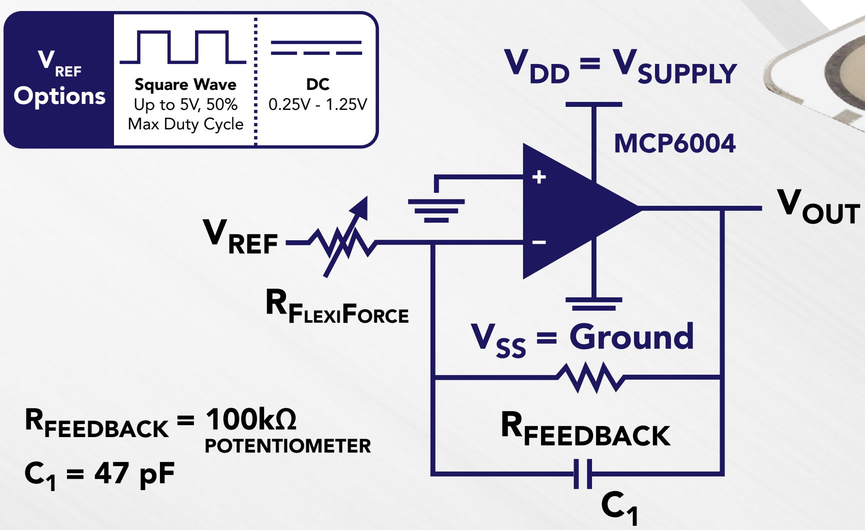
# FlexiForce™ Integration Guide

## *Edition 2*


Tekscan™

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# COMPANY & SENSOR OVERVIEW

## PURPOSE

The purpose of this document is to provide critical design information for OEM design engineers who are looking to optimize sensor feedback and response within their device while meeting their project's budgetary constraints. The information in this document will help the design engineer to:

- Gain an understanding of FlexiForce™ sensors to help optimize their design and reduce the cost of the force sensing module.
- Minimize the overall project time of designing and embedding a FlexiForce sensor - from prototype to production implementation.

## COMPANY OVERVIEW

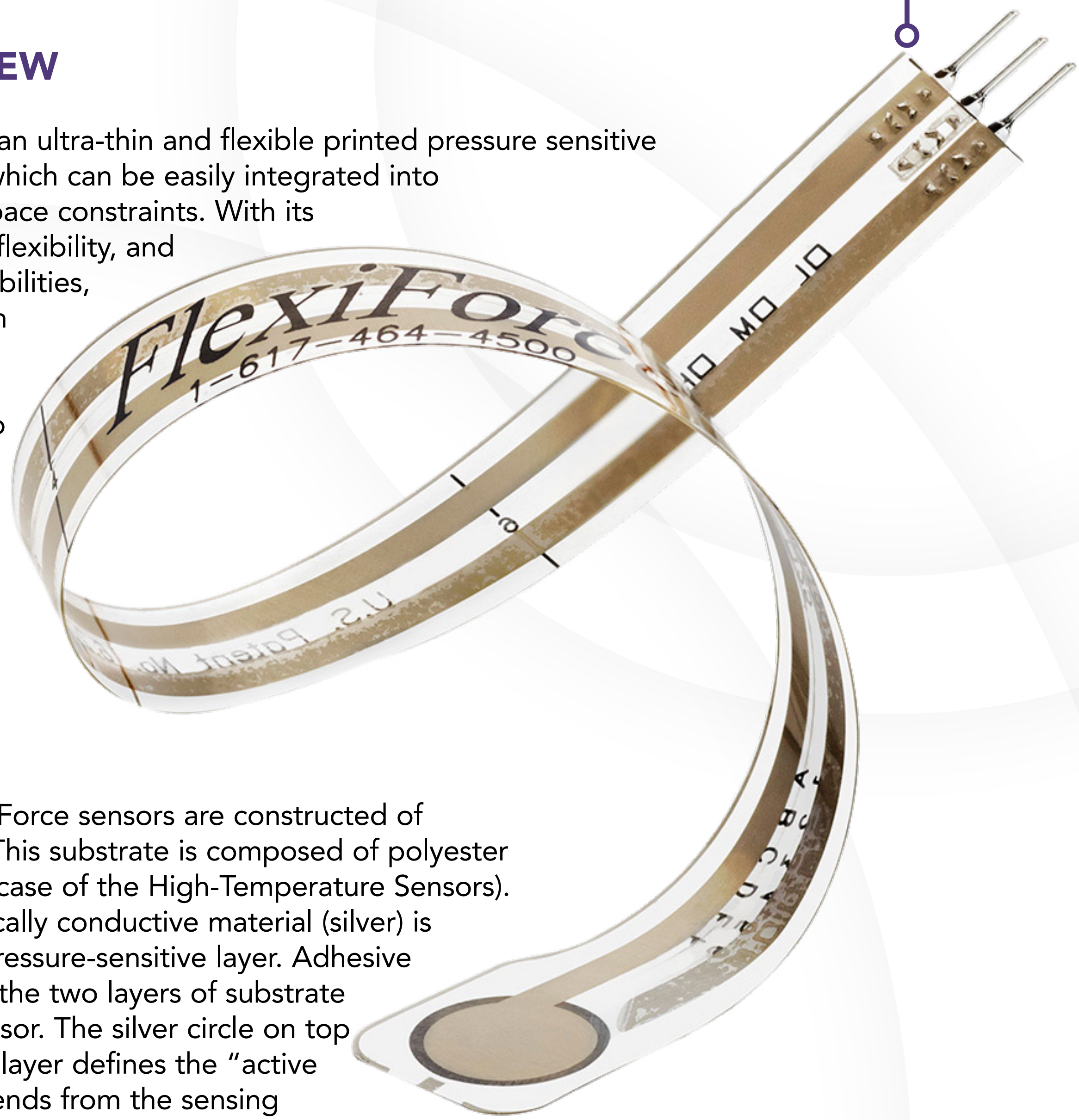
Tekscan is the world leader in ultra-thin force & pressure measurement sensors and systems. Tekscan's sensors and systems are used in a continually expanding array of important applications in industry, medicine, and dentistry. Our team of full-time, experienced application, electrical, mechanical, and software engineers has a proven track record of exceptional results in very challenging design applications. Tekscan operates in an ISO 9001:2008 compliant & 13485:2016 certified facility in Boston, MA.

Tekscan's FlexiForce division specializes in designing and manufacturing custom and off-the-shelf standard sensor options for OEM applications as well as R&D and Test & Measurement applications. The unique construction and durability of these force-sensitive resistor sensors enables Tekscan custom-design force sensors to meet the specific needs of many OEM customers.

The FlexiForce product allows engineers to overcome challenges of size and space by providing a force-sensitive layer built on thin, light, and flexible material that is mechanically ideal for integrating into sleeker, smaller devices and applications. Our sensors are integrated into many applications and products in various industries including: medical, industrial, and robotic.

## SENSOR OVERVIEW

The FlexiForce sensor is an ultra-thin and flexible printed pressure sensitive variable resistor circuit, which can be easily integrated into applications with tight space constraints. With its paper-thin construction, flexibility, and force measurement capabilities, the FlexiForce sensor can measure force between almost any two surfaces and is durable enough to stand up to most environments. FlexiForce has better force sensing properties, linearity, hysteresis, drift, and temperature sensitivity than any other thin force sensors.




As shown in **Fig. 1**, FlexiForce sensors are constructed of two layers of substrate. This substrate is composed of polyester film (or Polyimide in the case of the High-Temperature Sensors). On each layer, an electrically conductive material (silver) is applied, followed by a pressure-sensitive layer. Adhesive is then used to laminate the two layers of substrate together to form the sensor. The silver circle on top of the pressure-sensitive layer defines the "active sensing area." Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads.

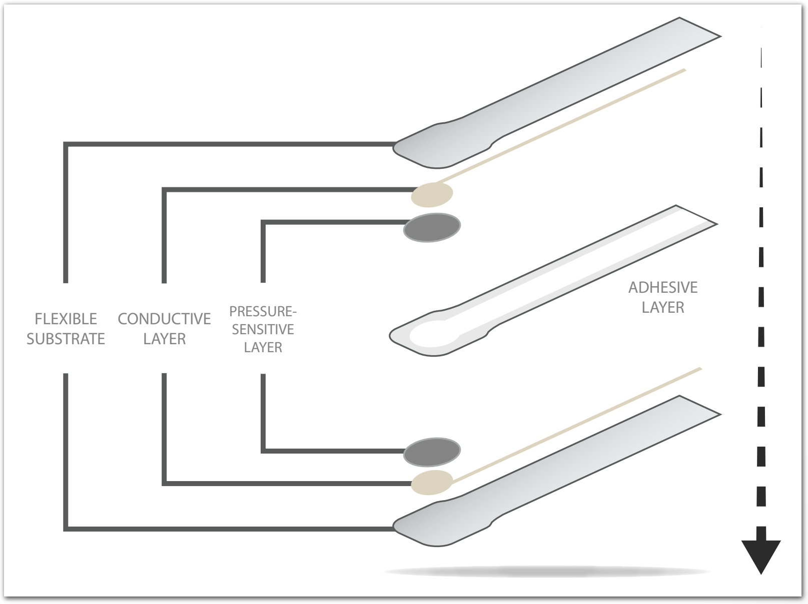



FIGURE 1: COMPOSITION OF A FLEXIFORCE SENSOR

# STANDARD SENSOR OPTIONS (AVAILABLE OFF-THE-SHELF)

## PHYSICAL PROPERTIES

| | A101 (Click to View Product Page) | A201 (Click to View Product Page) | HT201 (Click to View Product Page) | A301 (Click to View Product Page) | ESS301 (Click to View Product Page) | A401 (Click to View Product Page) | A502 (Click to View Product Page) |
|---|---|---|---|---|---|---|---|
| Thickness | .203 mm (0.008 in.) | | | | | | |
| Length | 15.6 mm (0.62 in.) | 197 mm (7.75 in.)<br>152 mm (6 in.)<br>102 mm (4 in.)<br>51 mm (2 in.) | | 25.4 mm (1.0 in.) | | 56.8 mm (2.24 in.) | 81.3 mm (3.20 in.) |
| Width | 7.6 mm (0.30 in.) | 14 mm (0.55 in.) | | | | 31.8 mm (1.25 in.) | 55.9 mm (2.20 in.) |
| Sensing Area | 3.8 mm diameter (0.15 in.) | 9.53 mm diameter (0.375 in.) | | | | 25.4 mm diameter (1.0 in.) | 50.8 mm x 50.8 mm (2 in. x 2 in.) |
| Connector | 2-pin male square pin | 3-pin male square pin | | 2-pin male square pin | | | |

## TYPICAL PERFORMANCE

The specs listed below are based on ideal loading conditions under a bladder. For information on Sensor Response Time, please contact a FlexiForce Applications Engineer.

| | Standard Pressure-Sensitive Layer (A101, A201, A301, A401, A502) | High Temp Pressure-Sensitive Layer (HT201) | Enhanced Stability Pressure-Sensitive Layer (ESS301) |
|---|---|---|---|
| Linearity Error | <±3% of full scale | <±3% of full scale | <±8.6% of full scale |
| Repeatability | <±2.5% | <±3.5% | <±2.5% |
| Hysteresis | <4.5% of full scale | <3.6% of full scale | <5.5% of full scale |
| Drift | <5% per logarithmic time scale | <3.3% per logarithmic time scale | <3.8% per logarithmic time scale |
| Operating Temperatures | -40°C - 60°C (-40°F - 140°F) | -40°C - 240°C (-40°F - 400°F) | -40°C - 85°C (-40°F - 185°F) |
| Force Range | Up to 4,440 N (1,000 lb) | Up to 222 N (50 lb) | Up to 440 N (100 lb) |
| Temperature Sensitivity | Output variance up to 0.2% per degree F | Output variance up to 0.16% per degree F | Output variance up to 0.2% per degree F |
| Durability | ≥ 1 million actuations | ≥ 1 million actuations | ≥ 1 million actuations |

# STANDARD SENSOR OPTIONS (AVAILABLE OFF THE SHELF)

## LINEARITY ERROR: ±3% OF FULL SCALE

Linearity refers to the sensor's response (conductance output) to the applied load, over the range of the sensor. This response should ideally be linear; and any non-linearity of the sensor is the amount that its output deviates from this line. A calibration is performed to "linearize" this output as much as possible. FlexiForce standard sensors are linear within ±3%.

## REPEATABILITY: ±2.5%

Repeatability is the ability of the sensor to respond in the same way to a repeatedly applied force. As with most measurement devices, it is customary to exercise, or "condition" a sensor before calibrating it or using it for measurement. This is done to reduce the amount of change in the sensor response due to repeated loading and unloading. A sensor is conditioned by loading it to 110% of the test weight four or five times. Follow the full procedure in the Conditioning Sensors section.

## DRIFT: <5% PER LOG TIME

Drift is the change in sensor output when a constant force is applied over a period of time. If the sensor is kept under a constant load, the resistance of the sensor will continually decrease, and the output will gradually increase. It is important to take drift into account when calibrating the sensor, so that its effects can be minimized. The simplest way to accomplish this is to perform the sensor calibration in a time frame similar to that which will be used in the application.

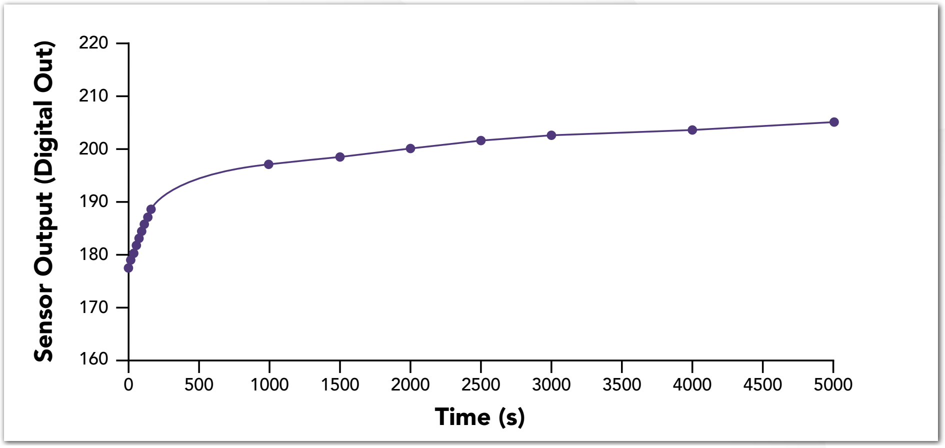



FIGURE 2: SENSOR DRIFT

## HYSTERESIS: <4.5% OF FULL SCALE

Hysteresis is the difference in the sensor output response during loading and unloading, at the same force. For static forces, and applications in which force is only increased, and not decreased, the effects of hysteresis are minimal. If an application includes load decreases, as well as increases, there may be error introduced by hysteresis that is not accounted for by calibration.

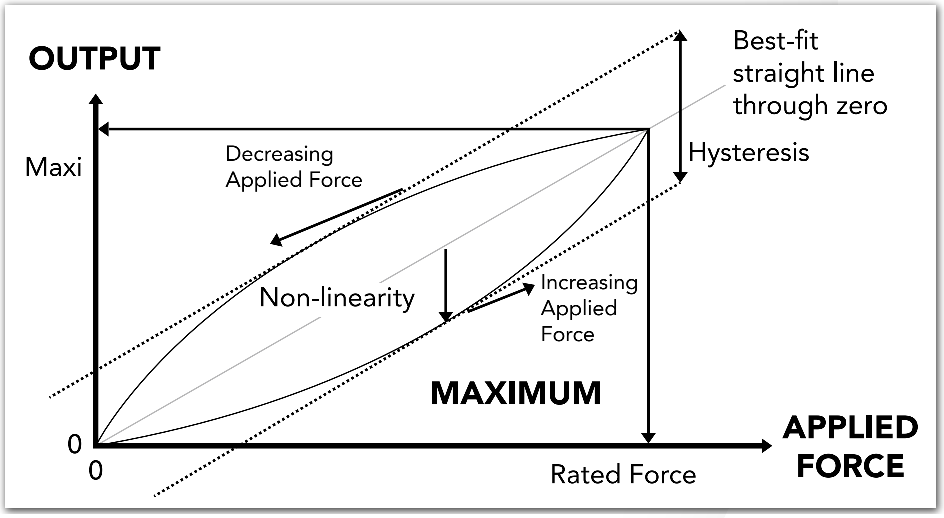


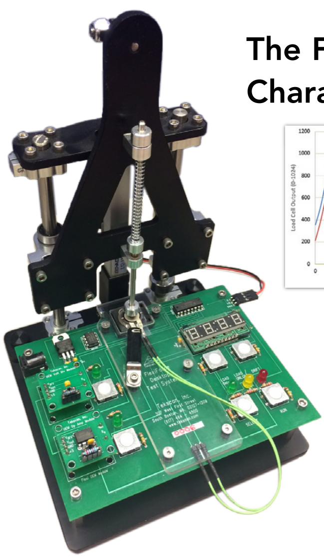

FIGURE 3: HYSTERESIS

# FlexiForce OEM Development Products

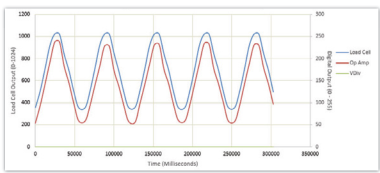
Engineers and designers integrating FlexiForce sensors into OEM products often have questions about how the sensor will perform in their specific application. How will the sensor react to different electronics and interface materials? How will it perform in the final design?

Tekscan application engineers have many years of experience supporting OEM customers through the sensor integration process, and have developed this set of tools to help you advance more seamlessly through each phase of FlexiForce sensor integration, from proof of concept testing and prototyping through field testing and commercialization.

Tekscan offers two **FlexiForce OEM Development Products** to help you obtain important sensor testing data and help you stay efficient on your way through the sensor integration process.

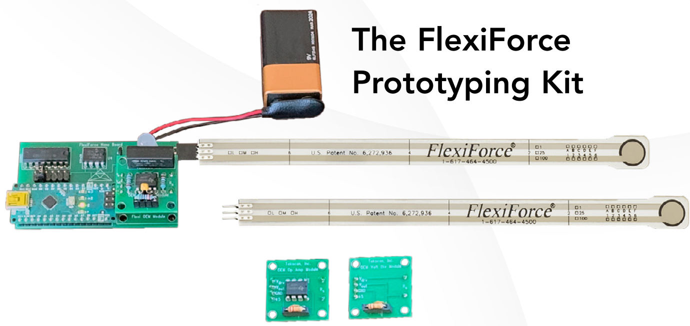


### The FlexiForce Sensor Characterization Kit



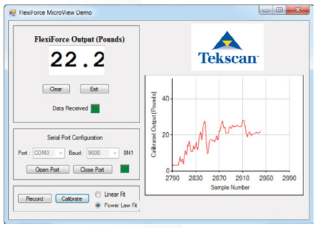
Learn More!

- An all-in-one testing fixture to help collect baseline sensor performance in a controlled loading environment
- Test interfacing materials with pre-programmed loading profiles in open-source software:
  - Linearity
  - Hysterisis
  - Drift
  - Repeatability
- Use with any FlexiForce Standard Sensor model, except the A101



### The FlexiForce Prototyping Kit

Learn More!




- A compact, plug & play kit to help engineers and designers progress smoothly through later integration phases
  - Begin collecting data in minutes!
- Test with different circuitry and make sensitivity adjustments with ease
- Use with any FlexiForce Standard Sensor model, except the A101

# BEST PRACTICES

Our team of FlexiForce engineers has collaborated with OEM manufacturers in various industries and applications to successfully integrate our sensors into their products. Every application and customer is unique, making the integration process a challenge. We recognize that every application and customer is unique, and our experience in working across varied applications and environments helps ensure a smoother integration process.

The following pages will share key areas of consideration when selecting, loading and calibrating FlexiForce sensors.

**WE STRONGLY ADVISE WORKING WITH OUR DEDICATED TEAM OF MECHANICAL, ELECTRICAL, AND APPLICATION ENGINEERS TO ENSURE A SUCCESSFUL PROJECT OUTCOME.**


## SENSOR LOADING

**Recommendations:**

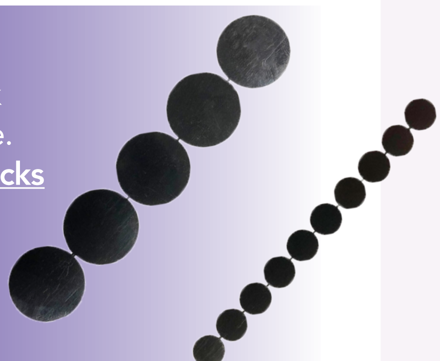
- Ensure a consistent mechanical loading through the active area of the sensor to obtain a linear output.
- Use controlled loading for better sensor performance.
- If load area is larger than the sensor's active area, apply a puck **(Fig. 10, page 15)** to the active sensing area to guarantee consistent loading.

### CAUTION: SENSOR LOADING WARNING

- If the sensor load is not consistent and controlled, you will not obtain a linear output as shown in **Fig. 4 (page 13)**. When loading is not applied to the active area of the sensor, the output of the sensor can be erratic and/or nonlinear. Localized high pressure points on the sensor may result in non-linear output. Manufacturing tolerances can cause stress concentrations with high stress points resulting in non-linear output.

### DID YOU KNOW?

Tekscan sells peel-and-stick pucks from our online store. Visit www.tekscan.com/pucks to purchase.



### Pros Use Pucks

**Customer Challenge:** A customer's device produced inconsistent results whenever an uneven distribution of force was delivered to the active sensing area.

### TEKSCAN'S SOLUTION:

Our team of expert engineers determined that the customer's embedded FlexiForce sensor application design did not incorporate a load concentrator, or "puck." Pucks should be sized to cover 70-85% of the sensing area to improve force transmission. There are 3 key reasons to use pucks:

**1) To ensure that 100% of the applied force is concentrated within the sensing area.**
**2) To provide a better representative sample of repeatable data when the load area is significantly smaller (less than 30% of the sensing area).**
**3) To protect against sensor damage from point loads delivered at very high pressures.**

Testing should be performed with different materials to determine the best puck material for the application. Neoprene, polycarbonate, delrin, aluminum, stainless steel are a few examples that could be used for pucks.

**SO ASK YOURSELF:**
*Am I considering the impacts that uneven force distribution or repetitive forces can have on my device's performance?*

BEFORE YOU BUILD

## SENSOR SELECTION

**Recommendations:**

- Before selecting a FlexiForce sensor, talk to our team of engineers to ensure you end up with the proper sensor for your application. Our team will be able to advise you on which sensor works best with your electrical circuit and mechanical design.
- Force range, environmental conditions, and validation tests are key factors in selecting a FlexiForce sensor. Application specifics, load, timeline, and operating temperature are all integral factors to consider while designing a successful product.
- Our team of engineers recommends using a sensor with a lower force range and adjusting the circuit during electrical testing. This results in a more cost-effective solution for production implementation.

### CAUTION: SENSOR SELECTION WARNING

- Choosing the wrong FlexiForce sensor may lead to inaccurate sensor output or a non-functioning sensor. If you choose the wrong sensor due to force range, it is likely you will have to redesign your electrical circuit or make mechanical alterations to your product design.
- If your application involves certain environmental conditions, such as high temperatures, using the wrong type of sensor will lead to sensor and design failure.

### Smarter Sensor Selection

**Customer Challenge:** A customer selected their embedded FlexiForce sensor model on the basis of an application-specific force range, yet experienced issues with sensor output and resolution.

### TEKSCAN'S SOLUTION:

Our team of expert engineers determined that while the sensor's force range was acceptable for their application, the customer's design required a sensor that could achieve a higher resolution through the dynamic range of the application. Force ranges are just one aspect to consider when selecting the optimal FlexiForce sensor for your application. **Always contact our support team before purchasing your sensor – we will ask the right questions to make sure the sensor you choose will achieve your specific goals.**

**SO ASK YOURSELF:** *What different internal or external variables could influence my device's sensor performance?*


## CALIBRATION

**Recommendation:**

- Calibration of the sensor should be incorporated into your design – this is critical after assembly. The more calibration range you have available, the easier, lower-cost and more flexible your product will be to assemble and produce.

### CAUTION: CALIBRATION WARNING

- Dealing with large mechanical and electrical tolerances can be a hurdle with sensor integration and can impact obtaining a linear sensor output. Creating a calibration process is important for eliminating part and assembly variability from the system and end product.

### Calibration Always Adds Value

**Customer Challenge:** A customer was planning to embed multiple FlexiForce sensors in their product design. The company felt calibration of all sensors was too costly and involve too much process time. Over time, sensor accuracy suffered.

### TEKSCAN'S SOLUTION:

FlexiForce sensors require individual calibration – and in some cases, periodic calibration in the field – which can spell the difference between a reliable product and a failed design if ignored. We highly advise designing a calibration protocol for production calibrating every sensor within its assembly to eliminate potential inaccuracies and help extend the life of the sensor within the application. This can help avoid costly product redesigns.

**SO ASK YOURSELF:**
*Am I addressing FlexiForce calibration requirements within my design?*

# CIRCUITRY

**Recommendation:**

- Our suggested **op-amp circuit** is recommended to maintain a constant voltage across the sensor and produces the most linear output for your sensor.

## CAUTION: CIRCUITRY WARNING

- Alternative circuits tend to result in apparent non-linear behavior. If you choose to use a constant current, voltage divider, or additional in-line resistance with the sensor, the linearity of the sensor will be altered. Our team of engineering experts is happy to help customers with circuit integration.


### Never Short on Circuits

**Customer Challenge:** A customer design included a resistor in line with an embedded FlexiForce sensor, which greatly reduced the linearity of the sensor.

**TEKSCAN'S SOLUTION:**
Our team of expert engineers helped the customer rework their electrical circuit to successfully integrate within the design constraints and operate with the desired performance. Always contact us before specifying your device's circuitry. We also recommend the **FlexiForce Sensor Characterization Kit** and **FlexiForce Prototyping Kit** as great resources to help you determine how circuits will perform in your design.

**SO ASK YOURSELF:**
*What type of circuit performance & attributes are important to me? Cost? Linearity? Resolution? Dynamic range?*

### Circuit Saturation

**Customer Challenge:** A customer's designed circuitry was not performing correctly with several sensors from a batch. Some would saturate before reaching the maximum force, others would produce too low an output through the force range.

**TEKSCAN'S SOLUTION:**
Our team of engineers helped the customer rework their electrical circuit to include adjustability and tenability to work with all sensors within Tekscan's sensor variation specification.

**SO ASK YOURSELF:**
*Will my circuit function appropriately across a sensor variation of +/- 40%?*

## CALIBRATION OVERVIEW

Calibration is the method by which the sensor's electrical output is correlated to an engineering unit of force, such as pounds or Newtons. To calibrate:

1) Apply a known force to the sensor, and equate the sensor resistance output to this force.

2) Repeat this step with a number of known forces that approximate the load range to be used in testing.

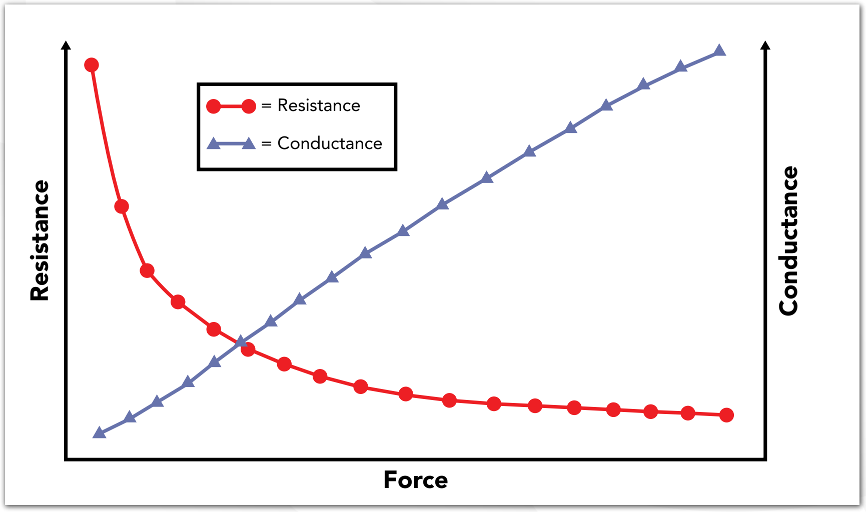



FIGURE 4: RESISTANCE & CONDUCTANCE CURVE

3) Plot Force versus Conductance (1/R). A linear interpolation can then be done between zero load and the known calibration loads to determine the actual force range that matches the sensor output range. This must be done for each sensor as there is significant variation in electrical sensitivity from sensor to sensor.

## FLEXIFORCE ADVANTAGES VS. COMPETITORS

- **Area independent:** The top to bottom FlexiForce transduction method provides an **area independent** output that measures force not pressure. This feature allows for more consistent force measurement.

- **Accuracy and Linearity:** The change in resistance occurs in the z-axis, normal to the plane of the sensor, resulting in improved accuracy and linearity.

- **Durability and Higher Forces:** A standard FlexiForce sensor can measure and withstand forces over 1,000 lb. This large dynamic force range provides maximum design flexibility.

- **100% Tested:** FlexiForce sensors are 100% tested for both sensor properties  and sensor-to-sensor variation. This ensures that our customers receive fully functioning sensors that meet their specifications.

# INTEGRATING THE FLEXIFORCE SENSOR

# MECHANICAL INTEGRATION

## SENSOR TOLERANCES

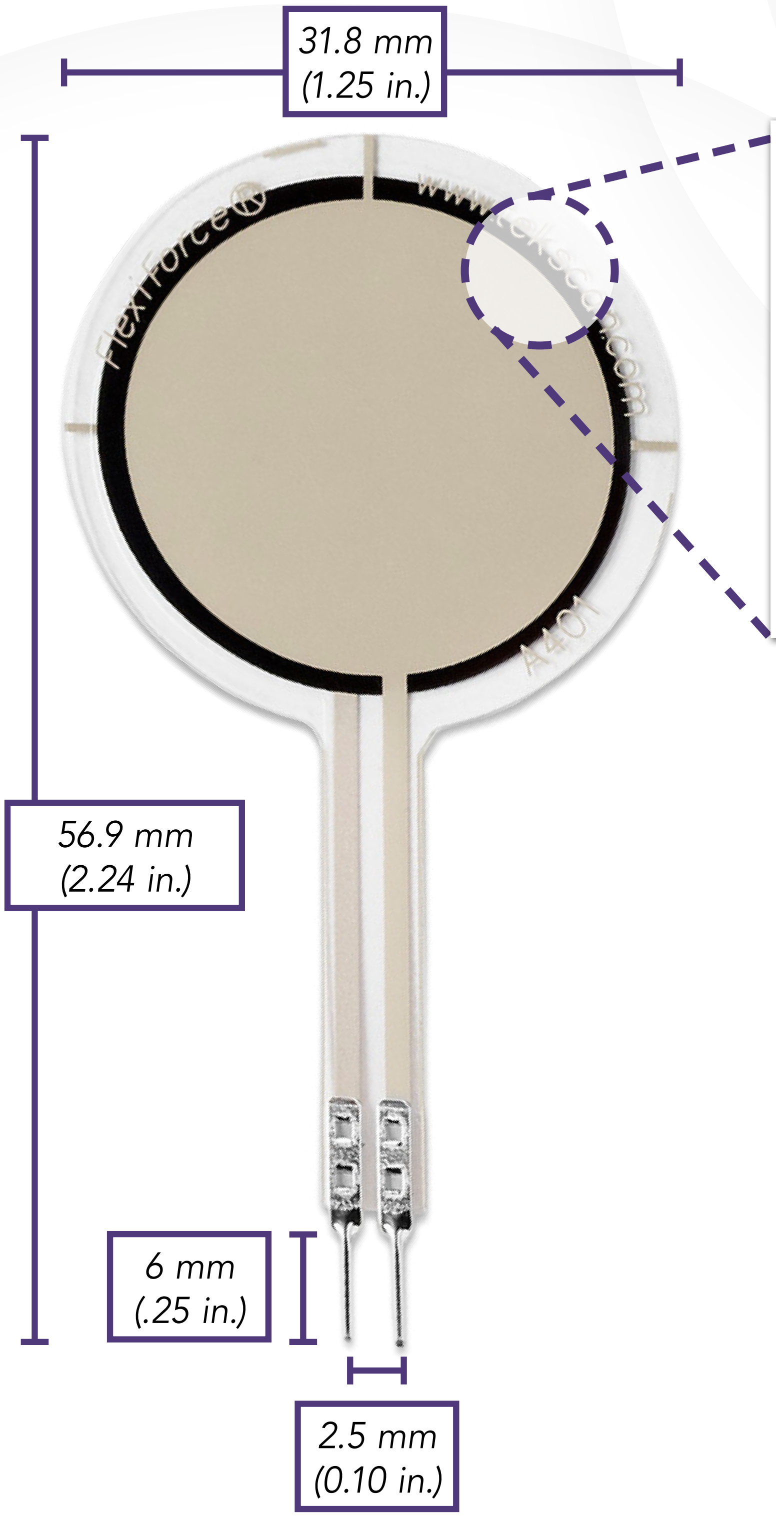



FIGURE 5: TYPICAL SENSOR LAYOUT
(A401 PICTURED)

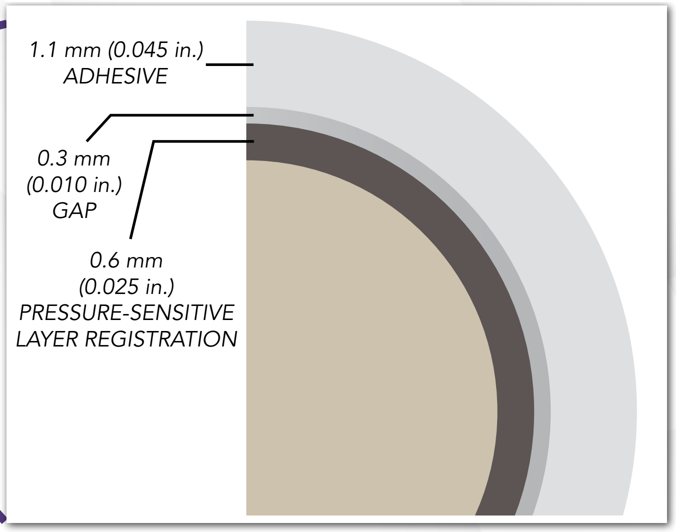



FIGURE 6: SENSING AREA DETAIL

## MECHANICAL LOADING/FIXTURING

- The active sensing area, or force sensing area, of a FlexiForce sensor is the silver area within the black perimeter. In the case of standard FlexiForce sensors, this is always a silver circle:

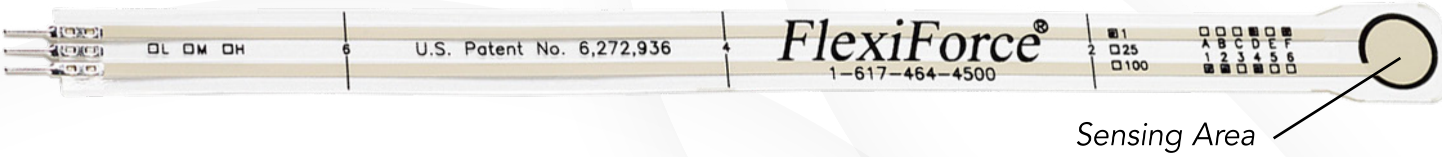



**FIGURE 7: FLEXIFORCE A201 SENSOR**

- Concentrate all of the force on the active sensing area to ensure best repeatability
  - Ideal characteristics for load applicator:
    - > Ensures force applied is normal/perpendicular to the plane of the sensor (see Minimize Shear below).
    - > Ensures force is always applied to the same location on the sensor.
    - > Ensures force is always applied 100% within the silver-colored sensing area. We recommend under-sizing the load applicator to ensure load remains within the active sensing area after taking into account part-to-part tolerances of customer device and sensors.
  - When a load actuator is not ideal, use a "**puck**" (see **Fig. 9**):
    - > If the load actuator is too large for the sensing area, a puck (shim) will allow for 100% of the force to be transferred to the active sensing area. A puck can also be used when the surface area of the applied load is much smaller than the active sensing area. Using a puck will result in a more robust design as it improves measuring capabilities.
    - > The puck should be adhered to the active sensing area to ensure load is always applied to the same location on the sensor (thin double-sided tape is typically used).
    - > For the puck material, we recommend using the softest interface material that will still maintain dimensional stability at applied force levels. This ensures there is no squirming/shear force resulting from the compression of the puck, and also reduces any chance of "edge loading" (high pressure zones along the edges of the active sensing area) that might occur with too hard a material.
  - Sometimes it is not possible to concentrate 100% of the force on the sensing area (aka offloading). In such cases, it is important that the sensor is calibrated in the final device/ setup so that any change in sensor output due to offloading is taken into account.

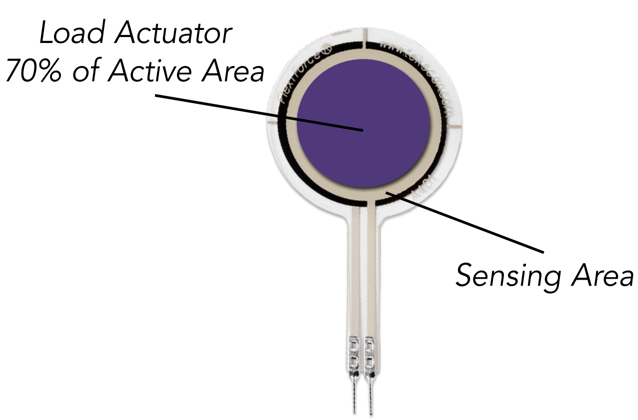



**FIGURE 8: LOAD ACTUATOR POSITIONING**

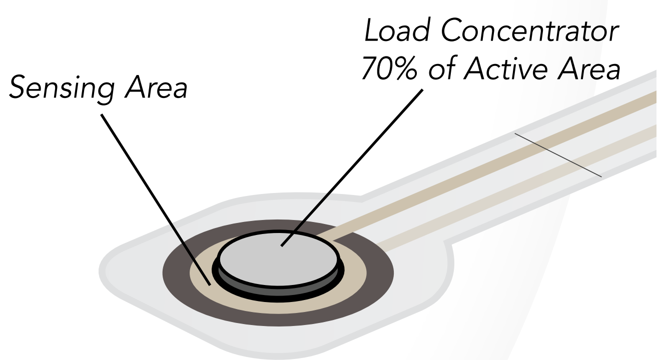



**FIGURE 9: MECHANICAL "PUCK" FOR LOAD CONCENTRATION**

- Minimize sensor surface shear
  - Applied force must be normal/perpendicular to the plane of the active sensing area.
  - Small shear forces will decrease force sensitivity over time. If you see this decrease, shear force exposure should be examined. On a short-term basis can be recalibrated. Long-term – could result in inadequate force resolution.
  - Large shear forces can break the adhesive bond between the top and bottom substrate layers of the sensor, resulting in sensor failure.

## VENTING/"PILLOWING"

- Standard FlexiForce sensors, and most custom sensors, are vented to equalize the internal pressure at the sensing area region with the external atmospheric pressure. Without the vent, there is the possibility of pressure build up, or "pillowing", within the sensor which would affect force sensing repeatability.

- The vent could serve as a possible pathway for external contaminants, such as oils, chemicals, etc. to enter the sensor. This needs to be accounted for in both the design of the sensor and the design of the surrounding fixture/device.

- Internal venting designs are available with custom sensors to seal the sensor from harsh environments.

## CLEANING/CHEMICAL COMPATIBILITIES AND CONCERNS

- Sensors can be lightly cleaned using Isopropyl Alcohol. To clean take a rag or cloth that is slightly damp and quickly wipe the surface of the sensor. Be sure not let the damp rag or cloth linger on the surface of the sensor, especially if pin connectors are installed as the pins create an opening that can quickly wick the alcohol. It is important not to immerse sensors into the alcohol, even if quickly dipping.

- Sensors should not be immersed in any liquids or oils. Take care that any adhesive or over-coating materials do not outgas near the sensing area or any open vents that may be present on the sensor.

## MOUNTING

- Typically mounting is done with thin, double-sided tape. Tekscan can provide this as a "peel 'n stick" backing on the sensors. Most Tekscan custom sensors are supplied with 3M tape part # 9482PC.

- Holes can be designed in sensors for screw/clamp type mounting.

- **DO NOT USE** – Hard setting adhesives or epoxies that will affect the way force is transmitted to the sensing area, or any compound that could potentially outgas and contaminate the pressure sensitive materials within the sensor.

## TERMINATION OPTIONS

**ZIF Compatible Termination** – ZIF/LIF compatible termination is available on a custom basis. ZIF/LIF connectors allow for ease of assembly and provide a small connector footprint and height for applications with tight space constraints. Please contact a Tekscan Representative for more information about spacing and size guidelines.

**Conductive Epoxies or Z-Axis conductive tapes** – Conductive epoxies or z-axis conductive tapes can be applied to the exposed traces of a FlexiForce sensor to connect the sensors directly to an FPC/PCB. This method results in the lowest sensor price to the customer because the additional manufacturing steps for pin crimps or ZIF compatible terminations are not required. It also provides the lowest possible mated height compared to any other electrical termination options.

**Pins and Solder Tabs** – Standard FlexiForce sensors are available with pins that can be inserted into PCB headers with 2.54 mm (0.1 in) spacing or they can be soldered to directly. A variety of connector pins, pin housings, and solder tabs are available on a custom basis.

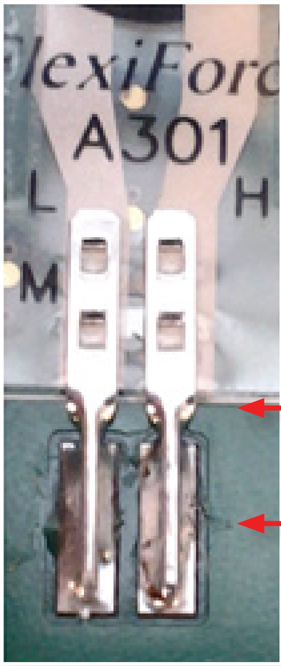
## CONSIDERATIONS FOR SOLDERING FLEXIFORCE SENSORS TO PCB SOLDER TABS

**NOTE: It is recommended that solder flux NOT be used when soldering FlexiForce sensors. The flux has a tendency to run and creep into the sensor via the crimped area of the pins. The flux can then penetrate the sensing area of the sensor via the air vent running down the middle of the sensor and result in an unusable sensor. In cases where flux is necessary, use as little as possible and take great care to ensure no flux gets on crimped area of pins.**

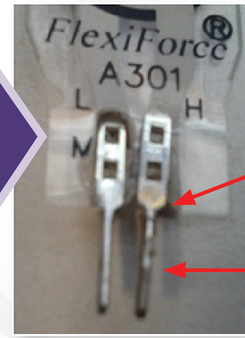
- **Soldering Iron Tip Diameter:** 1.6 mm (.063 in) or smaller
- **Soldering Temperature:** Lead-free solder at 454.4°C (850°F)
- Tin solder pads, tin soldering tip
- Solder sensor pin to tinned solder pad, applying solder/soldering iron for **no more than 3 seconds at a time**. If more time is needed to complete soldering, remove soldering iron from pin, allow sensor to cool for 5-7 seconds and reapply solder/soldering iron.
  - An alligator clip may also be used to sink heat away from the sensor as shown on the right. This is beneficial in applications where it can be used, but not necessary.

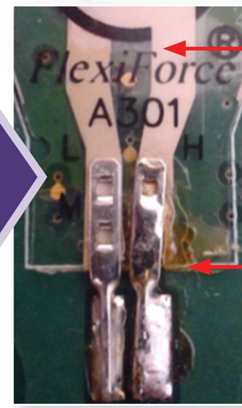

ALLIGATOR CLIP EXAMPLE

## EXAMPLE OF A PROPERLY SOLDERED SENSOR




## EXAMPLES OF A IMPROPERLY SOLDERED SENSORS




## PROCEDURE FOR VERIFYING SOLDER TECHNIQUE

1. Place unsoldered sensor on PCB
2. Use calibration loading fixture to apply 3-5 step load, measuring resistance at each load. Precondition sensor with 3 or 4 loadings at max load before taking measurements
3. Solder sensor to PCB
4. Apply the same preconditioning and loading profile to sensor, measuring resistance at each load
5. Compare measurements before and after soldering. All values should be within 5% of each other for a given sensor

# ELECTRICAL INTEGRATION

## RECOMMENDED EXCITATION CIRCUIT (DUAL SOURCE) - OPTIMAL FORCE RANGE ADJUSTMENT

The dual source circuit provides excellent linearity in voltage output with respect to force applied to the FlexiForce sensor. It also provides the most versatility in terms of force range adjustment by adjusting the circuit parameters of reference voltage ($V_{REF}$) and the feedback resistor ($R_{FEEDBACK}$). With this circuit, the user can effectively change the force range of the same FlexiForce sensor from under 4.4 N (1 lb) to over 4,448.2 N (1,000 lb).

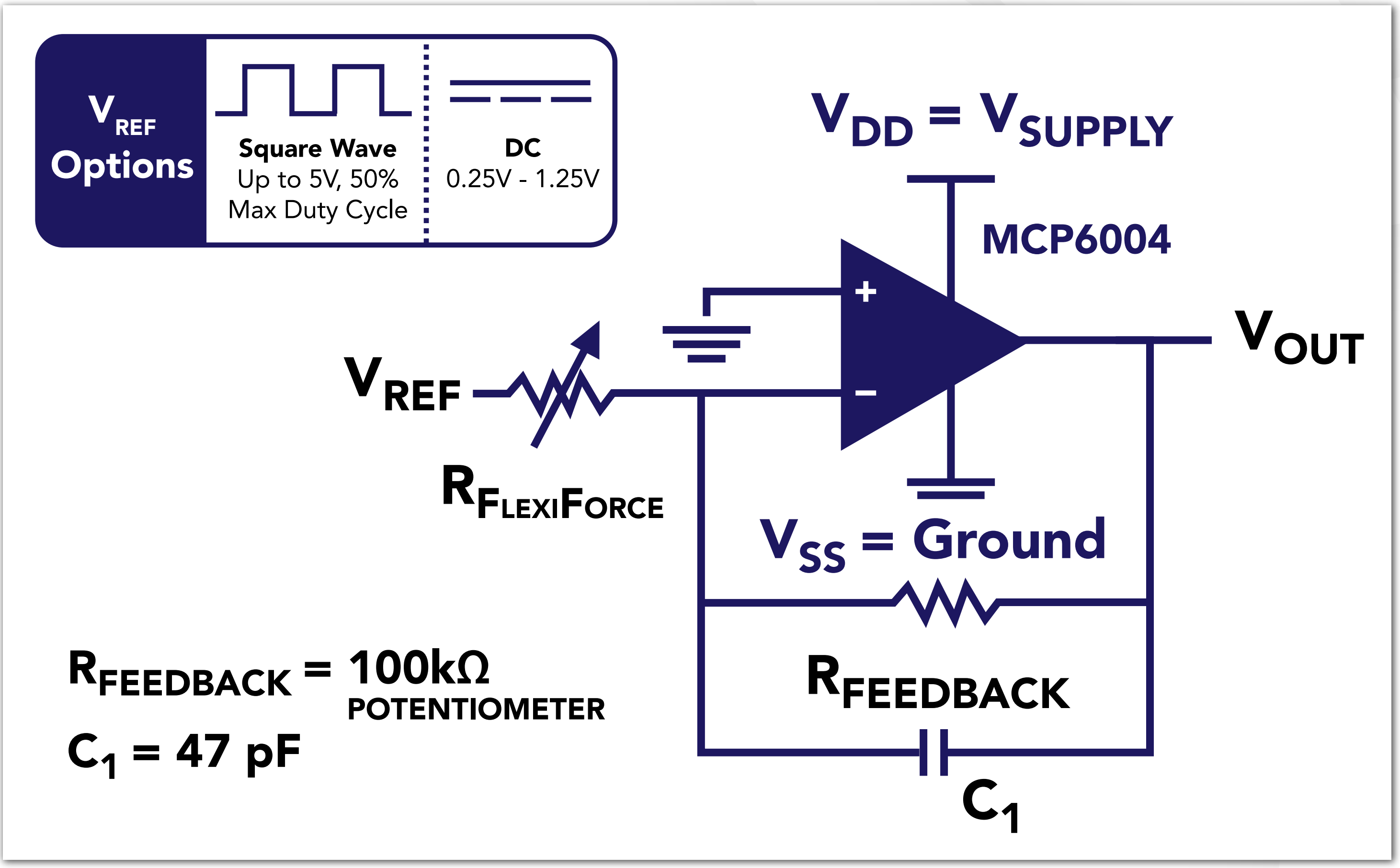



FIGURE 10: DUAL SOURCE EXCITATION CIRCUIT

**100K POTENTIOMETER AND 47 pF ARE GENERAL RECOMMENDATIONS; YOUR SPECIFIC SENSOR MAY BE BEST SUITED WITH A DIFFERENT POTENTIOMETER AND CAPACITOR. TESTING SHOULD BE PERFORMED TO DETERMINE THIS.**

**POLARITY OF $V_{REF}$ MUST BE OPPOSITE THE POLARITY OF $V_{SUPPLY}$.**

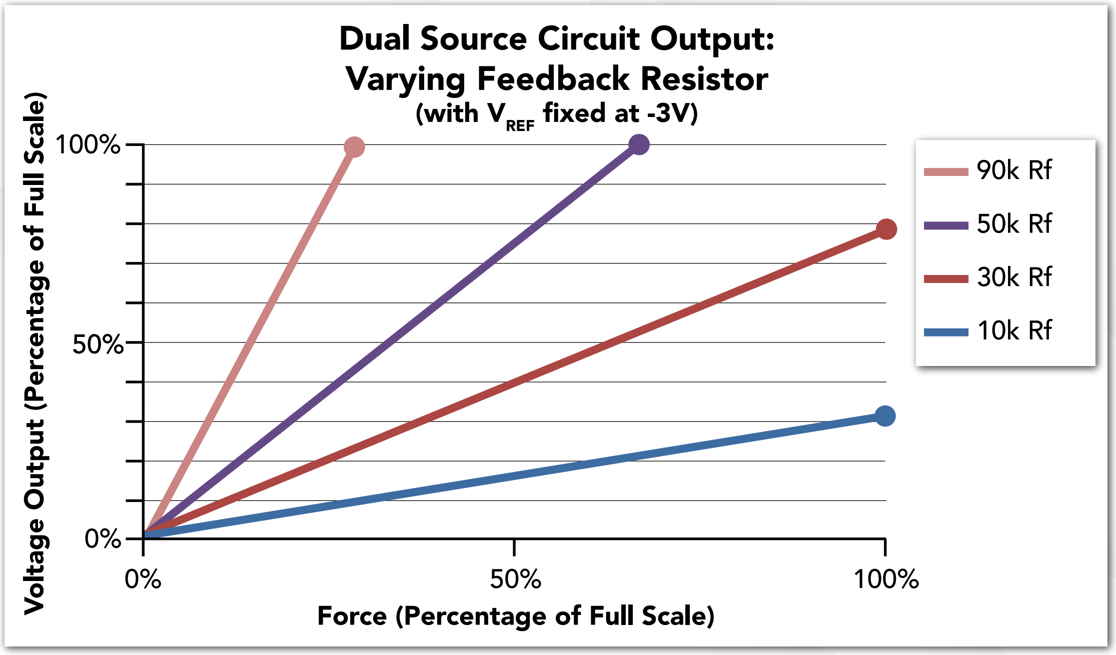



**FIGURE 11**

**Fig. 11** shows the relationship of the output voltage vs. force applied to the sensor with drive voltage, $V_{REF}$, fixed at -3 volts. By inspecting this graph, it is seen that decreasing Rf decreases the sensitivity of the circuit output for a given force (extended force range). Conversely, larger Rf values increase the slope of the voltage output versus force curve and therefore increase the sensitivity of the circuit (decreased force range). **Fig. 12** shows the $V_{OUT}$ versus Force relationship with a varying drive voltage, $V_{REF}$, and fixed Rf resistance value of 50kΩ. Similarly to the effects of varying the feedback resistor value, an increase drive voltage will result in higher sensitivity (decreased force range) and a decreased voltage will result in lower sensitivity (extended force range).

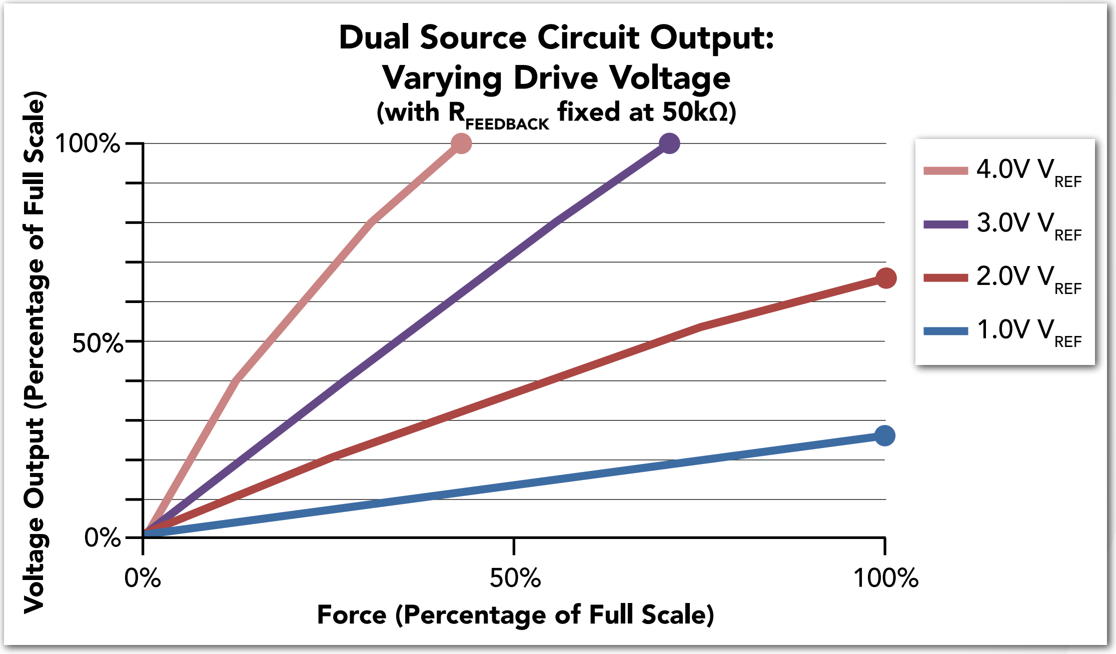



**FIGURE 12**

## RECOMMENDED EXCITATION CIRCUIT (SINGLE SOURCE) - LOW/BATTERY POWER DEVICES

The single source circuit also provides excellent voltage vs. force linearity while also being easy to implement in a portable device. However, the range of force adjustment that can be achieved by adjusting sensor reference voltage and the feedback resistor is more limited than with the recommended dual circuit. This circuit is the better choice for implementing in a device once the proper circuit parameters and sensor sensitivity have been defined.

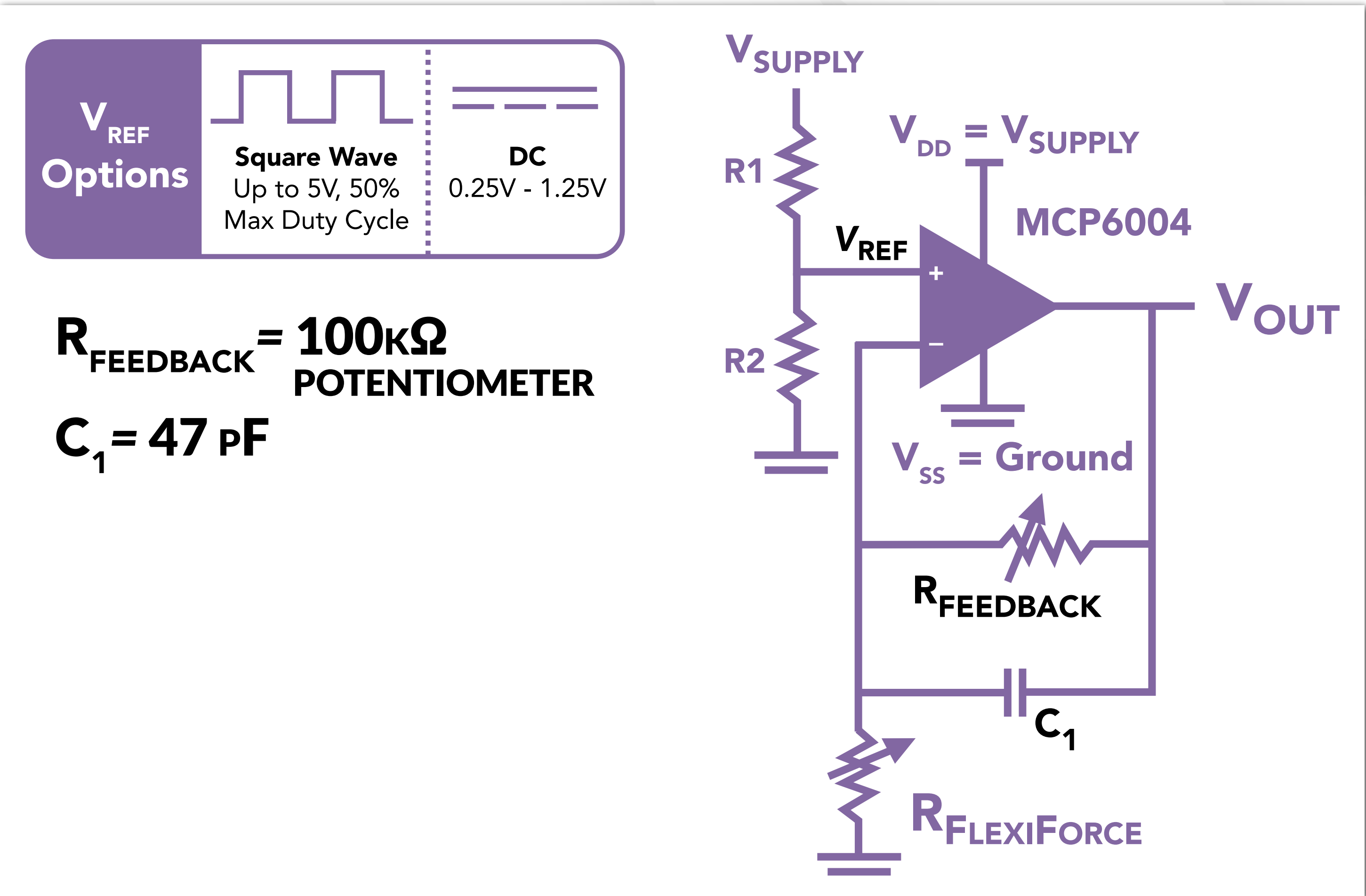



**FIGURE 13: SINGLE SOURCE EXCITATION CIRCUIT**

**100K potentiometer and 47 pF are general recommendations; your specific sensor may be best suited with a different potentiometer and capacitor. Testing should be performed to determine this.**

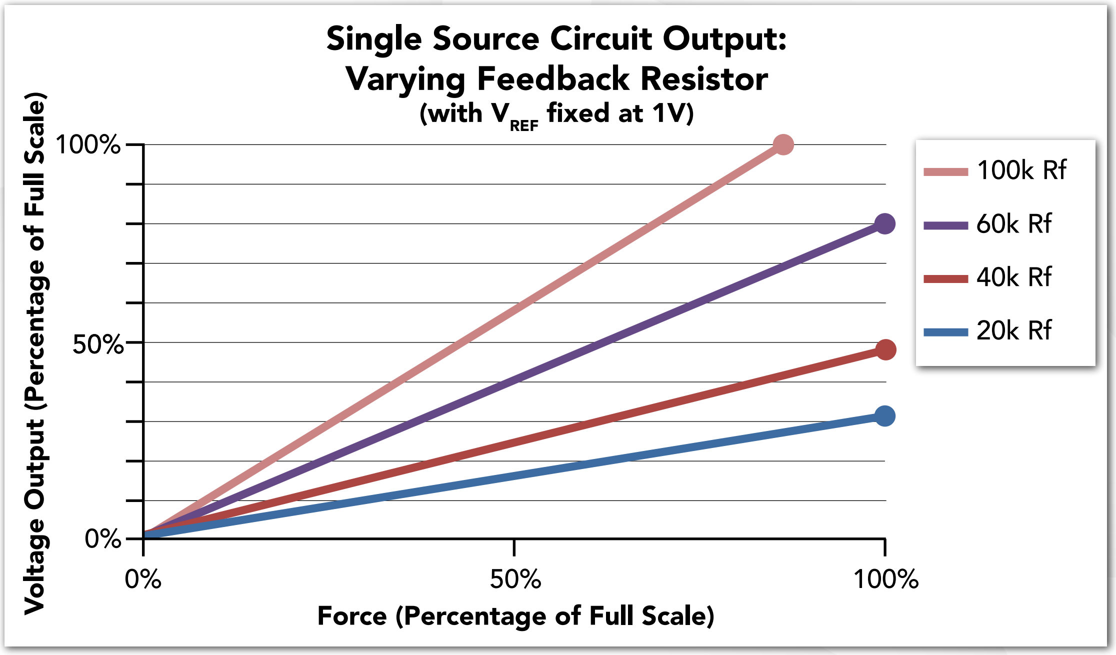



FIGURE 14

**Fig. 14** above shows the relationship of the output voltage versus the force applied to the sensor with the sensor drive voltage, $V_{REF}$, fixed at 1 volt. By inspection of this graph it is seen that decreasing Rf will decrease the sensitivity of the circuit output for a given force (extended force range). Conversely, a larger Rf value will increase the slope of the voltage output versus force curve and therefore increase the sensitivity of the circuit (decreased force range). **Fig. 15** shows the $V_{OUT}$ versus Force relationship with a varying drive voltage, $V_{REF}$, and fixed Rf resistance value of 50kΩ. Similarly to the effects of varying the feedback resistor value, an increase drive voltage will result in higher sensitivity (decreased force range) and a decreased voltage will result in lower sensitivity (extended force range).

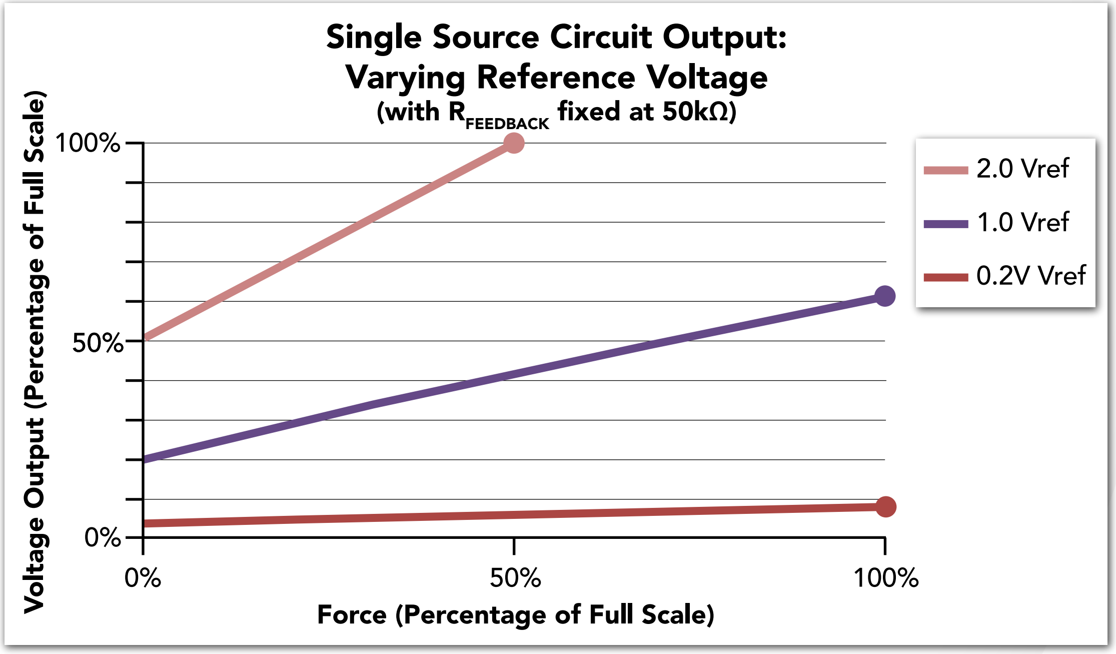



FIGURE 15

## MODIFIED SINGLE SOURCE CIRCUIT (TRI-STATE CIRCUIT) - IDEAL CIRCUIT FOR OEM'S

The tri-state circuit is virtually identical to the single source circuit mentioned above except that it allows for the adjustment of the sensor drive voltage via the use of a digital out on your microprocessor. This allows for the digital adjustment of the force range (sensitivity) which provides the ideal method to compensate for mechanical and electrical variations from both the sensor and the mechanical stack-up of the loading apparatus/device.

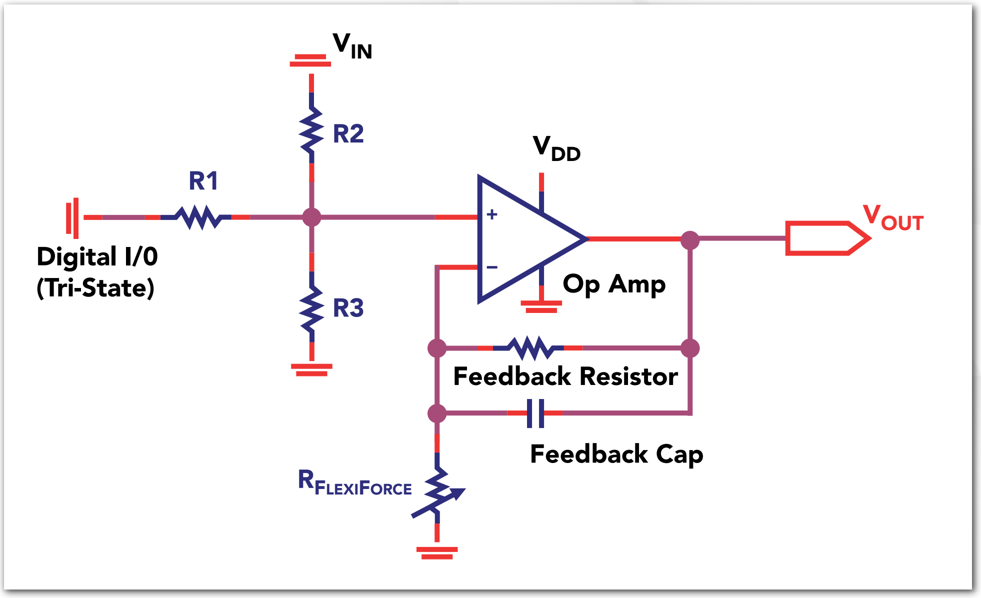



FIGURE 16

## NOT RECOMMENDED EXCITATION CIRCUIT (VOLTAGE DIVIDER) - DOES NOT REQUIRE OP-AMP CHIP

The voltage divider circuit is by far the simplest and most compact circuit configuration that can be used with FlexiForce sensors. However, the output is very non-linear which typically limits this circuit to applications requiring less accuracy.

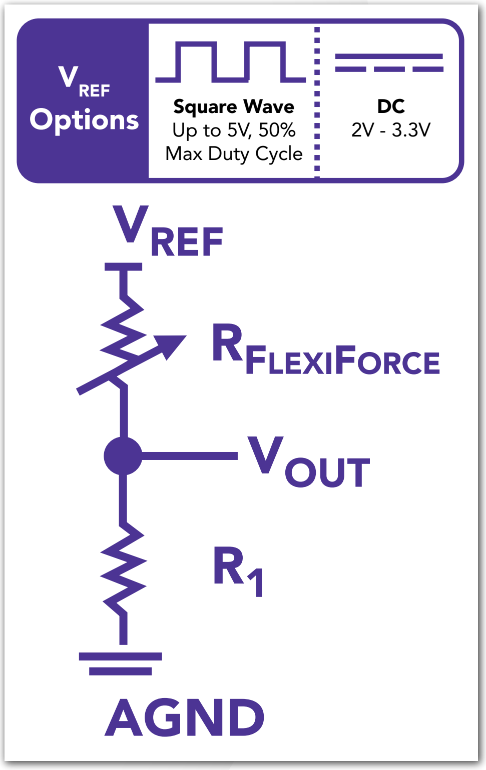



FIGURE 17

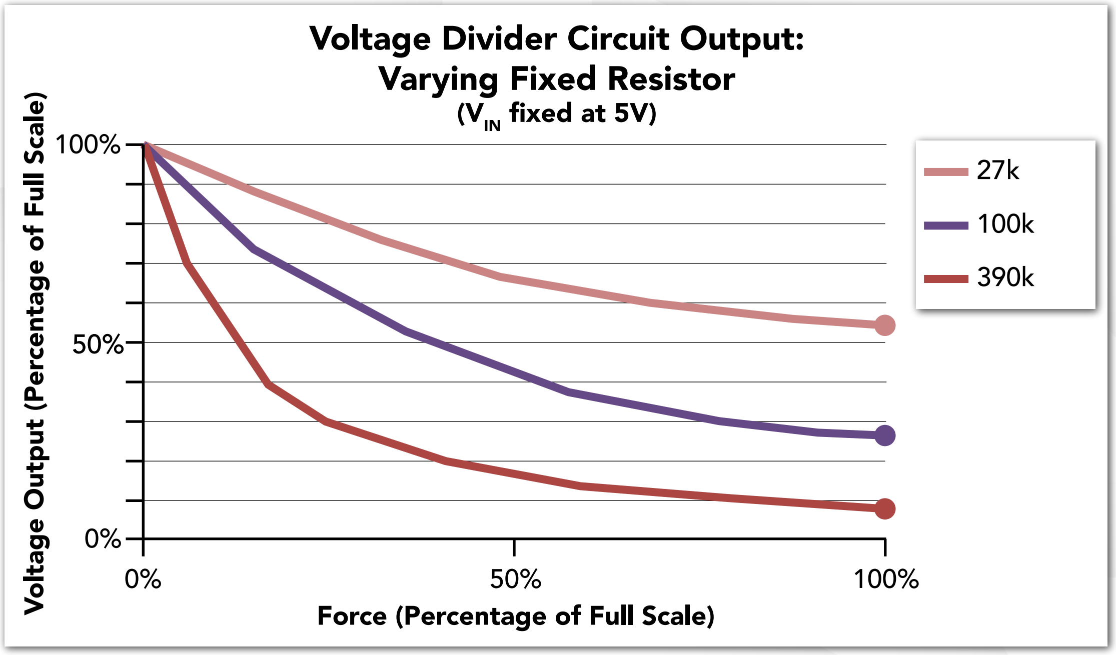



FIGURE 18

**Fig. 18** shows the relationship of the output voltage versus the force applied to the sensor with VIN fixed at 5 volts. The feedback resistor value can be adjusted to optimize sensitivity, but increased sensitivity also results in increased non-linearity with this circuit configuration.

# CUSTOMIZED SENSOR PROCESS

## CUSTOM SENSOR FORM AND QUOTATION

- The custom sensor form asks for all the necessary design details, prototype and production schedule, and desired piece price target so that Tekscan can provide a quick turn around on quote.

- After the custom sensor form is received, we provide a formal quotation at the requested prototype and production quantities. A detailed concept drawing is also included with the quote.

## CUSTOM QUOTATION

- Quotation includes detailed design concept drawing, NRE, prototype pricing, and production volume pricing

- Design and Tooling (NRE) Fee consists of:
  - Engineering design time for sensor concept and final tooling design.
  - Test hardware and software.
  - Production grade printing screens for internal sensor layers (conductive, semi-conductive, adhesive, dielectric).
  - Production grade die cutting tools necessary for manufacturing tools alignment and for cutting sensors from manufactured sheet-form.

## COST DRIVING FACTORS

- Overall size of sensor is a major cost driver. The sensors are all manufactured in a sheet form so the total number of sensors that can be made in one sheet has a major impact on production throughput.

- Sensor electrical termination configuration is also a major cost driver. ZIF compatible configurations and solder tabs increase sensor cost. The ideal connection method is to connect directly to sensor traces via conductive adhesive and/or heat bonding.

# APPENDIX; SENSOR INTEGRATION CASE EXAMPLES

The following pages present unique, real-world sensor integration stories to assist you through the integration process. For more context, figures, testing results, and other questions on these applications, contact a **FlexiForce application engineer** today.

# CASE EXAMPLE: CALIBRATING FOR A RELATIVE MEASUREMENT APPLICATION

For many devices or designs embedded with FlexiForce sensors, the force sensor is used to correlate voltage output to an absolute unit of force (e.g., newton, kilogram, pound, etc.). This is considered an *Absolute Measurement Application*. These types of applications follow a **typical calibration procedure**.

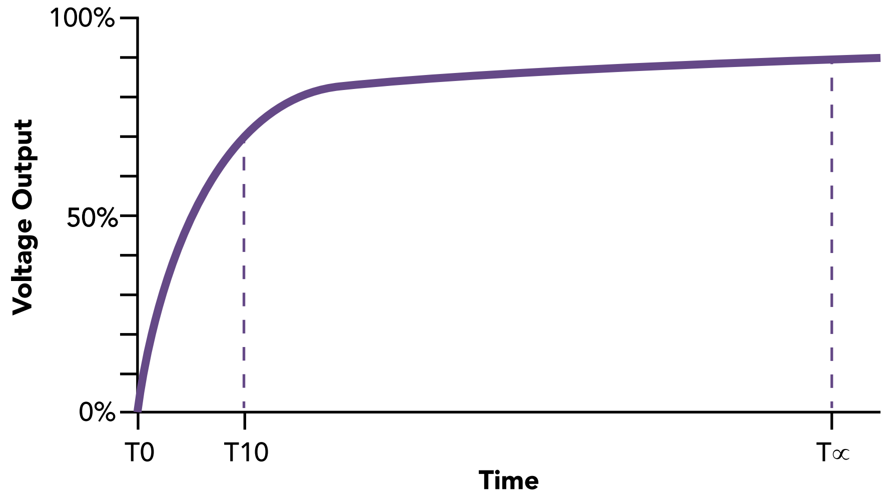
On the other hand, when a force sensor is used to correlate change in voltage to a change in force, these are considered *Relative Measurement Applications*. These force-sensing applications take a different calibration procedure.

## COMMON APPLICATION GROUPS THAT FOLLOW A RELATIVE MEASURMENT CALIBRATION APPROACH INCLUDE:

- Occupancy detection
- Contact detection
- Occlusion detection
- Inventory management
- Seal integrity management
- Battery monitoring
- Applications subject to routine temperature changes
- Theft detection
- Presence detection
- Sensing differential pressure or force
- Triggering
- Threshold detection
- Theft detection

## USING RELATIVE MEASUREMENT TO ACCOMMODATE FOR SENSOR DRIFT

**Figure 1: Calibrating for Drift over Time**




As per our **specifications**, and when the sensor is powered with our recommended circuit, FlexiForce sensors typically have an output drift rate <5% / logarithmic time. This means the design engineer should have some expectation that the absolute measurement may have a change over time.

With relative measurement applications, instead of looking at a specific absolute voltage output, the design engineer can instead correlate the change in voltage to the relative change of the force application. Put simply, for relative measurement applications, the design engineer should look for the differential voltage output as a function of force (or, the slope of V vs F curve).

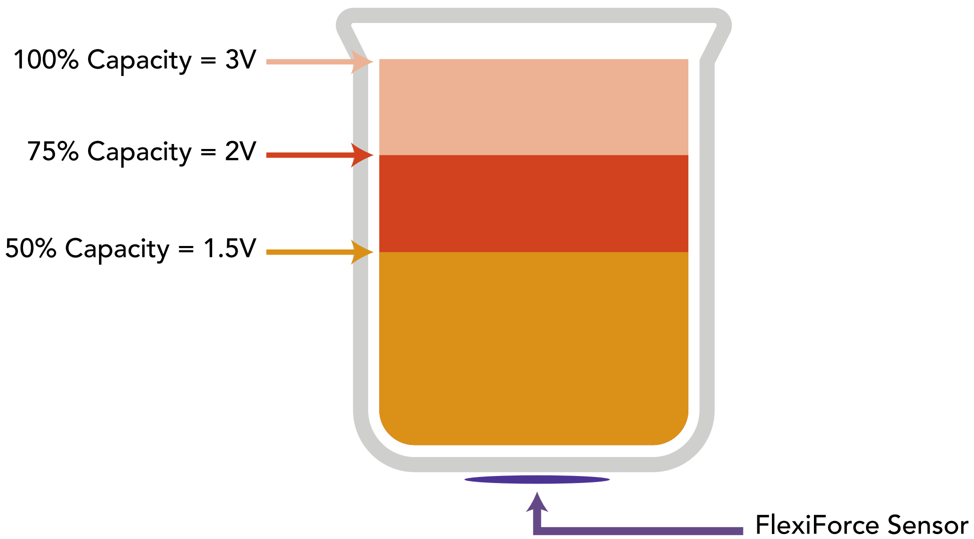
### EXAMPLE: ACCOUNTING FOR DRIFT IN A FLUID LEVEL DETECTION APPLICATION

In this example, a customer wanted to use a FlexiForce sensor as a method to determine the level of fluid within a container. As illustrated in **Figure 2**, the sensor in this application was positioned below the container.

Because sensor drift is going to cause the sensor's output voltage to gradually change over time, using absolute voltage outputs to determine fluid level within a container becomes a challenge. For instance, if the container is half-full for an extended period of time, the static load would cause the output to increase under static load, and could falsely indicate the actual fluid level within the container.

Using a relative measurement is useful in this application, because, unlike absolute values, the slope of the V vs F curve stays relatively constant regardless of how much the output has changed (**Figure 3**). For this application, the design engineer targeted a change in voltage (relative to 100% full) to indicate the fluid level in the container.

**Figure 2: Fluid Level Calibration Summary**

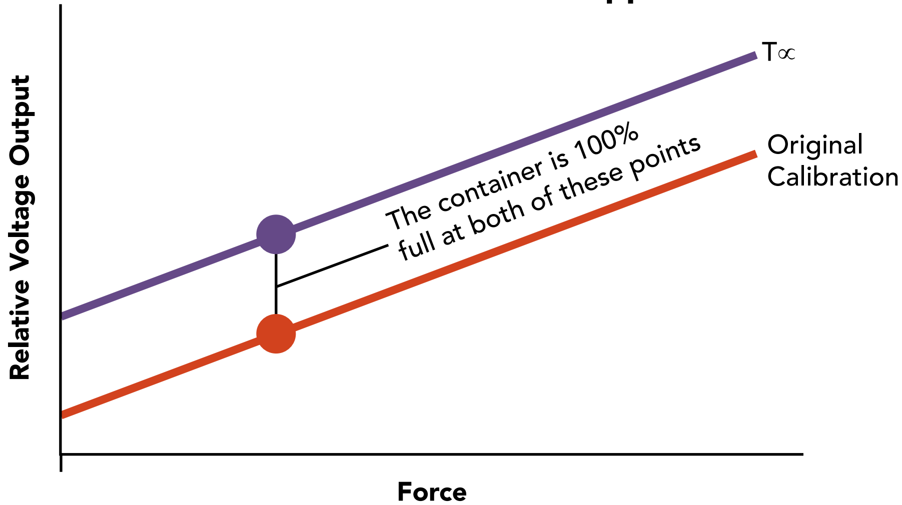



## CALIBRATION PARAMETERS

| Container Level | Circuit Output (V) | Change in Output (V) |
|---|---|---|
| 100% | 3V | 0V |
| 75% | 2V | -1V |
| 50% | 1.5V | -1.5V |

Over time, as illustrated in **Figure 3,** the customer began to notice that at 100% full, the voltage output for the container increased from 3V to a reading of 4V. However, because the differential voltage (with respect to force) remains the same, the design engineer can be confident that a decrease in 1 volt, regardless of the absolute value, will mean the container fluid level has decreased by 25%. **This is one of the principle reasons FlexiForce sensors have been successful in relative measurement applications, as well as detecting contact and/or touch over a length of time.**

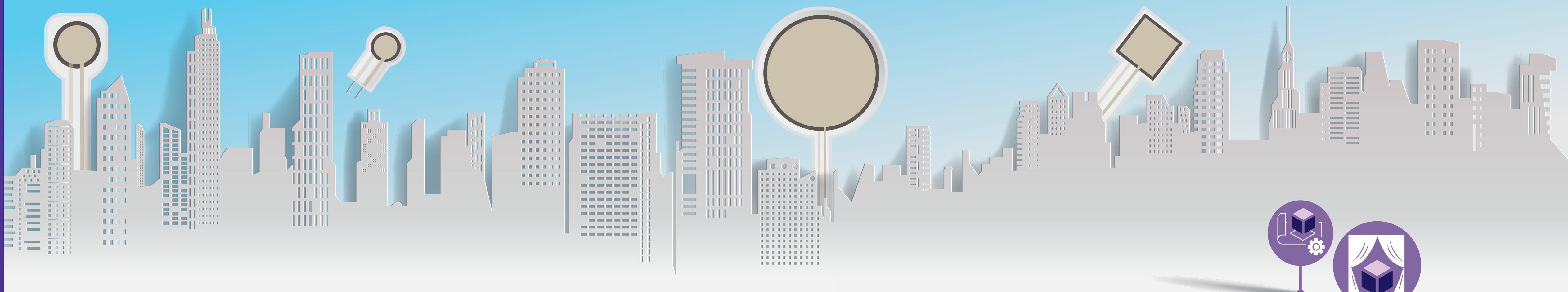
**Figure 3: Accommodating Voltage Output Change of a Relative Measurement Application**



# The 6 Phases of Force Sensor Integration

A Technical Concept-to-Market Application Story for Integrating FlexiForce™ Sensors into a Design


Tekscan™



INTRODUCTION

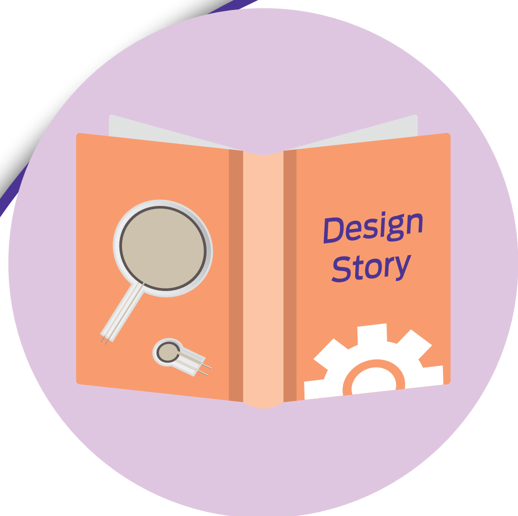
# Efficiency is Key on the Integration Journey

As the “drivers” of innovation, engineers rely on their experience and instincts to make important choices on their design journey. However, the choices they make early in the process can make a major impact, especially when integrating sensing technologies, like FlexiForce™ sensors, into their design.

While every journey a device takes from concept to completion follows a unique path, there are six core phases to sensor integration that serve as checkpoints en route to finalization:

1. **Sensor Characterization**
2. **Proof-of-Concept**
3. **Prototyping**
4. **Field Testing**
5. **Final Embedded Device**
6. **Transfer to Production**

This eBook provides a real-world story of a design team who went through these six stages of integrating a FlexiForce sensor into a smart, compact, electronic device. Take notice of the choices made and lessons learned through their integration process, as they will help you navigate your own design journey.



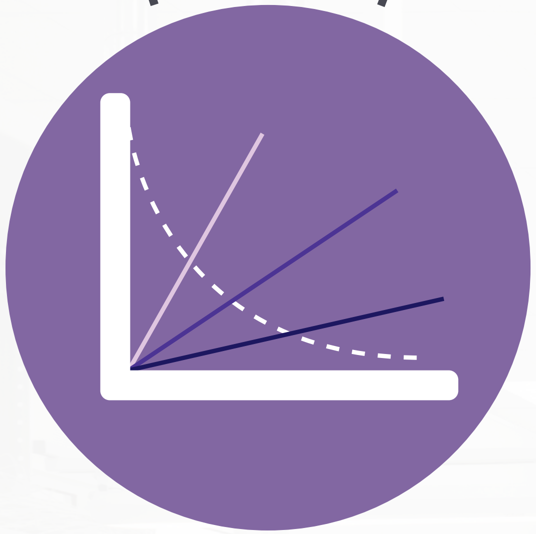

# DEVICE SUMMARY:

A design team was developing a next-generation, automated, wearable, drug-delivery pump. Their challenge was to incorporate a method to monitor potential blockages that could occur within the pump's delivery system. This called for a force-sensing technology that could not only sense any relative expansions within the device, but also be able to fit within a very tight form factor within a small pump, and not cause a major burden on the device's battery life.

After doing their research, the design team discovered FlexiForce sensors, a thin, piezoresistive force-sensing technology that offers a flexible form factor to fit into paper-thin spaces. The team purchased FlexiForce sensors from the **Tekscan online store** – making their first step into the sensor integration process.

Approximate position for the embedded force sensor.

Phase 1



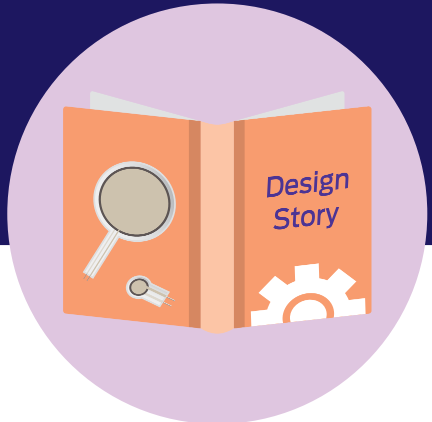
## SENSOR CHARACTERIZATION

The **Sensor Characterization Design Phase** is the vital process of establishing and understanding the fundamental functionality of the sensor technology – in this case, FlexiForce sensors. This is a crucial element of the integration process as it gives engineers and designers:

a) A baseline of sensor function in an ideal, controlled loading environment
b) Quantifiable data on sensor interface configurations (interfacing materials, circuits, etc)
c) A topline understanding of sensor linearity, hysteresis, drift, and repeatability via pre-programmed loading profiles
d) An introduction to sensor calibration via the correlation of sensor output to known loads.

### During this phase, engineers and designers are looking to answer:

1. What is the fundamental performance of a FlexiForce sensor?
2. How does a FlexiForce sensor perform with the circuits and material interfaces we are considering for the application?




# PHASE 1: SENSOR CHARACTERIZATION

The engineers needed a sensor characterization schematic, but rather than building a loading fixture, and creating circuits from scratch, they turned to the **FlexiForce Sensor Characterization Kit** (Figure 1) to streamline this process.

The Kit includes:

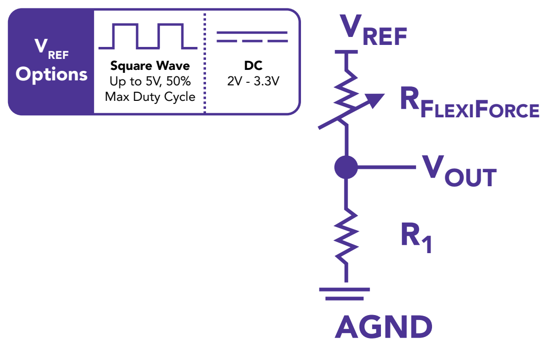
- Four (4) FlexiForce A301 sensors
- A linear actuator loading fixture
- A 454 g (1 lb) load cell, positioned below the loading platform of the fixture
- Three (3) analog circuit modules
  - o Voltage divider
  - o Inverting op-amp circuit
  - o Non-inverting op-amp circuit
- Open-source software

The engineers began by loading the FlexiForce sensor to the circuit, and applying the expected force and frequency to the sensor. They monitored raw sensor output from the Microview interface.

To their surprise, the team found that the sensor output varied across the different circuit types, and when loading with different interfacing materials. After a few rounds of testing, they decided on a voltage divider (Figure 2).


**Figure 2:** The FlexiForce Sensor Characterization Kit allows for interchangable analog circuit modules, such as the Voltage Divider shown here. Inverting and non-inverting op-amp circuit modules are also included with the kit.

**Voltage Divider**




**Inverting Op-Amp**

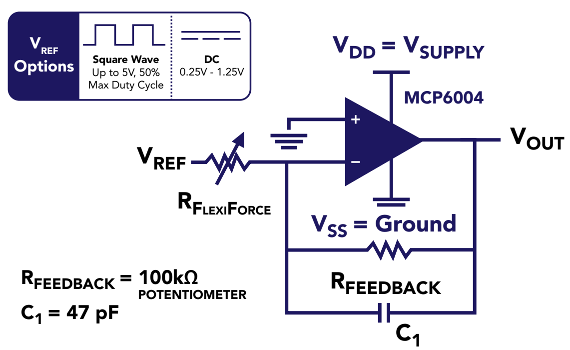
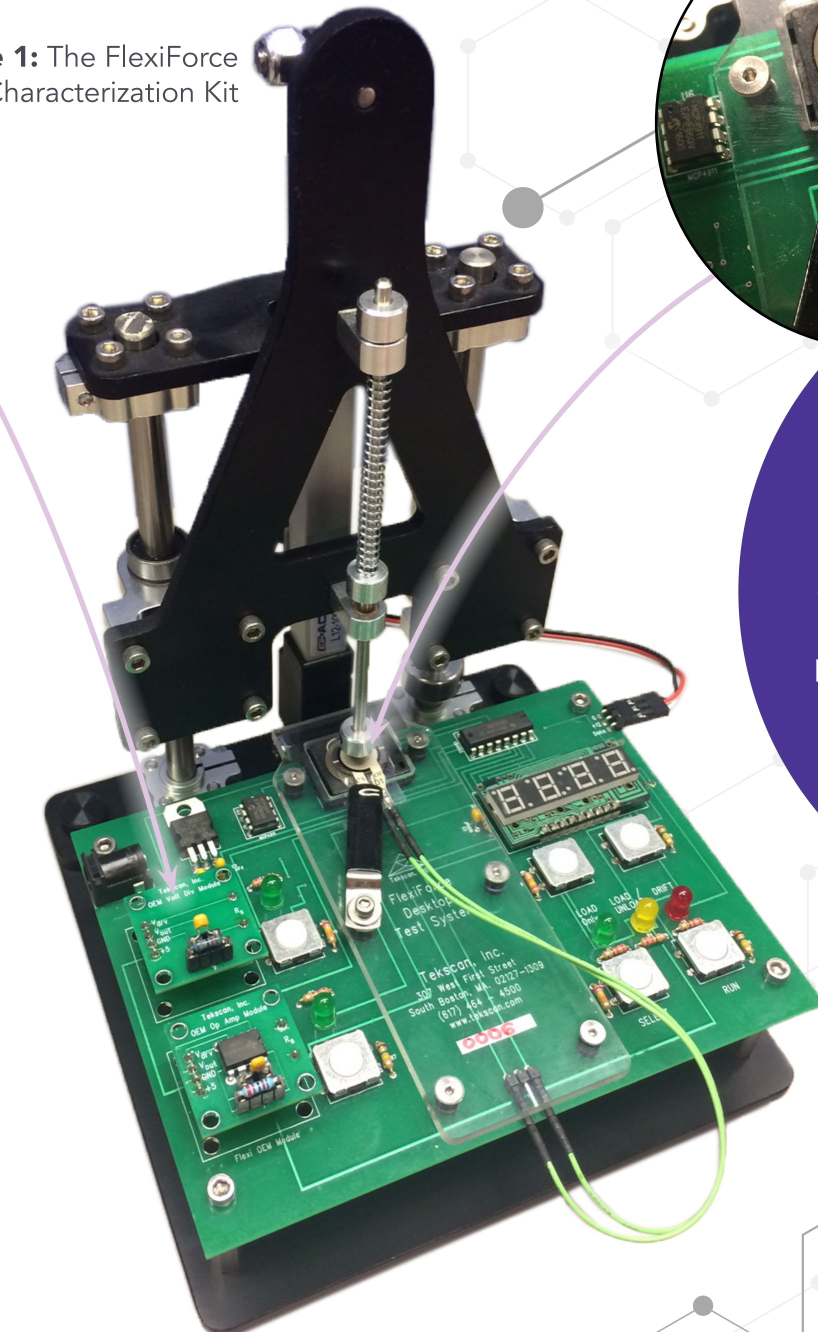
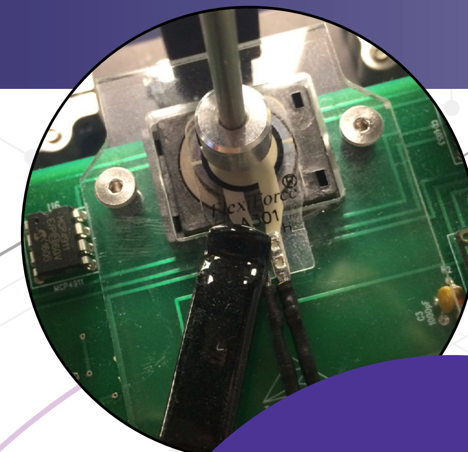



**Figure 1:** The FlexiForce Sensor Characterization Kit





A calibrated load cell is included in the loading fixture of the FlexiForce Sensor Characterization Kit, providing an experimental control to compare against FlexiForce sensor output. This is an important element to characterization, as it provides users with an understanding of sensor capability and performance under known loads. This data will prove valuable in later design phases, as it provides a known baseline for performance that can be referenced when troubleshooting or debugging.

Phase 2

## PROOF-OF-CONCEPT

After characterizing sensor performance and determining desired circuit and interface materials, the **Proof-of-Concept phase** is where engineers and designers determine the application viability of their sensor configuration.

### During this phase, engineers and designers are looking to answer:

1. Can I successfully capture my intended measurement with the FlexiForce sensor and the electrical/mechanical configuration I have chosen in a “one-off” representative mock-up of my application?

# Phase 2: Proof-of-Concept

The intended use of the FlexiForce sensor in this application was occlusion detection in an insulin pump. The design team developed a concept with the FlexiForce sensor placed below a plastic tube (Figure 3), similar to the material that would be used in the final design. With the help of the **FlexiForce Prototyping Kit** (Figure 4), the engineers could effectively test the sensor in their concept using:

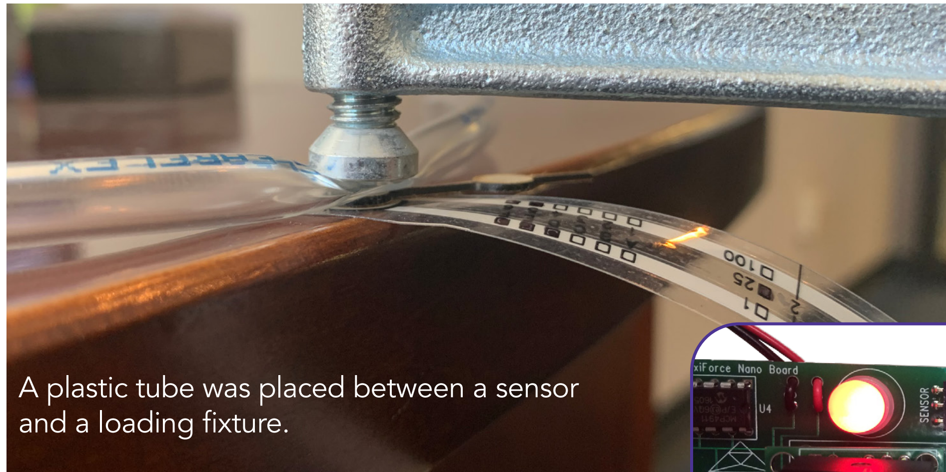
- A voltage divider analog circuit module that they selected during the characterization phase
- A polycarbonate load concentrator, and
- Open-source software, which allowed the designers to monitor live force feedback

However, the design team realized that the current reference voltage of the circuit was not providing enough sensitivity to capture a robust measurement of the occlusion event. They were easily able to increase the reference voltage from 0.5V to 1.0V using the jumper on the board of the FlexiForce Prototyping Kit. This increase in reference voltage provided the increased sensitivity and resolution to reliably-capture occlusion in the tube.

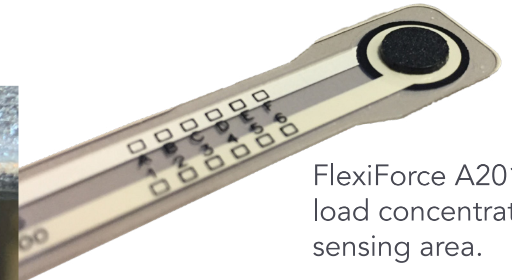
After more testing, the team determined that the polycarbonate concentrator was also not providing the output they desired, and opted to go with a stainless steel substrate for their concentrator.

Now that the concept was proven, the team was ready to move onto the next design phase.

**Figure 3:** Proof-of-concept schematic.

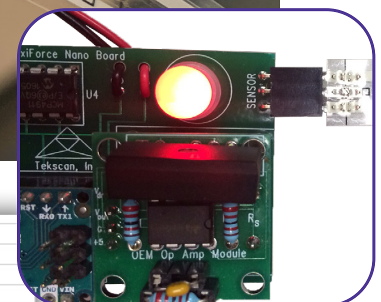


A plastic tube was placed between a sensor and a loading fixture.

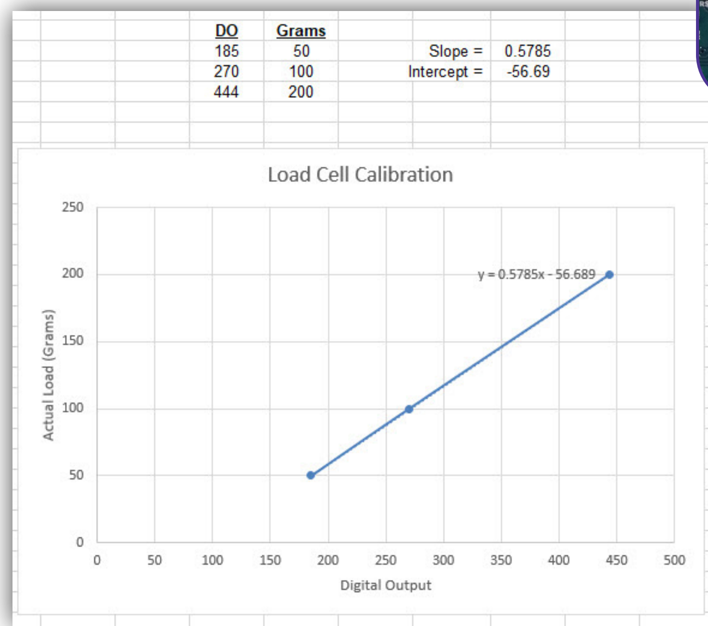


FlexiForce A201 with a polycarbonate load concentrator adhered to the sensing area.

Why use load concentrators? **This article** explains.



Force output from FlexiForce Prototyping Kit (LED light).




Data capture from FlexiForce Prototyping Kit open-source software.

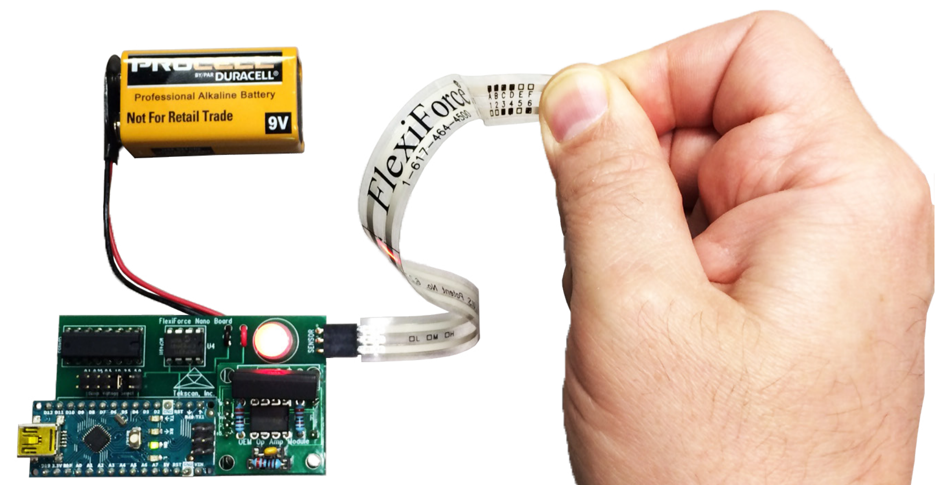



**Figure 4:** The FlexiForce Prototyping Kit

# Phase 3

## PROTOTYPING

After proving the sensor will function under the parameters and loading profiles tested in the Proof-of-Concept, the **Prototyping Phase** is the initial build of a product or device with the sensor embedded. This can become an iterative process where multiple prototypes are tested – often referred to as alpha- and beta-prototypes – that allow the engineer to evaluate a device's performance at varying build sophistications.

### During this phase, engineers and designers are looking to answer:

1) How am I going to calibrate the sensor for my application?
2) How am I going to accommodate for sensor-to-sensor variation?
3) Can I reliably capture the desired measurement with the FlexiForce sensor embedded in a working device prototype?

# Phase 3: Prototyping

The Alpha Prototype consisted of the infusion pump's housing, the fluid delivery tube, the embedded sensor, and the voltage divider analog circuit module used in Characterization and Proof-of-Concept Phases. With the linearity of the circuit chosen during the Sensor Characterization Phase, and the adjustments made in Proof-of-Concept Phase, the design team developed a simple two-point calibration procedure with the help of the FlexiForce Prototyping Kit. The team actually went back to the FlexiForce Characterization Kit loading fixture to apply known loads to the sensor and the chosen interface materials for calibration.

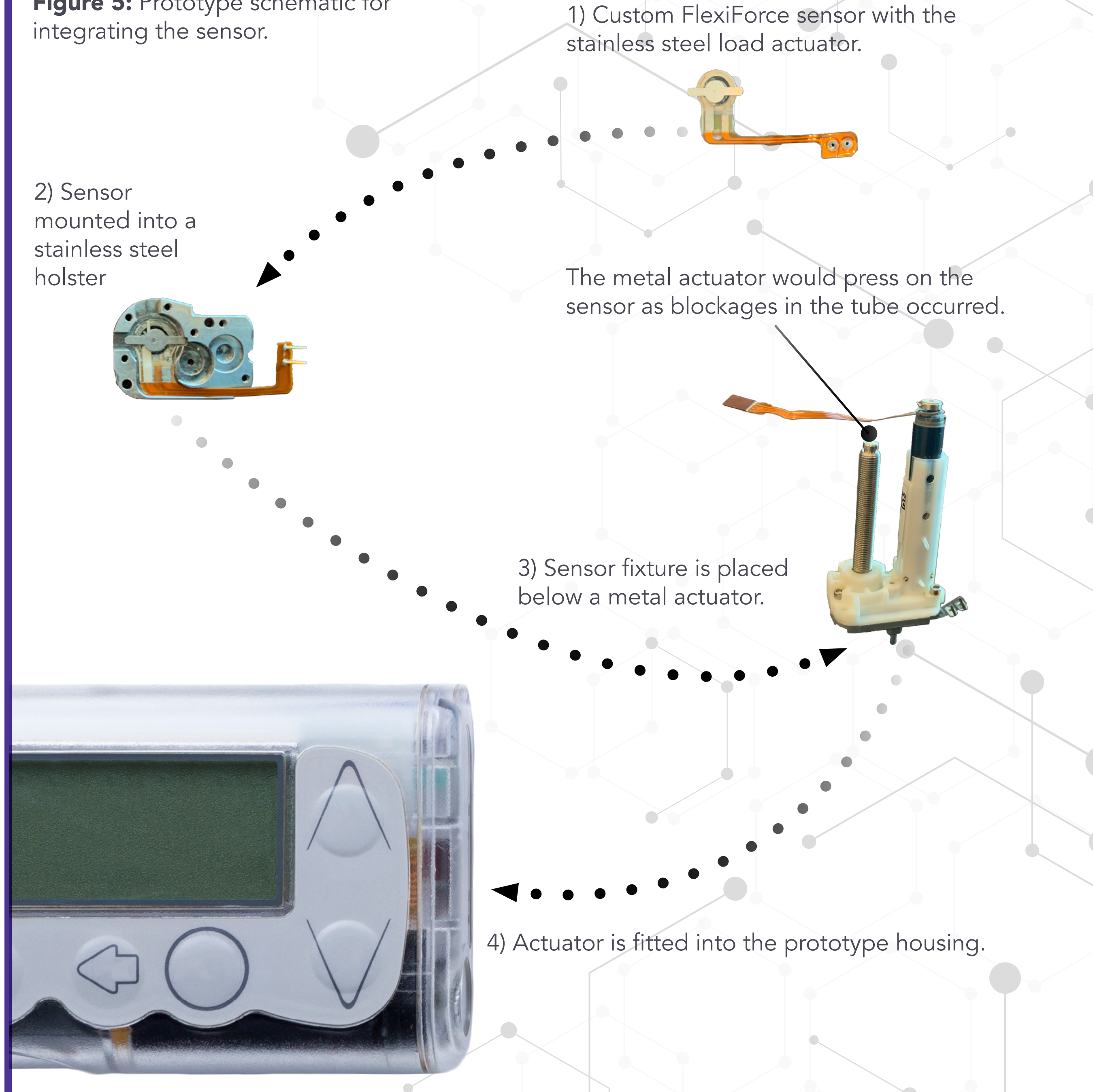
From there, the engineers were able to test performance by running fluid through the tube, and monitoring feedback in a separate board display. **Because the team had characterized the sensor, and proved concept with the same circuitry and material configuration in previous Phases**, they were able to troubleshoot any unforeseen performance issues with their benchmark data.

Once the team was satisfied with the sensor performance within their Alpha Prototype, they constructed a Beta Prototype with the same housing and tube, as well as the rest of the HMI components planned for the design (digital screen, dials, buttons, etc). This version of the prototype also incorporated the first rendition of the printed circuit board (PCB) for the application. For the sensor interface circuit of the PCB, the team was able to use the open-source circuit diagrams and layouts of the analog circuit modules to ensure the same type of circuit was integrated into their PCB. They also incorporated adjustable reference voltage via digital-to-analog converter (DAC) to accommodate sensor-to-sensor variation.

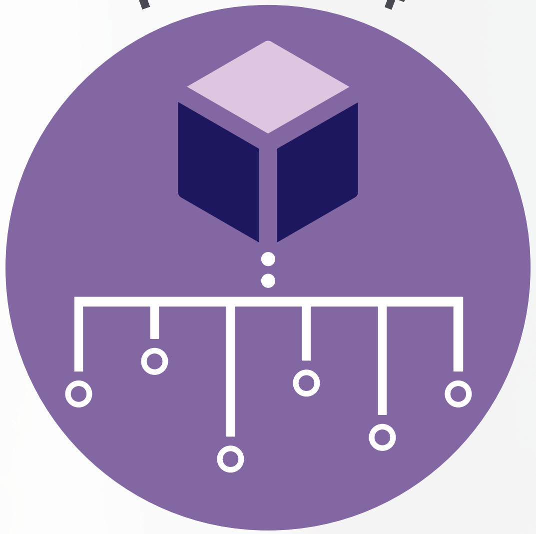
While finalizing the beta prototype, the team noticed the data being output by the sensor was not stable. The sensor output was not repeatable given the assumed constant, cycled load applied to the sensor. The team went back and compared the data collected in the alpha prototype to the repeatability data collected for the same sensor and same circuit in the loading fixture of the FlexiForce Characterization Kit. By looking at the data collected during the repeatability test in characterization, the team was confident that the sensor would produce a repeatable output with their repeatable load.

Next, the team turned toward the assembly of the tubing in the prototype to examine whether it was delivering consistent load to the sensor. They discovered the tubing was configured in such a way that it could slightly move off the sensor during use, which was the likely cause of the erratic data they were observing. The team modified the assembly that held the tubing in place so that it would remain in contact with the sensor, finalized the prototype, and presented it to product management for final approval.

**Figure 5:** Prototype schematic for integrating the sensor.



# Phase 4



## APPLICATION & FIELD TESTING

The **Application & Field Testing Phase** involves creating multiple prototypes to test their performance, longevity, and repeatability. The goal of this phase is to prove whether a design will perform its desired function in the field across the expected lifecycle of the product. For certain products, including medical devices, this is often the phase where the product design is submitted for any third-party approvals.

### During this phase, engineers and designers are looking to answer:

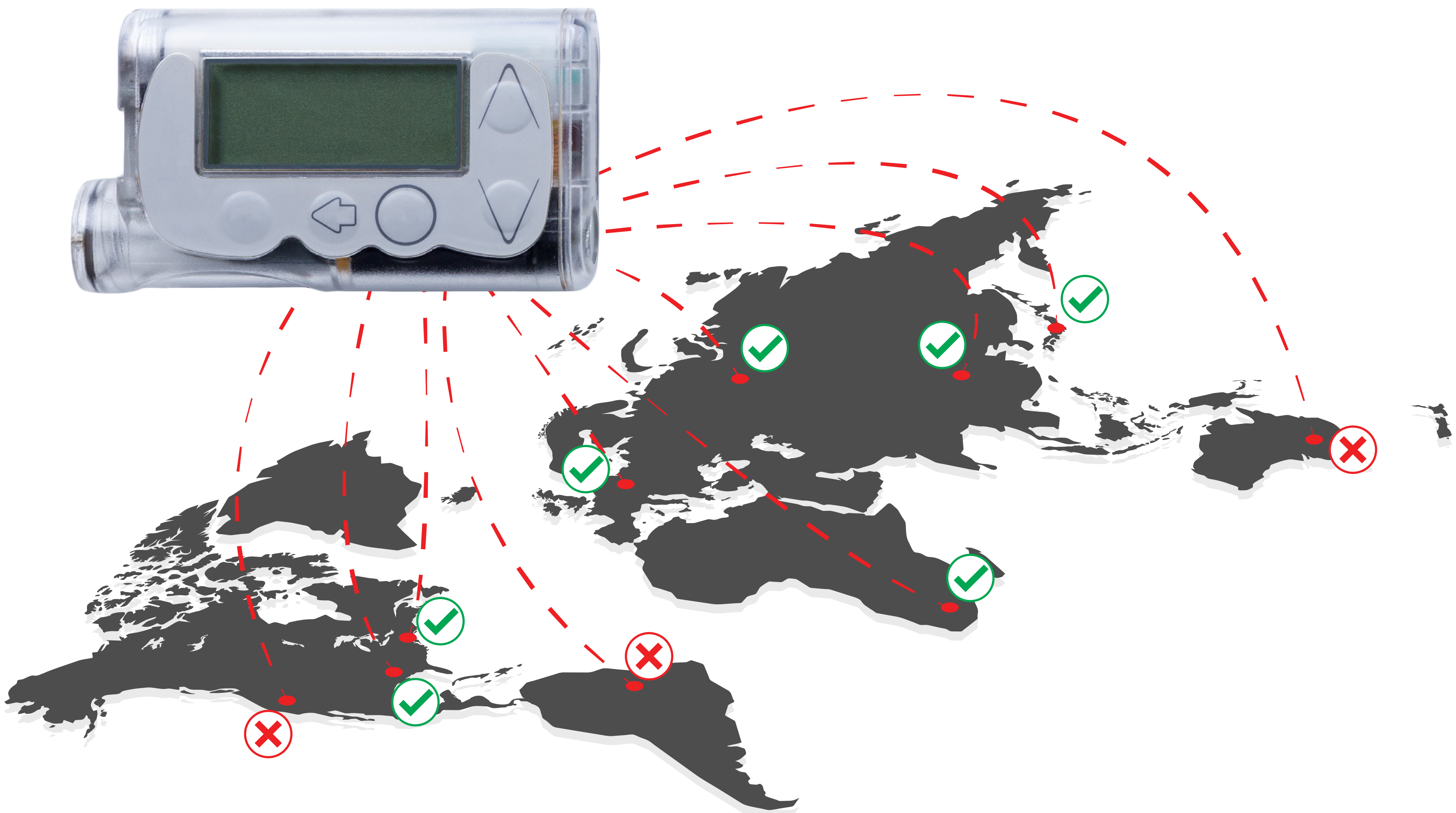
1) Does field deployment call for additional design considerations not accounted for in previous phases?
2) Does the selected material/electronics configuration operate as expected through the anticipated life of the product in the field?

# Phase 4: Application & Field Testing


The design team developed 10 infusion pump prototypes, and deployed them to 10 different users for a duration of six weeks. After the testing duration, it was determined the force sensors in three out of the 10 prototypes were not detecting occlusion effectively. Initially, they suspected that the sensor was at fault.

Upon further review, the sensors were actually performing to expectations when the prototypes were brought back to the lab for testing. In reality, the design team determined that the adhesive used to keep the sensor in place on the pump was not holding up as well in humid conditions, and was affecting sensor performance.

After another round of field-testing with a new adhesive, the force sensor performed well across all prototypes. **Had the design team not taken the time to characterize and fully-vet the sensor early in the process**, they more than likely would have missed this seemingly minor but important mechanical error.



Phase 5

## FINAL EMBEDDED DESIGN

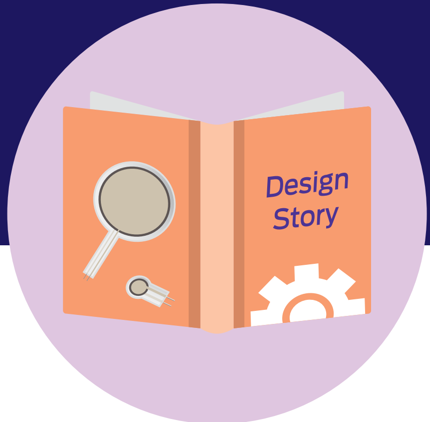
Phase 6

## TRANSFER TO PRODUCTION

Phases 5 and 6 work in tandem with one another, with some subtle differences. As its name suggests, the **Final Embedded Design Phase** is the documentation of final design specifications for transfer to mass production. These specifications include calibration/recalibration routines, sensitivity adjustment, and other variables. It is important to consider how these design specifications can be executed as efficiently as possible in mass production.

Finally, the **Transfer to Production Phase** is the manufacturing process for the mass population of consumers or end users. In most cases, this phase concludes the integration process, but there is always potential for some design challenges to arise in this final phase that may require going back to one of the previous stages to remedy the issue.

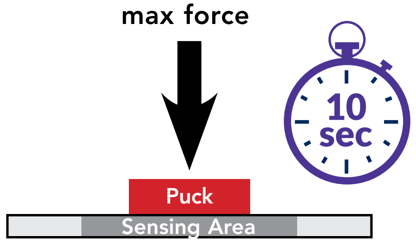
# Phases 5 & 6: Final Embedded Design & Transfer to Production




Because the infusion pump was a medical device, detailed documentation of each step of the manufacturing process was crucial. The design team worked closely with the manufacturing department to account for all of the important nuances of the sensor integration process, and to ensure these steps could be repeated for the mass population of users.

## CALIBRATION WALK-THROUGH EXAMPLE

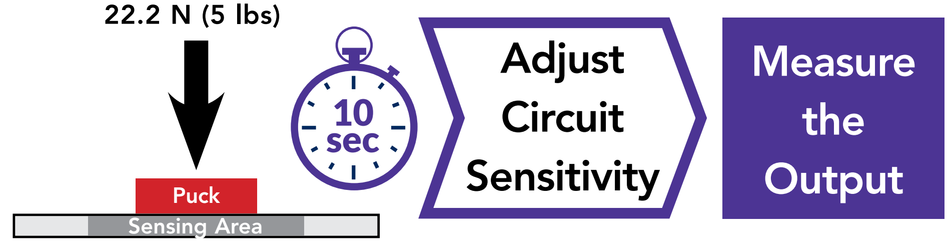
### 1 Condition The Sensor (Recommended)




**Conditioning is only required prior to factory calibration.**

Apply & remove force at 120% of the expected max force 3-5 times, 10 seconds each time.

### 2 Adjust Circuit Sensitivity To 90% Of Circuit's Max Output




**NOTE: In this example, the circuit saturates at 3.3V. Max expected load is 22.2 N (5 lbs).**

Apply max expected force. Adjust sensitivity so that output is 90% of the circuit's maximum output. Remove force.

### 3 Plot Force Vs Recorded Output

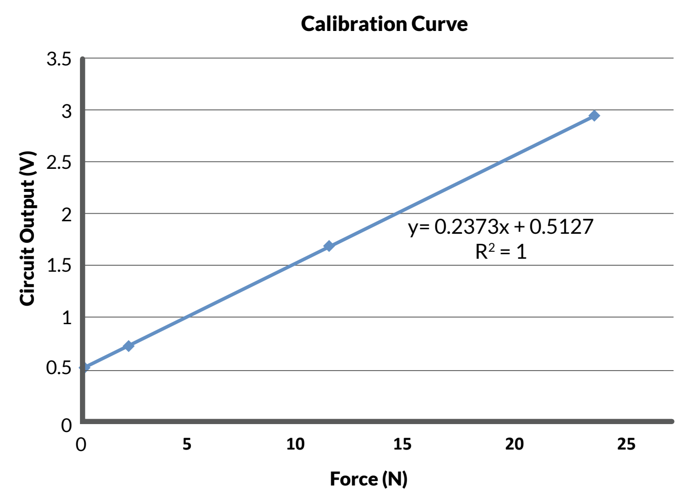
We generally recommend a two-to-three point calibration. First record the circuit output with the sensor unloaded, then:

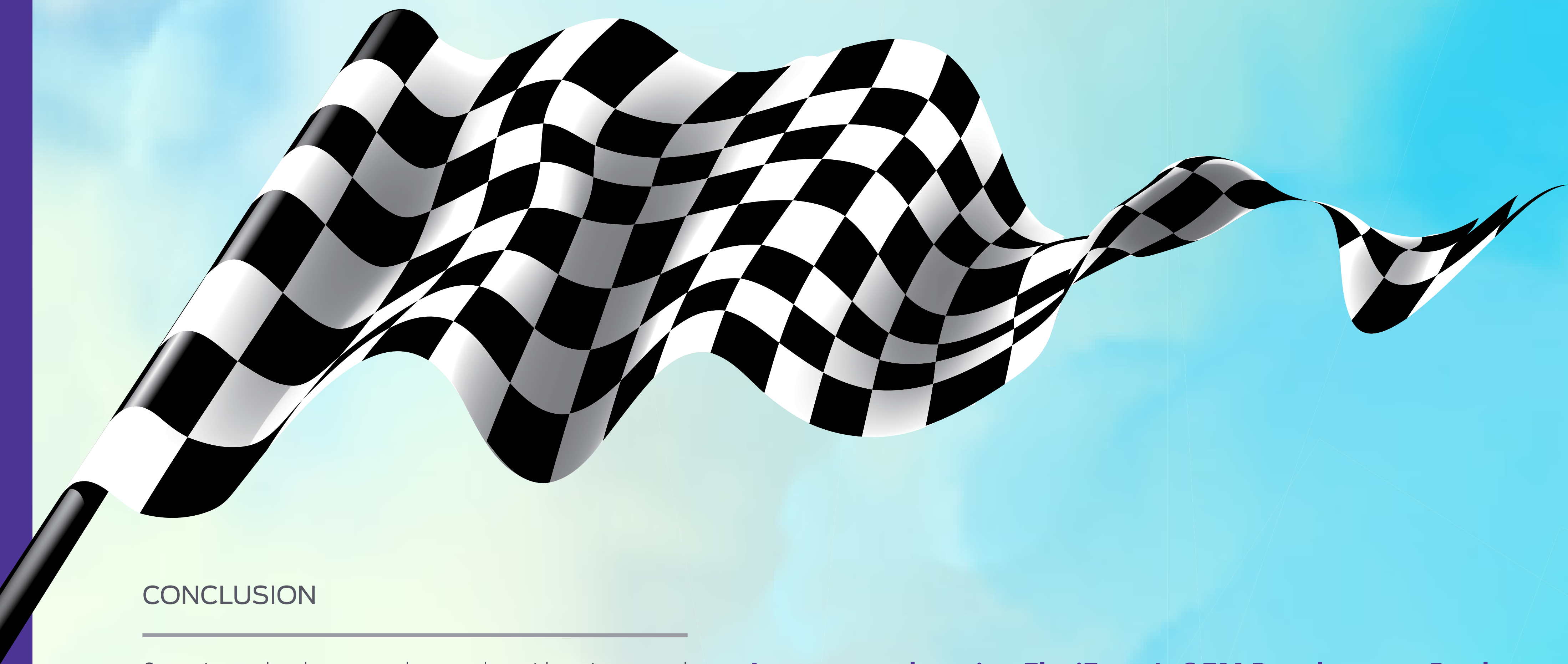
1. Apply a low calibration point of 10% max load
2. (Optional) Apply a mid calibration point at 50% max load, if desired
3. Apply a high calibration point at 100% of max load

Record circuit output at each load.

In this example, we are recording circuit output with the sensor unloaded, then applying 2.2 N,13.3 N, and 22.2 N (0.5 lb, 3 lbs, and 5 lbs, respectively) sequentially at the expected loading time interval.

| Force (N (lbs)) | Circuit Output (V) |
|---|---|
| 0 (0) | 0.51 |
| 2.2 (0.5) | 0.75 |
| 13.3 (3) | 1.70 |
| 22.2 (5) | 2.96 |





## CONCLUSION

Sometimes, the shortest path to market with an integrated device may not seem shortest at first, but the paybacks come in many ways. As this design story shared, the team chose not to take any shortcuts through the integration process, which proved valuable when any unforeseen challenges arose.

Before moving into proof-of-concept and prototyping, the design team made sure to test the FlexiForce sensor technology thoroughly with different circuitry, interface materials, adhesive methods, and other design variables. Because they had a baseline understanding for sensor performance – obtained early in the Characterization Phase – they could account for sensor variations, where designers who skipped this step may have erroneously dismissed the technology as a poor fit.

**In summary, by using FlexiForce's OEM Development Products, the design team was able to efficiently answer crucial questions from concept to market:**

1) What is the fundamental performance of a FlexiForce sensor?
2) How does a FlexiForce sensor perform with the circuits and material interfaces we are considering for our application?
3) Can I successfully capture my intended measurement with the FlexiForce sensor and the electrical/mechanical configuration I have chosen, in a "one-off" test that is representative of the application?
4) How am I going to calibrate the sensor for my application?
5) How am I going to accommodate for sensor-to-sensor variation?
6) Can I reliably capture the desired measurement with the FlexiForce sensor embedded in a working device prototype?
7) Does deployment in the field call for design considerations that were not accounted for in prototyping?
8) Does the selected material/electronics configuration operate as expected through the anticipated life of the product in the field?

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