Reliability Test Fixture for Flexible Hybrid Electronics

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Reliability Test Fixture for Flexible Hybrid Electronics

Final Design Review

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Statement of Disclaimer

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Executive Summary

During the 2016-2017 school year, the Cal Poly NextFlex Group, in conjuncture with the Cal Poly Industrial and Manufacturing Engineering Department, was comprised of professors, undergraduate students, and graduate students all working towards the manufacturing of flexible hybrid electronics (FHEs). FHEs, which are comprised of a flexible plastic substrate (thermoplastic polyurethane), screen-printed silver ink, and a thin silicon wafer, have a wide range of potential applications.

At the time of this project, FHEs and other flexible electronics did not have a set of test standards to characterize their mechanical and electrical properties. The Cal Poly NextFlex Group recruited three Cal Poly Mechanical Engineering students (known as the BendatroniX Team) from the Fall 2016 Senior Project class to create a Reliability Test Fixture to test the FHEs that they were manufacturing.

Over the course of three quarters, the team designed, built, and validated a reliability test fixture that characterized the electrical integrity of the FHEs as a function of mechanical strain. The fixture was comprised of four clamps that mated with an Instron tensile testing machine. One of the clamps had a unique pogo pin housing that monitored the electrical resistance across the FHEs while it was stretched. Upon the conclusion of the project, the BendatroniX Team trained Cal Poly NextFlex students on how to use the fixture so that they could continue to test and characterize the tensile properties of different FHE configurations.

The following report details the design, build, and test process that the BendatroniX Team performed to create the Reliability Test Fixture for FHEs, seen below, by Spring of 2017.

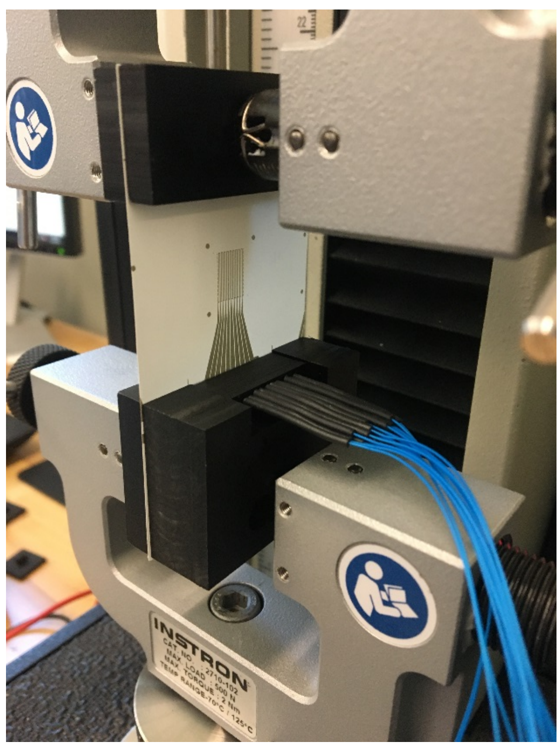

Figure i. Reliability Test Fixture for Flexible Hybrid Electronics

1.0 Introduction

Following a government focus towards increasing manufacturing in the United States, the Cal Poly Industrial and Manufacturing Engineering Department was invited to work on a project with Jabil Circuit Inc. to develop flexible hybrid electronics (FHEs). The Cal Poly team that worked on this project included Dr. Xuan Wang, Dr. Jianbiao John Pan, Dr. Malcom Keif, and Dr. Xiaoying Rong, along with students Josh Ledgerwood, David Otsu, Wade Bedinger, Allison Tuuri, Wesley Powell, Roy Garcia, and Steven Dallezotte. In support of their ongoing research, the Cal Poly NextFlex Group sponsored a team of mechanical engineering students (known as the BendatroniX Team) to design and prototype various electromechanical fixtures.

1.1 Problem Statement

During the time of the project, there was an industry interest in learning the mechanical limits of various Flexible Hybrid Electronics (FHEs); however, there were no standardized procedures that outlined how to conduct such tests. The Cal Poly IME NextFlex Group, in conjunction with Jabil Circuit, Inc., needed reliable test fixtures and procedures to allow them to characterize the electrical integrity of flexible hybrid electronics as a function of mechanical strain.

As the Cal Poly IME Department team focused on the manufacturing and assembly of the flexible electronics with Jabil Circuit, Inc., the BendatroniX Team focused on the method of testing the electronics for failure points due to stretching and bending. The teams worked together to determine the optimal printed design of the FHE circuit, the different loading cases to be tested, and the final design/product for the FHE reliability test fixture. In order to assist readers with the numerous acronyms located throughout this report, common terms and their corresponding definitions are located in Table 1.

Table 1. Common terms and definitions used in this document.

Term	Definition
IME	Industrial and Manufacturing Engineering
IPC	Institute for Printed Circuits
FHE(s)	Flexible hybrid electronic(s)
MATE	Materials Engineering
NextFlex Group	Group consisting of Jabil Circuit, Inc., Cal Poly IME Department, and Cal Poly Students
PCBA	Printed circuit board assembly
TPU	Thermoplastic polyurethane

2.0 Background Research

With the rapid advancement of circuit technology, today's electronics are continuously being reduced in size while still increasing in computing power. One particular way these developments have started to take shape is through the field of flexible hybrid electronics (FHEs). Circuits that are printed on thin, flexible substrates have introduced the electronics industry to new applications that traditional, rigid, printed circuit boards (PCBs) could not offer in the past. As seen in Figure 1, there are many applications where FHEs could be utilized, such as smart fabrics or contact lenses.

Figure 1. Examples of FHE applications include wearable electronics, such as in smart fabrics or contact lenses [1].

2.1 Introduction to Flexible Hybrid Electronics

According to the Association Connecting Electronics Industries (formerly the Institute for Printed Circuits), printed electronics are made "…by printing (generally additive deposition) processes on or between a wider variety of surfaces than more traditional rigid or flexible printed circuit boards (paper, textiles, glass, etc.)." [2] Currently, the Nextflex Group is interested in developing a new product that utilizes printed electronic manufacturing techniques. This new product is known as a flexible hybrid electronic and is comprised of two main components that are electrically connected:

1. Silicon-based circuit (~70 micrometers in thickness)
2. Thermoplastic polyurethane (TPU) substrate with silver applied via screen-printing

The silver pattern is screen-printed onto the TPU substrate at Cal Poly's IME tech lab and Graphic Communications printing room by the Cal Poly research group. A sample of this substrate can be seen in Figure 2. In order to create a complete FHE sample, the silicon-based circuit and the TPU are electrically daisy-chained together. This sewing-connection process is completed on Jabil Circuit, Inc.'s campus. It was predicted that throughout the timeline of this project, approximately 300 completed FHE samples would be manufactured. Of these, the BendatroniX Team planned to use a number of them to validate their fixture designs.

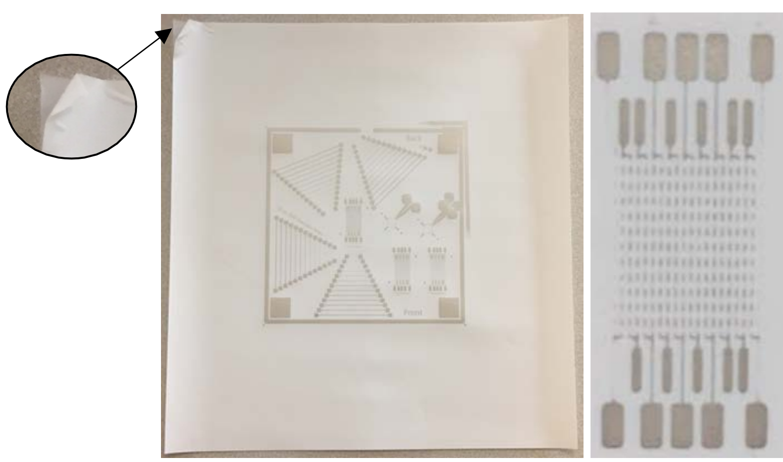

Figure 2. Left: First prototype of the full TPU substrate. The silver circuit design is screen-printed on the substrate and will eventually have a silicon circuit board sewn onto it. Note that it is necessary to peel the substrate from the backing material before testing. Right: Initial circuit design before silicon wafer is attached.

Unfortunately, the Nextflex Group had encountered an issue with FHE technology; there was no available information that characterized the electrical behavior of FHEs in different loading cases. Nevertheless, the Nextflex Group needed procedures to reliably test and compare the performance of their FHE prototypes. The goal of the BendatroniX Team was to create several electromechanical fixtures and develop procedures that, when used to test FHEs, would allow the Nextflex Group to characterize the mechanical and electrical behavior of their FHEs in a variety of loading cases.

Although there were no standards outlining how to test the point of mechanical and electrical failure of FHEs in industry, the IPC has published a useful working draft titled *IPC-9204: A Guideline on Flexibility and Stretchability Test Methods for Printed Electronics* that compiled a number of "suggested test methods deemed appropriate for consideration in materials and properties testing" [2]. The mechanical parameters included in the document described procedures for testing stretchability, bending, torsion, rolling, and crumpling of flexible electronics. Table 2 summarizes the tests included in the scope of this project (stretchability and bending). Refer to Appendix A for the detailed procedures and figures of the tests in Table 2 as seen in IPC-9204.

Table 2. Summary of stretching and bending tests of interest from IPC-9204 [2]

Test #	Test Name	Description
6.1	Stretchability Limit	Tensile test to find elongation limit of specimen.
6.2	Cyclic Stretchability	Repeated elongation cycles under a specific tensile load.
6.3	Stretchability Under Constant Load	Specimen is stretched and held for a prolonged duration under a constant tensile load.
6.4	Stretchability Under Constant Torsion	Specimen twisted to specific torsional angle and repeatedly stretched.
6.5	Stretchability Under Cyclic Torsion	Specimen twisted to specific torsional angle, stretched, held, and then both torsional and tensile loads are released. Procedure cyclically repeated.
7.1	Variable Radius Bending	Specimen is bent in a U-shape between two plates that are then raised and compressed to cyclically change the radius of the specimen.
7.2	Variable Angle Bending	Maintained under a specific tensile load, the specimen is flexed back and forth to a specific angle about a mandrel.
7.3	Free Arc Bending	Specimen is fixed horizontally to two fixtures. One fixture moves back and forth, thus changing the bending radius cyclically.
7.5	Loop Bending	Specimen is held in a looped fixture with fixed lateral tension while a probe applies a strain on the center of the specimen.

2.2 Current Testing Methods

A brief examination of the tests listed in Table 2 revealed that a tensile-testing machine could be used to perform multiple tests on the FHEs. The ideal tool would be a low-load Instron machine, like the one found in the Materials Engineering (MATE) Research Lab at Cal Poly. One of the many advantages of using an Instron machine is that it allows for a variety of fixture accessories to be attached via clevis pin.

The Instron machine available to the BendatroniX team at Cal Poly's MATE lab is an Instron 5278 Mini 55, which uses either a 100N or 500N load cell. It is pictured below in Figure 3. Jabil Circuit, Inc. currently has a 5kN dual column testing Instron (model #5965). Due to the universal nature of Instron fixture attachments, fixtures designed to be used on Cal Poly's MATE Lab's low-load Instron could also be used on Jabil's high-load Instron without significant modification. The BendatroniX Team was trained on how to use the Instron Mini 55 by Dr. Blair London, a professor from the Cal Poly MATE Department.

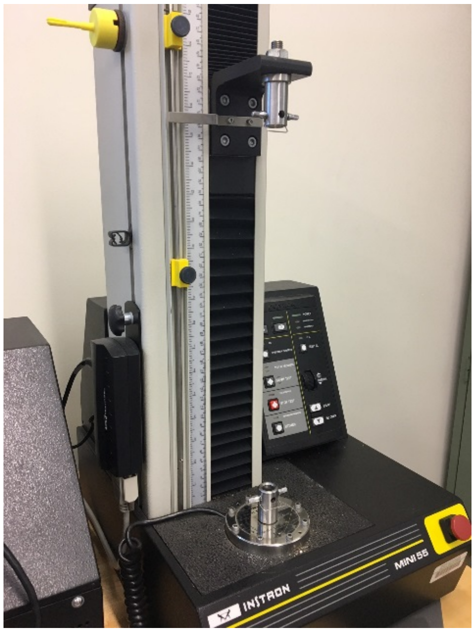

Figure 3. The Instron 5278 Mini 55 available for use through the Cal Poly MATE Department. The maximum load attainable is 500N, which will be suitable for the tests required.

Today, Instron no longer manufactures the Mini 55 Model. However, the 3342 model of the 3300 Series Single Column Universal Testing System is the most similar machine to the Mini 55 with readily available specifications [3]. Therefore, for the purposes of providing specifications for the Mini 55, the 3342 model will be used as a substitute. This model is ideal for axial load applications, with a load capacity of 500N and a vertical test space of up to 651mm.

The Instron website also features accessories compatible with their machines for a variety of tests. These are interchangeable attachments that serve several purposes. For example, a 3-point bend test accessory with a load capacity of 2000N (catalog no. 2810-42) is available and uses a Type Om fitting to attach to the Instron machine. For reference, a Type Om fitting uses a 12mm connection and a 6mm clevis pin, as seen in Figure 4. Stock test accessories can also be modified, for example, by inserting a different anvil and creating a 4-point bend test. Accessories such as these can also be made in-house at Cal Poly, like the 3-point bend apparatus used by Cal Poly's MATE Department, shown in Figure 4 below.

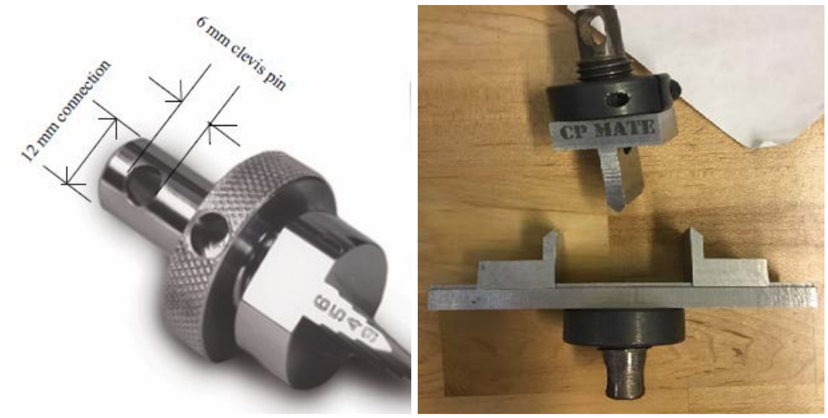

Figure 4. Left: Examples of Instron connection and clevis pin dimensions [3]. Right: Accessory used by the Cal Poly's MATE Department to perform 3-point bending tests. Fixtures such as this will be made in order to perform a variety of tests on FHEs. Personal photograph by author.

Additionally, Instron has a thin film roller grip fixture that is specifically made for gripping thin film samples. This is an ideal clamp for gripping the ~70μm TPU substrate; however, the fixture is advertised as only being capable of static testing. Additionally, the fixture is expensive (~$3000). Currently, the Cal Poly's MATE lab has a thin film clamp that the BendatroniX Team could test if this type of grip seems feasible.

Figure 5. Instron thin film grips for 25mm specimen width (catalog no. 2713-006) [3].

2.3 Current Research Initiatives

After studying tests performed in industry and exploring the available equipment, the BendatroniX Team investigated how both industry and research-based FHE manufacturers tested their samples. The research initiatives that offered the most insight for the scope of this project will be discussed.

In August 2012, Agilent Technologies published a document titled *On Characterization of Mechanical Deformation in Flexible Electronic Structures* [4]. The purpose of this report was to determine the viability of Agilent's nano-mechanical instrument (T150 UTM) in testing FHEs on a 3-point bend fixture. A schematic drawing of the mechanism can be seen in Figure 6, while the actual T150 UTM can be seen in Figure 7. The sample preparation and staging procedures are outlined in the cited article and will be used for future reference. While there is not a 3-point bend test outlined in the IPC tests in Table 2, the BendatroniX Team can still use the Agilent fixture as inspiration for their future designs.

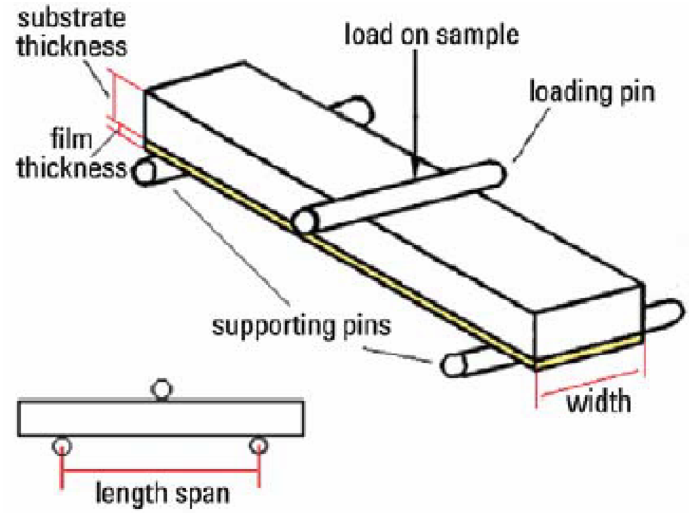

Figure 6. Schematic drawing of the 3-point bending fixture used by Agilent Technologies [4]. Note how the anvils used appear to be rounder than those used by the Cal Poly MATE Department.

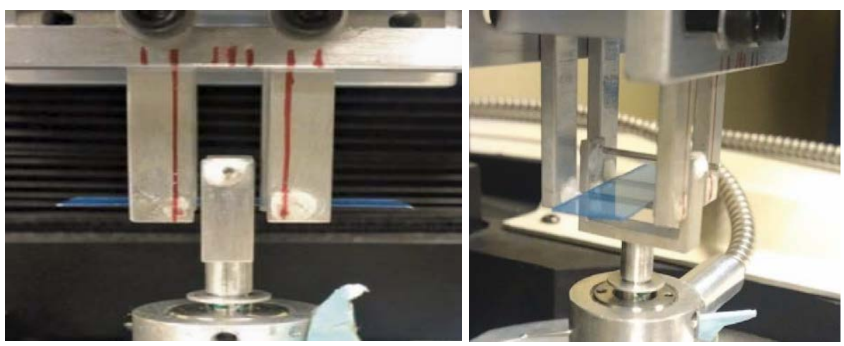

Figure 7. Photos of the 3-point bend fixture used by Agilent Technologies [4]. Note that bending is induced by pulling the fixture apart rather than pushing it together, as is the case with the Cal Poly MATE Department fixture.

Another useful resource was Lydia Leppänen's thesis, *Bendability of Flip-Chip Attachment on Screen Printed Interconnections* [5]. Leppänen researched the various ways of attaching the silicon chips to flexible substrates and evaluated each configuration's bendability. Her test most closely related to Test 7.1 Variable Radius Bending, outlined in Table 2. As seen in Figures 8 and 9, Leppänen used an Instron 4411 Universal Tensile Machine as a bending device with custom plate attachments that bent the sample. The resistance monitoring system comprised of 3D-printed contact chips (as seen in Figure 9) that interacted with corresponding measurement cards and the LabVIEW program.

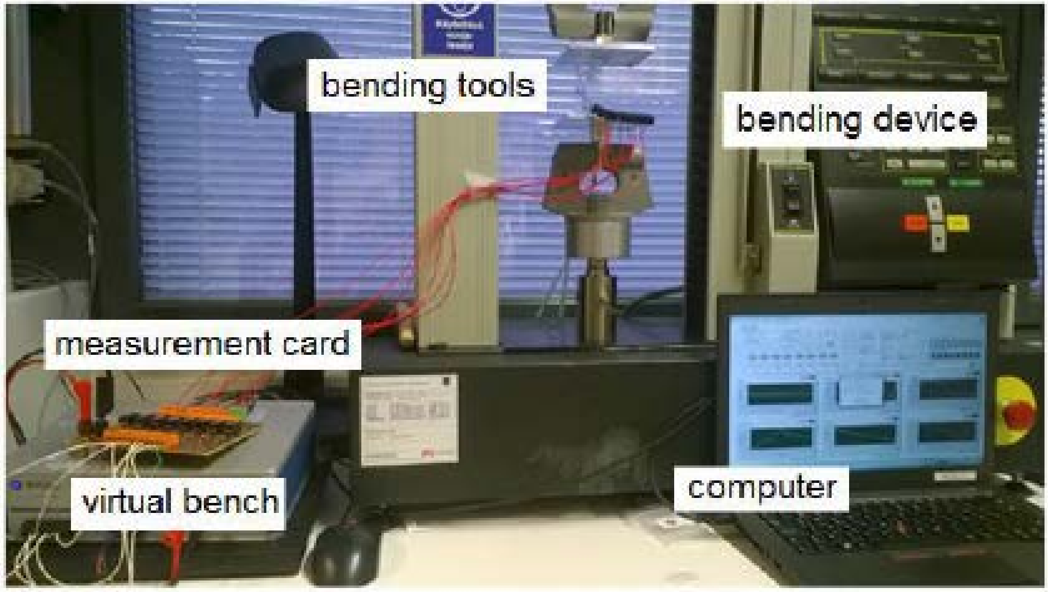

Figure 8. Photo of test apparatus used by Lydia Leppänen [5]. Note the careful routing of the resistance monitoring wires to avoid getting caught in the Instron.

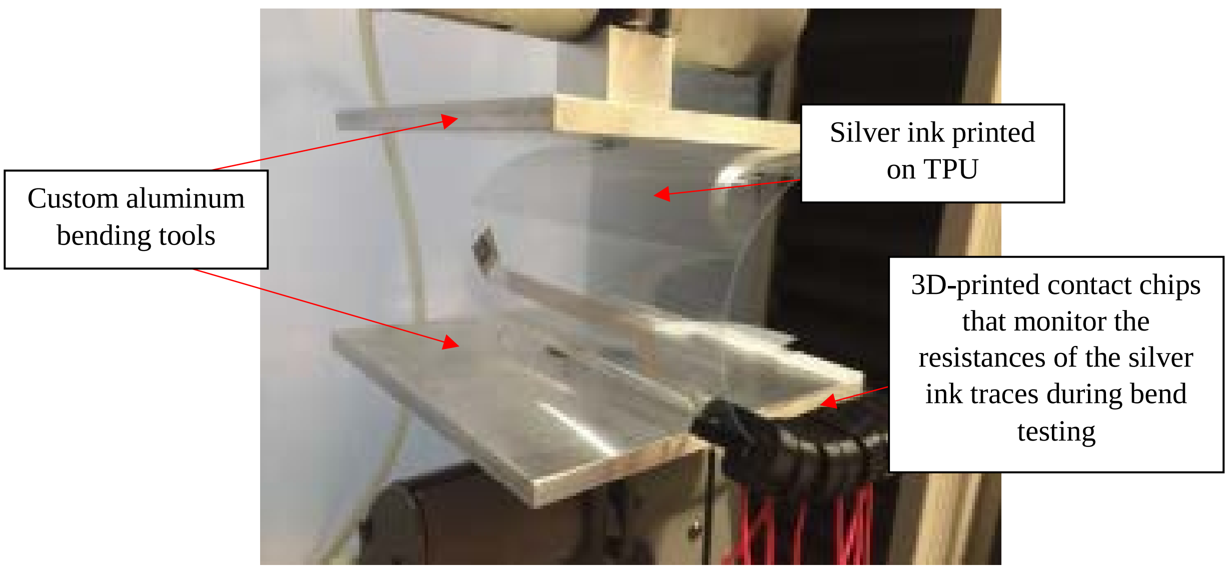

Figure 9. Variable radius bending test performed by Lydia Leppänen [5]. Note the attachment of several black contact chips followed by red wires used to monitor the resistance of the FHE. This is one method of data acquisition that could be pursued for this project.

Leppänen outlined her procedure in the following manner:

1. Fixture plates installed onto Instron.
2. Levelness of the plates measured (the plates should be as parallel as possible).
3. 3D-printed contact chips are attached to FHE.
4. FHE is curved slightly, inserted into fixture, and taped to both of the plates.
5. Reference point (initial distance between plates) is measured with slide gauge and recorded.

6. Control program in Instron opened and specific compressive test initiated (desired bending speed is pre-determined).
7. Resistance monitoring program in LabVIEW is simultaneously opened and initiated.
8. When all of the FHE channels are broken or the bending cannot be completed, the measurements are stopped and the test is completed.

Leppänen's outlined procedure is extremely useful because it provides a published example of a mechanical test procedure for an FHE specimen. Additionally, it satisfies one of the IPC tests from Table 2 and can be used as a reference during future designs.

Byoung-Joon et al. utilized a custom bending fatigue system manufactured by the CK Trading Company in Seoul, South Korea, in order to "determine the mechanical reliability of inkjet-printed and evaporated films" for FHE substrates [6]. A schematic diagram of the system can be seen in Figure 10. This system is a combination of Test 7.1 Variable Radius Bending and Test 7.3 Free Arc Bending Test from Table 2. The substrate was fixed to the plates via metal grips (labeled "Resistance measurement" in Figure 10) that allowed for conductivity measurements to be taken during the test. The moving plate oscillated over a range of 10mm at a frequency of 5Hz. The vertical gap between the plates was 11.4mm, which resulted in a maximum tensile strain of 1.1% during the test [6].

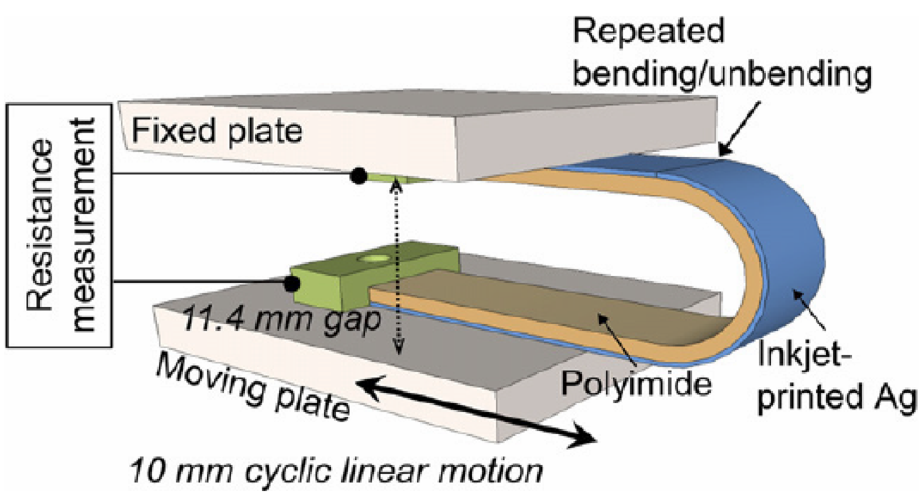

Figure 10. Schematic diagram of the test configured by Byoung-Joon Kim et al. [6]. Note that the linear oscillation of the moving plate relative to the fixed plate creates a region of dynamic loading at a constant bend radius. Also note that the grip site is used to monitor resistance of the FHE.

In order to learn more about the electromechanical properties of TPU with screen-printed silver traces, the BendatroniX Team examined the research performed by Suikkola et al. in their publication, *Screen-Printing Fabrication and Characterization of Stretchable Electronics* [7]. Their group screen printed silver onto 50µm thick TPU as seen in Figure 11. The silver circuit was designed in a loop pattern to allow the resistance monitoring apparatus to be affixed on the same side of the sample (unlike the original circuit design of the NextFlex Group which had terminals on opposite sides, as seen in Figure 2). Additionally, the samples were annealed before any tests were performed to neutralize any cold work that may have resulted from the printing process.

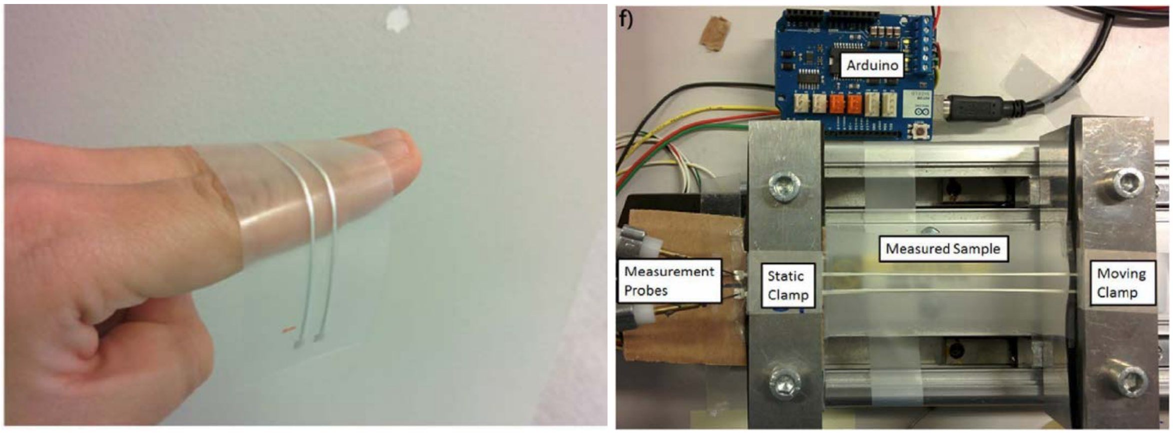

Figure 11. Left: Sample of the FHE used by Suikkola et al. [7]. Note that the print appears similar to that of the BendatroniX Team's sample, except that the terminals to be measured across are at the same end of the sample. Right: Testing apparatus used by the Suikkola group [7]. Measurement probes are located on the static side of the fixture while the moving clamp stretches the sample via linear actuator.

Suikkola et al. performed both static and dynamic tests on their samples to observe how the resistance of the traces changed with variations in sample strain. The linear actuator system is shown above in Figure 11. In order to learn more about the apparatus design, the BendatroniX Team reached out to the Suikkola team for more details [8]. According to Matti Mäntysalo, Signatone measurement probes were used in conjunction with rigid supports to monitor resistance outside of the clamps. The supports must be structurally stable and all associated cables must be fixed in a way so that they do not cause any stress on the probes. Alternatively, he recommended designing a specific test fixture or using conductive adhesive to connect the monitoring system to the sample.

In order to reduce noise in the data, the measurement probes were placed on the static side of the sample. This could potentially pose as a problem for the BendatroniX Team, since the terminals that need to be monitored are located on opposing ends of the FHE samples. As seen in Figure 11, the Suikkola group's sample (including the silver traces) passes through both the static and the dynamic clamps. According to Mäntysalo, their group used a "soft rubber insulator" between the metal clamps that did not damage the annealed sample traces. However, he did mention that if this test were to be used with samples that had thinner traces (i.e. from inkjet printing), then the clamps may cause damage to the traces.

3.0 Objectives

The overall goal of the BendatroniX Team was to provide the NextFlex Group with a fixture that gripped and monitored the resistance of the FHE sample during a mechanical test. If time permitted, the team would create varying fixtures that satisfied as many of the mechanical tests in Table 2 as possible, with the priority being a functioning tensile test. The NextFlex Group requested that the BendatroniX team deliver a resistance monitoring system as soon as possible in order to perform further research; therefore, the project was split into two parts. The first part was to design a fixture for tension testing because it was the simplest and could be made with the focus on the resistance monitoring function. A tiered method was used to determine when to begin the second part of the project, which was designing fixtures to satisfy multiple testing configurations, such as a variable bending radius test. The schedule for the project has been outlined in the Management Plan section of this report.

The scope of the project is portrayed in Figure 12. The BendatroniX Team would not be responsible for providing a data acquisition (DAQ) system; however, they potentially could use a DAQ provided by Jabil, Inc. Since the team utilized the Instron machines and computers available at Cal Poly and Jabil, the choice of mechanical test apparatus was outside the scope of the project.

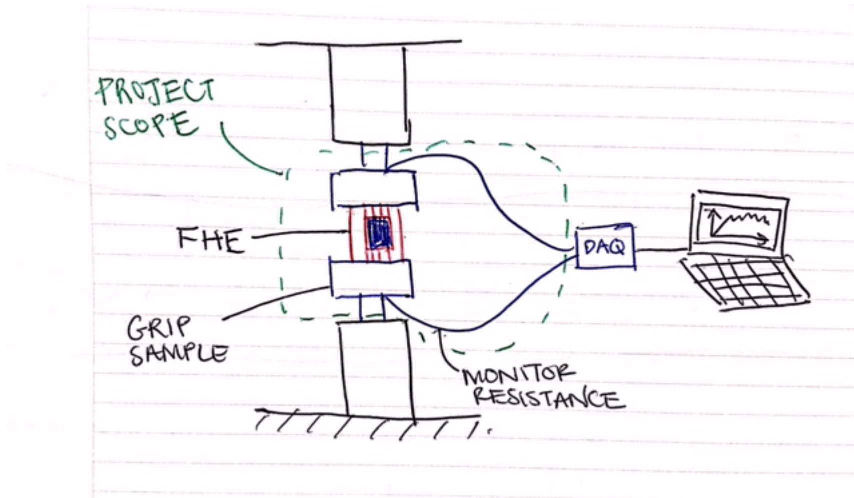

Figure 12. Boundary of project scope sketch. The project scope outlines what the BendatroniX Team will aim to deliver the NextFlex Group.

3.1 Product Specifications

After determining the scope of the project, the BendatroniX Team needed a way to translate the NextFlex Group's requirements into engineering specifications. The conversion of the requirements to engineering specifications was achieved using a process based on market and customer needs known as the Quality Function Deployment (QFD). Using this process, a House of Quality Chart was generated that helped the BendatroniX Team develop and prioritize a list of engineering specifications that are testable, non-redundant, and meets the NextFlex Group's needs. Each requirement given by the NextFlex Group was weighted by importance and compared to the engineering specifications determined by the BendatroniX Team to define the most vital correlations. These customer requirements and engineering specifications were compared to competitor solutions found in industry (Cal Poly MATE Department's 3-point bend fixture, Agilent Technologies system, etc.). A list of customer requirements can be seen in Appendix B and the House of Quality Chart can be seen in Appendix C. Additionally, the corresponding list of engineering specifications is summarized in Table 3.

Table 3. Engineering specifications listed in order of importance to the NextFlex Group and the BendatroniX Team.

Spec. #	Specification Description	Target (units)	Tolerance	Risk	Compliance
1	Ability to accurately measure electrical resistance during test	Yes	± 5%	M	I, T, S
2	Preservation of sample post-staging	No visible/electrical damage	N/A	M	I
3	Individual fixture(s) configurations should be capable of static testing	Yes	N/A	M	I, T
4	Individual fixture(s) configurations should be capable of dynamic testing	Yes	N/A	M	I, T
5	Manufacturability	Able to be manufactured at Cal Poly	N/A	M	I, T
6	Total cost	$2000	Max	M	I
7	Set-up time	[5 minutes]*	+ 1 minute	M	T
8	Durability of fixtures	[5 years]*	Min	L	A

Key

Abbreviation	Description
[ ]*	Proposed target, subject to change
L, M, H	Low, medium, high risk to achieve target
A, I, S, T	Analysis, Inspection, Similitude, Testing

<u>Specification #1:</u> *Ability to accurately measure electrical resistance during test*
The majority of FHE samples will be tested until failure. Therefore, the user must be able to monitor the electrical properties of the FHE for the duration of the test to determine exactly when failure occurs. The fixture must measure resistance to the specified tolerance to result in accurate data readings so that the resistance change to an open circuit can be detected. This is a high priority for both the NextFlex Group and the BendatroniX Team because the point of failure will define the mechanical and electrical behavior of the FHE.

<u>Specification #2:</u> *Preservation of sample post-staging*
Before the FHE sample undergoes a mechanical test, it must be loaded into the appropriate fixture. This is known as the staging process. It is crucial that the fixture does not damage the sample during this process, otherwise the test measurements may not be accurate. In order to guarantee that this does not happen, a FHE sample will be tested for electrical properties (i.e. resistance) before it has been loaded into the fixture. Then, once the FHE sample is completely staged in the fixture, it will be tested for the same electrical

properties. As long as the electrical properties between pre- and post-staging remain the same, the specification will be met.

Specification #3: *Individual fixture(s) configurations should be capable of static testing*
In order to meet budget requirements, it is desirable that the fixtures are designed to be as versatile as possible, while also being economical. Therefore, each fixture is ideally able to be used for both static and dynamic testing. Since not every fixture design will be capable of accomplishing this, separate specifications have been designated for static and dynamic testing capability. This specification assesses the fixture’s viability for static testing only.

Specification #4: *Individual fixture(s) configurations should be capable of dynamic testing*
In order to meet budget requirements, it is desirable that the fixtures are designed to be as versatile as possible, while also being economical. Therefore, each fixture is ideally able to be used for both static and dynamic testing. Since not every fixture design will be capable of accomplishing this, separate specifications have been designated for static and dynamic testing capability. This specification assesses the fixture’s viability for dynamic testing only.

Specification #5: *Manufacturability*
All custom hardware for this project will be manufactured at Cal Poly by the BendatroniX Team. Therefore, it is imperative that the fixtures can be produced using equipment found on campus, such as band saws, grinding wheels, mills, lathes, etc.

Specification #6: *Total cost (Maximum: $2000)*
The NextFlex Group, who are providing the funding for this project, have stated that the BendatroniX Team may not exceed a budget of $2000 on the entirety of the project.

Specification #7: *Set-up time (Maximum: 5 minutes)*
Although background research did not provide the BendatroniX Team with set-up times for known procedures, it was estimated that 5 minutes would be an appropriate amount of time to prepare a fixture and data acquisition system for an Instron. However, due to lack of previous knowledge, the time limit may be altered as benchmarking and prototyping continues. This specification may be tested with a focus group or by observing the lab technicians at Jabil preparing the completed test fixtures.

Specification #8: *Durability of fixtures (Minimum: 5 years)*
In general, the fixtures should be both reliable and reusable. A minimum fixture lifetime of five years was estimated as a reasonable time span considering the rate of technological advancements that may require the fixtures to be redesigned. This time limit is subject to change.

3.2 Management Plan

In order to have a successful project, all three members of the BendatroniX Team agreed to collaborate on the entirety of the design, build, and test stages. Thus, everyone on the team was exposed to a variety of skills, tools, and experiences that would lead to a successful product by June 2017. To ensure that all of the team's goals were met, the team had split up lead responsibilities among the three members. As a lead, he/she was responsible for signing off on a final product before it is incorporated into the project. Julia was the Communications Lead. She was responsible for communicating with the NextFlex Group through email, phone, and in person, and is also responsible for the final review of all the technical reports. Maya was the Secretary and CAD/Drawing Lead. Her Secretary role included preparing meeting agendas, recording meeting minutes, and keeping the online file drive organized; while her CAD/Drawing responsibilities include reviewing and signing off on all CAD models and drawings before manufacturing. Paul was the Manufacturing Lead. He was responsible for ensuring that the models were designed for manufacturability, making sure the team is safe in the machine shop, and managing the overall project budget.

Throughout this project, the BendatroniX Team followed a fundamental design process; starting with ideation, then evaluation of designs, Preliminary Design Review (PDR), prototyping, detailed design, Critical Design Review (CDR), fabrication, and then testing, with continuous iteration of the process as needed. The Gantt chart in Appendix D was created by the BendatroniX team with this design process as a guide and was kept as a live document so that necessary changes could be made.

4.0 Design Development

Once the NextFlex Group approved the list of specifications, the BendatroniX Team ideated solutions to fulfill the two main functions of the fixture: 1) continually monitor the resistance of the circuit until failure and 2) secure the FHE sample. Various methods of ideation were used including brainwriting, brainstorming, and SCAMPER. Throughout the ideation process, over 100 different ideas were generated. Some examples of the team’s concepts are described below.

Initial prototyping was completed to replicate the real-life size of the FHE samples as seen in Figure 13. This assisted in the team learning just how small the samples were and the corresponding challenges, such as grip area and force. Additionally, the BendatroniX team explored different test configurations and modeled clamps that could fulfill either one or multiple configurations. Rather than doing a traditional tension clamp, the team considered creating a torsional clamp as seen in Figure 14.

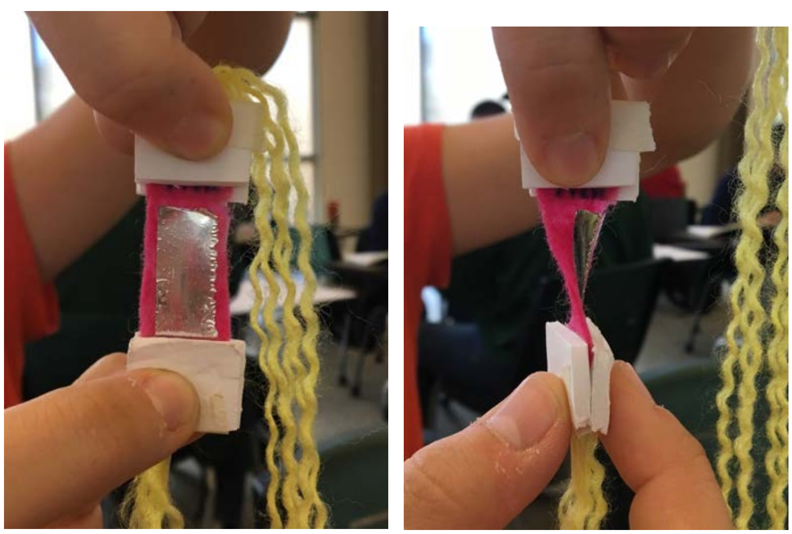

Figure 13. Prototyped replica of FHE sample (pink) with silicon circuitry (silver) with tension clamp.

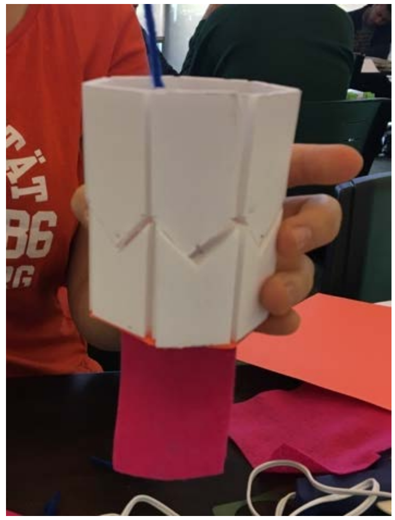

Figure 14. Prototyped replica of FHE sample with torsional clamp.

In addition to prototyping, the BendatroniX Team heavily utilized brainstorming via whiteboards. A central theme or concept was written in the middle of the board and different branching ideas were sketched or generated. Examples of these ideation sessions are shown in Figure 15.

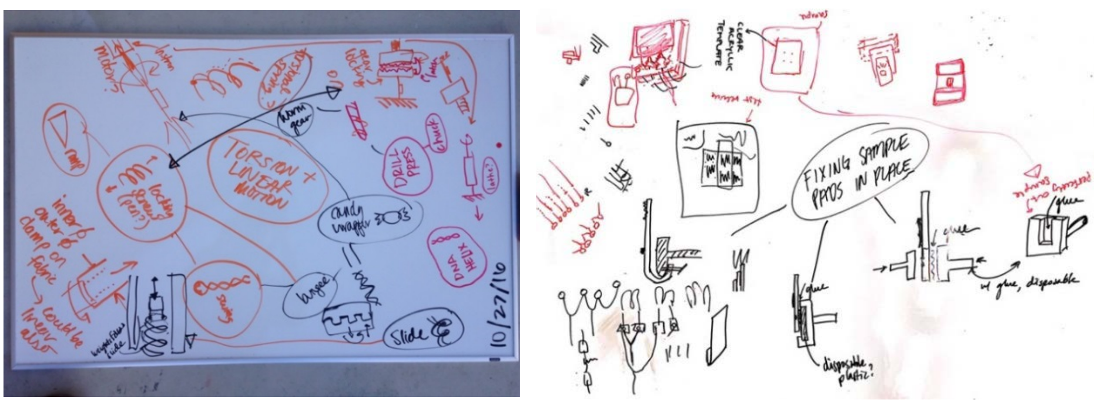

Figure 15. Left: brainstorm for finding ways of creating a fixture that has the ability of completing a tensile and a torsional test. This was completed before the scope of the project was narrowed to a tensile tester. Right: brainstorm for fixing the sample in place within the tester clamps.

During the initial brainstorming, the BendatroniX Team realized how difficult it would be to monitor the resistance of the sample from both ends of the circuit during the tensile test, as seen in Figure 2. After reviewing what the Suikkola group did with their tensile tester, it appeared that the task would become much easier if the circuit could be designed so that the resistance monitoring only occurred on one side of the sample, rather than both the top and bottom [7]. Thus, the BendatroniX Team recommended to the NextFlex Group that the terminals be redesigned to allow for the resistance monitoring to be completed on the stationary Instron clamp. The updated silver trace pattern can be seen below in Figure 16 with two different terminal configurations. Note that the pitch between the terminal pads for both designs is the same, thus allowing for the same fixture to be used to monitor the resistance.

The two different circuit configurations were developed considering the thinness of the trace leading to the terminal. To avoid failure occurring where the thin trace meets the terminal pad, the fan design was created to provide a gradual thickening of the trace. The extra 11th terminal was added to provide a controlled resistance reading. The reading across the first and tenth terminals should be equal to the first and 11th terminals because of the shorted circuit. If the readings are not equal, it could indicate that the fixture is not properly functioning.

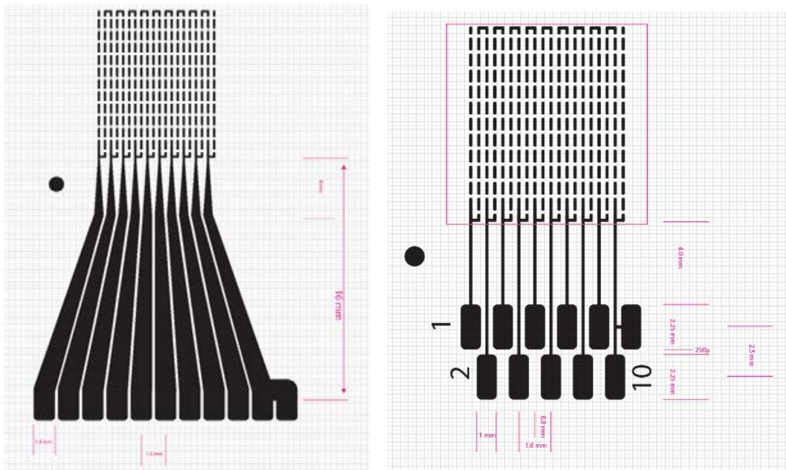

Figure 16. Left: Terminal pads fanned out to 16mm beyond where the silicon circuit is located. All 11 pads are collinear with a 1.6mm pitch. Right: Terminal pads extended 4mm beyond the silicon circuit and are staggered with a 1.6mm pitch along each row.

4.1 Functionality

Pugh matrices were used to evaluate how well different function ideas met the specifications listed in Table 3. The top functions were permuted until a series of complete concept designs were generated. Two main themes encompassed all of the ideas, which the team called “external” and “internal” monitoring.

External monitoring allows for off-the-shelf Instron clamps to be used solely to grip the FHE sample, which must be larger than just the circuit. Separately, some type of external monitoring attachment (alligator clips, conductive adhesive, solder) would connect the silver ink terminals of the sample to the DAQ. A generic sketch of this idea can be seen in Figure 17.

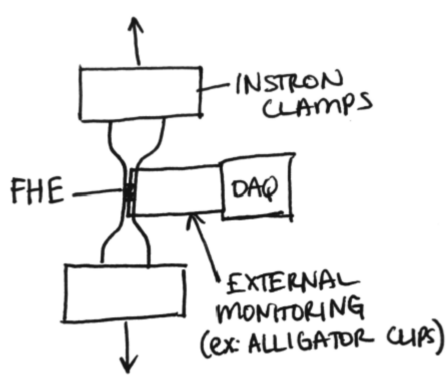

Figure 17. Sketch of a generic external monitoring system. Off-the-shelf Instron clamps and a larger FHE sample can be used. Possible external monitoring methods include solder, conductive tape/ink, and alligator clips.

Internal monitoring requires that a custom clamp be designed that both grips and monitors the resistance of the FHE sample. Various internal resistance monitoring options were considered, including contact pads and spring-loaded needle probes. Furthermore, different clamping configurations were considered including the plate clamps, a male/female interface, and the thin film roller clamps. A generic sketch of this concept can be seen in Figure 18.

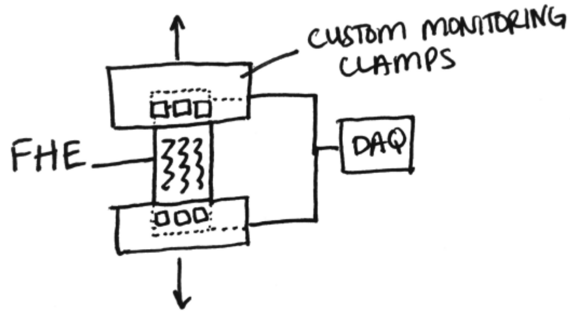

Figure 18. Sketch of generic internal monitoring system. Custom clamps would be made on a small pre-cut FHE sample. Internal monitoring methods include contact pads and needle probes.

4.2 Concept Generation

Within these two overarching themes, nine specific configurations were analyzed that combined different resistance monitoring methods with different clamping methods. A weighted decision matrix was created that compared all of the configurations with the product specifications outlined in Table 3. The top five configurations are located in Table 4 and the entire decision matrix can be seen in Appendix E. In order to receive feedback from the NextFlex Group, the BendatroniX Team created solid models of the top four concepts.

Table 4. Simplified results of decision matrix. Full decision matrix in Appendix E

Configuration Description	Final Weighted Score (out of 10)
Custom clamps with internal monitoring	7.60
Custom spring loaded plate clamps with internal monitoring	7.40
Custom male/female clamps with internal monitoring	7.36
Custom male/female clamps with external monitoring	6.84
Instron plate clamps with external monitoring	6.60

As seen in Table 4, the top five configurations were all weighted very closely, with the top configuration being custom clamps with internal monitoring. This differs from the other configurations because it is simpler to create one clamp that has internal resistance monitoring via contact pads, pins, or wiring. The only reason that the second place configuration is slightly less is because adding a spring force to assist with clamping would become more complicated and increase the chance of misalignment. By using male/female clamps, the design would allow for better alignment of the samples when they are loaded into the fixture, but are more complicated to manufacture because the clamps will be small. Finally, the last two configurations both include external monitoring. While this is an easier option, it is much harder for the user to verify if contact is being maintained during the test and there is a much higher chance that the external monitors (i.e. alligator clips) would fall off. After reviewing the general ideas from the decision matrix, a series of designs were created and are further explained below.

1. Instron plate clamps with external resistance monitoring

This design utilizes basic plate clamps that can be purchased from Instron to secure the sample, like the ones shown in Figure 19. Resistance monitoring is accomplished by using a custom alligator clip or adhering wires to the terminals via soldering or conductive ink/tape. In order to accommodate the external resistance monitoring, a larger sample size would be required for testing as seen in the concept model in Figure 20. The major concerns with this concept is that the external monitoring must not damage the sample (ex: alligator clips ripping through the TPU) and that the external monitoring maintain a constant and reliable connection during the test.

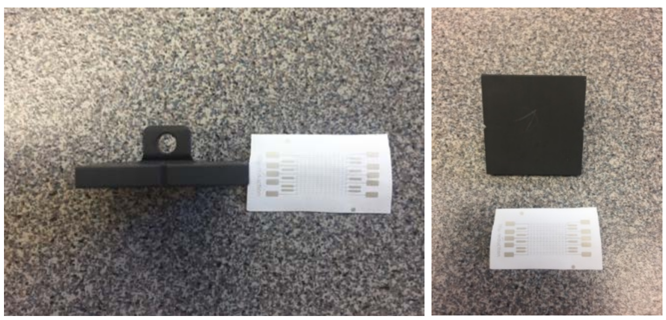

Figure 19. Photos of sample and flat Instron clamp for scale. Examples of stock Instron steel plate clamps that could be used with an external monitoring system.

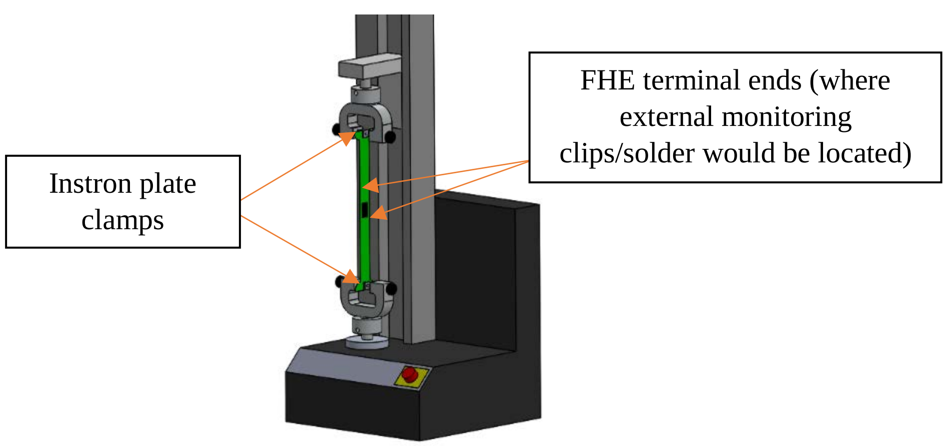

Figure 20. Concept model of Instron Mini with classic plate clamps, external resistance monitoring, and FHE sample (TPU represented as green, actual silver ink circuit represented as black square in the middle of the TPU).

2: Custom plate clamps with contact pads

This concept incorporates a custom plate clamp with an internal resistance monitoring system. As seen in Figure 21, the plate clamps provide the main gripping surface, while evenly spaced contact pads monitor the resistance of the FHE terminals. Unlike the external resistance monitoring configurations, this configuration requires that FHE sample be small enough for the clamps to grip the actual terminals. This allows for an accurate and even strain percentage throughout the sample. The main problem with this concept is that there is an alignment problem associated with loading the sample into the fixture. The user is unable to see if the contacts of the clamp properly align with the FHE terminals; thus, consistent resistance monitoring is not guaranteed. It may be possible to make clamp out of a transparent material like acrylic to help with the alignment problem; however, further analysis will need to be completed to asses if acrylic would be an appropriate clamping material for this application.

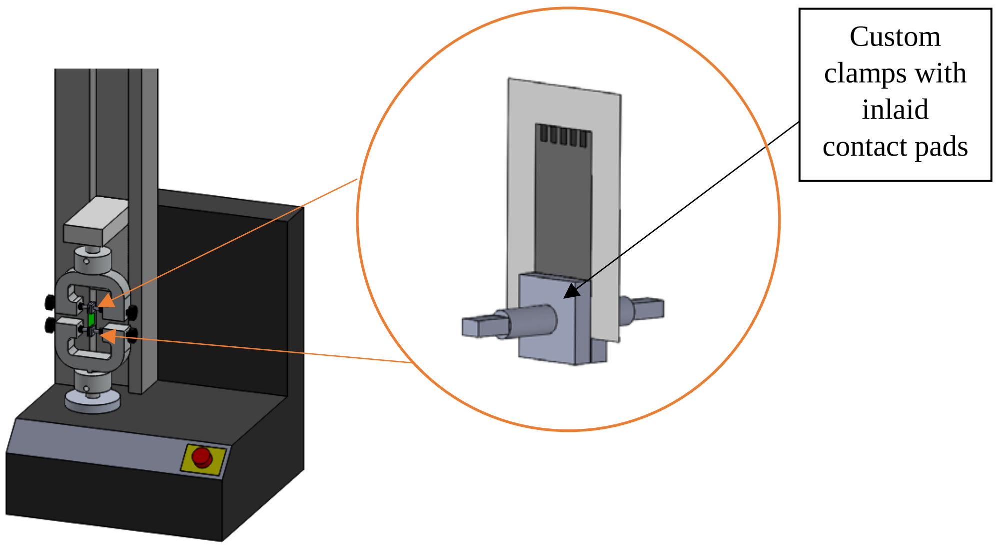

Figure 21. Solid model of Concept 2. Note that the clamps make direct contact with the circuit; however, due to the nature of the clamp, the user cannot tell if the contact pads are lined up with the silver ink terminals.

3: Male/female clamp with contact pads

In order to assist in the alignment problems associated with Concept 2, the male/female connection concept was generated. Like Concept 2, a custom clamp would be designed with flat contact pads. However, the male/female connecter would ensure that the contact pads would better align with the FHE terminals. The only caveat is that the FHE sample would need to be cut the same size every time in order to perfectly fit in the clamp fixture. If a sample is cut incorrectly, then the terminals and the contact pads would still not align. The concept models for this design can be seen in Figure 22.

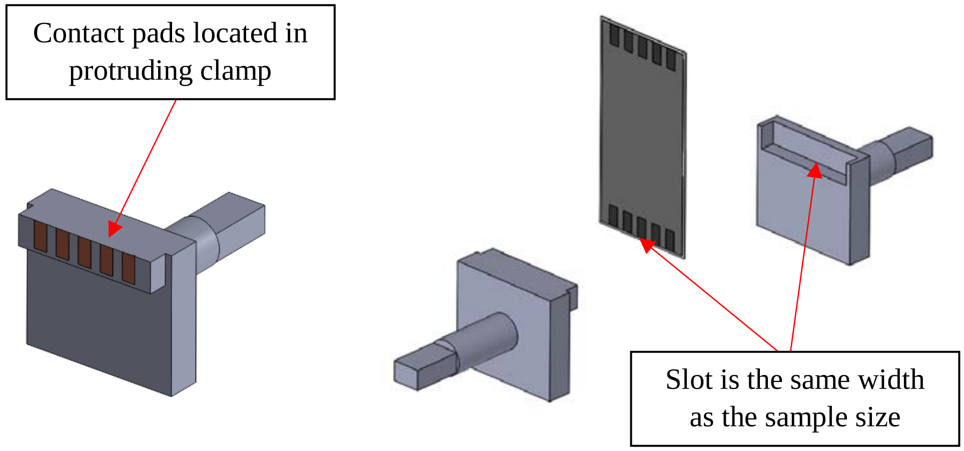

Figure 22. Solid models of Concept 3. Note that the male and female parts aid in alignment of the FHE, but require the same size sample each time.

4: Plate clamp with needle probes

This design incorporates needle probes within the plate clamp. Spring-loaded needle probes would ensure consistent contact with the terminals even if the flat surfaces of the clamps were not fully flush with each other. In addition, the rake design allows for the user to see if the probes contacting the terminals as seen in Figure 23. The major concern with this concept is that the needles might scratch and damage the FHE terminals. It is possible that custom needles could be designed to alleviate this problem, but further benchmarking is required to support this claim.

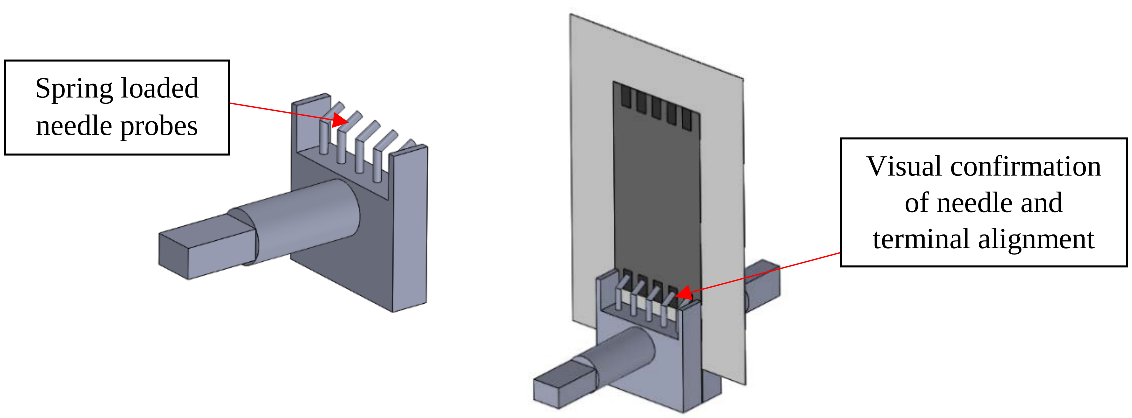

Figure 23. Solid models of Concept 4. Note that the internal needle probes guarantee contact for each terminal on the circuit, yet introduce potential of scratching the sample.

5: Plate clamp with PCBA and pogo pin resistance monitoring

This concept follows the traditional plate clamp model to grip the substrate. In order to monitor the resistance of the terminals, a custom PCBA outfitted with pogo pins would be used. Pogo pins are typically used in electronics to connect two PCBA's. Pogo pins are applicable to this design because they are spring-loaded and can allow for a constant connection within a controlled distance between the terminals and the pins. By designing the fixture in such a way that the PCBA can be removed, different pogo pin configurations can be used in the future if the FHE terminals are redesigned. Additionally, the male/female configuration from Concept 3 could be utilized to further assist with contact alignment. A possible conflict with this concept is finding pogo pins that are small enough in diameter for the pitch of the silver ink terminals. The concept model of this configuration can be seen in Figure 24.

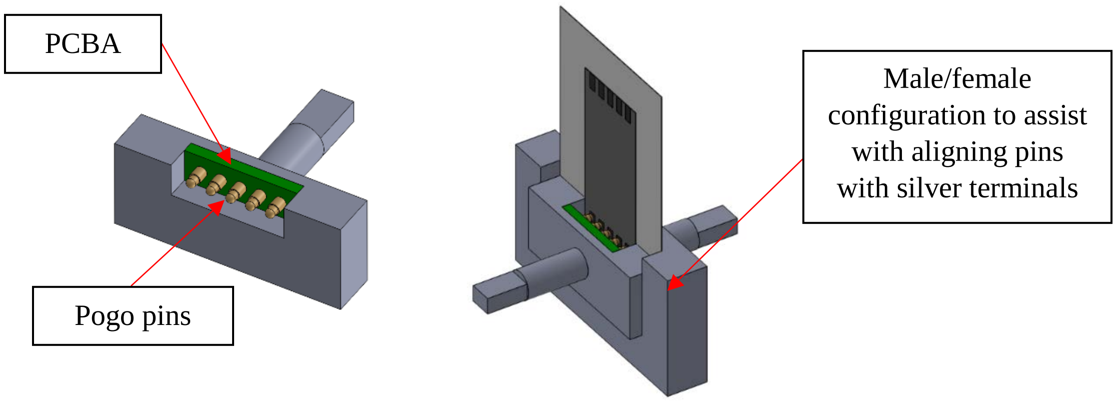

Figure 24. Solid models of Concept 5. Continuous contact with the circuit will be provided by the pogo pin array. The discrete pogo pins allow for individual terminal contact with visual alignment confirmation, but no risk of damage to the sample.

Following feedback from the NextFlex Group and the results of the BendatroniX Team's decision matrix, the team will be pursuing the pogo pin (Concept 5) configuration. However, it was determined by the BendatroniX Team and NextFlex Group that including a PCBA may not be necessary. Instead, the BendatroniX Team plans to use a multimeter to manually measure the resistance changes from each pogo pin during incremental changes in tension during the test.

4.3 Preliminary Failure Mode Analysis

The BendatroniX Team needed to account for all failure modes during their design process to ensure the design was reliable. The two main functions of the pogo pin clamp design were evaluated to determine all potential failure modes including the causes, effects, severity, and recommended counteractions. For example, one of the main modes of failure could be improper alignment of the FHE sample when loaded into the custom clamps. By incorrectly loading the sample, the test may not work properly due to pogo pin misalignment, and the sample could be damaged in the process. One recommended action to prevent this would be to design a way to fix the FHE to the back clamp so that it could not slip. For the function of monitoring resistance, a potential failure mode could be a faulty pogo pin providing inaccurate results (possibly from prior damage due to misalignment during the clamping process). A way to counter this failure mode could be to enforce perpendicularity and positional tolerances to ensure the pogo pins line up properly. The full failure mode effects and analysis (FMEA) table is attached as Appendix F, where the criticality of each potential cause and effect was ranked to determine the most important factors to consider in the design.

4.4 Material Selection

Ideally, the four clamps would be made out of the same material; however, the BendatroniX Team did not know what material would best. In order to determine the ideal clamp material, the BendatroniX Team tested the friction of TPU with steel, aluminum, and Delrin (acetal resin). These materials were chosen because, while the current Instron jaw faces are generally made out of steel, aluminum and Delrin are much lighter and easier to machine. An angle test was completed to find the coefficient of static friction of each material with the TPU. A c-clamp test was also completed to determine if a TPU sample would slip when it was clamped between blocks of each material (i.e. sandwiching TPU between two aluminum masses and pulling on the TPU). The setup, procedures, and results from both tests are outlined in Appendix G.

The conclusion of both tests proved that Delrin would be the ideal material to use for the clamp. Delrin had the highest coefficient of friction with the TPU, at 0.53, and had the least slippage during the c-clamp test. Aluminum would be the second choice, as it did not allow much slippage in the c-clamp. Steel performed to satisfaction, but it proved to be too heavy and difficult to machine. Therefore, the BendatroniX Team will manufacture the clamps out of Delrin and verify that it meets the design specifications to prevent slippage.

5.0 Detailed Design

After the NextFlex Group approved Concept 5, the BendatroniX Team moved forward with the pogo pin configuration design. Before a finalized fixture could be designed, the BendatroniX Team consulted with the NextFlex Group to create a customized FHE screen print pattern. Two different terminal configurations were selected that are referred to as the staggered and fan patterns. The terminal pitch between both configurations is 1.6mm. An additional terminal was added to provide a short between terminals 10 and 11. This will allow the BendatroniX Team to complete reliability testing on the completed fixture. Finally, four fiducials (locating marks shaped like crosses) were added to each FHE to provide an accurate locating mark for the BendatroniX Team to cut the samples to the correct size. This will be further explained in Section 5.5. The final FHE print pattern can be seen in Figure 25.

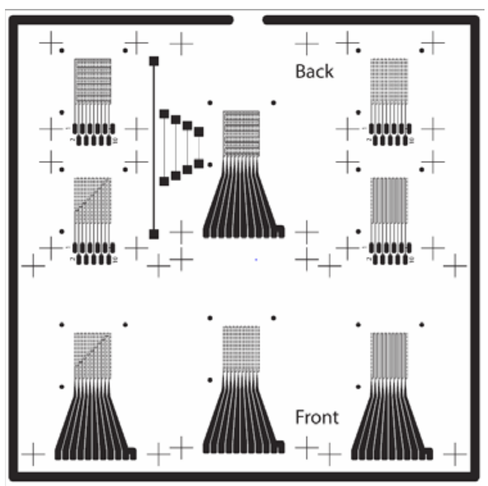

Figure 25. 4in x 4in FHE print pattern with four fan configurations and four staggered configurations.

Once the layout of the FHE terminals was completed, the BendatroniX Team was able to test a TPU sample using the Instron pneumatic side action grips. The TPU sample performed as expected and the BendatroniX Team decided to move forward with designing custom face plates that can monitor the terminal resistance via pogo pins as outlined by Concept 5 in the previous section. To see the Instron setup, refer to Figure 26.

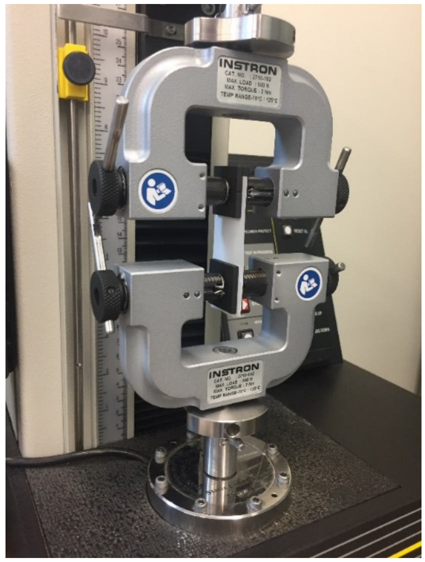

Figure 26. Test sample of TPU used in Instron pneumatic side action grips.

After the FHE sample pattern was confirmed and the Instron testing was completed, a number of design considerations were researched further, including resistance monitoring, pogo pin selection, and installation of the FHE sample before the detailed design was completed.

5.1 Resistance Monitoring

During the initial prototyping stages, the BendatroniX Team thought that using a PCBA would be a straightforward way to manage the terminal outputs; however, after further consideration the team realized that this would be more complicated than originally planned. In order to monitor the failure of the FHE, the resistance needs to be monitored across each section of the circuit. One way to do so is to have 10 multimeters continuously monitor each of the terminals independently; this option is unrealistic due to the its complexity. Another option would be to use a multiport multimeter, but this would require additional research and programming for monitoring software. While this is a viable option, the BendatroniX Team has decided to forgo this option in order to focus on manufacturing a fixture as soon as possible.

In order to simplify the resistance monitoring problem, the first prototype design will have the user manually record the resistance data. Once the FHE is loaded into the fixture, each of the FHE terminals will make contact with a corresponding pogo pin. Each of the pogo pins will have a wire connected to the stationary back end (further explained in section 5.2) that the user will have access to during the tensile test. A handheld multimeter will be used to monitor the two corresponding terminals that the user wishes to observe. Multiple multimeters will be needed to observe more than one trace. Once the test is ready, the FHE sample will be continuously stretched at a constant rate of strain percentage per second. At specified time intervals, a resistance reading will be recorded across the entire circuit (from the first and last pogo pins) from the multimeter. Once the resistance reaches the failure value (~2000 Ohms), the test can be stopped and the operator can use the multimeter to read the resistance associated with each of the intermittent pogo pins until the failure can be located. In future revisions of the fixture, automated data acquisition can be utilized to simplify the process of reading multiple multimeters throughout the duration of the test.

5.2 Pogo Pin Housing Fixture

In order for the pogo pin design to be successful, appropriate pogo pins are required. A variety of pogo pins were researched including Yokowo's Small Diameter Pogo Pins, Mill-Max's Discrete Spring-Loaded Contact Pins, and Emulation Technology Inc.'s Ultra-Mini Pogo Pins. The biggest dilemma in selecting an appropriate pogo pin was finding one that could successfully achieve a 1.6mm pitch. While Yokowo's pins could achieve a 0.9mm pitch, they were not available for individual purchase. None of the Mill-Max pins' achieved the appropriate pitch either. Thus, the BendatroniX Team decided to use Emulation Technology's Ultra-Mini Pogo Pins due to their large selection of pins that achieved an appropriate pitch. A variety of sample ultra-mini pogo pins were ordered from Emulation Technology. After examining the samples, the 1.0mm pitch pogo pin was selected due to its smaller size and ease of installation within the overall fixture design. To see the Emulation Technology drawing for the pogo pin (drawing: SKT2496) refer to Appendix H. Images of the pogo pin sample can be seen in Figure 27.

Figure 27. Sample of Emulation Technology Inc. Ultra-Mini Pogo Pin with recommended installation pitch of 1.0mm.

Due to the fragile nature of the pogo pins, Emulation Technology recommends that the they be inserted between two supporting fixture blocks as shown in Figure 28. The shoulders of the counter bores hold the pin in compression rather than press fitting the pins into holes. Emulation Technology also recommend that the fixture pieces be made of Delrin due to its favorable machining properties. An example of the Emulation Technology pogo pin housing can be seen in Figure 28.

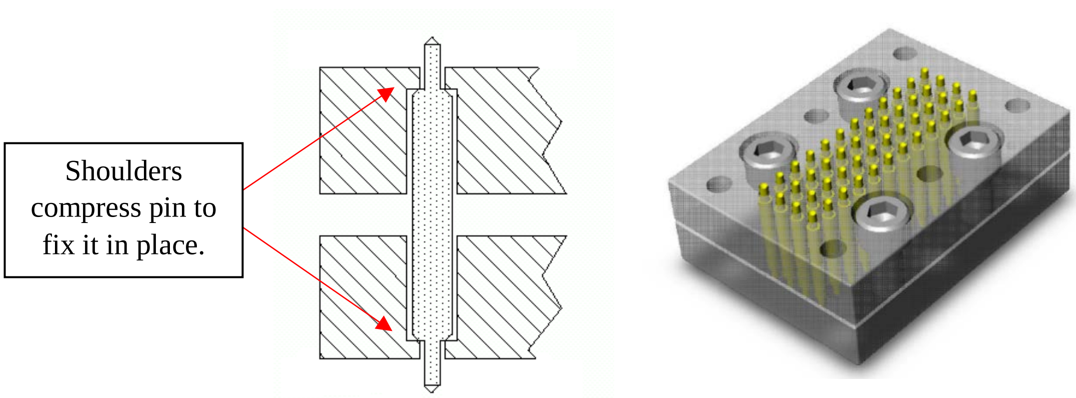

Figure 28. Recommended installation fixture for Emulation Technology's Ultra-Mini Pogo Pin. Left: Cutaway cross-section view. Right: Semi-transparent isometric view [9].

In order to accommodate both the stagger and fan terminal configurations shown in Figure 16, the BendatroniX Team designed the pogo pin housing subassembly to feature two rows that will consist of 16 pogo pins total (top row: 11 pins, bottom row: 5 pins, pitch of 1.6mm). The material of the pogo pin housing was designed to be Delrin for electrical insulation and favorable machining properties. Due to the small size of the pogo pins and corresponding fixture, the BendatroniX Team initially intended to use a CNC mill to manufacture the parts on campus. One of the biggest challenges that the BendatroniX Team faced was ensuring that the pogo pin housing could actually be machined. The sandwich design recommended by Emulation Technology was modified for machinability by adding a pocket and adjusting thickness of the plates. The original design can be seen in Figure 29. To see the corresponding detailed drawings, refer to Appendix H.

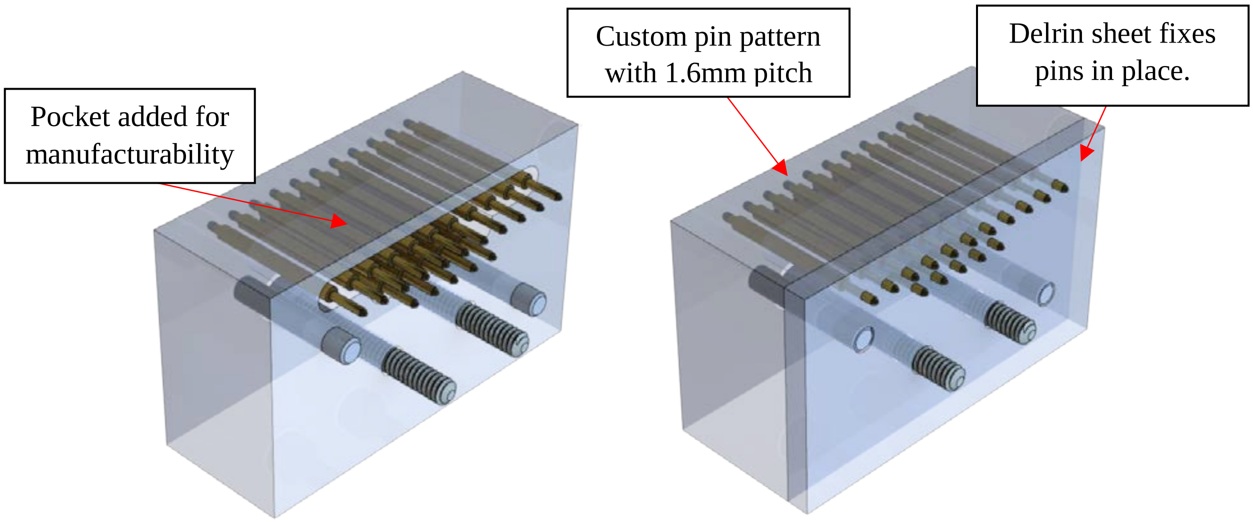

Figure 29. Pogo pin housing designed for in-house manufacturing using CNC milling processes. This design was used as a starting concept for the actual design made by Emulation Technology.

After completing the pogo pin housing design, the BendatroniX Team recognized the complexity of designing such a small assembly. Consequently, they decided to hire Emulation Technology to manufacture the pogo-pin subassembly. Since Emulation Technology already manufactures mini pogo pins and related attachments, it made the most sense for them to make the pogo pin housing as well. In addition, the selected pogo pins were rated at a 1.00mm minimum pitch, so the BendatroniX Team believed that Emulation Technology would easily achieve the 1.6mm required pitch of the NextFlex Group's FHE design. As seen in Figure 30 below, Emulation Technology planned on encapsulating the pogo pins with FR-4, which is a glass-reinforced epoxy laminate sheet commonly used for printed circuit boards. One of the major benefits of having Emulation Technology manufacture the pogo pin housing subassembly is that it will include a custom wire array that will fit onto the stationary back end of the pogo pins and output a discrete wire for each pogo pin (30in of 30-gauge wire). This eliminates the need for the BendatroniX Team to solder wires to the back of the pogo pins. By having 30in of output wire, the user would be able to monitor each of the terminal resistances throughout the tensile stretch.

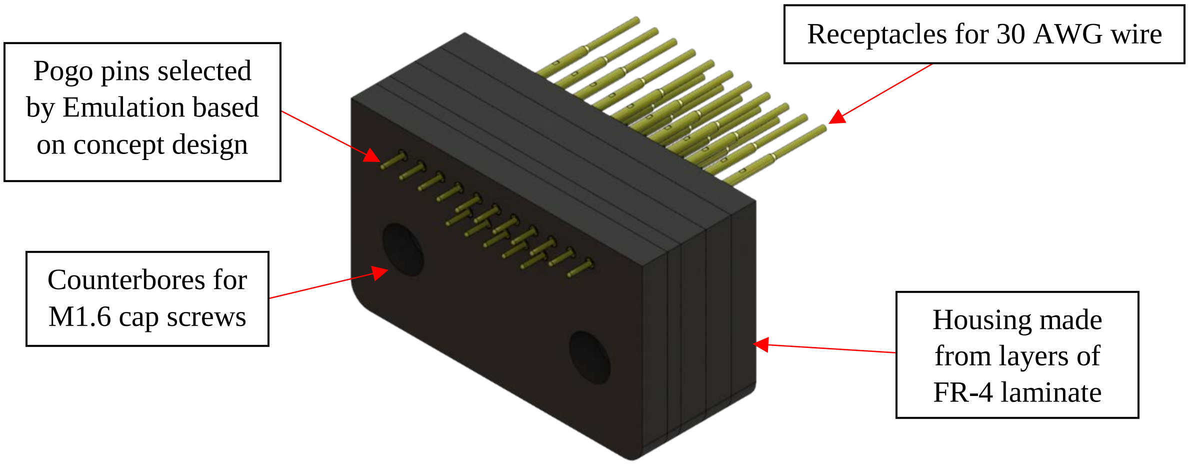

Figure 30. Pogo pin housing designed by Emulation Technology based on the BendatroniX Team's concept. Detailed drawings for the housing and pins can be found in Appendix H.

5.3 Assembly Plan

The BendatroniX Team designed a custom clamp face ("U-block") that will mate with the pogo pin housing subassembly via two screws as seen in Figure 31. A tab is located on the back of the U-block to mate with the Instron side action grips. There are two clearance holes in the U-block to allow for sample-aligning dowel pins to properly fit. This will be explained further in following sections. To see the detailed drawing of the U-block, refer to Appendix H.

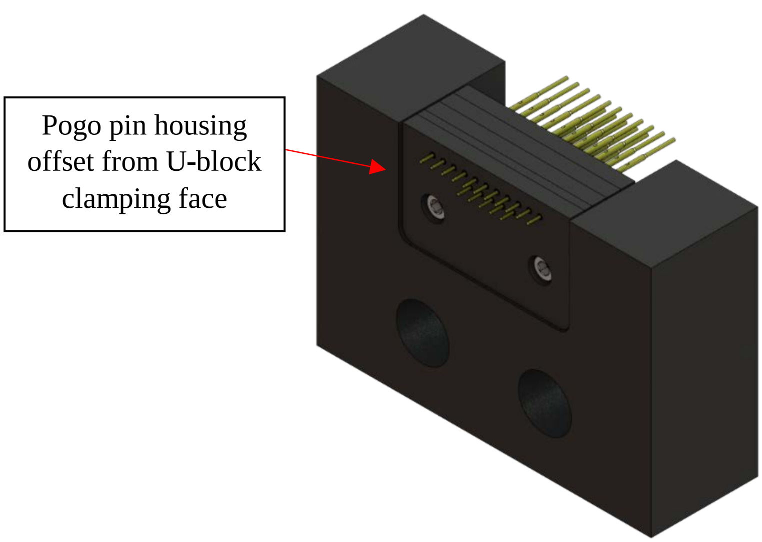

Figure 31. Manual monitoring clamp assembly. The pogo pin assembly is offset from the U-block surface to prevent bottoming out the plungers of the pogo pins when clamping.

The U-block and pogo pin housing only account for a portion of the complete design. Three more custom clamps were designed, as seen in Figure 31. The bottom left clamp has the same outer perimeter of the U-block, and the two align using Delrin dowel pins. This purpose of these pins is to help align the FHE sample to the pogo pins and clamps. This will be outlined further in Section 5.4. The two top clamps are identical and their only purpose is to grip onto the top section of the FHE during the tensile test. To see the entire assembly drawing and related detailed drawings, refer to Appendix H.

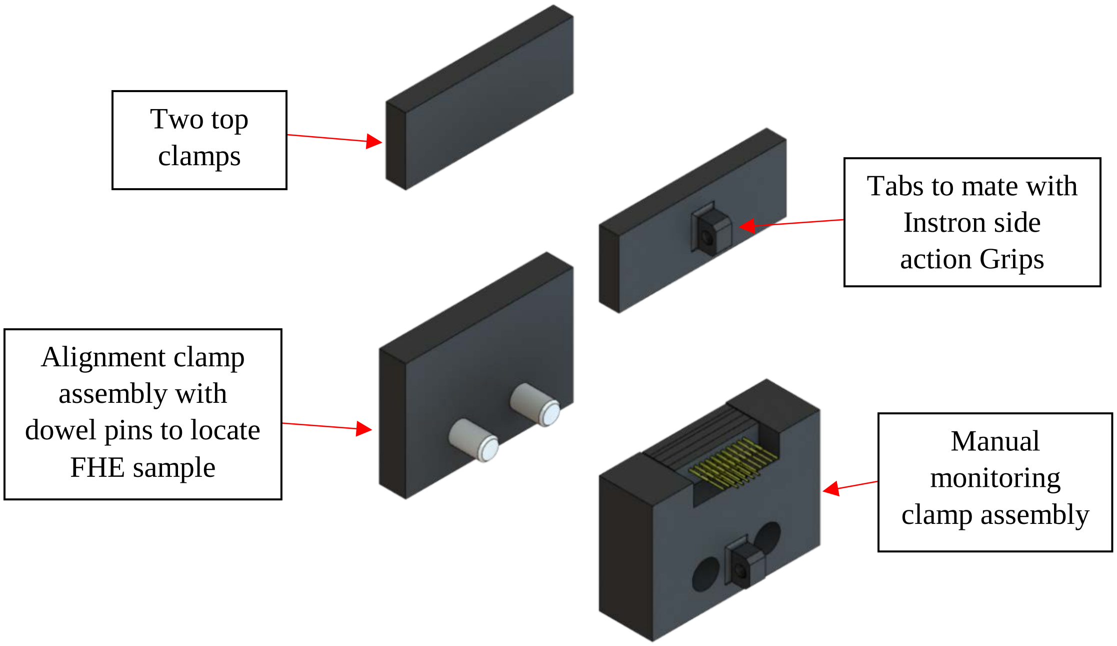

Figure 32. All four of the custom designed clamps. To see complete assembly drawings, refer to Appendix H.

The assembly of the entire design is comprised of three levels with the final assembly being Level 0. Level 1 is comprised of the two top clamps, the alignment clamp assembly, and the manual monitoring clamp assembly as seen in Figure 32. Level 2 is comprised of the components that make up the two clamp subassemblies. A simplified version of the Bill of Materials can be seen in Table 5, while the complete version can be seen in Appendix I.

Table 5. Simplified Bill of Materials

Assembly Level	Part Number	Description		
		Lvl 0	Lvl 1	Lvl 2
0	100000	Final Assy		
1	101000		Manual Monitoring Clamp Assy	
2	101010			Emulation Pogo Pin Assembly
2	101004			Screws
2	101005			U Block
1	102000		Alignment Clamp Assy	
2	102001			Alignment Block
2	102002			Dowel Pins
1	103000		Top Clamp	
1	104000		Fanned Die	
1	105000		Staggered Die	

5.4 Alignment Plan

One of the biggest challenges that the BendatroniX Team faces is staging the FHE sample correctly to ensure that the pogo pins maintain continuous contact during the tensile test. The current plan is to use an acrylic template to cut identical FHE samples reliably with the added cross fiducials for both the fanned and staggered configurations, as seen in Figure 33. The inner rectangle aligns with the fiducials while the outer perimeter of the acrylic aligns with the outer perimeter of the upper and lower clamps.

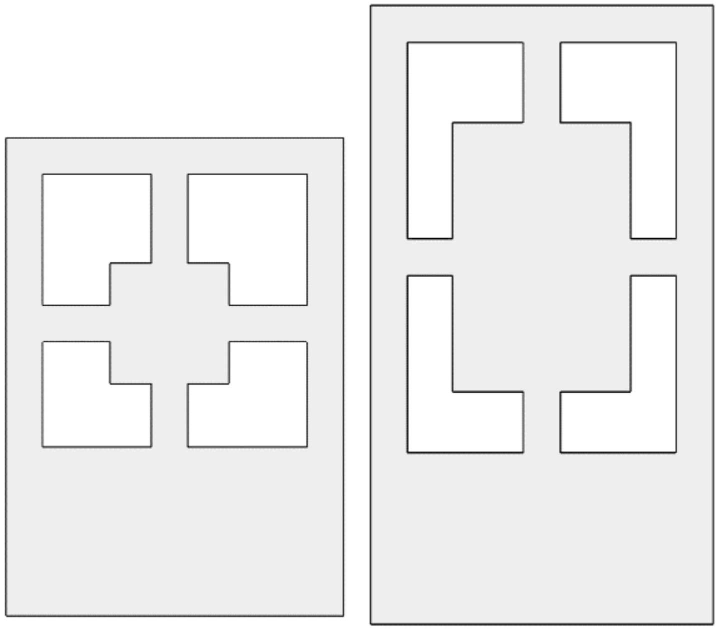

Figure 33. Geometries of acrylic templates used to cut FHE samples to the appropriate size. Left: staggered configuration. Right: fan configuration.

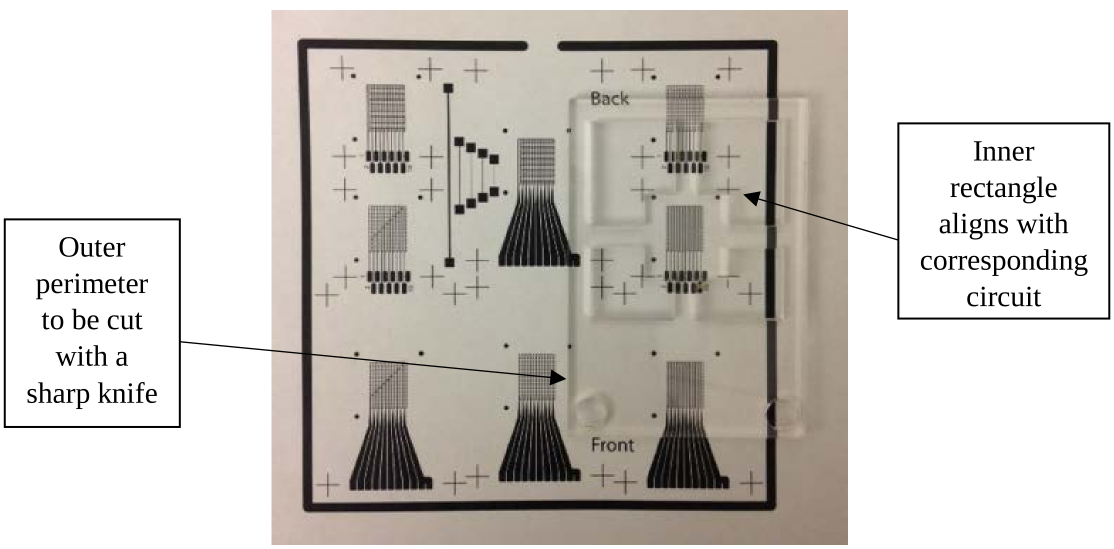

Figure 34. Example of prototyped acrylic template lining up on top of FHE sample. User would cut along the outer perimeter of the template using a sharp knife and a custom hole punch to remove the two lower holes.

The user aligns the inner rectangle of the acrylic template along the fiducials of the circuit of choice as seen in Figure 34. Then, using a sharp knife, the user cuts along the outer perimeter to create a uniform sample. The BendatroniX Team has verified that a sharp knife will work during preliminary testing with the TPU. Next, the user will use a hole punch to make the two 0.25in diameter holes in the sample. These holes will allow the user to lay the FHE sample over the bottom alignment clamp with the corresponding 0.25in dowel pins.

Once the sample is cut, it will be loaded on the back clamp in the Instron. The user adjusts the side action jaws to clamp the two bottom clamps together. Based on the alignment of the FHE sample in the clamp, the pogo pins should align with the FHE terminals. After the bottom clamps are secured, the user ensures that the top of the sample is in between the top two clamps. The top jaw is then manually lowered until the top of the top clamps are parallel with the top of the FHE sample. The clamps were specifically designed so that when they are aligned as so, a uniform strain will be experienced by the FHE sample. The alignment concept steps can be seen in Figure 35.

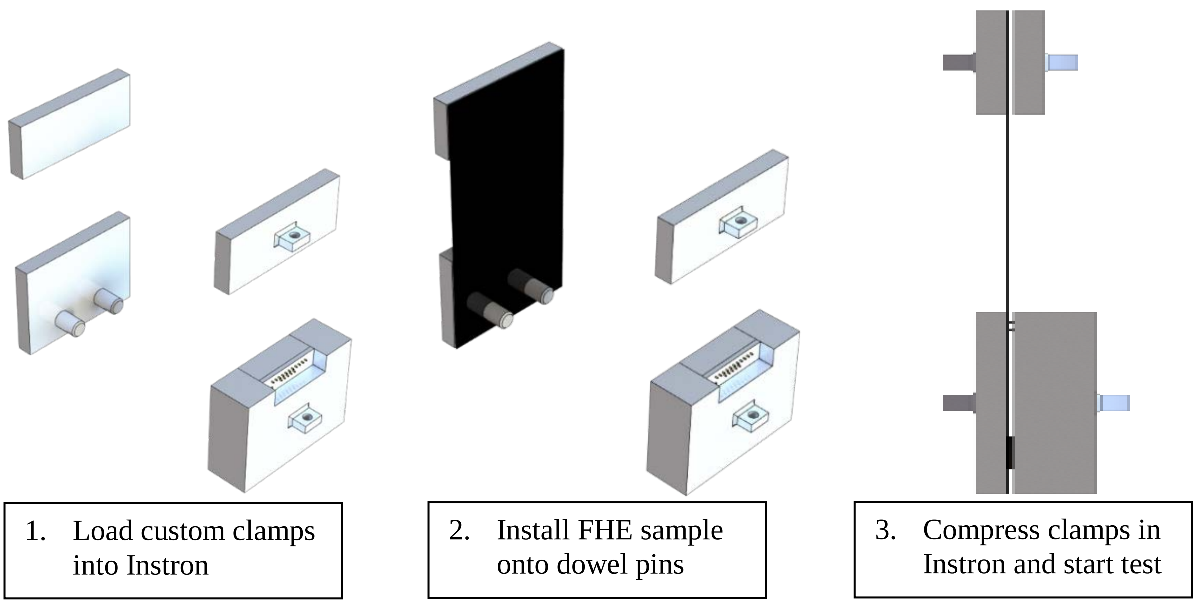

Figure 35. Concept for loading the cut FHE sample into the clamps. The dowel pins on the alignment block locate the FHE sample so that the terminals line up with the corresponding pogo pins.

5.5 Manufacturing Plan

Pogo Pin Housing

As mentioned in Section 5.2, the original plan to manufacture the pogo pin housing involved using on-campus CNC resources. It was determined after multiple consultations from different sources, however, that this effort would likely produce unreliable results. Because the BendatroniX Team's design hinges upon precisely located terminals and pogo pins, they have decided to outsource the fabrication of the pogo pin housing to Emulation Technology. Additionally, opting to have Emulation Technology incorporate wires into the pogo pin housing allows the BendatroniX Team to avoid complications and safety concerns associated with soldering to Delrin.

Emulation Technology will manufacture two of the pogo pin housings. This will allow the BendatroniX Team to use one of the housings for the tensile test and the other housing for a future test configuration. One of the drawbacks of having the parts manufactured by Emulation Technology is that if any of the housing components break (torn wire, broken pogo pin, etc.), the housing will need to be sent back to Emulation Technology to be repaired. While this is inconvenient for the user, the BendatroniX Team believes that as long as the clamps are maintained well, there will be a low risk of damage occurring.

Pending approval from the NextFlex Group, the Bendatronix Team plans on moving forward with Emulation Technology. The lead time for the completed subassemblies is approximately 4-5 weeks from the expected start date of February 10, 2017.

Clamps

Before manufacturing begins on the clamps, Dr. Wang has offered to let the BendatroniX Team use the IME Department's 3D printing equipment to verify clamp geometry. This will be helpful in determining appropriate fits for all the clamps where they interface with the side action grips. Once the final clamp geometries have been confirmed, manufacturing will begin.

All of the clamps, including the U-block, alignment clamp, and both top clamps, will be machined with the CNC resources at Cal Poly. The manufacturing process will consist of three mill operations; one for the fronts of each clamp, one for the backs, and another for the locking pin hole. Nathan Harry, the CNC Supervisor for the Mechanical Engineering Department shops, has been instrumental in providing consultation throughout the design process.

Acrylic Templates

The acrylic templates used to cut FHE samples to the appropriate sizes will be made using the laser cutter in the Cal Poly machine shop. Because the machine functions by burning the material it cuts, the main challenge in taking this approach is accounting for the kerf of the laser. Prototype acrylic templates have revealed that the minimum laser kerf is about 0.5mm. The BendatroniX Team will tune the dimensions of the templates until the final dimensions are appropriate for reliably cutting samples.

5.6 Cost Analysis

To ensure that the BendatroniX Team stayed within the NextFlex-specified budget of $2000, an initial budget plan was determined. The team will still utilize the Cal Poly MATE's Instron device and fixtures for future benchmarking; thus, they will not need to purchase any further fixtures from Instron. The BendatroniX Team received a quote from Emulation Technology, and with the agreement of the NextFlex Group, went forward with purchasing the outsourced pogo pin housing. In the preliminary budget outlined in Table 6, it can be seen that the pogo pin housing will be the most expensive cost due to the complexity of the subassembly and the cost of labor. As the table shows, the estimated total cost to make the clamps is about $1851.33; however, the team plans on using scrap Delrin thus reducing the price to $1824.79, which leaves some room in the budget to use for extra materials or another clamp configuration design. The final budget can be found attached as

Table 6. Budget

Item	Source	Part No.	Qty.	Price per	Cost
Emulation Technology 2300 Series Compression Mount Board to Board Socket*	Emulation Technology	2300-0016-XLB2X11-90_P2	2	$880.46	$1760.95
Black Delrin ® Acetal Resin Sheet 1" Thick, 6" x 6"	Mc-Master Carr	8575K146	1	$26.33	$27.65
Acetal Dowel Pins 1/4" Diameter, 1/2" Long	Mc-Master Carr	97155A636	1	$3.47	$3.47
Black-Oxide Alloy Steel Socket Head Screw; M1.6 x 0.35mm Thread, 12mm Long (Pack of 25)	Mc-Master Carr	91290A043	1	$7.10	$7.10
Clear Cast Acrylic Sheet 12" x 24" x 1/8"	Mc-Master Carr	8560K257	1	$15.76	$15.76
Heavy Duty Paper Hole Punch 1/4" Hole Diameter, 3 Adjustable Holes	Mc-Master Carr	12775T48	1	$37.51	$37.51
High-Speed Steel Three-Flute End Mill 1/8" Mill Diameter, 3/8" Shank Diameter, 3/8" Length of Cut	Mc-Master Carr	2849A73	1	$19.57	$26.73
General Purpose Tap for Closed-End Hole Threading, M1.6 Thread Size	Mc-Master Carr	26015A633	1	$13.05	$13.05
			Total		$1,892.22

* Includes tooling, labor, and tax

5.7 Safety Considerations

A series of safety considerations for the test fixture have been compiled in Table 7. While this is not complete, the BendatroniX Team wanted to provide a preliminary list of possible risks associated with the project. This list will continue to be updated as future designs are formed.

Table 7. Safety considerations associated with final fixture(s)

Safety Risk	Possible Solution
Parts projecting from test platform during tensile test	User wears eye protection
Sharp edges or sharp needles scratching user	Dull fixtures as much as possible during manufacturing process
Pinching user skin during installation of fixtures	Appropriate warning labels. Design fixture such that pinch points are avoided (i.e. small enough where fingers won’t fit, fingers would be pushed out of the way, etc.)

5.8 Maintenance & Repair Plan

The part of the clamp that is at greatest risk of damage is the pogo pin housing. A pogo pin could fail or a wire could become disconnected. After consulting with Emulation Technology, the team found that the only way to repair a damaged housing would be to send it back to the manufacturers and pay the resulting cost to fix it. This is because the encapsulating housing that holds the pogo pins and connects the wires will be one piece. Therefore, proper maintenance and care should be specified to the user, such as proper handling of each individual wire (i.e. not pulling on them carelessly) and proper storage of the clamps. The BendatroniX Team recognizes this is somewhat out of their control since they will not be with the user every time. Thus, the team will attempt to make the fixture as easy and straightforward to use as possible. For example, zip-tying the output wires into one cable will lessen the complexity of the part or including colorful labeling in the user manual to ensure that the clamps are installed correctly.

6.0 Manufacturing

Manufacturing the complete set of clamps took approximately seven weeks including the four weeks that Emulation Technology required to complete the pogo pin housing. The finished pogo pin housing can be seen in Figure 36.

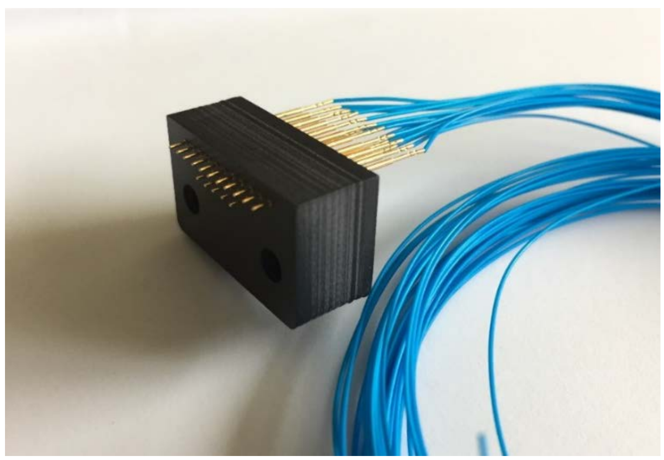

Figure 36. Completed Emulation Technology pogo pin housing assembly. The pogo pin receptacles are connected to 30in of 30-gauge wire.

Future Refinements

Overall, the pogo pin housing assemblies received from Emulation Technology met expectations. Unfortunately, a dimensional error that was made early the design stage was not fixed and resulted in the rows of the pogo pins in the housing being closer together than intended. The vertical distance between the centroids of the staggered terminals is 2mm, but the vertical distance between the corresponding pogo pin rows came out to 1.6mm. While this minor flaw is not ideal, if aligned correctly, the pogo pins are still capable of maintaining consistent contact with the terminals during testing.

In a future iteration of their design, the BendatroniX Team would like to add more pogo pins to the second row of the pogo pin housing assembly. The second row exists for the staggered configuration, which currently has five terminals. Adding more pogo pins on the bottom row of the housing allows more freedom of the circuit position relative to the rest of the sample, making Instron set up more lenient. It should be noted that this could cause an increase of cost for the pogo pin housing, which was already the most expensive part purchased. The updated drawings of the new pogo pin housing are included in Appendix J.

One problem that the team predicted early on was the fragility of the pogo pin housing; however, due to the nature of the reliability testing, the design was built. On the second day of testing, one of the wires was slightly tugged at an angle and the pogo pin receptacle on the wire-end of the housing broke as shown in Figure 37. While the team was still able to complete their testing, they contacted Emulation Technology with the problem and Emulation Technology offered to fix the broken terminal as well as offer a solution to prevent future breaks. Emulation Technology shrink-wrapped plastic around the exposed pins on the back side of the receptacle. The plastic both stiffens and insulates the pogo pins from one another. The repaired pogo pin housing can be seen in Figure 37.

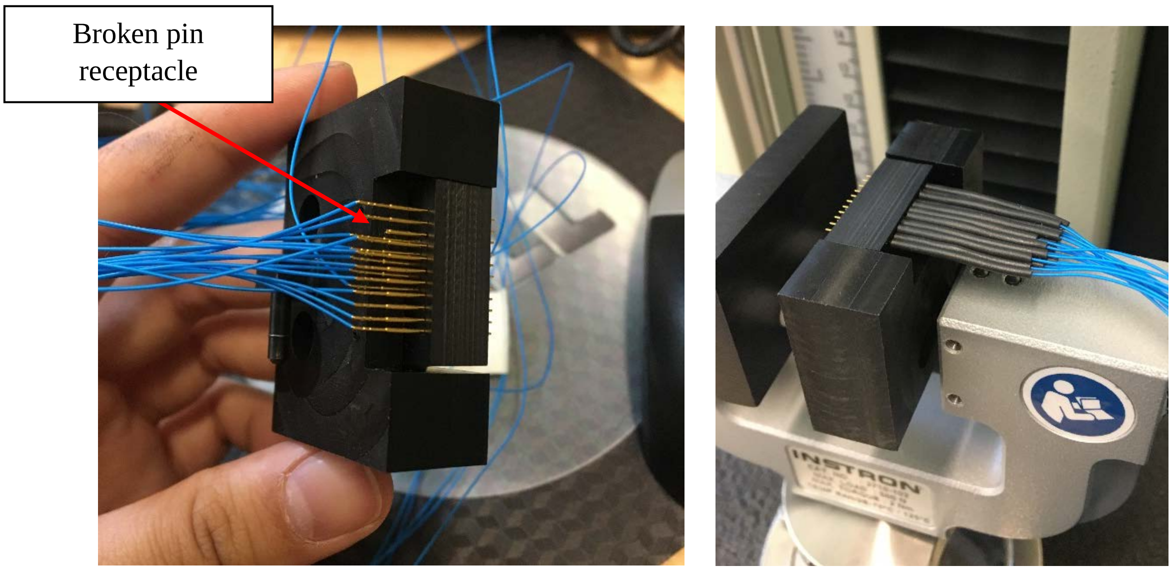

Figure 37. Right: pogo pin housing with broken receptacle as indicated. Left: repaired pogo pin housing with shrink wrap plastic around the pogo pins.

6.1 Milling

All of the Delrin clamps were machined from either purchased stock or scrap donated by Cal Poly's FSAE team. First, the material was manually milled to the outer dimensions of the corresponding clamps. A four-flute, 1/2in, high-speed steel end mill was used to face each side. The spindle speed was 2000 RPM and the feed rate was approximately 70 inches per minute.

Future Refinements

While the BendatroniX Team thought that machining the clamps would be a simple task, it took much longer than anticipated to mill each of the clamps to the appropriate size. On two different occasions, blocks came out undersized and the milling process had to be restarted. Additionally, since the scrap Delrin used was much larger than the desired block size, the machining process took an excessive amount of time for the alignment and monitoring clamps. If the clamps were to be made again, the BendatroniX Team would purchase stock Delrin in a size closer to the desired bounding dimensions of the clamps. The extra cost in purchasing more stock is worth the saved machining time.

Another consideration is making the clamps out of a harder material. While the Delrin was easy to machine, it also dented easily. If the user accidentally drops one of the clamps, the corners deform and become dull.

While this does not pose an immediate problem, more material research should be performed to reach a long-term design solution.

6.2 CNC Milling

The BendatroniX Team hired Nathan Harry, a student shop technician from the Mechanical Engineering department, to machine the more complicated features of the clamps, including tabs, dowel pin holes, and the pogo pin housing shelf. The CAM software used was HSMWorks and the machine was a HAAS VF-3. Each of the clamps post-CNC milling can be seen in Figure 38. Some important details were noted when creating the CAM and milling the clamps:

- When creating the fillet around the base of the clamp tabs, cutter compensation was set to **0.003”** to ensure that the tabs could properly mate with the Instron side action grips.
- A **#30** drill bit is sufficient to create the pin hole in each of the clamps tabs. This clearance hole allowed the corresponding Instron pin to fit smoothly.

Figure 38. CNC-milled top blocks, alignment block, and U-block. Note that the dowel pins have been press fit into the alignment block after machining.

Future Refinements

The only refinement that the team would do for the CNC milling was have more of the facing of the clamps be completed by the CNC mill versus by hand. This would help reduce manual milling time and streamline the process to make the clamps more repeatable and easier to manufacture.

6.3 Post Processing

After the clamps were CNC milled, the top clamps required no further post processing. Acetal dowel pins were press fit into the alignment clamp. This was somewhat difficult because the clamps needed to be held tightly without damaging them (since Acetal is easy to deform). The outer sides of the alignment clamp were covered with a rag and secured in a vice clamp. Two people were required to press fit the pins into place. One person held the dowel pins in place with pliers while the other person gently hammered them using a plastic mallet. While there was not an alignment fixture to ensure that the dowel pins had accurate cylindricity, the clearance holes in the mating U-block were large enough to account for any misalignment. The completed alignment clamp can be seen in Figure 39.

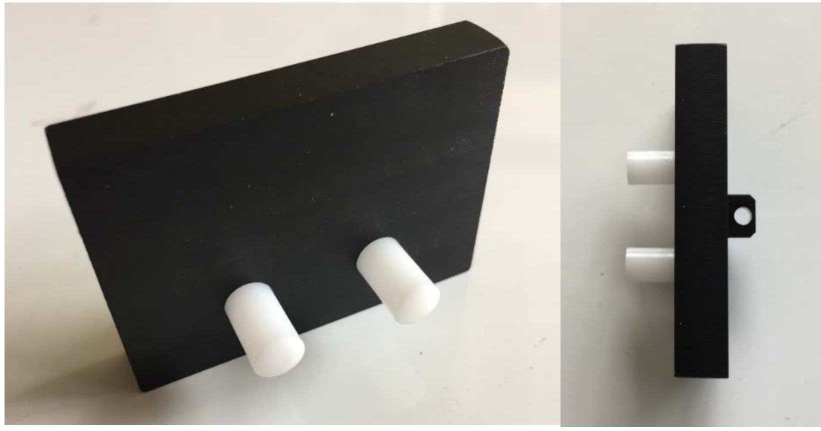

Figure 39. Model and top view of the completed alignment block with press fit dowel pins.

In order to complete the U-block, the two holes that mated the pogo pin housing to the block needed to be tapped for the M1.6 x 0.35mm socket head cap screws. Two U-blocks were manufactured and a hand tap was used to tap the first U-block. Unfortunately, since the tap was so small, the tap broke and was permanently lodged inside of the U-block as seen in Figure 40. Thus, for the second U-block, a tabletop hand tapping machine like the one seen in Figure 40 was used to help reduce the amount of torque applied to the tap.

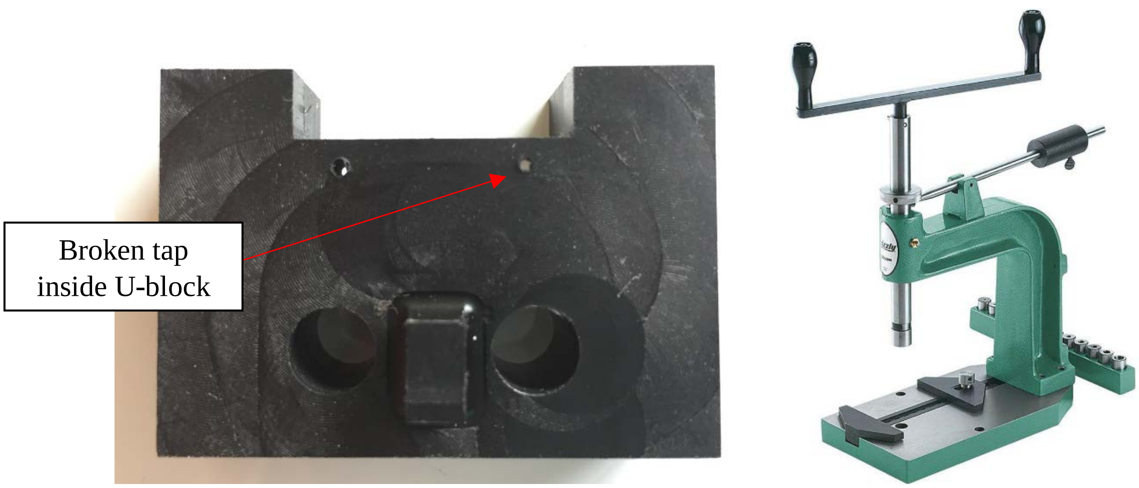

Figure 40. Left: U-block with tap broken inside. Right: example of the hand tapping machine used to alleviate the problem.

After the U-block was successfully tapped, the pogo pin housing was attached to the U-block using the socket head cap screws. Unfortunately, only one of the screws could fit into the U-block. Whether this was a function of the tolerances not being held for the pogo pin housing or the U-block was not determined. Luckily, a single screw was still enough to secure the pogo pin housing in the U-block. The assembled pogo pin housing and U-block can be seen in in Figure 41.

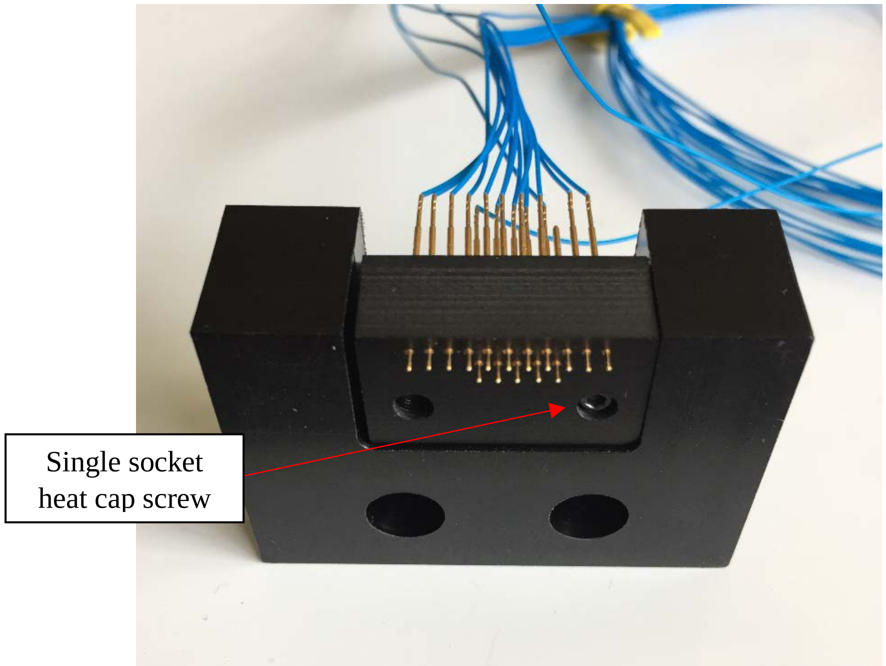

Figure 41. Assembled U-block clamp with pogo pin housing. Only one socket head cap screw is mating the two pieces as the second hole does not align properly.

Future Refinements

Because the current design uses an off-the-shelf paper hole punch to punch alignment holes in the FHE samples, the BendatroniX Team initially thought that the distance between the edge of the paper and the centroid of the cut hole was 5/16. After prototyping the first alignment block, the team realized that the distance was actually 1/4in. While the alignment clamp was a somewhat easy block to remake, it still took time and resources. The updated alignment block can be seen in Appendix J.

Additionally, rather than CNC milling the holes into the U-block, the team recommends hand drilling the holes with the pogo pin housing held fixed in the clamp. This will guarantee that the holes will line up correctly. Another possible solution is to take the pogo pin housing and find the exact center to center distance using coordinate measuring machine (CMM) and then update the CAM model accordingly.

6.4 Sample Preparation

In order to isolate individual circuits for testing, an acrylic template is used. There is a template for each circuit configuration as seen in Figure 42. These templates were made using a laser cutting machine out of 0.125in thick, clear acrylic plate. The user lines up the inner corners of the acrylic square with the four cross fiducials printed on the FHE sample. Keeping the backing on the TPU, samples are cut out using a sharp blade around the perimeter of the templates. The result is a sample that is the correct outside dimensions for use in the Instron.

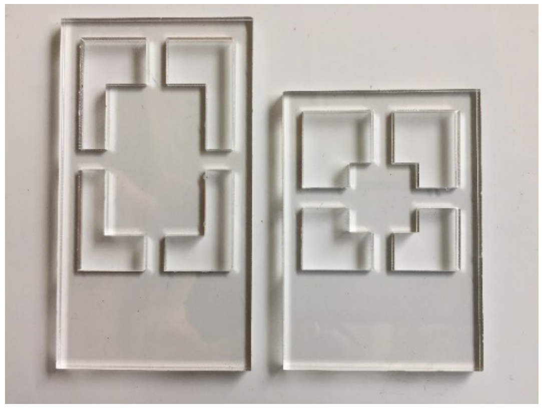

Figure 42. Acrylic templates used to cut samples from printed circuit sheets.
Left: fanned configuration. Right: staggered configuration.

After the samples are cut to size, alignment holes are added to match the dowel pins on the alignment clamp. These holes are made using the 0.25in heavy duty hole punch. The hole punch has been specifically set up so that when the user inserts the cut sample into the lower-most edge and presses the punch, the appropriate locating holes are cut out as seen in Figure 43.

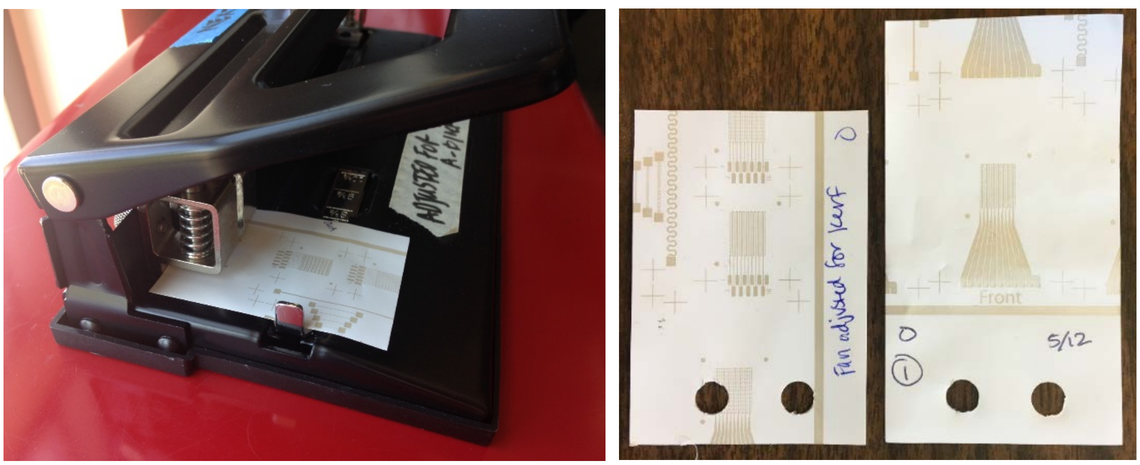

Figure 43. Left: example of how to align a sample in the heavy duty hole punch. Right: a staggered and fanned FHE sample ready to load into the Instron.

Future Refinements

The BendatroniX Team recognizes that properly aligning the FHE sample to the pogo pins is extremely critical. It was noticed, after receiving the pogo pin housing from Emulation Technology, that the distance between the two rows of pins was smaller than expected. This was due to a dimensioning error in the design that went unnoticed. To correct for this, the acrylic templates were adjusted to match with the new dimensions of the pogo pin housing. This was a simple fix that properly aligned the terminals on the TPU to the pogo pins. The updated drawing for the pogo pin housing and (should it ever need to be ordered again) can be seen in Appendix J. Another area for refinement are the acrylic templates. When cut at their nominal dimensions, the laser cuts the templates slightly undersized. Thus, the critical dimensions of the acrylic templates were adjusted for kerf (1mm) and the updated designs can also be seen in Appendix J.

7.0 Design Validation

Prior to manufacturing the clamps, the BendatroniX Team compiled a list of tests that they planned on completing to verify that the fixture design worked. A summary of the tests is included in Table 8 and the full test plan can be seen in Appendix K.

Table 8. Summary of design verification test plan

Test Number	Test Description	Acceptance Criteria
1	Monitor test terminal that is shorted for circuit continuity	Hear continuity beep
2	Compare resistance of sample pre-staging with multimeter versus staged sample in Instron (before test completed)	± 5% resistance change
3	Load sample, stretch to a low strain (~5%?), and cut sample with scissors and verify that resistance steps to infinity	Multimeter reads "Overload"
4	Monitor for circuit continuity, stage sample, remove sample, and monitor for continuity again to verify no damage was done to the traces during staging	± 5% resistance change
5	Stage sample. Remove sample and verify that no physical damage was not inflicted during staging (i.e. holes, tears, etc.)	No holes or tears in the TPU
6	Draw a pattern on the TPU. Load TPU sample with pattern along the top edge of the clamp. Complete tensile test. While the TPU sample is still loaded, verify that the clamped portion of the sample did not slip out of the clamp	Visibility of drawn pattern in the same place
7	Set up entire sample run and record total time required	5 minutes or less

7.1 Verification Testing

Following the test descriptions labeled in Table 8, the BendatroniX Team verified that the reliability tester worked. The test results are further outlined in the Design Validation Plan & Report attached as Appendix K and the tests results are summarized below. Each of the FHE samples was cut from oven-cured silver ink circuits printed on TPU. The samples were cut to size using the corresponding acrylic template, holes were punched using the heavy duty hole punch, the backings were removed from the TPU, and then the samples loaded into the clamps on the Instron. When the terminals required resistance monitoring during one of the tests, the corresponding wires for the terminals of interest were attached to a multimeter via electric tape as seen in Figure 44.

Figure 44. Test set up for verification testing when resistance monitoring was required. In this picture, the wires were being held manually to the multimeter. In later tests, the wires were attached to the multimeter probes with electric tape to ensure a more reliable connection.

Item No. 1 – Shorted Terminal Verification

The BendatroniX Team included a shorted terminal in the FHE samples (the eleventh terminal). This was included for verification purposes. During an actual test, if the shorted terminal had a continuity beep on the multimeter, the user would know that the pogo pins were still maintaining contact and failed electrically (as opposed to a mechanical failure such as slip). Seven samples were loaded into the reliability fixture and the tenth and eleventh terminals were monitored for continuity. All seven samples passed.

Item No.'s 2 and 4 – Compare continuity with pre-, during-, and post-staged samples

In order to ensure that the clamps themselves were not causing any damage to the silver ink traces, the resistance across the first and tenth circuits was recorded pre-, during, and post- staging in the Instron. If the resistance change was less than ± 5% across the entire process, then the sample passed. Of the seven samples tested, only one failed with a resistance change of 10.9%. Additionally, the resistance changes between when the samples had a backing to when the backing was removed was also recorded as a comparison. The results can be seen in Table 9.

Table 9. Summary of results for staging verification testing.

Sample Name	Sample w/ a Backing [Ohms]	Sample w/o a Backing [Ohms]	% Change Due to Backing Removed [%]	Sample Loaded in Instron [Ohms]	% Change Due to Loading Sample [%]	Sample Removed from Instron [Ohms]	% Chance Due to Entire Staging Process [%]
01A	65.0	86.5	33.08%	87.80	1.50%	96.00	10.98%
02A	56.1	68.4	21.93%	67.50	1.32%	68.30	0.15%
03A	--	60.0		62.10	3.50%	57.40	4.33%
04A	38.4	50.1	30.47%	53.40	6.59%	50.10	0.00%
05A	56.3	71.3	26.64%	72.00	0.98%	70.00	1.82%
06A	42.5	53.6	26.12%	54.30	1.31%	54.30	1.31%
07A	60.2	82.2	36.54%	78.70	4.26%	82.10	0.12%
							Fail

The two samples that failed had resistance changes of approximately 7% and 11%; however, according to the "% Change Due to Backing Removed" column, each of the samples underwent 20-30% change when the backing was removed alone. This implies that while it is not ideal that the samples failed, the order of magnitude at which they failed is much smaller compared to what the samples undergo when the backing is simply removed. Thus, the BendatroniX Team determined that the reliability fixture does not cause significant damage to the samples during staging and can continue to be used for future testing.

Item No. 3 – Reliability Fixture Detects When Sample Is Mechanically Cut in Half
To ensure that the fixture is able to detect when the sample fails, an extreme failure case was tested. The sample was loaded and stretched to approximately 10% strain. Using scissors, the sample was cut in half and the resistance between terminals 1 and 10 were monitored. After the cut, the resistance reading jumped to overload implying that the circuit was open. Only one sample was tested and it passed the test criteria.

Item No. 5 – Fixture Causes No Physical Damage to Sample
Five samples were examined physically pre- and post- staging into the reliability fixture on the Instron. They were examined for any physical damage including puncture holes, rips, crumples, etc. Five samples were tested and all five samples passed.

Item No. 6 – Slip Test
In order to ensure that the samples are not slipping in the reliability fixture, five samples were loaded into the Instron and marked with a black marker along the top of the alignment clamp as seen in Figure 45. The samples were then stretched to varying strains and the slip was recorded. According to the criteria outlined in the DVP&R, all of the samples failed. This can be seen in Figure 45 where the line drawn is no longer aligned along the top clamp and the sample can be seen slipping in the top clamps.

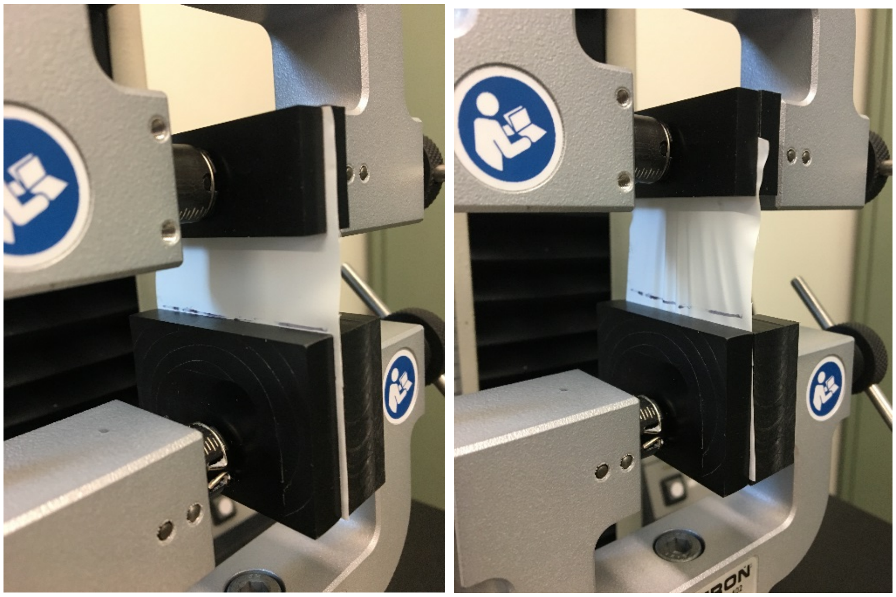

Figure 45. Testing slippage of TPU. Notice how it appears that the sample is slipping from the clamps. This can be solved with double-sided tape or not streching the sample to such a high strain.

While this was initially a major concern for the BendatroniX Team, they realized after future testing that at the strains required for the reliability testing, the sample terminals remain in contact with the pogo pins throughout the entire test. This can be seen in Figure 46 where the pogo pin indentations are seen after the sample has been removed from the reliability tester. Thus, while the clamps technically failed the test according to the DVP&R, they are still capable of completing their reliability testing. If a test ever needs to be completed in the future where slip is absolutely unacceptable, double-sided tape can be used on the top and bottom sets of clamps to better hold the sample in place.

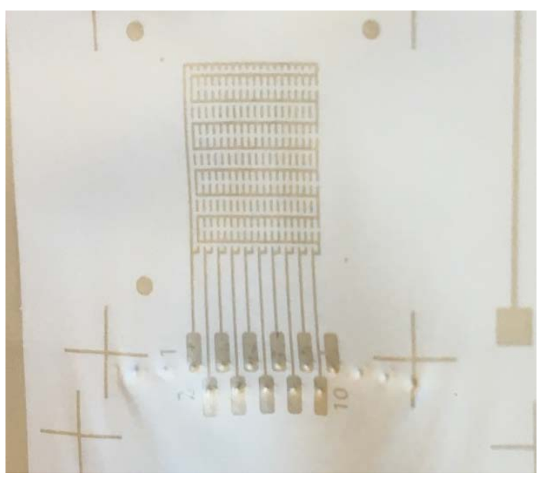

Figure 46. Indents of pogo pins indicate constant contact to terminals.

Item No. 7 – Setup Time

The set time was recorded by one of the BendatroniX Team members who had experience running the tests. The set up time did not include cutting the samples, but did include screwing the pogo pin housing into the

U-block. The test was ended just prior to attaching the pogo pin wires to the multimeter as this will most likely change in future configurations. The set up time was 4min 27sec, thus passing the requirement.

7.2 TPU Sample Testing

Once the BendatroniX Team verified that the clamps functioned as designed, testing on actual TPU samples began. The NextFlex Team wanted to find the strain percentage at which the printed circuit failed (prior to the completed hybrid with silicon chip attached). Failure was defined as reaching a resistance value of ~2000 Ohms rather than physically seeing the circuit tear. This is because the particles of silver in the ink would disconnect from each other, opening the circuit, before the TPU would yield. The ink that the NextFlex Team used was expected to fail between 30-40% strain, so the BendatroniX team ran the tensile test at a rate of 0.1% strain/sec to a strain of 50%. This preliminary testing of the FHE sample allowed the BendatroniX Team to fine tune the test procedure.

Four tests were successfully completed (after a variety of trial runs) with the vertically-chained circuits (denoted with 'B') from TPU samples that were oven-cured. During these four tests, the resistance changes across two sets of traces (terminals 2 to 3 and 4 to 5) were measured on the staggered FHE samples. Prior to making the measurements, the resistance across one of the pogo pin housing wires was measure to be approximately 1 Ohm. Since this was relatively small compared to the resistance readings, the data was not adjusted to account for this resistance change. An example of a fanned FHE test can be seen in Figure 47.

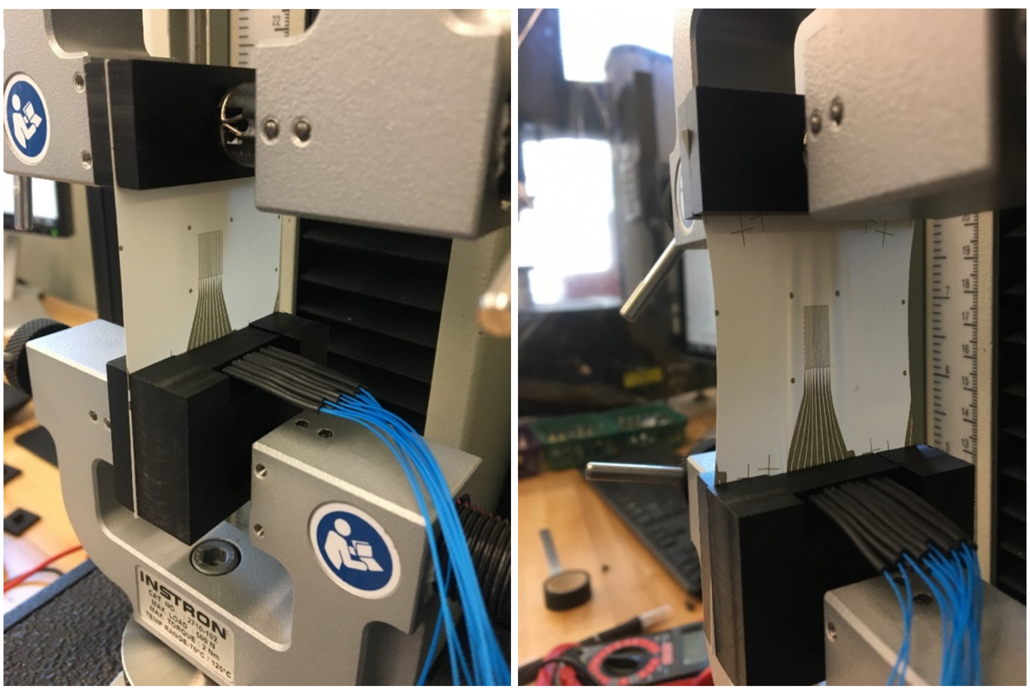

Figure 47. Fanned Sample 011 stretched in reliability tester until failure. Notice how the sample warps in the middle.

The raw data for the four samples can be seen in Appendix L. The tests concluded that, of the eight sections of silver traces analyzed (two traces per sample), the traces failed at on average at 38% strain with a standard deviation of 8.5. While this is a large standard deviation, the sample size is only eight and there were somewhat larger failure points (the largest strain failure being 51%). While the two different traces often failed at different percentages, this may be a factor of the location on the circuit and how the strain effect could differ in the center compared to the edge of the TPU and clamps (i.e. the traces on the outside of the clamps may be experiencing slightly different strain than the traces on the middle of the clamps). This phenomenon is something the BendatroniX Team recommends researching further. The results from Sample 05B can be seen in Figure 48. Note how the resistances were plotted versus time and strain. The time plot was included to show the resistance changes experience by the sample after immediate release from the Instron. To see the results for the rest of the three samples, refer to Appendix L.

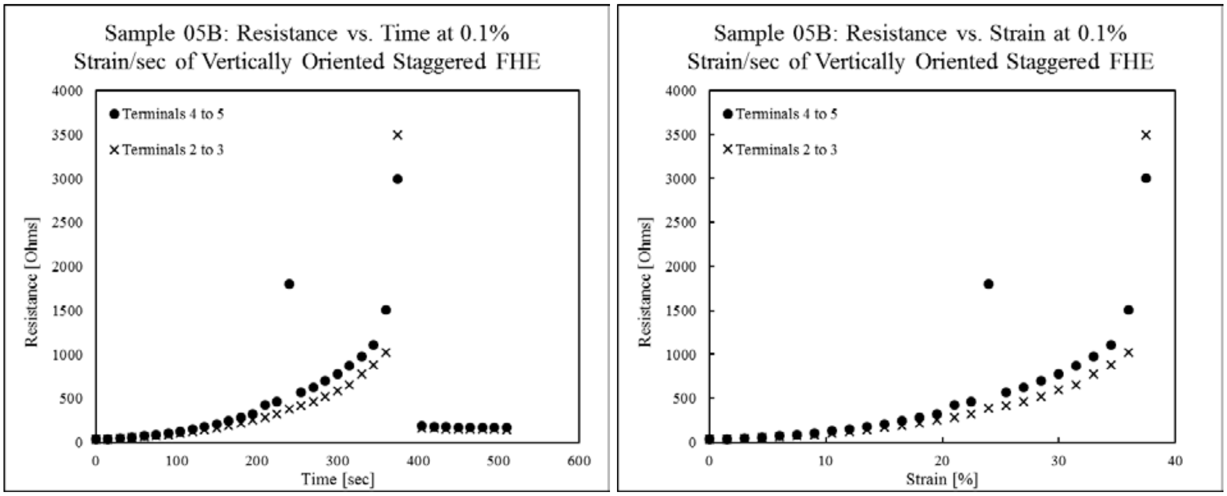

Figure 48. Resistance change across two sets of terminals for staggered sample 05B when the sample was being stretched at 0.1% strain/sec.

While the majority of the sample tests were completed on the staggered terminals, one fanned terminal was tested for comparison. The resistance across terminals 1 to 2 were recorded. The raw data from the test can be seen in Appendix M and the results can be seen in Figure 49.

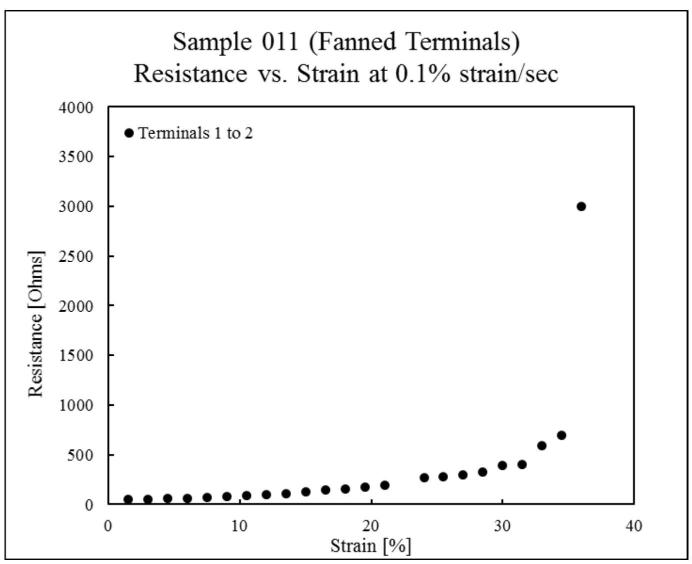

Figure 49. Resistance change across terminals 1 to 2 for fanned sample 011 when the sample was being stretched at 0.1% strain/sec.

8.0 Next Steps

At the conclusion of validation testing described in Section 7.0, the BendatroniX Team was confident that the reliability testing clamps would fulfill the objective required of the NextFlex Group. The team began exploring a second configuration of reliability testing. Due to a variety of factors, the team was not able to the entire design and verification for the second configuration; however, the team was able to complete an in depth concept design. The second configuration would ideally be used on the Instron like the original fixture. The second test mimics a three-point bend test where the sample TPU is held flat in between the two clamps via latches (note that the sample alignment and U-block clamps can be used in the design) and probed with a rod. By varying the rod diameter, different bend radii can be achieved as seen in Figure 50.

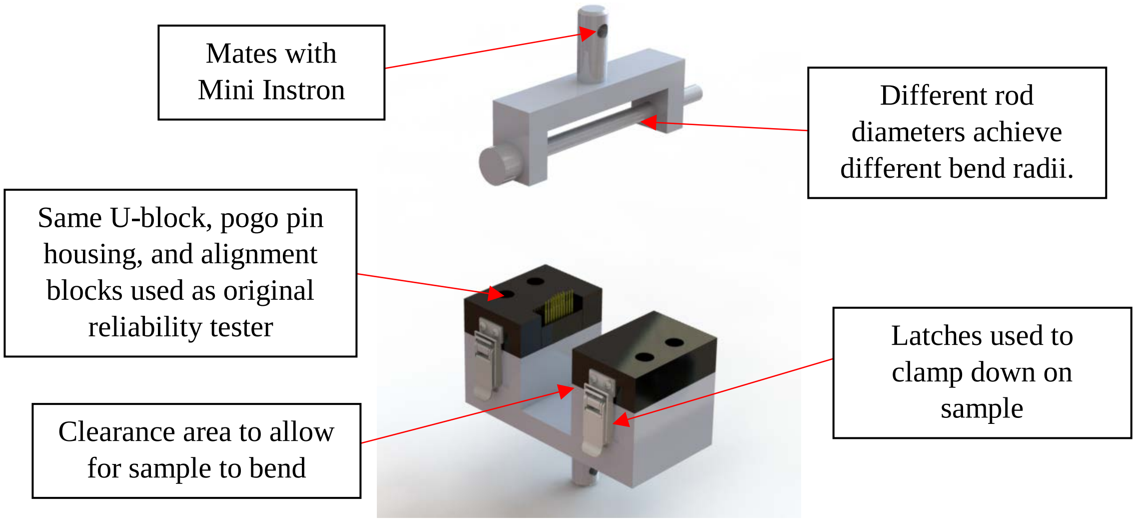

Figure 50. Concept model of second bending configuration. The sample is held between the clamps via two latches and the previous clamps used in the first configuration can be reused.

In order to verify the concept, the BendatroniX Team worked with the new IME senior project group (who will continue on this project after the BendatroniX Team completes) to rapid prototype the second configuration. The 3D printed parts were slightly altered to mate with the Instron Side Action Grips and C-clamps were used to clamp down on the sample rather than the original latch design. The test set up can be seen in Figures 51 and 52.

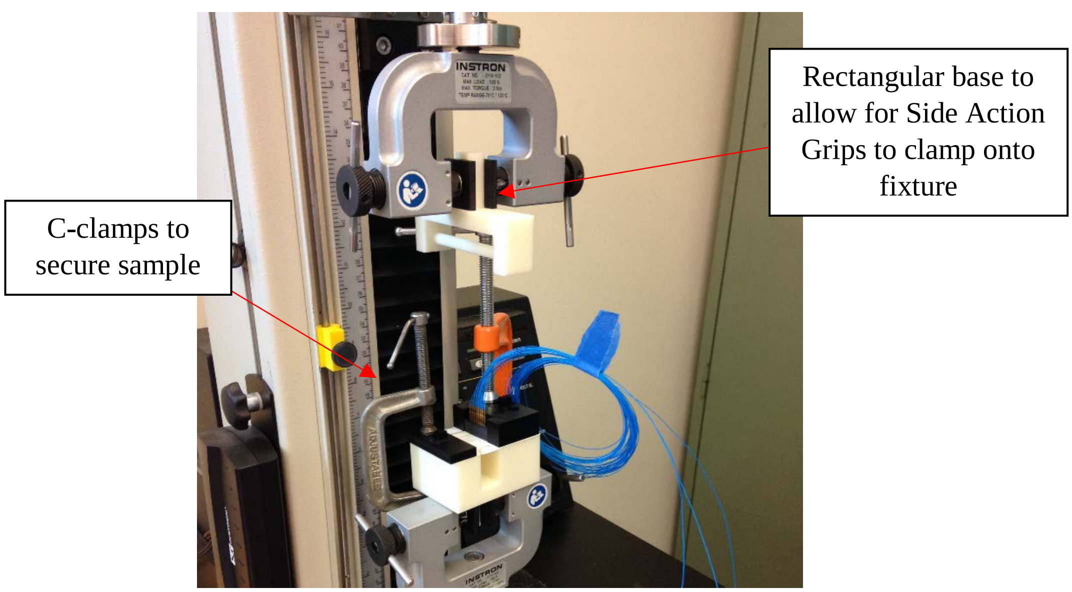

Figure 51. Second configuration test set up. Two C-clamps used to clamp down on the sample.

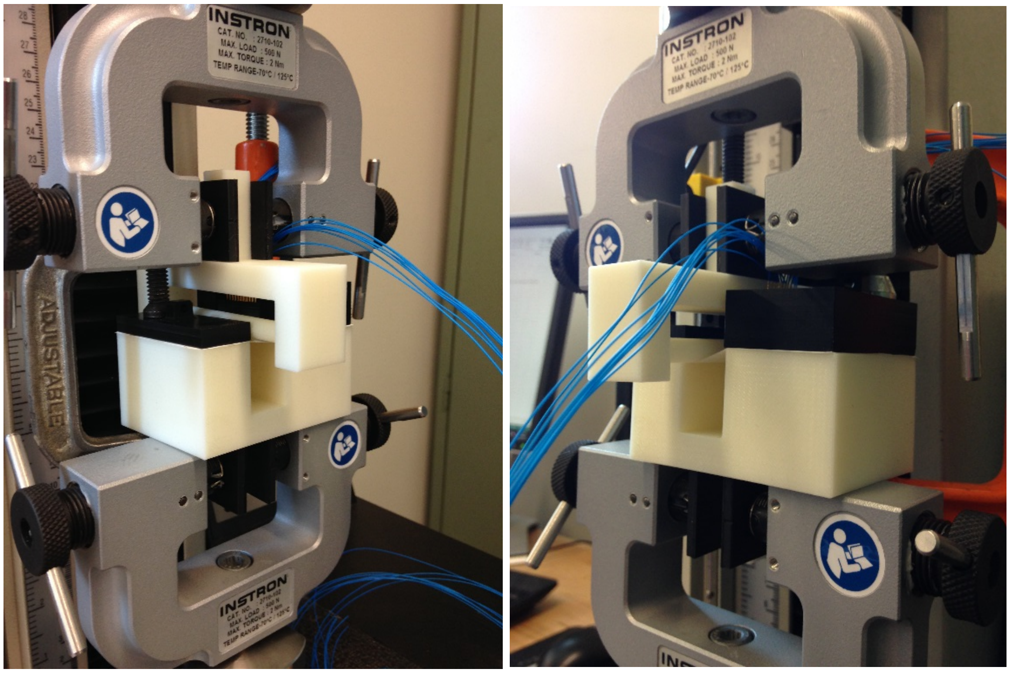

Figure 52. Left: rod just barely touching sample prior to beginning of test. Right: rod lowered 6mm down from initial starting position.

In order to monitor the resistance change, the resistance change across terminals 1 to 2 was plotted versus the depth that the rod was lowered from the initial position. Unfortunately, the parts jammed after the rod reached a depth of 6mm and the test was terminated; however, data was still collected and follows the expected trend as seen in Figure 53.

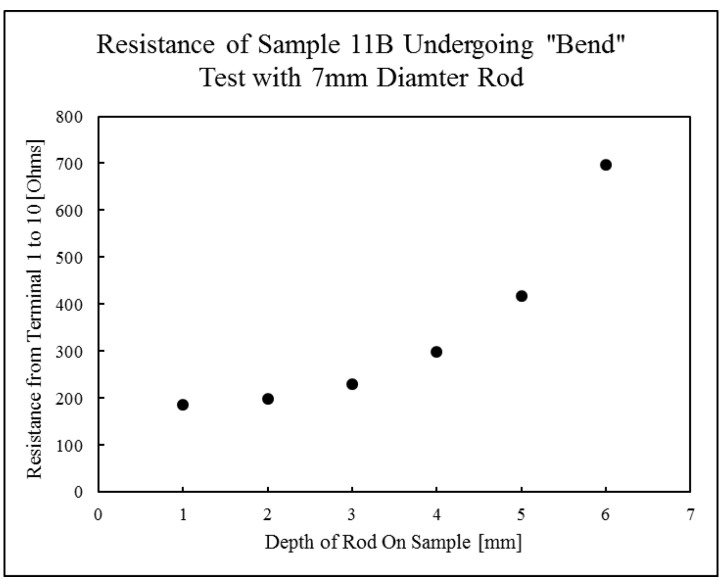

Figure 53. Resistance change across terminals 1 to 2 for staggered sample 11B undergoing the bend test with a 7mm diameter rod as seen in Figure 52.

This data shows that the concept is valid and that the next senior project team can proceed with refining the design. The BendatroniX Team recommends the following changes for future prototypes for the bend test fixture:

1. Rather than push down on the sample, pull up on the sample from the bottom. This prevents any damage to the silver ink circuit.
2. Rotate the entire fixture 90 degrees in the Instron. In the current configuration, the top clamp pushes down on the pogo pin wires and could possibly damage them. By rotating the fixture, the wires can be better protected.
3. Rather than using the Side Action Jaws, actual clamps that mate with Instron should be designed. This will allow for better alignment and a more reliable test.
4. Create a top fixture that allows for different diameter rods to be used to allow for different bend radii to be tested.
5. Have the end of the test be determined by a small force rather than a displacement. This will create a test that more closely resembles a true 3-point bend test.

9.0 Conclusion

The BendatroniX Team has designed an innovative reliability test fixture to aid in the development of the expanding industry of flexible electronics. After months of ideation, building, testing, and verification, the BendatroniX Team has successfully built a fixture that will fulfil the needs of the NextFlex Group. Additionally, the team has created a useful concept design for a future bend test configuration fixture. Moving forward, the team will train NextFlex members on how to use the reliability fixture to collect collect useful data for future research. Overall, the BendatroniX Team has learned a lot along the way and are extremely proud of their final design!

Many people and organizations helped the BendatroniX Team throughout the year and the team would like to extend their gratitude to the following:

Dr. Jianbiao Pan, IME
Dr. Malcom Keif, GrC
Dr. Xiaoying Rong, GrC
Dr. Blair London, MatE
Michael Santos, Jabil, Inc.
Josh Ledgerwood, IME

Wesley Powell, MatE
Allison Tuuri, MatE
Steven Dallezotte, IME
Roy Garcia, IME
Nathan Harry, ME

NextFlex Group
Jabil, Inc.
Cal Poly ME Department
Cal Poly IME Department

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Appendices

Appendix A: IPC – 9204

Stretchability testing	Cyclic stretchability Test	Stretchable printed ink	N/A
	Stretchability Under Constant Load Test	Stretchable printed ink	N/A
	Stretchability Under Constant Torsion Test	Stretchable printed ink	N/A
	Stretchability Under Cyclic Torsion Test	Stretchable printed ink	N/A
Bending test	Variable Radius Bending Test	Flexible display, flexible battery	IEC 62715-6-1
	Variable Angle Bending Test	Flexible battery	N/A
	Free Arc Bending Test	Flexible display, flexible OLED lighting	N/A
	DeMattia Flexibility Test	Wearable electroluminescent lighting	ASTM D813, ASTM D430, ISO 7854
	Loop Bending Test	Wearable keyboard	N/A
	Folding Endurance Test	Wearable wristband	ISO 5626, IEC 62899-1
Torsion test	Torsion Test	Flexible electroluminescent display	N/A
Rolling test	Rolling Flex Test	Roll to roll printing, epaper	ASTM F2750
	Coiling Flex Test	Roll to roll printing, epaper	N/A
	Sliding Plate Test	Flexible display, epaper, flexible battery	N/A
Crumpling test	Crease Test	Printed ink circuit	ASTM F2749
	Schildknecht Flex Test	Wearable garment	ISO 7854
	Crumple Flex Test	Wearable garment	ISO 7854, ASTM F392
	Vamp Flex Test	Wearable garment and footwear	ISO 5402-2
	Bally Flex Test	Wearable garment and footwear	ASTM D6182

6 STRETCHABILITY TESTING PRINCIPLES FOR PRINTED ELECTRONICS

The tests in 6.1 through 6.5 are examples of those which can be used to evaluate the functionality of the printed electronic devices under repeated or constant stretch conditions.

6.1 Stretchability Limit Test

This test method can be used to determine the elongation limit, in percentage, of printed electronics by uniaxial tensile testing. Samples may be prepared in the original product form, or test coupon such as straight edge strips or "dog bone" strips as described in ASTM E-345, or other forms agreed upon

- Sample size
- Environmental test conditions
- Test/Travel speed
- Holding time
- Minimal bending radius
- Specimen orientation to the plate (compression or extension)
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the number of cycles.

7.4 DeMattia Flexibility Test

This test can be used to evaluate resistance of printed electronics to crack growth of a pierced specimen when subjected to bending or flexing, in reference to ASTM D813, ASTM D430 and ISO 7854. This test is applicable to printed electronics and materials that undergo alternate bending and stretching during their use conditions.

This test utilizes a DeMattia Flexometer. A test setup is shown in Figure 7-4. The two ends of the specimen are held tightly between two grips, with the specimen lying in the same vertical plane. One grip is stationary, while the other moves. The reciprocation of the grip enables alternate stretching and bending of the specimen. Closely monitor the functionality or resistance of the circuit before and after the testing, or throughout the testing either periodically or continuously.

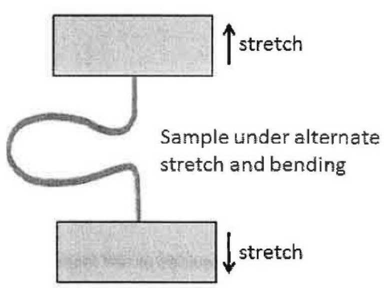


Figure 7-4 DeMattia Flex Test Setup

Include the following data or information in the test report:

- Description of the test samples
- Sample size
- Environmental test conditions
- Test speed
- Stretch strain limit
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the stretch strain and number of cycles.

between users and suppliers. A schematic test set up for evaluating stretchability of printed ink is shown in Figure 6-1.

The stretchable circuit is held firmly between two fixtures. The bottom fixture remains stationary, while the top fixture is movable. By moving up the top fixture, the specimen is stretched to a certain percentage until the circuit physically or electrically fails during the stretchability test. It is important to continuously monitor the functionality or resistance of the circuit.

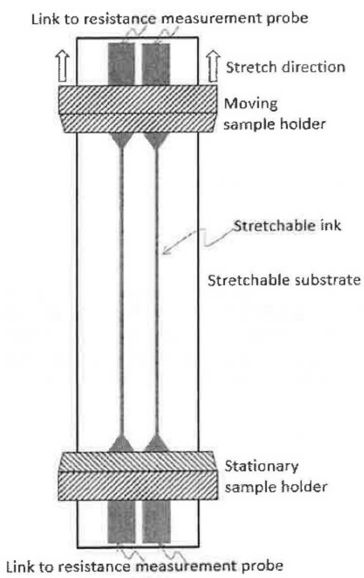


Figure 6-1 Stretchability Testing of Printed Ink

Include the following in the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Strain rate
- Initial length, displacement and force
- Stretchability limit (in percentage)
- Failure criteria
- Continuous electrical test results
- Inspection before and after test

Plot the electrical test data versus the stretch percentage.

6.2 Cyclic Stretchability Test

This test method can be used to verify if a stretchable/wearable printed electronics device can withstand repeated elongation cycles under a tensile load. Set up the test as shown in Figure 6-1, with the stretchable circuit held firmly between two fixtures. The bottom fixture remains stationary, while the top fixture is movable. By moving the top fixture up and down, the specimen is stretched to a certain percentage and then, after a certain holding time, returns to initial state when load is released. The specimen is stretched again to repeat for second cycle. Continuously monitor the functionality or resistance of the circuit.

Include the following in the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Strain rate
- Initial length, displacement and force
- Stretch percentage
- Holding time
- Failure criteria
- Number of cycles per specimen
- Continuous electrical test results
- Inspection before and after cycling

Plot electrical test data versus the stretch percentage and number of cycles.

6.3 Stretchability Under Constant Load Test

This test can be used to evaluate the functionality of the printed electronic devices under constant elongation conditions. As shown in Figure 6-1, the stretchable circuit is held firmly between two fixtures. The bottom fixture remains stationary, while the top fixture is movable. By moving up the top fixture, the specimen is stretched to a certain percentage and then maintained at the same elongation percentage for a prolonged duration. Continuously or periodically monitor the functionality or resistance of the circuit.

Include the following in the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Strain rate
- Initial length, displacement and force
- Stretch percentage
- Holding time
- Failure criteria
- Electrical test results
- Inspection before and after test

Plot electrical test data versus the stretch percentage and holding time.

6.4 Stretchability Under Constant Torsion Test

This test can be used to evaluate the functionality of printed electronics devices under combined torsion and stretch conditions. As shown in Figure 6-1, the stretchable circuit is held firmly between two fixtures. The bottom fixture remains stationary, while the top fixture is movable and rotational. The specimen is twisted to certain torsional angle by rotating the top fixture, and then the top fixture moves up to stretch the specimen to a certain elongation percentage. After a certain holding time, the tensile load is released to allow the specimen to return to its original non-stretched state while the specimen is kept at the same torsion. After a certain holding time, the specimen undergoes the second stretch cycle. Continuously monitor the functionality or resistance of the circuit.

Include the following information and data in the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Torsion angle and direction
- Torsion speed
- Stretch strain rate

- Initial length, displacement and force
- Holding time
- Stretch percentage and limit
- Failure criteria
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the stretch percentage, torsion angle and number of cycles.

6.5 Stretchability Under Cyclic Torsion Test

This test can be used to evaluate the functionality of printed electronic devices under combined cyclic torsion and stretch conditions. As shown in Figure 6-1, the stretchable circuit is held firmly between two fixtures.

The bottom fixture remains stationary, while the top fixture is movable and rotational. The specimen is twisted to certain torsional angle by rotating the top fixture, then the top fixture moves up to stretch the specimen to a certain elongation percentage; after a certain holding time, both the tensile load and torsional load are released to allow the specimen to return to its original state. After a certain holding time, the specimen undergoes the second torsion and stretch cycle.

Continuously monitor the functionality or resistance of the circuit.

Include the following information and data in the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Torsion angle and direction
- Torsion speed
- Strain rate
- Initial length, displacement and force
- Holding time
- Stretch percentage and limit
- Failure criteria
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the stretch percentage torsion angle and number of cycles.

7 BENDING TEST PRINCIPLES FOR PRINTED ELECTRONICS

7.1 Variable Radius Bending Test

This test can be used to evaluate the functionality of the printed electronic devices under repeated bending conditions with changing bending radius.

The specimen may be prepared in the original product form, or test coupon such as straight edge strips or other forms agreed upon between users and suppliers. A schematic test setup is shown in Figure 7-1.

The specimen is bent in a U shape between two parallel plates, with each ends affixing to a plate. The bottom plate is stationary, while the top plate is movable. The maximum distance between the two plates should be sufficiently larger than twice the minimal bending radius of the specimen. By moving the top plate up and down, the specimen can be bent in a constantly changing bending radius with repeating cycles. If the specimen is too small to be fixed to the plates, the specimen may be attached to a carrier (e.g., steel or aluminium foil) using adhesive, and then the carrier is fixed to the plate. Use caution to ensure that the adhesive has adequate strength and that the specimen can conform to the bending shape.

Continuously or periodically monitor the resistance of the circuit.

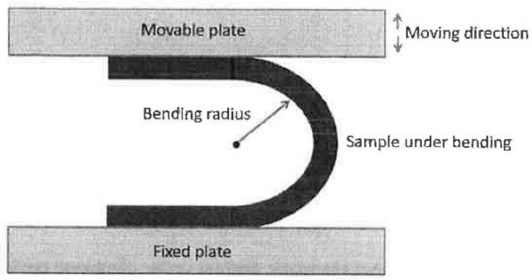


Figure 7-1 Variable Radius Bending Test Setup

Include the following information and data in the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Travel speed
- Holding time
- Minimal bending radius
- Maximum bending radius
- Specimen orientation to the plate (compression or extension)
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the bending radius and number of cycles.

7.2 Variable Angle Bending Test

This test can be used to evaluate bending endurance of flexible printed electronics during their application.

The specimen may be prepared in the original product form, or test coupon such as straight edge strips or other forms agreed upon between users and suppliers.

Figure 7-2 shows a schematics of variable angle bending test. The flex circuit is affixed to a certain weight which keeps the circuit under required tension. The circuit flexes back and forth to a certain bending angle around a mandrel. Functionality or resistance of the circuit can be monitored before and after the testing, or throughout the testing either periodically or continuously.

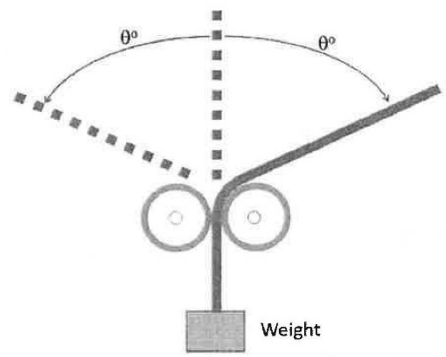


Figure 7-2 Variable Angle Bending Test Setup

Include the following information and data in the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Bending speed
- Holding time
- Bending angle
- Mandrel material and diameter
- Weight information
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the bending angle and number of cycles.

7.3 Free Arc Bending Test

This test can be used is to evaluate the functionality of the printed electronic devices under repeated bending conditions with variable bending radius.

The test set up is shown in Figure 7-3. The specimen is affixed to two fixtures at the same horizontal level. One fixture is stationary, while the other one is movable. By moving back and forth the movable fixture, the specimen can be bent in constantly changing bending radius with repeating cycles. Monitor the functionality or resistance of the circuit before and after testing, or throughout the testing either periodically or continuously.

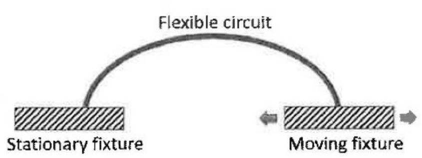


Figure 7-3 Free Arc Bending Test Setup

Include the following information and data in the test report:

- Description of the specimen

- Sample size
- Environmental test conditions
- Test/Travel speed
- Holding time
- Minimal bending radius
- Specimen orientation to the plate (compression or extension)
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the number of cycles.

7.4 DeMattia Flexibility Test

This test can be used to evaluate resistance of printed electronics to crack growth of a pierced specimen when subjected to bending or flexing, in reference to ASTM D813, ASTM D430 and ISO 7854. This test is applicable to printed electronics and materials that undergo alternate bending and stretching during their use conditions.

This test utilizes a DeMattia Flexometer. A test setup is shown in Figure 7-4. The two ends of the specimen are held tightly between two grips, with the specimen lying in the same vertical plane. One grip is stationary, while the other moves. The reciprocation of the grip enables alternate stretching and bending of the specimen. Closely monitor the functionality or resistance of the circuit before and after the testing, or throughout the testing either periodically or continuously.

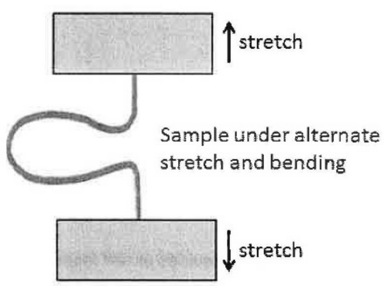


Figure 7-4 DeMattia Flex Test Setup

Include the following data or information in the test report:

- Description of the test samples
- Sample size
- Environmental test conditions
- Test speed
- Stretch strain limit
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus the stretch strain and number of cycles.

7.5 Loop Bending Test

This test can be used to evaluate the maximum allowable strain that a flexible printed circuit can withstand in flexural loading, in reference to IPC-9707. This test is applicable to printed electronics and materials that undergo flexural bending during their use conditions.

The specimen may be prepared in the original product form, or test coupon such as ink printed film or sheet, or other forms agreed upon between users and suppliers. The test setup is shown in Figure 7-5. The specimen is retained in a looped fixture which maintains a certain lateral tension on the specimen. A rounded-tip probe applies a strain on the center of the specimen. The maximum strain can be obtained by physically or electrically breaking the specimen in a single cycle. The specimen can also experience cyclic strains by moving the test probe up and down. Continuously or periodically monitor the functionality or resistance of the circuit. A strain gauge may be attached to the specimen to measure the strain during the test.

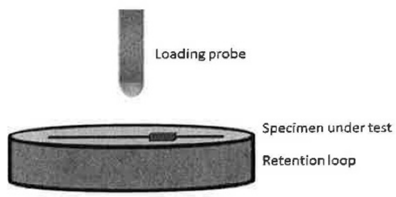


Figure 7-5 Loop Bending Test Setup

Include the following information and data on the test report:

- Description of the specimen
- Sample size
- Environmental test conditions
- Lateral tension
- Test speed
- Holding time
- Maximum strain/load
- Specimen orientation to the loop (compression or extension)
- Number of cycles per specimen
- Electrical test results
- Inspection before and after cycle

Plot the electrical test data versus applied strain and the number of cycles.

7.6 Folding Endurance test

This test can be used to evaluate folding endurance of flexible printed electronics during their application, in reference to ISO 5626 and IEC 62899-1.

This test utilizes the MIT Folding Endurance Tester (shown in Figure 7-6). The equipment has a movable part which holds the specimen and bends it by 180 ° (90 ° on both sides of the vertical direction), a bending part for applying constant curvature to the specimen and a mechanism for applying constant tension to the specimen.

Appendix B: Customer Requirements

As seen in the House of Quality Chart in Appendix C.

Customer Requirement	Relative Weight
Ability to interface with an Instron	19%
Monitor sample failure	17%
(re)Usability	17%
Preserve the sample post-staging	14%
Cost	14%
Safe to use	11%
Ability to test a variety of configurations	8%

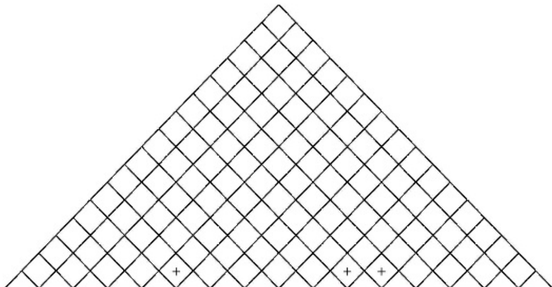
Appendix C: House of Quality Chart

QFD: House of Quality
Project: BendatroniX
Revision: 1
Date: 10/20/16

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



WHO: Customers

Row #	Relative Weight	Dr. Wang	Jelal	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	1 Total Cost	2 Green Rip Test	3 Exposed live wire	4 Eye protection	5 Change in resistance post-staging	6 Mechanical preservation post-staging	7 Setup time	8 Durability	9 Accessibility to electrical resistance monitoring during test	10 Compatibility with Instron	11 # of FPC test configurations	12 Static and dynamic capabilities	13	14	15	16	Our Current Product	MATE 3pt Test Fixture	Instron 3pt/4pt test Fixture	Byoung-Joon Kim Plate Fixture	Thesis Bending Test	Agilent Technologies 3pt Bend Test	Row #
					Direction of Improvement	▼	▲	▼	◇	◇	◇	▼	▲	◇	◇	▲	◇											
1	14%	1	7	9	Cost	●	V	V	V				●	●	V	○	○					5	5	2	4	5	1	1
2	11%	2	2	9	Safe	▽	●	●	●		▽											2	3	3	4	4	4	2
3	14%	5	3	9	Preserve sample		○			●	●											5	4	5	5	5	5	3
4	17%	4	6	9	(re)usability		○	▽	▽	▽	▽	●	●	●	●	○						4	4	5	5	5	5	4
5	17%	6	4	9	Monitor failure	○		●		●	●	●		●			●					5	0	0	5	5	3	5
6	19%	7	5	9	Instron				▽			○	○		●		●					5	5	5	0	5	5	6
7	6%	2	1	9	Variety of configurations	●				○	○	○		○	●	●	●					4	0	1	1	1	1	7
8																												8
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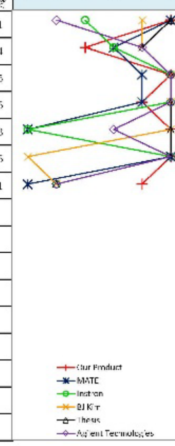
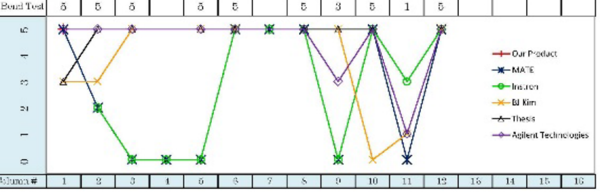
NOW: Current Product Assessment - Customer Requirements



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target	$8,000	No rip	NA	# procedure	0 Ohms	No visible damage	5 minutes	5 years	Yes	2 models	6 configurations	Yes				
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9				
Technical Importance Rating	264.29	203.57	277.38	146.43	320.24	330.95	382.14	335.71	453.67	410.71	167.86	438.28				
Relative Weight	7%	5%	7%	4%	9%	9%	10%	9%	12%	11%	4%	12%				
Weight Chart																
Our Product	5															
MATE 3pt Test Fixture	5	2	0	0	0	5	5	5	0	5	0	5				
Instron 3pt/4pt Test Fixture		2	0	0	0	5	5	5	0	5	3	5				
Byoung-Joon Kim Plate Fixture	3	3	5		5	5			5	0	1	5				
Thesis Bending Test	3	5	5		5	5		5	5	5	1	5				
Agilent Technologies 3pt Bend Test	5	5	5		5	5		5	3	5	1	5				

Current Product Assessment - Engineering Specifications

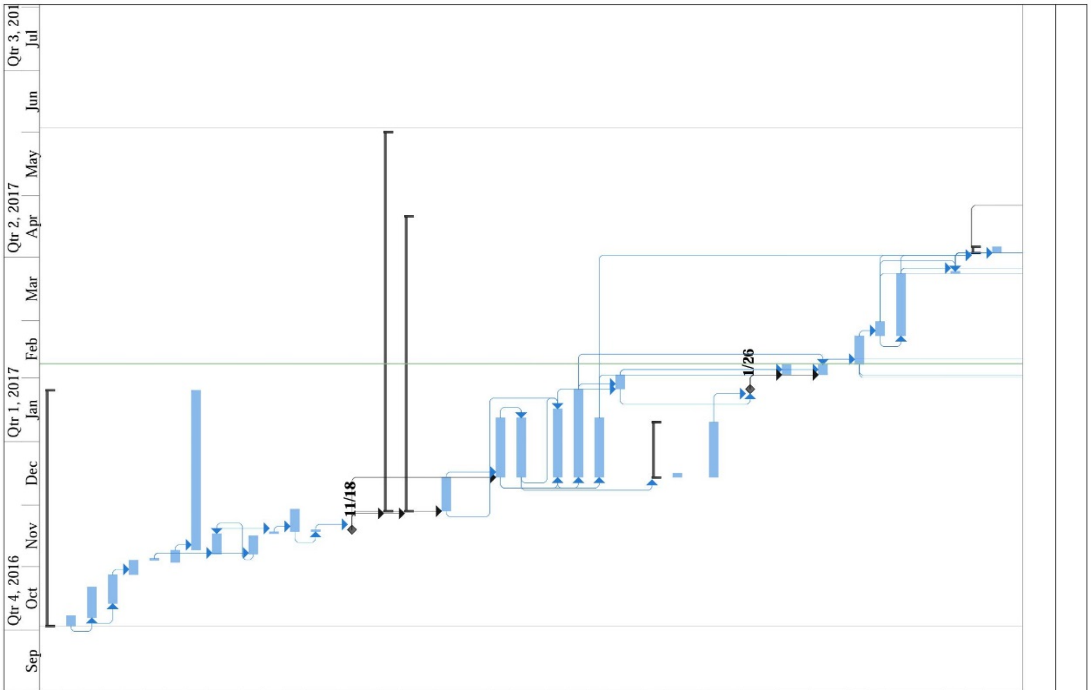


Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Template Revision: 4.9 Date: 9/23/2016
Christopher Ruhlen

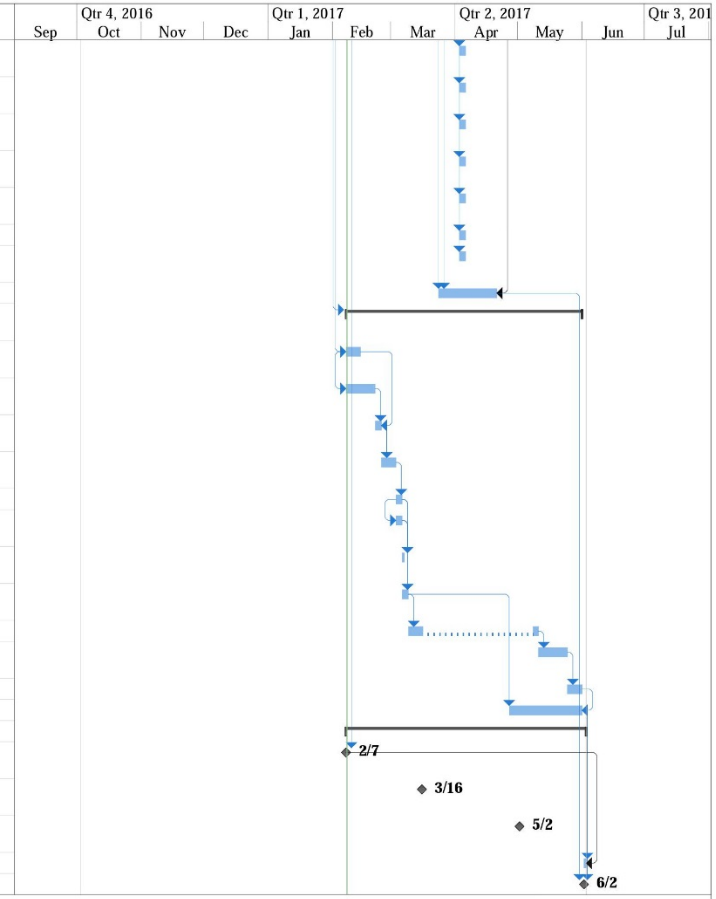
Appendix D: Gantt Chart

ID	Task Mode	WBS	Task Name	Duration	Start	Finish
1		**1**	**Project Scope**	**62 days**	**Mon 10/3/16**	**Wed 1/25/17**
2		1.1	Define Problem	1 wk	Mon 10/3/16	Fri 10/7/16
3		1.2	Background Research	11 days	Fri 10/7/16	Fri 10/21/16
4		1.3	Project Proposal	2 wks	Fri 10/14/16	Thu 10/27/16
5		1.4	Ideation	1 wk	Fri 10/28/16	Thu 11/3/16
6		1.5	Visit Jabil, Inc.	1 day	Fri 11/4/16	Fri 11/4/16
7		1.6	Schedule Instron Training	4 days	Thu 11/3/16	Tue 11/8/16
8		1.7	Instron Training	7 wks	Wed 11/9/16	Wed 1/25/17
9		1.8	Work on Preliminary Design Review (PDR)	8 days	Mon 11/7/16	Wed 11/16/16
10		1.9	Evaluate ideas	7 days	Mon 11/7/16	Tue 11/15/16
11		1.10	PDR Due	1 day	Thu 11/17/16	Thu 11/17/16
12		1.11	Present PDR to Sponsor	2 days	Fri 11/18/16	Mon 11/28/16
13		1.12	Present Final Designs to Cal Poly Group	1 day	Fri 11/18/16	Fri 11/18/16
14		1.13	CP Group Approve Final Designs	0 days	Fri 11/18/16	Fri 11/18/16
15		**2**	**Build Configurations**	**112 days**	**Mon 11/28/16**	**Wed 5/31/17**
16		**2.1**	**#1 Detail Design: Monitor Resistance**	**83 days**	**Mon 11/28/16**	**Thu 4/20/17**
17		2.1.1	Finalize PCBA/Pogo Specs (pitch, terminal width, thickness)	2.5 wks	Mon 11/28/16	Wed 12/14/16
18		2.1.2	Design Pogo Pin Layout	1 wk	Wed 12/14/16	Thu 1/12/17
19		2.1.3	Prototype Pogo Pin Holder and Analyze	1 wk	Wed 12/14/16	Thu 1/12/17
20		2.1.4	CAD Model of Clamps	1.5 wks	Wed 12/14/16	Mon 1/16/17
21		2.1.5	Clamp Tolerance Analysis	3 wks	Wed 12/14/16	Thu 1/26/17
22		2.1.6	Analysis of Pogo Shear	1 wk	Wed 12/14/16	Thu 1/12/17
23		2.1.7	Complete Detailed Drawing of Clamp	1 wk	Thu 1/26/17	Thu 2/2/17
24		**2.1.8**	**Material Selection**	**3 days**	**Wed 12/14/16**	**Tue 1/10/17**
25		2.1.8.1	Research TPU Friction Data	2 days	Wed 12/14/16	Fri 12/16/16
26		2.1.8.2	Test Material Samples w/ TPU	3 days	Wed 12/14/16	Tue 1/10/17
27		2.1.9	Complete Bill of Materials and Budget	0 days	Thu 1/26/17	Thu 1/26/17
28		2.1.10	Sponsor Approval of Drawings/BOM	3 days	Thu 2/2/17	Tue 2/7/17
29		2.1.11	Sponsor Approval of CDR pt. 1	3 days	Thu 2/2/17	Tue 2/7/17
30		2.1.12	Order Materials	2 wks	Tue 2/7/17	Tue 2/21/17
31		2.1.13	Manufacture Clamp	1 wk	Tue 2/21/17	Tue 2/28/17
32		2.1.14	Order Pogo Pin Housing from Emulation Technology	4.5 wks	Tue 2/21/17	Thu 3/23/17
33		2.1.15	Assemble Clamp	1 day	Fri 3/24/17	Fri 3/24/17
34		**2.1.16**	**Validate**	**3 days**	**Mon 4/3/17**	**Wed 4/5/17**
35		2.1.16.	Test Resistance Monitoring	3 days	Mon 4/3/17	Wed 4/5/17



Page 1

ID	Task Mode	WBS	Task Name	Duration	Start	Finish
36		2.1.16.	Test Resistance Pre/Post Loading	3 days	Mon 4/3/17	Wed 4/5/17
37		2.1.16.	Test Resistance Step to Infinity	3 days	Mon 4/3/17	Wed 4/5/17
38		2.1.16.	Test For Resistance Damage from Staging	3 days	Mon 4/3/17	Wed 4/5/17
39		2.1.16.	Test For Physical Damage from Staging	3 days	Mon 4/3/17	Wed 4/5/17
40		2.1.16.	Test for Sample Slippage	3 days	Mon 4/3/17	Wed 4/5/17
41		2.1.16.	Test Set Up Time	3 days	Mon 4/3/17	Wed 4/5/17
42		2.1.16.	Verify Geometric Tolerances	3 days	Mon 4/3/17	Wed 4/5/17
43		2.1.17	Refine as needed	3 wks	Fri 3/24/17	Thu 4/20/17
44		**2.2**	**#2 Detail Design: Variable/Fixed Radii**	**76.5 days**	**Tue 2/7/17**	**Wed 5/31/17**
45		2.2.1	Ideation for Variable Radius Configuration	1 wk	Tue 2/7/17	Tue 2/14/17
46		2.2.2	Prototype and Analyze for Design 2	2 wks	Tue 2/7/17	Tue 2/21/17
47		2.2.3	Sponsor Approval of Designs	3 days	Tue 2/21/17	Fri 2/24/17
48		2.2.4	CAD Model of Variable Radius Clamp	1 wk	Fri 2/24/17	Fri 3/3/17
49		2.2.5	Detailed Drawing	1 day	Fri 3/3/17	Mon 3/6/17
50		2.2.6	Complete Bill of Materials and Budget	1 day	Fri 3/3/17	Mon 3/6/17
51		2.2.7	Sponsor Approval of Drawings/BOM	1 day	Mon 3/6/17	Tue 3/7/17
52		2.2.8	Sponsor Approval of CDR pt. 2	3 days	Mon 3/6/17	Thu 3/9/17
53		3 wks	Order Materials	1.5 wks	Thu 3/9/17	Wed 5/10/17
54		2 days	Manufacture Radius Clamp	2 wks	Thu 5/11/17	Wed 5/24/17
55		2.2.11	Validate	1 wk	Thu 5/25/17	Wed 5/31/17
56		2.2.12	Refine as needed	5 wks	Thu 4/27/17	Wed 5/31/17
57		**3**	**Class Deliverables**	**78.5 days**	**Tue 2/7/17**	**Fri 6/2/17**
58		3.1	Present CDR Update in Class	0 days	Tue 2/7/17	Tue 2/7/17
59		3.2	Present Manufacturing & Test Review to Class	0 days	Thu 3/16/17	Thu 3/16/17
60		3.3	Hardware Safety Demo for Class	0 days	Tue 5/2/17	Tue 5/2/17
61		3.4	Finish Final Design Review	1 day	Fri 6/2/17	Fri 6/2/17
62		3.5	Senior Project Expo	0 days	Fri 6/2/17	Fri 6/2/17



Appendix E: Decision Matrix

		Concept																	
		External										Internal							
Specification	Weight	Instron clamp w/ ext clips		Instron clamp w/ solder		Instron roller grip w/ ext clips		Instron roller grip w/ solder		Male/female w/ ext clips		Flat clamp w/ contacts		Spring loaded clamp w/ contact		Instron roller grip w/ contact pads		Male/female w/ contact	
Resistance monitoring	35%	7	2.5	9	3.2	7	2.5	9	3.2	7	2.45	7	2.5	7	2.5	7	2.5	7	2.45
Static	10%	7	0.7	7	0.7	9	0.9	9	0.9	8	0.8	7	0.7	7	0.7	9	0.9	8	0.8
Dynamic (overall)	10%	5	0.5	6	0.6	2	0.2	2	0.2	6	0.6	6	0.6	7	0.7	2	0.2	6	0.6
Set Up Time	7%	5	0.4	3	0.2	5	0.4	3	0.2	5	0.35	7	0.5	7	0.5	7	0.5	7	0.49
Preservation post-stage	15%	6	0.9	1	0.2	6	0.9	1	0.2	6	0.9	9	1.4	8	1.2	9	1.4	9	1.35
Durability	3%	8	0.2	3	0.1	8	0.2	3	0.1	8	0.24	9	0.3	7	0.2	9	0.3	9	0.27
Manufacturability	10%	10	1	10	1	10	1	10	1	5	0.5	7	0.7	6	0.6	8	0.8	4	0.4
Cost	10%	5	0.5	5	0.5	5	0.5	5	0.5	10	1	10	1	10	1	5	0.5	10	1
TOTAL	**1**		**6.6**		**6.4**		**6.5**		**6.2**		**6.84**		**7.6**		**7.4**		**7**		**7.36**

Appendix F: Failure Mode Effects and Analysis

Design Failure Mode and Effects Analysis

Product: Resistance Monitoring Clamp

Prepared by: Maya Manzano

Team: BendatroniX

Date: 11/30/16 (orig)

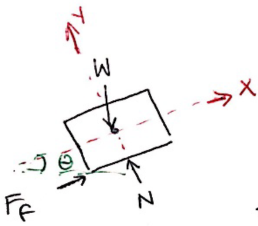
Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
Gripping the sample	Major Slippage	No data results	8	Designed incorrectly	3	24	Design in a way to fix sample to back clamp	Julia - 12/8/16				
		Damage sample	8	Incorrect sample installation	5	40						
				Material	2	16						
	Minor Slippage	No data results	8	Designed incorrectly	3	24						
		Damage sample	8	Incorrect sample installation	3	24						
				Material	2	16						
	Uneven Contact	Poor data results	5	Manufacturing	5	40	Enforce flatness and parallel tolerance	Paul - 12/12/16				
		Damage sample	8	Incorrect clamp installation	5	40	Warning in procedure	Julia - 6/2/17				
		Damage fixture	5									
	Clamps don't meet	No data results	8	Manufacturing	5	40	Enforce dimensional tolerances	Paul - 12/12/16				
		Lose sample	8	Designed incorrectly	3	24						
Monitor resistance	Circuit Shortage	Poor data results	5	Designed incorrectly	3	15						
				Moisture	1	5						
				Material	2	10						
	Damaged Pogo Pin	Poor data results	5	Misalignment	5	40	Enforce perpendicularity tolerance	Paul - 12/12/16				
		Damage to sample	8	Defective part	1	8						
		Damage to PCB	5	Excessive clamping force	2	16						
	Damage to PCB	No data results	8	Incorrect PCB installation	5	40	Warning in procedure, design slot to square up PCB	Maya - 12/8/16				
		Damage pogo pin	5	Manufacturing	5	40	Enforce flatness and dimensional tolerances	Paul - 12/12/16				
		Damage sample	8	Designed incorrectly	3	24						
	Damage to Circuit	Poor data results	5	Manufacturing	5	25						
				Incorrect sample installation	5	25						

Appendix G: Friction Test

The purpose of testing the friction properties of the TPU was to determine which material to make the clamp out of. The three materials explored were steel, aluminum, and Delrin. Steel was used by Instron to make their clamp faces. Aluminum is lighter and easier to machine than steel. Delrin is good for its non-conductive properties, but was expected to interact poorly with the TPU.

1. Angle Test

Using basic statics theory, the coefficient of static friction, μ, of the TPU substrate with a certain block of material can be calculated by finding the maximum angle at which the block would begin to slip on a ramp. The calculations can be seen below in Figure F.1. The greater the coefficient of friction, the more reliable the material would be to use for the clamp to avoid slippage of the FHE sample.



$$\Sigma F_x = 0: F_f - W\sin\theta = 0$$
$$\mu N - mg\sin\theta = 0$$
$$\mu = \frac{mg\sin\theta}{N}$$
$$\Sigma F_y = 0: N - W\cos\theta = 0$$
$$N - mg\cos\theta = 0$$
$$N = mg\cos\theta = 0$$
$$\mu = \frac{mg\sin\theta}{mg\cos\theta}$$
$$\boxed{\mu = \tan\theta}$$

Figure F.1. Calculations showing that the coefficient of friction is correlated to the angle of the ramp.

The test was set up by fixing a printed protractor to a wall and aligning a foam board ramp to the center point, as seen in Figure F.2. The TPU substrate was secured to the ramp and the block of material was placed at the edge. The ramp was slowly raised until the block began to slip. The angle was measured and the test was repeated two more times. The first run of the test with each material used a rough, machined face of the material block. The second run-through used a smooth, finished side of the block.

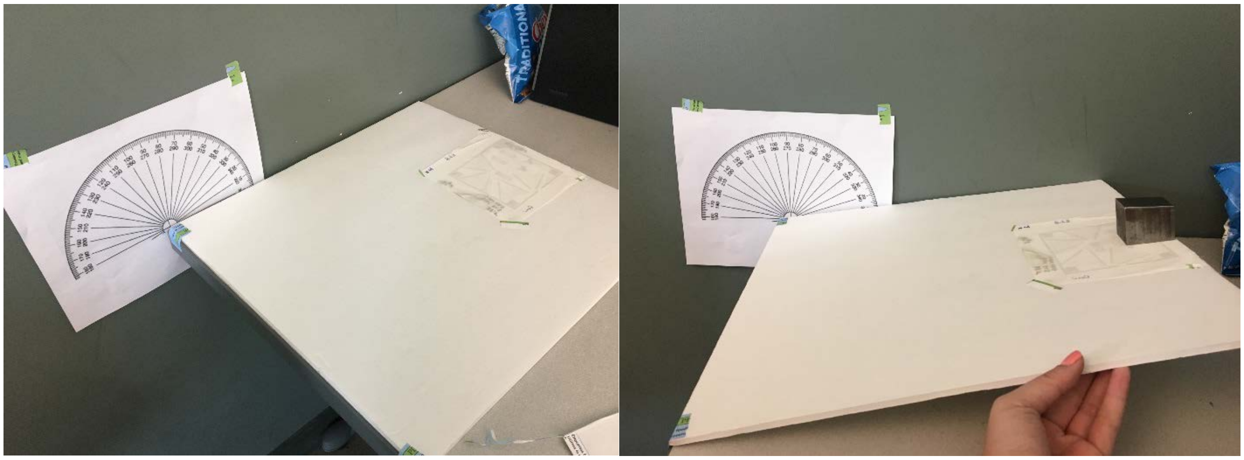


Figure F.2. Angle test set up. Left: the ramp started at 0°. Right: he ramp was raised to an angle until the block began to slip.

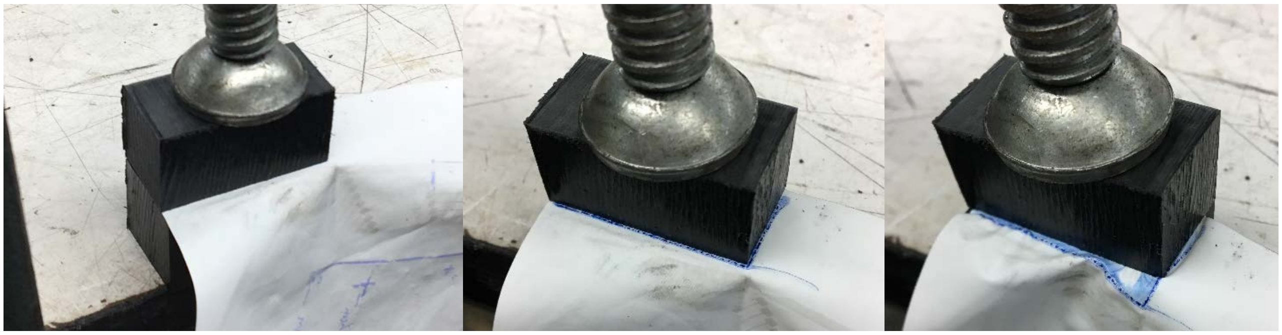
The results from this experiment are tabulated in Table F.1, and show that Delrin had the highest angle and coefficient of friction. Using the smooth side of the Delrin block against the TPU, a friction coefficient of 0.53 was achieved, which was the highest value overall. The rough side of the Delrin also had the highest coefficient of all the rough sides tested, at 0.38. This led the BendatroniX team to believe that Delrin would be the best material to make the clamp out of, in contrast to their engineering judgement. Usually plastic does not have great friction characteristics, but the team believes the malleability of the Delrin allows for more contact surface with TPU, thus creating better friction contact. In order to ease the skepticism of the BendatroniX team, another friction test was done to confirm the material selection.

Table F.1. Coefficient of friction results calculated from angle test.

Material	Steel		Aluminum		Delrin	
	Rough	Smooth	Rough	Smooth	Rough	Smooth
Trial 1	21°	25°	23°	20°	22°	29°
Trial 2	19°	24°	21°	18°	19°	28°
Trial 3	18°	24°	21°	18°	22°	27°
Average	19.3°	24.3°	21.7°	18.7°	21°	28°
Coefficient of Friction	**0.35**	**0.45**	**0.4**	**0.34**	**0.38**	**0.53**

2. C-clamp Test

To simulate the TPU being gripped in the Instron, a c-clamp was used to secure a TPU sample in between two blocks of a certain material to determine if slippage occurred. Each of the three materials (steel, aluminum, and Delrin), was tested by halving the blocks and placing the TPU sample in between two smooth sides, since the angle test proved that the smooth, machined sides had better coefficient of friction values than the rough surfaces. The set up for this test can be seen in Figure F.3 below. An outline of the block was drawn to mark where the TPU started before the test. Then the TPU was pulled to simulate a tensile test. Finally, the movement of the drawn outline was noted as indication of minor or major slippage.



A) B) C)

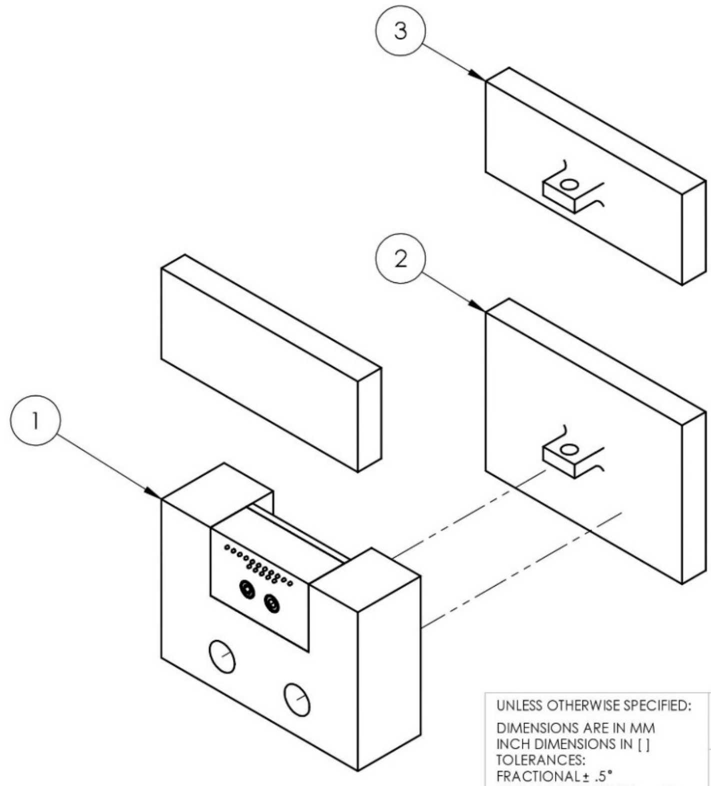
Figure F.3. TPU clamped by Delrin blocks during c-clamp friction test. A) Delrin block was halved and secured using a c-clamp. B) The blue line outlines the block to show where the TPU started. C) The blue line moved slightly indicating the TPU slipped while being pulled on.

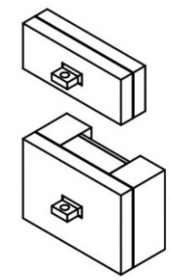
With this less formal test, the BendatroniX team decided that the Delrin and aluminum performed much better than the steel. The TPU experienced major slippage in the steel, possibly due to the hardness of steel not conforming to the TPU surface. The Delrin, again, performed surprisingly well not allowing much slippage of the TPU. The aluminum also did well to not let the TPU sample slip from the clamp.

In conclusion, the BendatroniX team has decided to manufacture the clamping block out of Delrin. The plastic material will avoid shorting the electronics and will sufficiently secure the TPU substrate from slipping during testing. Delrin is relatively cheap and is more easily machinable than steel and aluminum.

Appendix H: Detailed Drawings

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	101000	MANUAL MONITORING CLAMP ASSEMBLY	1
2	102000	ALIGNMENT CLAMP ASSEMBLY	1
3	103000	TOP CLAMP	2





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TOLERANCES:
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ONE PLACE DECIMAL ± .05
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

TITLE: COMPLETE ASSEMBLY

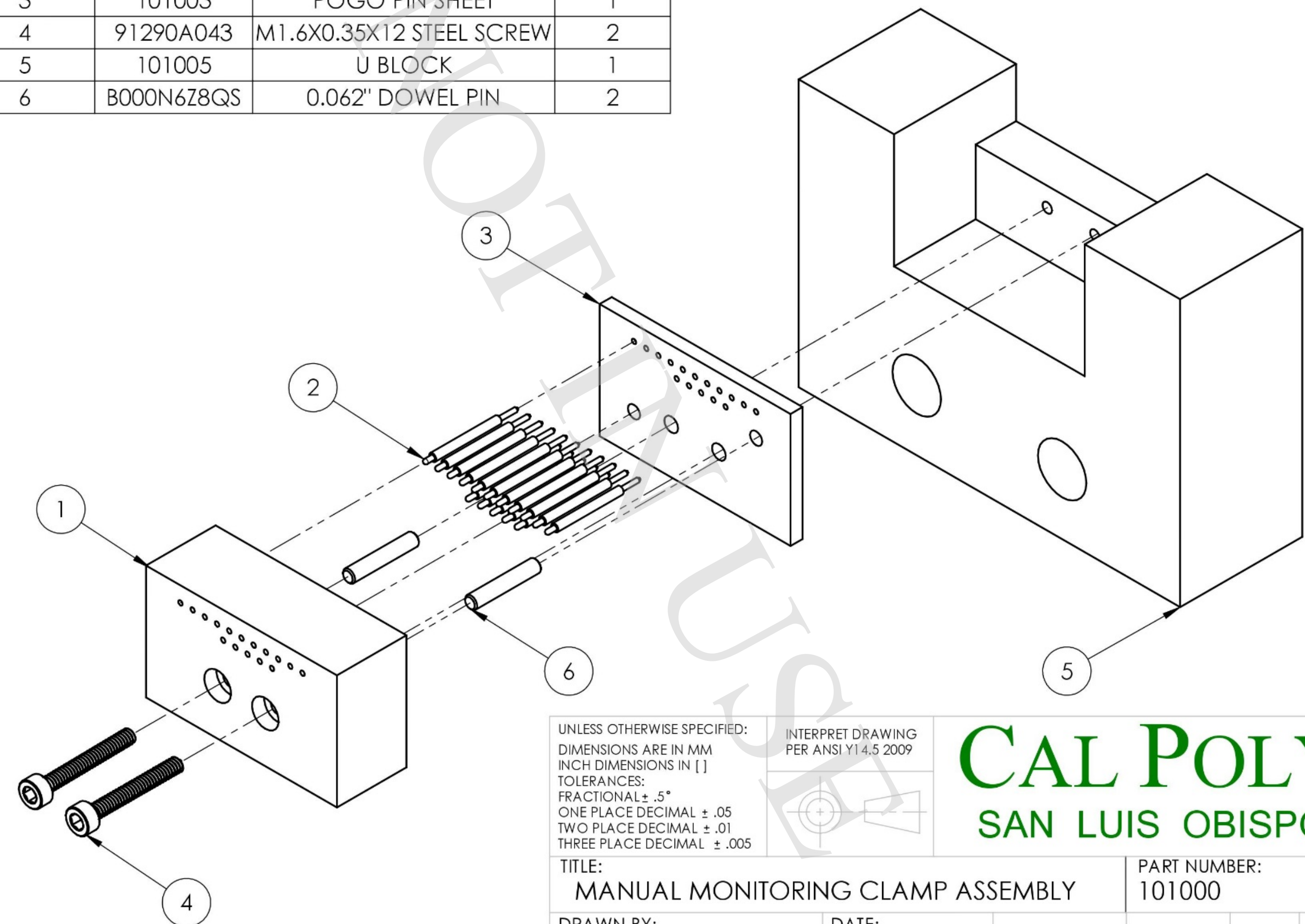
PART NUMBER: 100000

DRAWN BY: JULIA ROCHE

DATE: 02/05/2017

SCALE: 1:1 | REV 2 | SIZE A

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	101001	POGO PIN BLOCK	1
2	SKT2496	EMULATION POGO PIN	16
3	101003	POGO PIN SHEET	1
4	91290A043	M1.6X0.35X12 STEEL SCREW	2
5	101005	U BLOCK	1
6	B000N6Z8QS	0.062" DOWEL PIN	2



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ONE PLACE DECIMAL ± .05
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

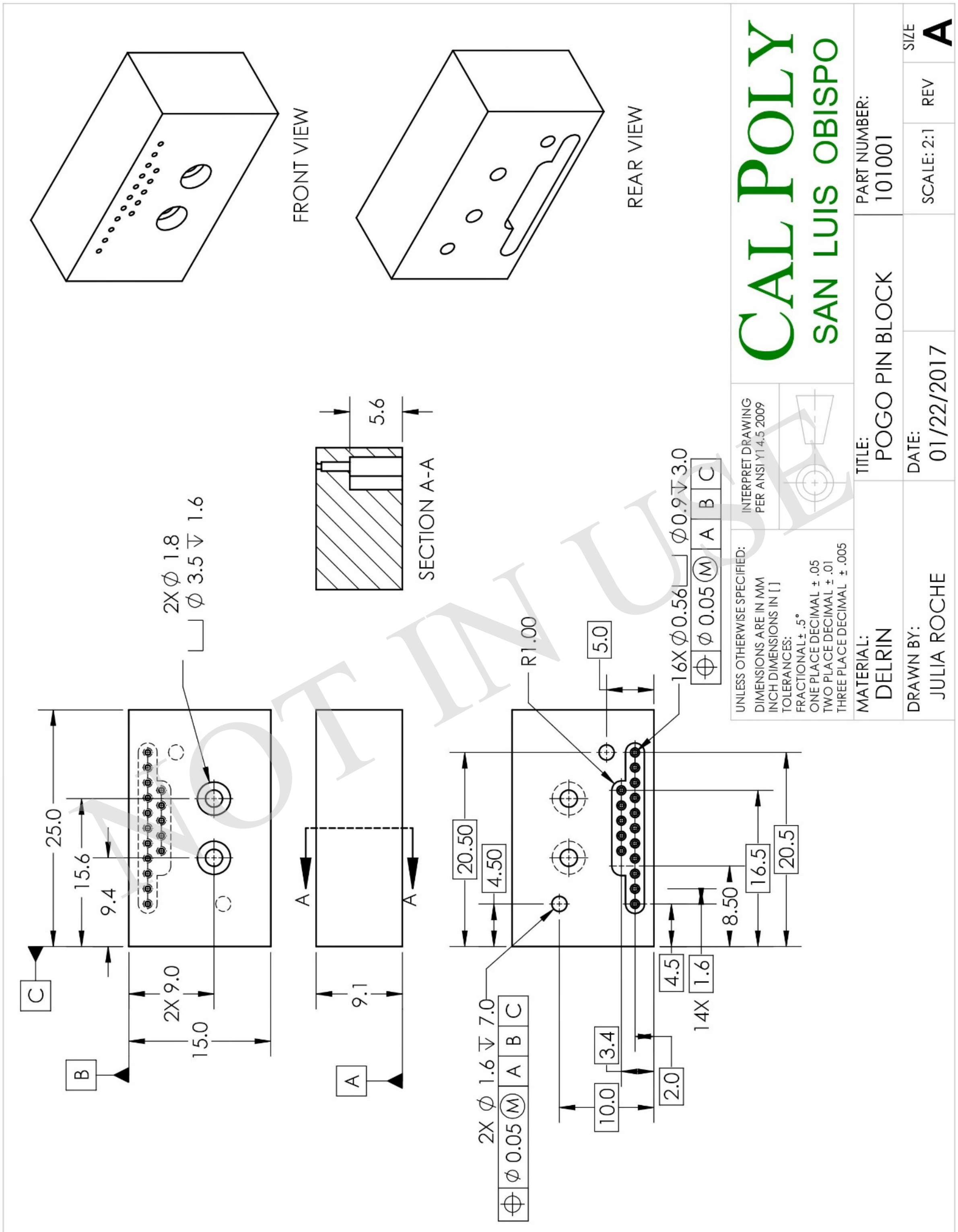
TITLE: MANUAL MONITORING CLAMP ASSEMBLY

PART NUMBER: 101000

DRAWN BY: JULIA ROCHE

DATE: 02/05/2017

SCALE: 2:1 | REV 2 | SIZE A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REAR VIEW
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2X 9.0
15.0
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5.6
R1.00
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Ø 0.05 Ⓜ A B C
2X Ø 1.6 ↧ 7.0
Ø 0.05 Ⓜ A B C
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FRACTIONAL ± .5°
ONE PLACE DECIMAL ± .05
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
DELRIN
TITLE:
POGO PIN BLOCK
PART NUMBER:
101001
DRAWN BY:
JULIA ROCHE
DATE:
01/22/2017
SCALE: 2:1
REV
SIZE
A

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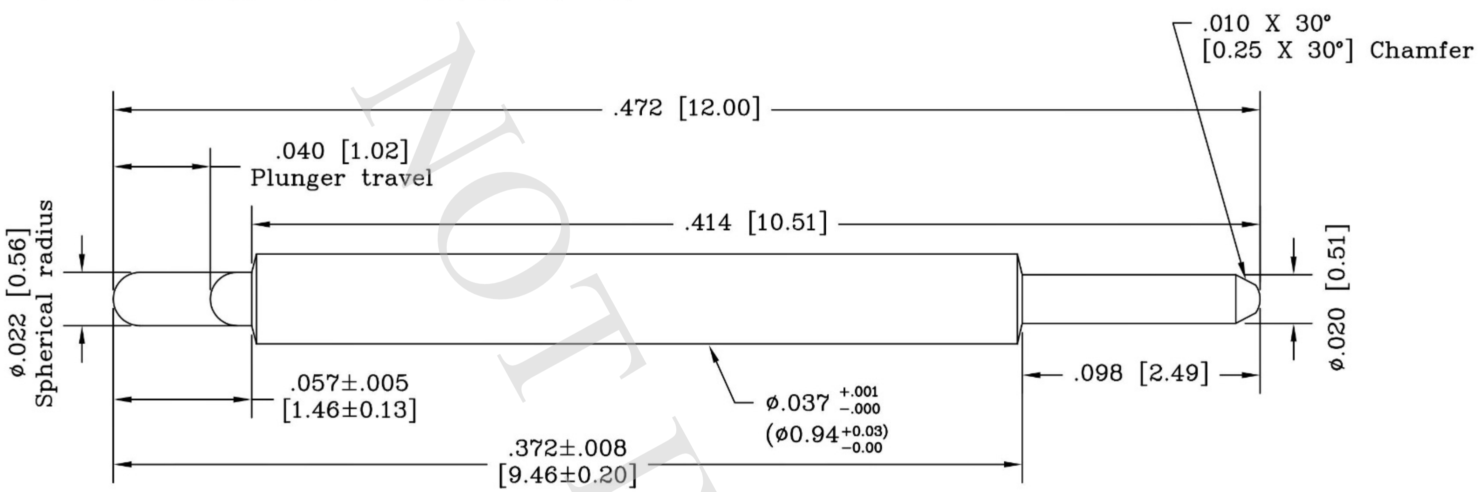
B	ADDED DIMENSION ø.037	11/30/06	H.N.

SKT2496



Probe Specifications

Mechanical

Full Travel:	.057 (1.48)
Recommended Working Travel:	.040 (1.02)
Mechanical Life Exceeds:	100,000 cycles

Operating Temperature −35°C to +105°C
Consult factory for other temperature requirements, and applications below −40°

Electrical (Static Conditions)
Current Rating: 5 amps continuous

Probe Resistance 50 milliohms

Materials and Finishes
Plunger: Brass, gold plated
Barrel: Brass, gold plated
Spring: Music wire, gold plated

Spring Force in Oz. (grams)

Spring Type	Preload	Working Travel
As shown	.83 (23.55)	2.85 (80.87)

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED

Emulation Technology, Inc.
VLSI and SMT ADAPTERS and ACCESSORIES
2344 Walsh Avenue, Bldg.F
Santa Clara, Ca 95051
TEL:(408)982-0660
FAX:(408)982-0664

SHEET: 1 OF 1	DATE: 07/11/06	REVISION: B	ASSEMBLY DRAWING
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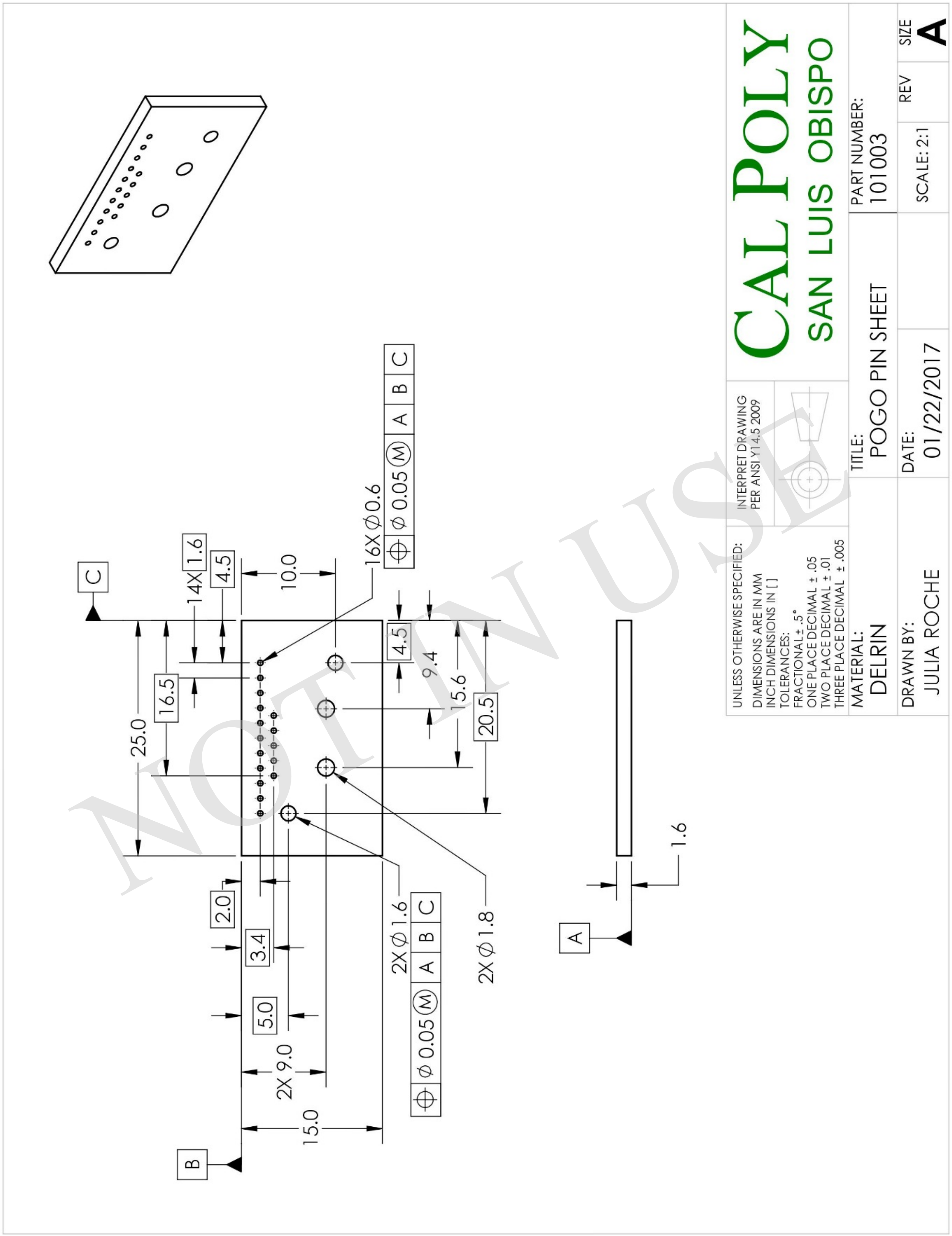
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JULIA ROCHE
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01/22/2017
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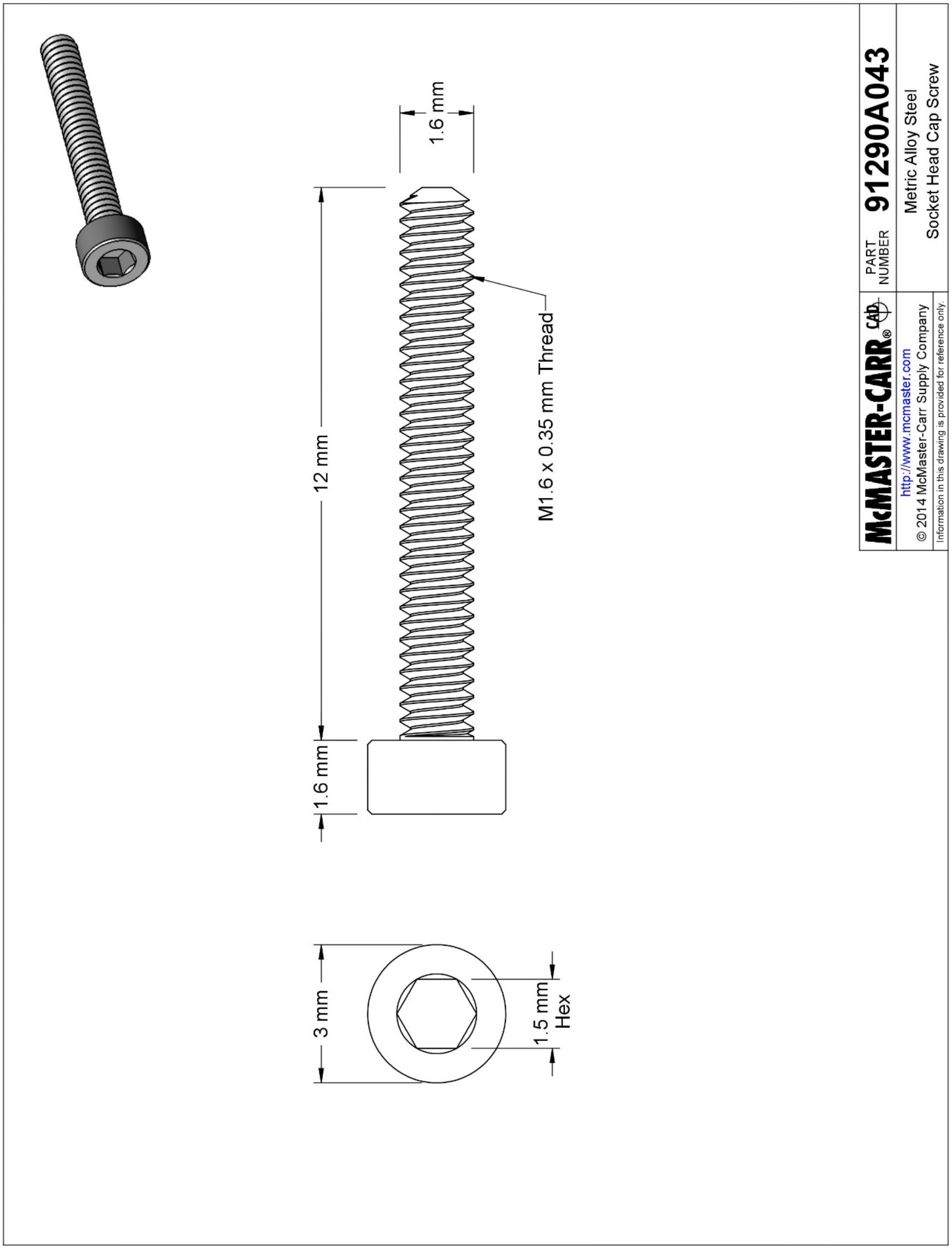
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CAD
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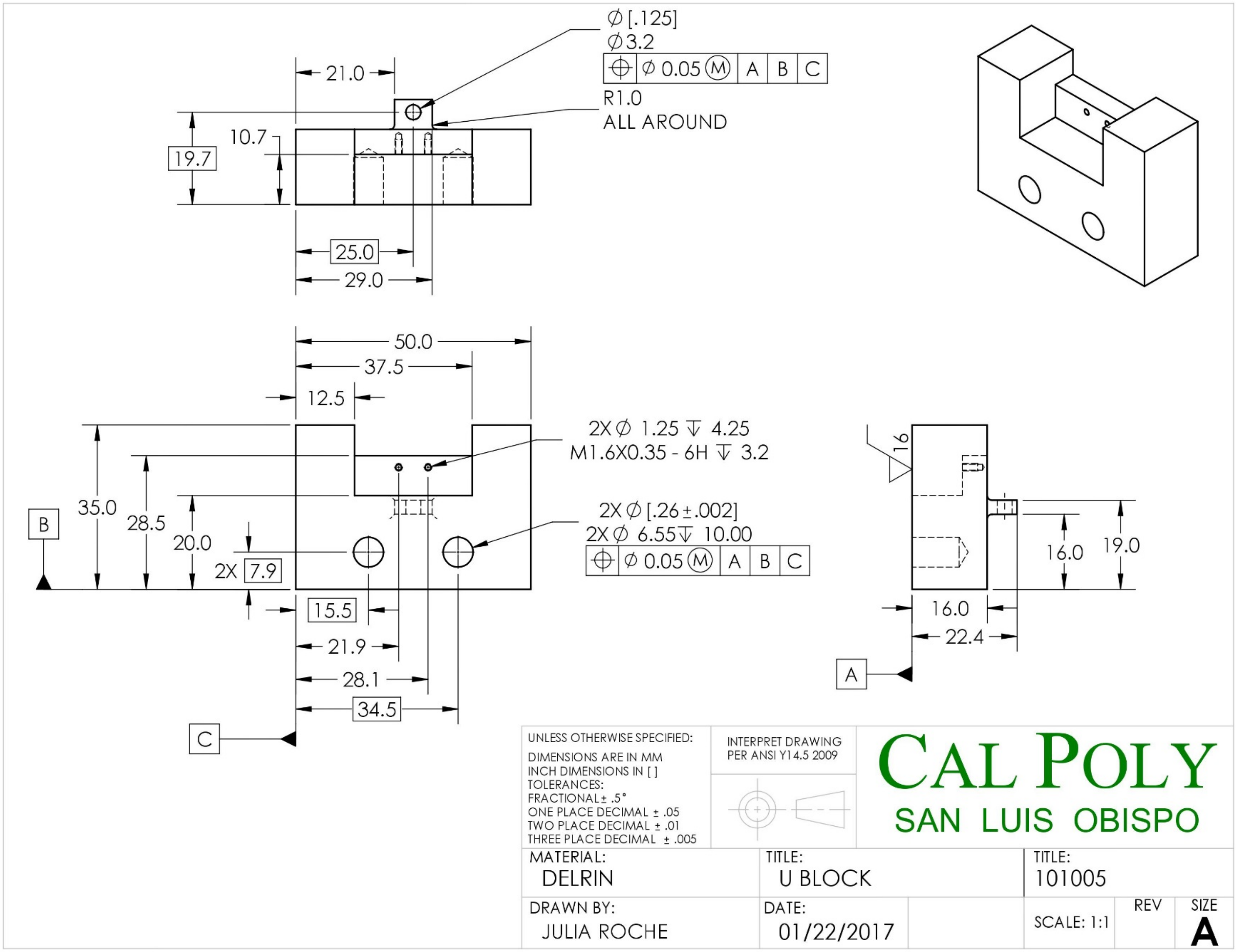
91290A043
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Metric Alloy Steel
Socket Head Cap Screw
Information in this drawing is provided for reference only.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2X Ø 6.55 ↧ 10.00
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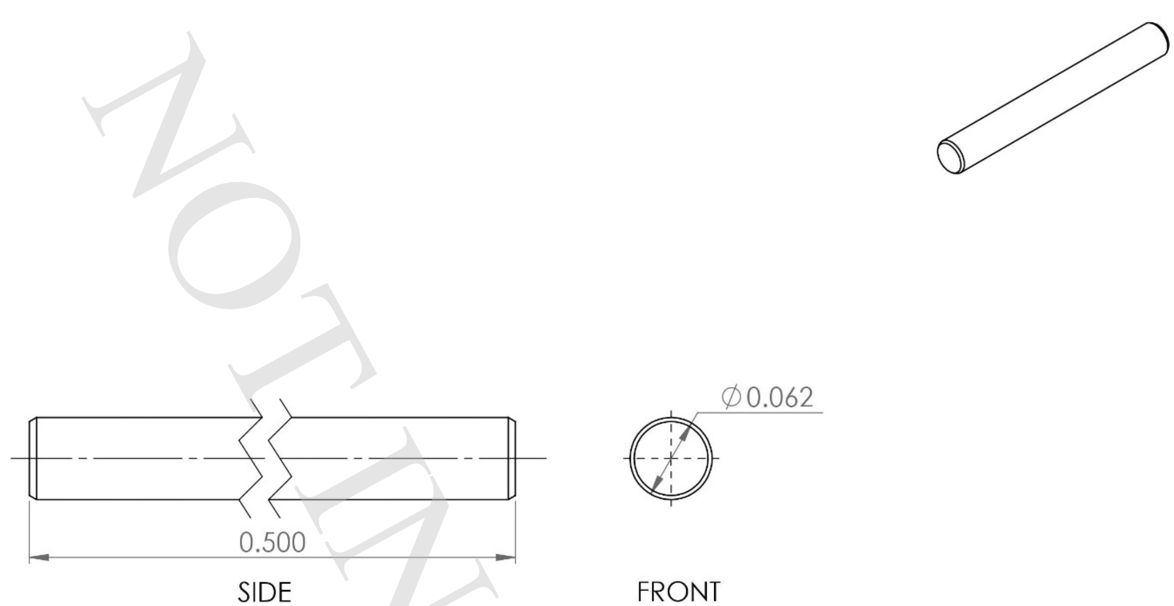
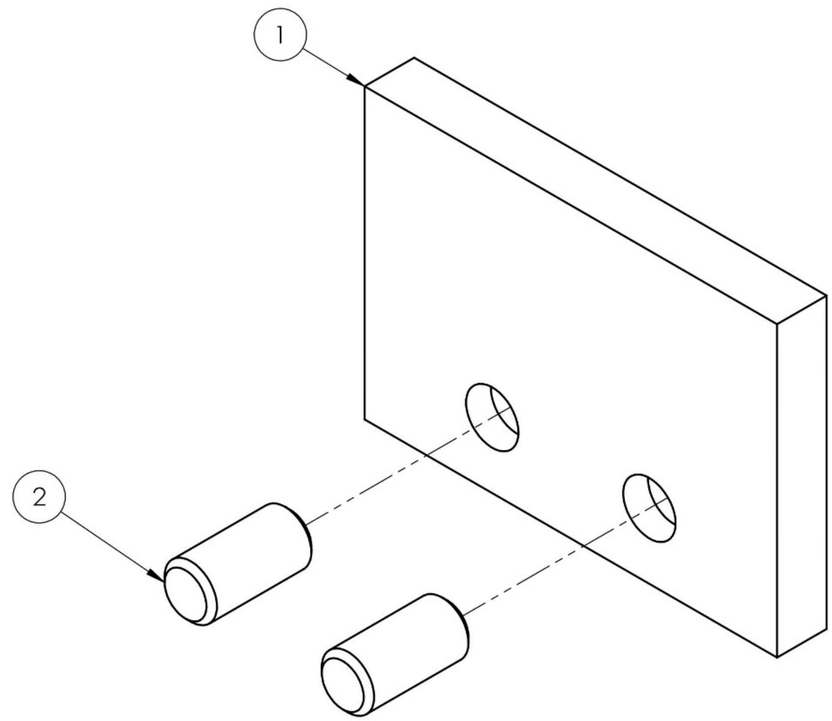
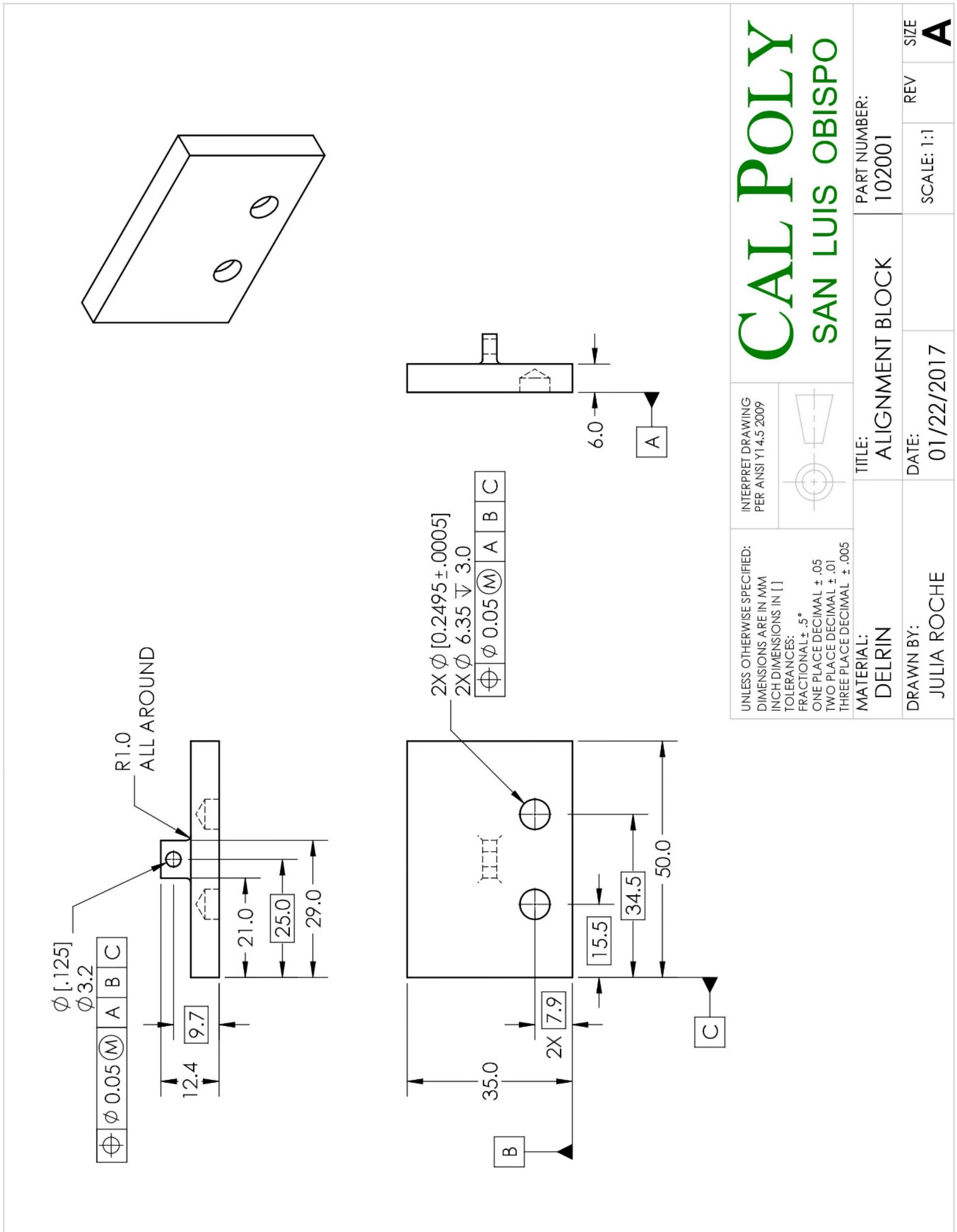


ITEM NAME: Acetal Dowel Pin, Plain Finish, Standard, 0.062" Nominal Diameter, +/-0.005" Diameter Tolerance, 0.500" Length (Pack of 100)	ASIN : B000N5Z8QS BRAND : Small Parts	MATERIAL : Acetal # UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES # INFORMATION IN THIS DRAWING IS PROVIDED FOR REFERENCE ONLY	http://www.amazonsupply.com amazonsupply

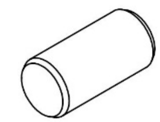
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	102001	ALIGNMENT BLOCK	1
2	B000N62H3E	0.25" DOWEL PIN	2

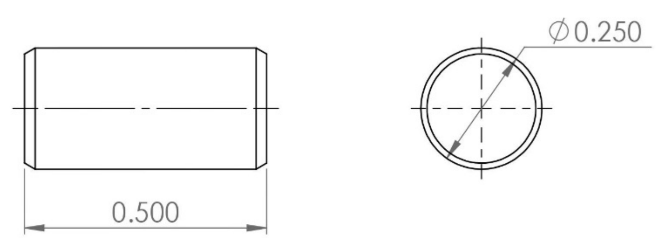


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MM INCH DIMENSIONS IN [ ] TOLERANCES: FRACTIONAL ± .5° ONE PLACE DECIMAL ± .05 TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	INTERPRET DRAWING PER ANSI Y14.5 2009	CAL POLY SAN LUIS OBISPO
TITLE: ALIGNMENT CLAMP ASSEMBLY		PART NUMBER: 102000
DRAWN BY: JULIA ROCHE	DATE: 02/05/2017	SCALE: 2:1 REV 2 SIZE A


R1.0
ALL AROUND
∅[.125]
∅3.2
∅0.05 Ⓜ A B C
12.4
9.7
21.0
25.0
29.0
2X ∅[0.2495±.0005]
2X ∅6.35 ↧ 3.0
∅0.05 Ⓜ A B C
6.0
A
35.0
2X 7.9
15.5
34.5
50.0
B
C
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
INCH DIMENSIONS IN [ ]
TOLERANCES:
FRACTIONAL ± .5°
ONE PLACE DECIMAL ± .05
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
DELRIN
TITLE:
ALIGNMENT BLOCK
PART NUMBER:
102001
DRAWN BY:
JULIA ROCHE
DATE:
01/22/2017
SCALE: 1:1
REV
SIZE
A

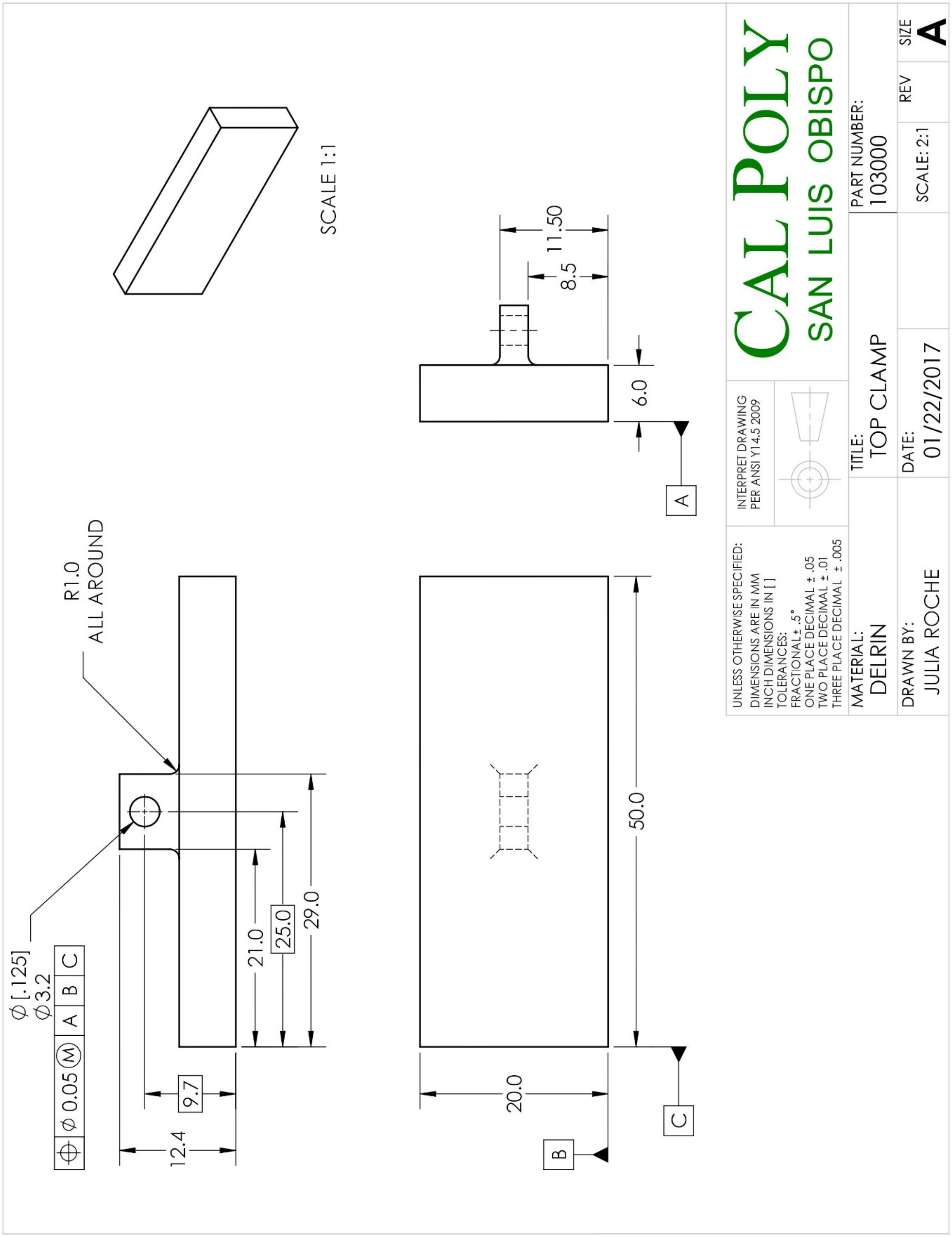
B000N62H3E

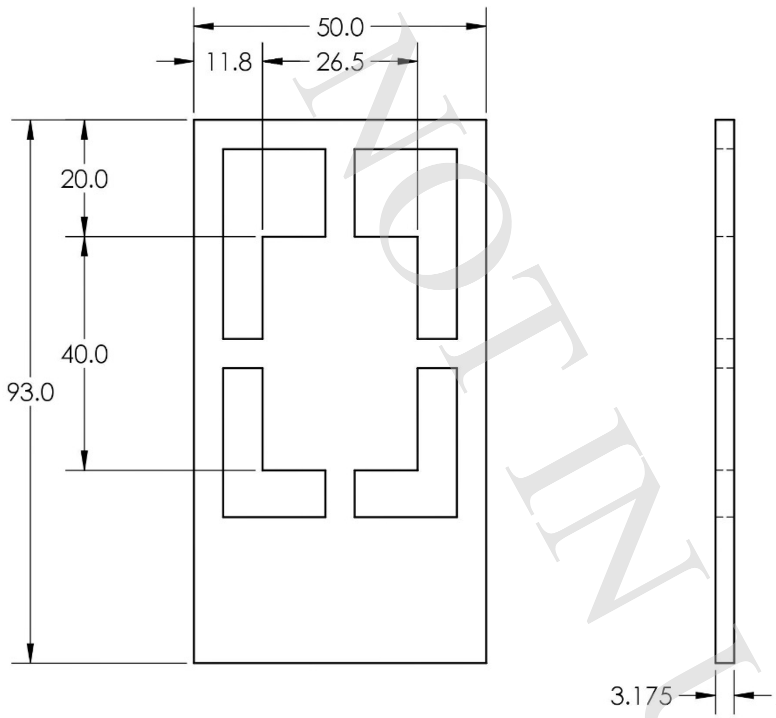


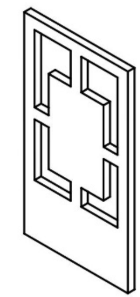


SIDE FRONT

ITEM NAME: Acetal Dowel Pin, Plain Finish, Standard, 0.250" Nominal Diameter, +/-0.005" Diameter Tolerance, 0.500" Length (Pack of 100)	ASIN : B000N62H3E BRAND : Small Parts	MATERIAL : Acetal # UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES # INFORMATION IN THIS DRAWING IS PROVIDED FOR REFERENCE ONLY http://www.amazonsupply.com amazonsupply


CAL POLY
SAN LUIS OBISPO
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
INCH DIMENSIONS IN [ ]
TOLERANCES:
FRACTIONAL ± .5°
ONE PLACE DECIMAL ± .05
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING
PER ANSI Y14.5 2009
MATERIAL:
DELRIN
DRAWN BY:
JULIA ROCHE
TITLE:
TOP CLAMP
DATE:
01/22/2017
PART NUMBER:
103000
SCALE: 2:1
REV
SIZE
A
SCALE 1:1
R1.0
ALL AROUND
Ø [.125]
Ø 3.2
Ø 0.05 Ⓜ A B C
12.4
9.7
21.0
25.0
29.0
20.0
50.0
6.0
8.5
11.50
A
B
C





ISOMETRIC VIEW
SCALE 1:2

NOTE:

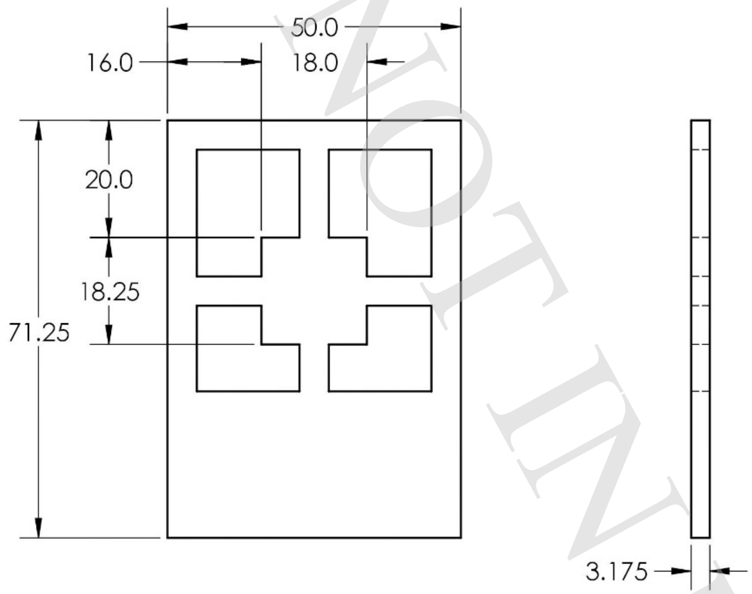
PART MANURFACTURED ON LASER PRINTER USING .DXF FILE. ONLY KEY FEATURES DIMENSIONED.

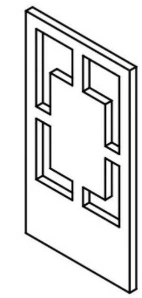
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
INCH DIMENSIONS IN [ ]
TOLERANCES:
FRACTIONAL ± .5°
ONE PLACE DECIMAL ± .05
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

MATERIAL: ACRYLIC	TITLE: FANNED DIE	PART NUMBER: 104000
DRAWN BY: JULIA ROCHE	DATE: 2/8/2017	SCALE: 1:1 · REV · SIZE A





ISOMETRIC VIEW
SCALE 1:2

NOTE:

PART MANURFACTURED ON LASER PRINTER USING .DXF FILE. ONLY KEY FEATURES DIMENSIONED.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MM INCH DIMENSIONS IN [ ] TOLERANCES: FRACTIONAL ± .5° ONE PLACE DECIMAL ± .05 TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	INTERPRET DRAWING PER ANSI Y14.5 2009	CAL POLY SAN LUIS OBISPO
MATERIAL: ACRYLIC	TITLE: STAGGERED DIE	PART NUMBER: 105000
DRAWN BY: JULIA ROCHE	DATE: 2/8/2017	SCALE: 1:1 · REV · SIZE A

Appendix I: Bill of Materials

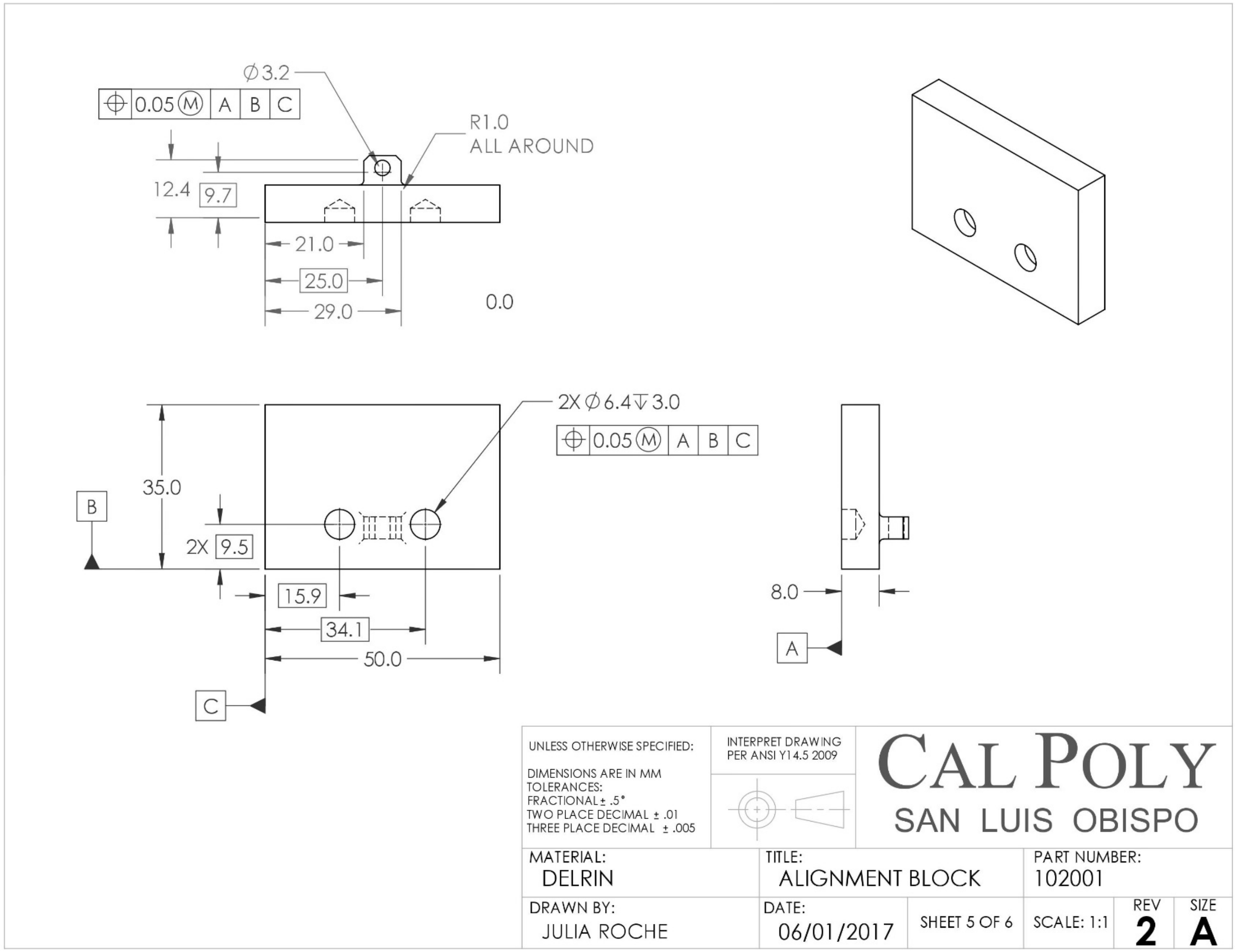
Team Members: Paul Swartz, Maya Manzano, and Julia Roche

Indented Bill of Material (BOM)
Team 55: Flexible Electronic Reliability Tester

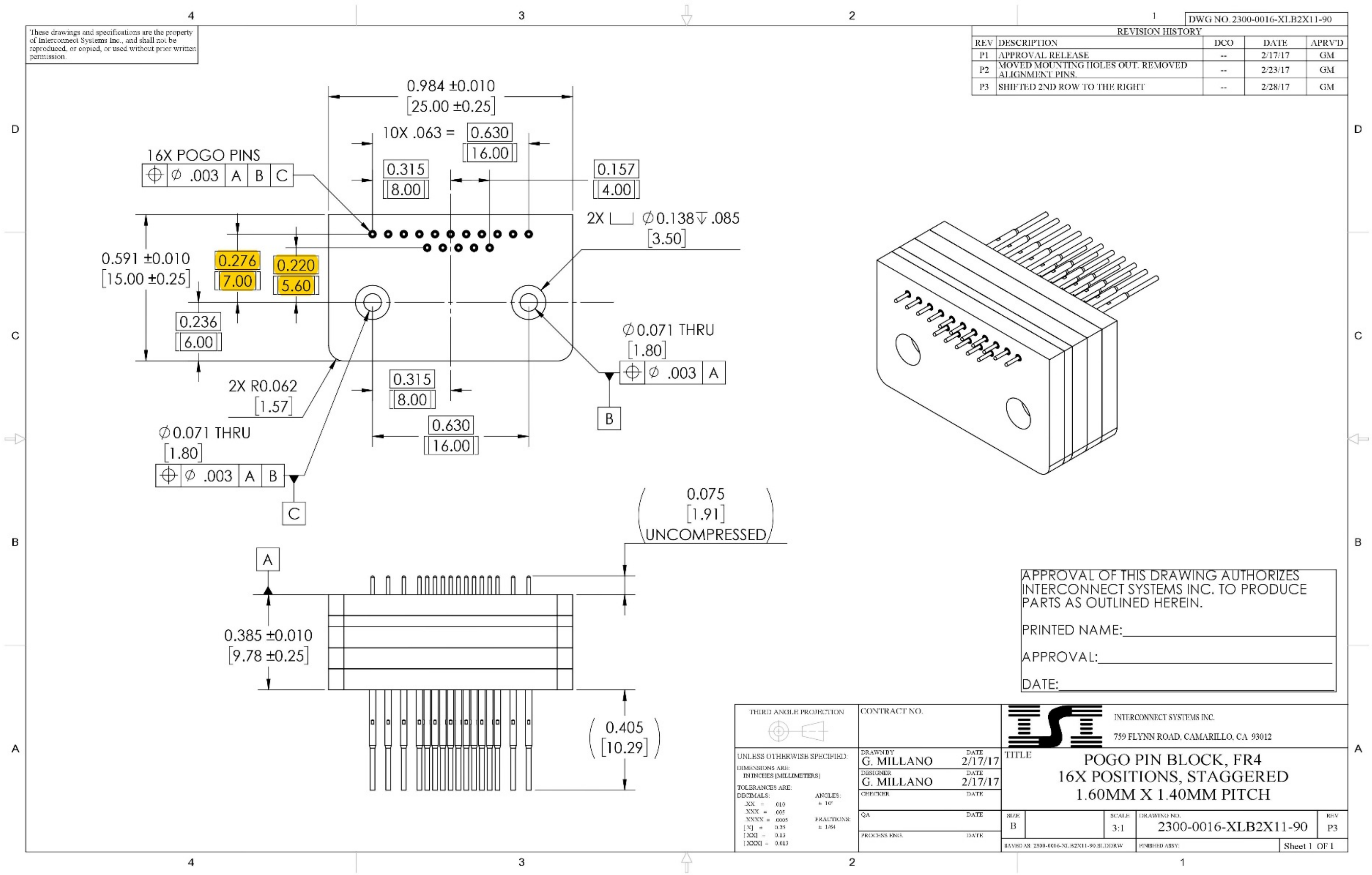
Assembly Level	Part Number	Description			Material Vendor	Labor	Qty	Cost	Ttl Cost
		Lvl 0	Lvl 1	Lvl 2					
0	100000	Final Assy			------	------			
1	101000		Manual Monitoring Clamp Assy		------	------			
2	101010			Emulation Pogo Pin Assembly	Emulation Technology	Emulation Technology	1	$ 1,760.95	$ 1,760.95
2	101004			Screws	McMaster	------	2	$ 0.51	$ 1.01
2	101005			U Block	McMaster	Mustang '60	1	$ 54.33	$ 54.33
1	102000		Alignment Clamp Assy		------	------			
2	102001			Alignment Block	McMaster	Mustang '60	1	$ 52.97	$ 52.97
2	102002			Dowel Pins	Amazon	------	2	$ 0.14	$ 0.28
1	103000		Top Clamp		McMaster	Mustang '60	2	$ 52.97	$ 105.94
1	104000		Fanned Die		McMaster	------	1	$ 2.45	$ 2.45
1	105000		Staggered Die		McMaster	------	1	$ 2.45	$ 2.45
	Total Parts						**11**		**$ 1,977.94**

*Mustang '60 labor costs per part = 5hrs at $20/hr

Appendix J: Updated Detail Drawing



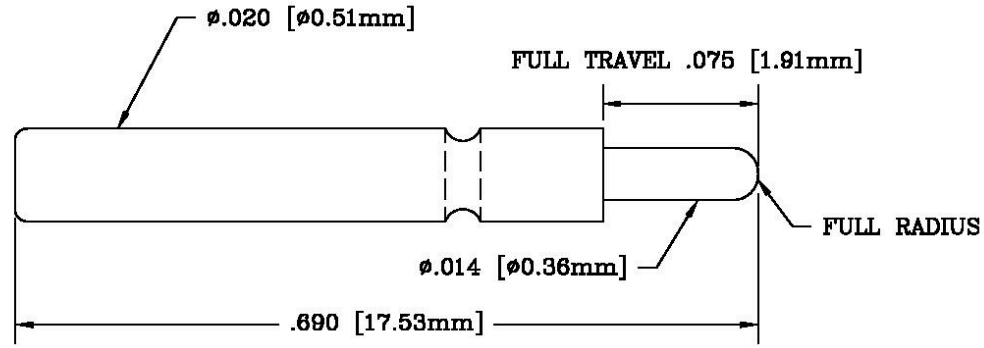
⌀3.2
⌖ 0.05 Ⓜ A B C
R1.0
ALL AROUND
12.4
9.7
21.0
25.0
29.0
0.0
2X ⌀6.4 ↧ 3.0
⌖ 0.05 Ⓜ A B C
35.0
B
2X 9.5
15.9
34.1
50.0
C
8.0
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL: DELRIN
TITLE: ALIGNMENT BLOCK
PART NUMBER: 102001
DRAWN BY: JULIA ROCHE
DATE: 06/01/2017
SHEET 5 OF 6
SCALE: 1:1
REV 2
SIZE A



These drawings and specifications are the property of Interconnect Systems Inc., and shall not be reproduced, or copied, or used without prior written permission.
DWG NO. 2300-0016-XLB2X11-90
REVISION HISTORY
REV | DESCRIPTION | DCO | DATE | APRV'D
P1 | APPROVAL RELEASE | -- | 2/17/17 | GM
P2 | MOVED MOUNTING HOLES OUT. REMOVED ALIGNMENT PINS. | -- | 2/23/17 | GM
P3 | SHIFTED 2ND ROW TO THE RIGHT | -- | 2/28/17 | GM
0.984 ±0.010 [25.00 ±0.25]
10X .063 = 0.630 [16.00]
0.315 [8.00]
0.157 [4.00]
16X POGO PINS
⌖ Ø .003 A B C
2X ⌴ Ø0.138 ↧ .085 [3.50]
0.591 ±0.010 [15.00 ±0.25]
0.276 [7.00]
0.220 [5.60]
0.236 [6.00]
Ø0.071 THRU [1.80]
⌖ Ø .003 A
B
2X R0.062 [1.57]
0.315 [8.00]
0.630 [16.00]
Ø0.071 THRU [1.80]
⌖ Ø .003 A B
C
0.075 [1.91] UNCOMPRESSED
A
0.385 ±0.010 [9.78 ±0.25]
0.405 [10.29]
APPROVAL OF THIS DRAWING AUTHORIZES INTERCONNECT SYSTEMS INC. TO PRODUCE PARTS AS OUTLINED HEREIN.
PRINTED NAME:
APPROVAL:
DATE:
THIRD ANGLE PROJECTION
CONTRACT NO.
INTERCONNECT SYSTEMS INC.
759 FLYNN ROAD, CAMARILLO, CA 93012
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE: IN INCHES [MILLIMETERS]
TOLERANCES ARE:
DECIMALS: ANGLES:
DRAWN BY G. MILLANO DATE 2/17/17
DESIGNER G. MILLANO DATE 2/17/17
CHECKER DATE
QA DATE
PROCESS ENG. DATE
TITLE
POGO PIN BLOCK, FR4
16X POSITIONS, STAGGERED
1.60MM X 1.40MM PITCH
SIZE B
SCALE 3:1
DRAWING NO. 2300-0016-XLB2X11-90
REV P3
Sheet 1 OF 1

REV	DESCRIPTION	DATE	BY
A	NEW DRAWING	06/03/04	H.N.
B	ADDED SPRING FORCE NOTE	01/15/07	H.N.

SKT2008



PROBE SPECIFICATIONS

MECHANICAL DATA:

FULL TRAVEL:	0.075 [1.91mm]
RECOMMENDED WORKING TRAVEL:	0.050 [1.27mm]
MECHANICAL LIFE EXCEEDS:	1 X 10 CYCLE

OPERATING TEMPERATURE:	−55°C TO +105°C
ELECTRICAL (STATIC CONDITIONS): CURRENT RATING:	2 AMPS
AVERAGE PROBE RESISTANCE:	50mΩ

MATERIALS & FINISH:

PLUNGERS: HEAT−TREATED BERYLIUM COPPER, GOLD PLATED OVER HARD NICKEL

BARREL: HEAT−TREATED BERYLLIUM COPPER, HPA−GOLD PLATED (I.D & O.D OVER HARD NICKEL)

SPRING: MUSIC WIRE, SILVER PLATED

SPRING FORCE IN OZ. (GRAMS)

PRELOAD:	0.39 (11)
2/3 TRAVEL:	1.39 (39)

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED

Emulation Technology, Inc.
—VLSI and SMT ADAPTERS and ACCESSORIES—

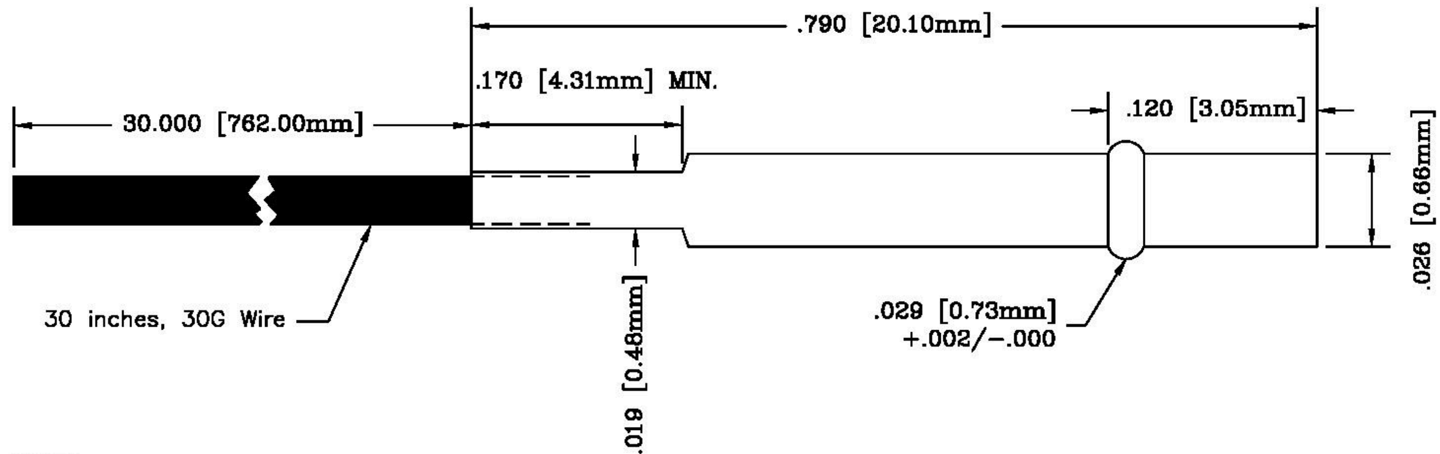
741 FLYNN ROAD
CAMARILLO, CA 93012

TEL:(805)383-8480
FAX:(805)383-8484

SHEET: 1 OF 1	DATE: 06/03/04	REVISION: B	ASSEMBLY DRAWING
CHECKED: Perry Munroe	DRAWN: Huy Nguyen		ITEM: POGO−PIN−17.5−1
Scale N/A	DO NOT SCALE DRAWING		DESCRIPTION: POGO−PIN−17.5−1

REV	DESCRIPTION	DATE	BY
A	NEW DRAWING	08/14/09	JAG
B	ADDED LABEL AND PAGE 2	03/01/11	JAG

SKT3315



NOTES

1. Mounting Hole Size:
   .0265/.0276 (0.67/0.70)
   A 0.70mm drill is most commonly used.

2. Recommended Wire Gauge:
   30 AWG

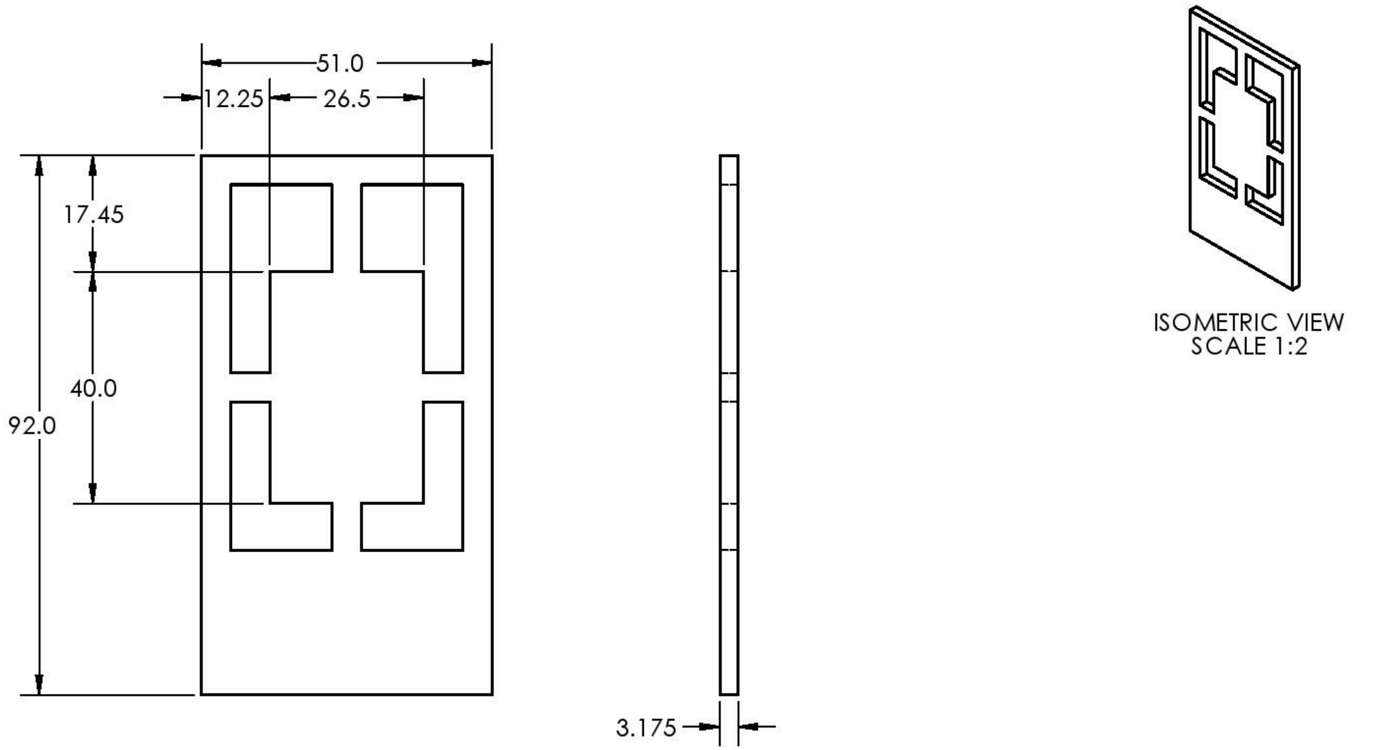
3. Connections:
   To order without 30 inches of 30 AWG wire attached, use part no. POGO-REC-17.5-1.

4. Materials and Finishes:
   Heat-treated beryllium copper,
   HPA-GOLD plated (I.D. and O.D.)
   over hard nickel.

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED

Emulation Technology, Inc.
VLSI and SMT ADAPTERS and ACCESSORIES
759 FLYNN ROAD
CAMARILLO, CA 93012
TEL:(805)383-8480
FAX:(805)383-8484

SHEET: 1 OF 2	DATE: 08/14/09	REVISION: B	ASSEMBLY DRAWING
CHECKED:	PREPARED BY: J. GELACIO		ITEM: POGO-REC-17.5-2
Scale N/A	DO NOT SCALE DRAWING		DESCRIPTION: POGO-REC-17.5-2



NOTE:

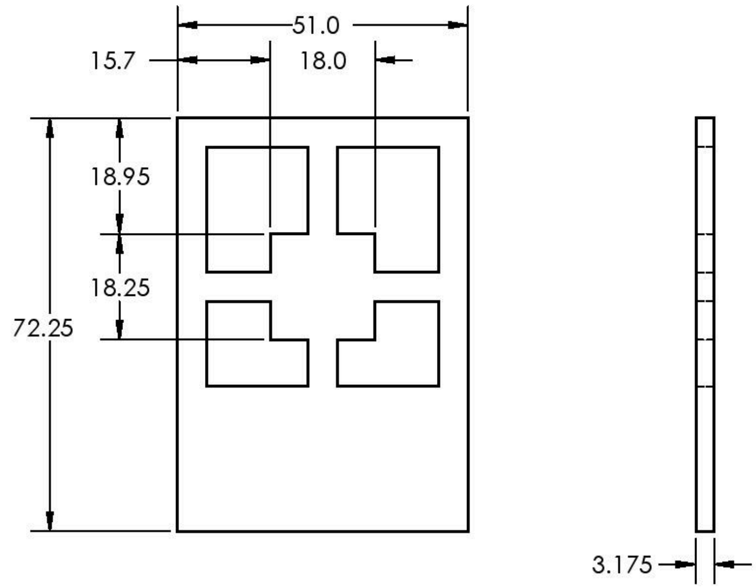
PART MANURFACTURED ON LASER PRINTER USING
.DXF FILE. ONLY KEY FEATURES DIMENSIONED.

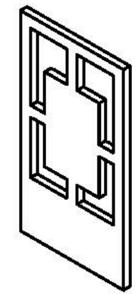
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
INCH DIMENSIONS IN [ ]
TOLERANCES:
FRACTIONAL ± .5°
ONE PLACE DECIMAL ± .05
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING
PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

MATERIAL: ACRYLIC	TITLE: FANNED DIE	PART NUMBER: 104000
DRAWN BY: JULIA ROCHE	DATE: 6/1/2017	SCALE: 1:1 — REV 2 — SIZE A





ISOMETRIC VIEW
SCALE 1:2

NOTE:

PART MANURFACTURED ON LASER PRINTER USING
.DXF FILE. ONLY KEY FEATURES DIMENSIONED.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MM INCH DIMENSIONS IN [ ] TOLERANCES: FRACTIONAL ± .5° ONE PLACE DECIMAL ± .05 TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	INTERPRET DRAWING PER ANSI Y14.5 2009	CAL POLY SAN LUIS OBISPO
MATERIAL: ACRYLIC	TITLE: STAGGERED DIE	PART NUMBER: 105000
DRAWN BY: JULIA ROCHE	DATE: 6/1/2017	SCALE: 1:1 · REV 2 · SIZE A

Appendix K: Updated DVP&R

ME428 DVP&R Format

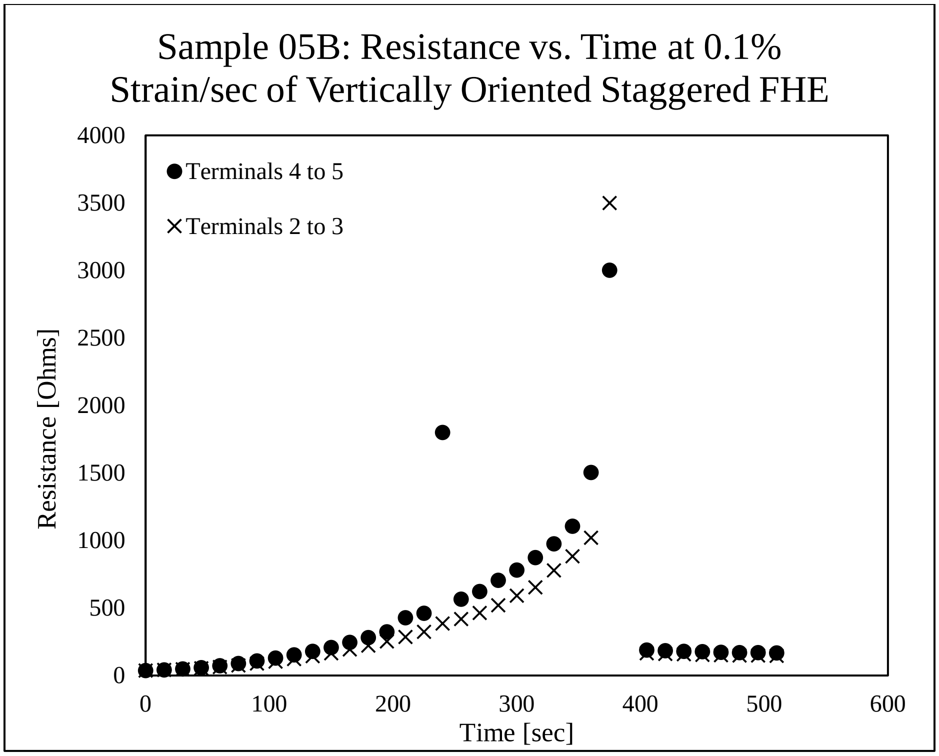
Report Date | Sponsor | Component/Assembly | REPORTING ENGINEER:

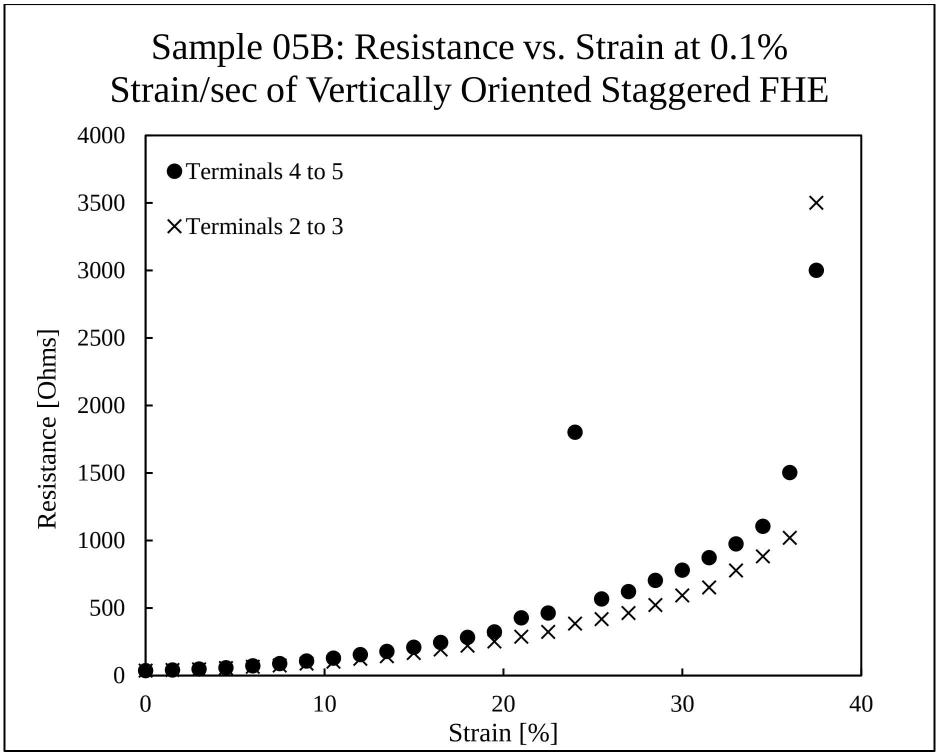
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED: Quantity	SAMPLES TESTED: Type	TIMING: % Complete	TIMING: Start date	TIMING: Finish date	TEST RESULTS: Test Result	TEST RESULTS: Quantity Pass	TEST RESULTS: Quantity Fail	NOTES
	TEST PLAN										**TEST REPORT**			
1	Specification 1	Monitor test terminal that is shorted for resistance continuity	Hear continuity beep	Julia	Hardware Verification	7	C	100%	5/8/2017	5/8/2017	Refer to "Test1" in OneDrive>testing	7	0	
2	Specification 1	Compare continuity of sample pre-staging with multimeter versus loaded sample in Instron (before test completed)	± 5% Resistance Change	Julia	Hardware Verification	7	C	100%	5/11/2017	5/11/2017	Refer to "Verification Testing_May 11"	6	1	
3	Specification 1	Load sample, stretch to a low strain (~5%?), and cut sample with scissors and verify that resistance steps to infinty	Step response	Julia	Hardware Verification	1	A	100%	5/11/2017	5/11/2017	Refer to "Verification Testing_May 11"	1	0	One sample tested and multimeter recoreded "overload" when the sample was cut in half.
4	Specification 2	Monitor for circuit continuity, load sample, remove sample, and measure continuity to verify no damage was done to the traces during staging	Hear continuity beep	Julia	Hardware Verification	7	C	100%	5/11/2017	5/11/2017	Refer to "Verification Testing_May 11"	6	1	Continuity beeping was not capable of monitoring the samples; however, resistance change was monitored from pre-staging to post-staging and compared to ± 5% resistance change as the passing criteria
5	Specification 2	Load sample. Remove sample and verify that no physical damage was inflicted during staging (i.e. holes, tears, etc.)	No holes in the TPU	Maya	Hardware Verification	5	C	100%	4/25/2017	4/25/2017	Refer to Maya's log book	5	0	
6	Specification 3/4	Draw a pattern on the TPU. Load TPU sample with pattern along the top edge of the clamp. Complete tensile test. While the TPU sample is still laoded, verify that the clamped portion of the sample did not slip out of the clamp	± 5% slippage of final strain (?)	Maya	Hardware Verification	5	B	100%	4/25/2017	4/25/2017	Refer to Maya's log book	0	5	All samples slipped according to this test; however, pogo pins stayed in contact with terminals throughout duration of test thus verifying that the function works and meets the specification. Wrong test completed (?)
7	Specification 7	Set up entire sample run and record total time required	5 minutes or less	Julia	Hardware Verification	1	C	100%	5/22/2017	5/22/2017	Refer to OneDrive>validation testing>May 22	1	0	Tested with sample cut and backing removed. Tested by experienced user. Test stops when wires are ready to be attached to multimeter as this will very per test. Only one sample tested as it is indicitive of entire process.

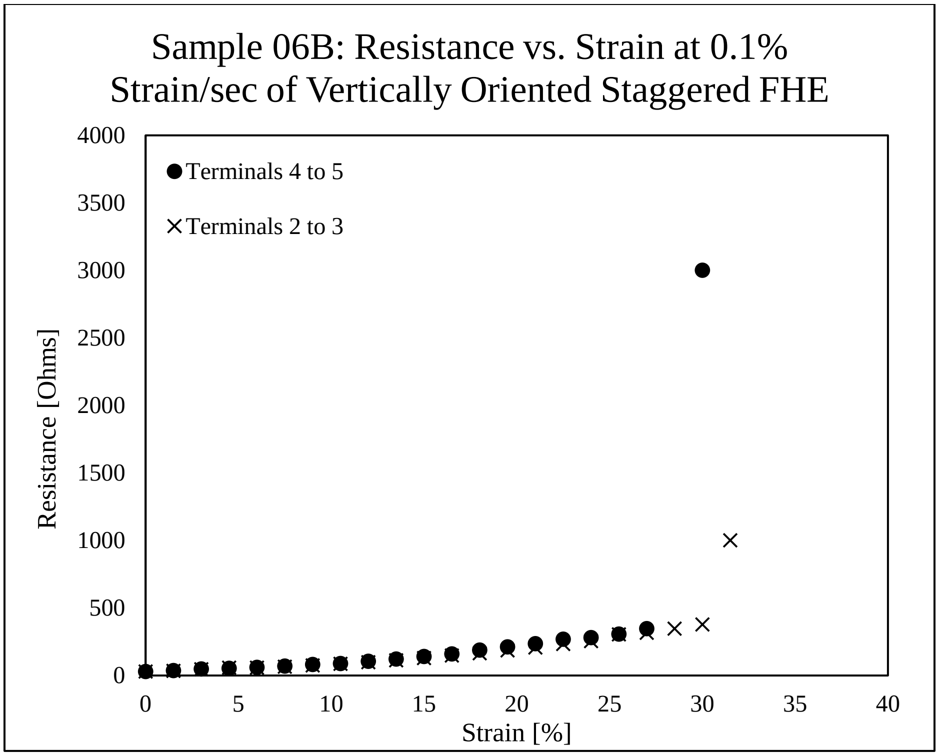
Appendix L: Raw Data for Staggered Sample Testing

Test completed on May 11, 2017.

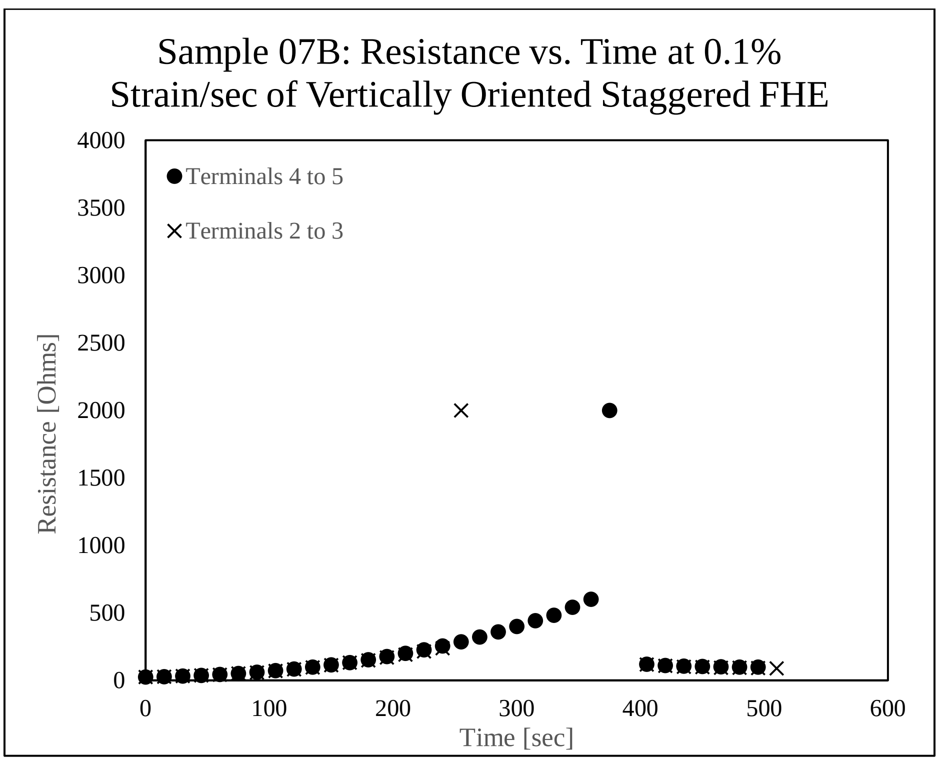
		Sample 05B		Sample 06B		Sample 07B		Sample 09B	
Time [sec]	% Strain	T2 to T3 [Ohm]	T4 to T5 [Ohm]	T2 to T3 [Ohm]	T4 to T5 [Ohm]	T2 to T3 [Ohm]	T4 to T5 [Ohm]	T2 to T3 [Ohm]	T4 to T5 [Ohm]
0	0.0	35.8	35.9	28.7	30.1	24.1	24.9	37.8	37.3
15	1.5	41.1	41.6	35.1	37.0	27.2	28.0	42.7	42.4
30	3.0	46.2	48.2	45.6	47.6	31.1	32.0	47.8	48.0
45	4.5	54.1	58.1	57.3	54.2	36.3	37.0	53.8	54.8
60	6.0	63.1	71.5	57.9	61.3	41.9	43.3	60.7	61.2
75	7.5	73.7	88.0	65.1	68.9	50.1	50.8	68.7	71.3
90	9.0	88.4	107.2	75.2	81.3	59.2	60.3	77.8	82.6
105	10.5	103.2	128.3	86.2	88.9	70.6	71.6	87.4	94.1
120	12.0	122.5	153.8	98.3	104.5	82.7	83.2	98.2	105.7
135	13.5	142.7	178.1	112.9	122.3	96.9	98.3	109.8	120.4
150	15.0	165.3	208.4	130.2	140.6	113.9	114.7	122.8	135.6
165	16.5	192.3	244.3	147.9	160.2	130.5	132.7	135.8	152.2
180	18.0	220.3	281.0	164.9	188.8	147.6	153.7	150.1	169.9
195	19.5	252.3	323.6	185.1	211.6	169.0	176.5	164.7	187.0
210	21.0	285.7	427.1	207.5	235.8	190.1	200.4	179.2	206.3
225	22.5	323.0	462.0	232.8	269.3	213.6	227.4	191.9	227.4
240	24.0	384.0	1800.0	255.0	280.3	238.2	255.3	216.0	250.0
255	25.5	417.0	566.0	303.3	307.3	**2000.0**	286.3	228.0	272.4
270	27.0	463.0	622.0	317.0	346.1		321.9	245.0	294.3
285	28.5	521.0	705.0	346.0			359.7	261.0	319.8
300	30.0	592.0	780.0	378.0	**3000.0**		400.1	279.0	348.3
315	31.5	652.0	872.0	**1000.0**			442.1	297.0	371.3
330	33.0	778.0	975.0				483.3	316.0	398.8
345	34.5	882.0	1105.0				542.1	337.0	430.1
360	36.0	1020.0	1503.0				601.0	357.0	460.8
375	37.5	**3500.0**	**3000.0**				**2000.0**	377.0	515.4
390	39.0							397.0	530.8
405	40.5							420.0	572.3
420	42.0							439.0	1251.0
435	43.5							468.0	2400.0
450	45.0							490.0	1380.0
465	46.5							524.0	1200.0
480	48.0							560.0	**3000.0**
495	49.5							606.0	
510	51.0							**2800.0**	

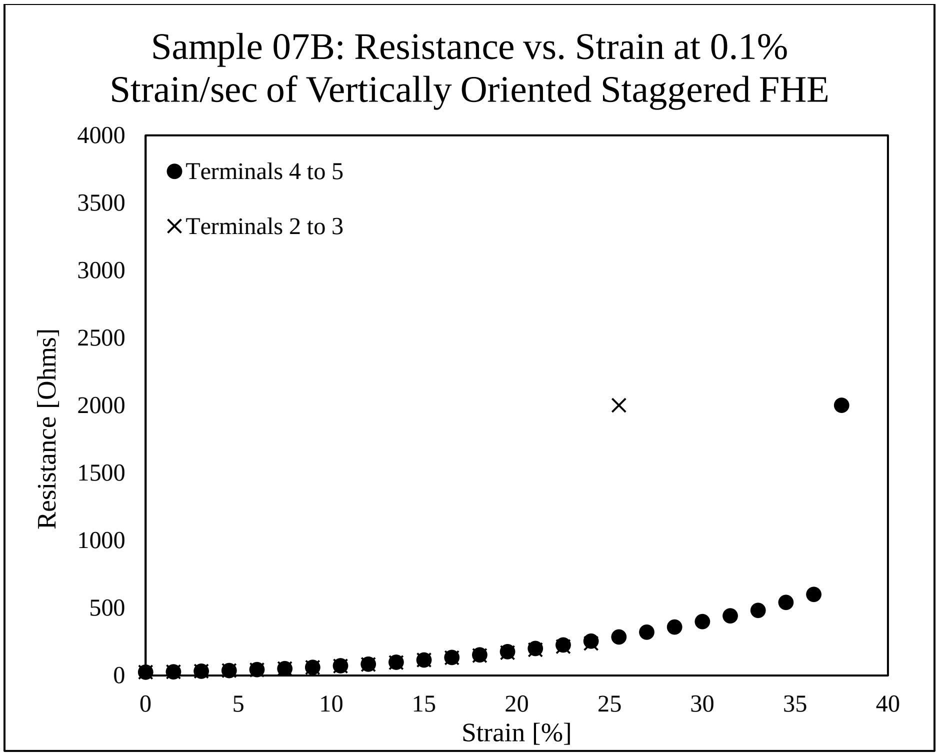

Sample 05B: Resistance vs. Time at 0.1% Strain/sec of Vertically Oriented Staggered FHE
Terminals 4 to 5
Terminals 2 to 3
Resistance [Ohms]
Time [sec]
0
500
1000
1500
2000
2500
3000
3500
4000
0
100
200
300
400
500
600


Sample 05B: Resistance vs. Strain at 0.1% Strain/sec of Vertically Oriented Staggered FHE
Terminals 4 to 5
Terminals 2 to 3
Resistance [Ohms]
Strain [%]
0
500
1000
1500
2000
2500
3000
3500
4000
0
10
20
30
40

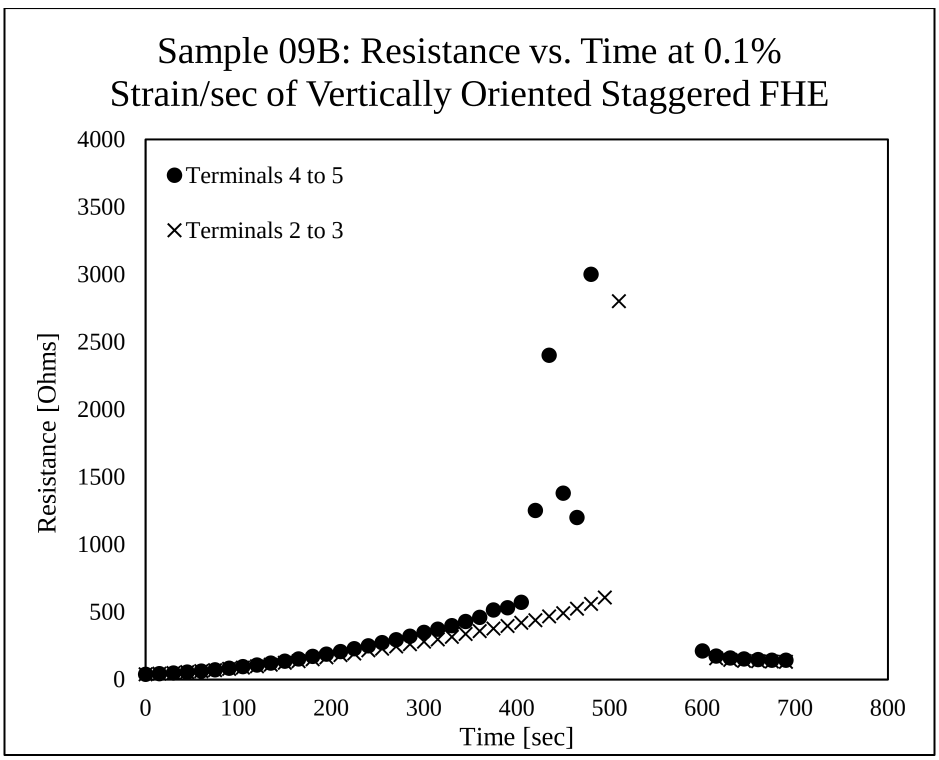


** Note: Sample 06B resistances were not recorded immediately after release from the Instron.

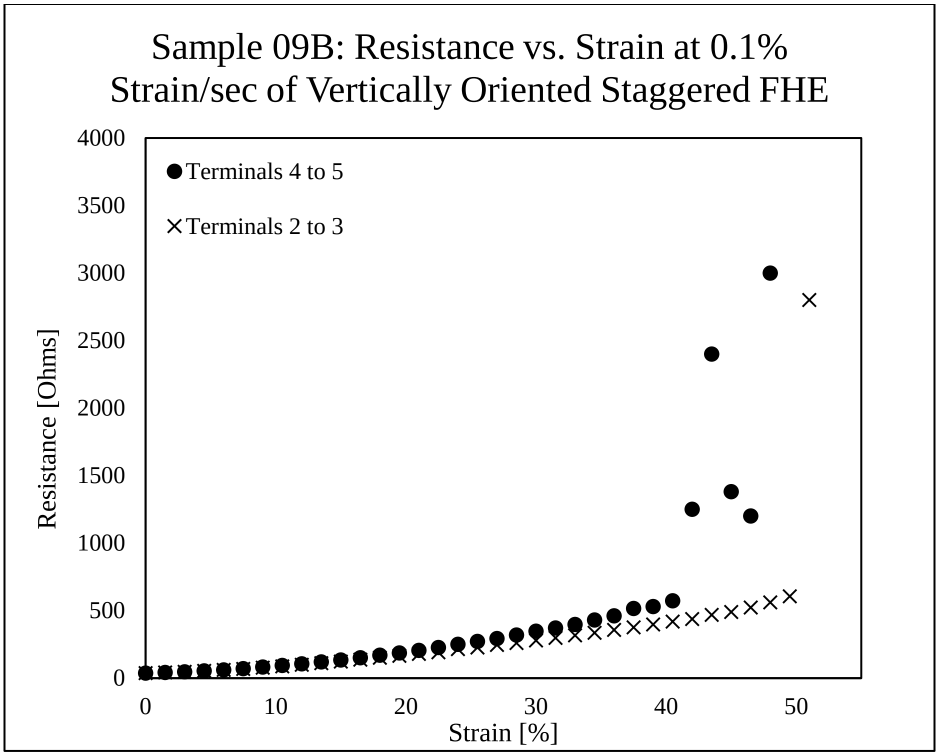




Sample 07B: Resistance vs. Strain at 0.1% Strain/sec of Vertically Oriented Staggered FHE
Terminals 4 to 5
Terminals 2 to 3
Resistance [Ohms]
Strain [%]
0
500
1000
1500
2000
2500
3000
3500
4000
0
5
10
15
20
25
30
35
40



Sample 09B: Resistance vs. Time at 0.1% Strain/sec of Vertically Oriented Staggered FHE
Terminals 4 to 5
Terminals 2 to 3
Resistance [Ohms]
Time [sec]
0
500
1000
1500
2000
2500
3000
3500
4000
0
100
200
300
400
500
600
700
800

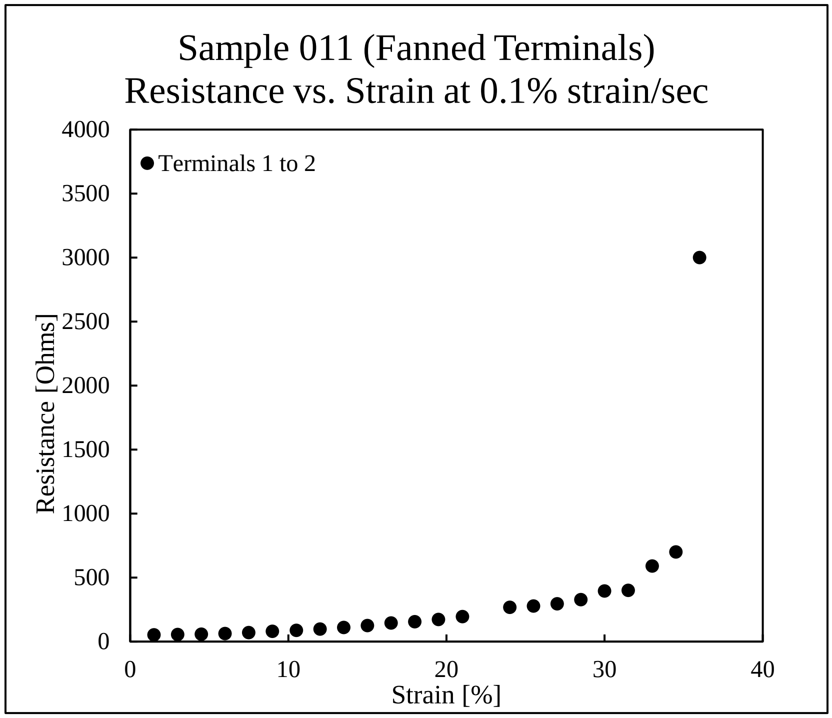


Sample 09B: Resistance vs. Strain at 0.1% Strain/sec of Vertically Oriented Staggered FHE
Terminals 4 to 5
Terminals 2 to 3
Resistance [Ohms]
Strain [%]
4000
3500
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50

Appendix M: Raw Data for Fanned Sample Testing

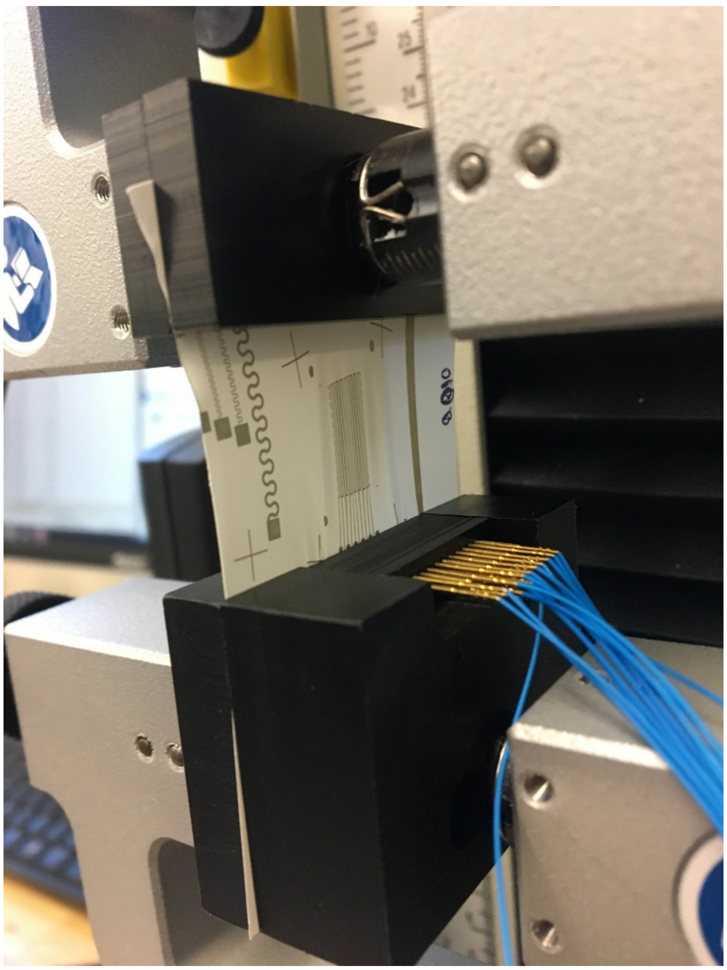
Test completed on May 23, 2017.

Sample 011		
Time [sec]	Strain	T1 to T2 [Ohm]
15	1.5	52.4
30	3	54.1
45	4.5	57.4
60	6	61.8
75	7.5	68.6
90	9	79.5
105	10.5	86.6
120	12	97
135	13.5	109.9
150	15	124
165	16.5	144.3
180	18	154.3
195	19.5	171.7
210	21	194.3
225	22.5	
240	24	268
255	25.5	278
270	27	294
285	28.5	328
300	30	396
315	31.5	400
330	33	590
345	34.5	700
360	36	3000



Reliability Test Fixture for Flexible Hybrid Electronic
Operator's Manual

Written by the ME BendatroniX Team
Julia Roche, Maya Manzano, and Paul Swartz
June 2017



Parts List

This section outlines the required parts and materials that may be needed for the varying reliability tests. The parts are all located in the "Newest Prototypes" bag in the BendatroniX bin in the Instron MATE lab.

Required parts:

- All four clamps shown below and the pogo pin housing:

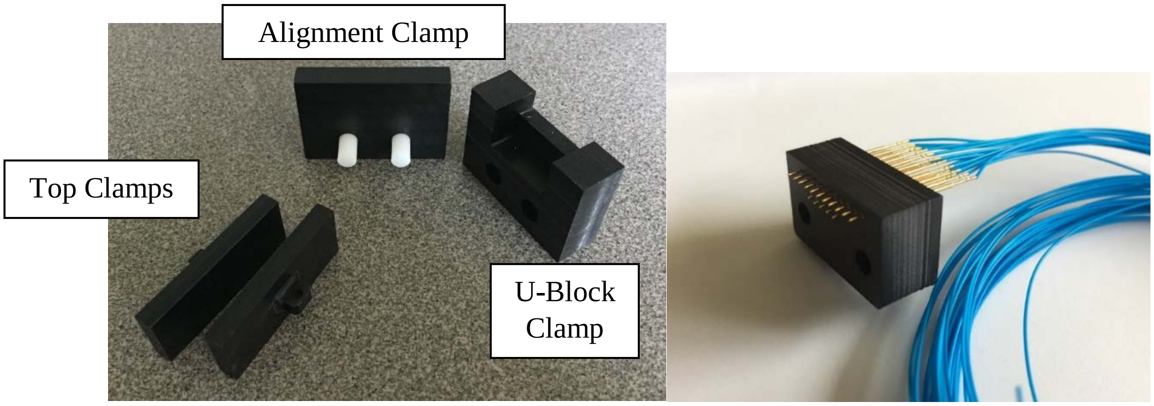


Figure N1. Left: four clamps required for validation testing. Right: pogo pin housing.

- M1.6 x 0.35, 12mm long screws (x2)
- 1.5mm hex key
- Acrylic cutting template (one for the staggered and one for the fanned):

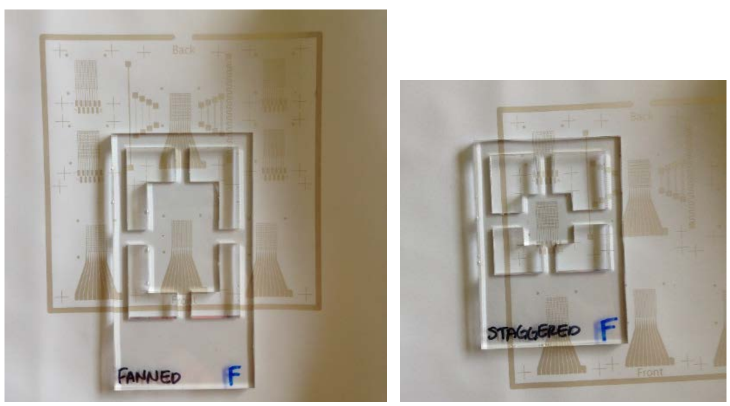


Figure N2. Acrylic dies for the fanned and staggered FHE configurations.

- X-Acto knife
- Electric tape
- Double-sided tape
- Instron side-action-grips (top and bottom)
    - Note: often already loaded into Instron Mini 55
- 1/8" Instron locking pin (x4)

    - Note: these are often already loaded in the Instron Mini 55. Instructions on how to retrieve them are located in Loading Clamps into Instron.
- Multimeter
- Electrical tape
- Stopwatch
- Data recording workbook (i.e. Microsoft Excel)

U-Block Clamp Assembly

Equipment Required

- Pogo Pin Housing (PPH)
- M1.6 x 0.35, 12mm long screw (x2)
- 1.5mm hex key

Setup

1. Confirm the PPH is complete with all pins and wires attached.
2. Place the PPH in the U-block with pins facing the flat side (without tab).
3. Tighten screw(s) until back face of PPH is mated to the corresponding U-block face and screws are flush with the U-block surface.

   Note: with current configuration, only one screw can be used at a time to load the pogo pin housing into the U-block.

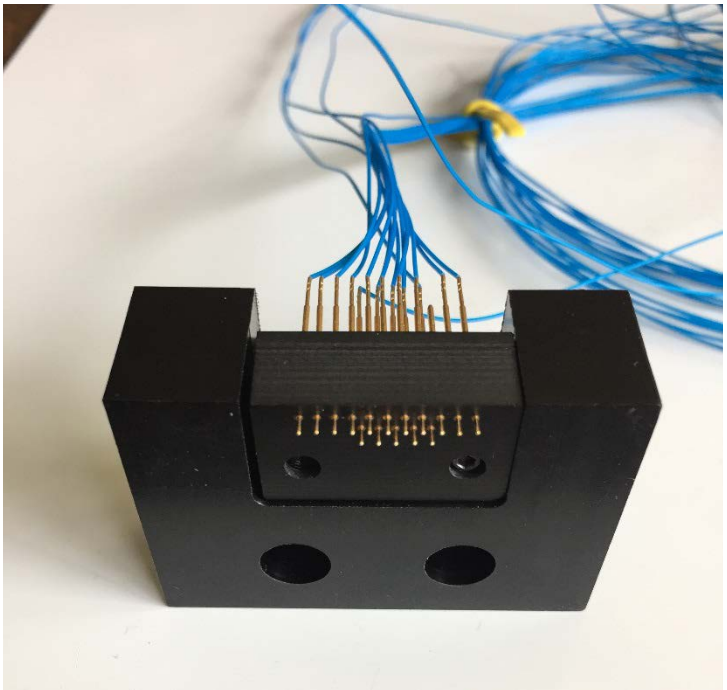


Figure N3. Pogo pin housing loaded into U-block. Note that only one screw can be used in current configuration

<u>FHE Sample Preparation and Loading</u>

Equipment Required

- Complete FHE design printed on TPU substrate
- Acrylic cutting template
- X-Acto knife

Setup

1. Lay the TPU substrate on a flat surface.
2. Select the circuit to cut out and align the inner square corners of the acrylic template with the cross fiducials on the substrate, as shown above in Figure N4.

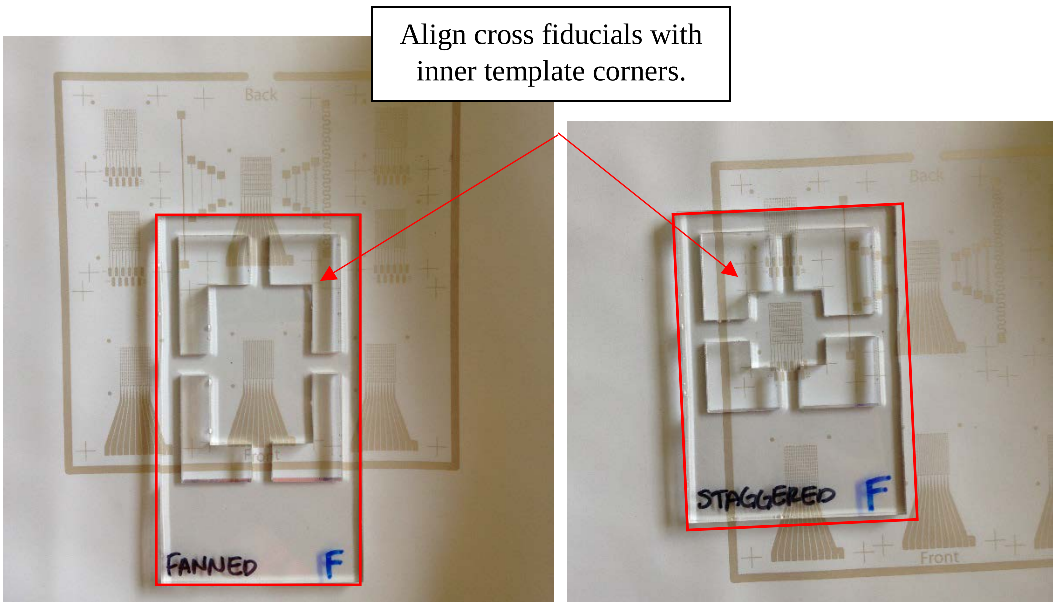


Figure N4. Select the correct acrylic die template and line up the cross fiducials with the inner corners of the acrylic die.

3. While pressing down on the template, carefully use the X-Acto knife to cut the substrate along the outer perimeter of the acrylic template (highlighted in red in Figure N4). It is okay to cut through unwanted circuits surrounding the desired FHE sample.

    WARNING! If the terminals are not lining up with the pogo pins during testing, this process will need to be adjusted or new acrylic templates will need to be manufactured (refer to Final Design Report for acrylic solid models). To adjust the cut, try varying how the inner corners of the die line up with the fiducials (shifting the acrylic die downwards relative to the fiducials will shift the pogo pin alignment). Further troubleshooting may be required.

4. Lift the template and remove the cut FHE test sample as seen in Figure N5.

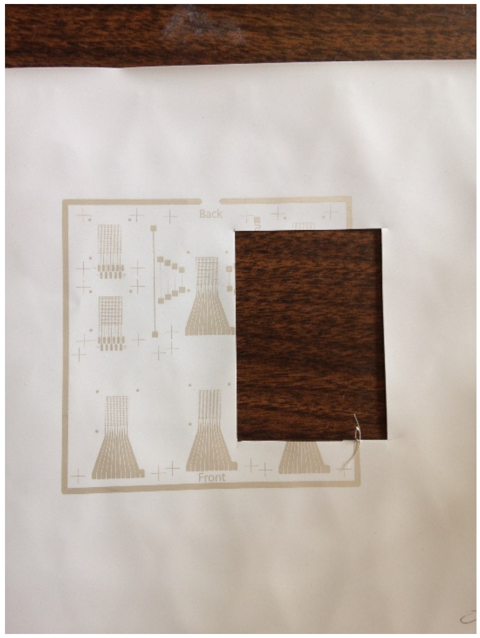


Figure N5. Cut sample removed from original TPU sample.

5. With the backing still on, insert the FHE sample (with the backing still on) into the hole cutter with the terminals facing the holes. To ensure that the sample is cut properly, push the sample all the way flush to the side metal brace.

   WARNING: Do not adjust the hole locations in the hole punch as they are perfectly lined up to cut the sample.

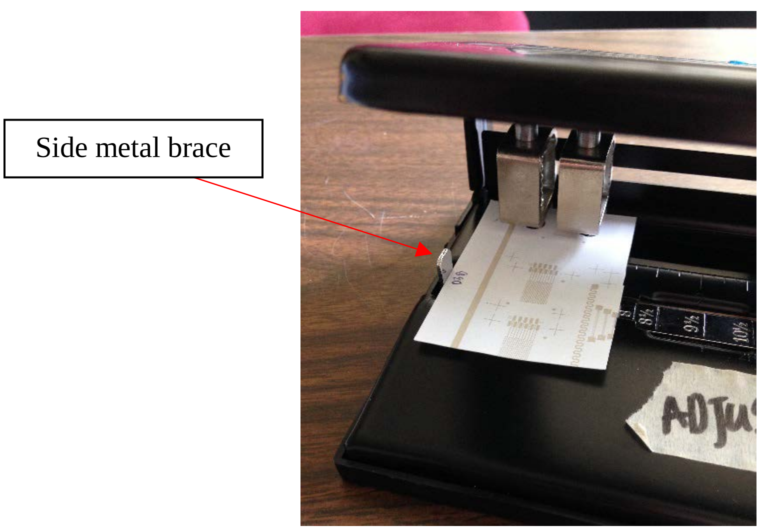


Figure N6. Insert cut sample (with backing still on) into the hole punch. Make sure sample is lined up against side metal brace.

6. Remove FHE sample from the hole cutter, label the sample with a pen, and carefully remove backing.
7. The sample is now ready for testing.

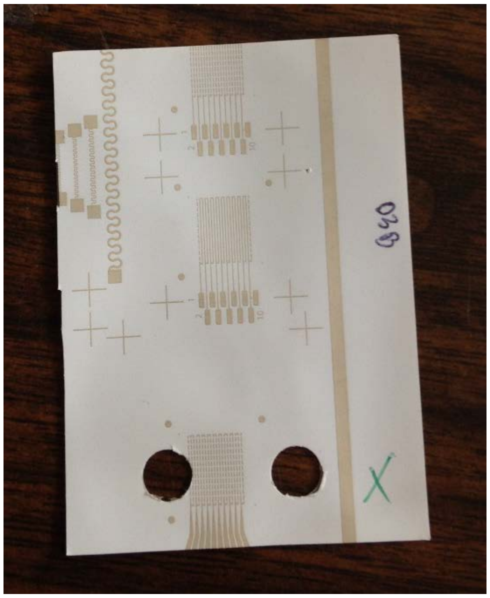


Figure N7. Labeled sample ready for testing.

<u>Loading Clamps into Instron</u>

Equipment Required

- Four clamps: U-block clamp assembly, alignment clamp assembly, top left, top right. For instructions on how to assemble U-Block Clamp, refer to U-Block Clamp Assembly.
    - Note: they are located in a Ziplock bag titled "newest prototypes."

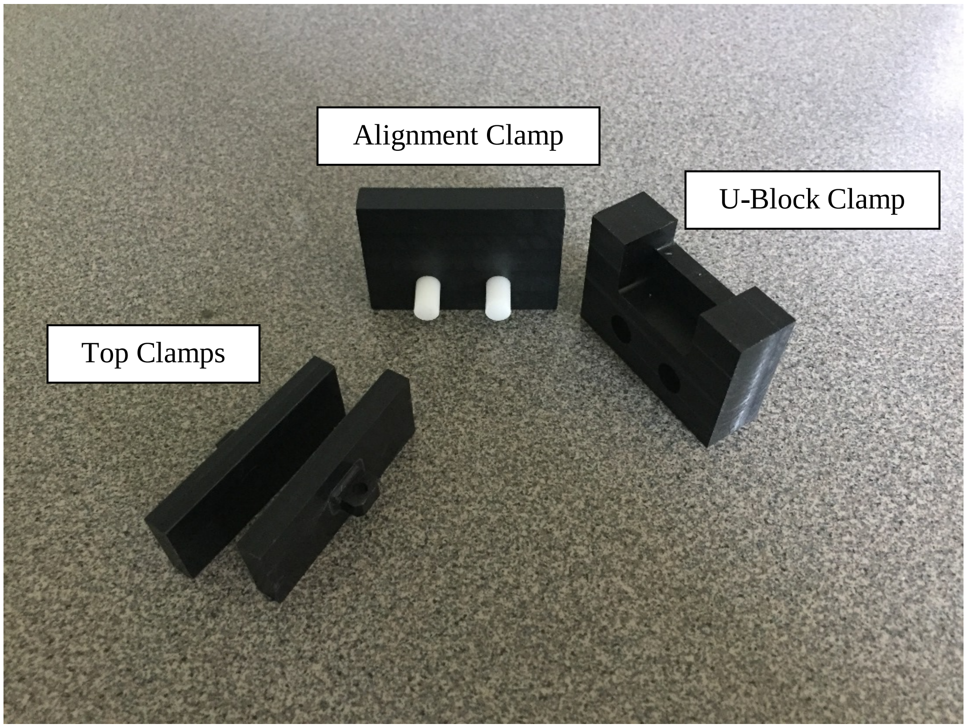


Figure N8. The four clamps required for testing. Note that in the Figure, the U-Block Clamp does not have the pogo pin housing attached. For instructions on how to attach pogo pin housing, refer to U-Block Clamp Assembly.

- Instron side-action-grips (top and bottom)
    - Note: often already loaded into Instron Mini 55
- Multimeter
- Electrical tape
- 1/8" Instron locking pin (x4)
    - These come from the flat clamps that are normally loaded in the Instron Mini 55. To locate them, remove the current flat clamps (remove by unscrewing the side-action-screw until the flat clamp falls out) from the side-action-grips and take the four pins from the clamps. Figures N9-N13 outline the steps necessary to get the pins.

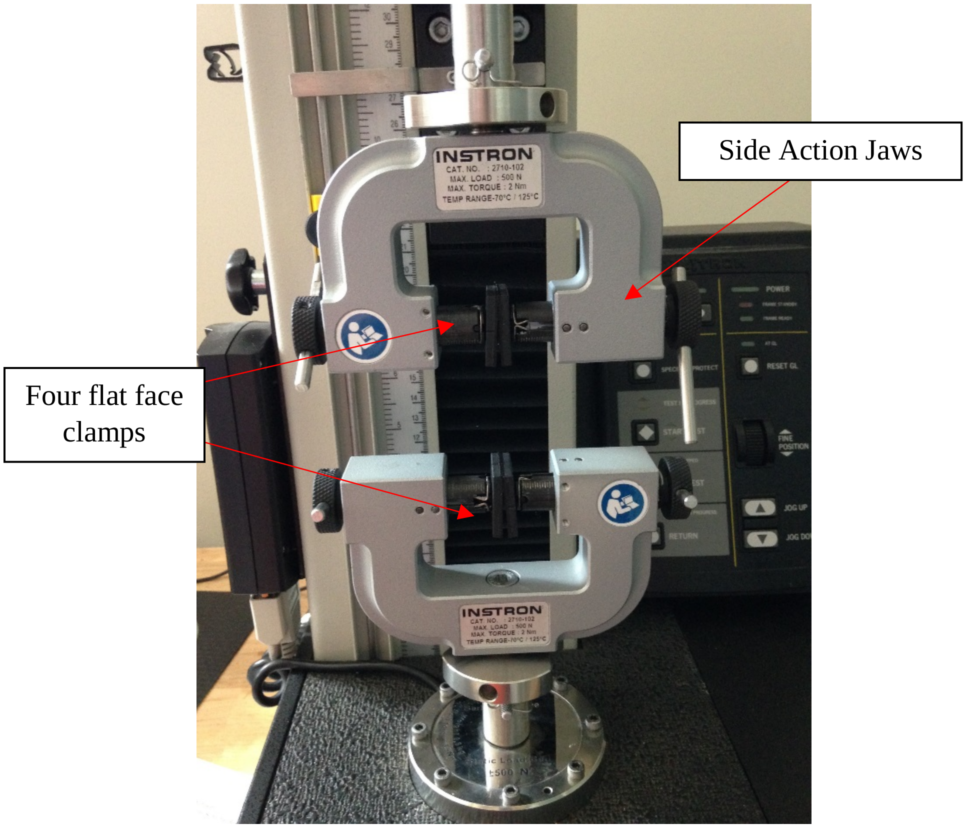


Figure N9. The Instron Mini 55 with side action jaws and flat face clamps already loaded.

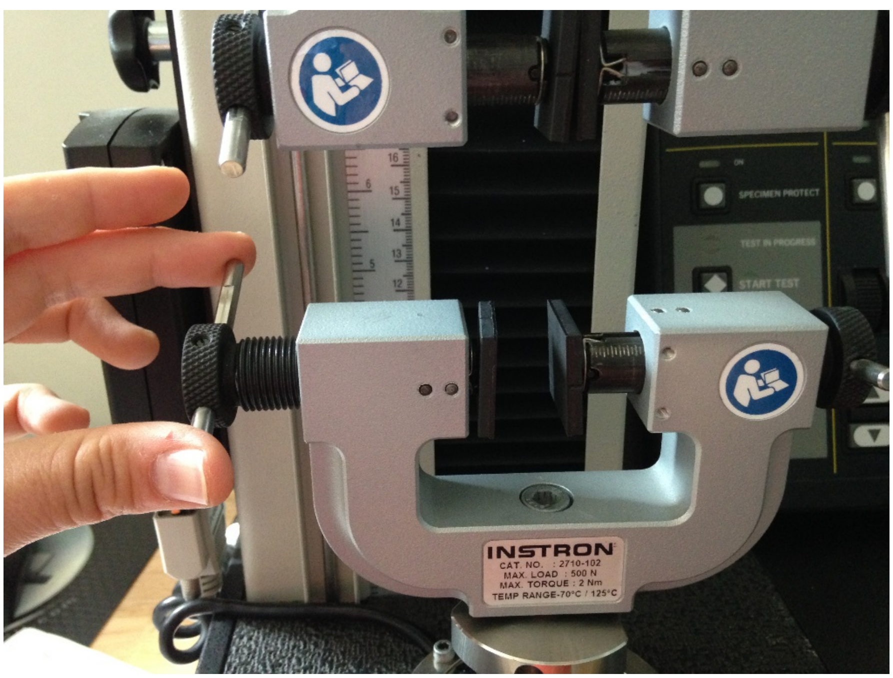


Figure N10. Twist side action jaws until flat clamps fall out.

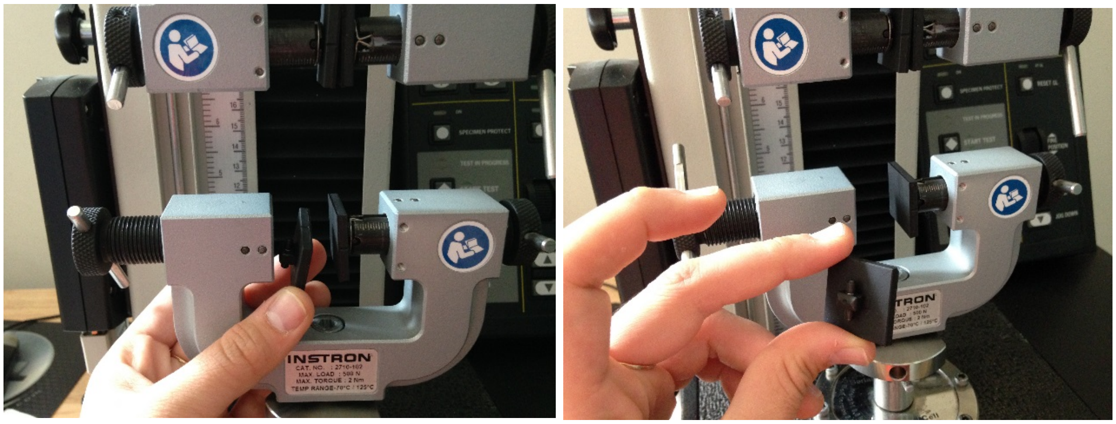


Figure N11. Remove the flat clamps. Make sure that the pin does not fall out.

Figure N12. Instron flat face clamp and 1/8” Instron locking pin.

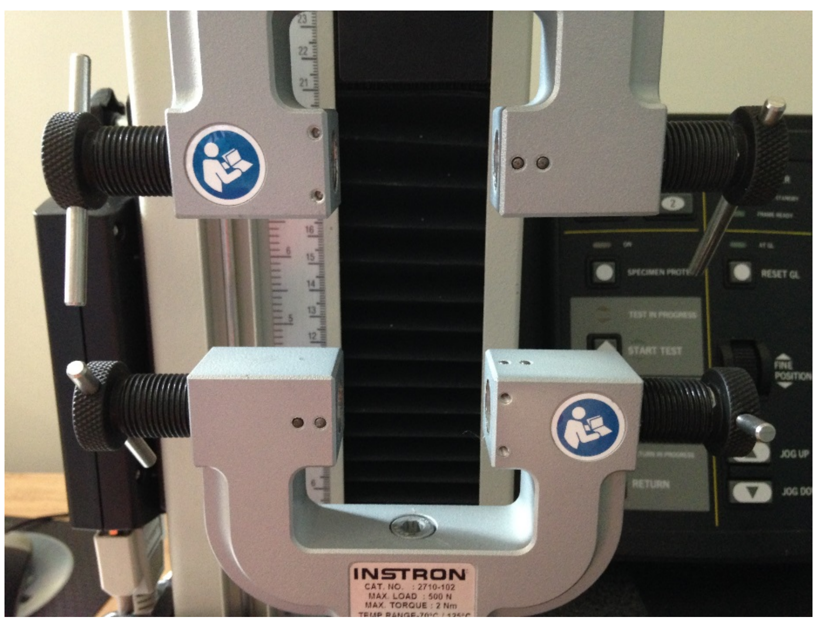


Figure N13. Instron ready for FHE testing set-up.

Setup

1. Insert 1/8" Instron locking pin into hole in tab on the back of U-block.

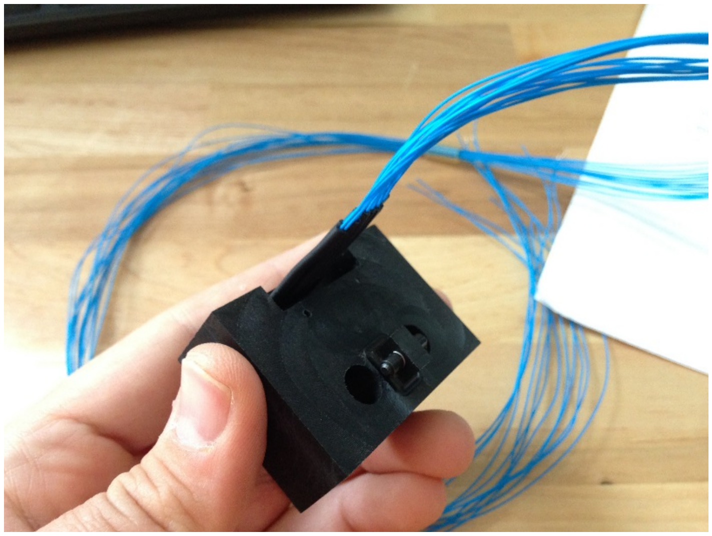


Figure N14. 1/8” Instron locking pin inserted into assembled U-Blovk Clamp.

2. Unscrew the bottom side-action-grips until fully back out (screw should already be screwed back from when you removed the flat clamps that were the default set up).
3. Insert U-block into the right-bottom grip and screw the jaw toward the center until the U-block “clicks” into place.
    a. Note: try to keep the wires out of the way of the screw by letting the drape over your hand. Do not fully center the clamps until the sample is loaded.

Figure N15. Insert assembled U-Block clamp into side action jaws. Push pin and tab into the jaw until it “clicks” into place.

4. Repeat steps 1-3 for top clamps. DO NOT INSTALL ALIGNMENT CLAMP! Ensure that the top clamps are high enough to allow for easy set-up of the bottom clamps.
    a. For the top clamps, there is a left "L" and a right "R" one corresponding to the way that the insertion tabs are located on the back of the clamp. Refer to "L" and "R" labels.

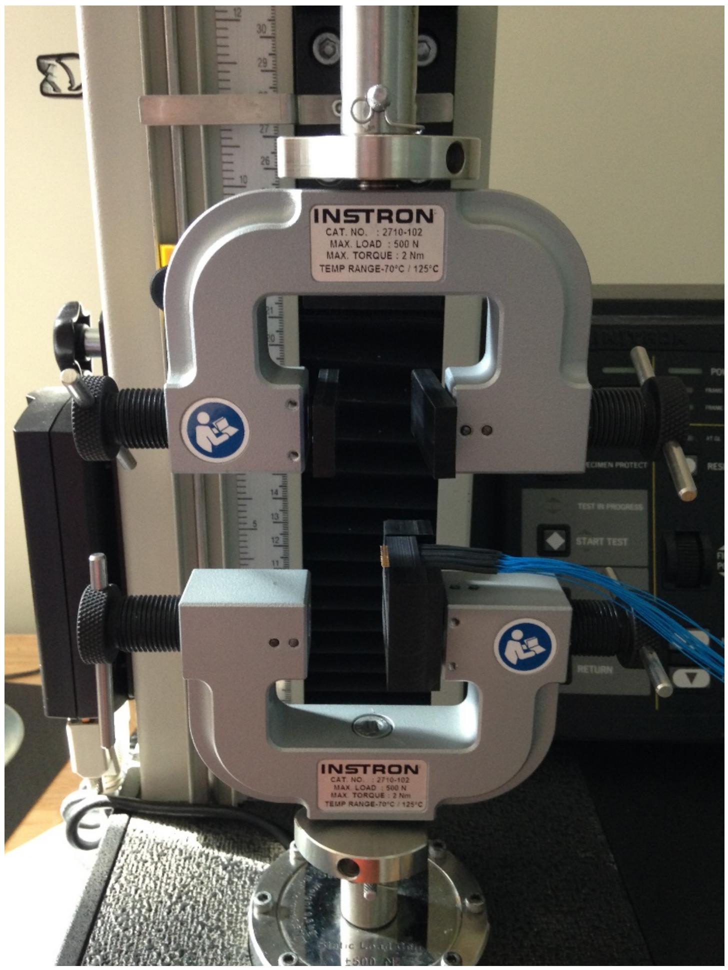


Figure N16. Top clamps and U-Block clamp assembly loaded into Instron.

5. Load pre-cut sample onto alignment block before loading block into Instron. Make sure the sample is loaded with the circuit facing towards where the pogo pins are so that they make contact.
6. When loading the alignment block, screw it in until the white dowel pins go into the clearance holes in the U-block. This prevents the sample from accidentally falling out.

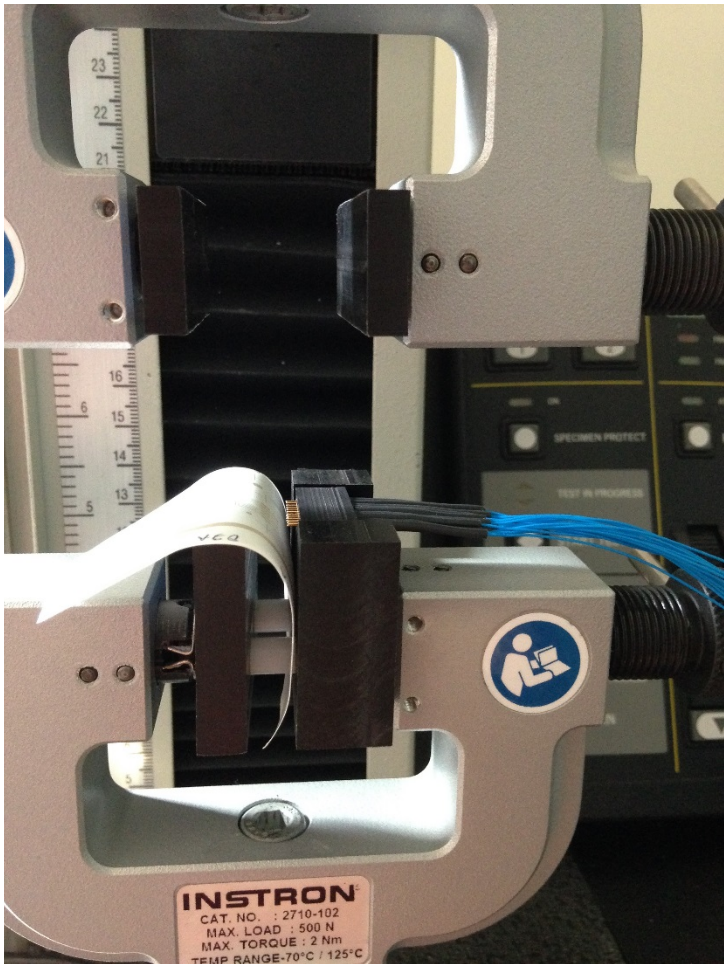


Figure N17. Load sample onto alignment clamp and then load alignment clamp with sample into the Instron. Screw together the alignment clamp and U-Block clamp to prevent sample from falling out.

7. To center and clamp the sample, there are ticks on each of the screws. Clamp the bottom of the sample and then the top. For the bottom, the U-block has 3 ticks and the alignment block has 10.

   WARNING! This is the most important step of alignment. When you clamp the two bottom clamps, you need to ensure that the pogo pins are making contact with the sample. This is best done by eye. When tightening the bottom clamps, look down at the terminals and see if they are lining up.

   - Fanned: every pin in the top row of the pogo pin housing should line up with each fanned terminal
   - Staggered: There should be three free (not touching a terminal) pogo pins on the top row on the user side and there should be two pogo pins on the top row on the back side. Refer to Figure N18.

TROULBESHOOTING: To make sure that the terminals are lined up with the pogo pins, tighten the bottom clamps together and then test the shorted terminals (as mentioned in Step 4) for conductivity. If they are conductive, then the pogo pins are lined up correctly. If not, re-open the clamps and readjust the sample.

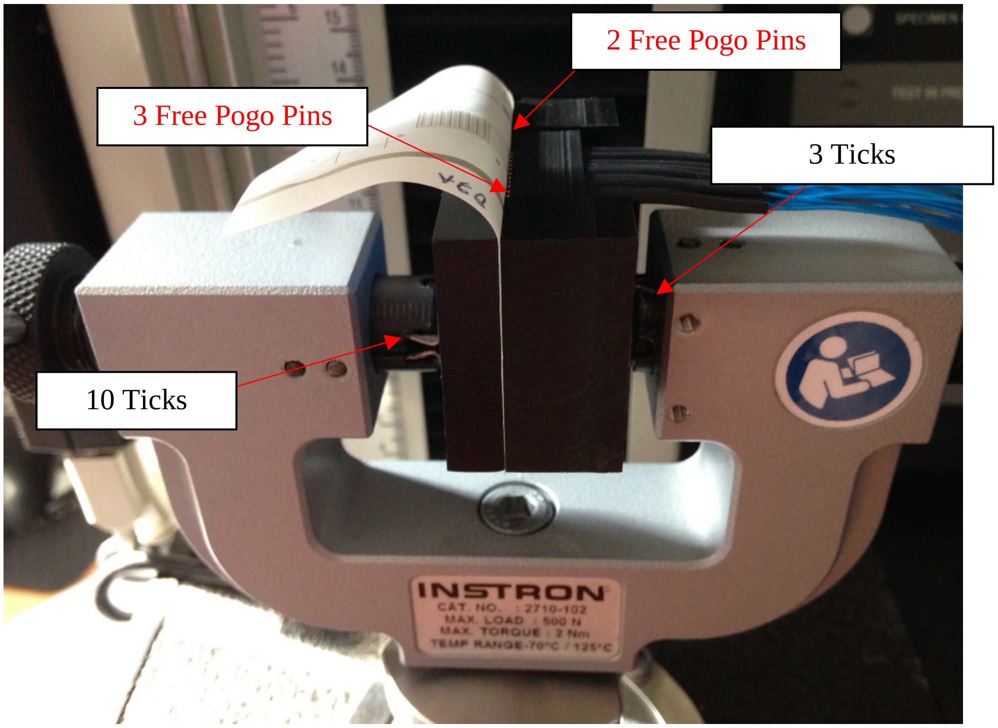


Figure N18. Sample clamped down with terminals aligned. Note the 10 ticks on the left and the 3 ticks on the right.

8. Once the sample is properly loaded in the bottom clamps, lower the top clamps until the top of the clamps is flush with the top of the sample.

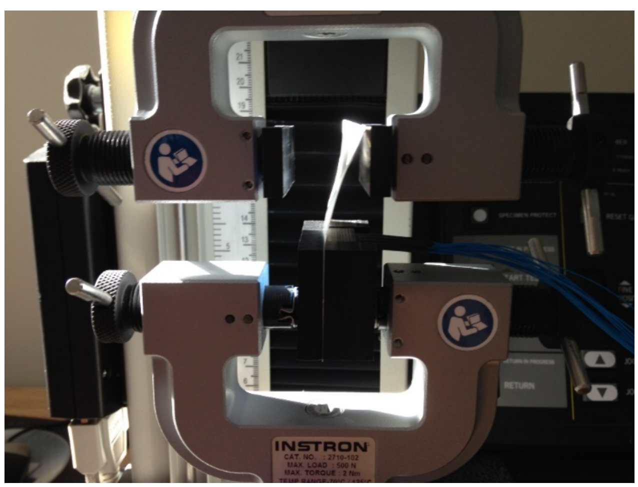


Figure N19. Jog the top clamps down until the top of the clamps are flush with the top of the sample.

9. Tighten the top clamps until each clamp has 12.5 ticks showing.

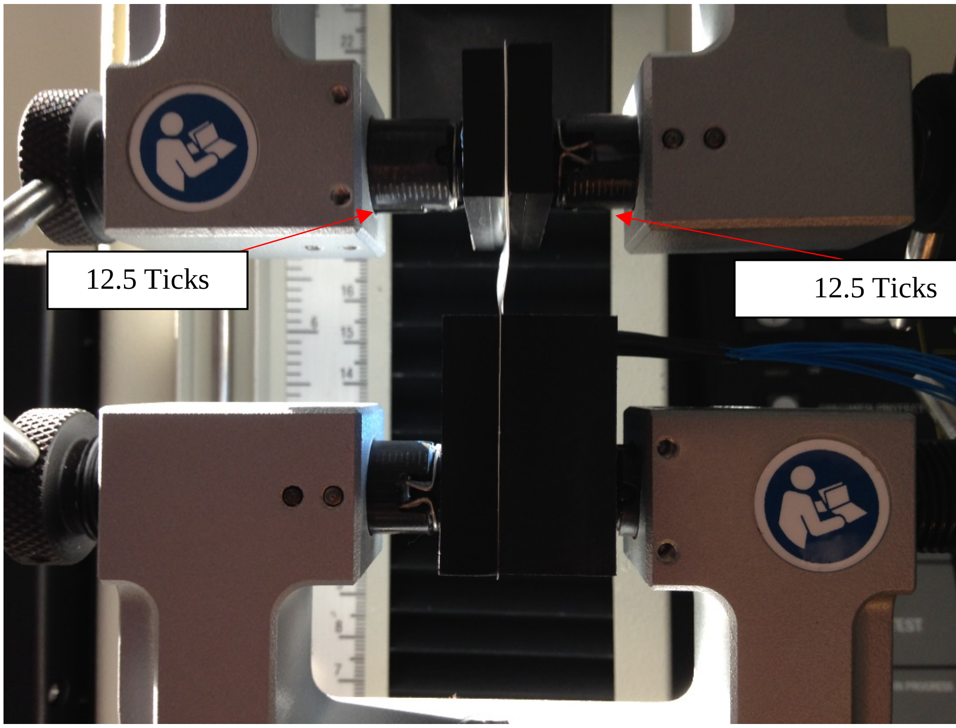


Figure N20. Clamp down on the top of the sample. Note the 12.5 ticks on each side.

10. Slightly jog the top clamps up to straighten the FHE sample.
11. Attach the appropriate wires of interest to the chosen resistance measuring system (ex: a multimeter and electrical tape or a breadboard). To make this process easier, labels can be attached to each wire. To help with trouble shooting later, make sure the two shorted wires are labeled and easily accessible. The shorted terminals are the last two terminals on the right for the staggered and fanned design.

Figure N21. Example of terminal wires of interest attached to multimeter.

12. Typical resistance readings across two terminals next to each other (i.e. terminals 1 and 2 or terminals 5 and 6) should read on the magnitude of 20-100Ω. Between the shorted terminals, the resistance reading should be on the magnitude of 1-10Ω.
13. The sample is now loaded and the appropriate tensile test (as seen below) can be completed.

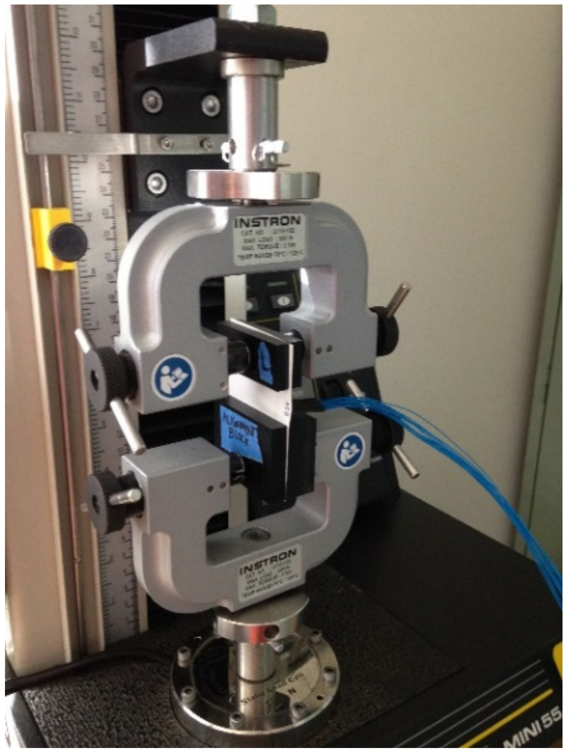


Figure N22. Sample loaded and ready for testing.

Tensile Testing

A variety of tensile tests can be performed on the FHE in order to determine different failure criteria. This section will provide a generic outline for completing any one of the tensile tests, followed by the exact steps necessary to complete each individual test. The tensile tests outlined in this manual are based on IPC-9204: A Guideline on Flexibility and Stretchability Test Methods for Printed Electronics. A generic concept sketch of the setup for the tensile tests can be seen in Figure N23.

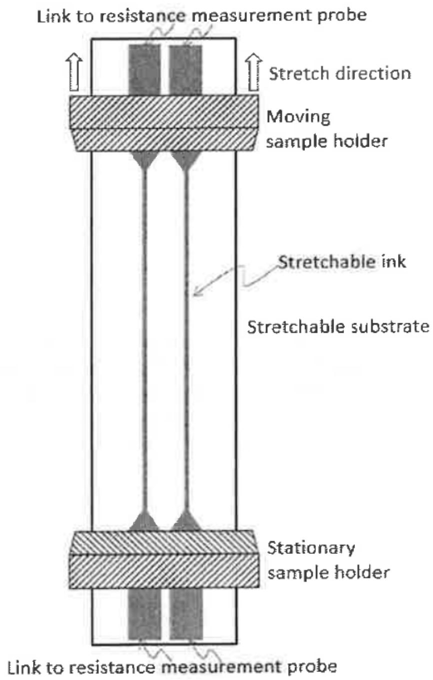


Figure N23. Concept sketch for stretchability limit test.

Equipment Required

- Instron Mini 55 and Bluehill Software
- Instron pneumatic side action grips
- 1/8" locking pins (x4 each)
- Top clamp (x2)
- U-block clamp assembly (refer to U-Block Clamp Assembly)
- Alignment clamp assembly
- FHE sample prepared for testing (refer to FHE Sample Prep and Loading for instructions on how to do this)
- For manual system:
  - Multimeter
  - Stopwatch
  - Data recording workbook (i.e. Microsoft Excel)
- For automated system:
  - Data acquisition system
  - Any additional equipment

Generic Setup

1. Load top clamps, the assembled U-Block clamp, and the alignment block clamp into the nuematic Side Action Grips (refer to Loading Clamps into Instron).
2. Ensure that the Instron Pnuematic Side Action Grips (with all clamps correctly installed) are loaded into the Instron Mini 55.
3. Cut FHE sample to the correct size. Measure the specimen width and height in your data recording workbook. Load FHE sample into clamps (refer to FHE Sample Prep and Loading).

   WARNING: Make sure the pogo pins make contact with the FHE terminals!
4. After proper tensile testing set up, select one of the IPC tests in the following section and follow the additional steps.

IPC 6.1: Stretchability Limit Test

This test method can be used to determine the resistance of the FHE as a function of tensile strain as outlined in IPC-1204 6.1. The FHE sample is loaded into the Instron, the resistance across the FHE is monitored, and the sample is stretched until the FHE fails.

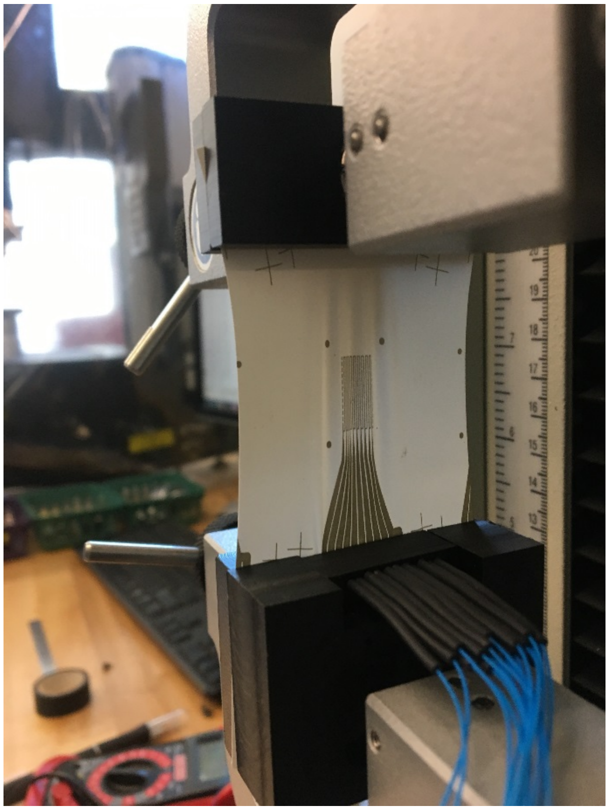


Figure N24. Example of FHE sample undergoing tensile testing.

Specific Setup

1. Load appropriate strain protocol into Bluehill Software (ex: stretching the sample 0.1% strain/sec until the sample reaches 20% strain).

   WARNING! When inputting the sample size into Bluehill, make sure to measure the exposed sample length each time. These are the design length x width, so the actual samples may vary slightly:

   - Staggered: 16.5mm x 50mm
   - Fanned: 37mm x 50mm

2. Ensure that multimeter is monitoring terminals of interest from the pogo pin housing.
3. Determine the time interval of resistance readings to be measured (ex: reading every 15 or 30 seconds).
4. Begin test and record resistance readings for each time interval in workbook.
5. Continue recording resistances until sample fails (~ 2000Ω).

6. If necessary, take multimeter and probe along PPH wires until the location of the circuit failure can be found.
7. Plot resistance versus strain to determine electrical failure point for FHE sample.

IPC 6.2: Cyclic Stretchability Test

This test method can be used to verify if the FHE can withstand repeated elongation cycles under a tensile load as outline in IPC-1204 6.2. The FHE sample is loaded into the Instron Tensile Tester, the resistance across the FHE is monitored, and the sample is cyclically stretched to a specific strain.

Specific Setup

1. Load appropriate fatigue protocol into Bluehill Software.
2. Ensure that multimeter is monitoring the terminals of interest.
3. Begin fatigue test.
4. Monitor resistance until failure point reached. At point of failure, stop fatigue test and record the number of cycles in workbook.
5. If necessary, take multimeter and probe along PPH wires until the location of the circuit failure can be found.

IPC 6.3: Stretchability Under Constant Load Test

Purpose

This test method can be used to verify the functionality of the FHE under constant tensile loading as outline in IPC-1204 6.3. The FHE sample is loaded into the Instron Tensile Tester, the resistance across the FHE is monitored, and the sample is stretched to a specific strain and held for a predetermined time or until failure occurs.

Specific Setup

1. Load appropriate fatigue protocol into Bluehill Software.
2. Ensure that multimeter is monitoring the terminals of interest.
3. Stretch sample to predetermined load.
4. Monitor resistance versus time until the sample fails or the resistance reading stabilizes.
5. If necessary, take multimeter and probe along PPH wires until the location of the circuit failure can be found.

IPC 7.4: DeMattia Flexibility Test

Purpose

This test allows the FHE to undergo alternate stretching and bending. While this test is similar to IPC 6.2, the clamps come close enough together to produce a bend in the FHE sample during the test as seen in Figure N25.

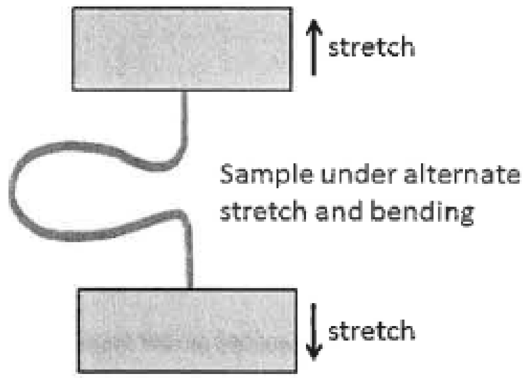


Figure N25. Concept sketch for DeMattia Flexibility test.

Specific Setup

1. Load appropriate DeMattia flexibility protocol into Bluehill Software.
2. Ensure that multimeter is monitoring the first and last wires from the pogo pin housing (corresponding to the first and last FHE terminals).
3. Begin DeMattia flexibility test.
4. Monitor resistance until failure point reached. At point of failure, stop fatigue test and record the number of cycles.
5. If necessary, take multimeter and probe along PPH wires until the location of the circuit failure can be found.

References

[1] Printed Electronics and Validation Subcommittee (D-65) of the Printed Electronics Committee (D-60) of IPC. *IPC-9204 Guideline on Flexibility and Stretchability Test Methods for Printed Electronics*. *2nd Working Draft*. July 2016. Print.