



University of Bath

BATH

BA2 7AY

United Kingdom

Tel +44 (0)1225 388388

**Rapid Prototyping Electronic Circuits:
Supplementary Manual based on Project EN310X**

Prepared by..... Mr E Sells

Reviewed by..... Dr A Bowyer

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SUMMARY

This document summarises the findings from project EN310X. It has been written as a manual to manufacture rapid prototyped components with integrated electronic circuits using a basic injection technique. This manual covers all stages from basic model design to the finished product.

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1 DESIGN FOR RAPID PROTOTYPING: SOLID EDGE V14

1.1 Potential Software Packages

Designs can be realised with rapid prototyping techniques by using 3D modelling software packages. The Stratasys Dimension rapid-prototyping machine and accompanying Catalyst software requires an STL file format. Thus any 3D solid modelling software package may be used with the provision that it has the capability to export to an STL format.

This manual is specific to the Stratasys Dimension rapid-prototyping machine and Solid Edge v14 (solid modelling software package licensed by the University of Bath). Therefore this section will refer to techniques used in Solid Edge v14.

1.2 Simple Part Conversion to STL Format

A simple part drawing can easily be converted into an STL format using the following method:

- Click 'File', 'Save As...'
- Enter Filename
- Click 'Save as type:' > "STL documents (*.stl)"
- Click 'Options' and ensure parameters match those specified in Figure 1.

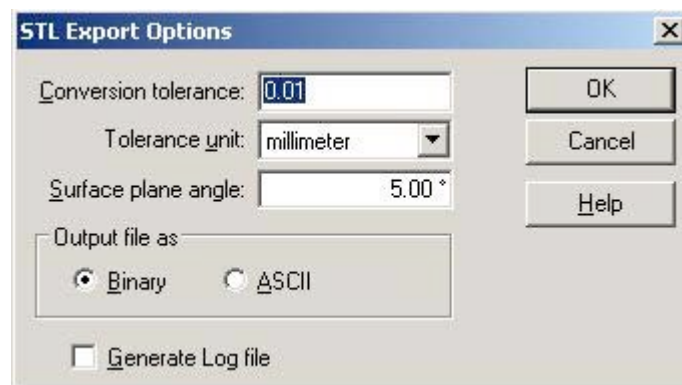


Figure 1: STL export parameters

- Click 'OK' on all dialogues
- To pre-process the file, go to Section 2

1.3 Assembly Conversion to STL Format

Whilst the majority of parts made on an RP machine are made in a part environment using Solid Edge, it is a natural progression for the RP designer to need the manufacture of components from the assembly environment. The conversion of the assembly model is not as simple as a part model and also includes some limitations.

1.3.1 Conversion Method

These steps enable a Solid Edge assembly to be converted into an STL file for Solid Edge v14.

- Save the assembly file
- Open a new part file
- Click 'Insert' on the top menu bar
- Click 'Part copy'
- Select required assembly (if not shown ensure 'files of type' is correct)
- Click 'File'
- Click 'Save as'
- Save as an STL file

1.3.2 Conversion Limitations

- It is a known flaw with the program that conversions of some tangent relationships cannot occur. Tangent relationships induce elements of zero thickness i.e. the software does not support non-manifold topology.
- Objects 'hidden' in the assembly file will be included in the STL file.

1.3.3 Design considerations

The following assembly elements should be considered to avoid part copy errors from an assembly to a part file:

- Tangent relationships should be avoided where possible
- If it is necessary to use tangent relationships, the problem can be eliminated by moving one of the components either away or towards its mating component. Thus the point of infinity is eliminated. Movement at the micron order is sufficient.

1.3.4 Support

Consultant for University of Bath, through Angie MacDonald:

Neil Parrott
UGS Solid Edge helpdesk
neil.parrott@ugs.com
T: 01215069555

2 PRE-PROCESSING: CATALYST

Pre-processing is required to convert the STL file into tool paths for the rapid prototyping machine to manufacture the component. The pre-processing package used and referred to in this manual is Catalyst v3.4.1 Build 1931 (Stratasys Inc.).

2.1 Importing an STL file

Any STL file can be imported providing it is no larger than the working box for the RP machine: 165 mm x 146 mm x 276.64 mm (width x depth x height).

Models are loaded into Catalyst by importing the STL file:

- File → Open...
- Small models will be queried as to whether the units should be metric or imperial.

2.2 Viewing the model in catalyst

It is essential to check that the model has been imported correctly. On occasion the order of magnitude for the size of the STL file will be incorrect (check that parameters defined in Section 1.2 are correct). In this instance the model will look correct in close up view, however when viewed with the rest of the working box the model will not appear (the magnitude of size is too small). This can easily be checked using the shortcut keys defined in Table 1.

Table 1: Shortcut keys for view modes within Catalyst

Shortcut Key	Function
F9	Fit envelope
F10	Fit view to box

2.3 Defining model orientation for manufacture

The orientation of the model during manufacture defines the quantity of the support material required. Orientation can be set as follows:

- STL → Orient by selected facet → ...
- Click on the side of the model to orientate to the selected orientation

2.4 Lay-up style parameters

For accurate design it is essential that the build styles are appropriate to the component. These styles are defined in Table 2.

Table 2: Parameters for RP manufacture using Catalyst

Parameter	Option	Definition
Build Style	Standard	Used for most parts.
	Draft	Uses thicker slices and wider tool paths to build the part more quickly but with less feature detail.
	Fine	Builds a part with fine feature detail by using a finer slice height and narrow toolpaths. The use of the finer slice heights and toolpaths will result in longer part builds than the other build styles.
Part surface	Best vertical quality	Default, will rotate the internal toolpaths by 90 degrees on each successive layer. This is the same as in earlier versions of Catalyst.
	Best horizontal quality	Improves horizontal surfaces by rotating the internal toolpaths by a smaller angle on successive layers. This may result in lower quality on vertical surfaces.
Part interior	Solid – fine	Solid interior, resulting in stronger parts.
	Solid – double wide	Solid interior, built with maximum width rasters for fast and stronger parts.
	Sparse	Sparse interior, which builds faster. Parts with sparse interiors are often better for casting, since they will be easier to burn out of the mould.
Support	Break-away	Supports are similar to sparse supports but consist of boxes instead of a continuous raster. There is no closed toolpath-perimeter curve around the break-away supports. They are easier to remove than other support styles for some materials but build slower than sparse supports. Break-away supports are not recommended for use with WaterWorks.
	Sparse	Minimizes the amount of support material used.
	Basic	Used for most parts.
	Surround	Used for tall, thin parts. Supports will fully surround all part features.
	Minimal	Used for small parts that have small features in need of supports. Minimal supports are designed to make support removal easier on these small parts. Do not use minimal supports on large parts or parts with tall columns of supports.

2.5 Initialising the lay-up process

Click on the green flag to initialise the lay-up process.

2.6 Job arrangement

Catalyst uses the following dialogue to ensure that the job is arranged correctly on the plate. The important features are indicated in Figure 2.

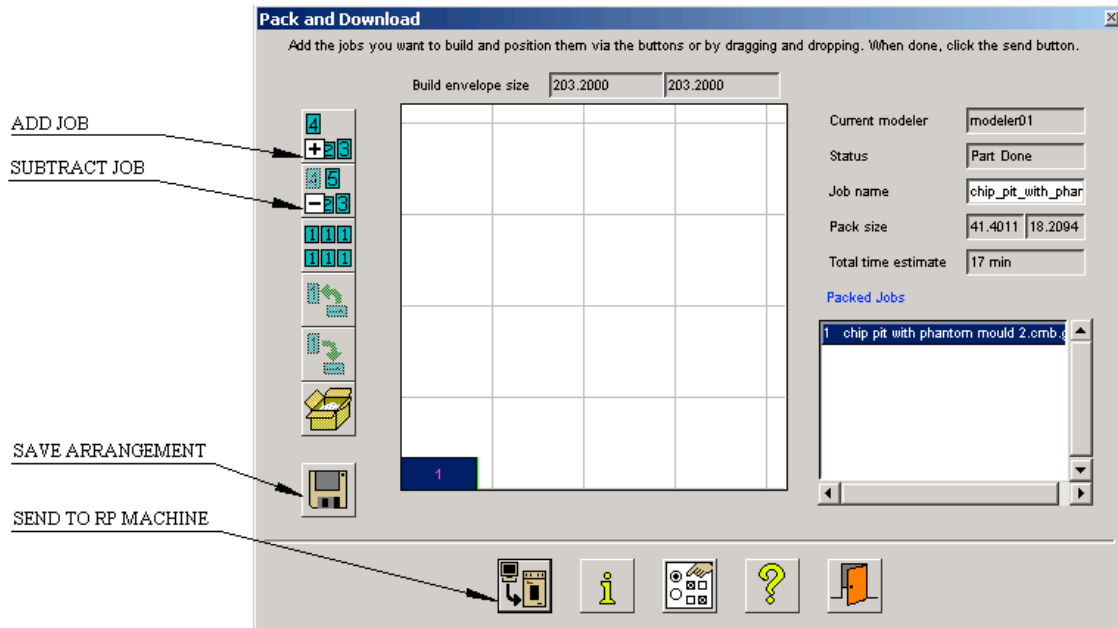


Figure 2: Job arrangement dialogue and important features in Catalyst

- Click on the “Send to RP Machine” to complete this stage.

2.6.1 Job rotation

Rotation of jobs to maximise footprint efficiency was not found to be possible at this stage. It is therefore recommended that the orientation is defined at the orientation stage defined Section 2.3.

2.6.2 Efficient job arrangement

In order for the Stratasys Dimension rapid prototyping machine to function precisely it calibrates the print head in relation to the foam plate surface at the start of every job.

After loading the machine with the foam plate and actioning the job the plate is raised to printing level and the printing unit sent along a path over the plate. The plate is pushed into the unit at four different locations along the path, depressing a switch on the print unit which is used to calculate the surface geometry of the plate.

Removing a part from the foam often forms cavities in the surface local to the origination of the part. Due the nature of machine use, jobs are often done on used plates which introduces the possibility of false calibration i.e. depression of the switch on a cavity surface abnormal to the geometry of the surface majority.

Figure 3 summarises the estimated locations of the calibration zones (given ± 12.5 mm tolerance for measuring error, resulting in $\varnothing 25$ mm area per zone). These zones should be avoided for job placement to preserve the useful life of the foam plate.

Assumptions for the locations of the calibration zones are defined in Appendix 8.1, and should be confirmed Stratasys.

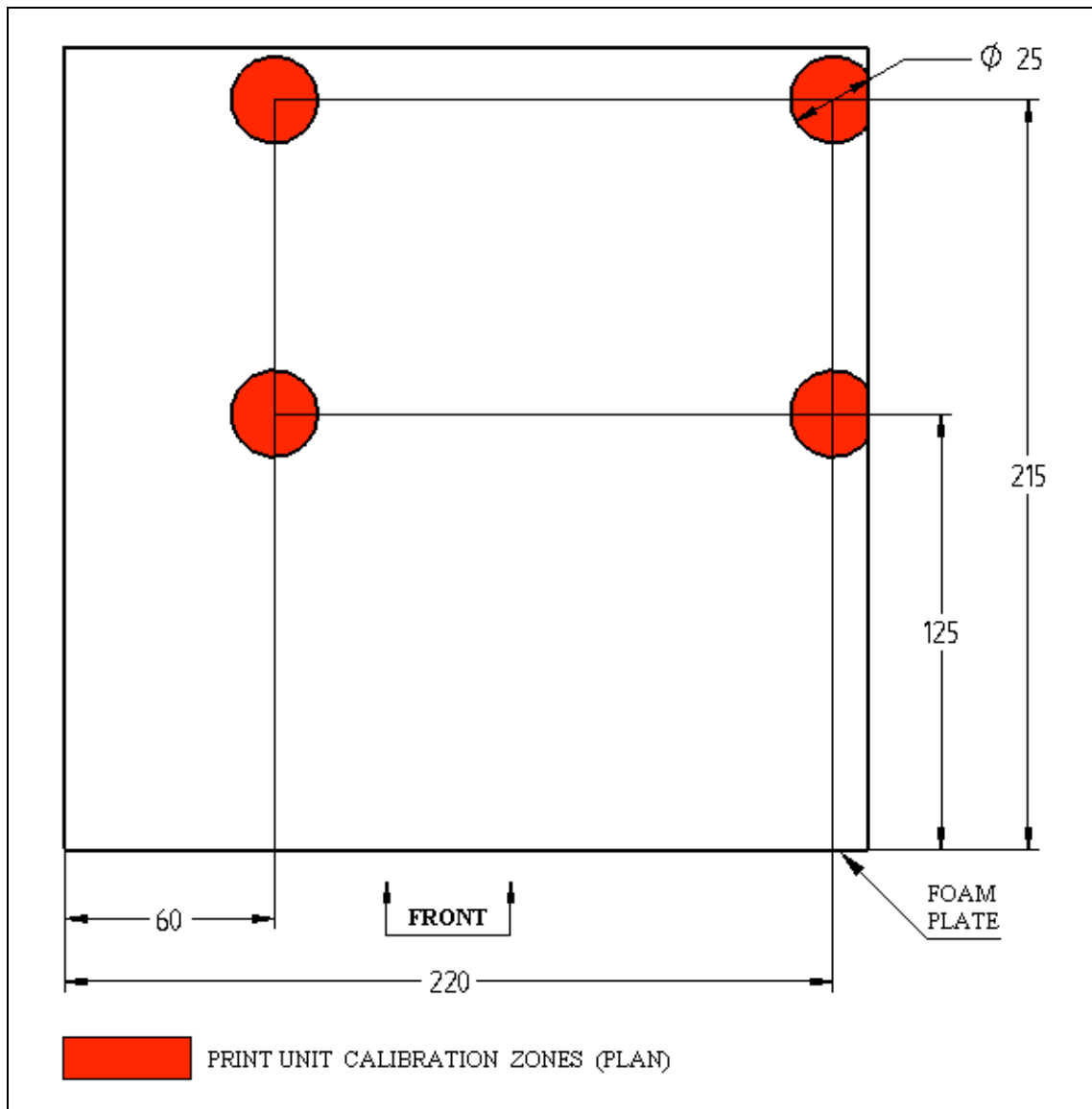


Figure 3: Estimates of calibration zones on plate

3 MANUFACTURE

Before continuing ensure that:

- Foam plate is inserted and locked into place
- Dead plastic bin is empty

After sending the job to the RP machine follow the onscreen instructions with the soft-key interface shown in Figure 4.

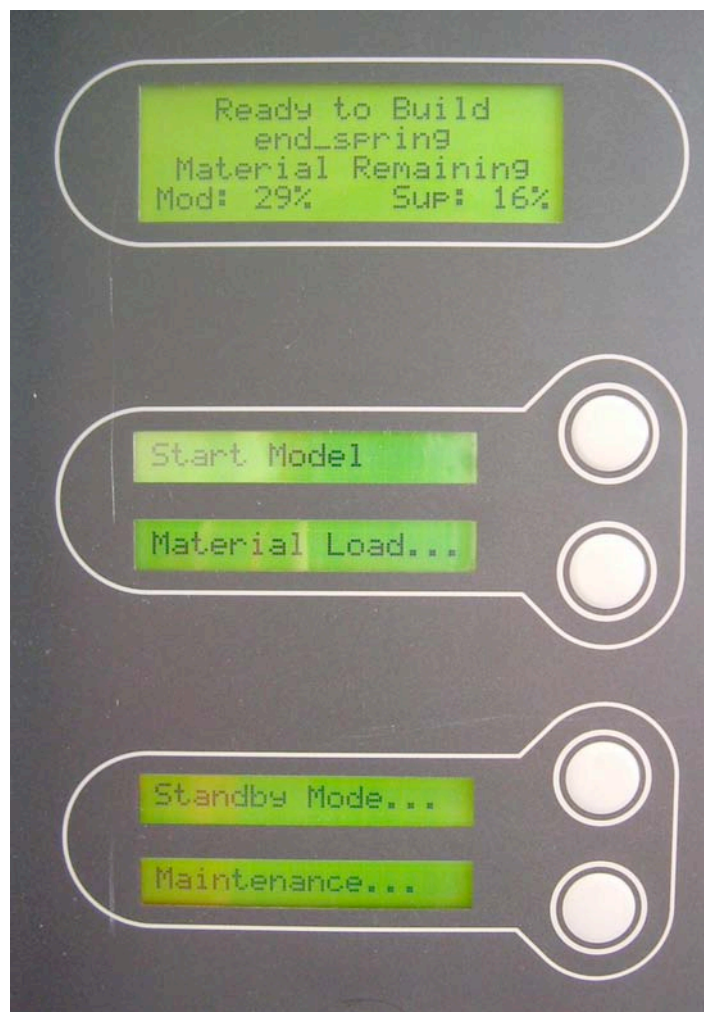


Figure 4: RP Dimension soft-key interface

4 COMPONENT DESIGN SPECIFICATIONS

This section summarises the findings from Project EN310X (October 2004) to form a specification for incorporating structurally sound features (relevant to Rapid Prototyping Electronic Circuits) on the Stratasys Dimension rapid-prototyping machine.

4.1 Surface casting channels

4.1.1 The Stratasys Dimension rapid-prototyping machine should be calibrated fully before manufacturing quality components.

4.1.2 Critical complex faces (e.g. chip terminals) should be orientated parallel to one of the two machine axis to ensure quality finishes.

4.1.3 Casting channels incorporated into rapid prototype design should be at least 1.1 mm wide.

4.1.4 Support walls should be at least 0.4 mm thick (assuming the wall orientation lies parallel to one of the major axis of the machine).

4.1.5 Channel entrances should be filleted to avoid thrombi.

4.1.6 Channel length and corner radii do not influence integrity.

4.1.7 Channels are sound up to and including inflections in the horizontal plane of 150°.

4.1.8 Channels depths may be as shallow as 0.25 mm without influencing channel integrity.

4.1.9 Inverse drafts may be may range from 0° to 45° overhang without influencing integrity or requiring support material.

4.2 Horizontal hole casting channels

4.2.1 Horizontal holes can be incorporated into the design of a rapid prototyped component using a triangular profile and overhang angles of up to and including 45° away from the vertical axis.

4.3 Chip away casting channels

4.3.1 Minimum wall thickness for thin walls is 0.4 mm. It is possible to design chip away moulds to enable solidification of alloy proud of the normal component surface using walls of minimum thickness.

5 INJECTION CASTING METHOD

This section defines the procedure used in project EN310X to enable accurate deposition of Bend Alloy. The alloy is melted and injected into casting channels of rapid prototyped components and allowed to solidify to achieve an electronic circuit.

5.1 Health and Safety

- Wear eye protection during molten alloy handling
- Wear gloves during molten alloy handling and during all processes which involve heated equipment.

5.2 Apparatus

- Rapid prototyped component with casting channels
- Two pairs of disposable latex gloves
- Hacksaw
- Bend Alloy metal ingot
- Glass petri dish
- Techne Dri-Block D8-3 hot plate oven.
- 5 ml BD Plastipak syringe
- 900 μm x 16 mm Monoject needle to accommodate 5ml syringe
- RS200-2531 pneumatic in-line air heater (750 Watts)
- Syringe hot-jacket (Figure 5 and Figure 6)
- Thermocouple

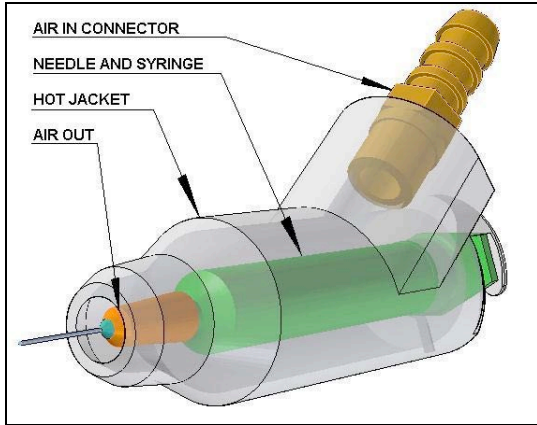


Figure 5: Hot-jacket assembly designed to maintain needle and syringe in excess of 70 °C (front view)

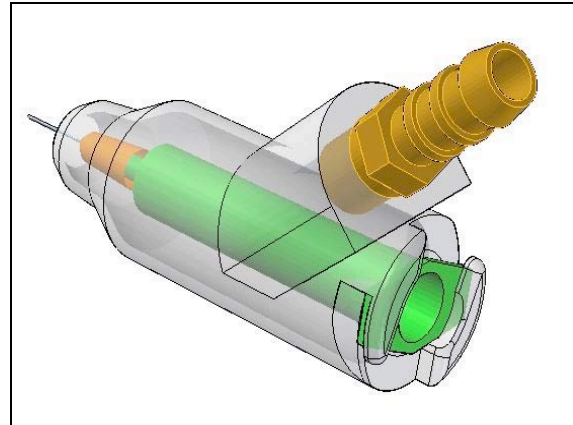


Figure 6: Hot-jacket assembly (rear view)

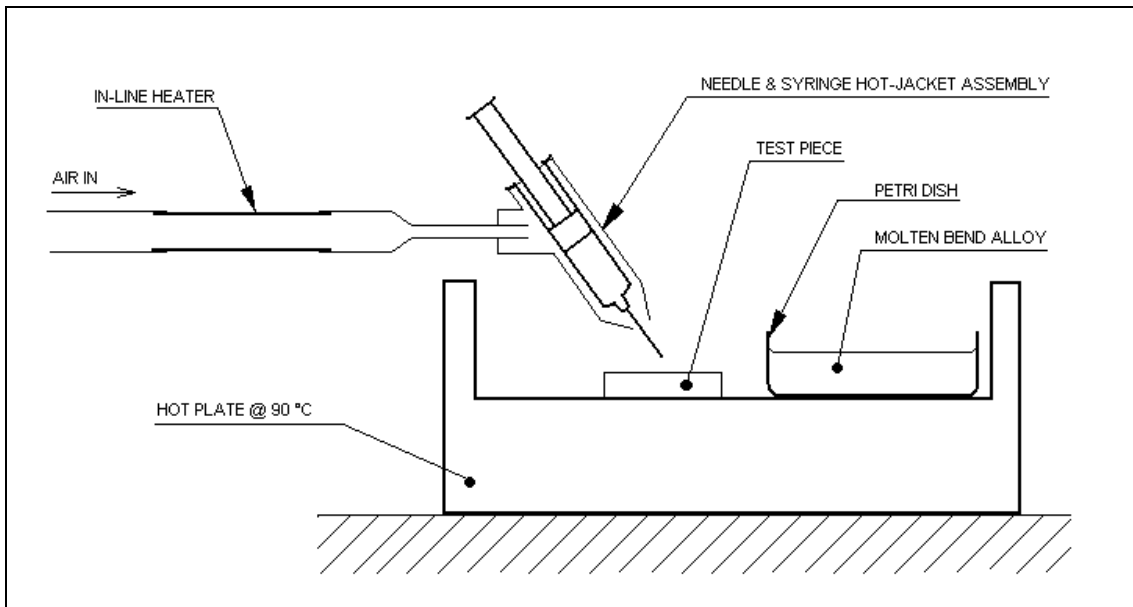


Figure 7: Apparatus setup for the injection process

5.3 Method

- 5.3.1 Preheat the hotplate to 90°C.
- 5.3.2 Connect the heated airflow assembly as defined in Figure 7.
- 5.3.3 Cut the required volume of Bend Alloy from stock to using the hacksaw, and then place it in the petri dish.
- 5.3.4 Load the component and the petri dish with the alloy onto the hotplate. Shut the lid and leave until the alloy melts (takes approximately 5 minutes for 1 cc of bend alloy)
- 5.3.5 Assemble the needle and syringe. Load the needle and syringe into the hot-jacket. Preheat the assembly for 5 minutes using an airflow of approximately 2 psi and a voltage over the in-line heater of approximately 100 Volts. Use a thermocouple and an adjusted heater voltage to maintain an exit air-flow temperature (from the hot-jacket) of approximately 90 °C. **Warning: Do not apply a voltage to the in-line heater without an airflow.****
- 5.3.6 After acclimatisation, reduce the hot jacket airflow to approximately 0.5 psi (so the airflow cannot blow away liquid alloy) and reduce the voltage over the heater to 80 Volts to achieve an air-over-needle temperature of approximately 80 °C.
- 5.3.7 Open the hot plate lid and suck molten alloy into the syringe from the petri dish.
- 5.3.8 Lift the needle to point vertically upwards and expel any trapped air by depressing the syringe plunger.
- 5.3.9 Inject molten alloy into the component as demonstrated in Figure 9. The best results are achieved by slightly overfilling the casting channel before applying suction to draw the alloy down into the channel (See Figure 10).
- 5.3.10 Once injection has been completed, switch off the hotplate and move the component to a cold surface to allow the casting to solidify.
- 5.3.11 Expel all molten metal from the syringe back into the petri dish.
- 5.3.12 Remove syringe from hotjacket and dispose of needle into the sharps disposal box.
- 5.3.13 Switch off the in-line heater. Allow heater to cool before switching off the air supply.

5.4 Process Photographs

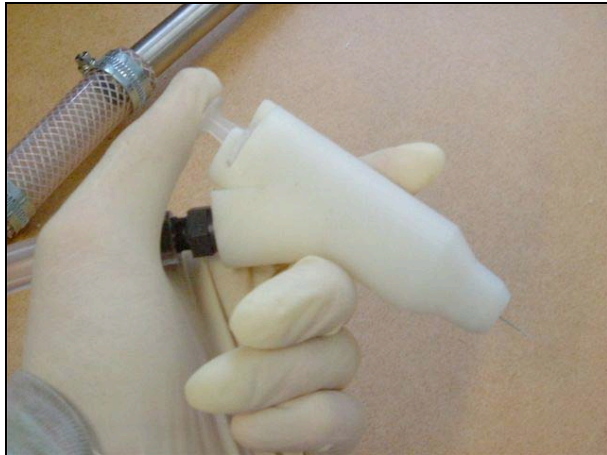


Figure 8: Hot jacket handling



Figure 9: Injection process into component on hotplate. Note molten alloy supply in petri dish also on hotplate.



Figure 10: Magnification of forged circuit around 90 ° bend (channel width 1.2 mm). Circuit is consistent throughout and does not suffer from overspill

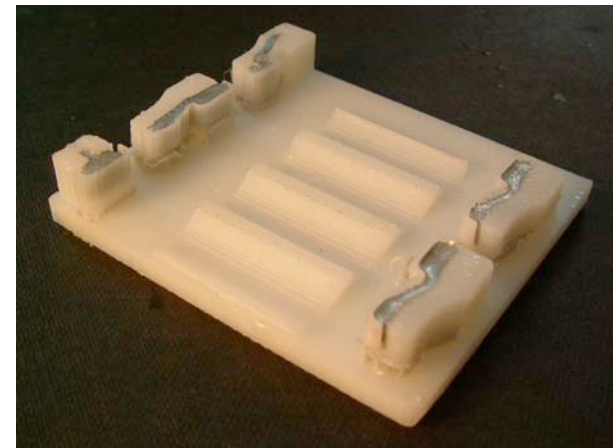


Figure 11: Finished product. Accurate deposition of bend alloy to complete battery case component.

6 INTEGRATION OF STANDARD COMPONENTS INTO THE CIRCUIT

6.1 Push fitting

6.1.1 Push fit summary

The ideal fitting procedure for most standards components (e.g. microchips, batteries etc.) into the prototyped circuit is the push fit for the following reasons:

- Process of pushing the component into place is simple
- It is possible to change the component without altering the physical state of the circuit – ideal for research based manufacture

It is possible to design the component in such way that alloy can be exposed beyond the channel (see fencing technique detailed in Section 7.1) to ensure a reliable connection for a push fit.

6.1.2 Examples of push fits

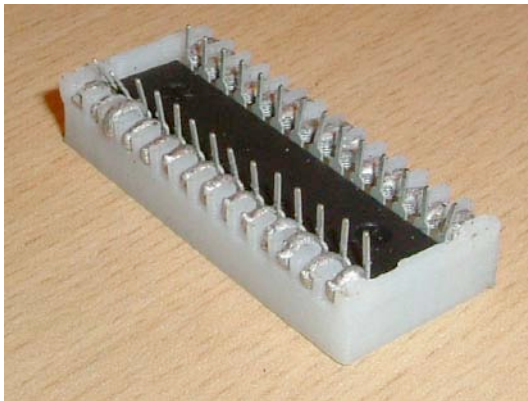


Figure 12: Chip pit. Push fit maintained by casted circuit terminals. Chip pins act as spring.



Figure 13: Battery case. Push fit on batteries maintained by battery terminals on spring clips.

6.2 Soldered contact

6.2.1 Summary

For fast integration of smaller electrical components which need not be replaced frequently (e.g. semiconductors, capacitors, connectors etc.) it is possible to melt the circuit at the local area and allow it to resolidify over electrical component to create a connection.

This can be achieved with the following equipment:

- Soldering iron (for a 30W iron, 60V = 90 °C @ tip)
- Flux

6.2.2 Example

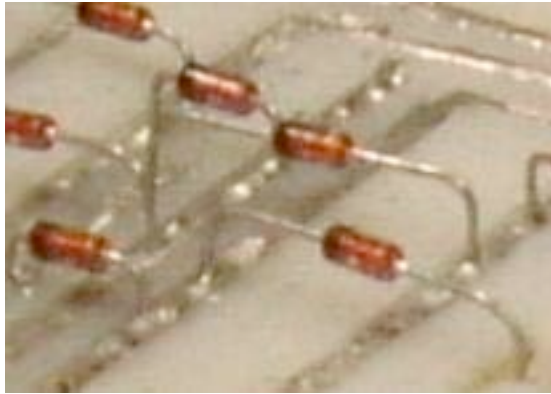


Figure 14: Semiconductors integrated into the circuit by spot soldering

7 DESIGN TECHNIQUES

7.1 Fencing

7.1.1 Fencing summary

In order to create push fits for electrical components (as described in Section 6.1) it is necessary to cast the molten alloy outside the physical boundaries of the circuit channel to ensure that an electrical contact can be made.

This can be simply achieved by using a simple method called “fencing”. Temporary supports (fences) are built into the design of the component and left in place during casting. The design of the fence allows the containment of the bend alloy in an accurate position until alloy solidification has occurred. Once the alloy is solid the fencing can be removed (peeled away) to reveal an exposed alloy terminal.

The key to making fencing which can be easily removed is to design it as a floating part. Thus Catalyst will automatically include chip-away support material to support the fencing. Whilst this makes it strong enough for casting purposes, it guarantees an easy removal of the fencing at the contact point with the component proper.

Fencing design should follow the specifications outlined in Section 4.

7.1.2 Example

In order to make the battery case it was necessary to have exposed terminals on the springs. Thus fencing was included in the design as shown in Figure 15.

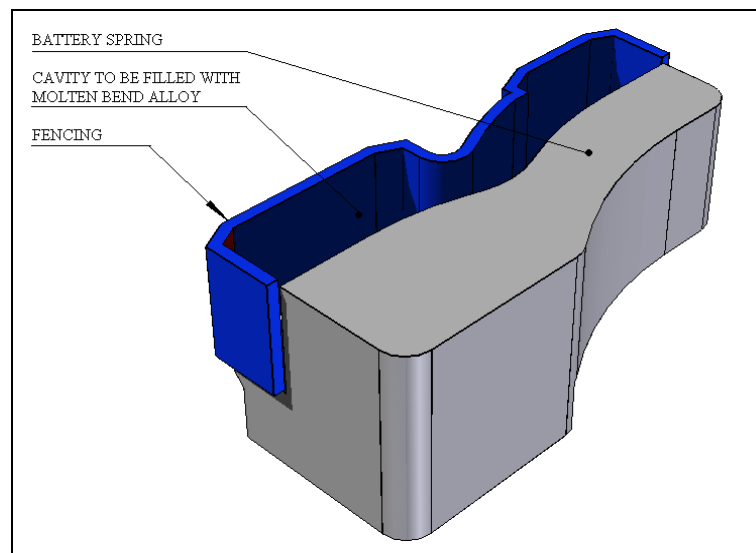


Figure 15: Fencing highlighted in blue. Note this fencing is floating. Catalyst will incorporate chip-away support material into the layup, below the fencing, to ensure that it will break away easily after casting.

Once filled with alloy using the injection technique, the fencing was then pulled away to reveal an exposed terminal (Figure 16).

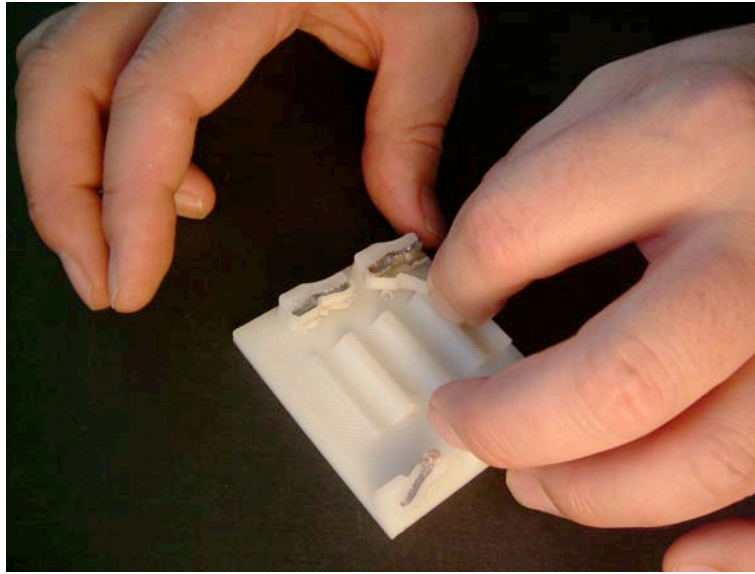


Figure 16: Simple removal of the fencing after alloy deposition and solidification

7.1.3 Anchoring

Due to the removal of material it is sometimes necessary to ensure that the solidified element does not become detached from the major component. For this reason cavities can be incorporated into the component design which will “lock” the alloy into local support material. This is shown in Figure 17.

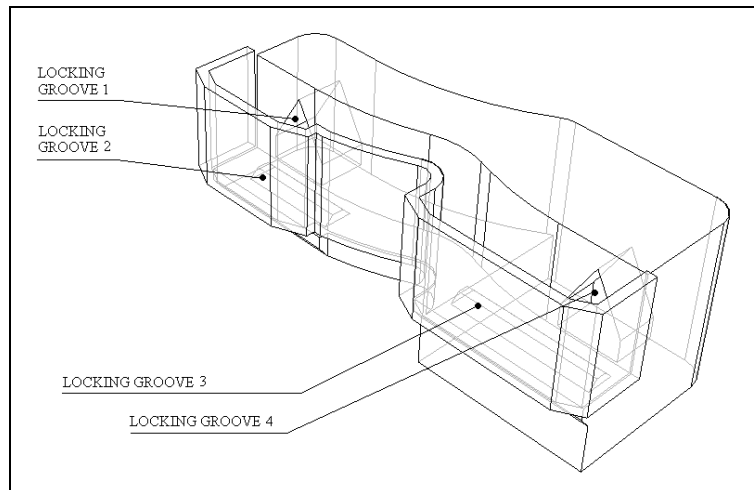


Figure 17: Locking cavities in battery spring to ensure that the metal component does not detach from the major component

7.2 Springs

Springs are most flexible in the horizontal plane rather than the vertical plane (e.g. battery spring). This is because of the “fibrous” lay of the components – an inherent property of the rapid prototyping manufacturing technique.

8 APPENDIX

8.1 Calibration zone assumptions

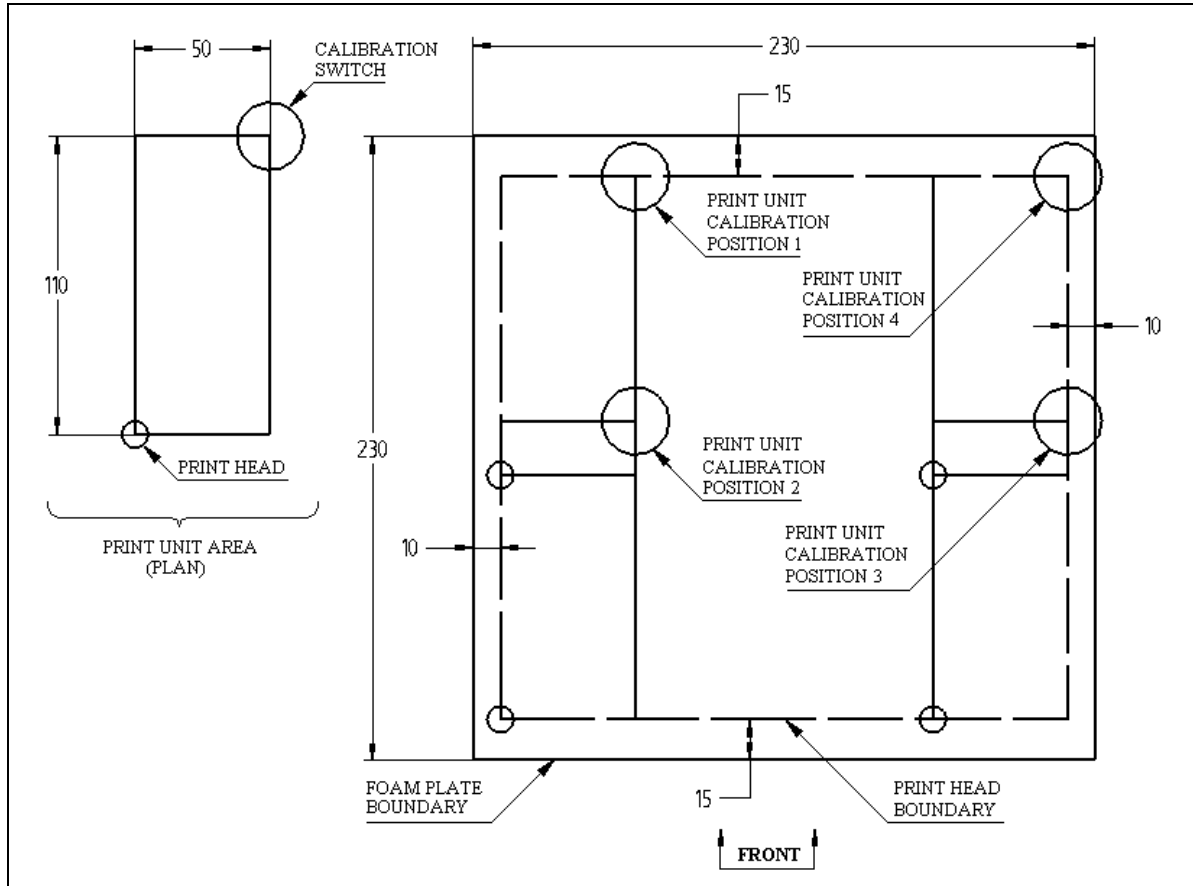


Figure 18: Geometry assumptions used to calculate the calibration zones on the plate