# Design Methodologies & Manufacturing Processes that Result in Automatic DFMA Improvements

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## Abstract:

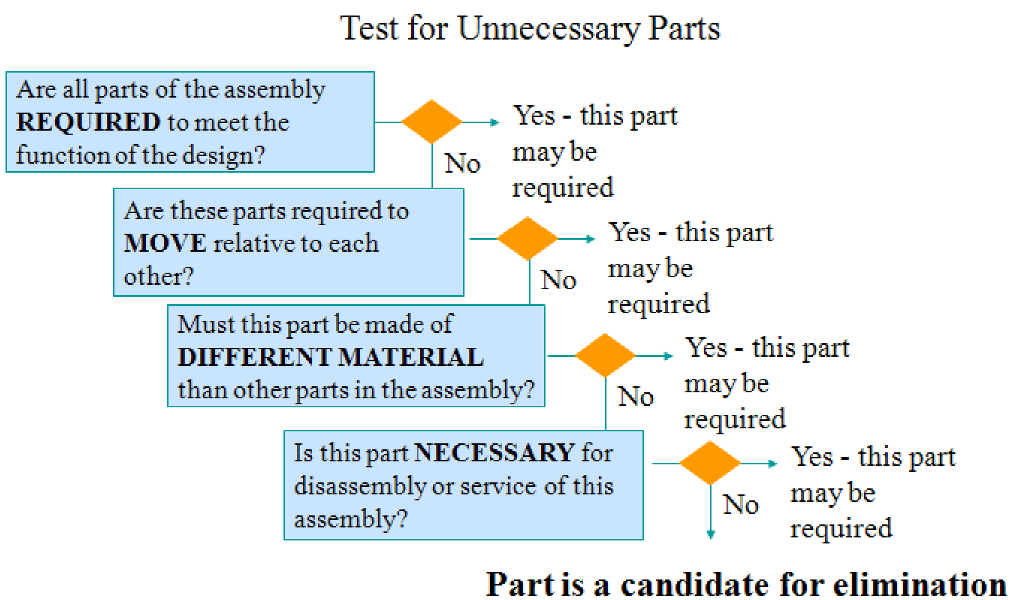
This paper examines several manufacturing processes which when implemented during the product design phase provide DFMA cost reductions just by virtue of using them. Case studies showing before and after improvements for processes like Molded Interconnect Device (MID), Electronic and Package Assembly Concept (EPAC) will be shown.

**The Origin of DFMA**

In the 1970's manufacturers discovered that peripheral equipment feeders and grippers needed to be designed and built so that a single general-purpose robot could pick up parts appropriately during product assembly. At this time, Boothroyd and Dewhurst did pioneer work in assembly automation in product design which included the analysis of parts for automated feeding. (Boothroyd, 1991) After manufacturers tackled the problem of introducing and manipulating parts by robots in the United States, manufacturers in the area of design for manufacturing and assembly (DFMA) shifted production focus to analyzing entire products and their constituent parts and subassemblies. The reasoning behind the shift was that if materials represent 70 – 80% of a product's final cost then the fastest way to reduce cost would be to eliminate parts/subassemblies.[1] The product designer began to try to achieve a design with the fewest part or subassemblies possible, a concept known as theoretical minimum part count[2] developed by Boothroyd and Dewhurst. Boothroyd and Dewhurst developed a procedure to determine whether a part could be eliminated using a set of simple questions. As shown below, if the answer to these questions is "NO" then the part is a good candidate for elimination. The exercise of how to design the product and hit the theoretical minimum part count still required the imagination and creativity of the design team.

[1] Meeker, David and Nicholas Dewhurst. "DFMA and its Role in Cost Management" *The 20 th Annual International Conference on DFMA* Warwick, RI June (2005)

[2] Manufacture and Assembly 2nd edition, G. Boothroyd, P.Dewhurst, W. Knight, Marcel Decker NY, NY, 2009. Pg's 12 & 94




## THAT CREATIVE SPARK

When you examine a product design, many of the connective parts, like brackets, fasteners, and sheet metal trays, create the product's internal structure. The infrastructure's only purpose is to hold together the parts and the subassemblies needed so that the product will function.  Coincidentally, these same parts are most often highlighted as parts for elimination when a designer asks the theoretical minimum part count questions.  A comparison of the original IBM Pro Printer with the Epson MX80 is probably one of the best early examples of the elimination of these connective parts.[3] The fundamental difference being that IBM eliminated all is the fasteners, brackets and unnecessary pieces of hardware to get down to the theoretical minimum part count in the ProPrinter.

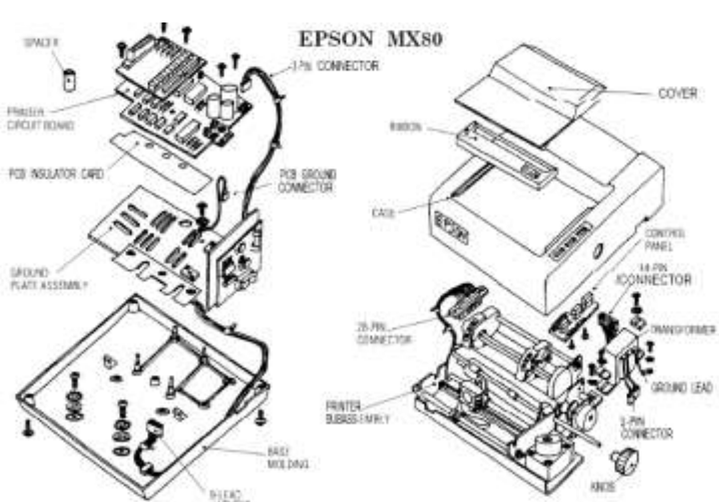



FIG. 1
The EPSON MX80 dot matrix printer final assembly consists of 45 parts or subassemblies as shown in this exploded view.

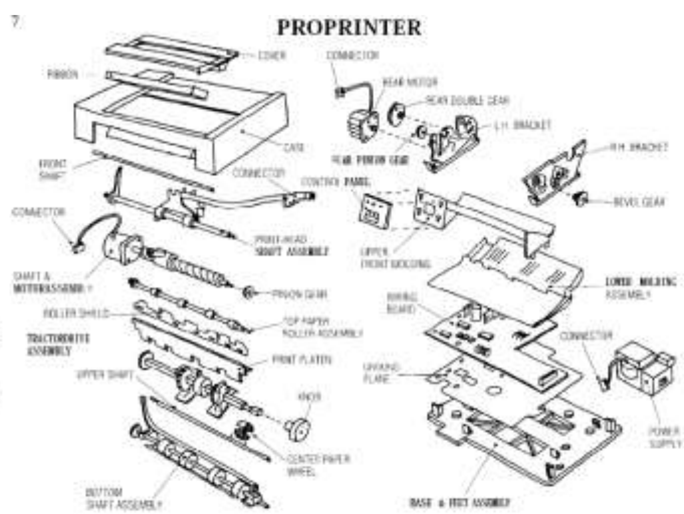
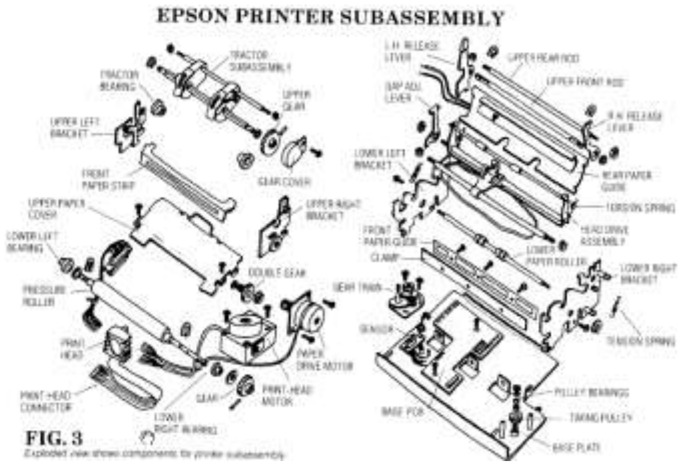



FIG. 5
Exploded view of IBM Proprinter highlights design simplification in this product.

[3] Design for Assembly in Action, Assembly Engineering January 1987




Comparing the two printers, one observes that IBM designers achieved an actual part count very close to the theoretical minimum for the ProPrinter as opposed to those for the Epson's MX80 which had an extra 111 parts. The expanded view of the MX80 shows that the printer subassembly by itself has an additional 103 parts.

| **Epson MX 80** | **IBM PRO Printer** |
|---|---|
| Total Assembly Time<br>1866 secs | Total Assembly Time<br>170 secs |
| Total Number of Operations<br>185 | Total Number of Operations<br>32 |
| Total parts/subassemblies<br>152 | Total parts/subassemblies<br>32 |
| Theoretical part count<br>41 | Theoretical part count<br>29 |

## Design Methodologies & Manufacturing Processes That Result in Automatic DFMA Results

Over the last decade several design methodologies and manufacturing process have appeared that when employed lead to automatic DFMA results.[4]
These processes include but are not limited to:

- Electronic Packaging and Assembly Concept EPAC
- 3D Molded Interconnect Devices and/or 3D Mechatronic Integrated Devices 3D MID
- Electro Magnetic Assembly Bonding EMABOND
- 3D Printing
- Hydroforming
- Stir Welding

Each of these design methodologies/processes when implemented enable the designer to achieve some of the tenets of DFMA, the primary one being reduced part count.

[4] Thank you to Dr. Luanne Isherwood for her inciteful comments and insights

# EPAC

## THE ORIGINS OF ELECTRONIC PACKAGING ASSEMBLY CONCEPT EPAC

In the 1990's as a result of steadily decreasing market prices and shorter life cycles, Hewlett-Packard's workstation business suffered. The need for faster development and production time was critical.

Faced with this challenge, the Hewlett-Packard Boblingen Mechanical Technology Center in Germany, reduced the time required to build its workstation's chassis and reduced the chassis' overall cost by reducing the number of components, as well as, reducing the number of different part numbers. As fortuitous result, Hewlett-Packard also reduced its logistics and administrative costs against tightening environmental protection guidelines; fewer parts and part numbers meant lower supply chain costs.

## Genesis of an Idea

For Hewlett Packard's designers to reduce the cost of building its workstation, the design team changed their thought process. As one of the designers noted, "The team could not get out of their minds the idea of fixing parts in such a way that they are enclosed and held by their by geometrical forms. The idea [was] similar to children's toys that require them to put blocks, sticks, cards, or pebbles into matching hollows and at the same time keep track of positions and maintain a certain order at any time during the game."[5][6]

The critical step turned out to be finding a suitable material for the interior of the enclosure since it needed to be:

- Pliable and bouncy
- 100% recyclable
- Nonconductive
- Able to hold tolerances
- Able to fix components without fasteners
- Moisture resistant
- Resistant to chemicals
- Heat resistant

The material that seemed most suitable was expanded polypropylene (EPP). To create the prototype with EPP foam to an already existing workstation required two days to fabricate the parts and assemble the workstation. The big question was "Would it run?" With a few minor alterations required for air flow, the workstation not only ran, but passed all environmental tests as well. Compared to the traditional workstation the **E**lectronic **P**ackaging **A**ssembly **C**oncept (**E-PAC**) workstation showed :

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[5] HP-PAC: A new Chassis and housing Concept for Electronic Equipment , J. Mahn, J. Haberle, S. Kopp,T. Schwegler *Hewlett-Packard Journal* Vol. 45, no.4, August 1994, pg's. 23-28

[6] Product Design of the Model 712 Workstation and External Peripherals, A.L. Roesner Hewlett-Packard Journal April 1995 pg's.75-78.

- 70 % reduction in housing parts
- 95 % reduction in screw joints
- 50 % reduction in assembly time
- 90 % reduction in disassembly time
- 30 % reduction in transport packaging
- 50 % reduction time and expenditure in developing the housing

Moreover, the E-PAC workstation included these additional benefits:

- Reduction in chassis parts
- One production step to produce molded parts
- Simple, fast, cost effective assembly
- Reduced product weight
- Good shock and vibration protection
- Cooling from air channels in the foam
- 100% recyclable material
- Reduced tolerance issues because of material flexibility

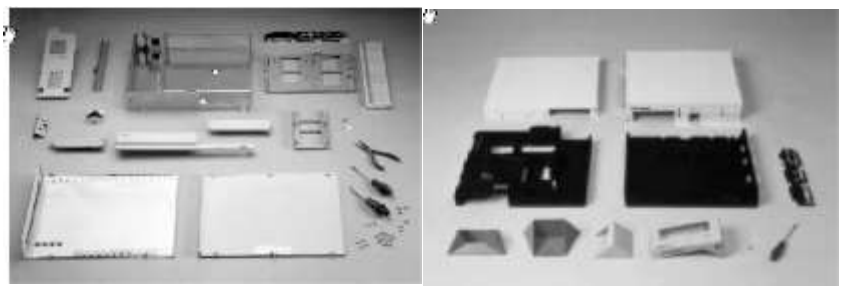
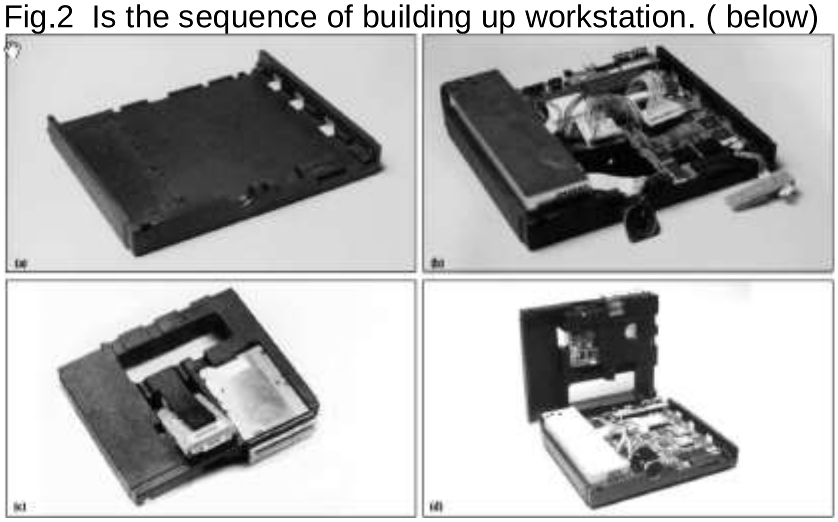
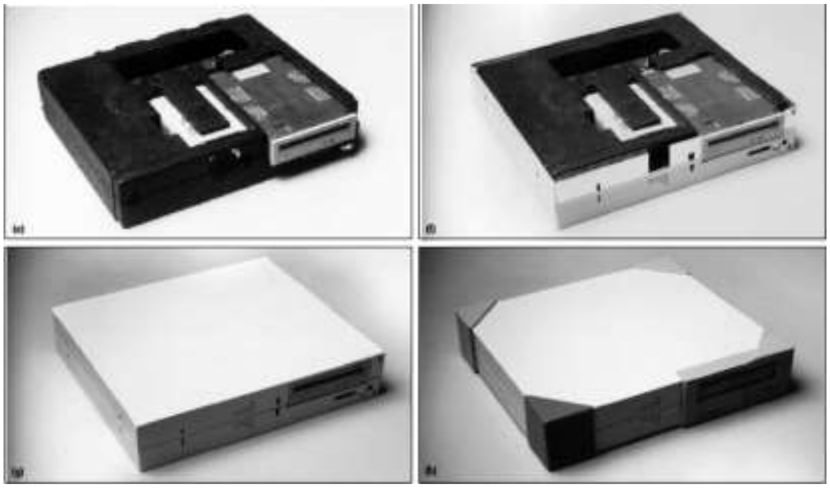


Fig.1 Difference between traditional chassis and E-PAC foam chassis
Fig.2 Is the sequence of building up workstation. ( below)





## Case Study

In 1994, Hewlett Packard pioneered and patented E-PAC and licensed it to DMT. In the U.S. Tegrant began to manufacture E-PAC. Since its creation, designers have used E-PAC in different industries for a variety of applications to solve difficult design, manufacturing and cost challenges. Industry examples include, computer workstations, data storage systems, medical devices, consumer electronics, household appliances, industrial systems and automobiles.

Using E-PAC yields dramatic DFMA results. Savings from its use ripple through the entire product life cycle enabling low expenditure, rapid prototyping of the design, and lower tooling cost for the entire product. In many cases an entire product's foam parts can be made with one tool.

Other areas where E-PAC properties offer unique solutions to product design include but are not limited to:

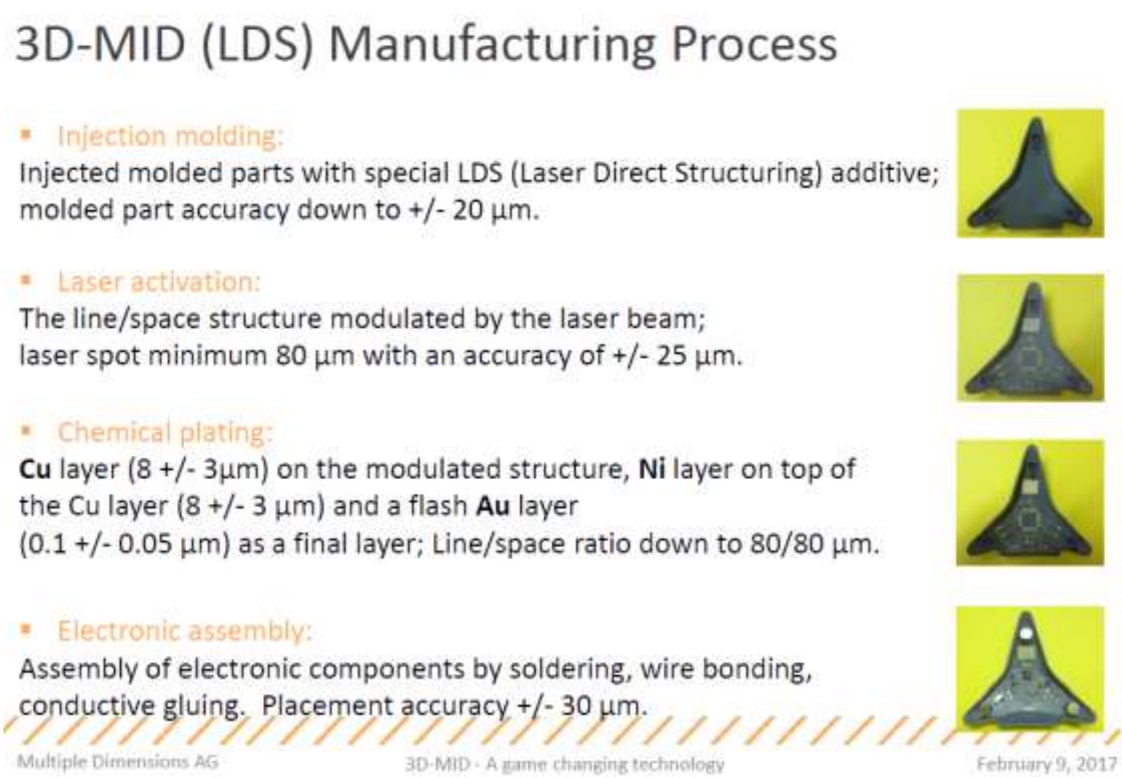
- Major product cost savings in product design and manufacture
- Part count reduction
- Reduced assembly and disassembly time
- Reduced serviceability time
- Elimination of most, if not all fasteners
- Sound absorption
- Sound transmission reduction
- Cooling efficiency improvements
- Thermal insulation
- Vibration isolation and damping
- Electrical insulation
- Tuning of sound and vibration
- Product weight reduction
- Reduction in shipping packaging
- RoHS Compliant -- No Phthalates -- CFC Free
- Excellent chemical resistance
- 100 % recyclable
- Meets most flammability requirements (UL, FMVSS,ASTM, etc.)

# 3D Molded Interconnect Devices 3D MID

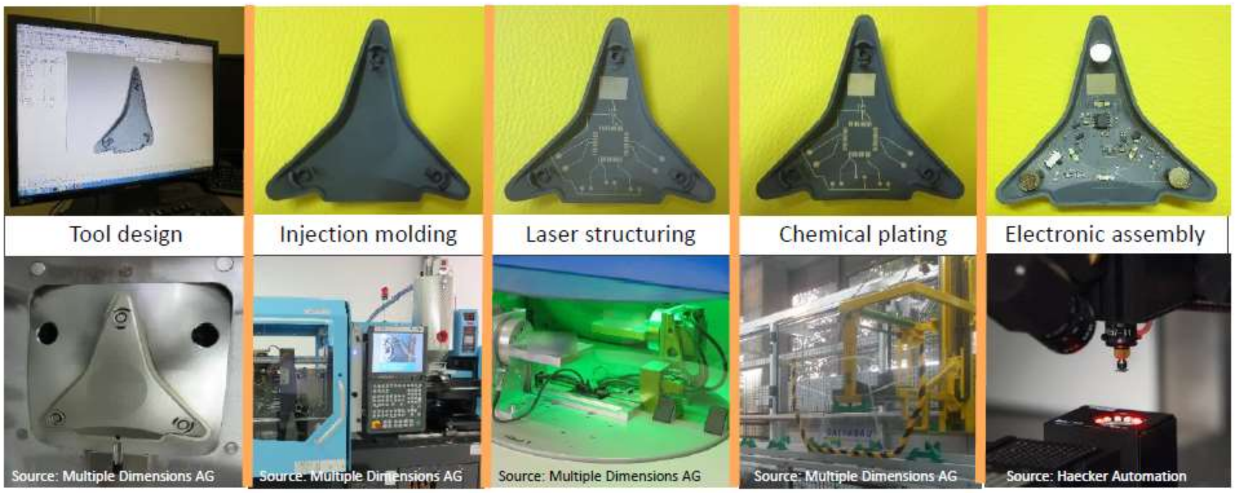
3D Molded Interconnect Devices or 3D Mechatronic Integrated Devices (3D MID) are also known as Laser Direct Sintering (LDS), the manufacturing process used to expose the copper in the plastic.

Laser Direct Sintering was invented at Hochschule Ostwestfalen-Lippe, University of Applied Sciences in Lemgo, Germany, between 1997-2001. Developed as a research cooperation with the former LPKF Limited, its inventors first exclusively licensed to LPKF. In 2002, LDS technology patents were transferred to LPKF Laser & Electronics AG.

The process of 3D MID begins with injection molding with an additive in the polymer, usually copper. A laser then ablates the top layer of plastic, exposing and forming a micro-rough surface of copper. Once exposed, the parts are then cleaned. Next, the parts are exposed to a copper bath to build up the copper; afterwards, a deposition of a thin layer of nickel, and usually a thin layer of gold are added. Different coatings can also be applied such as Sn, Ag, Pd/Au, OSP and others. After coating, the assembly of electronic components begins. In addition, if the plastic chosen has a high heat resistance then the part with components can be put through a standard solder reflow process.



# From design to electronic assembly




## Benefits:

3D MID applications are only limited by your imagination. The final of combining electrical and mechanical functionality yields:

- Part count reduction through combined parts
- Miniaturization and reduced weight
- Function integration
- Assembly simplification
- Reliability
- Flexibility in being able to use 3 dimensions and mechanical properties of polymers

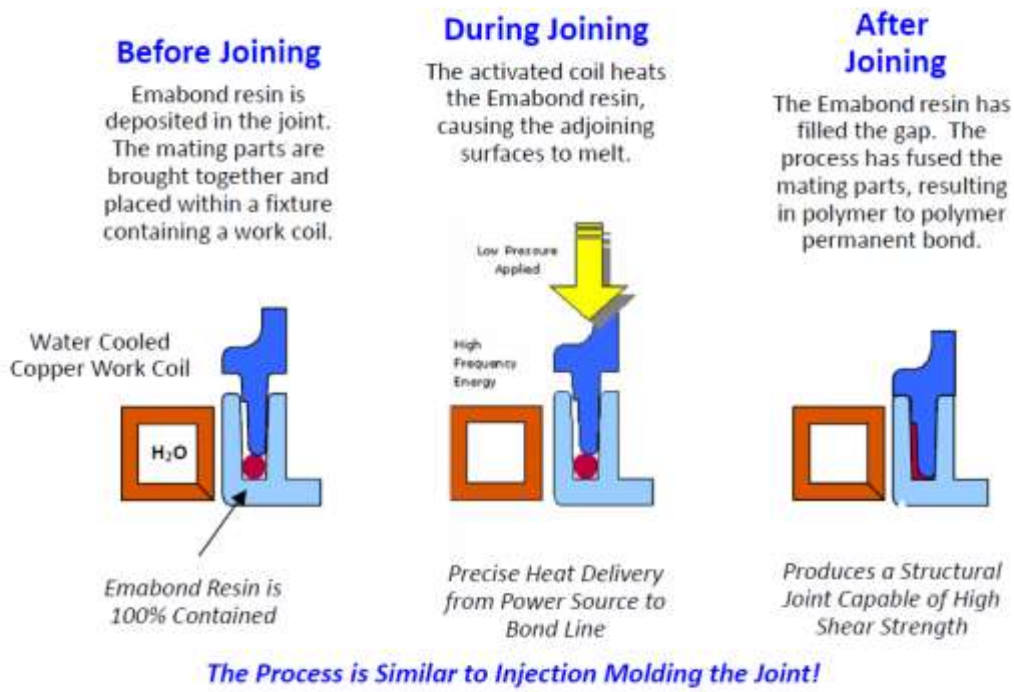
## Applications:

- Telecommunications
- Elimination of PBCs & Flex circuits
- Medical
- Automotive
- Security
- Connectors
- Packaging
- Military & Defense
- Measuring & Testing Equipment
- Antennas
- LEDs – Solar State Lighting, Camera, and Sensors

Thank you to Will Slade for supplying information and examples 3D-MID. Will Slade, Director - Multiple Dimensions -3D-MID Technology - Mobile: 612 728 5807 - www.multipledim.com

# Electronic Magnetic Assembly Bonding EMABOND

Emabond is a process that takes Electromagnetic High frequency 13.56 Mhtz energy + Emabond custom polymeric formulation which has added to it particles of iron or stainless steel and forms a polymer to polymer permanent bond.




The Emabond material is available in all types of custom formulated Susceptor materials and thermoplastics resins to match an application. It is also available in different forms:

- Sheet
- Die cut stamped gaskets
- Slit tape
- Injection molded rings
- 3D printed shapes
- Co-extruded
- ……..

The advantages of using this process is that regardless of the type of plastic, including blow-molded, fabrics, extrusions, thermoformed, or composite, welds are reliable. The process is compatible with almost any type of material. Some applications include high pressure vessels, fluid containers, dissimilar materials, internal components, large parts, multiple component weld lines, and difficult or inaccurate geometries.

An EMABOND Electromagnetic Process can be used when:

- A hermetic seal is needed.
- Joining dissimilar materials.
- Joining highly filled materials.
- Currently using an adhesive to bond your parts together.
- A surface treatment prior to welding or bonding is required.

- Screwing parts together with gaskets is used.
- Welding or bonding multiple bond lines.
- Superior joint strength is required.
- Tool access side of part is a A-Surface.
- Experiencing high or costly joint failures.

## CASE Study

### Application Needs

- Clean, aesthetic weld lines.
- 11 individual bond lines including 13 feet of perimeter weld.
- Create leak proof chambers for improved sound quality.


### Why Emabond?

- Complicated geometry eliminated vibration and cycle time/maintenance of Hot Plate could not meet specifications.
- Adhesive joining is least preferred given multiple joining interfaces and need for high structural loading.
- Emabond offered fast and reliable welding @ lower overall cost
- Material – filled PP
- Provided "Zero" failures

Thank you Steve Chookazian for his help and providing of EMABOND information.

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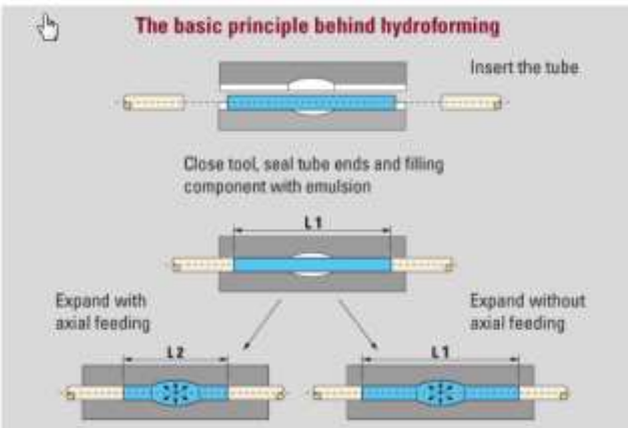
## Hydroforming

The process of hydroforming is based on a 1950's patent for hydramolding by Fred Leuthesser, Jr. and John Fox of the Schaible Company, Cincinnati, OH.[2] It was originally used in producing kitchen spouts because it not only strengthened the metal, it also produced less "grainy" parts allowing for easier metal finishing.

Hydroforming is a metal fabricating and forming process that shapes metals such as steel, stainless steel, copper, aluminum, and brass. This process is cost-effective. It requires a special type of die molding that utilizes highly pressurized fluid to form the metal.

Hydroforming can be either sheet hydroforming or tube hydroforming. In sheet hydroforming, high pressure water drives a blank sheet into the die on one side of the sheet, forming the desired shape. Tube hydroforming is the expansion of metal tubes into a shape using two die halves, which contain the raw tube. This type of hydroforming replaces the older process of stamping two halves and then welding them together. Tube hydroforming makes parts more efficiently by eliminating welding and allows the creation of complex shapes and contours. These parts posess a number of manufacturing benefits including seamless bonding, increased part strength, and the ability to maintain high-quality surfaces for finishing purposes. When compared to traditional metal stamped and welded parts, hydroformed parts are lightweight, have a lower cost per unit, and are made with a higher stiffness to weight ratio. [7,8]




## <u>The benefits to hydroforming include:</u>

- Creation of complex, 3-dimensional geometries and cross-sectional and perimeter enhancement in a few process steps.
- Costs reduced through material reduction due to thin-walled tubes (wall thickness, weight and installation space compared to cast or bent parts with the same or higher static strength)

- The ability to replace several work steps (joining, soldering, welding, milling) with only one hydroforming component.
- A high degree of measurement and form precision.
- Extensive repeat accuracy of geometries.
- Requires only one hydroforming tool to create complex parts.
- Elimination of subsequent operations due to geometry advantages.
- Allows material diversity: aluminum, stainless, brass, copper, nickel-based alloys.
- Standardization of components across entire product range.

[7] https://www.fischer-group.com/en/fischer_companies/fischer_hydroforming/fischer_hydroforming.php?navanchor=2110100

[8] https://americanhydroformers.com/what-is-hydroforming/

## 3D Printing

### 1981–1999: The Infancy of Additive Manufacturing

In 1981, Hideo Kodama of Nagoya Municipal Industrial Research Institute published his account of a functional rapid-prototyping system using photopolymers. A solid, printed model was built up in layers, each of which corresponded to a cross-sectional slice in the model.

Three years later, in 1984, Charles Hull made 3D-printing history by inventing stereolithography. It lets designers create 3D models using digital data that can then be used to create a tangible object. The key to stereolithography is a kind of acrylic-based material known as photopolymer. Hit a vat of liquid photopolymer with a UV laser beam, and the light-exposed portion will instantly turn into a solid piece of plastic, molded into the shape of your 3D-model design. 3D printing allows designers to prototype and test designs without a large upfront investment in manufacturing.

By 1992, 3D Systems created the world's first stereolithographic apparatus (SLA) machine which made it possible to fabricate complex parts, layer by layer in a fraction of time that it previously had taken. That same year, startup DTM produced the world's first selective laser sintering (SLS) machine — which shoots a laser at a powder instead of a liquid.

Since then 3D printing has taken off. A number of materials can be printed including: most polymers, composites, metals, and even human biological tissue to create primitive organs. Everyday new applications for 3D printing are found and new methods of 3D printing continue to evolve. The foot note below references an article with a list of the most current 3D print technology companies. [9] If you are looking for a great personal 3D printer https://www.prusa3d.com/ look no further.

[9] https://www.3dnatives.com/en/metal-3d-printer-manufacturers/

## Case Study

3 D printing has numerous applications; the following is an example of one create use. Creative Technologies prints 3D reusable packaging. They employ materials for printing that are strong enough to be used for the base and sides of trays for car parts. In addition, Creative Technologies can print TPE / TPU parts that touch the actual parts so as not to damage them. Its 3D printing process can meet their volume demand and the actual reusable packaging can be printed faster than it takes to get an injection molded tray done. The process has a number of advantages. Occasionally trays are destroyed and creating a replacement requires little effort. Also, as car models or components change, the main tray may still be suitable; only finger parts that come into contact with actual parts may need to be created. The example below shows a cost analysis for 3D printing versus injection molding to create a Wrangler Hood Assembly top fingers.

### 2020 JT Profighter – Cost Analysis

**3D Printed Top Fingers**

- $16,640
- 3D print finger and TPU tip
- $128 per assembled finger
  - 130 fingers required on initial order

**Injection Molded Fingers**

- $21,345
- Two new injection molds
  - $9,750 / each
  - Requires Capital approval
- Stand alone finger cost
  - $6.50 / each
  - 130 fingers required on initial order
- Two setup charges
  - $500 / each

creativetechniques

Thank you Rob Cole for sharing this case study.

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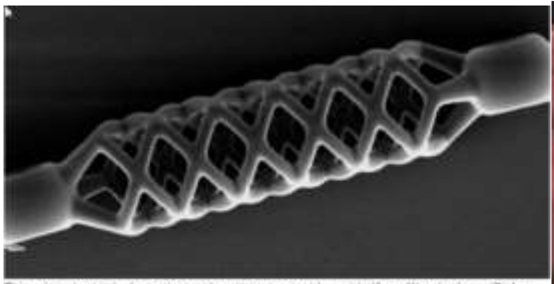
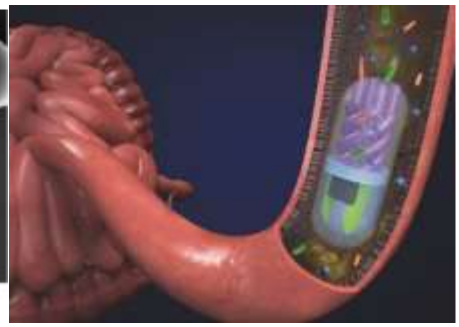
Two other recent announcements in the medical world also show how 3D printing is expanding into every direction.  Medical Design Briefs https://www.medicaldesignbriefs.com/ recently ran two stories on 3D advancements in medical world the first one from Tufts university on a 3D printed pill that samples gut microbiome and the second on a Indirect 4D printing of the worlds smallest stent just 50 micrometers long. [10][11]



This microstent is just 50 micrometers (0.05 mm) wide and half a millimeter long. (Picture: Carmela de Marco / ETH Zurich)



## Friction Stir Welding

Organized in 1946, **The Welding Institute** (**TWI),** located in Cambridge, England, is a research and technology organization that specializes in welding. TWI serves 700 Industrial Member companies across 4500 sites in 80 countries. TWI works across all industry sectors and in all aspects of manufacturing and fabrication and its services include consultancy, technical advice, research and investigation for industrial member companies and public funding bodies.

Friction stir welding (FSW) was invented by Wayne Thomas and Colleagues at TWI in 1991. [12][13]

[10] https://www.medicaldesignbriefs.com/component/content/article/mdb/stories/insider/35018
[11] https://www.medicaldesignbriefs.com/mdb/search?query=3D+printed+pill
[12] https://www.twi-global.com/
[13] https://en.wikipedia.org/wiki/The_Welding_Institute

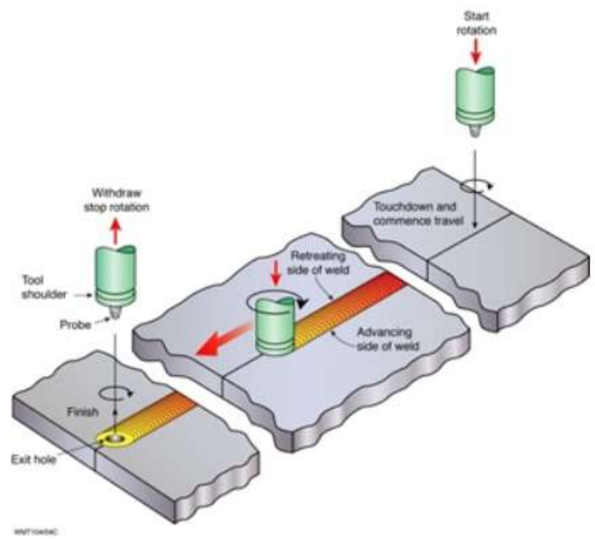
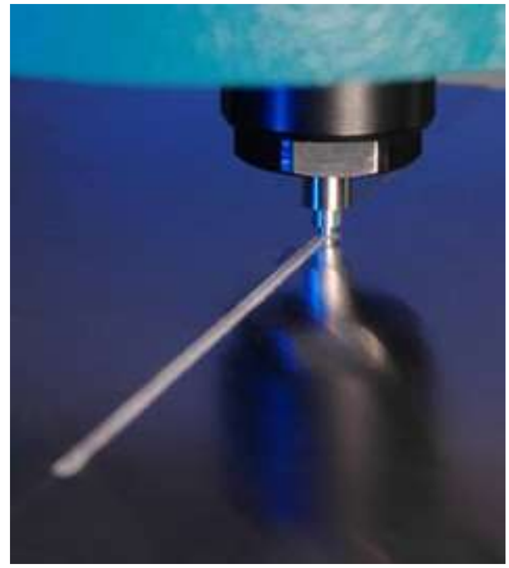


Figure 1: Schematic of the friction stir welding process



The process of friction stir welding spins a head slowly through a material melting it as it spins while moving forward, leaving behind a completely welded area. Massive plastic shear and mixing of the material in a zone surrounding the tool forms the solid state joint with material being swept from the leading edge of the tool and deposited at the trailing edge. The constraint of the flowing material maintains the high density and integrity of the weld zone. (See Figure 1) This process is capable of working on thick parts (larger than 75 mm) as well as very thin parts (down to 300µm).

## Advantages of the Process:

- Low distortion and shrinkage, even in long welds.
- Excellent mechanical properties in fatigue, tensile and bend tests; in many case improved micro structure and increased strength.
- No arc or fumes.
- No porosity in weld zone.
- No splatter during welding.
- Welds 3-dimensionally.
- Energy efficient.
- One tool can typically be used for up to 1000m of weld length in 6XXX series aluminum alloys.
- No filler wire required.
- No gas shielding for welding aluminum.
- Tolerance to imperfect weld preparations and joint match up - thin oxide layers can be accepted.
- No grinding, brushing or pickling required in mass production.
- Can weld aluminum larger than 75mm in one pass.

Has been used in cars, trains, airplanes and spaceships.

The centre tunnel of the Ford GT is made from two aluminium extrusions friction stir welded to a bent aluminium sheet and houses the fuel tank

The high-strength low-distortion body of Hitachi's A-train *British Rail Class 395* is friction stir welded from longitudinal aluminium extrusions

The bulkhead and nosecone of the Orion spacecraft are joined using friction stir welding.

Longitudinal and circumferential friction stir welds are used for the Falcon 9 rocket booster tank at the SpaceX factory

## Summary

All of the above design methodologies and manufacturing techniques when implemented yield DFMA-like results.  They simplify products and manufacturing processes; eliminate parts; save assembly labor; and overall reducing costs and improving quality.