DEVELOPMENT STATUS OF AN OCCAM ELECTRONIC ASSEMBLY METHOD

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ABSTRACT

The Occam assembly concept is under development as a low cost, solderless assembly method. This version of the process utilizes a "sticky" surface to hold conventional SMT parts in place until they can be covered with an encapsulant, restrained by a containment frame, that will permanently hold them in place with respect to one another. The encapsulant is added to cavities formed by the containment frame, and then cured to lock the parts in place. The assembly is then removed from the sticky surface thereby exposing the electrical contact points, inverted, and interconnects made between the electrical contact points utilizing screen printing or other suitable methods. The interconnect structure is then overcoated to protect it. The individual parts are removed from the containment fixture in the last step before test and shipment. Several variations of the process are presented. In general, the process eliminates the use of solder and related processes and does not expose components to temperatures greater than ~100C. In some applications, the process produces a "final" part ready for shipment to the end user by eliminating a case or additional enclosure. Finally, some preliminary economics of the process are presented suggesting applications where the process offers the greatest advantage.

Key words; Solderless Assembly, OCCAM, SMT assembly, electronic assembly

INTRODUCTION

The process described here envisions building electronic devices without the use of solder, without exposing components to high temperatures and with fewer steps. In addition, the process potentially enables lower cost manufacturing of the final devices.

Like any process, the OCCAM process is good for some applications and not good for others. In addition, any process, especially those as unique as those the OCCAM concept enables, require a material set, process equipment and related assembly processes. Also, as with any new process, a variety of issues arise that must be addressed to provide a "complete solution" really meaning a product that works without leaving the buyer with additional problems to solve.

We are exploring an OCCAM process that appears to lend itself to low cost assembly for devices with a minimal number of parts and limited interconnect requirements. That process, its implementation, solutions to detailed problems, the resulting options and outcomes, as well as some preliminary cost estimates are described below.

This process is only one implementation of the OCCAM concept; many others are possible and being explored elsewhere.

DISUSSION OF METHODOLOGY USED

After learning of the OCCAM concept, we discussed implementing it. We realized that we had capabilities to do so if we:

a. used conventional pick and place machines to place parts on a "sticky" surface to hold them during handling and encapsulation.
b. placed an encapsulation containment frame around the parts after placement
c. encapsulated the parts with a polymer overcoat ~3mm thick
d. removed the encapsulated parts from the "sticky" surface and turned it over.
e. screen printed the interconnect using a conductive ink system.
f. placed some parts on the interconnect, connected them with conductive epoxy and secured them with added epoxy.
g. saw singulated the array into final units.

We referred to this assembly sequence as OCCAM I illustrated in the following schematic drawings.

Figure 1 (1). Basic OCCAM I Assembly Concept

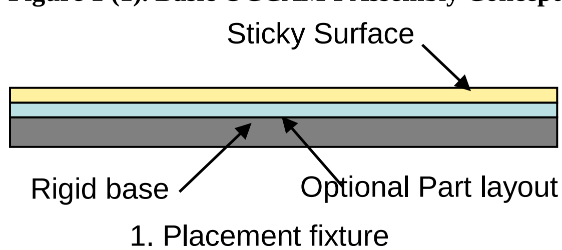
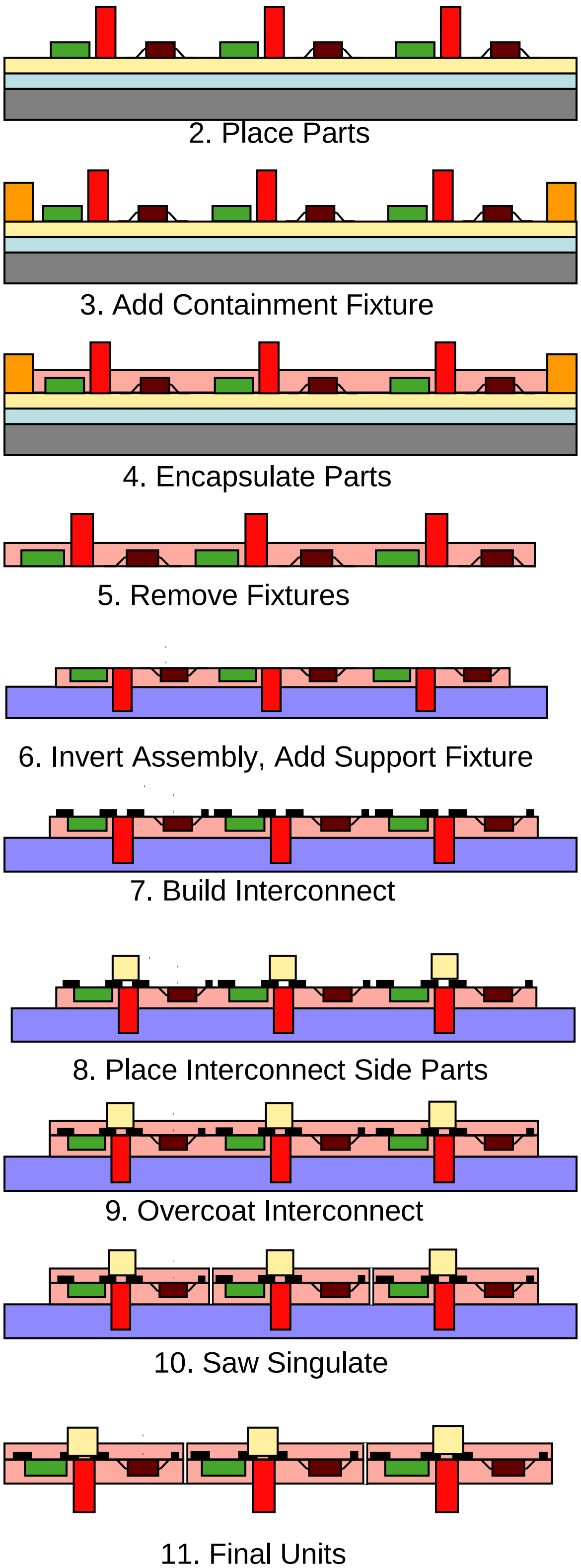


Figure 1 (2-11). Basic OCCAM I Assembly Concept



With this basic assembly concept in mind, the next step was to define the objectives of the immediate effort. These were:

1. Demonstrate a workable process.

2. Determine what issues need to be addressed.

3. Demonstrate that the process can yield functioning product.

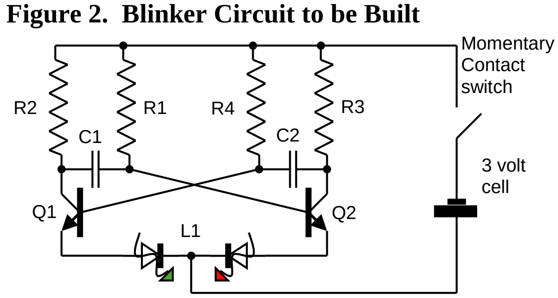
4. Provide a cost comparison of the OCCAM process with a conventional process.

The third step was to establish the Design Rules for the Occam I process.

The rules that emerged after some consideration are:
1. Build assemblies with as few steps as possible. This implies:
   a. Place all parts, including batteries and switches, in one pass with no secondary operations. (Implies <125C temperature and no immersion in fluids.)
   b. Fully encapsulate a battery
   c. leave switches exposed, above the encapsulant, to allow operation.
2. Design for a maximum trace resistance of <5% of the lowest resistor value in the circuit.
3. Use relatively large parts to minimize alignment issues.
4. Build in arrays to minimize handling.
5. Utilize a simple shape to facilitate saw singulation to minimize tooling costs.

The fourth step was to select an electronic product to build. The "blinker" shown in the schematic below was selected. This "product" met the design rules, was compatible with the process envisioned and allowed demonstrating that the product functioned by simply pushing the button to make the LEDs "blink".

Figure 2. Blinker Circuit to be Built



Blinker Circuit

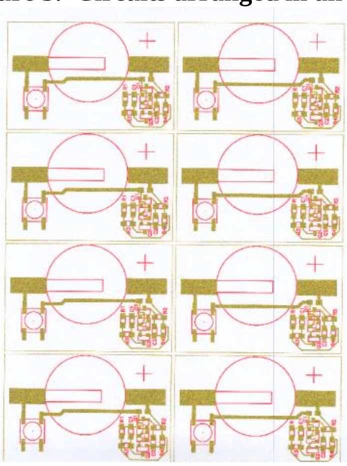
Table 1 has the Bill of Materials for this circuit.

Table 1. Blinker Bill of Materials

Ref Des	Value	Size
C1, C2	22uf	0805
R1, R4	47K	0805
R2, R3	470	0805
Li	Red, Green LED	SOT23
Q1, Q2	NPN	SOT23
Switch	Momentary Make	6 x 5 x 5 mm
Battery	3V Lithium	20 mm dia x 1.6 mm

The next step was to do a layout using as few layers of interconnect as possible. The resulting layout required only one layer and was repeated in a suitable array measuring about 75 mm x 100 mm, as shown in Figure 3.

Figure 3. Circuits arranged in an array.



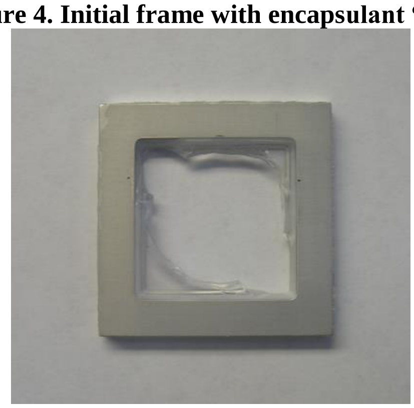
Results of Build Effort

Initial material selections were completed, tooling fixtures designed and fabricated, a pick & place program written, screens made, and parts and materials procured.

Then the build began with the following results.

1. When we tested the placement fixture with the sticky surface by pouring encapsulant into the containment fixture, we found that the encapsulant we had chosen stuck to the containment frame as shown in figure 4 below, even though the frame was coated with a mold release. The release capability was clearly inadequate.

Figure 4. Initial frame with encapsulant "stuck" to it.

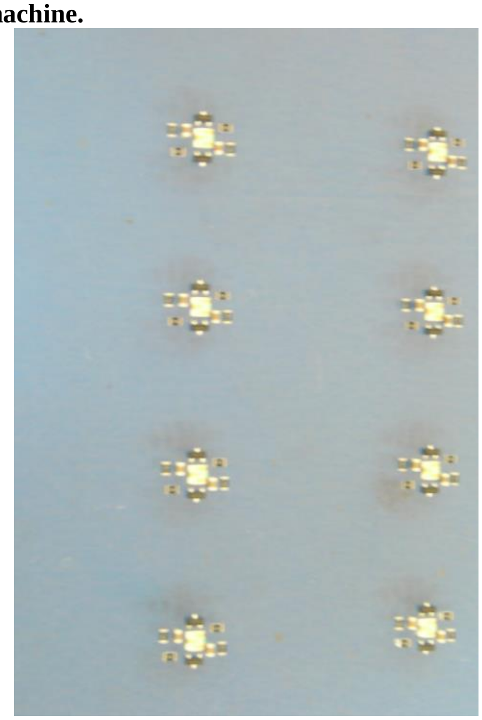


To eliminate that problem, the frame was fabricated from Teflon. This new frame, measuring ~125 mm square, and the placement fixture consisting of a sticky surface on a glass base, is shown in Figure 5 before any parts were placed or any encapsulant dispensed.

Figure 5. 125mm square Teflon containment frame on stick surface on glass base plate.

With these new fixtures, the next step was to place parts using a conventional pick & place machine. The result is shown in Figure 6 before the containment fixture was added. The battery and switch were not available in a form that allowed machine placement, so they are not in place at this stage.

Figure 6. SMT Parts placed on sticky surface by P&P machine.



Next, a layout transparency was placed behind the transparent placement fixture, the battery and switch put in position using the layout as a reference, the containment frame put in place and the array encapsulated by pouring the encapsulant into the frame.

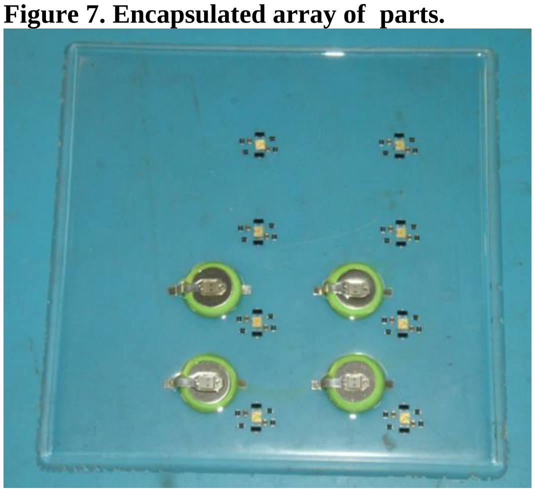
The results were not ideal. While the encapsulant flowed and covered the parts, several detrimental events took place.

First, we found that the switch "floated" because it was hollow and thus buoyant. But it did not keep floating. It had small holes in the housing that allowed encapsulant to enter the interior resulting in the now totally coated switch to sink ! When the encapsulant cured, the switch, of course, was ”frozen” and the contacts coated with encapsulant.

We decided to find a sealed switch or add the switch later as shown in figure 1 at step 8.

We did another run without the switch. Figure 7 shows the assembled array after encapsulant cure and removal of the fixtures.

Figure 7. Encapsulated array of parts.

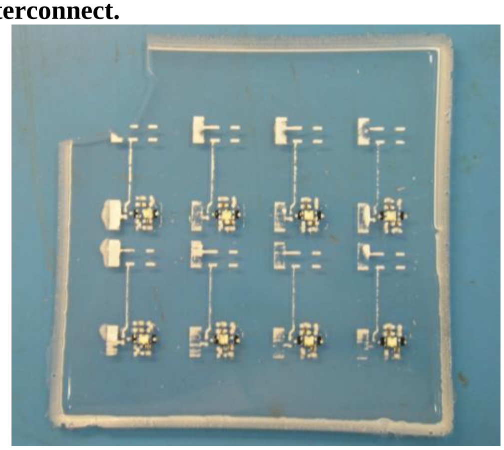


We did not have enough batteries for all of the sites, so we used what we had; hence the few blank battery locations.

After removal from the “sticky” surface, examination of the back side contact surfaces showed that some of the parts (in addition to the switch) had more encapsulant on the contacts than we would like. Nonetheless, we decided to proceed to the next step of screen printing conductive ink to interconnect the parts.

The initial result of that effort, done on another encapsulated sample that had no batteries, is shown in figure 8.

Figure 8. Encapsulated array with screen printed interconnect.



The corner of the encapsulated array was broken off inadvertently and this particular encapsulated array did not have batteries in it. More importantly, a close examination of the circuitry showed many breaks and poor print quality in spite of the relatively large feature sizes. We concluded that the ink we chose did not screen print well enough for this application; thus, we are seeking an alternative for further efforts.

An Alternate Method, OCCAM II

The work above suggested an alternate method that had added advantages. It became clear as we worked that the sawing step could be eliminated by making an encapsulant frame that had individual cavities for each of the units; individual parts need not be sawn but simply “popped” out of the frame. Figure 9 shows this version of the process.

Figure 9 (1-7_. An improved process that yields individual parts.

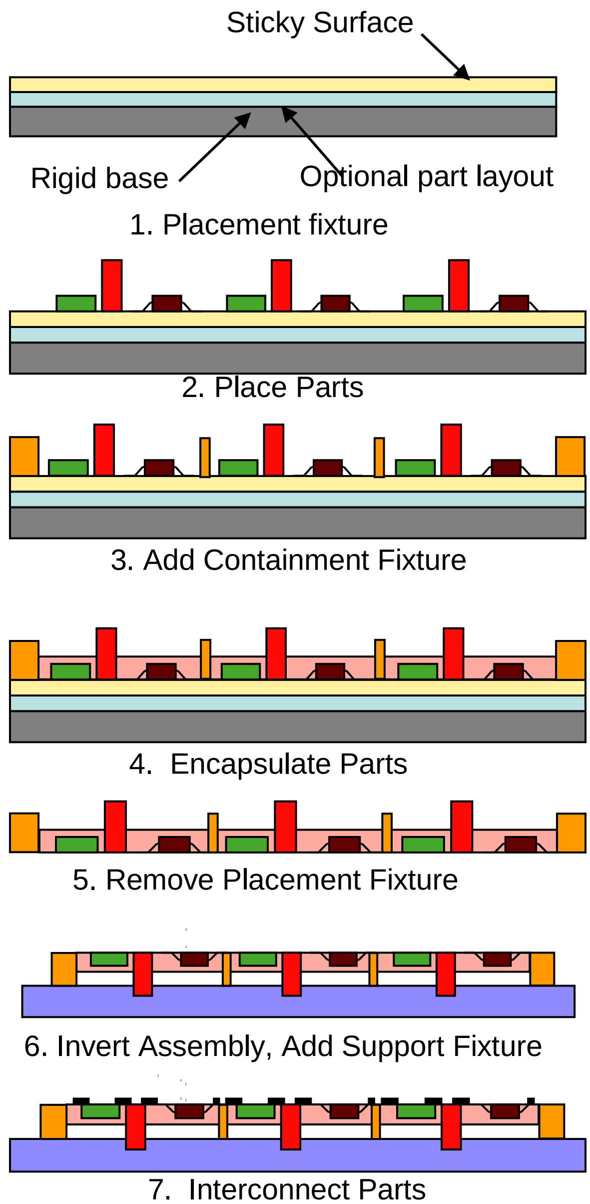


Figure 9 (8-11). An improved process that yields individual parts.

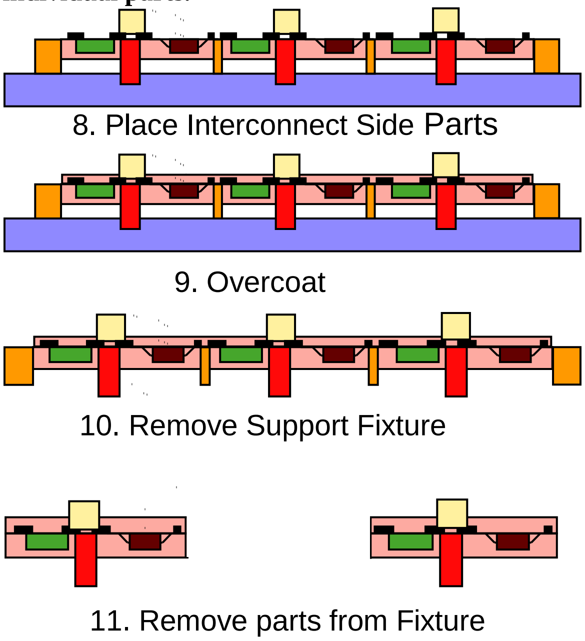
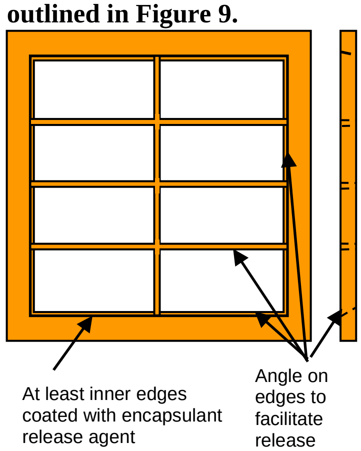


Figure 10. Encapsulation frame suitable for use with the process outlined in Figure 9.



This approach allows the process to yield a finished part for some types of products or devices with no additional processing.

Materials

The properties of the two principal materials discussed above are shown in table 2 and 3.

Table 2 Encapsulant Properties

TCE	90 ppm
Dielectric Constant	3.1
Cure Conditions	125C, 4 hrs
Modulus	470,000 psi
Flexural Strength	15,000 psi
Density	1.2
H_2O uptake	<0.4%
Shrink on cure	~1%
Other	Optically clear, electronic grade
Cost	$25/Kg; 2.5 cents/cc

Table 3. Conductive Ink Properties

Color	Silver
Electrical Resistivity	0.0002 ohm-cm ~0.08 ohm/sq @ 0.001" thick
Operating Temp	-20 to +140C
Viscosity	9,000 CPS
Specific gravity	2.2
Cost	$1.95/gm; 0.11 cent/cm^2 @ 25 um

RESULTS

Things Learned

- The placement machines do not need a footprint for each part. Machines can place parts based on a pair of fiducials, the edge of the part or even a "hand reference".

- Placing a layout transparency under the sticky surface allows parts to be hand placed, if necessary, before the encapsulant is dispensed.

- The sticky surface holds parts in place during handling & can be reused.
  - Parts tend to "float".
  - Some parts have holes encapsulant will enter. Holes must be avoided, plugged, or the part placed "later".

- Parts can be added on the interconnect side using conductive epoxy before application of the interconnect protection coating.

- Some parts (SOT23) have slightly out of plane lead bend intended to form solder fillets. The leads must either be "flattened" or the sticky surface must be soft to allow the tips to "sink" to protect them from the encapsulant.

- Encapsulation fixtures can be reused.

- A 125 C encapsulant cure temp allows a battery to be added during assembly and encapsulated.

- Since wash is not required, water sensitive parts can be machine placed.

- This PROMEX OCCAM process works best if:
  - Part count is small to minimize yield loss
  - None of the parts float
  - A single layer interconnect is adequate

- The process allows new capabilities:
  - Placement of parts that cannot tolerate temperatures above 125 C
  - A final shape can result from the encapsulation process without further processing

Needs Uncovered

- What material will yield a reusable sticky surface that will firmly & cleanly hold components ?

- What encapsulant ?
  - Will release from the sticky surface ?
  - Has adequate wetting characteristics
  - What interconnect will adhere to the encapsulants ?
  - Will encapsulant cure shrink damage parts and effect performance ?

- How can parts that float be accommodated ?

- How can parts with holes be accommodated ?

- What interconnect method will work ?
  - Screen printable ink ?
    - We are exploring alternatives
  - Multiple layer conductor/dielectric/via system ?
    - We are exploring alternatives

- What final shapes can be accommodated with PROMEX OCCAM II ?

Potential Costs OCCAM II vs SMT & Overmolding

A key parameter of any new assembly method is the cost incurred using the method. While much of this effort is early, and conclusions are hard to draw, it is useful to gather data to understand the cost structure that emerges from the OCCAM process. The cost structure will help guide development to minimize the eventual costs.

The assumptions for this preliminary analysis of the cost to build the "blinkers" in moderate volume are:

- The OCCAM II Process is used
- The blinkers built with conventional SMT are overmolded.
- Blinkers are built in lots of ~100,000.
- Parts are ~25 mm x 25 mm x 2 mm.
- Parts are built in 200 mm x 300 mm panels.
- A PCB for the SMT version costs $0.20.
- Encapsulant costs $20.00/liter, conductive inks $0.375 cents/cm^2 and mold compound $10.00 liter.
- Custom tooling costs are minimal and ignored.

The blinker BOM cost per the Digikey web site, except for the PCB which was estimated separately, is shown in Table 4.

Table 4. Blinker part costs

Ref Des	Digikey Cost in volume	
	OCCAM II	SMT
PCB		$0.20
C1, C2	$0.25	
L1	$0.52	
Q1, Q2	$0.027	
R1, R4	$0.028	
R2, R3	$0.016	
Switch	$0.23	
Battery	$0.55	
Total per Blinker	$1.94	$2.14
Price with 20% markup	$2.33	$2.57

The cost estimates to assemble the blinkers using the OCCAM II process are shown in Table 5, below.

Table 5. Blinker cost estimate OCCAM II process.		
Process Step	Part/material cost @ 20% markup	Direct Labor time, sec/part
BOM Cost with markup	$2.33	
Place parts		5
Encapsulate	$0.03	1
Remove fixtures		1
Screen interconnect	$0.01	1
Place Interconnect Side Parts		5
Overcoat interconnect		1
Remove from fixture		5
Test		2
Subtotals	$2.36	20
Add DL cost @ $60.00/hr.	$0.33	
Total Costs & markups	$2.70	
Scrap @ 5%	$0.13	
Final cost	$2.83	

The estimated cost using conventional methods is shown in Table 6. The process assumes that SMT placement is done on an array, the array broken into strips, the strips overmolded, the units tested, then singulated and deflashed.

Table 6. Blinker cost estimate Conventional SMT With Overmolding		
Process Step	Part/material cost @ 20% markup	Direct Labor time, sec/part
BOM Cost with markup	$2.57	
Stencil solder	$0.02	6
Place parts		
Reflow		
Overmold	$0.01	5
Singulate		10
Deflash		3
Test		2
Subtotals	$2.60	26
Add DL cost @ $60.00/hr.	$0.43	
Total Costs & markups	$3.04	
Scrap @ 2%	$0.06	
Final cost	$3.10	

The costs tradeoffs are simply these:

1. PCB cost vs cost for encapsulant, screen ink and screen printing.
2. Overmolding and deflash vs a final form from the encapsulation process.
3. Some products lend themselves to this process; and others do not.

In summary, the major savings arise from eliminating the PCB and the molding process.

CONCLUSION

The major conclusions that can be drawn from the effort to date are:

- The pros and cons of using the OCCAM Process are highly dependent on the product to be built.
- OCCAM can yield lower costs, especially for simple, low part count products when a final product results from the process.
- OCCAM reduces costs by:
  - eliminating the fab
  - eliminating some hand assembly
  - potentially eliminating, a final enclosure
  - allowing use of lower temperature parts

The most important conclusion is that work on materials and the process is needed to find combinations that work well together so the promise of the process can be realized.

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REFERENCES

1. Verdant Electronics White Paper on the OCCAM Process. Available as a download from www.verdant electronics.com with registration.