Electrical, Computer & Energy Engineering
UNIVERSITY OF COLORADO **BOULDER**

ECEN 5053-003 Homework Assignment

Course Name: Embedding Sensors and Actuators
Corresponding Module: C3M1
Week Number: 9
Module Name: Pressure Sensors
Student Name: **Rushi James Macwan**

Note: Correct answer is in Blue Font

Homework is worth 100 points.

Part 1: Each question is worth 10 points.

A. Answer the following questions about pressure sensor terminology:

A.1 What is the difference between proof pressure and burst pressure in a pressure sensor?

Sol.

Proof Pressure	**Burst Pressure**
Proof pressure is the maximum pressure applied to the sensor before its output sensitivity changes permanently.	***Burst pressure is the maximum pressure applied to the sensor before it ruptures and leaks fluid into the atmosphere.***
In other words, the specified pressure that may be applied to the sensing element of a transducer causing a permanent change in the output characteristics is known as proof pressure.	In other words, the specified pressure that will rupture the sensing element or transducer case causing leakage is known as burst pressure.
Proof pressure, overpressure or "over-range capacity," is the maximum pressure that may be applied to a device without changing its performance within the specifications. Typically after the sensor is exposed to an overpressure under the proof pressure limit, the device	Burst pressure is the maximum pressure that may be applied to the positive pressure port without physically damaging the internal sensing component. Burst pressure can also be defined as the maximum pressure the device is able to withstand before failure.

will return to its original state and operate normally.	
Often proof pressure is specified as a multiple of the upper limit of the devices ordered range. If the pressure is exceeded, the sensor will not fully recover, and will result in a positive zero shift.	Typically after exposure to a pressure above burst pressure, the sensor is no longer usable and would need to be replaced.

Courtesy: Reference Links: [1] [2] and class slides: C3M1V2

A.2 What is a differential pressure sensor?

Sol.

Differential pressure sensors will sense the difference in the pressure between two ports (upstream and downstream) and will produce an output signal reference to a calibrated pressure range. Thus, the differential pressure sensor will measure the difference between the pressures upstream and downstream of any given fluid and can help us calculate the fluid flow rate.

Courtesy: Reference Links: [1] [2] [3] and class slides: C3M1V9

A.3 What is pressure measurement error?

Sol.

The maximum difference between true pressure and the inferred pressure from the output for any pressure I within the operating pressure range of a pressure sensor is known as the pressure measurement error.

Courtesy: Reference Links: [1]

A.4 What is excitation?

Sol.

The external electrical voltage and/or current applied to a transducer for its proper operation (often referred to as the supply current or voltage) is known as excitation.

Courtesy: Reference Links: [1]

A.5 What is the difference between gauge pressure and absolute pressure?

Sol.

Absolute pressure is a pressure measurement relative to zero pressure. It is measured above total vacuum or zero absolute. Zero absolute represents total lack of pressure.

Whereas, gauge pressure is the pressure above atmospheric pressure. Represents positive difference between measured pressure and existing atmospheric pressure. Can be converted to absolute by adding actual atmospheric pressure value.

To summarize, gauge pressure is a form of differential pressure measurement in which atmospheric pressure is used as a reference while absolute pressure is a pressure measurement relative to zero pressure or vacuum.

Courtesy: Reference Links: [1] [2]

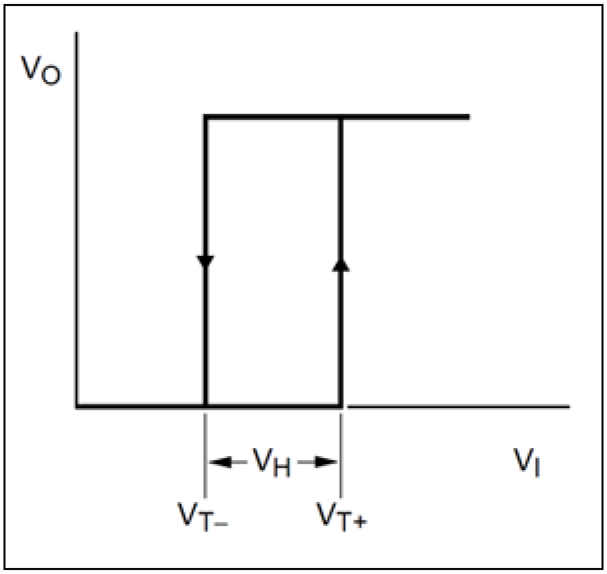
A.6 What is hysteresis in a pressure measurement? How does it differ mathematically from hysteresis in a voltage measurement?

Sol.

The difference in output at any given pressure in the operating pressure range when this pressure is approached from the minimum operating pressure and when approached from the maximum operating pressure at room temperature is known as the **pressure hysteresis**. This is the hysteresis in the pressure measurement.

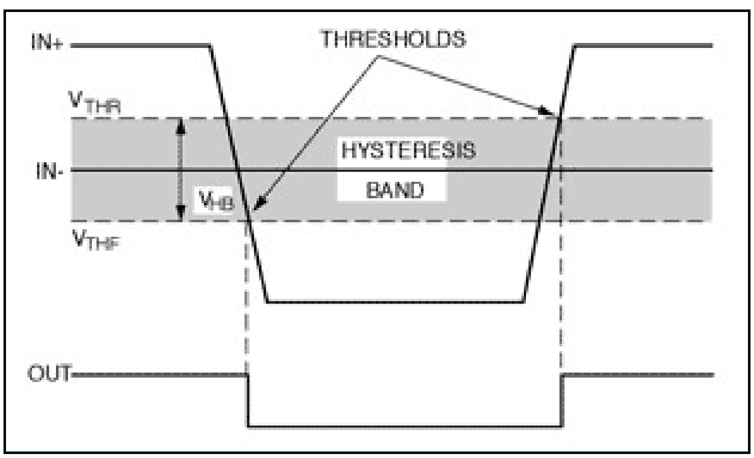
To be clearer, it is found that for a given pressure in the operating pressure range, there will be two output values when the pressure is approached from zero and when the pressure is approached from the maximum value. This two different sensor output values form the hysteresis in a pressure measurement of the pressure sensor for a given input pressure value and pressure variation curve.

However, as far as hysteresis in the voltage measurement is concerned, one way to illustrate **hysteresis in voltage measurement** is through **transfer function**, with the typical loop:



As long as the input voltage remains below *VT+* the output is low, but if it exceeds this value the output switches to high (the up-going arrow). Then the output remains high as long as the input voltage stays above *VT−*. When the input voltage drops below this threshold the output switches to a low level (the down-going arrow).

Based on this explanation, we can say that in voltage measurement, hysteresis means that noise levels less than a given specific hysteresis value on the datasheet of the electrical equipment won't influence the threshold passing. Which threshold applies depends on whether you go from low to high (then it's the higher threshold) or from high to low (then it's the lower one).



Example of hysteresis in voltage measurement:

Let's say we detect a low-to-high transition at 2.5 V. A 100 mV hysteresis would mean that the low-to-high transition is detected at 2.55 V and the high-to-low transition is detected at 2.45 V, with a 100 mV difference.

Courtesy: Reference Links: [1] [2] and class slide: C3M1V8

A.7 What is a leakage rate?

Sol.

The maximum rate at which a fluid is permitted or determined to leak through a seal is known as leakage rate. The type of fluid, the differential pressure across the seal, the direction of leakage, and the location of the seal must be specified.

Courtesy: Reference Links: [1]

A.8 What is the operating pressure range?

Sol.

The range of pressure between minimum and maximum pressures at which the output will meet the specified operating characteristics is known as operating pressure range.

Courtesy: Reference Links: [1]

A.9 What is the difference between thick film and thin film production technology?

Sol.

Thick Film – technology using screened on pastes to form conductor, resistor, thermistors, and insulator patterns; screened onto the substrate (usually ceramic) and cured by firing at elevated temperatures.

Thin Film – a technology using vacuum deposition of the conductors and dielectric materials onto a substrate (frequently silicon) to form an electrical circuit.

B. A platinum wire has Poisson's ratio v = 0.39, and resistivity ρ of 1.03×10^{-7} ohm-meter. When the wire is pulled, the lateral strain ε_L is 0.10 and the resistivity increases to 1.05×10^{-7} ohm-meter. What is the gauge factor of the platinum wire? (Type in a two-decimal number)

Sol. $\boxed{\mathbf{1.974174}}$

Using the equation given below as provided in the class slide, the gage factor can be calculated as shown below:

$$G = (d\rho/\rho)/\varepsilon_L + 1 + 2\nu$$

Where,

G = gauge factor, a measure of the sensitivity of resistance change with strain

ε_L = lateral strain

ν = Poisson's ratio

Here, $(d\rho/\rho)$ is the change in the resistivity divided by the resistivity value in Ohm-m. Thus, the Gauge Factor (G) can be calculated as shown below:

$$
\begin{aligned}
G &= ([(1.05 \times 10^{-7} - 1.03 \times 10^{-7}) / 1.03 \times 10^{-7}] / 0.10) + 1 + (2 \times 0.39) \\
&= 0.194174 + 1 + 0.78 \\
&= \mathbf{1.974174}
\end{aligned}
$$

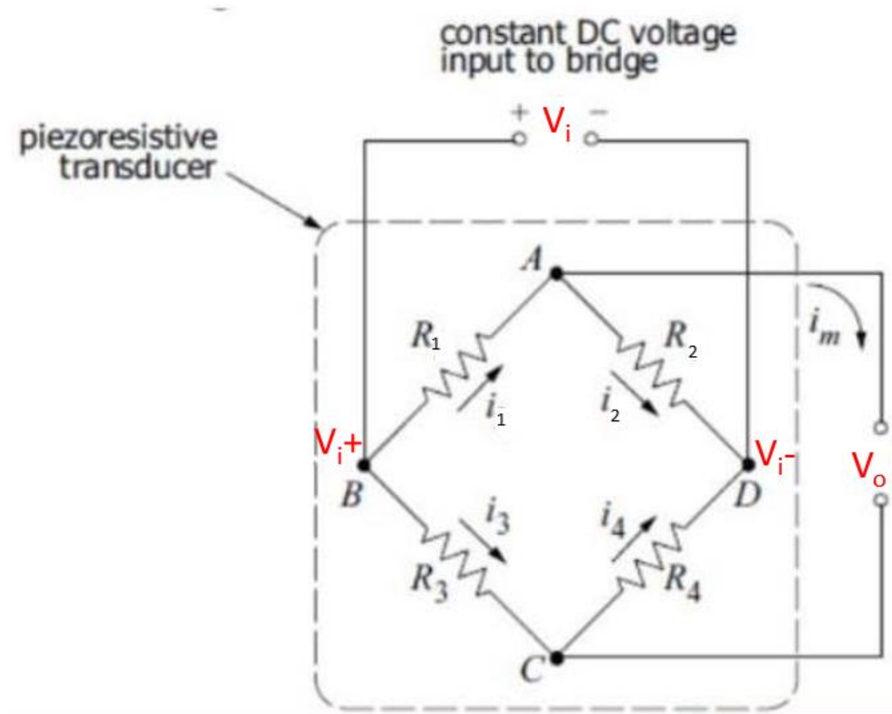
Thus, the gauge factor is **1.974174**.

Courtesy: Reference class slides: C3M1V3

C. A circuit for piezoresistive pressure sensor is arranged so that resistors R2 and R3 see tensile stress, resistors R1 and R4 see compressive stress, and the excitation voltage V_i of 5 volts is applied across the intersection of R1 and R3 and that of R2 and R4. When pressure is applied R1 = 993 ohms, R2 =1007 ohms, R3 = 1007 ohms, and R4 = 993 ohms. What is the output voltage V_o in volts? Type in a 3-place decimal.

Sol. **0.035 V or 35 mV**

Using the below given formula as provided in the class slide, we can calculate the output voltage in volts for the given circuit configurations of a piezoresistive pressure sensor:



$$V_o = (R_2/(R_1+R_2) - R_4/(R_3+R_4))\ V_{in}$$

Thus,

V_0 = [(1007/(993+1007)) – (993/1007+993)] x 5
= [0.5035 – 0.4965] x 5
= 0.007 x 5
= 0.035 volts = **35 mV**

Thus, the output voltage is **35 mV**.

Courtesy: Reference class slides: C3M1V4

D. A pressure sensor at the bottom of a large tank of ethanol is used to measure absolute pressure. (Don't get excited – the ethanol (a.k.a. booze) is not for you.) The column of ethanol is 3 meters high. What is the absolute pressure at the bottom in kilopascals? Type in a 1-decimal number.

Sol. **124.521 kPa**

Based on the referenced document, we can consider the below given equation for solving this problem; assuming that the density of ethanol is 789 kg/m^3 (reference):

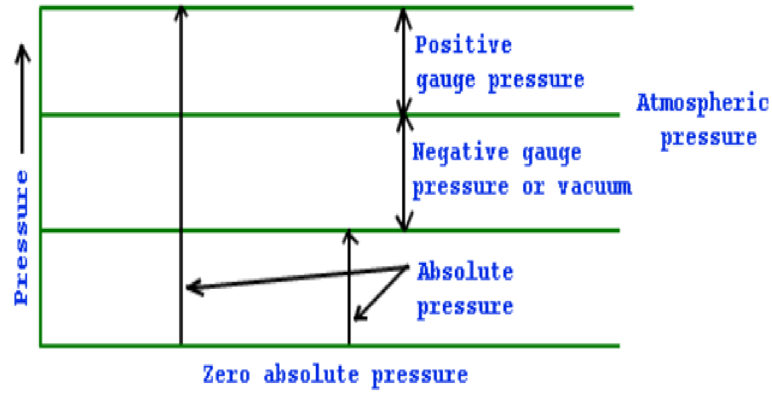


Diagram showing gauge, vacuum and absolute pressure

Absolute pressure formula (p_{abs}) is given by,

$$p_{abs} = p_{atm} + p_{gauge}$$

where p_{atm} is atmospheric pressure and p_{gauge} is gauge pressure.

Thus, P_{gauge} (gauge pressure) = height (h) x density (ρ) x gravitational acceleration (g)

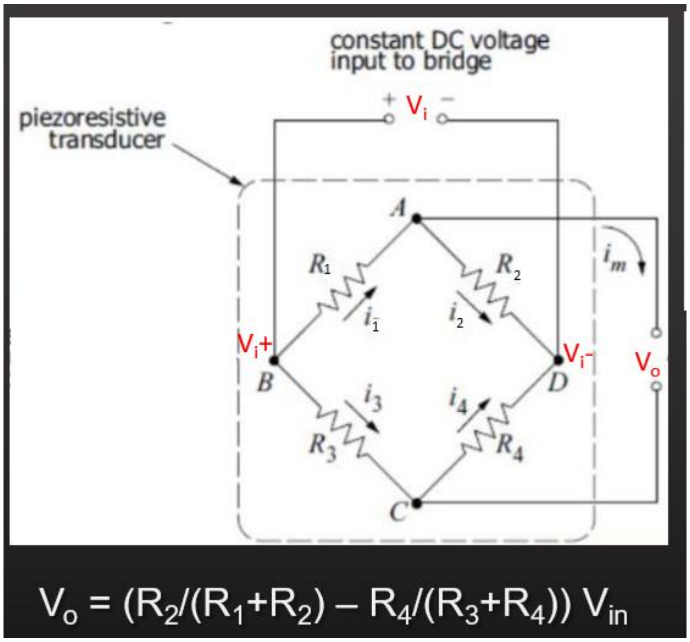
P_{gauge} = 3 x 789 x 9.8 = 23196.6 N/m^2
But, 1 N/m^2 = 1 Pa
Therefore, P_{gauage} = 23.196 kPa

Secondly, atmospheric pressure P_{atm} = 101.325 kPa (reference)

Finally, P_{abs} = (23.196 + 101.325) kPa = **124.521 kPa**
(based on the equation of absolute pressure)

Courtesy: Reference Link: [1]

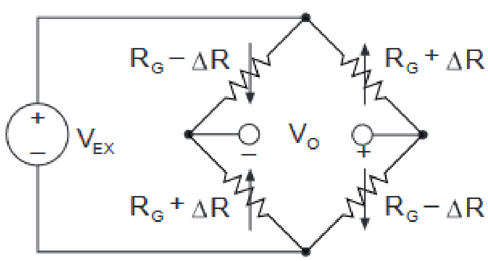
E. The sensitivity of a constant voltage strain gauge bridge circuit is defined as the ratio of the change of signal voltage to excitation voltage for some fixed strain change. The Wheatstone bridge circuit for 4 piezoresistive sensors is shown in the screenshot below, taken from one of our slide decks.



Use the formula shown to algebraically derive the formula for the sensitivity of the bridge: ΔV_o / V_i = εG, when $R = R_1 = R_2 = R_3 = R_4$.

Sol.

To solve this problem, based on the referenced document, it can be said that to increase the sensitivity of the bridge, by making all four arms of the bridge as active strain gauges. The mounting is done such that in a full-bridge circuit, two gauges are in tension and two gauges are in compression as shown in the below given circuit:

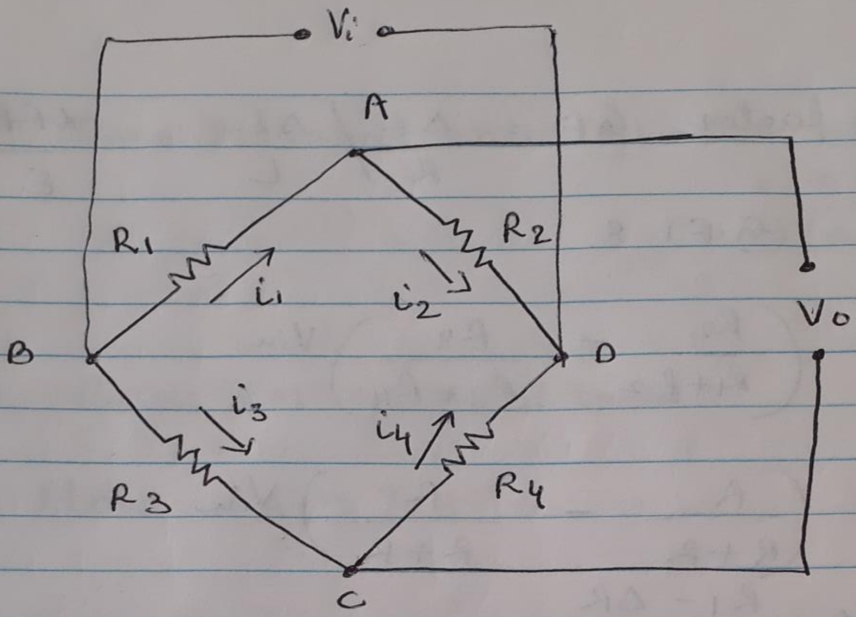


Considering, the data provided in this problem, we can replace R_G as R since $R = R_1 = R_2 = R_3 = R_4$.

Based on the above points, using the equation provided in the problem, our new resistance values be as below:

$R_1 = R – \Delta R$ (compression)
$R_2 = R + \Delta R$ (tension)
$R_3 = R + \Delta R$ (tension)
$R_4 = R – \Delta R$ (compression)

Putting the new values of resistances in the equation, we can calculate the value of output voltage to input voltage ratio which is equal to the ratio of change in the resistance value of a strain gauge to the value of resistance.



Based on this diagram,

let $R_1 = R_2 = R_3 = R_4 = R$

Where, R = Nominal resistance of strain guage.

Let, ΔR = strain-induced change in resistance

$$\therefore R_1 = R - \Delta R \quad \text{——} (1)$$

$$R_2 = R + \Delta R \quad \text{——} (2)$$

$$R_3 = R + \Delta R \quad \text{——} (3)$$

$$R_4 = R - \Delta R \quad \text{——} (4)$$

Putting Eq (1), (2), (3) and (4) in the below eqn:-

$$V_o = \left[\frac{R_2}{R_1+R_2} - \frac{R_4}{R_3+R_4} \right] \times V_i$$

$$\therefore \frac{V_o}{V_i} = \left[\frac{R+\Delta R}{2R} - \frac{(R-\Delta R)}{2R} \right]$$

$$\therefore \frac{V_o}{V_i} = \frac{R + \Delta R - R + \Delta R}{2R}$$

$$\therefore \frac{V_o}{V_i} = \frac{2\Delta R}{2R}$$

$$\therefore \boxed{\frac{V_o}{V_i} = \frac{\Delta R}{R}} \quad \text{— (5)}$$

Thus, $\boxed{V_o / V_i = \Delta R / R}$

We can relate the above equation with the gauge equation which is as under:

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

Where, GF (or G) = Gauge Factor

Thus, we can relate both of the equations as under:

Now, Gauge Factor $G = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$

$$\therefore \boxed{G = \frac{\Delta R/R}{\varepsilon}} \quad \text{— (6)}$$

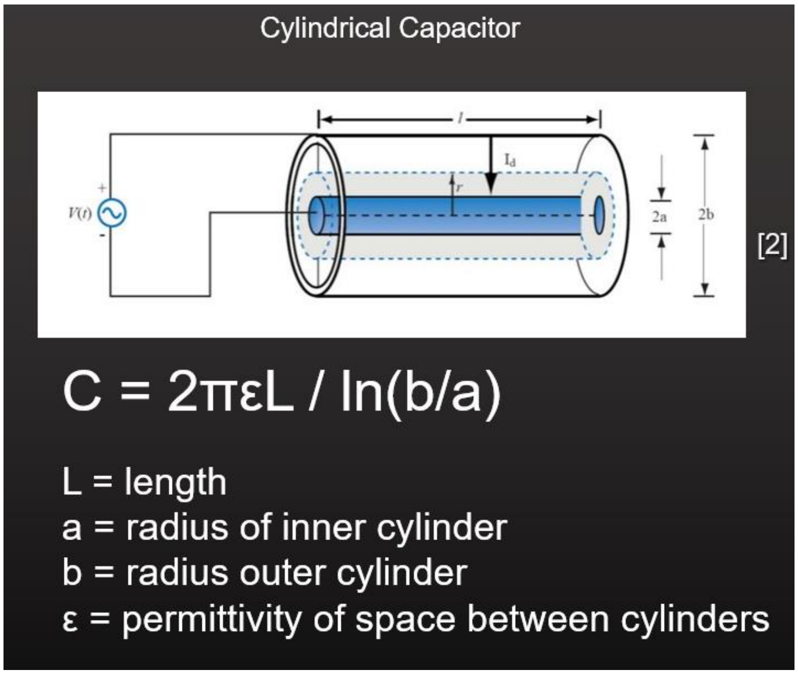
Combining Equations (5) and (6),

$$\boxed{\frac{V_o}{V_i} = \frac{\Delta R}{R} = G \cdot \varepsilon} \quad \text{— (7)}$$

Thus, the formula for the sensitivity of the bridge: $\Delta V_o / V_i = \varepsilon G$ can be derived as shown above.

Courtesy: Reference Links: [1]

F. Derive the expression for capacitance in a cylindrical capacitor, as shown in this screen shot from one of our slides.



Sol.

Based on the referenced documents, the capacitance for cylindrical or spherical conductors can be obtained by evaluating the voltage difference between the conductors for a given charge on each. By applying Gauss' law to an infinite cylinder in a vacuum, the electric field outside a charged cylinder can be found as under:

$$
\begin{aligned}
EA &= \frac{q}{\epsilon_0} \\
E &= \frac{q}{2\pi r \epsilon_0 L} \\
&= \frac{\lambda}{2\pi r \epsilon_0}
\end{aligned}
$$

Here, it is assumed that a long cylindrical conductor has a radius r_a and a linear charge density $+\lambda$. It is surrounded by a coaxial cylindrical conducting shell with inner radius r_b and linear charge density $-\lambda$. Now, we calculate the capacitance per unit length for this capacitor using the electric field value as obtained above, assuming that there is vacuum in the space between cylinders.

$$
\begin{aligned}
-\frac{dV}{dr} &= E \\
-\frac{dV}{dr} &= \frac{\lambda}{2\pi\epsilon_0 r} \\
\int_{V_a}^{V_b} dV &= -\int_{r_a}^{r_b} \frac{\lambda}{2\pi\epsilon_0 r}\, dr' \\
V_b - V_a &= -\frac{\lambda}{2\pi\epsilon_0}\left[\ln r\right]_{r_a}^{r_b} \\
-(V_a - V_b) &= -\frac{\lambda}{2\pi\epsilon_0}\ln\left(\frac{r_b}{r_a}\right) \\
V_{ab} &= \frac{\lambda}{2\pi\epsilon_0}\ln\frac{r_b}{r_a}
\end{aligned}
$$

Hence,

$$
\begin{aligned}
C &= \frac{Q}{V_{ab}} \\
&= \frac{2\pi\epsilon_0 L}{\ln\frac{r_b}{r_a}}
\end{aligned}
$$

Equation …. [1]

This is because, we have taken the linear charge density as below:

$$\lambda = \frac{q}{L}$$

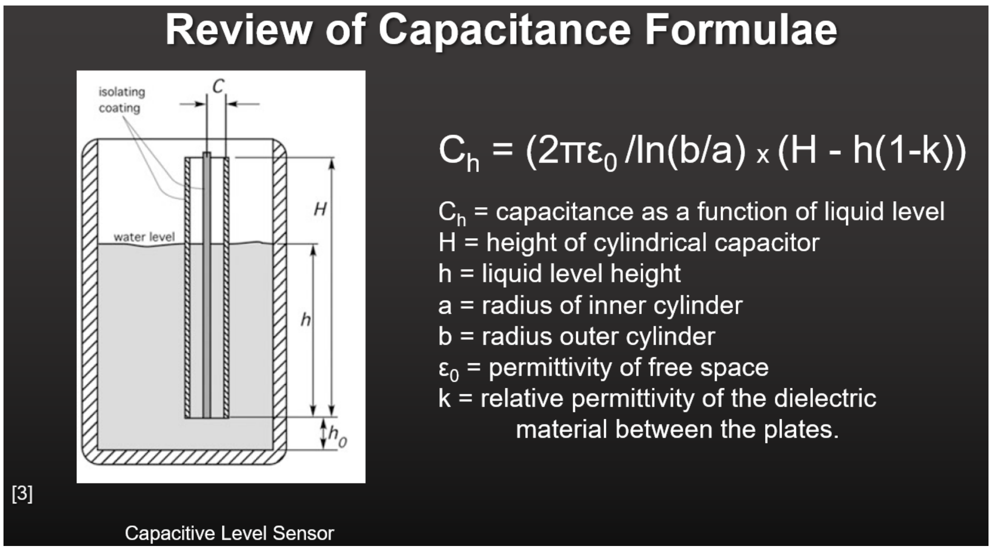
Furthermore, using Equation [1], if we replace **r_a by a and r_b by b** and if the given **capacitive cylinder is not in vacuum**, we will use the permittivity of the medium that it is in and therefore **ε_0 will become ε**, we can derive the required equation.

Thus, our capacitance formula will become as under:

$$\boxed{C = 2\pi\varepsilon L / \ln(b/a)}$$

Courtesy: Reference Links: [1] [2] [3]

G. Derive the formula for the capacitance of the capacitive level sensor, as shown in this slide from one of our slide decks:



Sol.

To derive the capacitive level sensor total capacitance equation for the liquid of height h, we have to use the previously derived equation of capacitance for a cylindrical capacitance.

In this problem, the total capacitance $C_h = C_1 + C_2$

Where,

C_h = Total capacitance of the capacitive level sensor of (total height = H)
C_1 = Capacitance of the capacitor part in free space (height = H – h)
C_2 = Capacitance of the capacitor part lying in the water (height = h)

The equation can be thus derived as shown below:

In this problem, we use the previously derived equation:-

$$C = \frac{2\pi \varepsilon L}{\ln\left(\frac{b}{a}\right)} \quad \text{——} (1)$$

For the capacitive level sensor,

Total capacitance $C_h = C_1 + C_2$ —— (2)

$C_1 \longrightarrow$ part of capacitance in free space

$C_2 \longrightarrow$ part of capacitance in water

$\varepsilon_0 \longrightarrow$ permittivity of free space

$\varepsilon = \varepsilon_0 \cdot k \longrightarrow$ permittivity of water

$\therefore$ Using Eq (1) and Eq (2), we get:-

$$C_h = \frac{2\pi \varepsilon_0 L_1}{\ln\left(\frac{b}{a}\right)} + \frac{2\pi \varepsilon L_2}{\ln\left(\frac{b}{a}\right)}$$

{ Note: For $C_1 \rightarrow$ permittivity is ε_0 and
For $C_2 \rightarrow$ permittivity is of water:- ε)

Here, the heights have been as under:-

$L_1 = H - h$

$L_2 = h$

$$\therefore C_h = \frac{2\pi \varepsilon_0 (H-h)}{\ln\left(\frac{b}{a}\right)} + \frac{2\pi \varepsilon h}{\ln\left(\frac{b}{a}\right)}$$

$$= \frac{2\pi}{\ln\left(\frac{b}{a}\right)} \left[\varepsilon_0 H - \varepsilon_0 h + (\varepsilon_0 \cdot k) h \right]$$

Note:- $\varepsilon = \varepsilon_0 \cdot k$ where $k \rightarrow$ dielectric constant

$$\therefore C_h = \frac{2\pi \varepsilon_0}{\ln\left(\frac{b}{a}\right)} \left[H - h + kh \right]$$

The above equation can thus be reduced to the below given equation:

$$\boxed{C_h = (2\pi\varepsilon_0 / \ln(b/a) \times (H - h(1-k))}$$

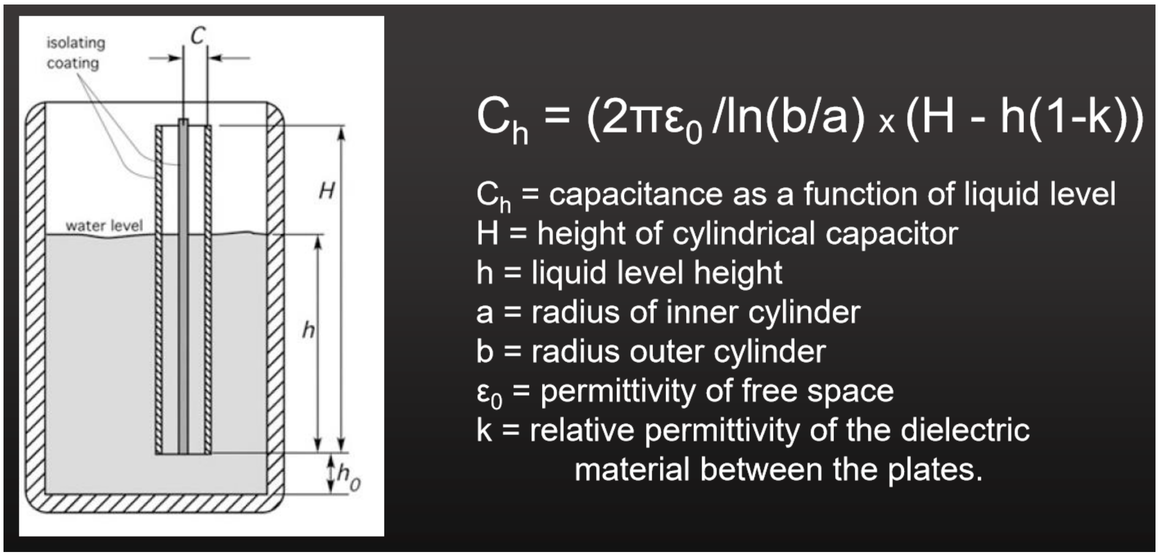
Courtesy: Reference Links: [1] and the Handbook on Modern Sensors

H. What is the capacitance in pF of a capacitive level sensor immersed in pure water with these attributes? (Type in a one decimal number)

Height of cylindrical capacitor, H =	4.3	m
Liquid level height, h =	4.1	m
Radius of inner cylinder, a =	0.8	mm
Radius of outer cylinder, b =	6.4	mm

Sol. $\boxed{\textbf{5.3507 pF}}$

To solve this problem, we can use the below given information provided in the class slide:



Thus,

ε_0 = $8.854187817... \times 10^{-12}$ F·m^{-1} (Reference)
k = 78.7 (at 298 K) (Reference)

Thus, permittivity of water $\varepsilon_W = \varepsilon_0 \times k = 6.968245811 \times 10^{-10}$ F·m^{-1}

Therefore, the capacitance in pF can be calculated as under:

C_h = $[(2 \times 3.14 \times 8.854 \times 10^{-12}) / \ln(6.4/0.8)] \times [4.3 - (4.1 \times (1 - \varepsilon_W))]$
= $[(55.6325 \times 10^{-12}) / \ln(8)] \times [0.2]$
= $[26.7535 \times 10^{-12}] \times 0.2$
= **5.3507 pF**

Courtesy: Reference class slide: C3M1V5

I. Go to Google Patents (www.patents.google.com) and download US patent 6,647,794. Read the patent and answer the following questions:

Q.1 Why is an accurate absolute pressure sensor needed for the gage pressure sensor in this patent?

Sol.

Gage pressure transmitters can be constructed using one differential pressure sensor that couples to both the process pressure and atmospheric pressure. Alternatively, two absolute pressure sensors can be used, with one absolute pressure sensor sensing the liquid pressure and the other absolute pressure sensor sensing the atmospheric pressure. When two absolute pressure sensors are used, a circuit in the transmitter calculates the pressure difference (gage pressure) electronically based on the two sensor outputs.

In gage transmitters that electronically calculate a pressure difference based on two absolute pressure sensor outputs, accuracy and repeatability of the sensors are particularly important to avoid introducing errors in the subtraction process. The barometric pressure range is quite limited, typically 0.9-1.1 atmospheres, and there is a desire to use a relatively low cost absolute sensor for sensing barometric pressure. Low cost absolute pressure sensors, however, often do not have the accuracy and repeatability found in process fluid sensors. These low cost sensors can introduce undesired errors into the electronic subtraction process.

Q.2 In figure 1 what are the functions of elements 110, 122, 121, 116, and 126.

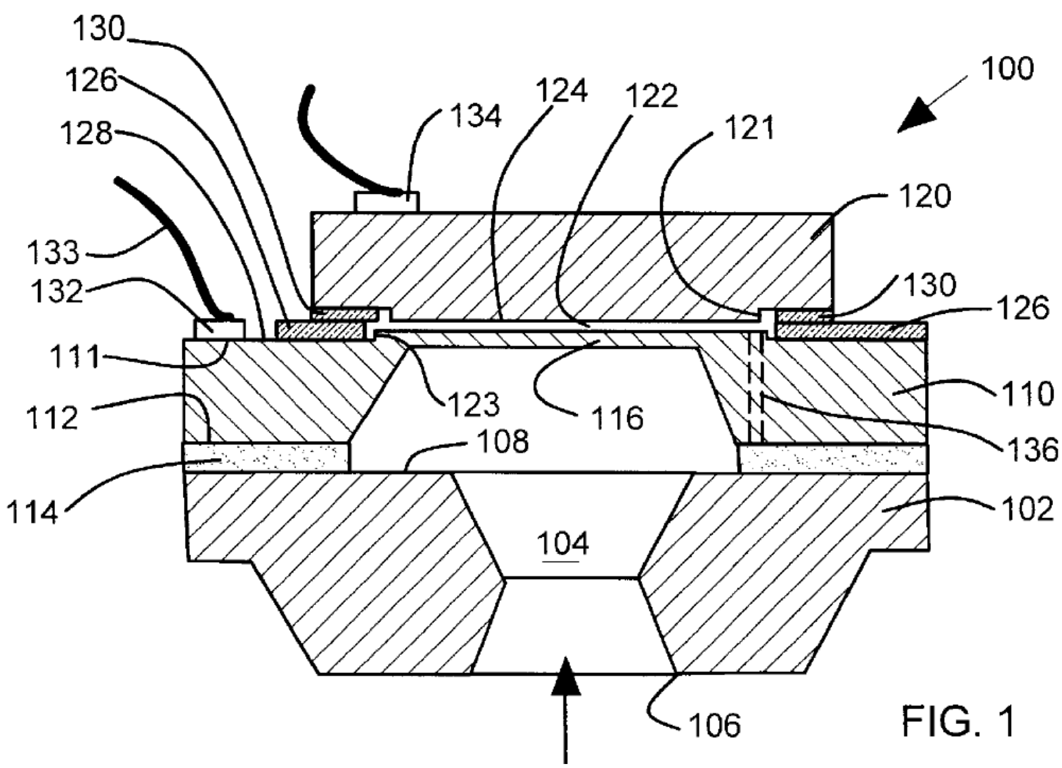


FIG. 1

Sol.

110 – The sensor layer

The sensor layer is bonded by an insulating bond to the mounting face in the base layer. The sensor layer includes a conductive diaphragm aligned with the passageway, forming a pressure cavity that is between the sensor layer and the base layer, the pressure cavity receiving the pressure and **the sensor layer**

receives and senses this pressure with reference to the vacuum cavity in the reference layer.

To summarize, the sensor layer provides the electrical and physical construction to sense the variations in the pressure that is exerted in the pressure cavity with reference to the vacuum cavity.

122 – The vacuum cavity

The pressure sensor includes a reference layer that is mounted on the sensor layer to form a reference vacuum cavity that is aligned with the conductive diaphragm. The reference layer includes a conducting surface facing the conductive diaphragm across the reference vacuum cavity to form a pressure sensing capacitor.

The vacuum cavity provides a spacing between the generally parallel capacitor plates. The spacing between the capacitor plates varies as the diaphragm is deflected by pressure P. Thus, the vacuum cavity, in general, provides a reference pressure level to the sensor layer for sensing the pressure to be measured with respect to the vacuum pressure.

121 – The mesa

The reference layer preferably includes a mesa that protrudes slightly and that faces the conductive diaphragm. **The mesa has a height that is selected to provide the desired spacing between capacitor plates in the vacuum cavity. The height of mesa can be selected to correct for the thickness of bonding layers. In addition to the mesa, or as an alternative to the mesa, a second mesa can be provided on the sensor layer to provide capacitor spacing control.**

To summarize, the mesa is useful for reducing the errors incorporated in pressure sensing due to the thickness of the bonding layers and provides a way to control the spacing between the capacitor plates in the vacuum cavity or the sensor layer.

116 – The conductive diaphragm

The sensor layer includes a **conductive diaphragm that is aligned with the passageway to receive pressure P**. The reference layer is mounted on the sensor layer to form a reference vacuum cavity that is aligned with the conductive diaphragm. The reference layer includes a conducting surface facing the conductive diaphragm across the reference vacuum cavity to form a pressure sensing capacitor.

The conductive diaphragm serves as a first capacitor electrode or plate whereas the conducting surface serves as a second capacitor electrode or plate.

To summarize, the conducting diaphragm serves as a capacitor electrode to sense the pressure that is to be measured with respect to the reference vacuum cavity.

126 – The first insulating layer

The sensor layer includes a first insulating layer surrounding the conducting diaphragm on a second face. The reference layer includes a second insulating layer bonded to the first insulating layer.

In one preferred arrangement, the reference layer and the sensor layer comprise silicon and the first and second insulating layers, comprise grown silicon dioxide and are fusion bonded together.

<u>The insulating layers, insulate the conductive portions of the sensor layer from the reference layer so that the pressure sensing capacitor is not shorted out</u>.

<u>Q.3</u> Figure 2 describes a method of electrical connections, which should be familiar to you. We discussed it during the lectures on capacitive pressure sensors. What is it, and how does it work in this patent?

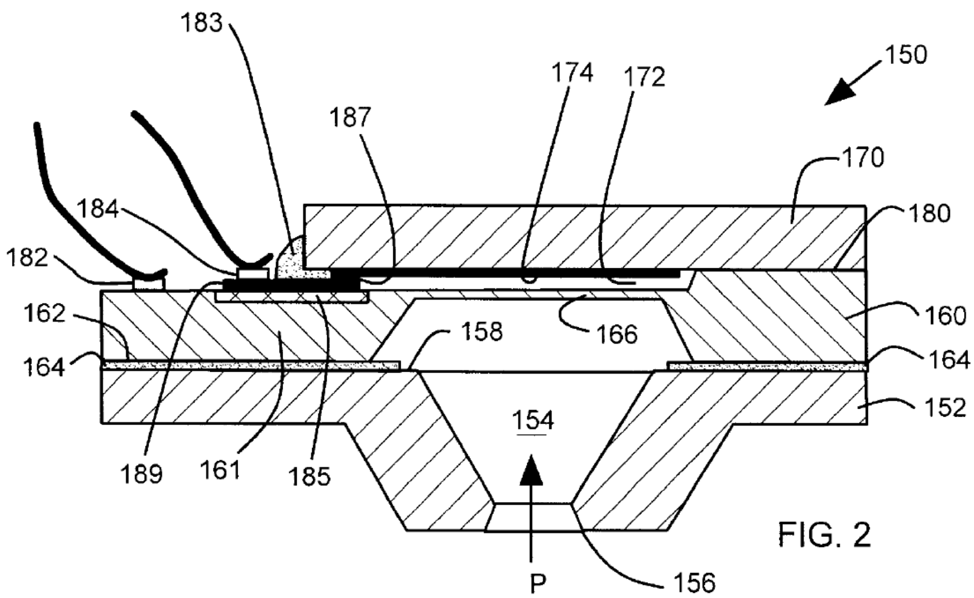


FIG. 2

Sol.

FIG. 2 illustrates a pressure sensor **150** that is similar to the pressure sensor **100** shown in FIG. 1, however, the pressure sensor **150** includes a reference layer **170** that is an insulating glass anodically bonded to a sensor layer **160** by way of an anodic bond **180**.

The **<u>base layer</u>** **152** surrounds a passageway **154** between an inlet **156** that receives a pressure P and a mounting face **158** on the base layer **152**.

The **sensor layer 160** has a first face **162** that is bonded by an insulating bond **164** to the mounting face **158**. The sensor layer **160** includes a conductive diaphragm **166** aligned with the passageway **154**. The insulating bond **164** preferably comprises a layer of glass frit.

The **reference layer 170** is mounted on the sensor layer **160** to form a reference vacuum cavity **172** that is aligned with the conductive diaphragm **166**. The reference layer **170** includes a conducting surface **174** facing the conductive diaphragm **166** across the reference vacuum cavity **172** to form a pressure sensing capacitor. The bulk of the reference layer **170** preferably comprises pyrex glass, and the conducting surface **174** preferably comprises a deposition of nichrome. Reference layer **170** is anodically bonded to sensor layer **160** using the well known anodic bonding technique for bonding pyrex to silicon.

After the anodic bond **180** is complete, then the sensor is heated in a vacuum to seal the reference vacuum cavity **172** with a small quantity of glass frit **183**. Glass frit **183** fills a small channel that is cut through the reference layer to allow an **electrical feedthrough to a first electrical bonding pad 184** from the conducting surface **174**.

The **first electrical bonding pad 184** is deposited on electrical conductor layer **189** that connects to the conducting surface **174** which forms a second plate or electrode of the pressure sensing capacitor. The first electrical bonding pad **184** and electrical conductor layer **189** are disposed on an isolation channel **185** on the sensor layer **160**. The electrical conductor layer **189** is in electrical contact with the conducting surface **174** by way of a metal bridge **187**.

A **second electrical bonding pad 182** is disposed on the sensor layer **160** and thus connects to the conducting diaphragm **166** which forms one plate or electrode of the pressure sensing capacitor. The second electrical bonding pad **182** is in electrical contact with the sensor layer **160**.

Q.4 What error condition is represented in figure 4?

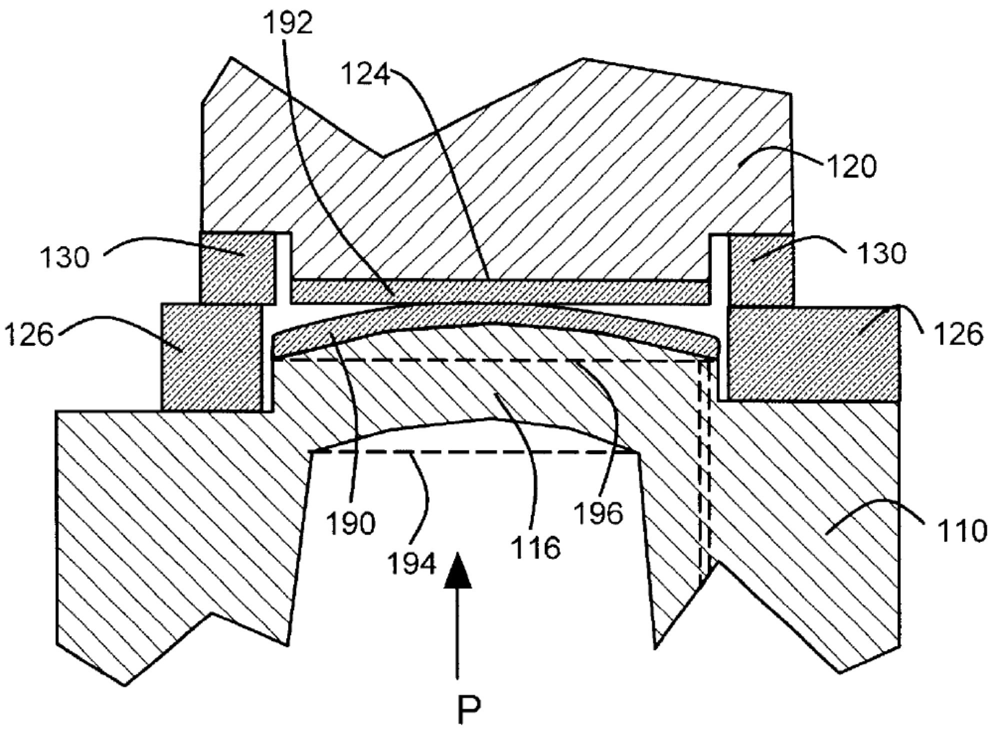


FIG. 4

Sol. **Overpressure Condition**

FIG 4 is not drawn to scale, but have an expanded vertical scale to better illustrate certain features. Also, FIG 4 is an illustration of the conductive diaphragms during overpressure conditions.

An overpressure condition is a condition where the pressure P exceeds the nominal measurement range of the pressure sensor. The oxide layers on the conducting surfaces provide support to the conducting diaphragm during overpressure conditions so that it does not break and the oxide layers prevent a short-circuit during the overpressure condition.

<u>Q.5</u> What is illustrated in figures 6 through 9?

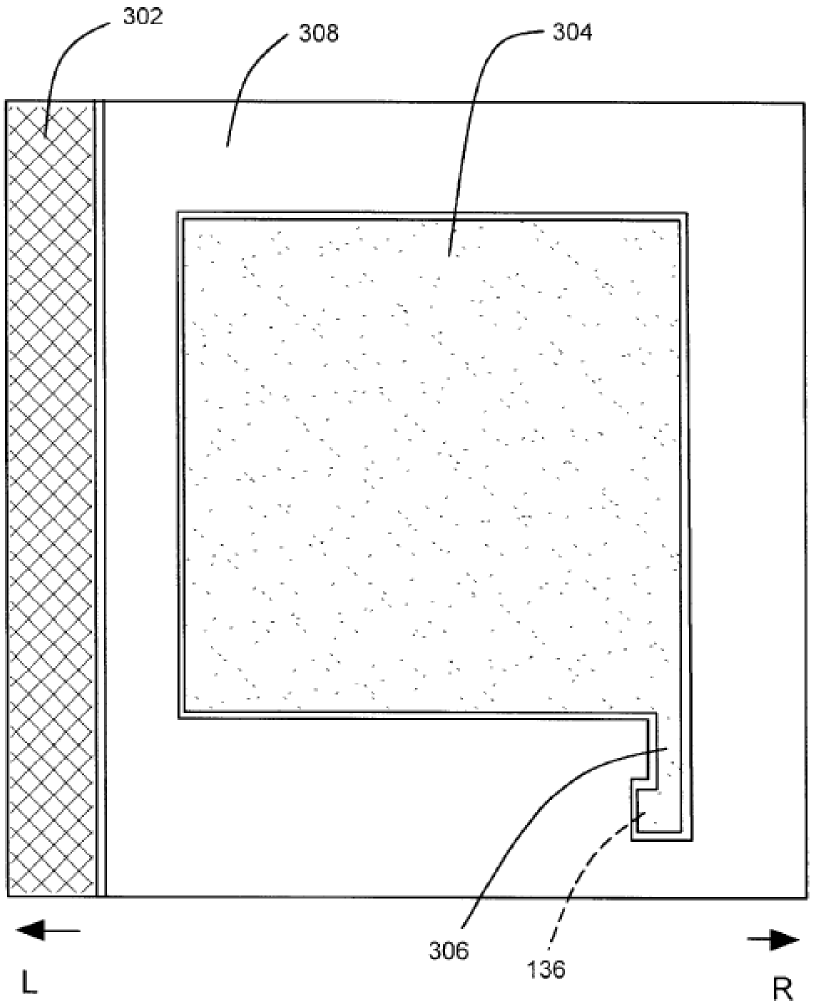


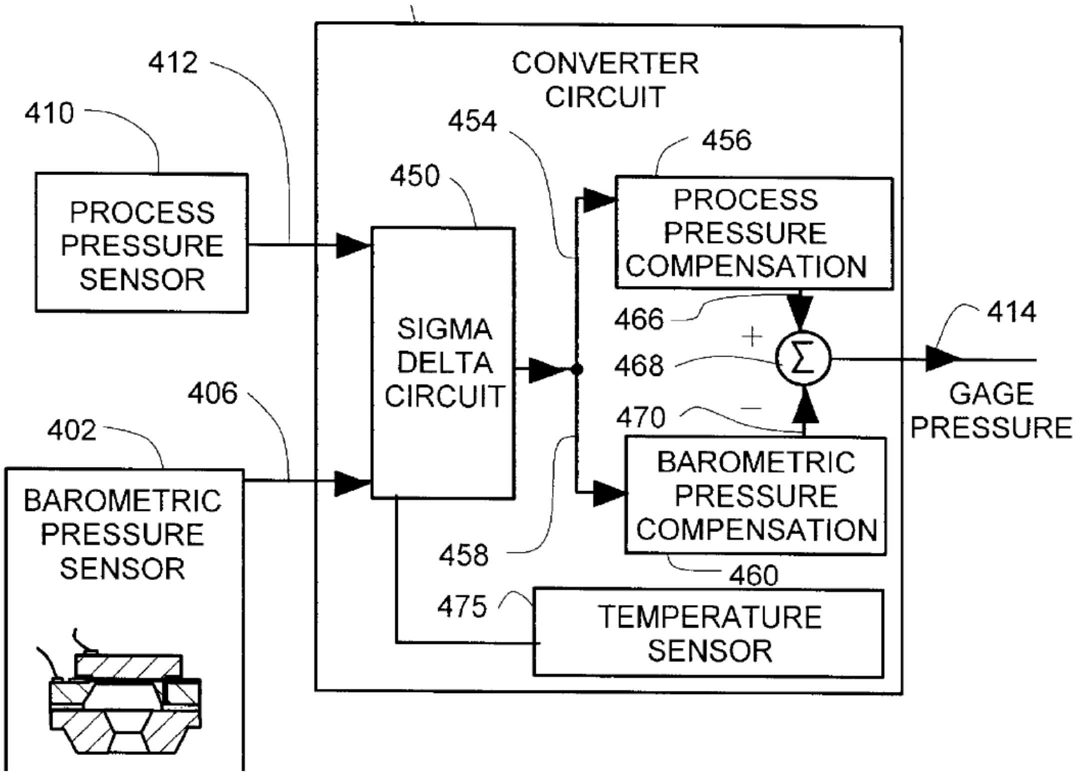
FIG. 6

Sol.

In figures 6 through 9, the following things are illustrated:

- A mask for a top surface of the sensor layer
- A mask for a bottom surface of the sensor layer
- A mask for a top surface of the reference layer
- A mask for a bottom surface of the reference layer

Q.6 What does the converter circuit do in Figure 11?



Sol.

The converter circuit on printed circuit board 408 generates an electrical output that represents gage pressure on leads 414.

The converter circuit 452 compensates a reading from the process pressure sensor and compensates a reading from the barometric pressure sensor and calculates the difference by subtracting the compensated barometric pressure reading from the process pressure reading.

J. A pressure transmitter has the following specifications:

Lower Range Limit, LRL =	1	MPa
Upper Range Limit, URL =	20	MPa
Reference Accuracy, Acc =	0.10%	% of span
Span error, E_S =	0.15%	% of span
Zero Error, E_Z =	0.10%	% of span
Thermal span error, E_{TS} =	0.05%	% of span
Thermal zero error, E_{TZ} =	0.12%	% of span

What is the total error budget in MPa? (Type in a three-place decimal.)

Sol. $\boxed{\text{(+/-) 0.04630 MPa}}$

Based on the referenced document, first we need to calculate the value of span:

Thus, span = URL – LRL = 20 MPa – 1 MPa = 19 MPa

Now, based on the value of the span, we can calculate the total accuracy by taking the RMS value of the individual errors in percentage of span.

Therefore,

Total accuracy

$= (+/-)\ SQRT(\ Acc^2 + E_S^2 + E_Z^2 + E_{TS}^2 + E_{TZ}^2)$
$= (+/-)\ SQRT\ [(19MPa)^2 \times (0.001^2 + 0.0015^2 + 0.001^2 + 0.0005^2 + 0.0012^2)]$
$= (+/-)\ SQRT\ [(19MPa)^2 \times (5.94 \times 10^{-6})]$
$= (+/-)\ (19\ MPa) \times 2.4372 \times 10^{-3}$
= **(+/-) 0.04630 MPa**

Courtesy: Reference Links: [1] [2]