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PAST, PRESENT AND FUTURE OF SOLDERLESS ASSEMBLY

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ABSTRACT

The forced transition to lead-free soldering foisted on the global electronics industry by a well meaning but misguided European parliament has actually resulted, according to the US EPA study, in a net worsening of the environment. One prospective response to the ongoing challenge facing the electronics industry is to eliminate solder from the electronic interconnection process. The concept is one that has deep roots in the electronics industry and it is now of growing interest to electronic product developers, especially among those in the military, aerospace and automotive markets but also in the portable electronics market. This paper will examine some of the many different methods that have been proposed or used over the years by the electronics industry and take a look forward at some solutions that might lie in the future

INTRODUCTION

Tin-lead solder is a proven technology for making the electromechanical interconnections required for joining components and substrates. However, this traditional and long standing approach to electronics manufacture and assembly has been significantly impacted by the European Union's unilateral decision to prohibit the use metallic lead in electronic solders. A host of new problems have arisen including some that were unknown when tin-lead was the de facto solder of choice. Now other problems, including ones that had once been conquered, have now reappeared. While rescinding the lead-free mandate would be of substantial benefit to the electronics industry, it is now generally agreed that this is highly unlikely since the electronics industry has made a nearly 50 billion dollar investment to comply.
Given this situation, there has been growing interest in methods which might obviate the need for solder completely.

To best understand the benefits of new approaches, it is necessary to understand standard practices of today for the manufacture of a conventional electronic assembly. There are many major and minor steps in the process and Table 1 provides a non exhaustive listing of the steps required for designing and fabricating both the printed board and the printed board as an assembly.

It is well known to those tasked with the assembly process that controlling all of the various aspects of the soldering process can be a very daunting undertaking. To the credit of those whose job it is to control the soldering process they have done a journeyman's job of a managing a highly complex task.

However, given the ongoing challenge with lead free solder there has been increasing interest shown in alternative processes for assembly, ones which step around the soldering process in favor of processes and which are simpler and in many cases the only viable alternative to solder.

SOLDERLESS ASSEMBLY RETROSPECTIVE

Like many technologies that are perceived as new, when one researches the matter, they will often find that the technology has more history than is seen at first glance. Such is the case with solderless technology. Solderless solutions have actually been employed to make electrical and electronic interconnections for more than a century.

Following the "press fit line of thought", one will note that connectors and sockets are other forms of solderless interconnection. Interference fit interconnection technologies (i.e. connectors) can be used to make interconnections between boards but can also be used to interconnect a component to printed boards when the temperature of solder assembly is too high for the component to endure. Such methods were common for the assembly of microprocessors. One solderless technology that is perhaps of greatest familiarity to any electronic hobbyist, mechanic or electrician is the simple twisting or two wires together. While it is an approach to making interconnections that might not be consider highly practical for many applications, twisted wire interconnection technology is one of record that has served the industry well in the past and it is still in use today. The specific terminology for the technology is *wire wrap* and it has been used as a prototyping method for making point to point interconnections. See Figure 1.

Another solderless assembly method which has been in use for several decades is that of press fit pin technology for backplanes and back panels. This technology was developed to make reliable interconnections between connector pins and plated through holes on large backplanes used by the telecommunications and internet server industry.

This solderless technology was developed because, like many of today's printed board assemblies, could not withstand the soldering process to make interconnection between the connector pins and the plated holes in the backplane. The temperatures required for soldering were simply too high for the organic resin based laminate of the back plane to survive.

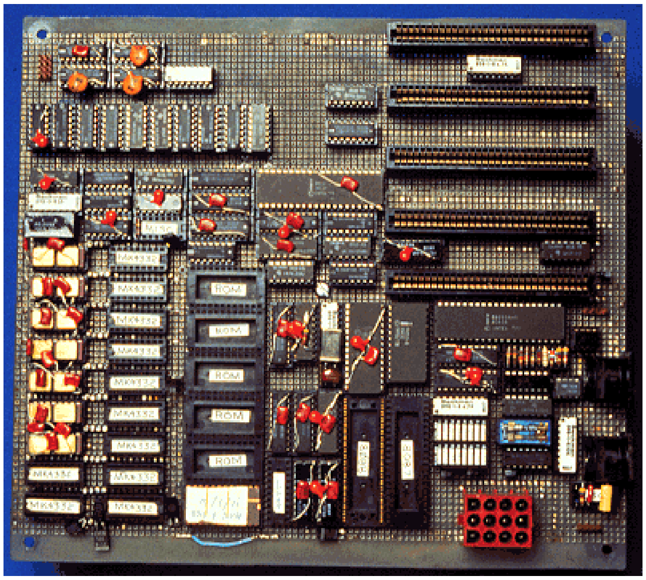
Design PCB Assembly	Fabricate PCB (multilayer)	Assemble PCB
1) Create schematic 2) Indentify components 3) Layout circuits 4) Validate signal integrity 5) Validate design DfM 6) Validate design DfR 7) Validate design DfE	1) Verify RoHS compliance 2) Cut core laminas to size & tool 3) Clean and coat with resist 4) Image and develop resist 5) Etch and strip resist 6) Treat exposed copper 7) AOI or visual inspect layers 8) Cut B-stage to size and tool 9) Lay up core and B-stage 10) Laminate 11) X-ray inspect (optional) 12) Drill (stack height varies) 13) Desmear or etchback 14) Sensitize holes 15) Plate electroless copper 16) Clean and coat with resist 17) Image an develop resist 18) Pattern plate copper 19) Pattern plate metal resist 20) Strip plating resist 21) Etch base copper 22) Clean and coat with soldermask 23) Image and develop 24) Treat exposed metal (options) Solder, NiAu, Sn, Ag, OSP, etc. 25) Electrical test 26) Route to shape 27) Package 28) Ship	1) Procure components 2) Verify RoHS compliance 3) Verify component solderability 4) Verify component MSL number 5) Kit components 6) Procure PCBs 7) Verify RoHS compliance 8) Verify PCB solderability 9) Verify PCB High Temp capability 10) Design solder stencil & purchase 11) Develop suitable reflow profile 12) Track component exposure (MSL) (Rebake components as required) 13) Position PCB & stencil solder paste (monitor solder paste) 14) Inspect solder paste results (height and skips) 15) Dispense glue dots (optional) 16) Place components 17) Inspect for missing parts 18) Reflow solder 19) Repeat Steps 13-18 if two sided assy (second set of fixtures required) 20) Perform hand assembly as required (odd sized or temperature sensitive) 21) Clean flux from surface and under (verify low standoff devices) 22) Test cleanliness 23) Underfill critical components 24) X-ray inspect soldered assembly (shorts, opens, voids, missing) 25) Electrically test 26) Rework and repair as needed 27) Package 28) Ship

Table 1 The major process steps for basis surface mount assembly are enumerated though there are some overlapping and repeated activities. There are also often many sub steps and checks for each of these steps. Please note that higher density, “build-up” type PCBs commonly require multiple image and plating steps. Note also that a number of the process steps used in placing balls on BGA parts and verification steps are also bypassed along with the thermal excursion of joining them to the package. These steps are not included in this accounting.

While, not a direct descendant of wire wrap technology, a new concept based on the use of twisted wires to make solderless electronic interconnections between PCBs was modified in recent years by some clever innovators for use in making interconnections in high performance and reliability applications. See Figure 2

While twisted wire type solutions have proven value, there is as well a technology of long standing for interconnection integrated circuits which cannot be ignored, wire bonding using either gold, aluminum, or increasingly, copper wire. The wire bonding, in general, involves the making of interconnections by mechanically scrubbing a wire against a contact on a chip component termination to make one contact and repeating the process on the other end to make interconnection to the substrate. The substrate is normally a package but it can be a printed board. The use of chip on board (COB) technology has been in use since the 1970s and it may see increased use in future technologies.

There are other types of metallurgical interconnection technologies that are worth mention, sintered paste, and transient liquid phase joining and welding. The sintered the materials used are different and the joining temperatures are lower. Transient liquid phase bonding is somewhat of a hybrid of soldering and welding, in that two metals are joined by heat and pressure. The metals react instantly once joining temperature is achieved and the resulting alloy has a melting temperature above either of the two joining metals.



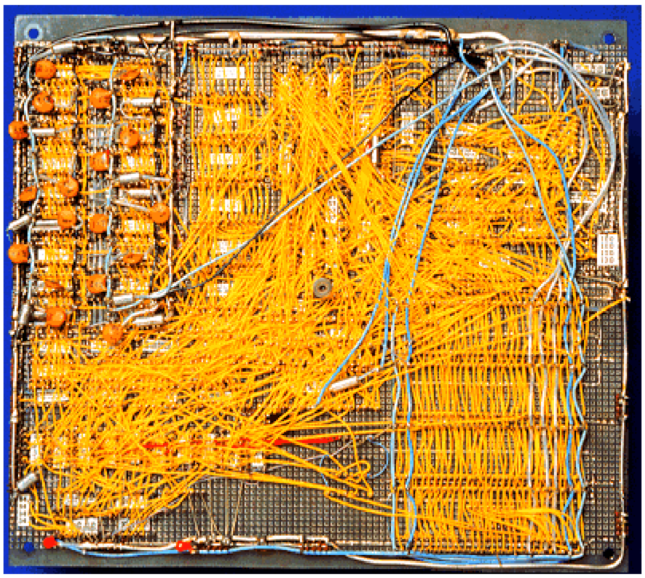


Figure 1 Shown in the photos above are the front and back side of a prototype motherboard assembly which was assembled using wire wrap interconnections which require no solder.

The last of the methods for joining is welding. Welding can be accomplished by one of several different methods including the use of lasers and resistance welding. The former case is fairly well known, the latter however is less common. In process, the leads of a device are welded to the circuit by completing a momentary high current circuit with pressure applied resulting in a metallurgical weld being paste solution is somewhat similar to soldering except that formed between lead and circuit. This process is relatively slow but may be of use in certain applications.

In addition to the mechanical interconnection solutions just reviewed, there are a host of adhesive based technologies that have been, and still are being successfully used to make electromechanical interconnections. In general, there are three basic types of adhesive based interconnections, conductive, anisotropic and non conductive. The first type is comprised of a resin mixed with a conductive material, most commonly silver, though there is an increasing interest in carbon based nanomaterials. The second type is an adhesive, in film or liquid form, which is infused with widely dispersed conductive particles which, in use, will allow for the conduction of electricity in the Z axis but not in X nor Y direction. The last is non conductive adhesive which can be used where signals are capacitively coupled or where operating voltages are sufficiently high to break through the thin bond line. In some cases a mechanical feature is designed to pierce the adhesive to make the connection. However, the first two methods see the greatest use.

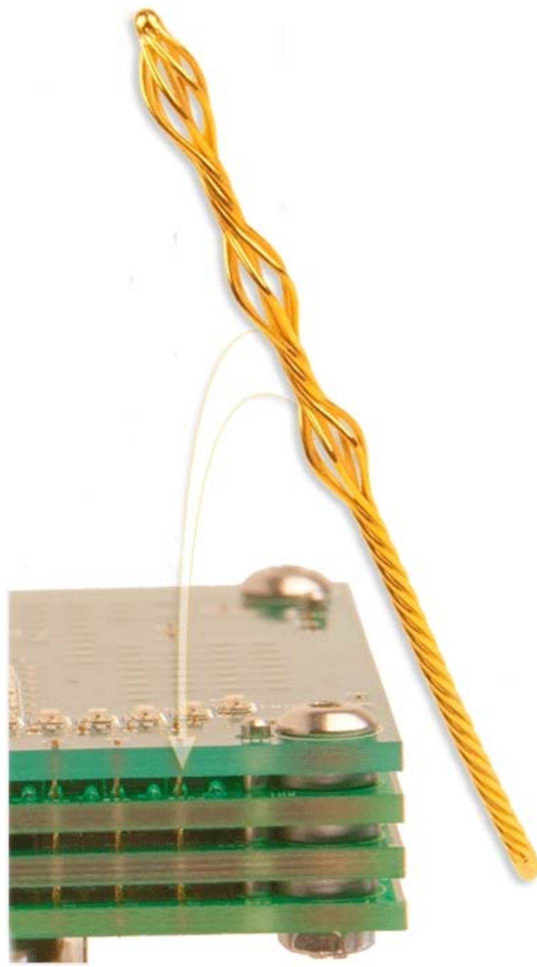


Figure 2 Example of a twisted wire interconnection for making interconnections between printed board assemblies

Conductive adhesives have been used in applications where the component is heat sensitive. An example of one such application is with plastic encapsulated LEDs. Such adhesives are also commonly used with membrane switch assemblies which are typically fabricated using screen printed or stenciled silver ink conductors and assembled on low temperature polymers such as polyester.

The other type of adhesive alternative to solder is the anisotropic conductive type adhesive. These joining materials are very commonly used for the interconnection of display driver circuits used to deliver the signals to various types of flat panel displays. The advantage of this type of adhesive is that it can reliably make the very fine pitch interconnections required for such applications.

As has been pointed out, the use of solderless technologies for interconnections has a long and colorful history, but there are more options in the works for the future

ELIMINATING SOLDER BY DESIGN

While the many solderless technologies just reviewed offer varied advantages in terms of efficacy and utility, there are other solutions which are in development wherein the soldering process is obviated by design rather than necessity. One such is a process which has come to be known as the Occam process, so named to honor the 13th century logician and philosopher who stressed simplicity as a test of efficiency. The Process is fundamentally a reverse order interconnection process, that is the components (i.e., tested and burned in IC packages and other devices including discrete and integrated passives, inductors, antennas, connectors and the like) are first attached to a carrier encapsulated and then subsequently interconnected using common printed circuit fabrication processes and technologies that are mature, low-risk, and industry-familiar. In the process, the encapsulated components and other circuit and interconnection elements are interconnected to one another by copper plating circuits after they are assembled into their final positions. The basic process steps of the Occam process embodiment are illustrated in Figure 3.

Thus in this new approach to interconnection, the conventional sequence of creating an electronic assembly is reversed so that the sequence in the most basic terms is now simply component placement followed by electrical interconnection.

In executing a solderless type of assembly process such as this, the components are first placed on temporary or permanent carrier. In the former case this could be a removable tacky film and in the latter case a permanent base to which the components are bonded using a permanent adhesive. The film and/or base temporarily immobilizes the components accurately in place until the structure is encapsulated locking the components in place. The result is that the entire array of tested and burned-in components becomes a monolithic assembly, with each and every component now permanently locked accurately in position and place. The bottoms of these terminations can then be exposed by removing the temporary base and film or by making holes in a permanent base by such means as mechanical abrasion or laser ablation.

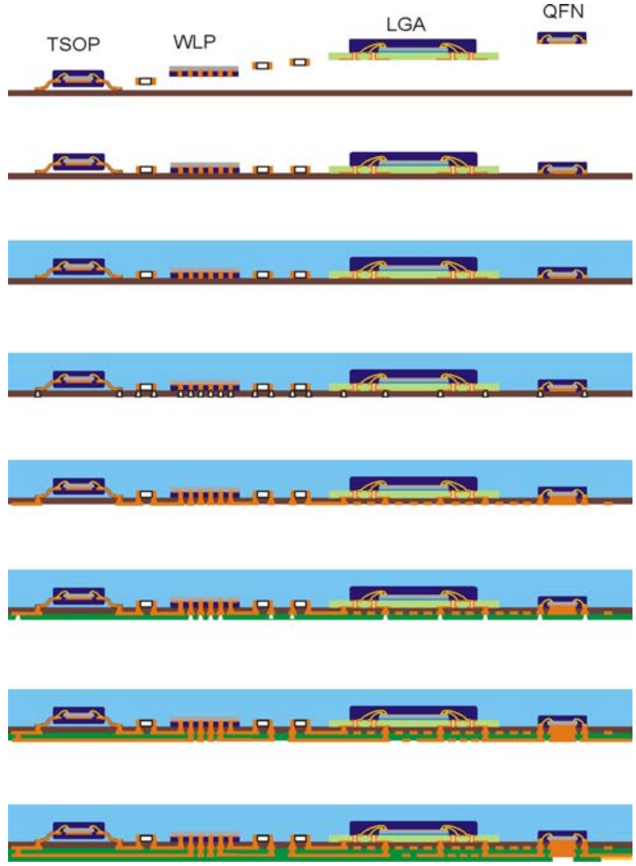


Figure 3 The Occam solderless process is comprised of the following steps from the top. Fully tested components are placed on carrier (permanent carrier in this series). The assembly is encapsulated, terminations are accessed by suitable method (e.g. laser), assembly is electrolessly plated, circuits are patterned. Additional dielectric is applied and additional circuits built up to meet design needs.

Using a suitable metallization technology such as sputtering or electroless plating, the connections to the component terminations are then created by copper plating to the exposed surfaces of the terminations distributed across the encapsulated assembly of electronic components' surface. While plating of metals is deemed to be the most desirable method at present, the evolving arena of conductive inks and inkjet printing technology could make possible a rapid prototyping method for building electronic assemblies using presently evolving direct write techniques. Figure 4 offers visual examples of the direct write concept concept.

There is a great deal of potential flexibility in the techniques proposed and it is anticipated that it should be possible to redesign electronic circuits up to the moment of interconnection, opening the doors to the prospect of prototyping in real time.

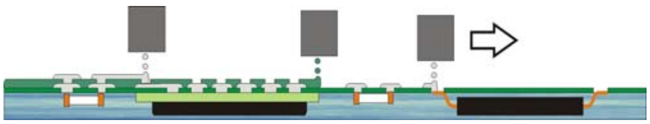


Figure 4 The reverse manufacturing process associated with the Occam process can be readily adapted to direct write technologies such as is illustrated above. After encapsulating and clearing terminations, inkjet systems can deliver alternating layers of insulating and conductive inks to create a circuit in a matter of minutes.

Solderless processes such as the one described here are expected to result in electronic assemblies that will not only be low cost but also easily provide many important design needs such as thermal enhancement, hermeticity, EMI shielding as well as the embedment of electromechanical and optical components among other prospective future choices.

Low Temperature Assembly Advantage

Because the process does not involve exposing the assembly to the extreme temperatures required needed for lead-free soldering concerns over component moisture sensitivity level (MSL) are eliminated. (For the reader's reference, MSL is a measure of the risk of component damage due to explosive outgassing of absorbed moisture in the package during soldering devised by the Joint Electronic Device Council or JEDEC.) While traditional lead-free solder processing is limited to a maximum temperature of 220°C, SAC alloys approach 260°C and the vapor pressure of water more than doubles over this amount of temperature increase.[i]

Thus it is deemed a significant advantage that, for assemblies created using soldlerless assembly processes, all of the components can be treated as if they were MSL-1. This means that IC packages do not require dry storage, special handling, pre-baking or accurate hold time recordkeeping in normal environments. Moreover, the process also allows the use of components that are not capable of withstanding lead-free soldering temperatures (aluminum electrolytic capacitors, certain optoelectronic devices, connectors, etc.) Another prospective advantage is that heat spreaders, heat sinks or even heat pipes can be embedded directly into or made an integral part of the assembly. This a direct result of the fundamental attribute of soldlerless type assembly that no high temperature soldering is required,

Circuit Design Advantages

Just as with a standard printed wiring board the interconnect structure, a circuit pattern must still be designed and fabricated. However, with this new approach, a number of design constraints can be relaxed. For example, there is no need for large component pads or lands that are required for soldering the components to the PCB and thus it is possible to simplify the circuit routing for area array. This design freeing feature allows a higher circuit density but is also offers a potential reduction in the number of layers required for the design. Another advantage is that there is no need for drilling high-aspect-ratio vias all the way through the assembly as special structures have been anticipated to address the need when it is encountered.

This solderless process is also amenable to implementation using the interconnected mesh power system (IMPS) design approach developed at the University of Arkansas by Professor Len Schaper and his colleagues. IMPS designs start with a grid of power and ground conductors that are three times the width of a selected minimum width signal conductor and separated by the minimum space. Signal conductors are then routed the spaces of the mesh with the power and ground narrowed to accommodate them when and where required.

While IMPS structures were designed with IC multichip modules in mind, the concepts are applicable to higher level interconnections. Thus a similar Power Mesh concept was developed at HP for courser features commonly found on standard PCBs and using full metal ground planes[ii]. The mesh is never broken or disconnected. All of the signal conductors are coplanar transmission lines referenced to both power and ground, and the reference is preserved when the signal goes from X to Y. Crosstalk is very low, because there is always an AC ground conductor between every pair of signal conductors. The initial mesh establishes the allowed signal tracks. The concept is ideal for components laid out using a common grid pitch and under such circumstances any EDA router can be used to lay out the signal wiring in the channels.

A design rule check is still used to impose minimum clearance on the power and ground to narrow traces as required. The general design method has been shown capable of significant layer reductions compared to traditional design approaches while offering lower noise and lower crosstalk, based on measurements.[iii] These innovative wiring architectures can replace as many as 14-18 layer of conventional through-hole wiring. For example a 14 layer board of standard design could be reduced to as few as 4 layers and an 8 layer board potentially down to 2 layers. When coupled to a solderless process, such as the one which has been described here, and used to create a direct HDI interconnection to component terminations without the need for soldering, the combination could well support requirements for I/O connections up into the 400 I/O cm^2 (2500 I/O per in^2)[iv]. Finally, highly dense structures are possible with the solderless process because components can be densely tiled with edges abutted or even stacked with components resting atop other components.

Stacking of Assemblies

Another advantage of solderless structures built in a reverse manner, is that the assemblies can be stacked and interconnected both on the edges and in mezzanine fashion simultaneously. The result of such structures is a highly dense IC package assembly.

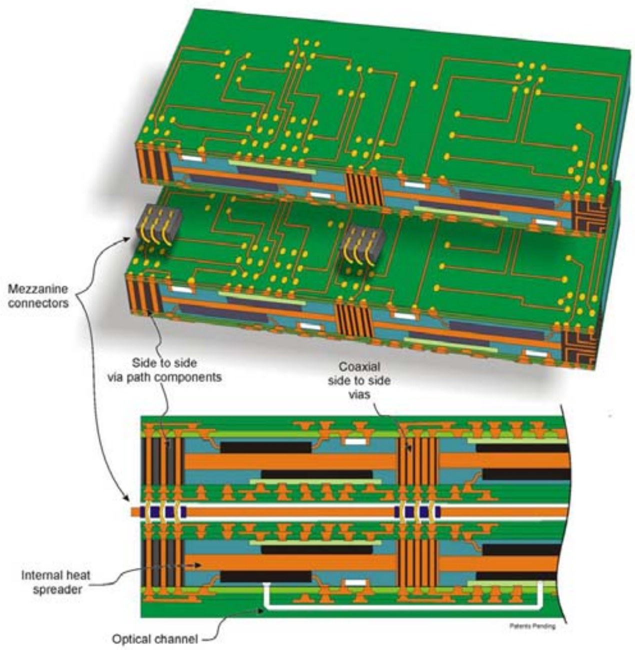


Figure 5 Using a reverse interconnection process without solder offers design constructions which are not normally possible. The structure above has many useful features including built in heat spreading technology, short path routing and the potential for built in optical channels for future circuit requirements

It is not beyond the realm of reason that it could be possible to create an interconnection structure that could approach supercomputer performance within a one meter or even smaller sized cube. This is made possible by the significantly reduced signal pathways and the provision of clean power.

There is also the prospect for including ESD management solutions within the assembly rather than on the IC itself. Such approaches would further reduce power demand as both the I/O and the core power requirements are minimized, especially when clean channels are provided by interconnections within the overall system. Even so, energy densities will not be zero and thus the advantages of having an integral heat spreader or even a heat pipe built within the assembly and directly connected to the IC packages or in the case of flip chip packages, directly to the chosen integral heat spreader technology. A prospective embodiment of such and assembly is provided in Figure 5.

CONCLUSIONS

In summary, solderless assembly technologies have long been a part of the electronic interconnection process tool set. With the deleterious effects of high temperature solders now looming large on the manufacturing community and the increase in early failure of electronic assemblies, it is believed that solderless alloy free electronics (SAFE) will become a new standard for assembly as time progresses. Given some of the recent reliability results reported by OKI for embedded device technology, it is assumed that solder alloy free electronic processes, such as that represented by the Occam process, will give the OEM a new choice for producing products that should prove a highly reliable and cost effective approach to electronic assembly and the printed circuit manufacturer the possibility to reinvent and redefine the circuit manufacturing process in a way that adds significant value while reducing overall costs and increasing reliability while easily clearing the hurdles put in place by the EU's RoHS legislation.

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