Electronics Integration Guide

(For FlexiForce® Sensors)

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INTRODUCTION

The purpose of this document is to describe a few basic circuits for integration with standard *FlexiForce*® A201 or custom sensors. These circuit schematics and descriptions allow the user to obtain an analog voltage output with respect to force applied to the sensor. This voltage can then be input to the Analog-to-Digital converter of a Data Acquisition System or custom electronics application. Without the use of a drive circuit, the sensor outputs a non-linear resistance that decreases with respect to applied force. The relationship of conductance, or inverse resistance, with respect to force is linear.

The first three drive circuits provide a relatively linear output voltage versus input force relationship. Our recommended circuit, the Triple-Source Inverting Amplifier circuit provides the most linear output and should be used whenever there are 3 power sources available. The Dual-Source Inverting Amplifier circuit is a variation of the recommended circuit and is best used when only two power sources are available. The Single-Source Voltage Divider Follower circuit is best used for electronics integration with only one available source or for a user that wants the simplest force to voltage conversion available and is not primarily concerned with linearity.

The remaining three circuits are designed with specific applications in mind. These are also basic circuits and should be improved upon before integration with a complete system. The Inverting Summing circuit provides a single output from multiple sensors. This is useful when multiple sensors are required to support a load, but only the total force measured is of interest. The Force Threshold Switch and Force Threshold Relay Switch circuits are variable switching circuits useful for any application where a certain amount of force applied is needed to switch on or off a device. The Force Threshold Relay circuit is used in applications where the load device requires higher current.

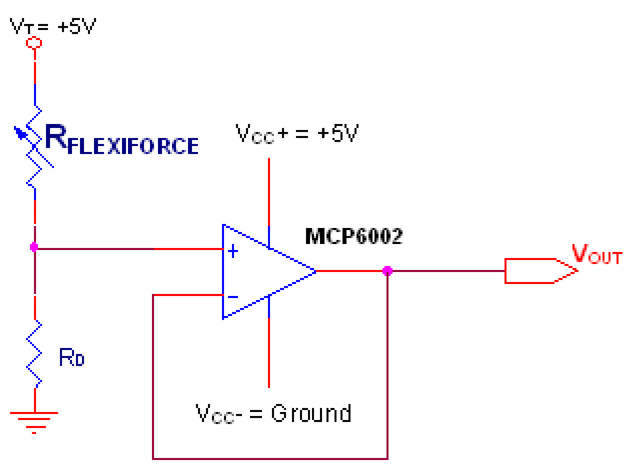
The final sections of this document discuss choosing op-amps, using battery-powered sources, the benefits of driving the sensor with AC versus DC voltages, and general sensor specifications.

CIRCUITS

SINGLE-SOURCE VOLTAGE DIVIDER FOLLOWER CIRCUIT

Overview

This design will allow you to convert the *FlexiForce* sensor's analog resistance output to a 0-5 volt DC output that increases as increasing force is applied. The Voltage Divider Follower circuit is only recommended for integration with electronics where only one power source is available. It does not provide a linear voltage output with respect to force applied.



Description

This circuit can be driven from a wall brick AC adaptor rated at 5VDC – 9VDC commonly used to power most of today's electronics. The power supply output current can be rated at as little as 100mA and the circuit consumes less than 10mA. Using batteries is not recommended unless a voltage regulator is connected (*see* Battery Power Sources).

The transfer function of the circuit is the ratio of the fixed resistance to the *FlexiForce* resistance,

$$V_{OUT} = (R_D/(R_D + R_{FLEXIFORCE})) * V_T$$

When the *FlexiForce* sensor is unloaded, its effective resistance is in the MΩ range and the output is low.

$$V_{out} = \sim(R_D/R_{FLEXIFORCE}) * V_T \mid \quad R_{FLEXIFORCE} >> R_D$$

As the force increases and the sensor's resistance decreases, the output voltage will increase. When the *FlexiForce* resistance equals the fixed resistance (R_D), $V_{OUT} = V_T/2$.

Increase in force correlates to increase in output voltage. The output range of this circuit is ~ $0V - V_T$.

Performance

Figure 1 - Divider Follower circuit with 100 lb. Sensor. Non-compliant, circular force actuator used with 0.045 sq. inch area. V_{cc}^+ (pin 8) is at 5V, V_{cc}^- (pin 4) is to ground, and V_T is at +5V with varying R_D.

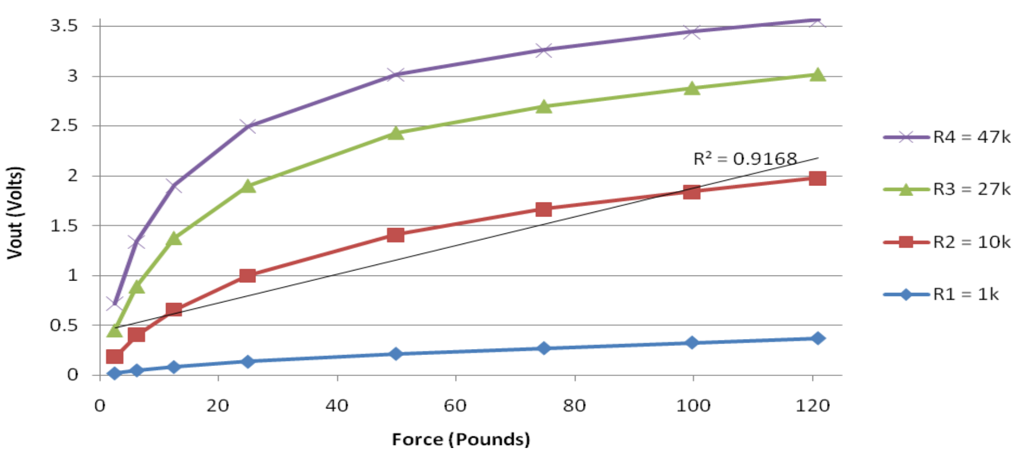
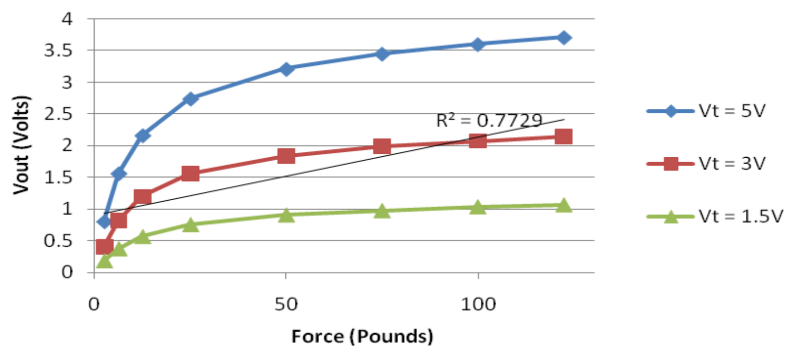


Figure 1 shows the relationship of the output voltage, V_{OUT}, versus the Force applied to the sensor with the drive voltage, V_T, fixed at +5 volts. As the value of R_D (represented by R1…R5) increases, the corresponding values of V_{OUT} also increase. By inspection of this graph it is seen that decreasing R_D will prevent saturation of the circuit output for a given force (increased force range). Conversely, applying a larger resistance will increase the slope of the V_{OUT} versus Force curve and therefore increase the sensitivity of the circuit (decreased force range). Below, Figure 2 shows the V_{OUT} versus Force relationship with a varying drive voltage, V_T, and fixed resistance. With our recommended circuit (*see* Triple-Source Inverting Amplifier Circuit (Recommended Circuit)), adjusting the drive voltage will have a similar effect to changing the resistance value, but with this circuit adjusting the drive voltage will not have a large effect on the sensitivity and force range. This is because the voltage at the op-amp rail changes as the drive voltage is adjusted due to the use of a single power source (op-amp rail limits maximum circuit output).

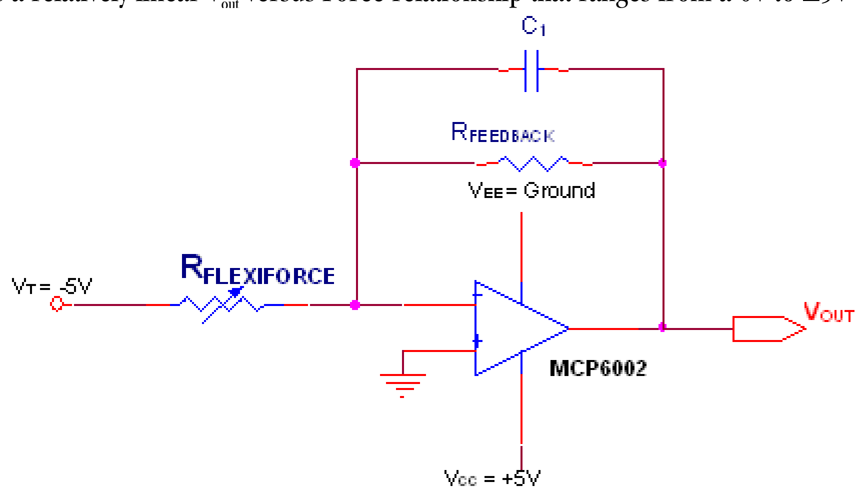
Figure 2 - Divider Follower circuit with 100 lb. Sensor. Non-compliant, circular force actuator used with 0.045 sq. inch area. V_{CC}^- (pin 4) is to ground and R_D is fixed at 100k• . V_{CC}^+ (pin 8) is set to 5V with voltage regulator (see [Battery Power Sources]) used to step down voltage for V_T input (3V and 1.5V).



DUAL-SOURCE INVERTING AMPLIFIER CIRCUIT

Overview

This circuit is recommended for testing and electronics system integration when more quantitative data output is required from the *FlexiForce* sensor than the Voltage Divider Follower circuit provides, but only two power sources are available. It provides a relatively linear V_{out} versus Force relationship that ranges from a 0V to ±5V output.



Description

This design requires a dual output power supply in the range of ±5V. Using batteries is not recommended unless a voltage regulator is connected (*see [Battery Power Sources]*).

The test voltage, V_T must be negative for this circuit. The negative V_T will result in a positive 0-5V output signal that can then be converted by an Analog to Digital Converter (ADC) and the binary values transferred to a test program.

The transfer function of this circuit is

$$V_{out} = -(R_{FEEDBACK}/R_{FLEXIFORCE}) * V_T$$

It is recommended that the capacitor (C_1), on the range of 47 to 270pF, be connected in parallel with $R_{FEEDBACK}$ due to the associative capacitance of the *FlexiForce* sensor. There will be substantial oscillation in the circuit output if it is omitted.

Performance

Figure 3 - Dual Source Inverting circuit with 100 lb. Sensor. Non-compliant, circular force actuator used with 0.045 sq. inch area. V_{CC} (pin 4) is at 5V, V_{EE} (pin 11) is to ground, and V_T is at –5V with varying $R_{FEEDBACK}$.

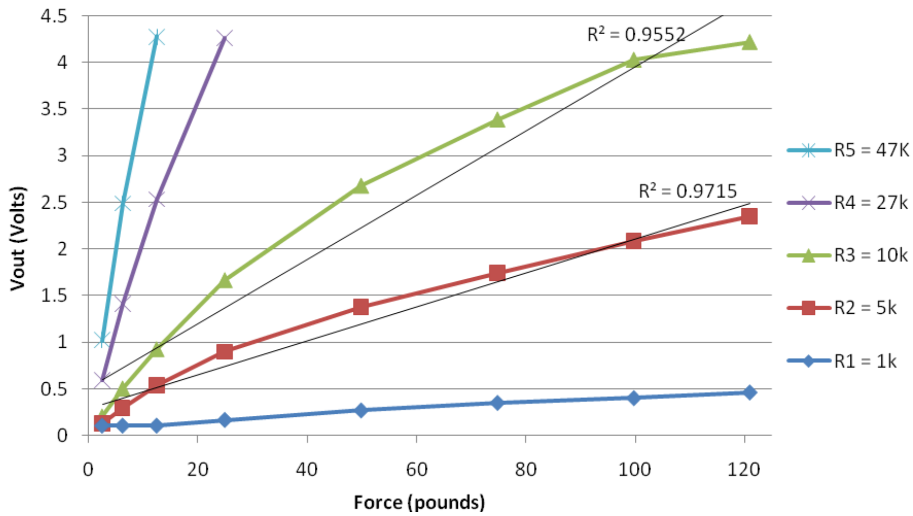
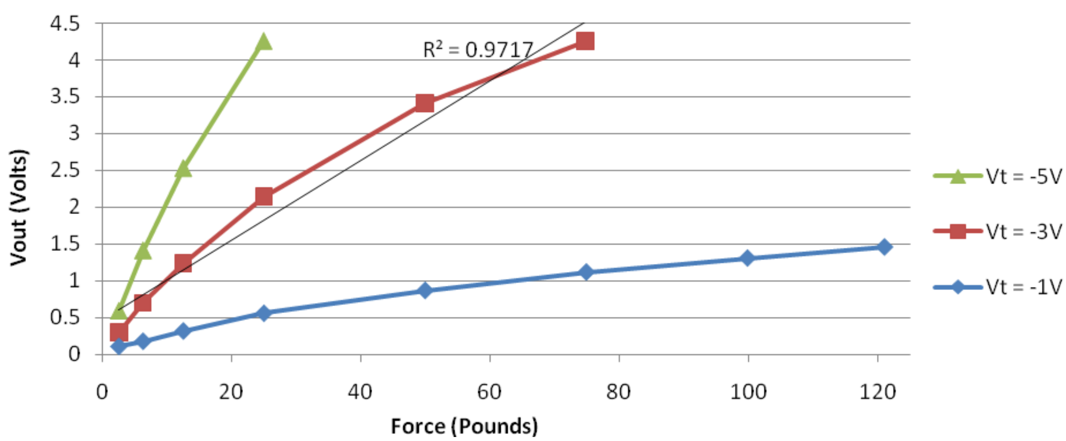


Figure 3 shows the relationship of the output voltage, V_{OUT}, versus the Force applied to the sensor with the drive voltage, V_T, fixed at –5 volts. As the value of $R_{FEEDBACK}$ (represented by R1…R5) increases, the corresponding values of V_{OUT} also increase. Below, Figure 4 shows the V_{OUT} versus Force relationship with a varying drive voltage and fixed resistance. By inspection of these graphs it is seen that decreasing $R_{FEEDBACK}$ and/or the drive voltage V_T will prevent saturation of the circuit output for a given force (increased force range). Conversely, applying a larger drive voltage and/or resistor will increase the slope of the V_{OUT} versus Force curve and therefore increase the sensitivity of the circuit (decreased force range).

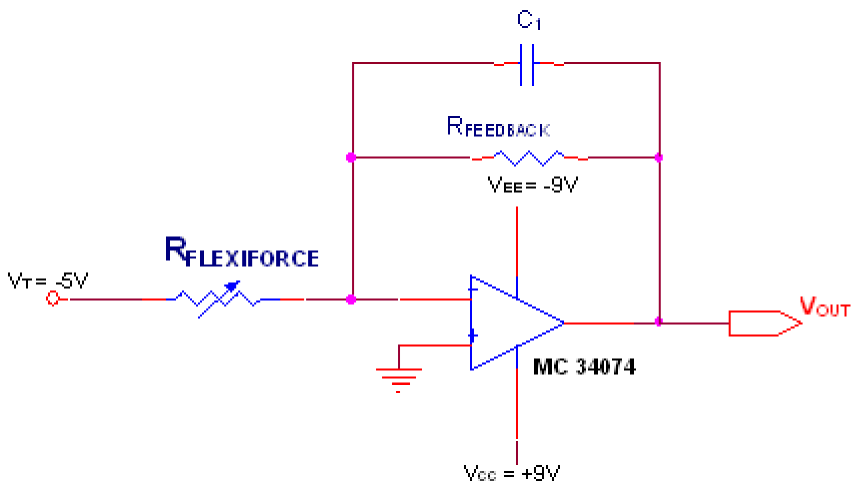
Figure 4 - Dual Source Inverting circuit with 100 lb. Sensor. Non-compliant, circular force actuator used with 0.045 sq. inch area. V_{CC} (pin 4) is at 5V, V_{EE} (pin 11) is to ground, and $R_{FEEDBACK}$ is fixed at 10k• with varying drive voltage (V_T).



TRIPLE-SOURCE INVERTING AMPLIFIER CIRCUIT (RECOMMENDED CIRCUIT)

Overview

This circuit is recommended for testing and electronics system integration when more quantitative data output is required from the *FlexiForce* sensors than can be provided by the two previous circuits. It provides a very linear V_{out} versus Force relationship that ranges from a 0V to ±9V output. The circuit is designed for a 0-5V output when $R_{FEEDBACK}$ is chosen to match the sensor resistance output that occurs at full load.



Description

This design requires a triple output power supply in the range of ±5Vand ±9V. Using batteries is not recommended unless a voltage regulator is connected (*see Battery Power Sources*).

The test voltage, V_T can be either positive or negative. Generally, V_T is chosen to be negative if a positive output is desired and/or if the analog output signal is to be converted by an Analog to Digital Converter (ADC) and the binary values transferred to a test program. If V_T is positive, the circuit will output a negative voltage when force is applied to the sensor.

The transfer function of this circuit is

$$V_{OUT} = -(R_{FEEDBACK}/R_{FLEXIFORCE}) * V_T$$

It is recommended that the capacitor (C_1), on the range of 47 to 270pF, be connected in parallel with $R_{FEEDBACK}$ due to the associative capacitance of the *FlexiForce* sensor. There will be substantial oscillation in the circuit output if it is omitted.

Performance

Figure 5 - Triple Source Inverting circuit with 100 lb. Sensor. Non-compliant, circular force actuator used with 0.045 sq. inch area. V_{CC} (pin 4) is at 9V, V_{EE} (pin 11) is at –9V, and V_T is at –5V with varying $R_{FEEDBACK}$.

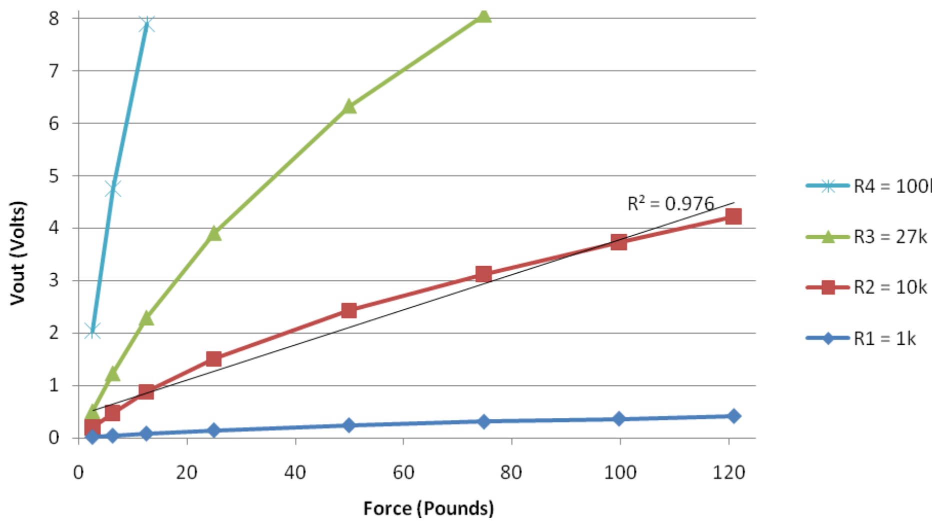
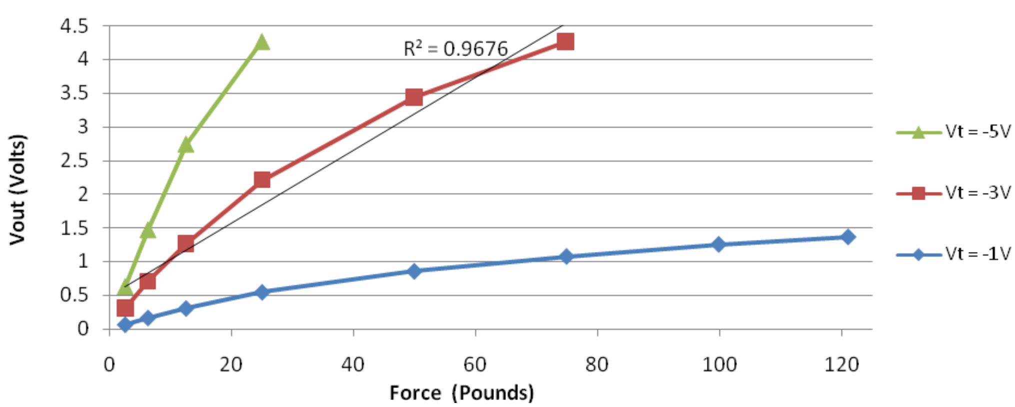


Figure 3 shows the relationship of the output voltage, V_{OUT} versus the Force applied to the sensor with the drive voltage, V_T, fixed at –5 volts. As the value of $R_{FEEDBACK}$ (represented by R1…R5) increases, the corresponding values of V_{OUT} also increase. Below, Figure 4 shows the V_{OUT} versus Force relationship with a varying drive voltage and fixed resistance. Through inspection it is seen that decreasing $R_{FEEDBACK}$ and/or the drive voltage V_T prevents saturation of the circuit output for a given force (increased force range). Conversely, applying a larger drive voltage and/or resistor will increase the slope of the V_{OUT} versus Force curve and therefore increase the sensitivity of the circuit (decreased force range).

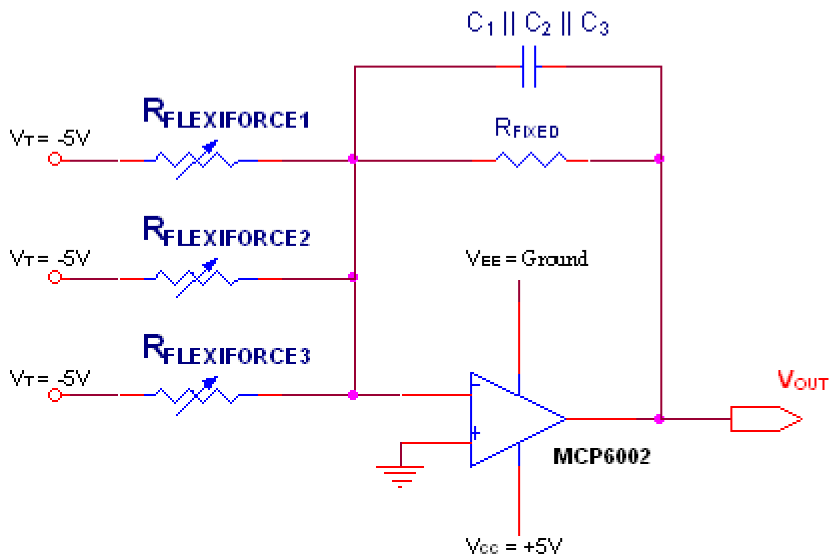
Figure 6 - Triple Source Inverting circuit with 100 lb. Sensor. Non-compliant, circular force actuator used with 0.045 sq. inch area. V_{CC} (pin 4) is at 5V, V_{EE} (pin 11) is at –5V, and $R_{FEEDBACK}$ is fixed at 10k• with varying drive voltage (V_T).



INVERTING SUMMING CIRCUIT

Overview

This circuit is designed for applications where multiple force sensors are required to give a single, combined output. An example of such an application would be to measure the force applied to a tripod or plate where multiple sensors are required to measure the compressive force but only a total force output is needed (*see* Application Diagram). Any number of sensors can be used and they can be modeled as a single sensor for calibration purposes.



Description

The circuit shown uses the Dual-Source Inverting Amplifier configuration, but the Triple-Source Inverting (split op-amp rails) setup can also be used. Using batteries is not recommended unless a voltage regulator is connected (*see* Battery Power Sources).

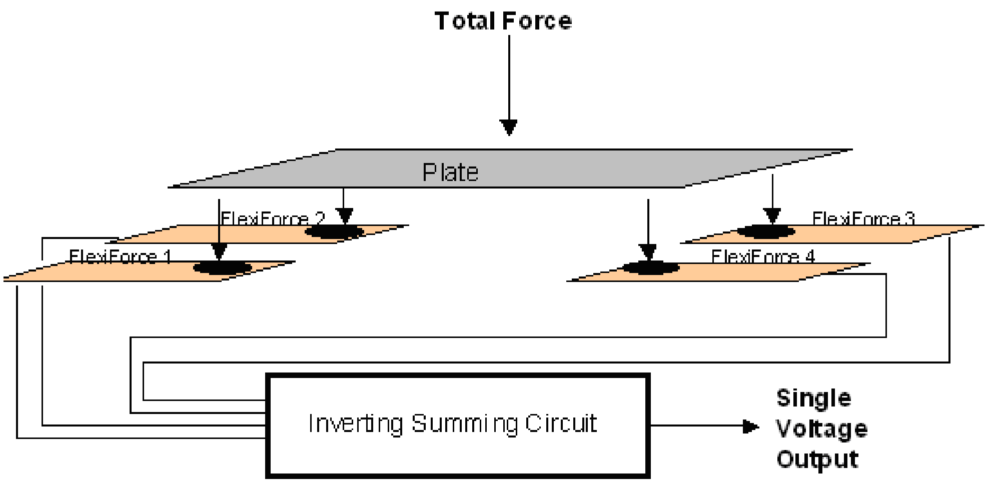
The test voltage, V_T must be negative for this circuit. The negative V_T will result in a positive 0-5V output signal that can then be converted by an Analog to Digital Converter (ADC) and the binary values transferred to a test program.

The transfer function of this circuit is:

$$V_{OUT} = -[R_{FEEDBACK}/(R_{FLEXIFORCE1} \,||\, R_{FLEXIFORCE2} \,||\, R_{FLEXIFORCE3})] * V_T$$

It is recommended that one capacitor for each sensor, on the range of 47 to 270pf, is connected in parallel with $R_{FEEDBACK}$ due to the associative capacitance of the *FlexiForce* sensors. There will be substantial oscillation in the circuit output if it is omitted.

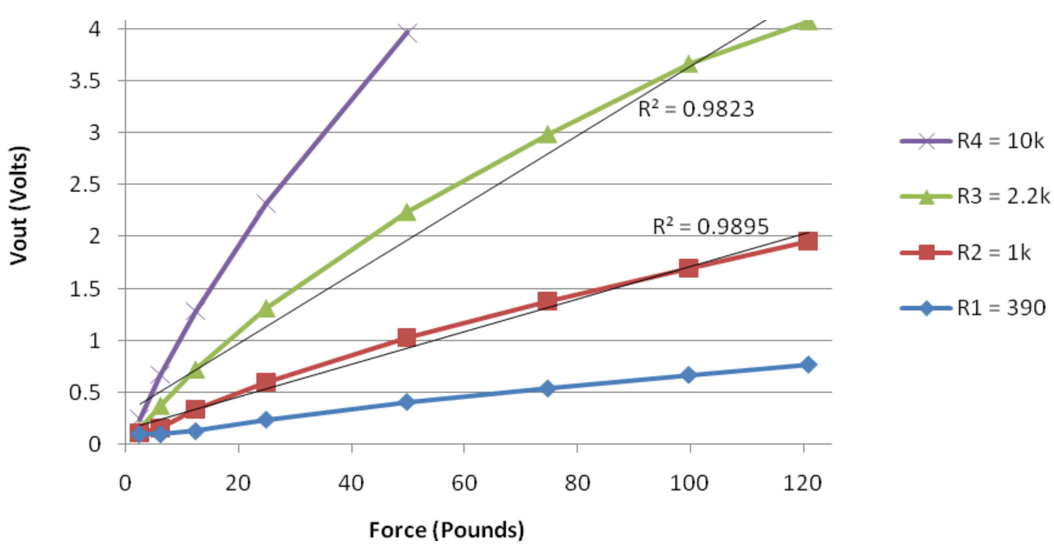
Application Diagram



Performance

As seen in the figure below, the response of the summing circuit is very similar to the Dual-Source Inverting Amplifier Circuit. The values of $R_{FEEDBACK}$ (represented by R1…R5) required are much lower due to the parallel configuration of the *FlexiForce* sensors.

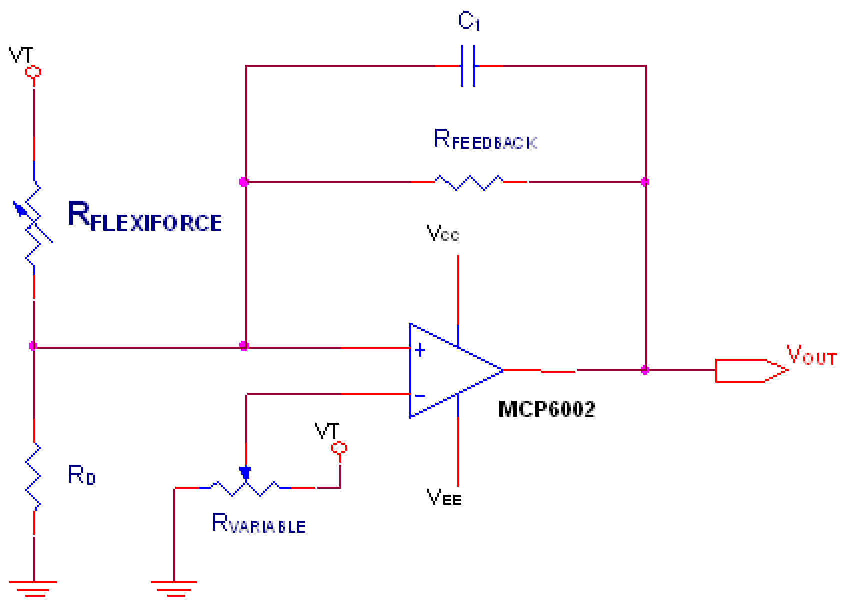
Figure 7 - Dual Source Inverting Summing circuit with 100 lb. Sensor. Non-compliant, circular force actuator used (3 sensors "stacked" under actuator) with 0.045 sq. inch area. V_{CC} (pin 4) is at 5V, V_{EE} (pin 11) is to ground, and V_T is at –5V with varying $R_{FEEDBACK}$.



FORCE THRESHOLD SWITCH

Overview

This circuit is designed for integration with a system requiring on/off switching at a specified force. The potentiometer, represented below by $R_{VARIABLE}$, is adjusted to set the specified force for the switch. Applications for this circuit include instances where only knowing the presence of a certain force is required. Examples of applications include, but are not limited to, security devices, occupancy detection, and over-load warning devices.



Description

As in the Single-Source Voltage Divider Follower Circuit, the non-inverting input (pin 3) is the voltage divider combination of the *FlexiForce* sensor and R_D. The voltage seen at the inverting input (pin 2) of the op-amp depends on $R_{VARIABLE}$, which sets the threshold for the op-amp output to go high or low. The op-amp output goes high, or the switch "turns on," when the non-inverting op-amp input is at a higher voltage than the inverting input.

If a variable threshold for switching is not required, then the variable resistor can be replaced by two resistors of equal value arranged as a voltage divider to ground. The damping resistor, $R_{FEEDBACK}$, provides a steady output for V_{OUT}.

The parallel combination of $R_{FEEDBACK}$ and $R_{VARIABLE}$ should be on the range of 100k• to 200k• .

It is recommended that capacitor (C_1), on the range of 47 to 270pf, is connected in parallel with $R_{FEEDBACK}$ due to the associative capacitance of the *FlexiForce* sensors. There will be substantial oscillation in the circuit output if it is omitted.

Performance

Figure 8 – "Switching force" versus threshold voltage at $R_{VARIABLE}$ (voltage seen by op-amp inverting input). Non-compliant, circular force actuator used with 0.045 sq. inch area. The parallel combination of R_D and $R_{FEEDBACK}$ used is 160k• . A Single +5V supply rail used for V_{CC} and V_T. V_{EE} is to ground.

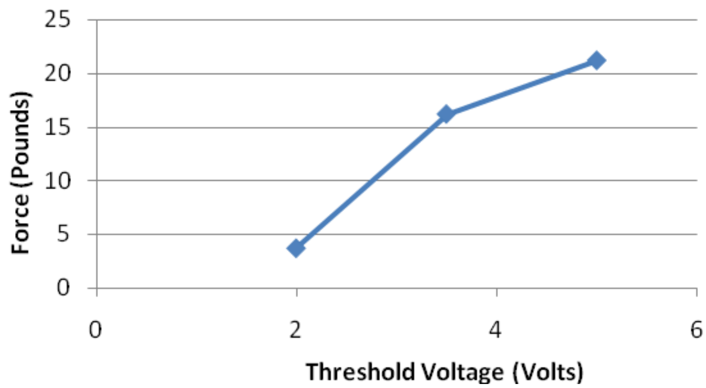
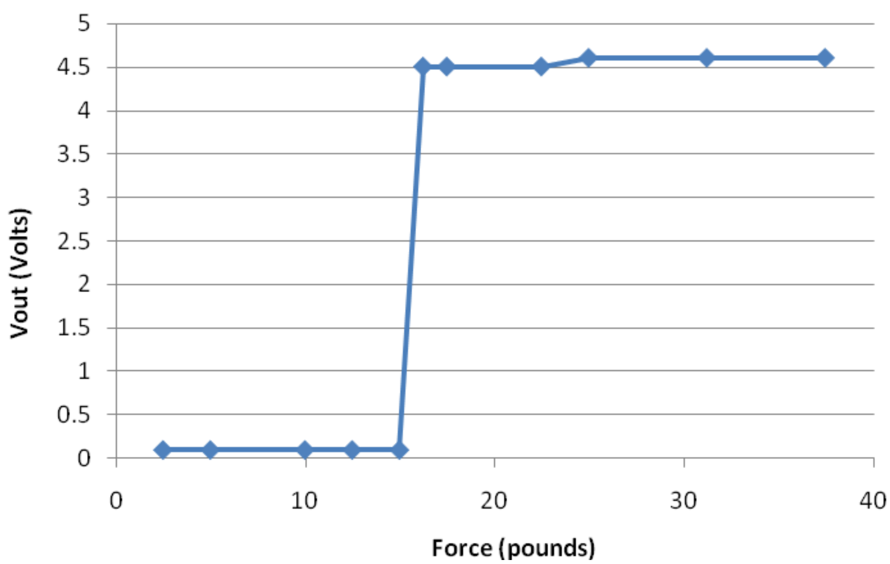


Figure 7 (above) shows the relationship of the "switching force," or the force required to toggle the circuit output high, versus the threshold voltage. The threshold voltage is seen at the inverting input of the op-amp and is manipulated by adjusting the potentiometer, $R_{VARIABLE}$. Below, Figure 8 shows the switch characteristic of the circuit at a fixed threshold voltage. The output remains at a constant voltage before and after the 15 pounds threshold force is applied.

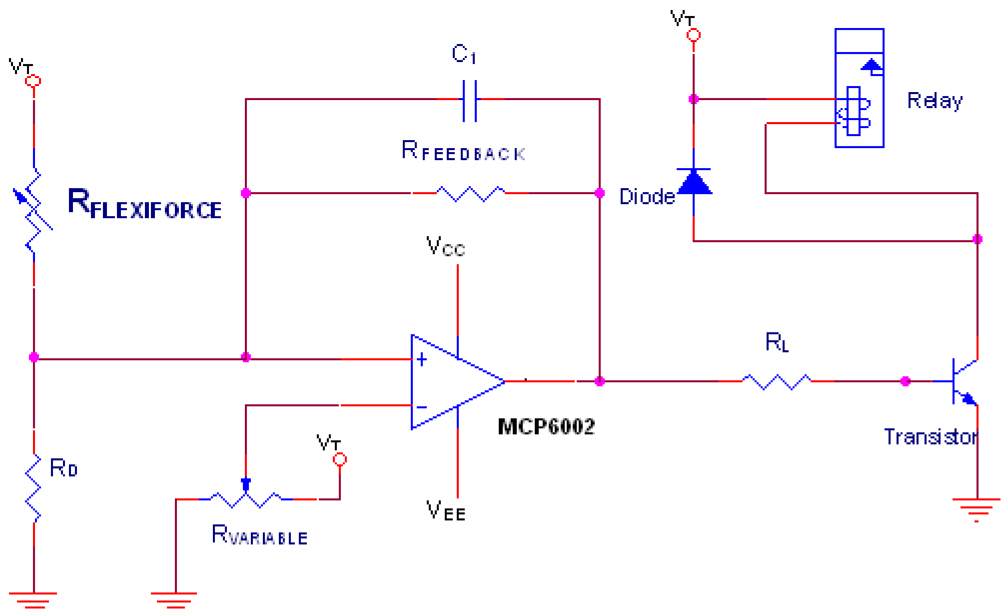
Figure 9 - Output voltage of Force Threshold circuit versus force applied. Threshold voltage is fixed at 3.5V. Non-compliant, circular force actuator used with 0.045 sq. inch area. . The parallel combination of R_D and $R_{FEEDBACK}$ used is 160k• . A Single +5V supply rail used for V_{CC} and V_T. V_{EE} is to ground.



FORCE THRESHOLD RELAY SWITCH

Overview

This circuit will toggle high/low in the same manner as the Force Threshold Switch, but it is designed for switching a relay. This circuit can also be used in automotive applications, but is designed for systems or devices requiring a higher current to "turn on."



Description

As in the Single-Source Voltage Divider Follower Circuit, the non-inverting op-amp input is the voltage divider configuration of the *FlexiForce* sensor and R_D. The voltage seen at the inverting input of the op-amp depends on $R_{VARIABLE}$, which sets the threshold for the op-amp output to toggle high or low. The op-amp output goes high, or the switch "turns on," when the non-inverting op-amp input is at a higher voltage than the inverting input.

If a variable threshold for switching is not required, then the variable resistor can be replaced by two resistors of equal value arranged as a voltage divider to ground. The damping resistor, $R_{FEEDBACK}$, provides a steady output for V_{OUT}.

The parallel combination of $R_{FEEDBACK}$ and $R_{VARIABLE}$ should be on the range of 100k• to 200k• . The choice of transistor depends on the current required for the relay being used.

It is recommended that one capacitor for each sensor, on the range of 47 to 270pf, is connected in parallel with $R_{FEEDBACK}$ due to the associative capacitance of the *FlexiForce* sensors. There will be substantial oscillation in the circuit output if it is omitted.

OP-AMPS, BATTERY-POWERED SOURCES, AND AC VS. DC VOLTAGES

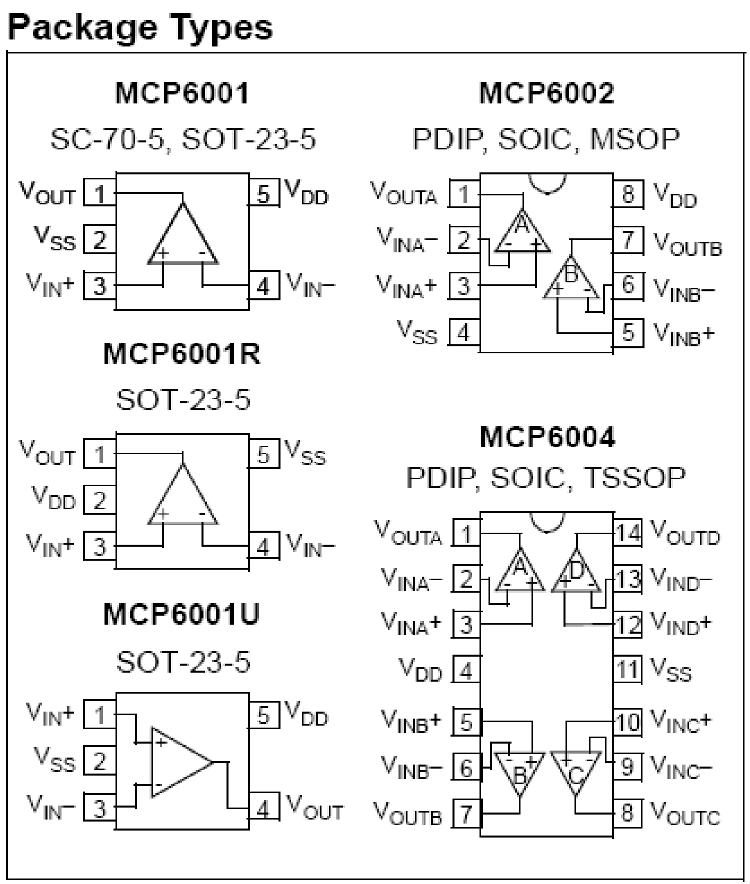
OP-AMP SELECTION

It is desirable to select a rail-to-rail op-amp (input and output); then the full output range extends to the rails, that is, +5V in the follower circuit and ±9V in the inverting op-amp circuit.

The recommended operational amplifier, and the one used for the testing depicted in this document, is the MCP6002 dual op-amp (pin diagram below).

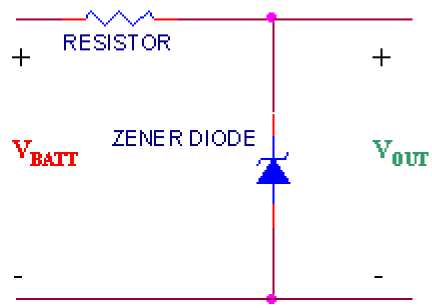
The V_{CC} and V_{EE} of the op-amp in the Triple-Source Inverting Amplifier circuit were chosen as +9V and -9V respectively for mainly due to the availability of ±9V supplies.

The circuit is set up to give a 0 to 5V output when the feedback resistor is adjusted to match the sensor resistance at the maximum force used.



BATTERY POWER SOURCES

Since battery power sources are unregulated, a small regulator must be used in conjunction with a battery to power the op-amp supply rails and/or the drive voltage, V_T. The simplest solution is to purchase a voltage regulator that is readily available at an electronics store. If a regulator is unavailable for the desired voltage output, then you can construct a regulator using a zener diode and resistor between the battery and circuit input as shown below.



V_{BATT} is the unstable voltage from the battery and V_{OUT} is the reduced stable voltage output from this simple regulator. The choice of the zener diode and resistor depends on the intended voltage drop from V_{BATT} to V_{OUT}. It is best to choose this drop to be at least 2 volts to make sure that the V_{BATT} ripple does not drop below the intended V_{OUT} value.

The voltage rating of the Zener Diode should be as close as possible to the desired value of V_{OUT}. From ohms law the Resistor value will be R = V/I, 'V' being the difference between V_{BATT} and V_{OUT} and 'I' being the maximum current for the load.

For example, the calculations for the #Single-Source Voltage Divider Follower Circuit with a 9V battery are as follows:

$R = V_{RESISTOR} / I_{MAX}$
$V_{RESISTOR} = V_{BATT} - V_{OUT} = 9V - 5V = 4V$
I_{MAX} = 100mA (*see Single-Source Voltage Divider Follower Circuit*)

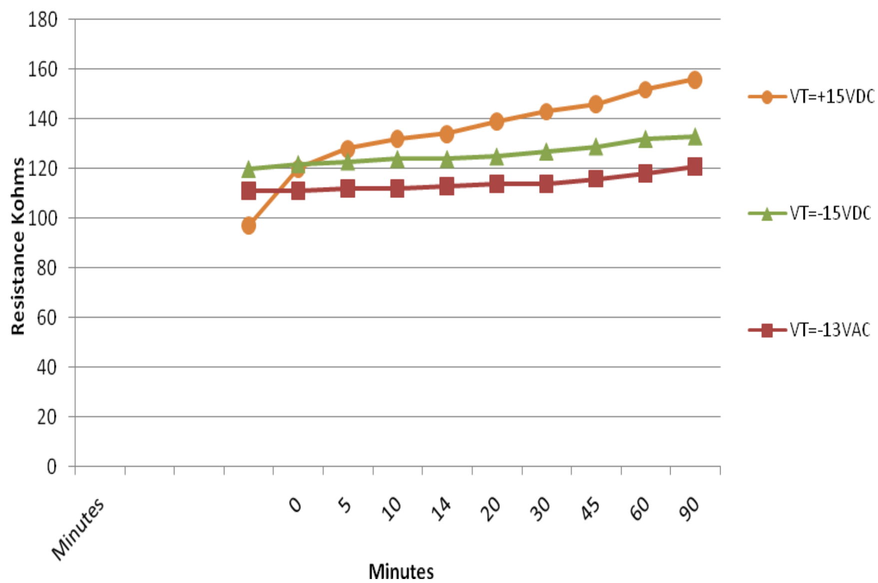
$R = 4V / .100\ A = 40\ \Omega$

AC VERSUS DC DRIVE VOLTAGE (V_T)

Higher drive V_T voltages, on the order of 15V, cause higher drift and increasing resistance over a period of several hours with a constant load. Setting the V_T voltage at nominal +5VDC and -5VAC will result in minimal drift.

In both cases, nominal 5VDC and nominal -5VAC, driving the sensor with an AC square wave results in reduced drift. Sensors in Tekscan sensor system handles are essentially driven with an AC voltage, that is, the sensor is driven or cycled for about 200µs "on" and 9800µs "off." When available it is recommended to drive the sensor with an AC square wave. If only DC sources are available it is recommended that less than 10V be used to drive the sensor.

Figure 10 - Data acquired using sensor in a voltage divider configuration without op-amp. Sensor is loaded with constant 60 lb force.



GENERAL A201/CUSTOM SENSOR SPECIFICATIONS AND CHARACTERISTICS

Dimensions	**Standard A201:** Sensing Area Diameter: 0.375” (9.53mm) Length x Width: 7.75” x .55” (197mm x 14mm) **Custom Sensor:** Maximum: 18” x 18” (0.46m x 0.46m) Minimum: 0.2” x 0.2” (5mm x 5mm)*
Thickness	.006” - .008” (0.15mm – 0.20mm)
Force Sensitivity Range	< 1 oz - 1000 lbs (20 g - 2200 kg)
Pressure Sensitivity Range	0.40 psi - 10,000 psi (2.8 kPa to 68.9 MPa)
Repeatability	± 2.5% of full scale
Linearity	< ± 5%
Drift	< 5% per logarithmic time scale**
Hysteresis	< 4.5% of full scale
Break force (turn-on)	0.3 oz - 0.7 oz (10 g – 20 g)
Unloaded Resistance	> 1 MΩ
Switch Characteristic	Zero travel (microns)
Response Time	5-20 μsec
Lifetime	> 1 million cycles
Operating Temperature	15°F - 140°F (-9° - 60° C)***
Temperature Sensitivity	0.2% per degree Fahrenheit (0.36% per degree Celsius)
Maximum Current	2.5 mA
Sensitivity to Noise	Little to none
EMI / ESD	Passive device
Connectivity	Standard pins/berg or custom (i.e. ZIF)

**Assumes sensor design incorporates shortest possible tail and single sensing area*
*** High DC drive voltages (V_T>10V) increase drift (see* *AC versus DC Drive Voltage (VT)**)*
****Operating temperature can be increased to 165°F (74°V) for loads of less than 10 lbs. Tekscan has tested sensors at temperatures as low as 15°F (-9°C), but customers have successfully used sensors at temperatures down to -40°F (-40°C).*