AN296202
MCO-0001002
AP-1067

APPLICATION INFORMATION

GUIDE AND USAGE OF RESISTIVE BRIDGES FOR PRESSURE MEASUREMENT WITH A17700

By Nevenka Kozomora
Allegro MicroSystems

ABSTRACT

The A17700 is the first Allegro interface IC designed for Wheatstone bridge configurations located on elastic carriers for pressure measurements. The A17700 interface chip conditions the signals from the Wheatstone bridge into an accurate output message dependent only on the measured pressure.

This application note explains the science behind the strain gauge used for pressure sensing, most common strain gauges on the market, sensing solutions presented by different strain gauge configurations, and A17700 input specifications.

In the appendix, there is a market example of strain gauge bridge specifications interpreted into A17700 input specifications.

STRAIN GAUGE

Strain gauges consist either of conductor tracks folded back and forth on themselves or a single semiconductor track bonded to the sample surface. Typical conductive materials include wires as Constantan (copper-nickel alloy) and Nichrome V (nickel-chrome alloy), metallic foils, and metallic thin films. The semiconductor gauge is cut from a single crystal of silicon or germanium doped with impurities to obtain N or P type. (*MIT Course Book*, n.d.).

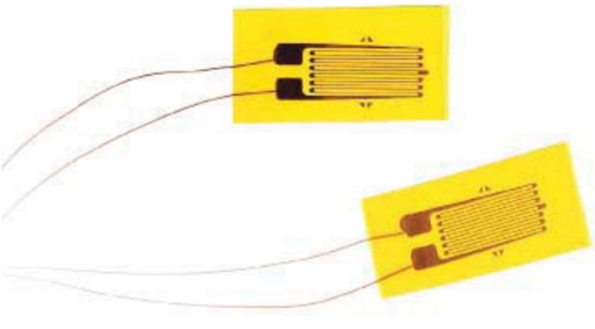

Figure 1: Typical metal foil strain gauges.

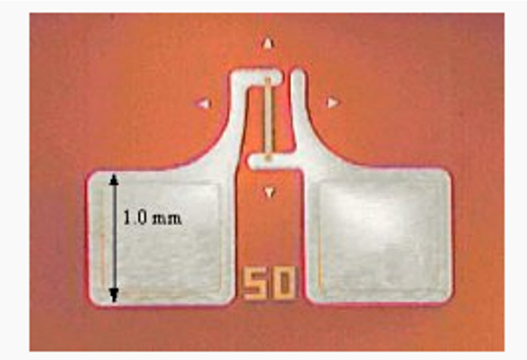

Figure 2: Vertical semiconductor strain gauge between metal pads.

The resistance of the strain gauge can be described in the following equation (*Roylance*):

$$R = \rho \times \frac{L}{A}$$

where R is the resistance of the strain gauge, L is the length, A is the cross sectional area, and ρ is the material resistivity.

If the circular wire is assumed such that $A = \pi r^2$, then after applying a logarithm to both sides and simplifying:

$$\ln R = \ln \rho + \ln L - (\ln \pi + 2 \ln r)$$

and the total differential gives the following equation:

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - 2\frac{\Delta r}{r}$$

The deformation in the strain gauges of the attached surface causes dimensional changes of its length, ΔL, cross section area, Δr, and change of material resistivity, $\Delta\rho$. This leads to proportional resistance change, ΔR, of strain gauge. Therefore, strain gauges placed in electrical circuits can be used for the measurement of force, pressure, tension, weight, etc.

The "Gauge Factor – GF" is commonly used as description of the strain gauge resistance to pressure. The previous equations can be further developed with replacement of material resistivity as follows:

$$\frac{\Delta\rho}{\rho} = \alpha\,\frac{\Delta v}{v} = \alpha\left(\frac{\Delta L}{L} + \frac{\Delta A}{A}\right) = \alpha\,(1 - 2v)\frac{\Delta L}{L}$$

where α is the material resistivity and v is volume, and wire radius is:

$$\frac{\Delta r}{r} = -v\frac{\Delta L}{L}$$

This helps in finding the gauge factor as proportional coefficient of relative resistance change, ΔR, and gauge relative length:

$$\frac{\Delta R}{R} = (\alpha\,(1 - 2v) + \ (1 + 2v))\frac{\Delta L}{L}$$

where GF is gauge factor:

$$\frac{\Delta R}{R} = GF\,\frac{\Delta L}{L}$$

$$GF = \alpha\,(1 - 2v) + \ (1 + 2v)$$

GF contains both factors of the strain gauge resistance change: response to dimensional change, v, and response to material resistivity, α.

Market-Available Strain Gauges

The most commonly used gauges on pressure membranes for mid and high pressure are metallic strain gauges, such as foil and thin-film gauges.

Foil strain gauges are made by rolling out the foil by a few micrometers on the carrier material. The top side is covered with a light-sensitive layer of the photographic negative of strain gauge. After exposure to light, the grid of wire filament (resistor) of approximately 0.001 mm is hardened, and non-hardened layers are washed way in further development process. Created foil gauge is bonded directly to the strain surface by a thin layer of epoxy resin. The signal from the foil gauge is altered by temperature and humidity due to swelling and creep of the polymer and bonding materials.

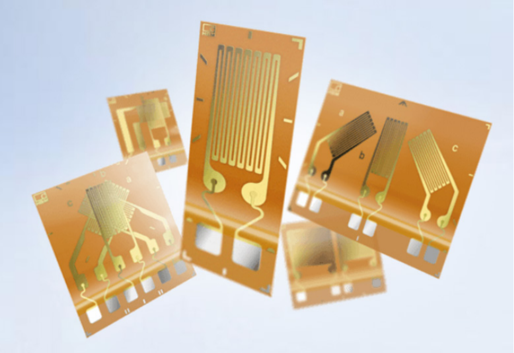

Figure 3: Foil Gauges by HBK

Thin-film strain gauges are produced by the self-named thin-film technique, using vapor deposition or sputter coating. Thin-film strain gauges become molecularly bonded to the sensor substrate material (typically steel or aluminum). This presents an advantage over foil strain gauges as thin-film strain gauges do not require an epoxy layer to be attached to the strain surface. However, any measurement configuration of multiple gages must be done on the same flat surface due to the sputter coating process. This manufacturing process is more complex and more expensive than for foil gauges. The change of the resistance is caused mostly by the deformation of the film. GF factor is typically 2, meaning the magnitude of the output from a thin-film strain gauge is much lower than a silicon strain gauge. However, with proper signal processing electronics, the lower output magnitude is rarely problematic. (*Strain Measurement Devices*, n.d.)

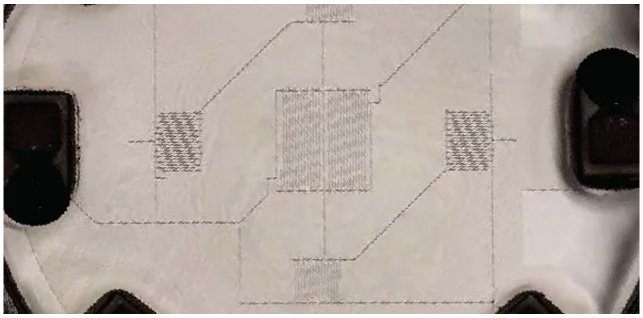

Figure 4: Thin Film Unsurpassed Accuracy

Thick-film strain gauges are printed on ceramic and metallic membrane. They are 1,000 times thicker than thin-film strain gauges. Because of their low production requirements, these are cheaper in price but not very stable long-term due to the aging of their thicker film. (*SMD Sensors*)

Semiconductor strain gauges change their resistance by the alternation in crystal structures when stretched or compressed. This is called the piezoresistive effect. The effect of stress on doped silicon and germanium has been known since the work of Smith at Bell Laboratories in 1954. The semiconductor strain gauges are typically made from N- or P-type silicon and are either manufactured as separate elements to be bonded to carrier or directly sputter-coated onto it. The latter enables an intense bonding and assures freedom from hysteresis, as well as resistance to aging and temperature stability. Semiconductor strain gauges tend to be more sensitive than the metallic variety. They are also usually separated from the medium by a separation membrane, with the pressure being passed on via a transfer fluid. The membrane can be integrated with the resistors all in one chip and thus produce a full pressure measurement cell in the size of just one chip called a piezoresistive pressure sensor. (A. Alvin Barlian)

Table 1 summarizes features of market-available strain gauges.

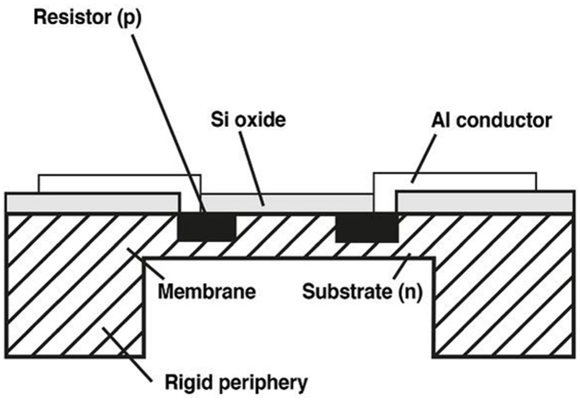

Figure 5

Table 1: Strain Gauge Feature Comparison

Type	Bridge Resistance	GF	Manufacturing Process	Environment Dependence (Temperature and Humidity)	Accuracy	Long-Term Stability
Foil strain gauges	Up to 5 kΩ	2-5	Bonding with Glue	High	Low	Lower due to glue usage
Thin-film strain gauges	1-10 kΩ	2	Sputter Coating	Low	High > 6 Bar Low < 6 Bar	High
Semiconductor strain gauges	Up to 5 kΩ	Up to 200	Bonding and Sputter Coating	High	High	High

Strain Gauge Bridge Configuration

The strain gauge increases or decreases the resistance based on the direction of the strain (Figure 6).

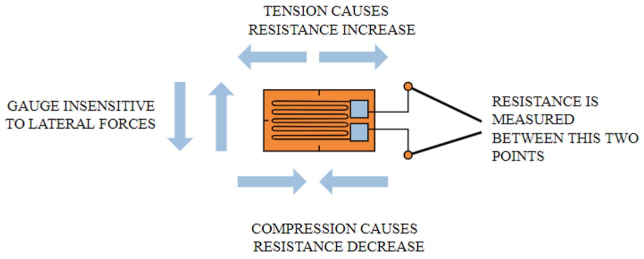

Figure 6: Resistance behavior of strained gauge

Therefore, strain gauges are commonly used as variable resistors in a quarter-, half-, or full-bridge Wheatstone configuration (Figure 7). The output voltage from the bridge is proportional to the deformation of the strain gauges, which are proportional to the movement of the membrane under applied pressure.

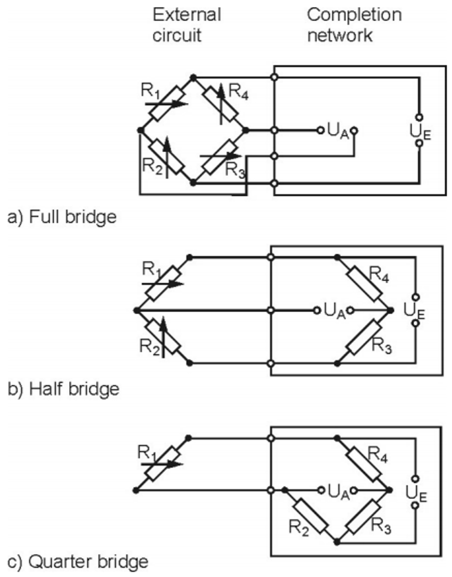

Figure 7: Possible bridge configuration of strain gauges

In the full-bridge Wheatstone configuration, two of the strain gauges are placed in a radial direction and two in a tangential direction. It is thus that two gauges become stretched and two gauges become compressed under deformation. For temperature effects to be compensated and for the signal to be as linear as possible, it is important that the strain gauges have matching resistances and are arranged in a precise geometry. If it is assumed that the strain gauges used in a Wheatstone configuration have the typical resistance of R_0, that it changes by ΔR when strained, and that V_{BRG} voltage is applied to the Wheatstone bridge, then output voltage is:

$$V_0 = \frac{\Delta R}{R_0} V_{BRG}$$

The Allegro Interface IC A17700 takes the bridge output voltage V_0 and applies temperature and pressure compensation to derive an accurate output message that is linearly dependent on pressure change.

A17700 Input Characteristics

The A17700 can be used with any full-bridge Wheatstone configuration connected as in Figure 8 below.

The A17700 IC can supply the input bridge of the 1.5 to 10 kΩ resistance with 3.3 V supply voltage. This is the voltage between the pins VBRG and VBRGGND. The pins VP and VN are reserved connections to the output of the external bridge.

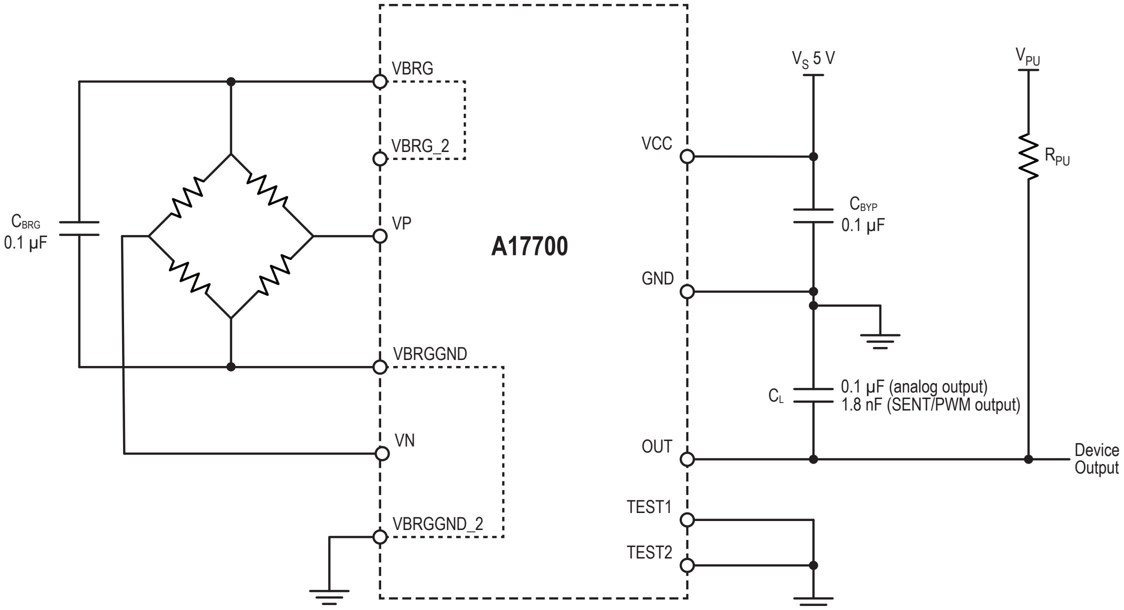

Figure 8: A17701 Application Circuit

Table 2: Bridge Electrical Characteristics

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
Bridge Supply Voltage	V_{BRG}	Voltage supplied to transducer bridge	3.15	3.3	3.45	V
Bridge Resistance	R_{BRG}	Resistance of transducer bridge	1.5	–	10	kΩ
Bridge Bypass Capacitor	C_{BRG}	Bypass capacitor	80	100	150	nF

The sensitivity of the Wheatstone bridge is defined as output voltage that is read from the bridge divided by input voltage that is applied to the bridge.

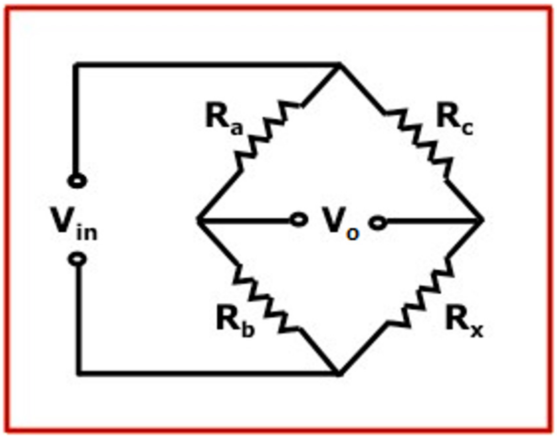

Figure 9: Wheatstone Bridge

$$Bridge\ Sensitivity = \frac{Vo}{Vin}$$

If the bridge is labeled with sensitivity of 10 mV/V, that means that for V_{IN} = 3 V, the bridge output, V_O, will be 30 mV.

Figure 10 shows the signal path from Wheatstone bridge output as A17700 input voltage, V_{IN}, to the input of ADC block, V_{IN_ADC}. Input Voltage, V_{IN}, gets multiplied with the choices of Gain1, Gain2 and adjusted with Offset coarse parameter before entering ADC.

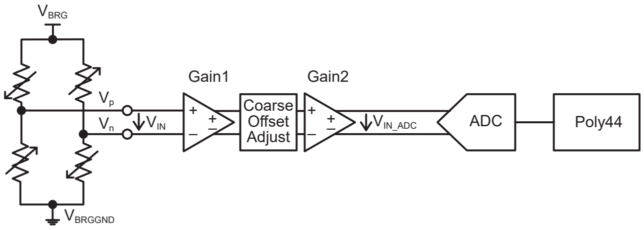

Figure 10: A17700 Analog front end

Voltage on the input of ADC block V_{IN_ADC} must be within the limits of the ADC input range of ±263 mV (Table 3). The Differential Input (V_P-V_N) specifications as limits of V_{IN} are determined with the applied Gain1, Gain2, and $OFFSET_{COARSE}$ values such that signal V_{IN_ADC} always stays within the ADC_{IN} limits. For example, the Differential Input (V_P-V_N) has limits of ±290 mV for "Gain1 = 3", "Gain2 = 1", and "Offsetcoarse = 0". If the Gain1 value is doubled as "Gain1 = 6", then the Differential Input (V_P-V_N) value must be halved to ±145 mV in order to ensure that signal will not go over the ADC input range.

The A17700 can handle a bridge sensitivity from 10 to 80 mV/V by combining the values of Gain1 and Gain2 parameters. The input signal can be adjusted with 80 mV/V of the offset by using the coarse offset adjustment. Details of how to apply sensitivity and gain adjustment can be found in additional documentation of the A17700.

The Allegro A17700 device can support a wide variety of Wheatstone bridge configurations on the market. Users must ensure that bridge configuration is compatible with the input specifications of A17700 described in the A17700 datasheet (Table 2 and Table 3). An example of bridge specifications for the A17700 input specifications is given in Appendix A.

Table 3: Analog Front End Characteristics

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
Differential Input (V_P-V_N)	V_{IN}	Gain1 = 3×, Gain2 = 1×, $Offset_{coarse}$ = 0, V_{BRG} = 3.3 V	–290	–	290	mV
ADC Input Range	ADC_{IN}		–263	–	263	mV/V
Bridge Sensitivity	BRG_{sens}	V_P-V_N at maximum input stimulus	10	–	80	mV/V
Bridge Sensitivity Programming Bits	–	Gain1 Trim bits	–	2	–	bits
		Gain2 Trim bits	–	4	–	bits
Bridge Offset [1][3]	$OFFSET_{coarse}$	Differential output offset, V_P-V_N, no input stimulus; Scales with Gain1; Gain1 = 3×	–80	–	80	mV/V

APPENDIX A: MARKET EXAMPLE WITH WHEATSTONE BRIDGE

Example #1: Using Merrit Sensor D Series with A17700.
(*Merit Sensor*, n.d.)

The table below shows the basic specifications for the Merit Sensor.

Table 4: D1C series of Merit Sensors

Parameter	Minimum	Typical	Maximum	Units	Notes
Electrical and Environmental					
Excitation (In)	–	5	15	V	Maximum: 3 mA
Impedance	4000	5000	6000	Ω	
Operating Temperature	–40	–	150	°C	Sentium® technology
Storage Temperature	–55	–	160	°C	
Performance					
Offset	–10	0	10	mV/V	Zero pressure; gauge only; @25°C
Non-Linearity	–0.25	0	0.25	%FSO	Best fit straight line; @25°C
Pressure Hysteresis	–0.1	0	0.1	%FSO	@25°C
Temperature Coefficient – Zero	–25	0	25	μV/V/°C	–40°C to 150°C
Temperature Coefficient – Resistance	2500	3000	3500	PPM/°C	–40°C to 150°C
Temperature Coefficient – Sensitivity	–1500	–2000	–2500	PPM/°C	–40°C to 150°C
Thermal Hysteresis	–	< 0.1	–	±%FSO	Zero pressure 25°C to 125°C
Long-Term Stability	–	< 0.25	–	±%FSO	
Burst Pressure	3×	–	–	–	Full-scale pressure
Full-Scale Output (@ 5 V excitation)					
15 psi (1 bar; 103 KPa)	60	75	90	mV	Other outputs available on request
100 psi (6.9 bar; 689 KPa)	120	150	180	mV	Other outputs available on request
300 psi (20.7 bar; 2068 KPa)	120	150	180	mV	Other outputs available on request

From the table, the following can be concluded:

1. Device can be powered with typical 5 V. A17700 can power the bridge with 3.3 V, so output from the bridge should be rescaled.
2. Bridge impedance is typically 5 kΩ which is within the range of A17700.
3. Operating and storage temperatures are within the range of A17700.
4. The offset of ±10 mV/V is within the range of A17700, as that points that for 3.3 V applied bridge voltage, the input signal at zero pressure can be ±33 mV.
5. Non-linearity of 0.25% FSO can be fixed with Poly(4.4).
6. Pressure hysteresis will directly affect output of the A17700.
7. There is a resistance change as 0.3%/°C that results in –0.2%/°C change of sensitivity over temperature.
8. Full-scale output is given at 5 V and should be rescaled for the 3.3 V bridge voltage. For example, for 100 psi, output at 5 V will be 150 mV. In the case of the A17700 that supplies 3.3 V, the output will be 99 mV. Further processing can be applied through the front end with gain and offset to bring the signal to the full input of the A/D converter.

BIBLIOGRAPHY

A. Alvin Barlian, W.-T. P. (n.d.). *Semiconductor Piezoresistance for Microsystems*. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2829857/

Entreprenurial MIT. (2015). Retrieved from 150 MIT: http://museum.mit.edu/150/82

Hofman, K. (n.d.). *Applying the Wheatstone Bridge Circuit*. Retrieved from http://fab.cba.mit.edu/classes/863.16/section.Architecture/people/Ge/KarlHoffmann.pdf

Merit Sensor. (n.d.). Retrieved from Merit Sensor D Series: https://meritsensor.com/assets/documents/pdf/D-series.pdf

MIT Course Book. (n.d.). Retrieved from MIT Public: http://web.mit.edu/machen/Public/1.050%20F09/Course%20Notes%20Chapter%204%201.050.pdf

Roylance, D. (n.d.). *Experimental Strain Analysis*. Retrieved from http://web.mit.edu/course/3/3.11/www/modules/expt.pdf

SMD Sensors. (n.d.). Retrieved from https://www.smdsensors.com/blog-understanding-strain-gauges-in-load-cells-thin-film-vs-bonded-foil-vs-silicon/

Strain gauges in pressure measurement technology. (2018, Feb 27). Retrieved from STS Sensors: https://www.stssensors.com/

Strain Measurement Devices. (n.d.). Retrieved from Strain Measurement Devices: https://www.smdsensors.com/blog-unsurpassed-accuracy-thin-film/

Revision History

Number	Date	Description	Responsibility
–	November 16, 2020	Initial release	Nevenka Kozomora