

# **IMPLEMENTATION OF STRAIN GAUGES**

Experimental Stress Analysis (ESA)



Bachelor's thesis

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ABSTRACT

Strain gauge sensors provides an excellent accuracy and a very high long-term stability for the measure of several physical quantities. It has over the years been of great benefit across many fields of Engineering and Sciences and in various industries.

This project work examines the implementation of strain gauge sensor in general with emphasis on bending strain. This includes the classification and types of strain gauge, the different configuration of circuit and the principle of operation, and the material and surface preparation for the mounting of the strain gauge sensor.

**Keywords** Strain gauge, Wheatstone bridge, Gauge factor.

**Pages** 27 pages

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## 1 INTRODUCTION

In nearly all fields of engineering, some requirements are needed in achieving the utmost perfection and precision. These includes; calculating, measuring, controlling, data logging and communicating.

This has led to the study of Measurement and Instrumentation in recent years. With the continuous rapid growth in technology, the need for small and efficient transducers such as the strain gauge to be integrated into High-end devices and control machines cannot be ignored. The stain gauge is, to a large extent used in various fields of engineering in order to measure quantities including force, stress, strain and moment. In particular, strain sensors are implemented in structural engineering to monitor strain experienced by beams. The figure 1 below show the key elements of a generalized measurement system.

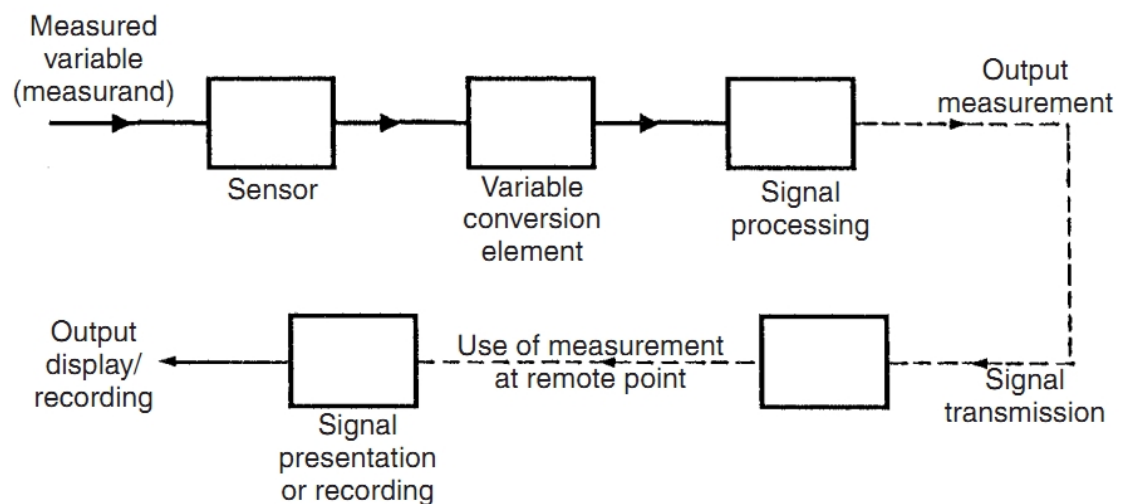


Figure 1. Generalized Measurement System (Brainkart, 2016)

### 1.1 Objectives

The main aim of this project was to study the strain gauge sensor and its operational principle. Furthermore, a laboratory experiment was performed and results recorded.

## 1.2 Motivation

The motivation for this project developed from the importance of sensing devices, in particular the strain gauge sensors to all fields of engineering. The challenges faced in my previously chosen project work that include time constraint, faulty device and delay in response by the company's contact person also contributed to my motivation.

## 2 STRAIN SENSOR

Strain sensor also called strain gauge is a sensing device that works on the principle of the change in resistance of its material when it experiences a stretch or compression, this material could be a conductor or semiconductor. This characteristic of strain gauges makes it suitable for measurement of quantities including force, tension, acceleration, pressure and displacement. (All Syllabus, n.d.)

The measure of the amount of strain undergone by a material is the change in length per unit length. For this reason, the strain of a material is dimensionless and it has no unit. However, the strain gauges output the strain experienced as either current (milliamperes) or voltage (millivolts).

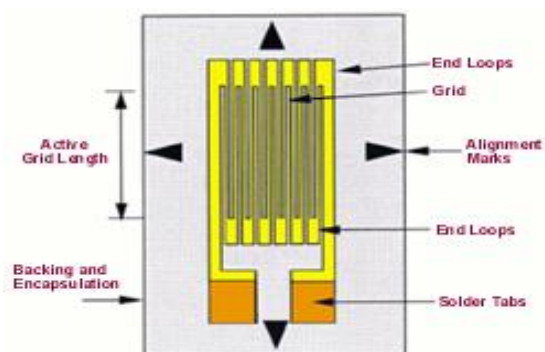


Figure 2. Strain gauge Sensor (Sensorland, n.d.)

### 2.1 Principle of Operation

The strain gauge measuring grid is made of copper nickel alloy, this material is of low and controlled temperature coefficient. The actual form of this grid is accurately produced using the technique called photo-etching. This method employs the use of thermoplastic films to encapsulate the grid, which then help shield the strain gauge against

mechanical and environmental damage. It also serves as a medium of transmission of strain from the test material to the material of the strain gauge.

The principle of operation of strain gauges is based on the change in the resistance of an electrical conductor. This change occurs as a ratio  $\Delta R/R$  and it is proportional to the change in the length of the conductor  $\Delta L/L$  as it undergoes stress. The change in resistance is due to the change in the physical size or deformation of the conductor and an alteration in the conductivity of its material.

Generally, Copper nickel alloy is known to be widely used in the construction of strain gauge, this is because the change in the resistance of the foil is proportional to the strain applied. (RS Components, 1996)

$$(\Delta R)/R \propto \Delta L/L \quad (1)$$

$$\Delta R/R = G \Delta L/L \quad (2)$$

$$\Delta L/L = E \quad (3)$$

$$\Delta R/(R) = GE \quad (4)$$

G is a constant known as the gauge factor

E is the strain

R is the resistance of the gauge before the application of stress

$\Delta R$  is the resistance produced by the strain

## 2.2 Gauge factor

The strain gauge fundamental parameter is its sensitivity to strain. It is a dimensionless parameter, expressed quantitatively as the gauge factor.

The Gauge factor is defined as the proportionality factor of the fractional change in electrical resistance to the fractional change in length (strain)

$$G = \Delta R/R / \Delta L/L \quad (5)$$

Normally, we often want that the change in the resistance of the strain gauge to depend only on the applied strain. Nevertheless, the material of the strain gauge, as well as the test object to which it is applied, will also be affected by a temperature change.

In order to reduce the sensitivity to the change in temperature, manufacturers of strain gauge process the material of the gauge to compensate for the thermal expansion of the material of the test object. It is crucial to note that compensation of gauges is not to eliminate the thermal sensitivity but rather to cushion its effect by minimizing it.

### 3 CLASSIFICATION AND TYPES OF STRAIN GAUGE

#### 3.1 Class 1

This is the classification of strain gauges based on their principle of operation. This category of strain gauge has three different types as listed below;

##### 3.1.1 Mechanical strain gauge

The mechanical strain gauges are often times applied to larger objects because of their construction. The measurement effect can only be studied under a microscope at the end of the test. They comprise of two separate plastic layers; the upper layer houses the pointer while the lower layer has a ruled scale mounted on it. (AZO Sensors, 2013)



Figure 3. Mechanical Strain Gauge (Slideshare)

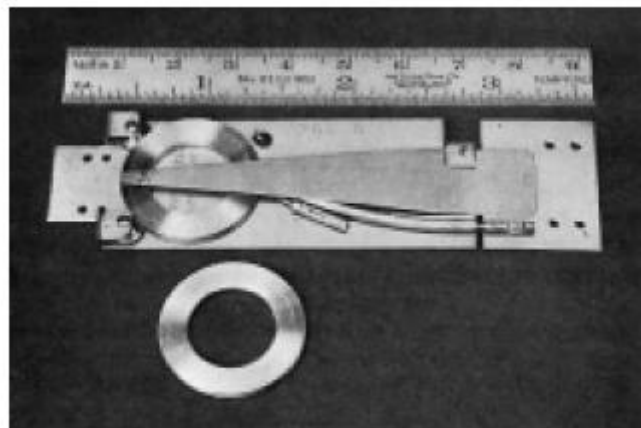


Figure 4. Mechanical extensometer (AZO Sensors, 2013)

### 3.1.2 Electrical strain gauge

This type of strain an electrical wire undergoes tension such that it still maintains its elasticity limits by not reaching the breaking point or the point of permanent deformation, this wire becomes narrower and longer hence, an increased change in the end-to end electrical resistance. (Chipkin Automation)



Figure 5. Electrical strain gauge (Slideshare)

### 3.1.3 Piezoelectric strain gauge

These strain gauges are active devices that generates electric voltage when strain is applied to it thus, the generated voltage can be used to compute the strain undergone by an object. The sensing material for this type of strain gauge is barium titanate. They are mostly known to be reliable and sensitive. (SNS Institutions)



Figure 6. Piezoelectric strain gauge (Slideshare)

### 3.2 Class 2

This classification is based on the mounting of the strain gauges on the test object. It comprises of four types.

#### 3.2.1 Unbonded non-Metallic Gauges

The gauge is composed of series of plates arranged in a stack. The change in displacement creates pressure difference in the stack which then causes changes in the resistance. They are mechanically actuated gauges that contains resistance elements arranged in such a way that when one part of the gauge displaced with respect to another developing a change in pressure on the measuring gauge. This change in pressure changes the resistance of the element and the recorded electrically. (SNS Institutions)

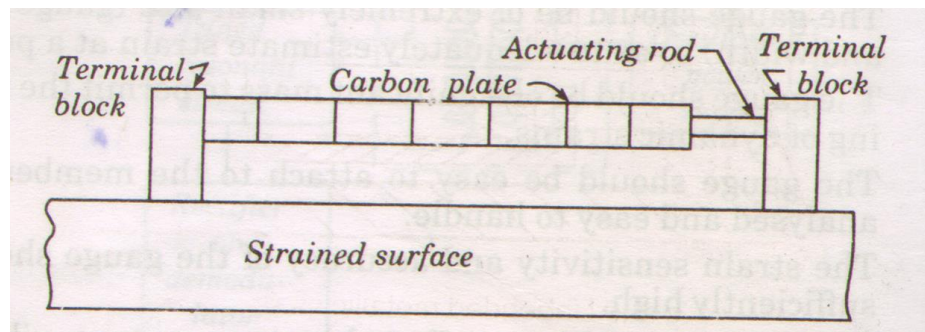


Figure 7. Unbonded non-metallic strain gauge (SNS Institutions)

#### 3.2.2 Unbonded Metallic Strain Gauge

This type of strain gauge operation is based on the fact that there is a change in electrical resistance of a metallic wire due to the change in tension of the wire. It is constructed by winding wire in three coils which are placed under initial tension into four arm Wheatstone bridge. As the compressive strain is applied the pre-strain would simply be relieved and the unbonded element would remain taut. This type of strain gauge was designed by Carlson and Eaton in 1930 and are rarely used for experimental stress analysis. However, the mechanism is incorporated in Accelerometers and pressure pick-ups. (AZO Sensors, 2013)

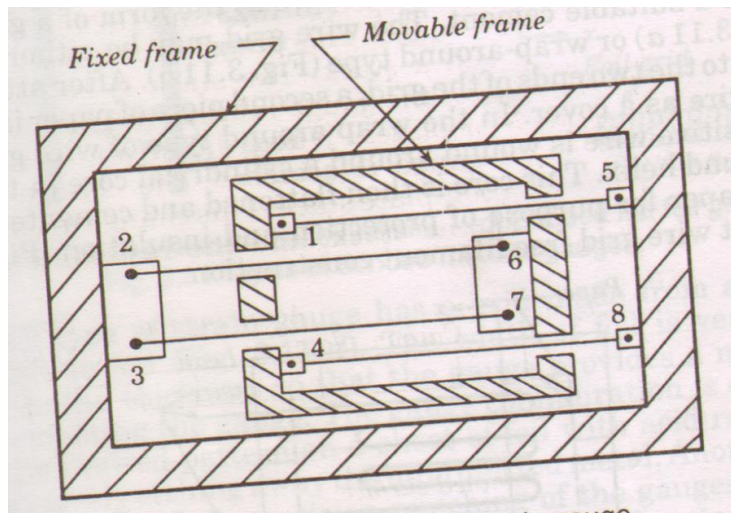


Figure 8. Unbonded metallic strain gauge (SNS Institutions)

### 3.2.3 Bonded non-Metallic Gauges

This is a strain gauge of non-metallic resistor element that is bonded directly to the surface of the test object that is to be measured for stress analysis. The bonding agent used is a glue. When used on metallic structures the surface is first coated with non-conducting material like carbon coating. This carbon coating is applied directly to the surface of the metallic test material that is to be measured. When the Carbon Coating Stretched, the carbon particles move apart but when the carbon coating compressed, the carbon particles moves closer creating a change in resistance. This change in resistance corresponds to the required strain. Carbon sheets are cut into strips of 6mm wide and 25mm long on each end and plated with silver band so that lead wires can be soldered. The limitation of this type of gauge is that its sensitivity and resistivity are affected by temperature and humidity.

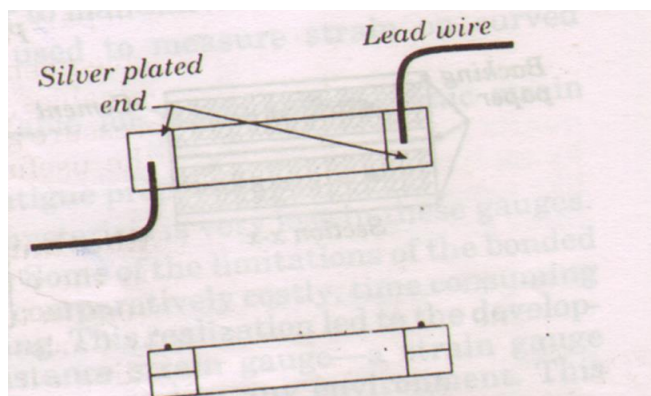


Figure 9. Bonded non-metallic strain gauge (SNS Institutions)

### 3.2.4 Bonded Metallic Gauges

This type of strain gauge has an element that is made up of a metallic wire, etched foil, vacuum-deposited film or semiconductor bar. It is cemented to the surface of the object.

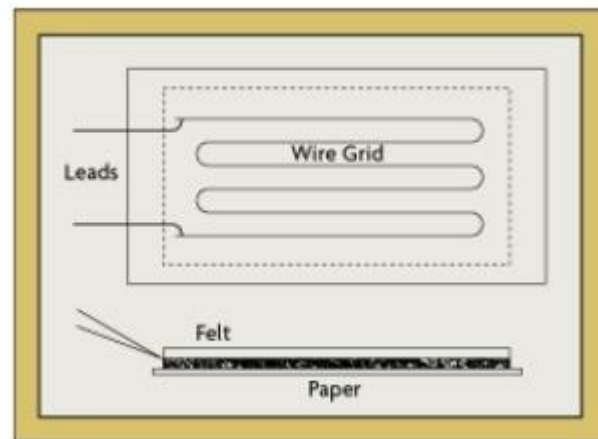


Figure 10. Bonded metallic strain gauge (Slideshare)

## 3.3 Class 3

This class of strain gauge identifies gauges based on their construction. It includes three different types;

### 3.3.1 Foil strain gauge

This type of gauge has a grid patterned metal foil photo-etched on the electrical insulator of the thin resin and the attached gauge leads.

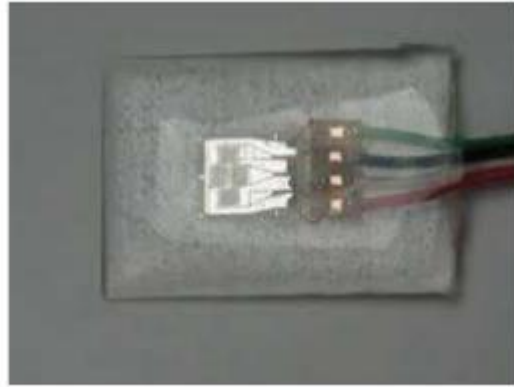


Figure 11. Foil strain gauge (Slideshare)

### 3.3.2 Semiconductor strain gauge

This type of strain gauge is also known as the piezoresistive strain gauge, this is because its measurement principle is based on the piezoresistive effect of germanium or silicon and measure the change in resistance with stress as opposed to strain. They are similar to the metallic strain gauge in construction and their measuring element is made up of a strip that is fixed to an insulating carrier foil provided with connecting leads. This gauge has a thin gold wire that suppresses the diode effects as a connection between the semiconductor element and the connecting strips. (AZO Sensors, 2013)

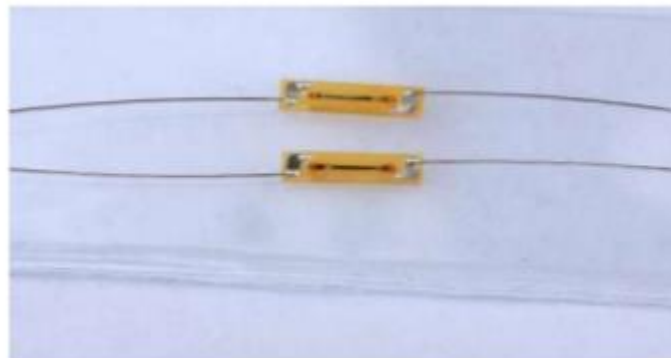


Figure 12. Semiconductor strain gauge (Slideshare)

### 3.3.3 Photoelectric strain gauge

A photoelectric strain gauge uses a photocell detector, two fine gratings and a beam of light to generate an electrical current which is proportional to the strain. This type of gauges is not common, they are delicate and expensive. (Chipkin Automation)



Figure 13. Photoelectric strain gauge (Slideshare)

#### 4 STRAIN GAUGE CONFIGURATIONS

The key to obtaining accurate measurement is to ensure that, the smallest change possible can be read. This means, the higher the accuracy of a measurement device, the higher the chances of small change or data that can be measured. There are three configurations of strain gauges, they are determined by the following factors;

- The type of strain required to be measured
- The total number of active elements in the Wheatstone bridge
- The orientation of the bridges' strain gauges

Since the principle of operation of strain gauges is measuring the change in resistance, therefore obtaining accurate strain data can only be achieved if only an extreme small change in resistance is measured. A Wheatstone bridge circuit is the most widely used circuit for the measure of static strain because of its unique sensitivity. The Wheatstone bridge circuit is used to convert the strain gauge's mechanical change (micro strain) into an electrical change (voltage), this voltage can be fed to the input of the A/D converter (ADC). (Measurement Computing)

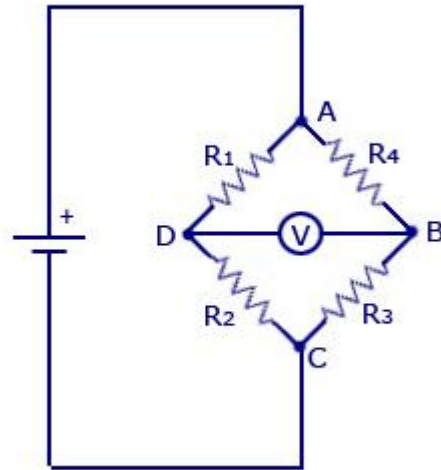


Figure 14. Wheatstone bridge circuit (John, 2011)

The bridge circuit is said to be balanced when all four resistors in the bridge are absolutely of equal value hence, the output voltage ( $V$ ) = 0. However, when any one or more of the resistors change value by only a fractional amount, the bridge produces a significant, measurable electrical voltage. When used on a material to determine its compression or expansion, a strain gauge replaces one or more of the resistors in the bridge, and as the strain gauge undergoes dimensional changes due to its bonding to the test specimen, it unbalances the bridge and produces an output voltage proportional to the strain.

The output voltage is zero for the condition that  $R_1, R_2, R_3,$  and  $R_4$  are equal or if the  $R_1: R_2 = R_3: R_4$ . This is shown by the following equation.

Considering the Fig. 14b

$$I = i_{1-2} + i_{4-3} \quad (6)$$

$$i_{1-2} = V_s / R_1 + R_2 \quad (7)$$

$$i_{4-3} = V_s / R_3 + R_4 \quad (8)$$

$$V_D - V_A = V_s R_1 / R_1 + R_2 \quad (9)$$

$$V_B - V_A = V_s R_4 / R_3 + R_4 \quad (10)$$

Subtracting equation 10 from equation 9

$$V_{out} = V_D - V_A - (V_B - V_A)$$

$$V_{out} = V_D - V_B \quad (11)$$

$$V_{out} = (R_1 R_4 - R_2 R_3) V_s / (R_1 + R_2) (R_3 + R_4) \quad (12)$$

$$V_{out} / V_s = (R_1 R_4 - R_2 R_3) / (R_1 + R_2) (R_3 + R_4) \quad (13)$$

If  $R_1 = R_2 = R_3 = R_4$  or  $R_1: R_2 = R_3: R_4$  the right-hand side of the equation 8 becomes zero.

Therefore

$$V_{\text{out}} / V_s = 0 \quad (14)$$

$$V_{\text{out}} = 0 \quad (15)$$

#### 4.1 Full-Bridge Circuits

A full-bridge circuit configuration of strain gauges is optimal for strain measurement however, half-bridge and quarter-bridge circuit of strain gauges are often adopted in most applications. The full-bridge configuration among all is highly sensitive, has the fewest error components, and the highest output that reduces the effects of disturbance such as noise on the measurements.

The full-bridge circuit strain gauge configuration as four strain gauges that are mounted on a test member: two of which are mounted on the surface under tension and the other two are mounted on the opposite surface under compression, as shown in Figure 1. Hence, as the member deflects, the two gauges under tension increases in resistance while the other two decreases in resistance and undergoes compression thereby, unbalancing the bridge and producing an output voltage that is proportional to the displacement of the gauges. (Inc, 2005)

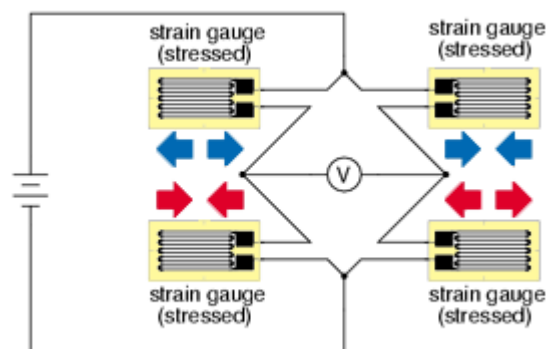


Figure 15. Full bridge strain gauge circuit (Circuits Today, 2010)

The full-bridge configuration is divided into three types;

##### 4.1.1 Configuration type I

- High sensitivity towards bending strain only
- Active strain gauges R1 and R2 measures the strain compression
- Active strain gauges R3 and R4 measures the tensile strain

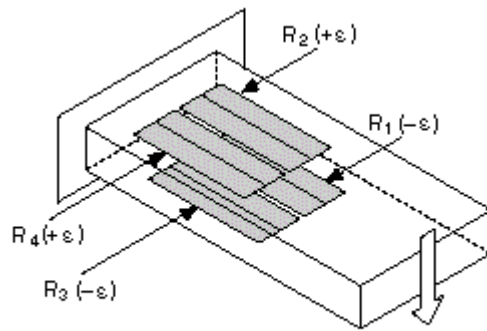


Figure 16. Full-bridge Strain Gauge Configuration I  
(National Instruments, 2016)

#### 4.1.2 Configuration type II

- Sensitive to strain resulting from bending only
- Active strain gauge R1 measures the Poisson's effect due to compression
- Active strain gauge R2 measures the Poisson's effect due to tensile
- Active strain gauge R3 measures the strain compression
- Active strain gauge R4 measures the tensile strain

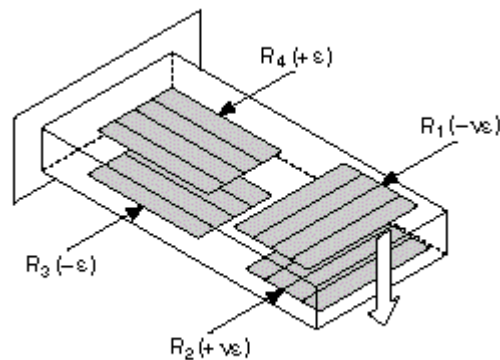


Figure 17. Full-bridge Strain Gauge Configuration II  
(National Instruments, 2016)

#### 4.1.3 Configuration type III

- Designed to measure axial strain
- Active strain gauges R1 and R3 measures the Poisson's effect due to the strain compression

- Active strain gauges R3 and R4 measure the tensile strain

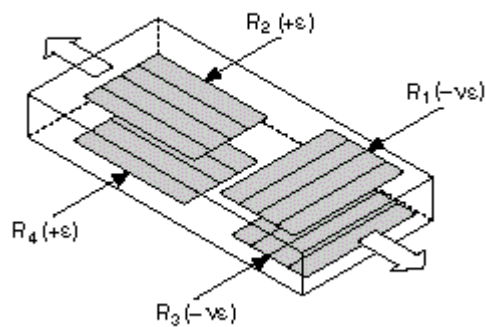


Figure 18. Full-bridge Strain Gauge Configuration III  
(National Instruments, 2016)

#### 4.2 Half-Bridge Circuits

The Half-bridge circuit consist of two strain gauges and two resistors, only two arms of the Wheatstone bridge are active. The two strain gauges are positioned on the specimen, and the two fixed resistors completes bridge. The change in resistance measured could be large due to the low sensitivity of the half-bridge circuit. Hence, the resistance does not change proportionally with the temperature and the accuracy of the temperature coefficients between the two strain gauges and fixed resistors cannot be guaranteed, this can introduce an additional nonlinearity error. However, the completion resistors are distanced from the strain gauges, the temperature differences contribute additional errors. In systems with long lead wires, the bridge completion resistors should be attached close to the gauges, but this might not always be practical due to test fixture limitations or other physical conditions. (Inc, 2005)

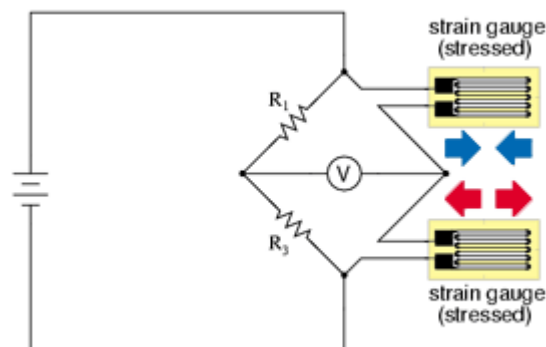


Figure 19. Half bridge strain circuit (Circuits Today, 2010)

The half bridge circuit is of two configuration types, namely type I and II.

#### 4.2.1 Configuration type I

- Designed for purpose of measuring axial or bending strain
- The Wheatstone bridge requires two completion resistors
- Active strain gauge  $R_4$  measures the tensile strain
- Active strain gauge  $R_3$  is compensating for the Poisson's effect

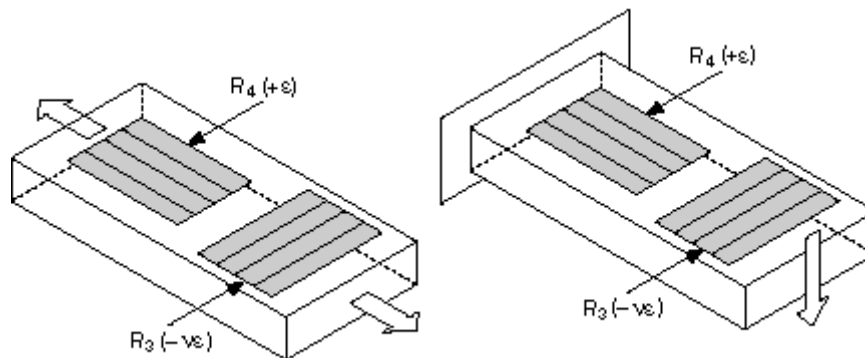


Figure 20. Half-bridge Strain Gauge Configuration I  
(National Instruments, 2016)

#### 4.2.2 Configuration type II

- Designed to measure bending strain only
- The Wheatstone bridge requires two completion resistors
- Active strain gauge  $R_4$  measures the tensile strain
- Active strain gauge  $R_3$  measures the compressive strain

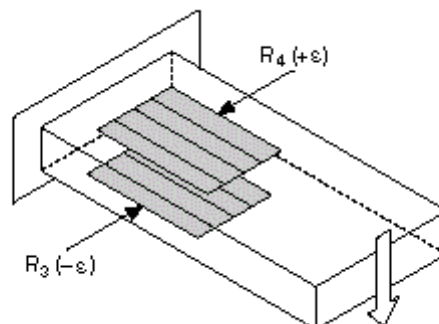


Figure 21. Half-bridge Strain Gauge Configuration II  
(National Instruments, 2016)

### 4.3 Quarter-Bridge Circuits

The Quarter-bridge circuit is the least sensitive of the three circuit combinations of strain gauge. It includes only one active strain gauge hence, noise is a potential problem. However, it is the cheapest and it's easier to build.

Ideally, it is often expected that the change in the resistance of the strain gauge to depend only on the applied strain. Nevertheless, the material of the strain gauge, as well as the test object to which it is applied, will also be affected by a temperature change. The quarter-bridge circuit has two configuration types namely type I and II.

The quarter-bridge type II help minimize the effect of this temperature change through the use two strain gauges; an active and a dummy gauge in its circuit. (National Instruments, 2016)

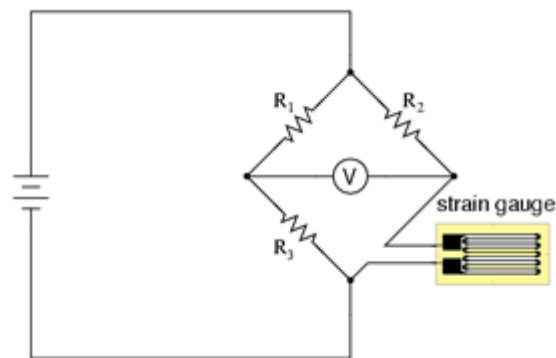


Figure 22. Quarter-bridge strain gauge circuit (Circuits Today, 2010)

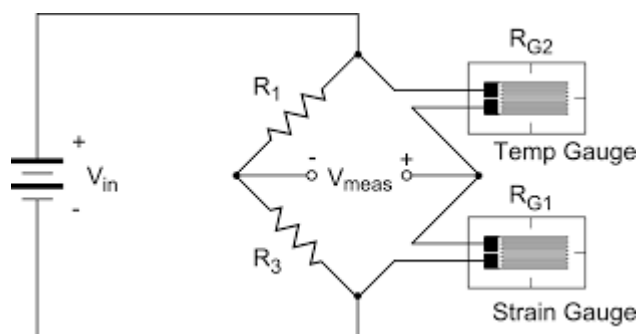


Figure 23. Quarter-bridge strain gauge circuit with temperature compensation (McGinty, 2012)

#### 4.3.1 Configuration type I

- Designed for the measure of axial or bending strain
- The circuit requires a passive completion resistor known as a dummy resistor
- Requires two completion resistors to complete the Wheatstone bridge
- Active strain gauge  $R_4$  measures the tensile strain

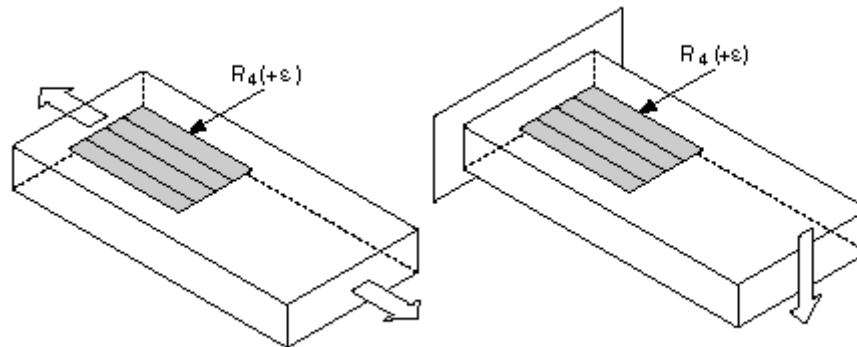


Figure 24. Quarter-bridge Strain Gauge Configuration II  
(National Instruments, 2016)

#### 4.3.2 Configuration type II

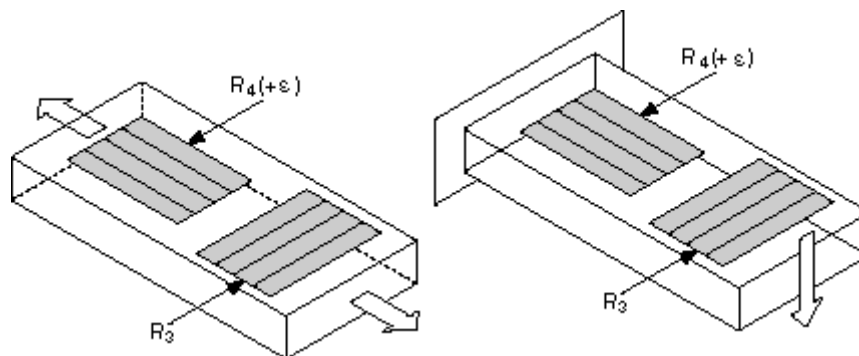


Figure 25. Quarter-bridge Strain Gauge Configuration II  
(National Instruments, 2016)

## 5 PREPARATION OF APPLICATION MATERIAL FOR STRAIN GAUGE MOUNTING

### 5.1 Material Surface Solvent Degreasing

Degreasing is a process performed to remove greases, organic contaminants, oils and soluble chemical residues. This process should always be performed first. This action is to prevent having subsequent abrading operations drive surface contaminants into the surface of the material. Materials such as titanium, cast iron, and cast aluminium are porous and may require heating to drive off absorbed hydrocarbons or other liquids.

Degreasing can be achieved using a hot vapor degreaser, an ultrasonically agitated liquid bath, aerosol type spray cans of CSM-2 Degreaser, or wiping with GC-6 Isopropyl Alcohol. One-way applicators, such as the aerosol type, of cleaning solvents are always preferable because dissolved contaminants cannot be carried back into the parent solvent. The entire test material should be degreased whenever possible but in the case of large materials that cannot be completely degreased, an area larger than the gauge's spot of application covering 100 to 150mm on all sides of the gauge area should be cleaned. This minimizes the chance of recontamination in subsequent operations, and provides an area adequately large for the application of protective coatings in the final stage of the gauge installation. (VPG Coporate, 2014).

### 5.2 Surface Abrading

Surface abrading is the next stage in the preparation for gauges installation procedure, the surface of the material is abraded in order to remove any loosely bonded adherents including scale, rust, paint, galvanized coatings, oxides, etc., and to make the surface texture of the material suitable for bonding. The abrading operation can be performed in several ways, depending upon the initial state of the surface of the material and the desired finish for gauge installation. For rough or coarse material surfaces, it may require starting with a grinder, disc sander, or file. Finish abrading is done with a sand paper or silicon carbide paper of the appropriate grit.

If grit blasting is preferred for use over abrading, either clean alumina or silica of 100 to 400 grit is satisfactory. In any case, the supplied air should be well filtered so that oil and other contaminant vapours that comes from the air compressor can be removed. It is important not to recycle or re-use the grit used in blasting in surface preparation for strain gauge bonding.

The nature and purpose of the installation of strain gauges are the major factor that determines the optimum surface finish for gauge bonding. For

general applications in stress analysis, a considerable smoothness in the surface of the material in the order of  $2.5\mu\text{m}$  rms is suitable, and has the advantage that it can be cleaned easily and thoroughly compared to rougher surfaces. Smoother surfaces, compatible with the thin glue lines required for minimum creep, are used for transducer installations. In contrast, when very high elongations must be measured, a rougher and preferably cross-hatched surface should be prepared. (VPG Coporate, 2014). The Table 1 below shows a summary of the recommended surface finishes for several classes of gauge installations.

Table 1. Surface finishes for Strain Gauge Installation (VPG Coporate, 2014)

CLASS OF INSTALLATION	SURFACE FINISH (rms)	
	$\mu\text{In}$	$\mu\text{m}$
General stress analysis	63 - 125	1.6 – 3.2
High elongation	>250	>6.4
	Cross-hatched	
Transducers	16 – 63	0.4 – 1.6

### 5.2.1 Wet Abrading

In wet abrading, abrading of the test material is done when the surface is wet by using M-prep conditioner A whenever it is possible. Conditioner A is a mildly acidic solution which generally accelerates the cleaning process and, on some materials, acts as a gentle etchant. It is not recommended for use on magnesium, synthetic rubber, or wood. (VPG Coporate, 2014)

### 5.3 Surface marking

The technique to accurately determine the strain gauge's location and orientation on the test material surface is by marking the surface with a pair of crossed reference lines at the point of measure of the strain measurement. These reference lines are drawn perpendicular to one another, with one line oriented towards the direction of the strain measurement. The strain gauge is then installed so that the triangular index marks defining the longitudinal and transverse axes of the grid are aligned with the reference lines on the material's test surface.

The reference lines should be drawn with a tool that burnishes, rather than one that scores or scribes, the surface. A scribed line may raise a burr or create a stress concentration. In either case, such a line can be detrimental to the performance of the strain gauge and to the fatigue life of the material's test part. As a recommendation a good burnishing tool is the 4H

drafting pencil. It is a satisfactory and convenient tool that burnish well on aluminium and most other nonferrous alloys.

However, graphite pencils should never be used on high temperature alloys, where the operating temperature might cause a carbon embrittlement problem. On these and other hard alloys, burnished alignment marks can be made with a ballpoint pen or a round-pointed brass rod. Reference lines are often applied following the abrading operation and before final cleaning. All the residue from the burnishing operation should be removed by scrubbing with Conditioner A as described in the next stage. (VPG Corporate, 2014).

#### 5.4 Surface Conditioning

After the layout lines are marked, Conditioner A should be applied repeatedly, and the surface scrubbed with cotton tipped applicators until a clean tip is no longer discoloured by the scrubbing. During this process the surface should be kept constantly wet with Conditioner A until the cleaning is completed. Cleaning solutions should never be allowed to dry on the surface. When clean, the surface should be dried by wiping through the cleaned area with a single slow stroke of a gauze sponge. The stroke should begin inside the cleaned area to avoid dragging contaminants in from the boundary of the area. Then, with a fresh sponge, a single slow stroke is made in the opposite direction. The sponge should never be wiped back and forth, since this may redeposit the contaminants on the cleaned surface.

(VPG Corporate, 2014)

#### 5.5 Surface Neutralizing

The final step in surface preparation is to bring the surface condition back to an optimum alkalinity of 7.0 to 7.5pH. This should be done by liberally applying M-Prep Neutralizer 5A to the cleaned surface, and scrubbing the surface with a clean cotton-tipped applicator. The cleaned surface should be kept completely wet with Neutralizer 5A throughout this operation. When neutralized, the surface should be dried by wiping through the cleaned area with a single slow stroke of a clean gauze sponge. With a fresh sponge, a single stroke should then be made in the opposite direction, beginning with the cleaned area to avoid recontamination from the uncleaned boundary. Then surface is now properly prepared for strain gauge bonding, and the gauge or gauges should be installed as soon as possible.

(VPG Corporate, 2014)

### 5.6 Strain gauge preparation

The strain gauge is put on a smooth surface such as a table, it is then picked up by placing a short length of Sellotape across the upper part. Holding the tape at both end and place the gauge on the surface of the test material in the desired orientation, then slowly remove the tape from one end toward the other. The tape is removed after the gauge has been bonded to the surface. (RS Components, 1996).

### 5.7 Bonding of adhesives and strain gauge

The three commonly used adhesives are the Epoxy resin, Phenol-Epoxy resin and Cyanoacrylate series.

The Cyanoacrylate series adhesive is recommended where fast bonding and thin glue is essentially required. This is because this type of adhesive is pressure sensitive and they react instantly upon water contained in the atmospheric air. (RS Components, 1996).

## 6 EXPERIMENTAL SETUP AND RESULTS

To ensure precise and accurate measurements from the cantilever setup, care was taken in the installation and connection of all associated equipment for this study. In this chapter, a detailed description of the experimental setup used for comparing the different circuit configuration of strain gauge circuit is provided, including the equipment and chemicals used.

### 6.1 Equipment

The equipment used for the successful execution of this Experimental stress analysis and their function is given below.

- Strain gauge: used to convert the compression or expansion from the test object into a change in electrical resistance that can be measured
- Aluminium beam: the test object that is subjected to expansion or compression
- Digital multi-meter: device used to measure the voltage and resistance
- DC voltage source: device that supply voltage to the circuit
- Connection wires: electrical conductors used to for the circuit connection
- Sand paper: used for abrading the surface of the test object for strain gauge installation

- Adhesive tape: used to pick up the gauge from flat surface and orientating on the test object
- Tweezers: used to remove the gauge from its sleeve
- Paper towel: used to wipe clean the abraded surface of the test object
- Soldering iron: used to join the strain gauge arms to the connection wires
- Soldering wire: used as the electrical bonding agent for the connection between the strain gauge and the connection wires
- Breadboard: an electronic circuit building board used to simulate the different circuit configuration.

## 6.2 Chemicals

- Neutralizer A: used to clean the abraded surface to bring it to the required pH level
- Adhesive bond: used to glue the strain gauge to the abraded surface of the test object

## 6.3 Experimental setup

The strain gauge is attached to a cantilever beam made of aluminium, the aluminium beam is attached to the table to simulate a cantilever beam as shown in the Fig. 26 - 29 below.

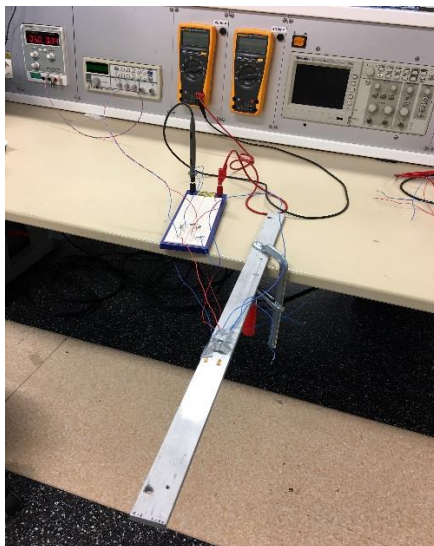


Figure 26.

Quarter-bridge circuit

The Fig. 26 above comprised of a strain gauge and three completion resistors to simulate a Quarter-bridge circuit configuration of strain gauge. The strain gauge (R1) is glued to the top surface of the Aluminium beam and connected in series to a completion resistor (R2), the connection is then connected to the series connection of completion resistors (R3) and (R4) in parallel. An excitation voltage is applied across nodes CA and the voltage drop across nodes DB is measured using a digital multi-meter as illustrated in Fig. 14

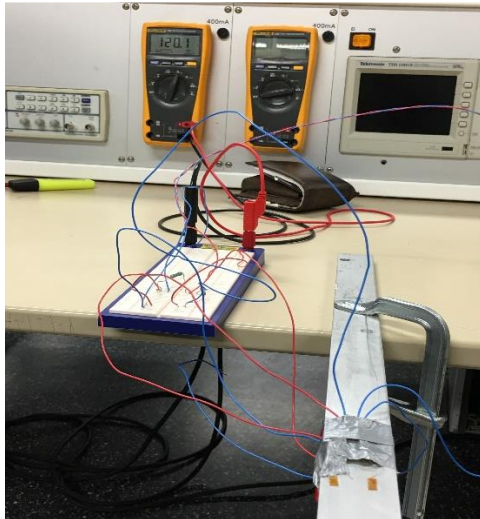


Figure 27. Half-bridge circuit

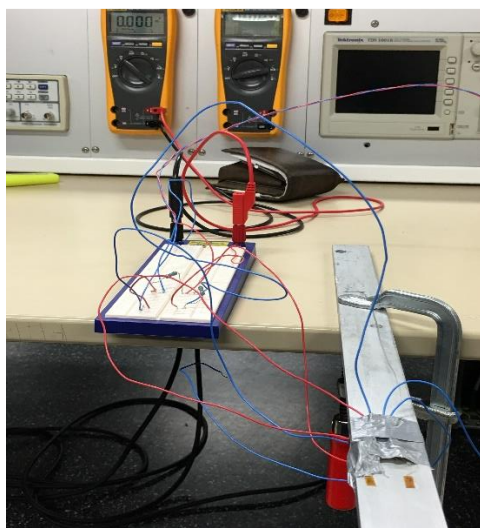


Figure 28. Half-bridge circuit

In the Fig. 27 and 28 above two strain gauges and completion resistors are used to simulate a Half-bridge circuit configuration of strain gauge. The strain gauge (R1) is glued to the top surface of the Aluminium beam and connected in series to another strain gauge (R2) that is glued to the bottom surface of the Aluminium beam, the connection is then connected to the series connection of completion resistors (R3) and (R4) in parallel. A direct current voltage is fed into the circuit through nodes CA and a digital multi-meter is connected across nodes DB to measure the voltage drop.

Fig. 27 shows a balanced strain gauge Half-bridge circuit when measuring the bridge resistance while Fig. 19b shows a balanced strain gauge Half-bridge circuit when measuring the output voltage.

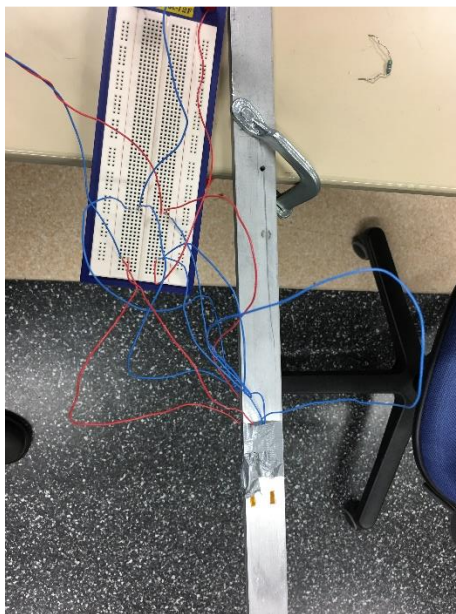


Figure 29. Full-bridge circuit

The Fig. 29 comprised of four strain gauges in series and parallel connection to simulate a Full-bridge circuit configuration of strain gauge. The strain gauges (R1) and (R4) is glued to the top surface of the Aluminium beam while strain gauges (R2) and (R3) are connected to the bottom surface of the Aluminium beam. The strain gauges (R1) and (R2) are connected in series the connection is then connected in parallel to the series connection of strain gauges (R3) and (R4). A direct current voltage is fed into the circuit through nodes CA and a digital multi-meter is connected across nodes DB to measure the voltage drop.

## 6.4 Result

The result measurement began by simulating each circuit configuration type one after the other following the procedures illustrated under each of the Fig. 26 – 29 above.

The Aluminium beam experiences a bending strain, this type of strain has the same absolute values but opposite signs. This means that the upper side and the underside of the beam has the same values but with opposite signs.

The compressive side strain is negative while the tensile strain side is positive.

Table 2. Experiment Measured Values

	Mass	$V_{out}$ (mV)	$R_b$ ( $\Omega$ )	$\Delta R = (R_b - R)$ $\Omega$	$V_{out} / V_s$
QB	0	5.3	124.9	4.9	0
	M1	5.1	124.6	4.6	0
	M2	4.8	124.4	4.4	9.6e-4
HB	0	0.00	120.1	0.1	0
	M1	1.2	121.0	1.0	2.4e-4
	M2	1.7	121.5	1.5	3.4e-4
$V_s$	5V				
R	120 $\Omega$				

The Table 2 above shows the results of the experiment performed.  
Where:

QB is the Quarter-bridge circuit

HB is the Half-bridge circuit

$V_s$  is the excitation or source voltage

$V_{out}$  is the output voltage

R is the resistance of the bridge without any weight applied

The absolute value of the strain for each of the bridge configuration circuit can be calculated as give below;

$$\text{Strain } |\epsilon| = 4 (V_{out} / V_s) / (BK) \quad (16)$$

K is the gauge factor of the strain gauge given as 2.1

B is the bridge factor

For bending strain, the bridge factor for Quarter and Half bridge circuit configuration are 1 and 2 respectively.

Therefore, for  $M = 0$ , for the both circuit configuration,

$$\text{Strain } |\varepsilon| \approx 0 \quad (17)$$

For QB when  $M = M1$

$$\text{Strain } |\varepsilon| = 4 (0) / (1*2.1)$$

$$\text{Strain } |\varepsilon| \approx 0$$

For QB when  $M = M2$

$$\text{Strain } |\varepsilon| = 4 (0.00096) / (1*2.1)$$

$$\text{Strain } |\varepsilon| \approx 0.0018$$

For HB when  $M = M1$

$$\text{Strain } |\varepsilon| = 4 (0.00024) / (2*2.1)$$

$$\text{Strain } |\varepsilon| \approx 0.0002$$

For HB when  $M = M2$

$$\text{Strain } |\varepsilon| = 4 (0.00034) / (2*2.1)$$

$$\text{Strain } |\varepsilon| \approx 0.0003$$

## 7 CONCLUSIONS

The three configuration types for strain gauge circuit were successfully connected and tested in this project. Each of the circuit was able to respond to inputs as predicted.

The Quarter-bridge circuit when subjected to inputs, responded slightly according to the measured values in the table 2 above and the calculated values.

The Half-bridge configuration on other hand was quite sensitive, it produces a more accurate measured and calculated data.

The Full-bridge circuit was highly sensitive which led to an unstable measurement.

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