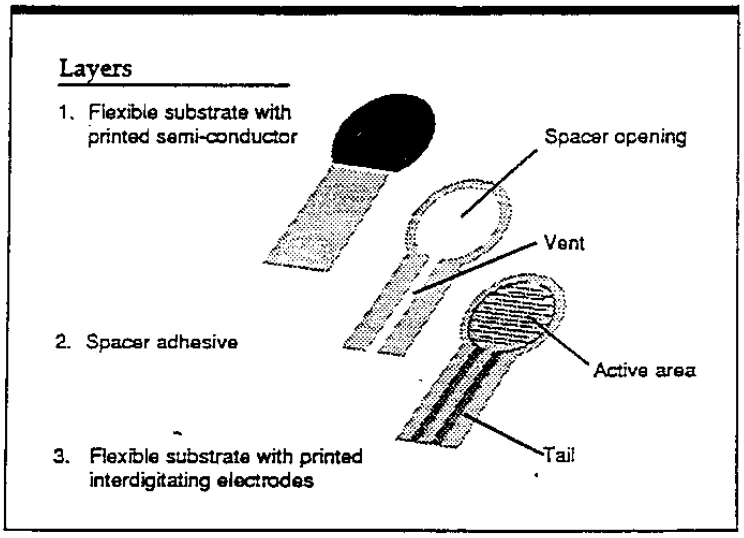
FSR an Overview of the technology

Force Sensing Resistors(FSR) are a polymer film device, which exhibits a decrease in resistance with an increase in the force applied to the active surface. Its force sensitivity is optimized for use in human touch control of electronic devices. FSRs are not a load cell or strain gauge, though they have similar properties. FSRs are not suitable for precision measurements.

FSR Construction



Force vs. Resistance

The force vs. resistance characteristic shown in Figure 1 provides an overview of FSR typical response behavior. For interpretational convenience, the force vs. resistance data are plotted on a log/log format. These data are representative of typical devices, with this particular force-resistance characteristic being the response of evaluation a model (12.7mm diameter circular active area). A stainless steel actuator with a 10.0mm diameter hemispherical tip of 60 durometer polyurethane rubber was used to actuate the FSR device. In general, FSR response approximately follows an inverse power-law characteristic (roughly 1/R)

Referring to Figure 1, at the low force end of the end of the force-resistance characteristic, a switch-like response is evident. This turn-on threshold, or "break force", that swings the resistance from greater than 100 kΩ to about 10 kΩ (the beginning of the dynamic range that follows a power-law) is determined by the substrate and overlay thickness and

Force vs. Resistance

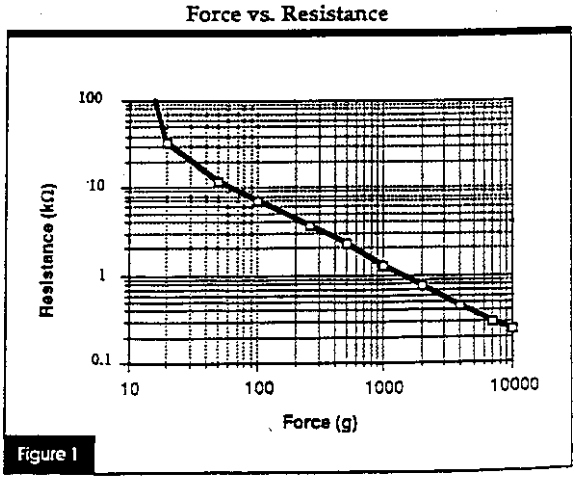


Figure 1

flexibility, size and shape of the actuator, and spacer-adhesive thickness(the gap between the facing conductive elements.) Break force increases with increasing substrate and overlay rigidity, actuator size, and spacer-adhesive thickness. Eliminating the adhesive or keeping it well away force is being applied, such as the center of a large FSR device, will give it a lower rest resistance. Any pre-loading of a FSR will also yield the same result.

Force vs. Conductance (0-10 Kg)

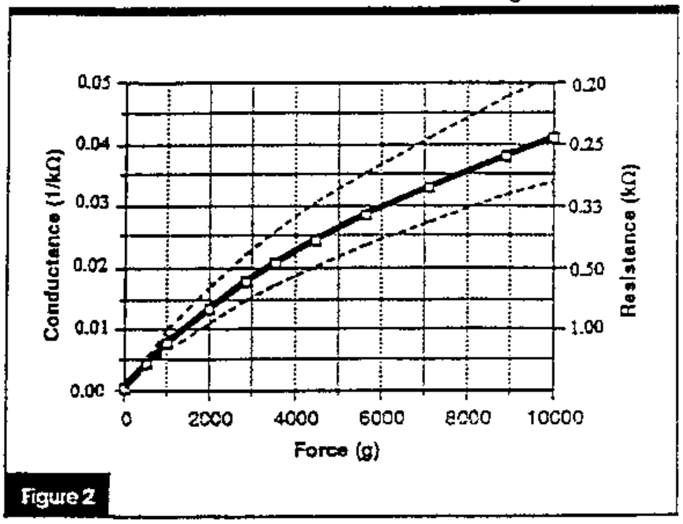


Figure 2

Force vs. Conductance (0-1 Kg) Low Force Range

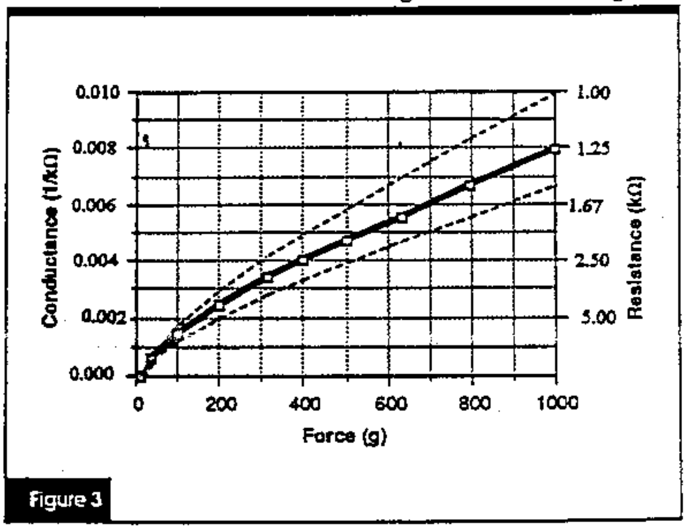


Figure 3

At the high force end of the dynamic range, the response deviates from the power-low behavior, and eventually saturates to a point where increases in force yield little or no decreases in resistance. Under the test conditions of Figure 1, this saturation force is beyond 10 kg. The saturation point is more a function of pressure than force. The saturation pressure of a typical FSR is on the order of 100 to 200psi. For the data shown in Figures 1, 2 and 3, the actual measured pressure range 0 to 175psi (0 to 22lbs applied over 0.125 in^2). Forces higher than the saturation force can be measured by spreading the force over a greater area; the overall pressure is then kept below the saturation point, and dynamic response is maintained. However, the converse of this effect is also true, smaller actuators will saturate FSR's earlier in the dynamic range, since the saturation point is reached at a lower force.

Force vs. Conductance

In Figure 2, the force is plotted vs. conductance (the inverse of resistance : 1/R). This format allows interpretation on a linear scale. For reference, the corresponding resistance values are also included on the right vertical axis. A simple circuit called a current-to-voltage converter give a voltage output directly proportional to FSR conductance and can be useful where response linearity is desired. Figure 2 also includes a typical part-to-part repeatability envelope. This error band determines the maximum accuracy of any general force measurement. The spread or width of the band is strongly dependent on the repeatability of any actuating and measuring system, as well as the repeatability tolerance held by TechStorm Inc. during FSR production. Typically, the part-to-part repeatability tolerance held during manufacturing range from ±15% to ±25% of an established nominal resistance.

Figure 3 highlights the 0-1 kg range of the force-conductance characteristic. As in Figure 2, the corresponding resistance values are included for reference. This range is common to human interface applications. Since the conductance response in this range is fairly liner, the resolution will be uniform and data interpretation simplified. The typical part-to-part error band is also shown for this touch range. In most human touch control applications this error is insignificant, since human touch is fairly inaccurate. Human factor studies have shown that in this force range repeatability error of less than ±50% are difficult to discern by touch alone.

FSR Integration notes

A step-by-step Guide to optimal Use

For best results, follow these seven steps when beginning any new product design, proof-of-concept, technology evaluation, or first prototype implementation:

1. Start with reasonable expectations (know your sensor).

The FSR sensor is not a strain gauge, load cell or pressure transducer. While it can be used for dynamic measurement, only qualitative results are generally obtainable. Force accuracy range from approximately ±5% to ±25% depending on the consistency of the measurement and actuation system, the repeatability tolerance held in manufacturing, and the use of part calibration.

Accuracy should not be confused with resolution. The force resolution of FSR devices is better than ±0.5% of full use force.

2. Choose the sensor that best fits the geometry of your application.

Usually sensor size and shape are the limiting parameters in FSR integration, so any evaluation part should be chosen to fit the desired mechanical actuation system. In general, standards FSR produce have a common semiconductor make-up and only varying actuation methods (e.g. overlays and actuator areas) or electrical interfaces achieve a different response characteristic.

3. Set-up a repeatable and reproducible mechanical actuation system.

When designing the actuation mechanics, follow these guidelines to achieve the best force repeatability.

- Provide a consistent force distribution. FSR response is very sensitive to the distribution of the applied force. In general, this precludes the use of dead weights for characterization since exact duplication of the weight distribution is rarely repeatable cycle-to-cycle. A consistent weight (force) distribution is more difficult to achieve than merely obtaining a consistent total applied weight (force). As long as the distribution is the same cycle-to-cycle, then repeatability wil1 be maintained. The use of a thin elastomer between the applied force and the FSR can help absorb error from inconsistent force distributions.

• Keep the actuator area, shape, and compliance constant. Changes in these parameters significantly alter the response characteristic of a given sensor. Any test, mock-up, or evaluation conditions should be closely matched to the final use conditions. The greater the cycle-to-cycle consistency of these parameters, the greater tile device repeatability. In human interface applications where a finger is the nude of actuation, perfect control of these parameters is not generally possible. However, human force sensing is somewhat inaccurate; it is rarely sensitive enough to detect differences of less than ±50%.

• Control actuator placement. In cases where the actuator is to be smaller than the FSR active area, cycle-to-cycle consistency of actuator placement is necessary. (Caution : FSR layers are held together by an adhesive that surrounds the electrically active areas.0 force is applied over an area which includes the adhesive, the resulting response characteristic will be drastically altered.) In an extreme case (e.g. a large, flat, hard actuator that bridges the bordering adhesive), the adhesive a prevent FSR actuation.

• Keep actuation cycle time consistent Because of the time dependence of the FSR resistance to an applied force, it is important when characterizing the sensor system to assure that increasing loads (e.g. force ramps) are applied at consistent rates (cycle-to-cycle). Likewise, static force measurements must take into account FSR mechanical settling time. This time is dependent on the mechanics of actuation and the amount of lone applied and is usually on the order of seconds.

4. Use the optimal electronic interface.

In most product designs, the critical characteristic is force vs. Output Voltage, which is controlled by the choice of interface electronics. A variety of interface solutions are detailed in the TechNote section of this guide. Summarized here are some suggested circuits for common FSR applications.

• For FSR pressure or force switches, use the simple interfaces detailed other pages.

• For dynamic FSR measurements or variable controls, a current-to-voltage converter is recommended. This circuit produces an output voltage that is inversely proportional to FSR resistance. Since the FSR resistance is roughly inversely proportional to applied force, the end result is a direct proportionality between force and voltage; in other words, this circuit gives roughly linear increases in output voltage for increases in applied force. This linearization of the response optimizes He resolution and simplifies data interpretation.

5. Develop a nominal voltage curie and error spread.

When repeatable and reproducible system has been established, data from a group of FSR parts can be collected. Test several FSR parts in the system. Record the output voltage at various pre-selected force points throughout the range of interest. Once a family of curves is obtained, a nominal force vs. output voltage curve and the total force accuracy of the system can be determined.

6. Use part calibration if greater accuracy is required.

For applications requiring the highest obtainable force accuracy, part calibration wil1 be necessary. Two methods can be utilized : gain and offset trimming and curve fitting.

• Gain and offset trimming can be used as a simple method of calibration. The reference voltage and feedback resister of the current-to-voltage converter is adjusted for each FSR to pull their responses closer to the nominal curve.

• Curve fitting is the most complete calibration method A parametric curve fit is done for the nominal curve of a set of FSR devices, and the resultant equation is stored for future use. Fit parameters are then established for each individual FSR (or sensing element in an array) in the set These parameters, along with the measured sensor resistance (or voltage), are inserted into the equation to obtain the force reading. If needed, temperature compensation can also to include in the equation.

7. Refine the system.

Spurious results on normally to trace to sensor error or system error. If you have any questions, contact TechStorm Inc. Sales Engineers to discuss your system and final data.

The Do's and Don'ts

Do’s

- Do, if possible use a firm, flat and smooth mounting surface.
- Do be careful if applying FSR devices to curved Surfaces. Pre-loading of the device can occur as the two opposed layers are forced into contact by the bending tension. The device will still function, but the dynamic range may be reduced and resistance drift could occur. The degree of curvature over which an FSR can be bent is a function of the size of the active area. The smaller the active area, the less effect given curvature will have on the FSR’s response.
- Do avoid air bubbles and contamination when laminating the FSR to any surface. Use only thin, uniform adhesives, such as Scotch®brand double-sided laminating adhesives. Cover the entire surface of the sensor.
- Do to careful of kinks or dents in active areas. They can cause false triggering of the sensors.
- Do protect the device from sharp objects. Use an overlay, such as a polycarbonate film or an elastomer, to prevent gouging of the FSR device.
- Do use soft rubber or a spring as part of the actuator in designs requiring some travel.

Don'ts

- Do not kink or crease the tail of the FSR device if you are bending it this can cause breaks the printed silver traces. The smallest suggested bend radius for the tails of evaluation parts is about 2.5 mm. Also, be careful if bending the tail near the active area. This can cause stress on the active area and may result in per-loading and false readings.
- Do not block the Tent FSR devices typically have an air vent that runs from the open active area down the length of the tail and out to the atmosphere. This vent assures pressure equilibrium with the environment, as well as allowing even loading and unloading of the device. Blocking this vent could cause FSR’s to respond any actuation in a non-repeatable manner. Also note, that if the device is to be used in a pressure chamber, the vented end will need to be vented to the outside of the chamber. This allows for the measurement of the differential pressure.
- Do not solder directly to the exposed silver traces.
- Do not apply excessive shear force. This can cause delamination of the layers.
- Do not exceed 1mA of current per square centimeter of applied force (actuator area). This can irreversibly damage the device.

General FSR Characteristics

These are typical parameters. The FSR is a custom device and can be made for use outside these characteristics.

Simple FSR Devices and Arrays

Parameter	Value	Notes
Size range	Max = 20” × 24” (51×61cm) Min = 0.2” × 0.2” (0.5 × 0.5cm)	Any shape
Device Thickness	0.008” to 0.050” (0.2 to 1.25mm)	Dependent on materials
Force Sensitivity Range	< 100g to > 10kg	Dependent on mechanics
Pressure Sensitivity Range	< 1.5 psi to > 150 psi (< 0.1 kg/cm^2 to > 10kg/cm^2)	Dependent on mechanics
Part-to-part Force Repeatability	±15% to ±25% of established nominal resistance	With a repeatable actuation system
Single Part Force Repeatability	±2% to ±5% of established nominal resistance	With a repeatable actuation system
Force Resolution	Better than 0.5% full scale	
Break Force (turn-on Force)	20g to 100g (0.7oz to 3.5oz)	Dependent on mechanics and FSR build
Stand-off Resistance	Typically 100K Ohms to > 1M Ohms	Unloaded, unbent
Switch Characteristic	Essentially zero travel	
Device Rise Time	1-2msec (Mechanical)	
Lifetime	> 10 million actuation	
Temperature Range	-30°C to + 170°C	Dependent on materials
Maximum Current	1 mA/cm^2 of applied force	
Sensitivity to Noise / Vibration	Not significantly affected	
EMI/ESD	Passive device	
Lead Attachment	Standard flex circuit techniques	

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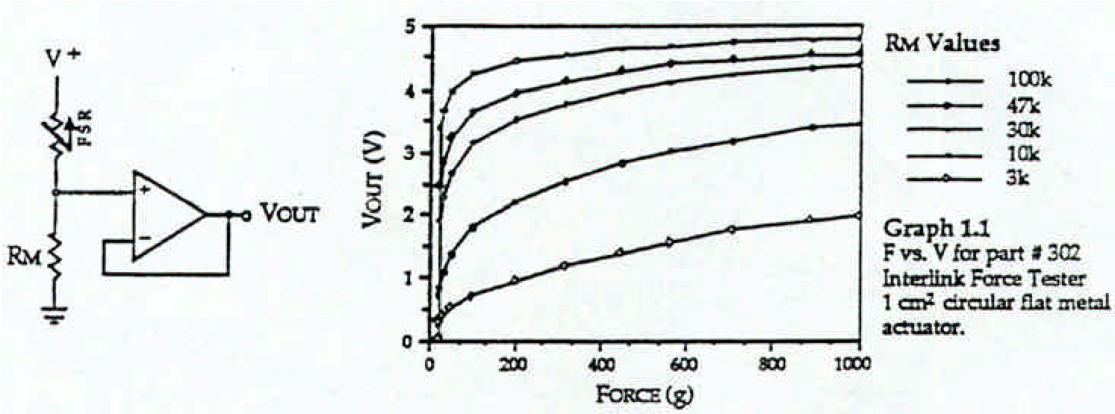
Basic FSR's



FSR Voltage Divider

For a simple force-To-voltage conversion the FSR device is tied to a measuring resistor in a voltage divider configuration. The output is described by the equation :

(Vout= V+) / [l +RFSR/RM].

In the shown configuration, the output voltage increases with increasing force. If RFSR and RM are swapped, He output swing will decrease with increasing force. These two output forms are mirror images about the line Vout = (V+)/2.

The measuring resistor, RM, is chosen to maximize the desired force sensitivity range and to limit current. The current through the FSR should be limited to less than 1 mA/square cm of applied force-Suggested op-amps for single sided supply designs is LM358 and LM324. FET input devices such as LF355 and TL082 are also good. The low bias currents of these op-amps source impedance of the voltage divider.

A family of FORCE vs. Vout curves is show on Graph 1.1 for a standard FSR in a voltage divider configuration with various RM resistors. A (V+) of + 5V was used for these examples.

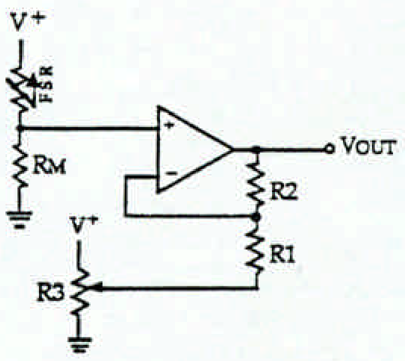


Figure 1.1

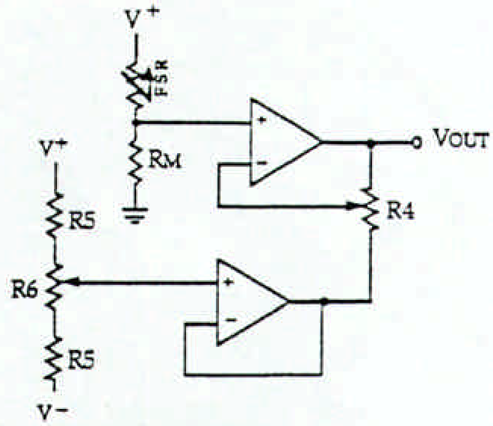


Figure 1.2

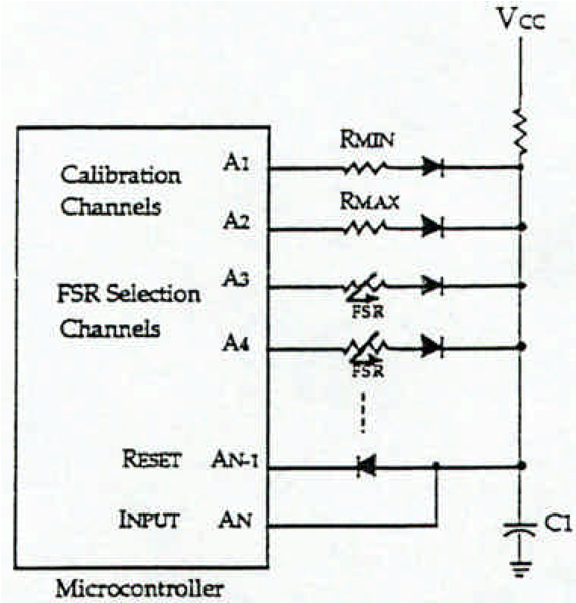
Adjustable Buffers

Similar to the FSR Voltage Divider, these interfaces isolate the output from the high source impedance of the Force Sensing Resistor. However, these alternatives allow adjustment of the output offset and gain.

In Figure 1.1, the ratio of resistors R2 and R1 sets the gain of the output. Offsets resulting from the non-infinite FSR resistance at zero force (or bias currents) can be trimmed out with the potentiometer, R3. For best results, R3 should be about one-twentieth of R1 or R2. Adding an additional pot R2 makes the gain easily adjustable.

Replacing R2 and R1 with a single pot can make broad range gain adjustment.

The circuit in Figure 1.2 yields similar results to the previous one, but the offset trim is isolated from the adjustable gain. With this separation, there is no constraint on values for the pot. Typical values for R5 and the pot are around 10kΩ.

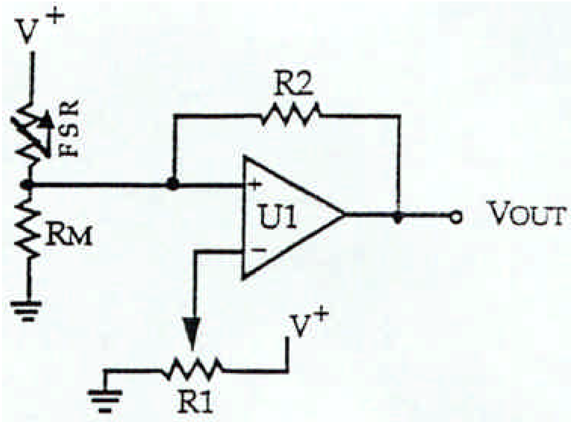


Multi-Channel FSR-to-Digital Interface

Sampling Cycle (any FSR channel):
The micro controller switches to a specific ESR channel, toggling it high, while all other FSR channels are toggled low. The RESET channel is toggled high, counter starts and the capacitor C1 charges, with its charging rate controlled by the resistance of the FSR (t – RC). When the capacitor reaches the high digital threshold of the INPUT channel, the counter shuts off, the RESET is toggled low, and the capacitor discharges.

The number of "counts" it takes from the toggling of the RESET high to the toggling of the INPUT high is proportional to the resistance of the FSR. The resistors RMIN and RMAX are used to set a minimum and maximum "counts" and therefore the range of the "counts". They are also used periodically to re-calibrate the reference. A sampling cycle for RMAX is run and the value is stored as the maximum of the range (after subtracting the RMIN value). Successive FSR samplings are normalized to the new zero. The full range is "zoned" by dividing the normalized maximum "count" by the number of desired zones. This will delineate the window size or with of each zone.

Continual sampling is done to record changes in FSR resistance due to changes in force. Each FSR is selected sequentially.



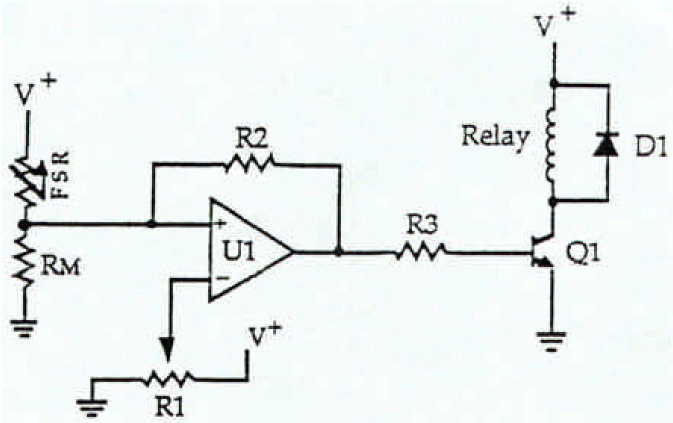
FSR Variable Force Threshold Switch

This simple circuit is ideal for applications that require on-off switching at a specified force, such as touch-sensitive membrane, cut-off, and limit switches. For a variation of this circuit that is designed to control relay switching, see the next page.

The FSR device is arranged in a Tollage divider with RM. An op-amp, U1, is used as a comparator. The output of U1 is either high or low. The non-inverting input of the op-amp is driven by the output of the divider, which is a voltage that increases with force. At zero force, the output of the op-amp will be low. When the voltage at the non-inverting input of the op-amp exceeds the voltage of the inverting input, the output of the op-amp would toggle high. The pot R1 sets the triggering voltage, and therefore the force threshold, at the inverting input. The hysteresis resistor, R2, acts as a "debouncer", eliminating any multiple triggerings of the output that might occur.

Suggested op-amps are LM358 and LM324. Comparators like LM393 and LM339 also work quite well. The parallel combination of R2 with RM is chosen to limit current and to maximize the desired force sensitivity range. A typical value for this combination is about 47kΩ.

Two fixed value resistors in a voltage divider configuration can replace the threshold adjustment pot, R1.



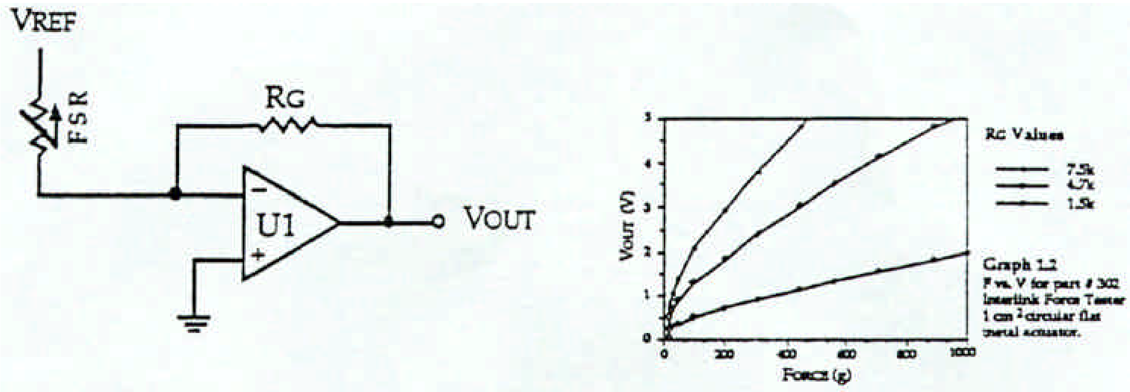
FSR Variable force Threshold Relay Switch

This circuit is a derivative of the simple FSR Variable Force Threshold switch on the previous page. It has used where the element to be switched requires higher current, like automotive and industrial control relays.

The FSR device is arranged in a voltage divider with RM. An op-amp, U1, is used as a comparator. The output of U1 is either high or low. The non-inverting input of the op-amp sees the output of the divider, which is a voltage that increase with force. At zero force, the output of the op-amp will below. When the voltage at the non-inverting input of the op-amp exceeds the voltage of the inverting input, the output of the op-amp would toggle high. The triggering voltage, and therefore the force threshold, is set at the inverting input f the pot R1. The transistor Q1 is chosen to match the required current specification for the relay. Any medium power NPN transistor should suffice. For example, an NTE212 can sink 2amps, and anNTE291 on sink 4 amps. The resistor R3 limits the base current(a suggested value is 4.7KΩ). The hysteresis resistor, R2, acts as a "debouncer', eliminating any multiple triggerings of the output that might occur.

Suggested op-amps are LM358 and LM24. Comparators like LhD393 and LM339 also work quite well, but must be used in conjunction with a pull-up resister. The parallel combination of R2 with RM is chosen to limit current and to maximize the desired force sensitivity range. A typical value for this combination is about 47kΩ.

The threshold adjustment pot, R1, can to replace by two fixed value resistors in a voltage divider configuration. The diode Dl is included to prevent fly back, which could harm the relay and the circuitry.



FSR Current-to-Voltage Converter

In this circuit, the FSR device is the input of a current-to-voltage converter. The output of this amplifier is described by the equation :

Vout=Vref · [-RG/RFSR]

With a positive reference voltage, the output of the op-amp must be able to swing below ground, from 0V to -Vref, therefore dual sided supplies are necessary. A negative reference voltage will yield a positive output swing, from 0V to +Vref.

Since this is a simple inverse relation between Vout and RFSR, the output equation can be rearranged to :

Vout=(-RG ·Vref) /RFSR.

Vout is inversely proportional to RFSR. Changing RG and/or Vref changes the response slope. The following is an example of the sequence used for choosing the component values and output swing:

For a human-to-machine variable control device, like a joystick, the maximum force applied to the FSR is -5V, and an output swing of 0V to +5V is desired, then RG should be approximately equal to this minimum RFSR. RG is set at 4.7 KΩ. A full swing of 0V to +5V is thus achieved. A set of FORCE vs. Vout curves is shown on Graph 1.2 for a standard FSR using this interface with a variety of RG values.

The current through the FSR device should to limited to less elan 1 mA/square cm of applied force. As with the voltage divider circuit, adding a resistor in parallel with RFSR will give a definite rest voltage, which is essentially a zero-force intercept value. This can be useful when resolution at low forces is desired.

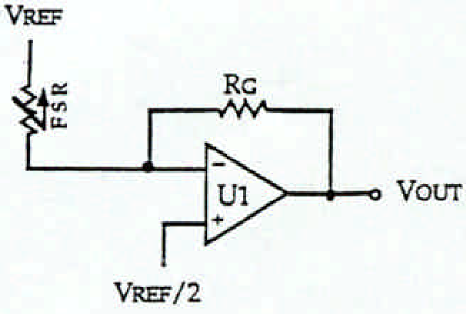


Figure 1.3

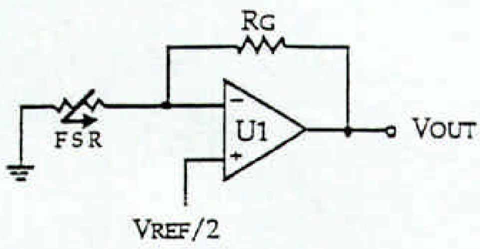


Figure 1.4

Additional FSR Current-to-Voltage Converters

These circuits are slightly modified versions of the current-to-voltage converter detailed on the previous page. Please refer to it for more detail

The output of Figure 1-3 is described by the equation:

Vout = [Vref/2] * [1-RG/RFSR]

The output swing of this circuit is from (Vref/2) to 0V. In the case where RG is greater than RFSR, the output will go into negative saturation.

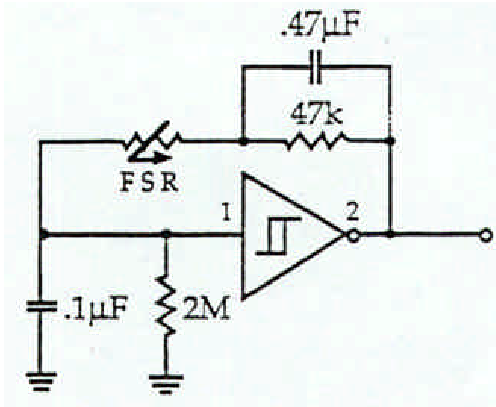
The output of figure 1.4 is described by the equation:

Vout=Vref/2· [1+RG/RFSR].

The output swing of this circuit is from (Vref/2) to Vref. In the case where RG is greater than RFSR, the output will go into positive saturation.

For either of these configurations, a zener diode placed in parallel with RG will limit the voltage built up across RG. These designs yield one-half the output swing of the previous circuit but only require single sided supplies and positive reference voltages. Like the preceding circuit, the current through the FSR should be limited to less than 1 mA/square cm of applied force.

Suggested op-amps are LMd358 and LM324.



FSR Schmitt Trigger Oscillator

In this circuit, an oscillator is made using the FSR device as the feedback element around a Schmitt Trigger. In this manner, a simple force-to-frequency converter is made. At zero force, the FSR is an open circuit. Depending on the last stage of the trigger, the output remains constant, either high or low. When the FSR is pressed, the oscillator starts, its frequency increasing with increasing force. The 2MΩ resistor at the input of the trigger insures that the oscillator is off when FSR with non-infinite resistance at zero force are used. The 47kΩ resister and the 0.47µF capacitor control the force-to-frequency characteristic. Changes in the "feel" of this circuit a be made by adjusting these values. The 0.1µF capacitor controls the frequency range of the oscillator. By implementing this circuit with CMOS or TTL, counting can control digital process leading and/or trailing edges of the oscillator output. Suggested Schmitt Triggers are CD401D6, CD4584 or 74C14.