KWIK CIRCUIT FAQ

SPICE Model for a Quarter Bridge Strain Gauge Sensor – by Michael Jackson

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FAQ: Quarter Bridge Strain Gauge Sensor Spice Model

Introduction

A KWIK (Know-how With Integrated Knowledge) Circuit application note provides a step-by-step guide to addressing a specific design challenge. For a given set of application circuit requirements, it illustrates how these are addressed using generic formulae and makes them easily scalable to other similar application specifications. This sensor model enables SPICE simulation of the electrical and physical properties of a strain gauge used in a quarter bridge configuration. The SPICE model uses parameters which characterize the physical behavior of a gauge which translates strain into electrical voltage. It also provides a typical excitation and signal conditioning circuit that can be used to demonstrate the behavior of the model.

Design Specifications Example

Strain is the amount of deformation of a body due to an applied force. Strain (ε) is defined as the fractional change in length, as shown in **Figure 1** below.

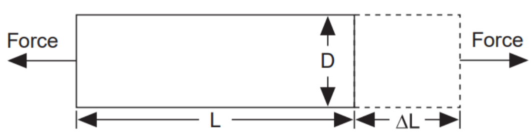

Figure 1. - Definition of strain

Strain can be positive (tensile) or negative (compressive). Although dimensionless, strain is sometimes expressed in units such as in/in or mm/mm. In practice, the magnitude of measured strain is very small. Therefore, strain is often expressed as microstrain (με), which is $\varepsilon \times 10^{-6}$. While there are several methods of measuring strain, the most common is with a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain applied. The most widely used gauge is the bonded metallic strain gauge which consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern. The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction (**Figure 2**).

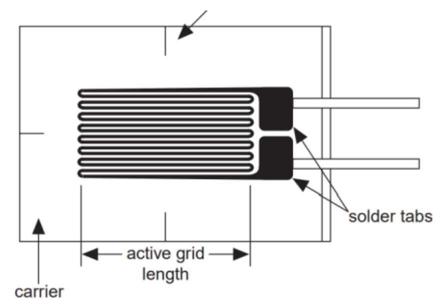

Figure 2. - Bonded metallic strain gauge

The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen. The strain experienced by the test specimen is transferred directly to the strain gauge, which responds with a linear change in electrical resistance. Strain gauges are available commercially with nominal resistance values from 30 to 3000 Ω, with 120, 350, and 1000 Ω being the most common values.

A fundamental parameter of the strain gauge is its sensitivity to strain, expressed as the gauge factor (GF). Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain):

$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

The Gauge Factor for metallic strain gauges is typically around 2. The gauge factor and maximum strain are typically specified on the datasheet for a strain gauge.

Design Description

Real world strain measurements rarely involve quantities larger than a few millistrain ($\varepsilon \times 10^{-3}$). Therefore, measuring strain requires accurate detection of very small changes in resistance (fractions of an Ohm). For this reason, strain gauges are almost always used in a bridge configuration with a voltage or current excitation source. The general Wheatstone bridge (**Figure 3**), consists of four resistive arms with an excitation voltage, V_{EX} applied across the bridge.

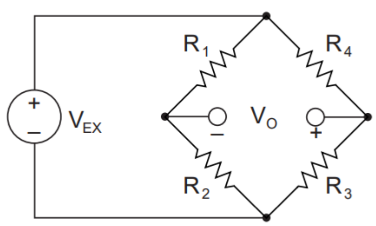

Figure 3. - Wheatstone bridge

The output voltage of the bridge, V_O, will be equal to:

$$V_O = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}\right] \bullet V_{EX}$$

By replacing one resistor with an active strain gauge (quarter bridge configuration), any changes in the strain gauge resistance will unbalance the bridge and produce a nonzero output voltage (**Figure 4**).

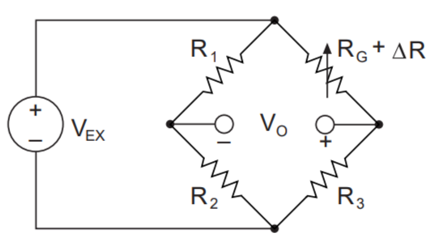

Figure 4. - Quarter bridge circuit

If the nominal resistance of the strain gauge is designated as R_G, then the strain-induced change in resistance, ΔR, can be expressed as

$$\Delta R = R_G \bullet GF \bullet \varepsilon.$$

If $R_1 = R_2$ and $R_3 = R_G$, the bridge equation above can be rewritten to express V_O/V_{EX} as a function of strain:

$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{4}\left(\frac{1}{1 + GF \bullet \frac{\varepsilon}{2}}\right)$$

Design Tips

1. Excite the sensor model using a low impedance voltage reference.
2. Connect the Wheatstone Bridge output to high input impedance signal conditioning circuitry being used for common mode, differential, full range, and accuracy simulations.
3. Use SPICE parameter stepping (.step param) with a DC Analysis (.op) to sweep from minimum to maximum strain applied to the sensor model (***Figure 5***).
4. The accuracy of the bridge readings will be determined by the nominal value and temperature tolerances of the bridge resistors and variations in the value of R_G. A complete bridge circuit is typically calibrated for the effects of temperature.

Design Procedure

1. From the datasheet for the strain gauge being modeled, enter the gauge factor (GF) into SPICE.
2. Enter the nominal strain gauge resistance (R_G) with no applied strain.
3. Set the sweep parameter (strain) to the desired usable range of the strain gauge. Strain in the SPICE model is entered as microstrain (i.e., 30000 microstrain = 30000u).
4. Run a SPICE simulation (using the sweep parameter) and confirm that the bridge output voltage matches the expected output.
5. Connect the sensor model to an excitation voltage and signal conditioning circuit to simulate the complete application.

Design Simulations

The simulation performs a sweep of strain from 0 to 30000 microstrain using a 4.096V excitation voltage and a strain gauge with a nominal resistance of 120Ω. A table, showing sample simulated versus calculated values for output voltage, is shown in **Table 1**.

A schematic of the sensor model is shown in **Figure 5** and a plot of the simulated results is shown in **Figure 6**.

Table 1. Simulated versus ideal Results

Strain (millistrain)	Calculated Output Voltage (mV)	Simulated Output Voltage (mV)
0	0.00000	0.00000
5000	0.01019	0.01019
10000	0.02028	0.02028
15000	0.03027	0.03027
20000	0.04016	0.04016
25000	0.04995	0.04995
30000	0.05965	0.05965

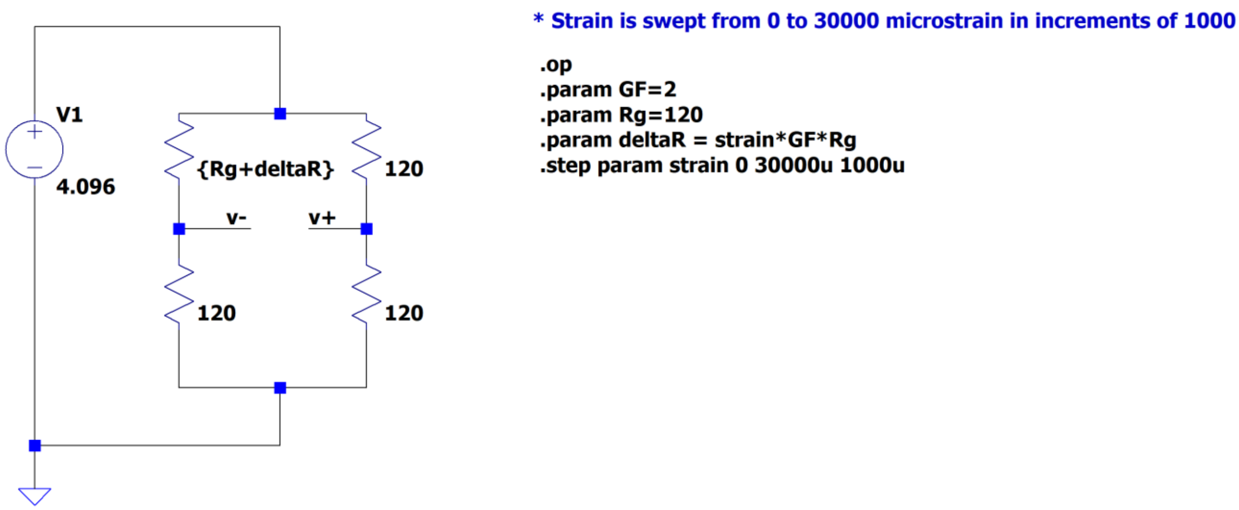

Figure 5. - Schematic showing ideal quarter bridge model and simulation parameters

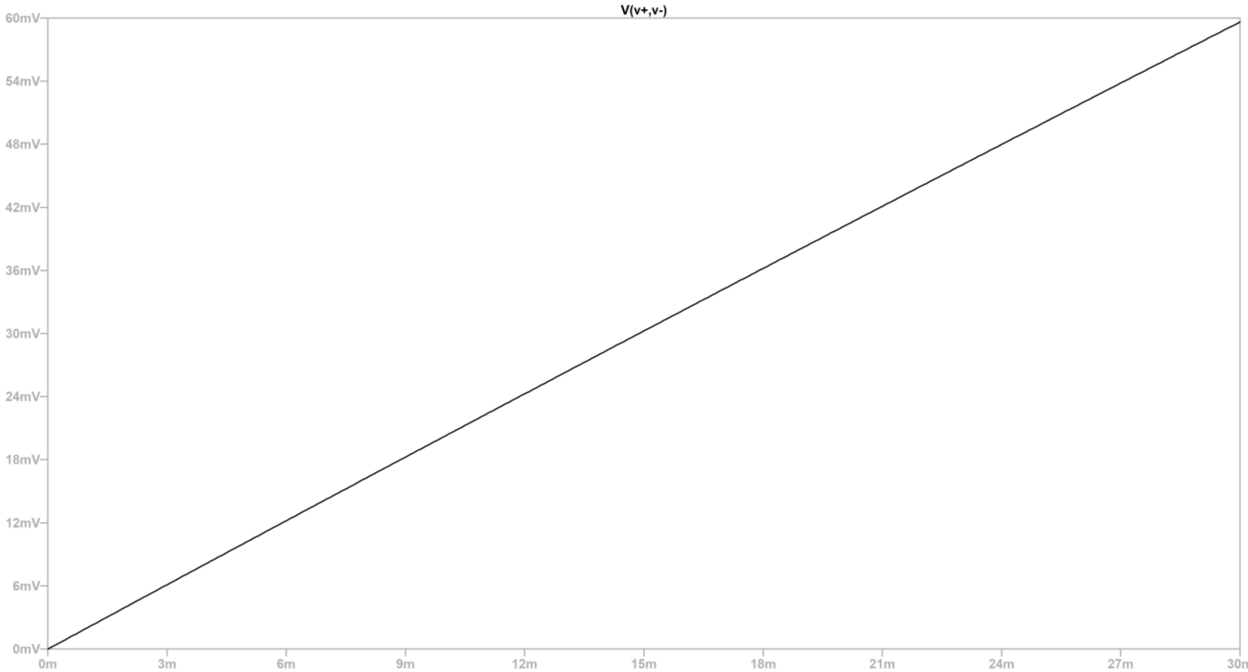

Figure 6. - Plot of simulated voltage versus strain (millistrain) using ideal sensor model and 4.096V excitation voltage

TYPICAL APPLICATION CIRCUIT

A practical application circuit for the sensor model is shown in **Figure 7**. A 4.096V voltage reference is buffered using an ADA4528 operational amplifier connected to a PNP output stage which can provides sufficient current to drive the low impedance bridge circuit. A 1kΩ resistor and 0.1µF provide loop stability while a 100Ω tail resistor is used to set the DC output voltage of the bridge to be within the common mode range of the AD8422 instrumentation amplifier (~3V) which conditions the output voltage from the bridge. A 250mV offset voltage (generated using a resistor divider buffered by another ADA4528) is applied to the AD8422 to maintain linear operation across the full range of applied strain.

The gain of the AD8422 is set to 115 by placing a 175kΩ resistor between its RG terminals. This value is chosen to keep the output voltage within the input range of an ADC also using a 4.096V voltage reference (the LT1461 could be used for this purpose but is not shown). The purpose of the resistors and capacitors at the input terminals of the AD8422 is to provide differential and common-mode filtering from noise injected into cables in a real application. These are the recommended values on the datasheet for the AD8422. A plot of simulated output voltage versus strain for the application circuit is shown in **Figure 8** while **Table 2** shows simulated output values.

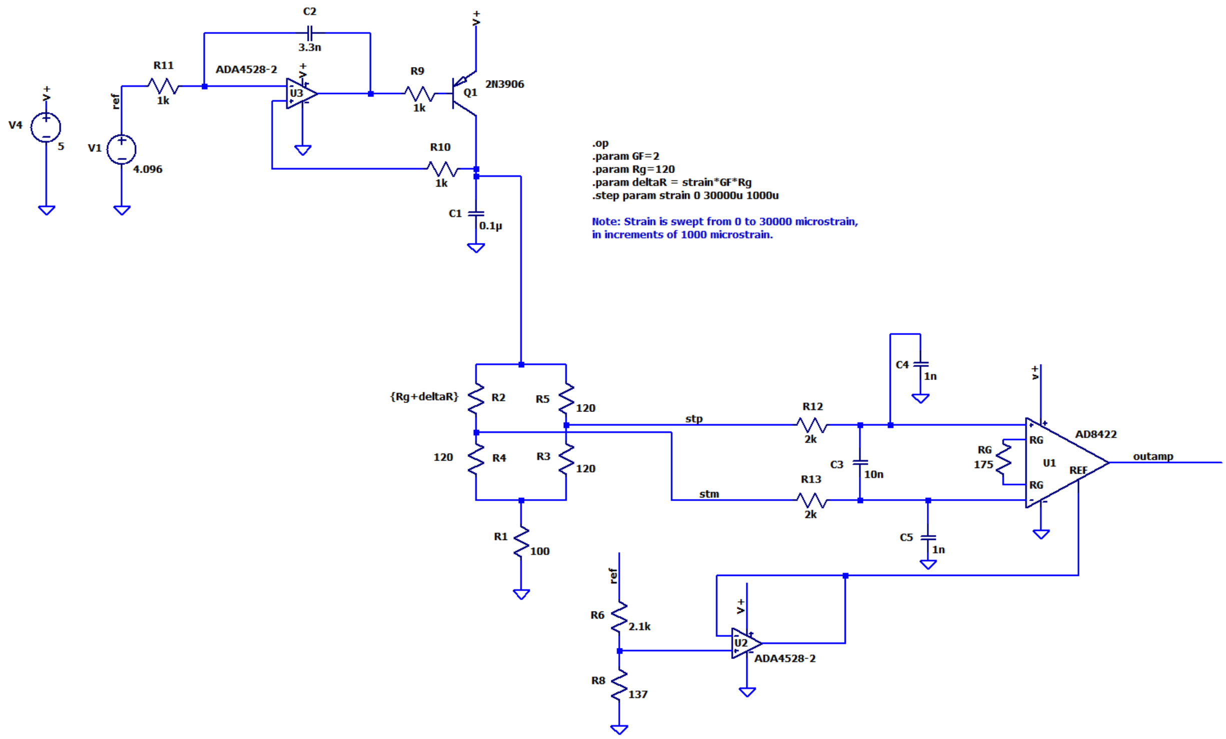

Figure 7. - Quarter bridge application circuit showing excitation and signal conditioning circuitry

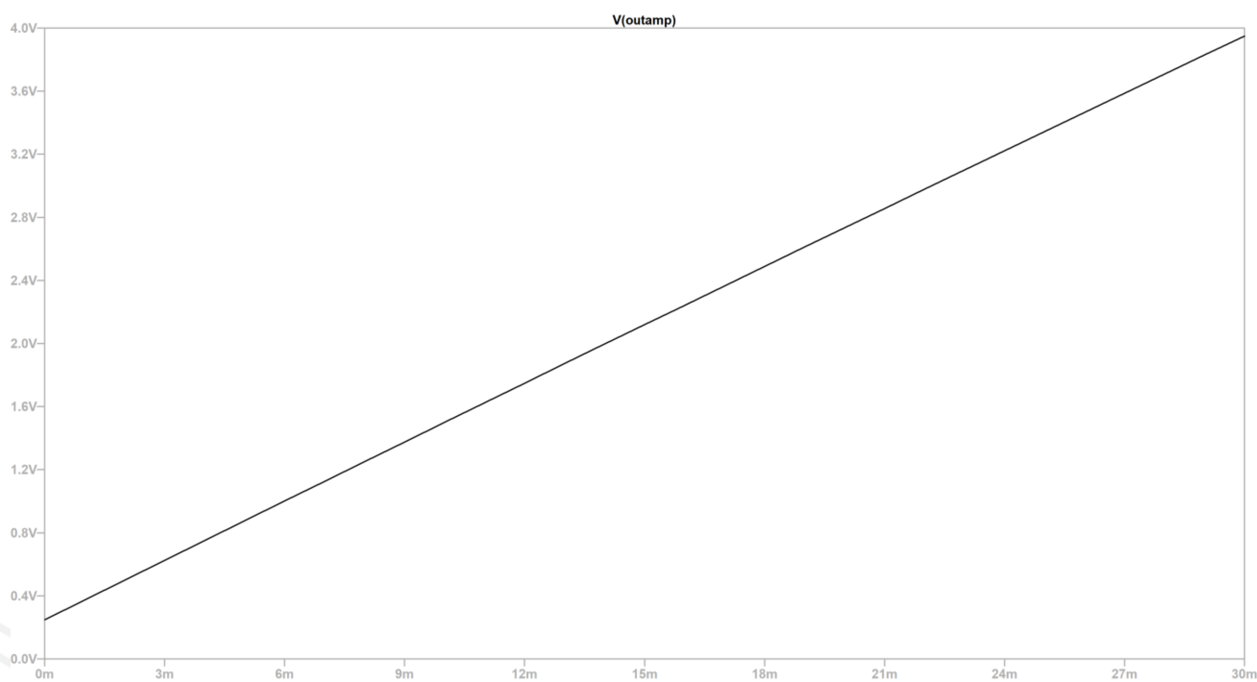

Figure 8. - Plot of simulated output voltage versus applied strain in a practical quarter bridge application circuit

Table 2. Simulated output voltage values for application circuit

Strain (millistrain)	Vout (V)
0	0.248
5000	0.87722582
10000	1.5013798
15000	2.1207662
20000	2.7354393
25000	3.3454525
30000	3.9508588

Design Devices

Table 3. Series Voltage References

Part Number	Vout (V) typ	Initial Accuracy (%) max	Vout Tempco (ppm/V) max	Vnoise (Vp-p) typ	Iout Sourcing (A) max	Vs+ (V) min/max
LT1461ACS8-4	4.096	0.04	3	32u	50m	4.06/20

Table 4. Instrumentation Amplifier

Part Number	Vos (V) max	Ibias (A) max	Gain (V/V) min/max	BW Low Gain (Hz) typ	Vnoise (V/rt-Hz) typ	Vs span (V) min/max
AD8422	60u	1n	1/1000	2.2M	8n	4.6/36

Table 5. Op Amps (for Reference & DAC Output Buffers, as needed)

Part Number	Vos (V) max	Ibias (A) max	GBP (Hz) typ	Vnoise (V/rt-Hz) typ	Iq/Amp (A) typ	Vs span (V) min/max
AD4528	2.5u	220p	6.2M	5.6n	1.5m	2.2/5.5

References

"Measuring Strain with Strain Gauges"
White Paper by National Instruments, 2020.

"Practical Design Techniques for Sensor Signal Conditioning"
Edited by Walt Kester, Analog Devices, 1999, ISBN-0-916550-20-6.
Education-library/practical-design-techniques-sensor-signal-conditioning.html

Instrumentation Amplifier Diamond Plot Tool
The Diamond Plot Tool is a web application that generates a configuration-specific Output Voltage Range vs. Input Common-Mode Voltage graph, also known as the Diamond Plot, for Analog Devices Instrumentation Amplifiers.

LTspice
LTspice® is a high-performance SPICE III simulator, schematic capture and waveform viewer with enhancements and models for easing the simulation of switching regulator, linear, and signal chain circuits.

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