through hole up to a level just below the compliant "football" of the pin. This eliminates electrical stubs caused by the barrel of the platted through hole below the pin itself. The smaller the diameter of the plated through hole, the better signal integrity that can be achieved. Thus compliant pin technology has enabled connectors and backplane channels to run above 25 Gbps with the potential to go greater than 56 Gbps.

Much of the credit for improved compliant pin performance has to go to the PCB fabrication houses who have consistently improved the quality of drilling, plating, and surface consistency. Good PCB fabricators are able to achieve aspect ratios (diameter of the hole / thickness of the board) of up to 15:1 in high volume production today.

Think about the evolution in this basic technology we have seen since its emergence just a few decades ago. Pretty amazing!

What are the benefits of spring-loaded contacts?

Probably the fastest growing type of interconnect being used by engineers is the spring-loaded contact. Spring-loaded contacts (aka SLCs) are ideal for creating solderless interconnections between mating modules, such as a handheld instrument to docking station, instrument to recharger, stacking PCBs, etc.



SLCs are ideal for new product design for the following reasons:

1. They're forgiving to stack-up tolerances and uneven mating surfaces.
2. They're ideal for blind mating applications—the SLC only needs to mate to a gold-plated PCB land.
3. They're extremely easy for engineers to use.

Typically the words Pogo and SLC are loosely interchanged by the engineering community. I am used to the phrase pogo, to describe a type of SLC with a hardened Beryllium Copper piston that is chisel, tulip, waffle, or pointed. These types of SLCs are used for piercing through dielectric surfaces (such as oxidation). These types of SLCs are traditionally used in Bed-of-Nails test beds, for high-cycling repetitive testing.

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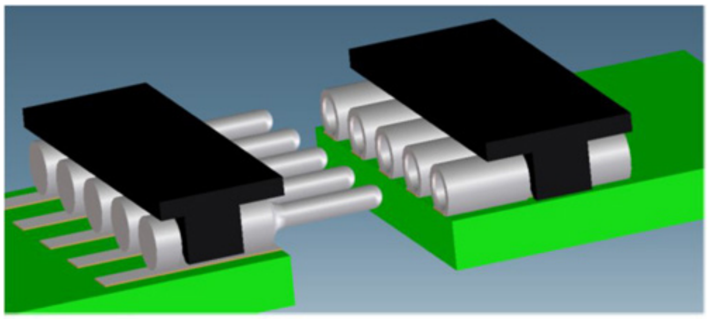
The other type of spring-loaded contacts have radius tipped pistons. Some manufacturers use BeCu, others use Brass. These types of SLCs are used in the docking station, recharging station, and stacking type applications.

There are countless manufacturers who make SLCs. Below you will find three uncommon styles and the advantages of each.

- **Horizontal SMT SLC** – Ideal for low-profile design, a good example is LED lighting strips, which are typically daisy-chained to increase length.
- **Floating Pin SLC** – This type of SLC is assembled into a molded cavity that permits vertical float, which will help it in applications upon uneven surfaces. This style SLC is ideal when used as an interposer between a top and bottom PCB when both PCBs will be mechanically clamped down together. This product achieves solderless interconnection.
- **Pin-in-Paste SLCs** – With the evolution of SMT assembly, emerging is the concept of assembling traditional through-hole components now using high-speed SMT pick-and-place. Assembling a through-hole component onto a SMT board is called intrusive-reflow or pin-in-paste. Simply, there is a through hole on a SMT board and solder paste is screen along the annular ring of the land. The through-hole component is reflowed soldered from the top side, instead of a solder fillet to a tail on the bottom like traditional wave soldering. Pin-in-Paste SLCs feature a short stubby tail (typically less than 1.5 mm in length), a tail purposely intended not to protrude beneath the PCB. Since the Pin-in-Paste SLC does have a tail, it naturally becomes much mechanically stronger than just a SMT SLC, and it has bulls-eye alignment, since the SLC cannot migrate on the PCB land during reflow.

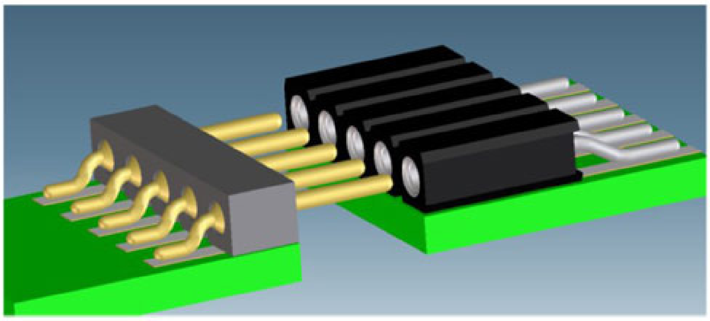
What are horizontal mount interconnects?

Horizontal mount screw machine pin-and-socket receptacle interconnects sit parallel to the surface of a printed circuit board. One reason why they're so advantageous from a product design standpoint is that their mating centerline is low profile to the PCB. These horizontal mount interconnects can come in two configurations: surface-mount and right-angle through-hole.



BARREL INTERCONNECT PAIR

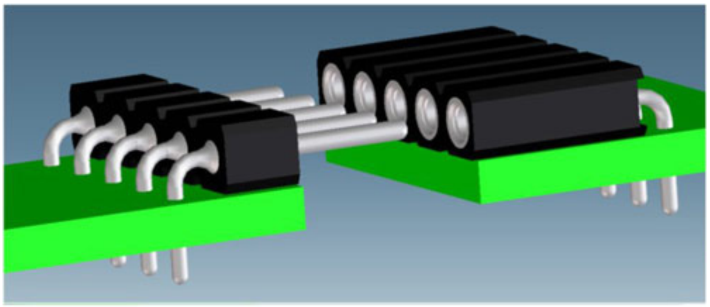
The primary advantage of surface mount horizontal interconnects is that they allow the product designer to use both sides of the identical location on a PCB. This doubles the packaging density.



S-BEND INTERCONNECT PAIR

Two common versions of horizontal mount interconnects include: the barrel and S-Bend tail. The advantage of the barrel style interconnect is that it only requires a small PCB footprint. The advantage of the S-Bend tail is that it allows for greater visibility of the solder joint for inspection and accessibility for rework. Both SMT versions can be packaged on tape and reel.

Typically horizontal SMT connectors should exhibit no greater than 0.005 in. variation of coplanarity over a 1 in. strip length. For strips longer than 1 in., the actual coplanarity will need to be determined.



RIGHT ANGLE INTERCONNECT PAIR

The primary advantage of through-hole right angle tail interconnects is that they are mechanically stronger than SMT connectors, as the pin tail is soldered inside a plated through-hole. It is now possible for even through-hole right angle tail interconnects to come on tape and reel too.

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Mutual to both SMT and through-hole screw machine interconnects is their construction. Screw-machine receptacles are precision-machined using brass alloy. Screw machine socket receptacles are assembled with a progressive die stamping, made of Beryllium Copper, called a "Contact Clip." Contact clips characteristically are configured in 3, 4, 6 and 8 multi-finger arrangements. The function of a contact clip is to provide the mechanical and electrical interface to the mating pin.

Because contact clips are heat hardened during manufacturing, they score the surface of the mating pin. This achieves a reliable gas-tight connection. However, contact clips are not locking mechanisms for the mated pin. The pin can be pulled out when required. Contact clips come in a variety of pin acceptance ranges, each with its own characteristic force parameters.

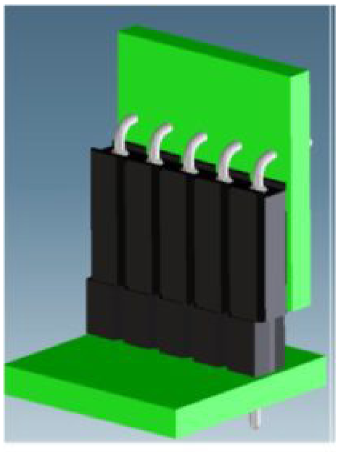
The two-piece construction of precision screw machine socket receptacles allows for cost savings to be realized as the shell can be plated tin for improved solderability while the contact clip is plated gold for corrosion resistance. Plating gold only where required results in cost savings.

One little known trick of using horizontal mount interconnects, is to combine them with a vertical mount interconnect, which forms space saving, perpendicular orientation on the PCB.

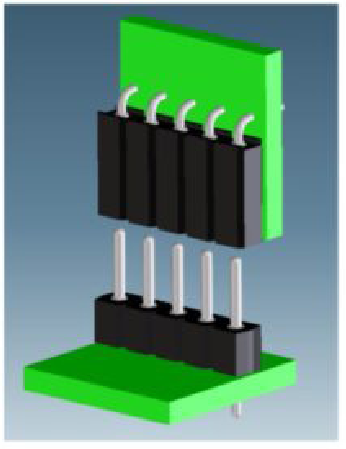
Another little known fact is that screw machine receptacles assembled with contact clips having a pin acceptance range of 0.030 in. diameter and 0.025 in. square posts, can effectively mate to common 0.025 in. square post header strips. This allows the product designer to create mating modules using square post headers with round screw machine socket receptacles.

Horizontal mount screw machine interconnects are typically manufactured with RoHs compliant platings and thermoplastics suitable for RoHs soldering profiles. As this blog presented in detail, horizontal mount screw machine interconnects have many useful applications and present product designers with cost effective, low-profile solutions.

Martin Houlroyd is Principal Engineer/Marketing Specialist at Preci-Dip. He has worked in the interconnect industry for 35 years. Email him at m.houlroyd@precidip.com.



PERPENDICULAR PCB FIG 02



PERPENDICULAR PCB FIG 01

When should you use floating pin technology?

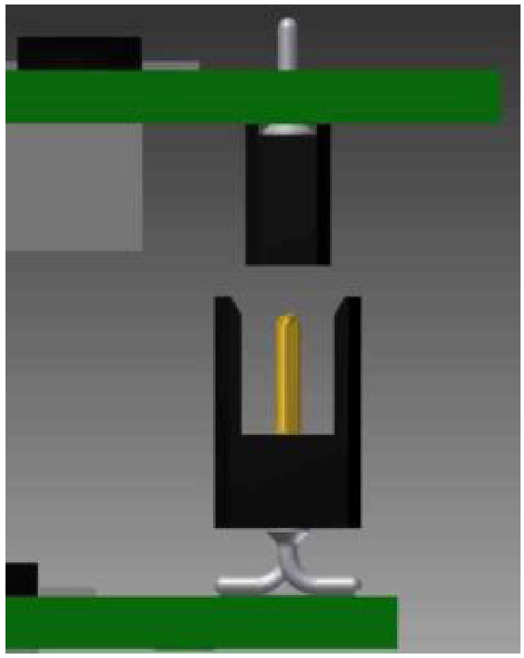
One of the biggest challenges facing assembly of SMT interconnects is maintaining lead coplanarity over a distance. The greater the distance, the more likely the PCB surface may display the effects of warp, twist, and thickness tolerances. If the device lead is seated too high above the solder paste, then this will be either a poor solder joint, cold solder joint or worse, an open circuit due to no solder joint. For a gull-winged interconnect, the device leads are visible, making them somewhat accessible for emergency repair, but if the device leads are part of an inline array, and an inaccessible pin location does not have a solder joint. This may make the entire assembly unusable and require external white wiring to physically jump the dead pin location.

There is a technique for screw machine socket receptacles that will allow the shell to achieve vertical travel inside the molded cavity. This is referred to as "Floating Pin" technology. It is an ideal solution for attaching interconnects on uneven surface PCBs.

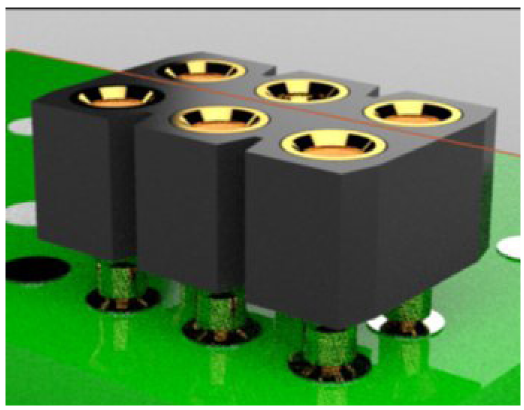
Floating pins are designed to move in a vertical direction inside counter-bore openings. This interconnect method is ideal in manufacturing situations where the SMT surface is uneven. This technique can be easily applied to pins, receptacles and spring pins. This simple method is a proven solution to assembling on uneven surfaces.

Pictured are examples of inline interconnects (SMT pin base concentric to body) and Gull-Wing termination (leads flank package outline).

Martin Houlroyd is Principal Engineer/Marketing Specialist at Preci-Dip. He has worked in the interconnect industry for 35 years. Email him at m.houlroyd@precidip.com.



Gull-Wing termination in which the leads flank the package outline.



Inline interconnects where the SMT pin base is concentric to the body.

How much gold is enough in connector designs?

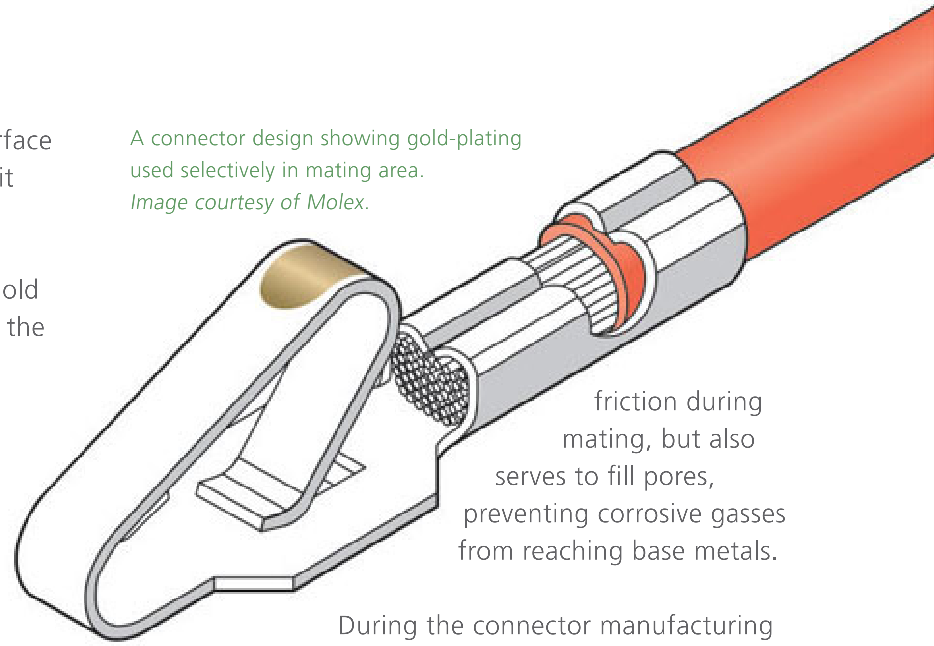
Precious metal plating on connectors protect the surface from corrosion. Sounds pretty basic, but there is a bit more to it.

There is the perception that gold is good and more gold must be better. Not necessarily so. It depends upon the application.

Corrosion typically occurs when corrosive elements in the air reach the connector contact base metal. Chlorine, hydrogen sulfide, nitrogen dioxide, and sulfur dioxide are examples of these corrosive chemicals that are present in small amounts in nature. If these chemicals contact the copper alloys typically used for connector contacts, a corrosive reaction occurs that generates a "bloom" of non conductive material disrupting conductivity in the connector, ultimately causing failure. You have probably seen this effect when a battery fails, generating a pile of greenish white powder.

The most common way to protect the contacts is by electroplating a combination of a heavy nickel covered with a protective layer of a noble precious metal that does not react at all with the corrosive materials in the air. Unfortunately, electroplating is subject to having pores, small openings that go from the surface all the way to the base metal. The level of porosity is determined by the composition of the plating, thickness, and process controls. A typical connector plating line will have controls in place where samples are taken from the process regularly and tested with sulfuric acid to reveal any porosity.

In the telecommunication industry, it is quite common to specify that the mating surface always be lubricated with a petroleum-based lubricant that not only reduces friction during mating, but also serves to fill pores, preventing corrosive gasses from reaching base metals.



A connector design showing gold-plating used selectively in mating area.
Image courtesy of Molex.

During the connector manufacturing process, electrical contacts are normally carried on a continuous strip through the stamping, plating, and forming processes that create the connector. At some point, the contact is removed from the carrier, exposing a small amount of bare metal. Depending on the requirements for the connector, this may be tolerable. Consumer connectors, for example, are often made with pre-plated material that will reveal bare metal at all the stamped edges. This is fine for a connector that only needs to last a few years.

Connectors for high performance applications like computers and 30-year life Telco applications will normally be stamped, then plated all over to assure that the minimum of bare metal is exposed and that none of these bare metal portions are anywhere near the contact area of the connector.

Up until the 1980s, Telco connectors were slathered with 50 micro inches (1.25 mμ) of precious metal plating over the entire contact. As the price of gold soared, the connector companies aggressively moved to selective plating techniques, just putting the heavy gold in the

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areas where the contacts mated. In the beginning, a stripe was used. As the price of gold continued to soar, more selective spot plating techniques were developed. Today almost all gold-plated connectors have a small spot of gold slightly bigger than the contact mating point. This selectivity really helped moderate the impact of precious metal cost on the total connector cost. Precious metal, however, remains an important cost element—25% of the cost for many connector styles.

The Telco operating companies learned they could reduce their cost significantly by requiring the minimum amount of precious plating possible while still meeting performance requirements. With so many connector designs, plating formulas, and producers, it was impossible to test them all, so the industry collaborated to produce a qualification test procedure and specification that each connector manufacturer could use to qualify their own connectors. This resulted in the Bellcore TR-NWT-001217 spec in 1995. This later evolved into the Telcordia 1217 core specification in 2008. These specs were performance based so that the user only needs to specify that a connector meet this specification rather than specifying connector plating or thickness.

This approach was a huge change for the Telco industry and enabled massive innovation in Telco connectors during the last 25 years that has given us much higher pin counts, lower mating forces, thinner platings that still work, and contact designs that can be optimized for electrical signal integrity rather than just mechanical performance. It has also enabled alternatives to gold plating to succeed in the market.

Be aware that there are two performance levels specified, one for dry, air-conditioned central office environments, and a second for outside plant where the equipment sees wide temperature swings and more corrosive atmospheres. Think of a cellular base station located near the beach or a chemical plant on the equator or the arctic circle.

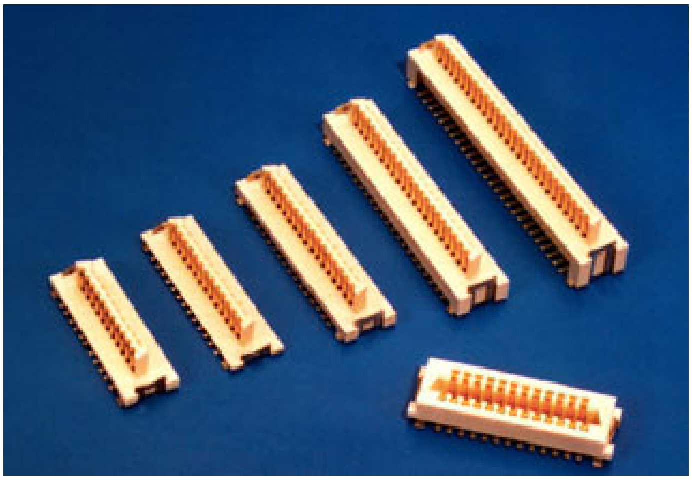
So, to answer the question of how much precious metal is enough, just specify that your connector needs to be compliant with the Telcordia 1217 Core spec and leave the thickness and precious metal composition to the connector manufacturers. Similar performance base specs exist for automotive, industrial, and military applications.

Gold alternatives in connector designs

When the price of gold shot up in the '80s, many connector manufacturers funded research into gold alternatives. In the early days, much of that work was focused on Palladium. As it turned out, Palladium is a rather brittle material that has a tendency to crack when formed after plating. But in the process, palladium nickel plating emerged as a plating formula that was ductile enough to work well in electronic connectors.

Customers were quite skeptical, as you can imagine. Who wants to be the first to bet the company's reputation just to save some money in gold costs. Not to mention the personal job risk of such a direction. So industry leaders, especially DuPont, went to work conducting the testing necessary to convince their customers that Palladium Nickel (PdNi) with a thin gold layer on top was as good as gold. In fact, they found that several characteristics of the PdNi plating enabled a plating that was more durable than gold. This was accomplished by using nickel under the plate, just like before, but adding a layer of PdNi on top and then a gold flash layer on the surface. The PdNi layer is harder and more durable than gold. The soft gold flash on the surface acts like a solid lubricant, moving around with each mating cycle, effectively filling in valleys in the PdNi plating and creating a smooth surface that proved to be quite durable when mated many cycles. So the PdNi plating with gold flash proved to be a superior plating to traditional 30-micro inch gold plating.

High cycle life is a very valuable characteristic for many connectors, especially in IO connectors that are mated and unmated every day, in test systems and even modular jacks. Molex, for example, reports that modular jacks plated with PdNi and gold flash are rated for 2500 mating cycles while the comparable gold plated jacks are only rated for 750 cycles.



Conan mezzanine connector system from FCI Electronics features palladium/nickel/gold plated electrical contacts.

PdNi plating with gold flash also proved to be superior to gold in porosity testing, environmental corrosion resistance, and creep corrosion. If using gold in a corrosive environment, the corrosion product actually grows or creeps across the surface of the gold, eventually contaminating the mating point and potentially causing failures. The chemistry of PdNi plating is such that the corrosion products do not creep. This allows some connector contacts with bare edges or points where the contact was removed from the carrier strip to pass environmental exposure while the comparable gold plated connector will fail.

PdNi plating with gold flash has become the preferred alternative for FCI, Molex, and TE Electronics, with products sold in very high volume for the last 25 years and performing well in the field.

Another alternative that is finding some success is nanocrystaline nickel, also used with a gold flash. This plating was invented at MIT and is licensed to the connector industry by Xtalic, a specialty plating chemistry firm in Connecticut. Contacts plated with this low-gold

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formula have also passed the rigorous requirements of Telcordia 1217 core environmental testing and IEC60603-7 PL 2.

By the way, precious metals used in connectors are all subject to the vagaries of the commodity market. Between 1999-2001, after the industry spent millions to prove that PdNi was acceptable and lower cost, the price of Palladium went through the roof, exceeding gold in similar applications. This spike in Palladium prices was largely driven by the use of Palladium as a catalyst in automotive catalytic converters. Fortunately, supply caught up with demand and now PdNi plating remains less expensive than gold plating. It might not always be that way, so caveat emptor.

Many connector companies offer parts with nickel plating with "gold flash" on top without specifying a thickness. This plating is normally less than 5 u-in. of gold and is largely cosmetic, not offering the protection of thicker gold plating. This kind of plating is most likely found in connectors used in low cost personal computers and similar commodity devices where long life is not important and cost is. You get what you pay for!

My message to you is that at least two plating alternatives have been through the qualification gauntlet at major connector suppliers and major OEMs and have proven to be reliable alternatives at a lower cost than 30 micro inch gold plating. PdNi with gold flash has proved to be superior. Performance testing based on Telcordia 1217 Core specifications has enabled connector manufacturers to prove that these alternatives to gold can perform well in even high end telecom and computing applications.

When selecting part numbers, be sure to consider the cost advantage of these gold alternatives. Your finance department will love you and the risk today is quite low. You might even get an award for a cost-saving suggestion that will help with the holiday shopping.

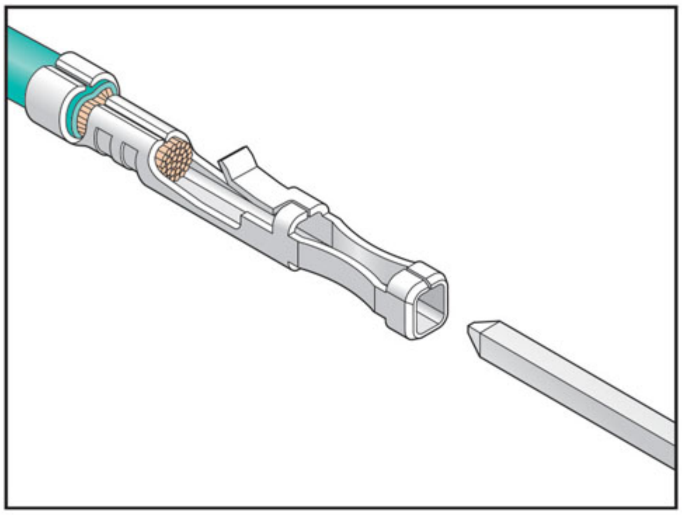
Are tin-plated connectors OK for my application?

Many electronic connectors are gold plated. Gold plating increases conductivity, especially at low voltages, protects the surface from corrosion, and increases the connector cycle life.

But with gold at more than $1400 per ounce, using gold adds expense, especially if it can be avoided in your application. For example, you won't find gold plating on your 120 or 220 V wall plug because the voltage is high enough that the electricity will flow right through normal surface contamination. But we seldom use such high voltage levels past the transformer in the electronics box.

So when can you get away with tin-plated interfaces? If a contact is mated only a few times during its lifetime, tin may be a suitable solution. For this to work, however, several other conditions must also be considered:

- Tin interfaces will develop a nonconductive film on the contact surface over time with normal exposure to air. One way to overcome this problem is using connectors with high normal forces greater than 100 grams per contact. Normal force is the amount of force that a receptacle contact places on the mating pin or blade. With >100 grams force, the mating contacts plow through the insulating films to mate fresh tin to fresh tin.
- The higher the normal force, the higher the connector mating force will be, so you will find that tin connectors are most often used in connectors with a limited number of pins. One of the largest consumers of tin-plate contacts is the appliance industry where cost is very important, but a connector is only disconnected if the machine is being repaired. Even then, the replacement part is likely to have a new connector. Keep in mind that appliance manufacturers typically offer only a 1-3 year warranty. After that, you become a paying service customer.



Connector illustration shows a tin version of the spoon on the female contact mating with a pin or blade.
Illustration courtesy of Cleaver Brinkerhoff.

- Connector engineers enhance normal force by designing connectors with contact geometry that concentrates force on a very small mating area. Imagine a pyramid mating with a flat surface, for example. That would be great for concentrating forces, but would be difficult to mate and would wear way too quickly. A lot of connector engineering involves designing the "spoon" on the receptacle contact so that it provides the optimum normal force, while keeping mating forces manageable.
- The best manufacturers of tin contacts will offer versions that are pre lubricated with a material that can help shield the tin from the oxygen in the air, reduce mating forces, and provide some lubricity to protect against damage from mating and micro-motion.

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Some environments are totally unsuitable for tin contact systems:

- Vibration can cause mating contacts to move a tiny bit all the time. This micro-motion will rather quickly produce "Fretting corrosion." Basically, as the contacts move relative to each other, fresh tin is exposed, which then oxidizes, and becomes insulating. Over time, the conductivity of the interface increases to unacceptable levels. This is one reason why when you have a connector failure, it will frequently be corrected by unmating and remating the connectors, clearing away some of the insulating debris. This vibration may be mechanical, or created by thermal cycling over time. One way to prevent fretting is to lock the mating connectors in place in such a way that the contacts cannot move relative to each other. This is normally accomplished by plastic housing features that positively lock mating connectors together.
- High temperatures must be avoided with tin-plated contacts. Several failure mechanisms, including intermetallic reactions between the copper and tin and mechanical creep of the tin plating, will create failures over time.
- If the contacts will be mated "hot," under power, the resulting spark can quickly erode holes in the tin plating, revealing underlying copper, which can quickly corrode and cause connector failures.

Tin plating will always have a place in connector applications. If you just pay attention to the guidelines above, you can have a successful design at the right cost. For more info about using tin contacts, I encourage you to read a white paper from TE called "The Tin Commandments: Guidelines For The Use Of Tin On Connector Contacts."