ECEN 5053-003 Homework Assignment

Course Name: Embedding Sensors and Actuators
Corresponding Module: C3M4
Week Number: 12
Module Name: Motion, Distance, and Humidity Sensors
Student Name: **Rushi James Macwan**

Note: Correct answer is in Blue Font

Homework is worth 100 points.

Part 1: Each question is worth 9 points.

A. Answer the following questions about PIR Motion detectors.

A.1 What are pyroelectric materials?

Sol.

Pyro-electricity is the ability of certain materials to generate an electrical potential when they are heated or cooled.

As a result of this change in temperature, positive and negative charges move to opposite ends through migration (i.e. the material becomes polarised) and hence, an electrical potential is established.

The materials exhibiting such kind of a behaviour are called pyro electric materials.

Courtesy: Reference Links: [1] [2]

A.2 What problem do you encounter in designing a motion detector because all pyroelectric materials are also piezoelectric? How do you resolve this problem?

Sol.

Since motion sensors use pyroelectric materials and since all pyroelectric materials are also piezoelectric materials, with a change in the temperature the pyroelectric materials will generate an electric voltage and simultaneously because it is also a piezoelectric material, if any vibration or mechanical stress is provided to the crystal (piezoelectric material), it will generate an extra electric voltage which can be act as an error or noise signal while reading the electric voltage generated due to its pyroelectric nature in sensing motion.

To resolve this problem, the motion sensor is permanently fixed into a place and is firmly fastened to prevent vibration. It uses Fresnel lens that helps it to condense the infrared light signals and which provides a larger range of IR to the sensor without any need to move the sensor. Thus, the sensor captures more IR radiation and it also focuses the IR radiation to a small point. This focal point moves across the sensor as the IR source moves and exposes one element at a time. A Fresnel lens can extend detection range to about 100 feet. This helps resolve the problem.

Courtesy: Reference Link: [1]

A.3 What is the difference between primary and secondary pyroelectricity?

Sol.

The pyroelectric effect observed at constant external strain is regarded as the primary pyroelectricity.

The pyroelectric effect associated with the process of thermal expansion is regarded as the secondary pyroelectricity. The temperature changes shortens or elongates individual dipoles. This affects randomness of dipole orientations due to thermal agitation.

The secondary pyroelectricity is generally much smaller than the primary pyroelectricity.

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

A.4 What happens to the pyroelectric effect in a material at the Curie point?

Sol.

All ferroelectric materials are pyroelectric and all ferroelectric materials have a transition temperature which is Curie point (Tc). At a temperature $T > T_c$ the crystal does not exhibit ferroelectricity, while for $T < T_c$ it is ferroelectric.

On warming towards the Curie point, above which the spontaneous polarisation of a pyroelectric disappears, the pyroelectric coefficient typically increases as the temperature dependence of the polarization becomes stronger. On decreasing the temperature through the Curie point, a ferroelectric crystal undergoes a phase transition from a non-ferroelectric phase to a ferroelectric phase.

Near the Curie point or transition temperatures, thermodynamic properties including dielectric, elastic, optical, and thermal constants show an anomalous behavior. This is due to a distortion in the crystal as the phase structure changes.

Courtesy: Reference Link: [1] [2]

A.5 What is the difference between the Pyroelectric charge coefficient P_Q and the pyroelectric voltage coefficient P_V?

Sol.

$P_Q = \frac{dP_S}{dT}$ Is the pyroelectric charge coefficient, and P_s is the "spontaneous polarisation"

The generated charge is $\Delta Q = P_Q A \Delta T$

$P_v = \frac{dE}{dT}$ is the pyroelectric voltage coefficient and E is the electric Field.

The generated voltage is $\Delta QV = P_v h \Delta T$ (h is the thickness)

The relation between charge and voltage coefficients follows directly from Q = CV $\frac{P_Q}{P_V} = \frac{dP_S}{dE} = \varepsilon_r \varepsilon_0$

Thus, the pyroelectric charge coefficient is the change in the spontaneous polarization with respect to the change in the temperature which can be used to find the change in the charge generated due to the pyroelectric effect.

On the other hand, the pyroelectric voltage coefficient is the change in the electric field strength with respect to the change in the temperature which can be used to find the change in the voltage generated due to the pyroelectric effect.

To conclude, pyroelectric charge coefficient is directly proportional to the change in the charge generated and the pyroelectric voltage coefficient is directly proportional to the change in the voltage generated. These coefficients decide the response in terms of change in charge and voltage with respect to the varying temperature.

Courtesy: Reference Link: [1]

A.6 Why is PbTiO3 a popular ceramic to use in practical applications for pyroelectric crystals?

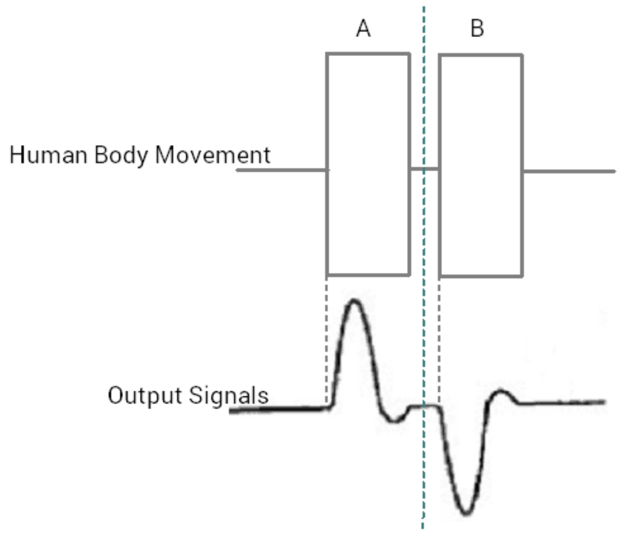
Sol.

PbTiO3 is a popular ceramic used in practical applications because it possesses a very high pyroelectric coefficient over a wide operating temperature range. This means that it is more responsive to the changes in the temperature and these responses are tangible. Thus, PbTiO3 suits much better for use over a wide temperature range where more accuracy is required. Also, the easy-availability of this ceramic material makes it even more desirable in the practical applications as pyroelectric crystals.

A.7 How does a differential PIR detector circuit work?

Sol.

The PIR sensor itself has two slots in it, each slot is made of a special material that is sensitive to IR. The lens used here is not really doing much and so we see that the two slots can 'see' out past some distance (basically the sensitivity of the sensor). When the sensor is idle, both slots detect the same amount of IR, the ambient amount radiated from the room or walls or outdoors. When a warm body like a human or animal passes by, it first intercepts one half of the PIR sensor, which causes a *positive differential* change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. These change pulses are what is detected.



This is the differential changes between the two slots drive the working mechanism of a differential PIR.

Courtesy: Reference Links: [1] [2]

A.8 Why must the value of the resistor R be very high, on the order of 10 giga-ohms?

Sol.

A large value of the resistor R in the order of 10 G-ohms is required and this is because the pyroelectric sensor provides an output current in the order of a few pico-amperes. Thus, in order to accurately sense the pyroelectric sensor output and to amplify the voltage read by the sense resistor, a very high R value is required which in turn provides appreciable output from the pyroelectric sensor.

A.9 What is the purpose of the fresnel lens in a PIR motion detector?

Sol.

The PIR sensor needs to have a large detection area and the Fresnel lens helps it to achieve this goal. The Fresnel lens condenses light which provides a larger range of IR to the sensor. Thus, the lens captures more IR radiation and it also focuses the IR radiation to a small point. This focal point moves across the sensor as the IR source moves and exposes one element at a time. A Fresnel lens can extend detection range to about 100 feet.

Courtesy: Reference Link: [1] [2]

A.10 Why does a PIR motion detector need temperature compensation for changes in ambient temperature?

Sol.

Because PIR's measure relative temperature (infrared energy) between the background and a subject, and since the body temperature of a subject will remain relatively constant, the room temperature may vary greatly; motion sensors that do not have temperature compensation will be more sensitive when the room is cooler, and less sensitive when the room is warmer. Therefore, temperature Compensation stabilizes the detector's sensitivity and it also enhances and adjusts the output.

Courtesy: Reference Link: [1] [2]

A.11 What is the name of the cat who gets caught by the motion detector in slide 2 of the slide deck C3M4V2.pdf and again in slide 5 of the slide deck C3M4V3.pdf?

Sol. OLIVER

B. A PIR motion sensor has the following attributes:

Sensor Capacitance, C_e =	500	µF
Sensor Area, A =	1.5	mm^2
Pyroelectric charge coefficient, P_Q =	12	Coulomb / m^2 - °C
Change in Temperature ΔT =	1.5	°C

What is the voltage across the sensor electrodes in volts? (Type in a three-decimal number)

Sol. $\boxed{\textbf{54 mV}}$

As given in the class slides, the following equations can be used to solve this problem:

$$\Delta Q = P_Q A \Delta T$$

$$C_e = \frac{\Delta Q}{\Delta V}$$

To find the change in the voltage across the sensor electrodes in volts (ΔV), we will be required calculate the change in the charge (ΔQ).

Using the equation ΔQ and putting all the values provided in the table,

$\Delta Q = 12 \times 1.5 \times 10^{-6} \times 1.5 = 27\mu C$

Now, putting this value in the equation for the sensor capacitance C_e, we get,

$\Delta V = \Delta Q / C_e = 27\mu / 500\mu = \boxed{\textbf{54 mV}}$

Thus, the voltage across the sensor electrodes is 54 mV.

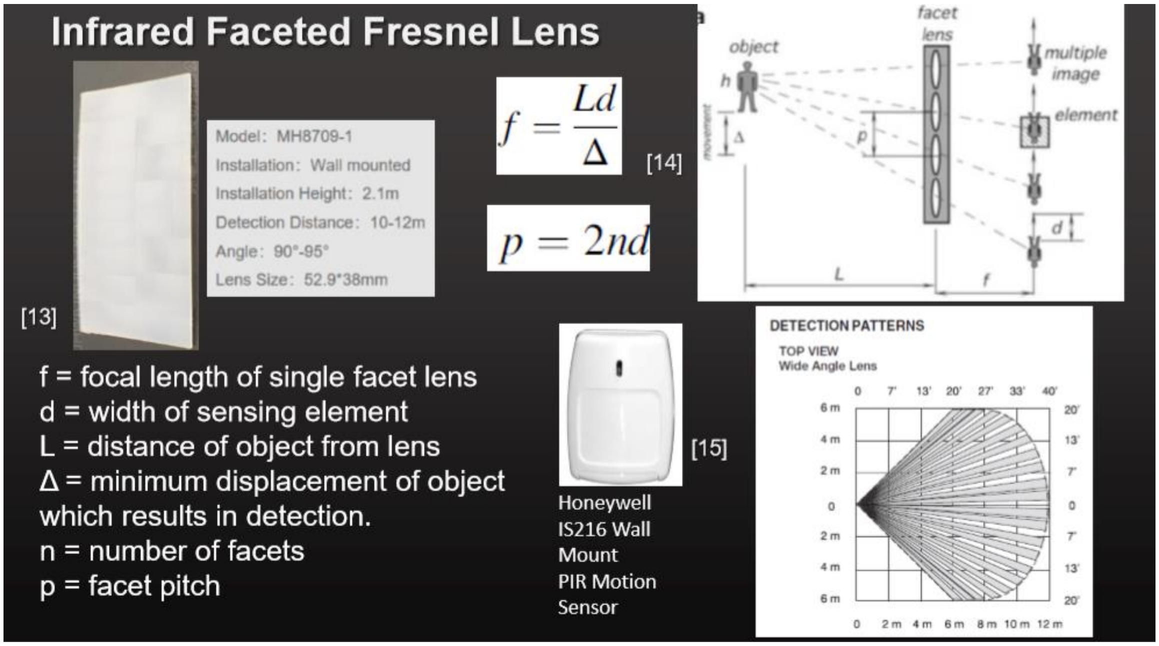
C. An infrared faceted lens is used in a PIR motion sensor designed to protect priceless art in a large museum room. It has the following attributes:

Focal length of single facet lens, f =	20.0	mm
Distance of object from lens, L =	11	m
Minimum displacement of object, Δ =	200	mm
Number of facets, n =	8	

What is the facet pitch of the lens in millimeters? (Type in a two-decimal number)

Sol. $\boxed{\textbf{5.8181 mm}}$

Using the information provided in the below given class slide, the facet pitch of the lens can be calculated:



Here, first of all, we will calculate the width of the sensing element (d) using the equation as shown below:

d = (f x Δ) / L = (20 mm x 200 mm) / 11 m = 0.363636 mm

Now, the facet pitch (p) of the lens can be calculated using the below given equation:

p = 2 x n x d = 2 x 8 x 0.363636 = **5.8181 mm**

D. A member of the Mission Impossible team of secret agents crawls into the fortified chamber of enemy headquarters. This chamber is protected by a PIR motion detector mounted on the 8-foot high ceiling above the center of the circular room. The agent starts at the outer most diameter, headed on a radial line for a safe located in the exact center of the room. He wants to steal the contents of the safe, and take this valuable information back to headquarters.

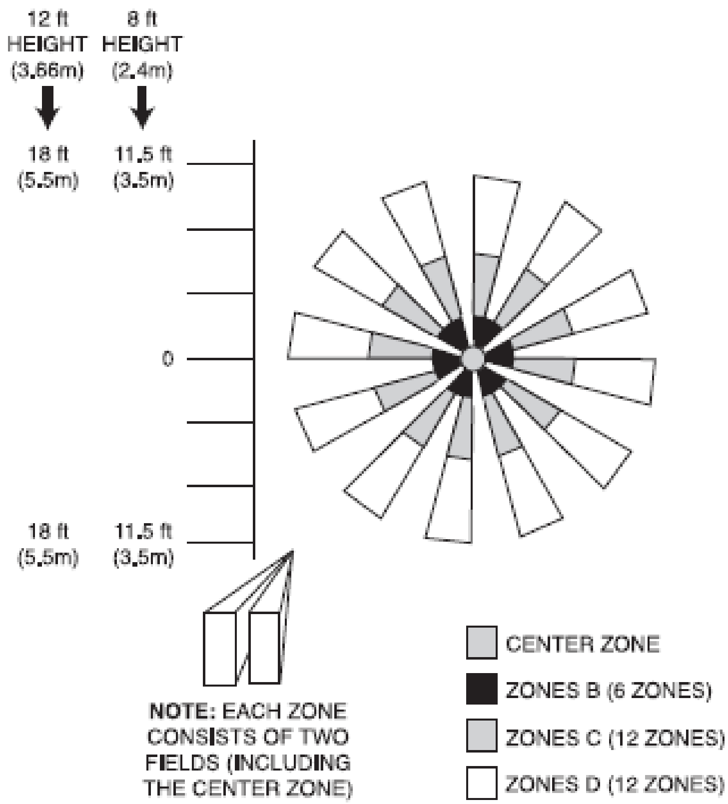
The detector has predetermined protection zones defined by these screen shots below. Miraculously (this is a movie, of course), the agent starts his crawl exactly centered between two of the zone D locations.

Suppose this agent's body is 1.5 feet wide at his widest point, and he always keeps his arms and legs inside this width.

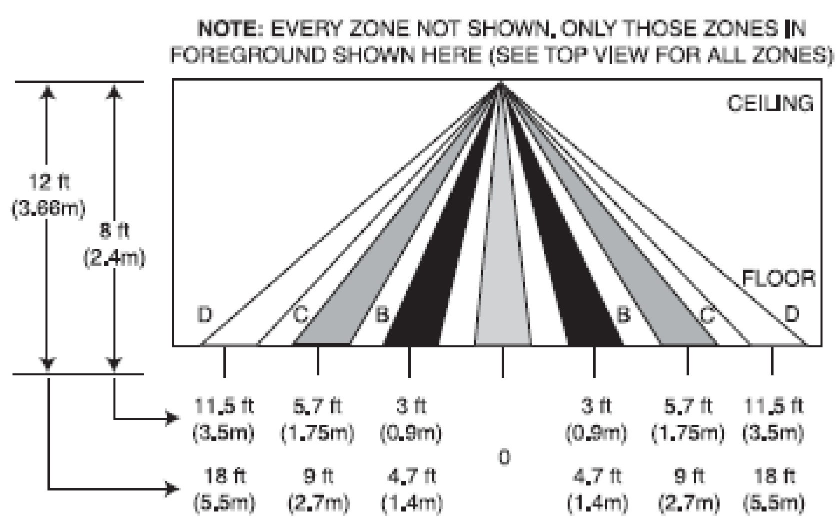
At what point will the motion detector find him, setting off the alarm and a wild ensuing chase scene in the movie?

(Denote a point on the top view to define your answer, and explain why you think this position is correct.)

Top View

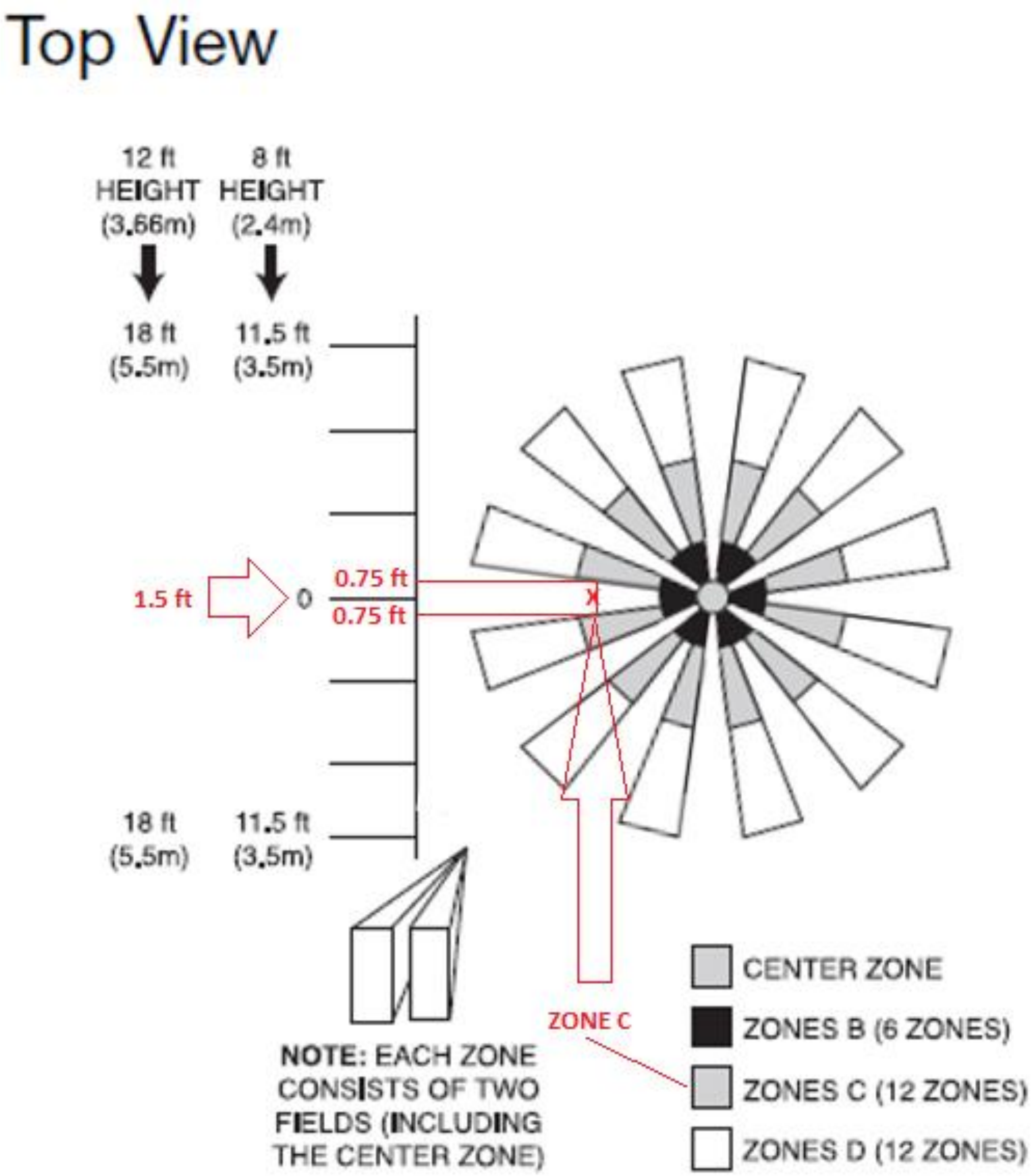


Side View



Sol.

Based on the information provided in the problem, the width of the person is given as 1.5 ft and the top view can be therefore correlated with the room dimensions as shown below:



As shown above, assuming that the person enters the room such that the zones fall on his two sides. In this case, it is assumed that the person moves from the 0 position on the scale towards the room center. Now, since the width of the person is 1.5 ft, on both the sides of the scale, the person will required 0.75 ft of space if he continues to move in the horizontal direction.

This implies that using the ray trace method, the distance between the two sectors of the PIR is getting narrower as the person moves towards the center. However, once the person moves beyond a tiny fraction of the Zone C of the sectors on his left and right, the distance between the sectors will reduce to a total of 1.5 ft or in other words only 0.75 ft on both sides of the person.

Thus, it can be concluded that the person will be caught and the alarm will start ringing once the person crosses between the **Zone C** area and moves a little towards the center such that the distance between the sectors on his both sides is no more than 0.75 ft.

E. Answer the following questions about ultrasonic position detectors.

E.1 Why does an ultrasonic position detector have a minimum range?

Sol.

An ultrasonic distance measurement system typically has a minimum range. Objects within this range cannot be reliably detected. A minimum range for a system can vary between 0 m and 0.3 m.

The minimum range is an undesirable aspect of the system caused by the use of transceiver transducers. A transceiver transducer transmits the sound and receives it. Therefore, there is a period after transmitting the sound during which the system must wait for the transducer to stop “ringing.” If the system immediately started waiting for the return signal, it would always measure a distance of zero, because it would immediately detect the ringing signal on the transducer. Therefore, the system must wait until the ringing on the transducer has sufficiently diminished for normal signal detection to begin. **The waiting time is directly proportional to the minimum detection range distance.**

Courtesy: Reference Links: [1]

E.2 What steps would you take to increase the maximum range of an ultrasonic position detector?

Sol.

The maximum detection range mainly depends on the following factors:

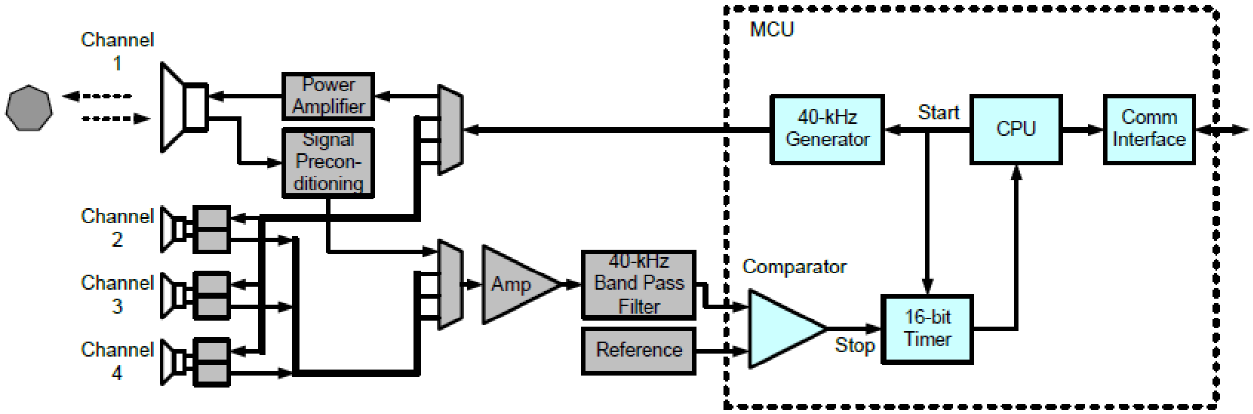
- The amount of power used to drive the transducer.
- The signal gain and signal-to-noise ratio (SNR) of the circuit used to measure the return signal.
- The properties of the transducer itself.

In general, if you need a large maximum range, then maximize the signal-driving power, the signal gain, and the SNR, and choose a transducer with lower ultrasonic resonant frequency (30 kHz to 50 kHz), good receiver sensitivity (>-70 dB), higher transmitting sound pressure level (>120 dB), maximum input voltage range (>120 Vpp).

Courtesy: Reference Links: [1]

E.3 Why is the power amplifier needed in this circuit for an ultrasonic parking assist system shown in the block diagram below.

Figure 3. Typical Ultrasonic Parking Assistance System



Sol.

The power amplifier converts the logic-level square wave generated by the MCU into a signal with much greater power. This conversion is necessary because the general purpose input/output (GPIO) pins of typical MCUs cannot drive high-voltage or high-current signals. Therefore, a power amplifier circuit is needed to deliver maximum power to the transducer. Typically, the power amplifier circuit uses the battery voltage of the vehicle and voltage boosting circuit to amplify the power driven to the load.

Courtesy: Reference Links: [1]

E.4 Why does an ultrasonic position detector measure the ambient air temperature and use it to perform temperature compensation?

Sol.

The speed of the sound depends on several factors, including temperature, density, and air composition. The influence of temperature on the speed of sound can easily be included in the calculations if air temperature was measured. It would also be possible to measure other environmental properties (such as humidity) that would also affect the sound speed to give even more compensation to improve accuracy. However, the added system cost of measuring environmental properties to do compensation often is not worth the improvements in accuracy.

Courtesy: Reference Links: [1]

E.5 What compensation does an ultrasonic position detector perform during echo processing?

Sol.

The ultrasonic position detector will wait for a certain amount of time period after the ringing signal is transmitted and before echo detection begins. This is the compensation performed for the echo detection with respect to the transducer response time.

Moreover, the detector will also compensate for the timeout error by checking for it’s appropriate conditions.

Courtesy: Reference Links: [1]

E.6 Why is a piezoelectric sensor used to both transmit and receive the ultrasonic waves?

Sol.

A piezoelectric sensor is used to both transmit and receive the ultrasonic waves because the piezoelectric crystal used for the sensor works as a transducer. When the sensor is required to transmit an ultrasonic sound wave, it provides some electrical signal to the crystal and in turn it vibrates and generates the ultrasonic sound waves that are to be transmitted. In response, the echo signal which the object reflects again falls onto the crystal which vibrates the crystal which in turn produces an electrical signal. Thus, the piezoelectric sensor is used to both transmit and receive the ultrasonic waves.

Courtesy: Reference Links: [1]

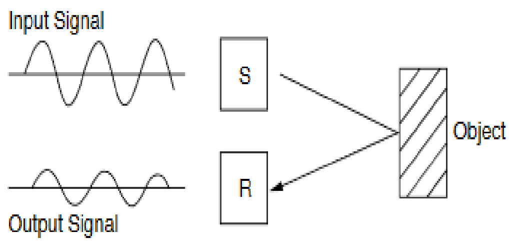
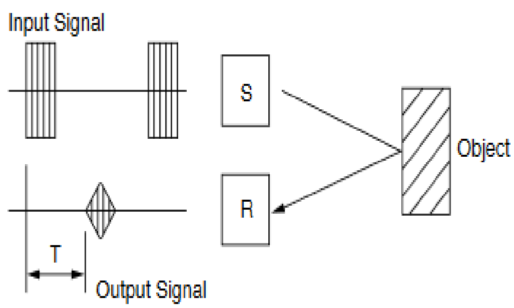
E.7 What is the difference between pulsed mode and continuous mode operation? What applications exemplify these modes of operation?

Sol.

In the pulsed mode operation, the ultrasonic position detector will send input signal in form of pulses to the transducer. In the continuous mode operation, the ultrasonic position detector will send a continuous input signal instead of a pulsed signal to the transducer.

Based on the same, the output signal for the two different modes will be different as can be seen below.

As a result of these characteristics, the following can be observed:

Function Method	Performance Principle (S: transmitter, R: receiver)	Applications
Detection of Signal level of continuous wave		Counting instruments Access switches Parking meters
Measurement of pulse reflection time		Automatic doors Level gauges Automatic change-overs of traffic signals Back sonars of automobiles

Courtesy: Reference Links: [1]

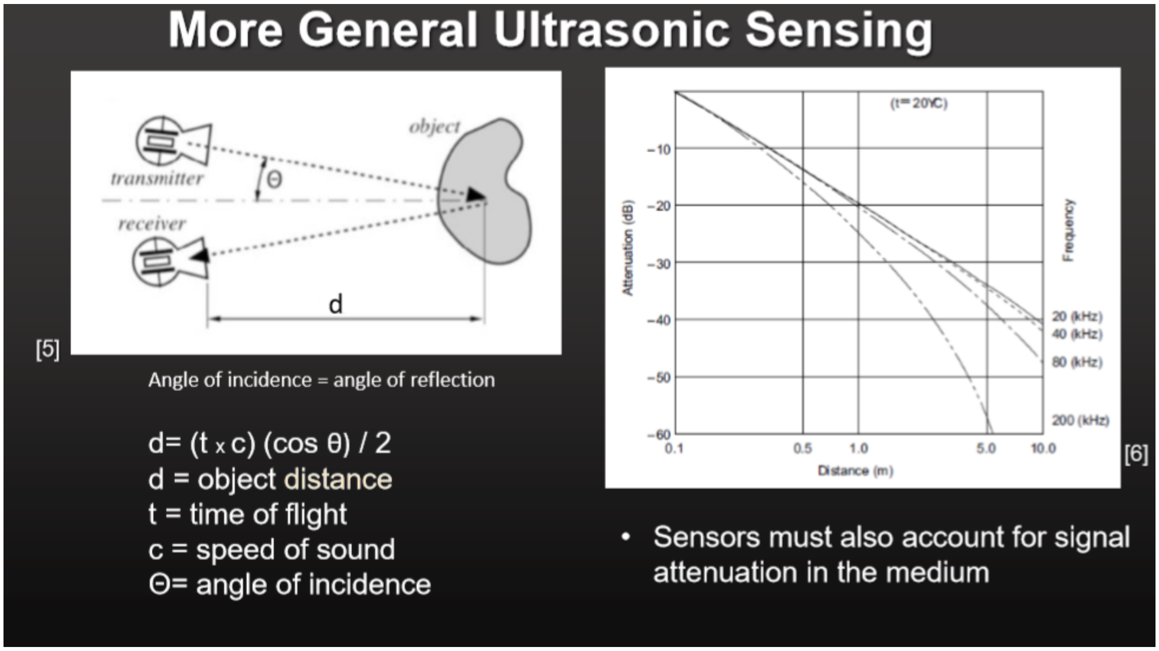
F. An ultrasonic transducer and receiver are located off axis from a direct line to the target. Other aspects of the setup and object detection are shown below:

Angle of transmitter and receiver from horizontal, Θ =	15.0	degrees
Time of flight, t =	0.04	seconds
Air temperature, T =	35	degrees C

What is the perpendicular object distance? (Type in a one-decimal number)

Sol. $\boxed{6.798\ m}$

Based on the information provided in the class slide as shown below, we can calculate the perpendicular object distance.



Here, to calculate the perpendicular object distance, first we need to calculate the horizontal object distance using the below equation:

$d = (t \times c)(\cos \theta) / 2$

Here, at an air temperature of 35°C, the speed of sound would be an average of that at 30°C and 40°C. Thus, the speed of sound will be:
$c = (349.1 + 354.7) / 2 = 351.9$ m/s

Thus,

$d = 0.04 \times 351.9 \times \cos(15°) / 2 = \boxed{\mathbf{6.798\ m}}$

G. Answer the following questions about microwave detectors.

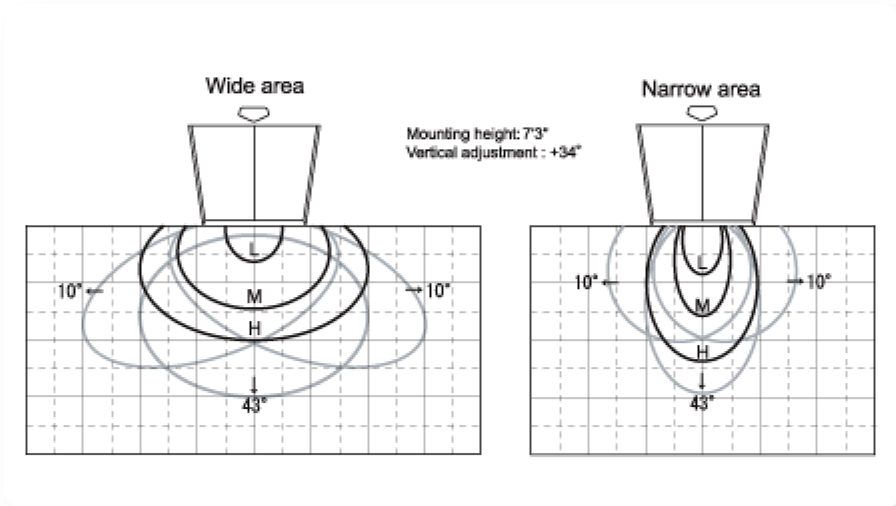
G.1 Why can't you use a microwave detector to sense a close-up object?

Sol.

The microwave detector cannot be used to sense a close-up object because the microwave signal pattern is such that it covers a very narrow area in the close-up area and this field area gets wider as the distance from the center increases.

Thus, the microwave detector should be used for detecting an object at a valid distance.

Also, since the microwave detector is an active motion sensor, once it sends the microwave signals, it will wait for some delay time after which time it will try to sense the echo signal. **Now, since the delay time is directly proportional to the minimum sensing distance and a finite delay time is necessary to sense a motion, there will be a finite minimum sensing distance. If the object is placed closer than this distance then the microwave detector will not be able to detect the object.**



Courtesy: Reference Link: [1] [2]

G.2 In what applications are Gunn oscillators used?

Sol.

Gunn Oscillators are used to generate microwave frequencies ranging from 10 GHz to few THz, as decided by the dimensions of the resonant cavity. In other words, Gunn oscillators to generate frequencies ranging from 100mW 5GHz to 1W 35GHz outputs. These Gunn oscillators are used for radio communications, military and commercial radar sources.

Apart from this, Gunn diode oscillators are extensively used as radio transmitters and receivers, velocity-detecting sensors, parametric amplifiers, radar sources, traffic monitoring sensors, motion detectors, remote vibration detectors, rotational speed tachometers, moisture content monitors, microwave transceivers (Gunnplexers) and in the case of automatic door openers, burglar alarms, police radars, wireless LANs, collision avoidance systems, anti-lock brakes, pedestrian safety systems, etc.

Courtesy: Reference Link: [1] [2]

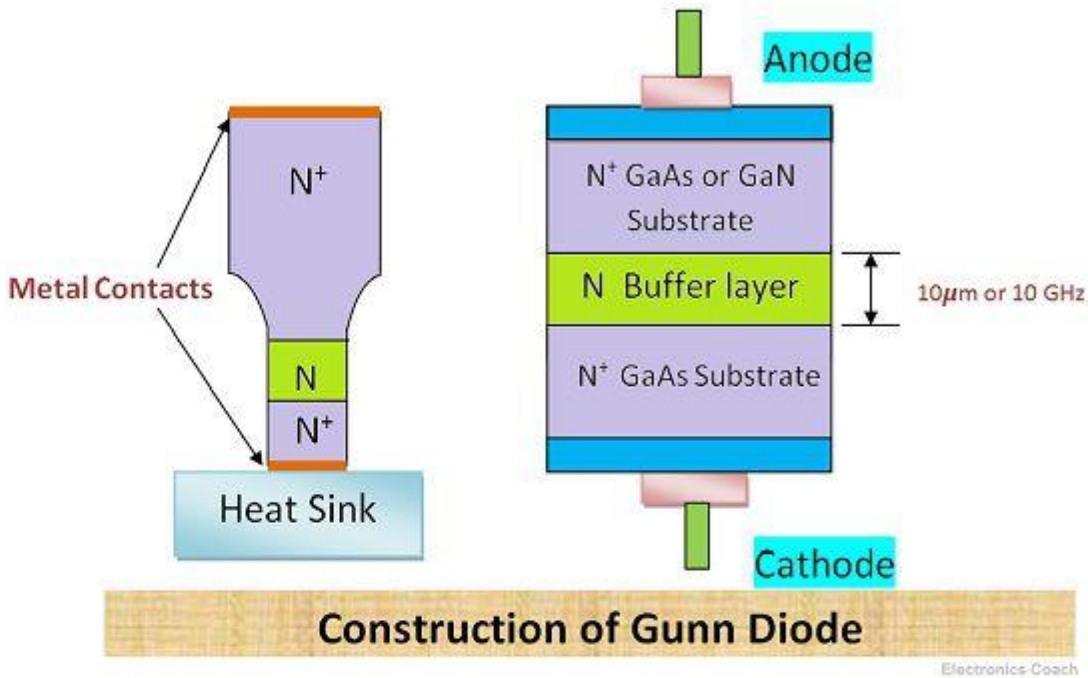
G.3 How is the semiconductor structure of a Gunn diode different from that of a typical semiconductor device?

Sol.

Gunn diode is composed of only N-type semiconductor because N-type semiconductor has electrons as majority carriers. And transferred electronic devices use such materials which have electrons as majority charge carrier. For such devices, the P-type semiconductor is of no use because it consists of holes as majority carriers. Therefore, Gunn diode is made up of only N-type semiconductor, not P-type.

Structure of Gunn Diode:

It is made up of three layers of N-type semiconductor. The semiconductors used in Gunn diodes are Gallium Arsenide (GaAs), Gallium Nitride (GaN), Cadmium Telluride (CdTe), Cadmium Sulphide (CdS), Indium Phosphide (InP), Indium Arsenide (InAs), Indium Antimonide (InSb) and Zinc Selenide (ZnSe).



Among these three layers the **top** most and the **bottom** most are **heavily doped** while the **middle layer** is **lightly doped** in comparison to the extreme layers. The middle layer is an epitaxial layer grown on the N-type substrate and the top most layer is formed by ion implantation technique.

The metallic contacts are provided on extreme layers to facilitate biasing. The heat sink is there so that the diode can withstand excessive heat and can be prevented from damage.

Courtesy: Reference Link: [1]

G.4 How does the structure of the Gunn Diode guarantee that only electrons will be charge carriers?

Sol.

Gunn diode is composed of only N-type semiconductor because N-type semiconductor has electrons as majority carriers. And transferred electronic devices use such materials which have electrons as majority charge carrier. For such devices, the P-type semiconductor is of no use because it consists of holes as majority carriers. Therefore, Gunn diode is made up of only N-type semiconductor, not P-type.

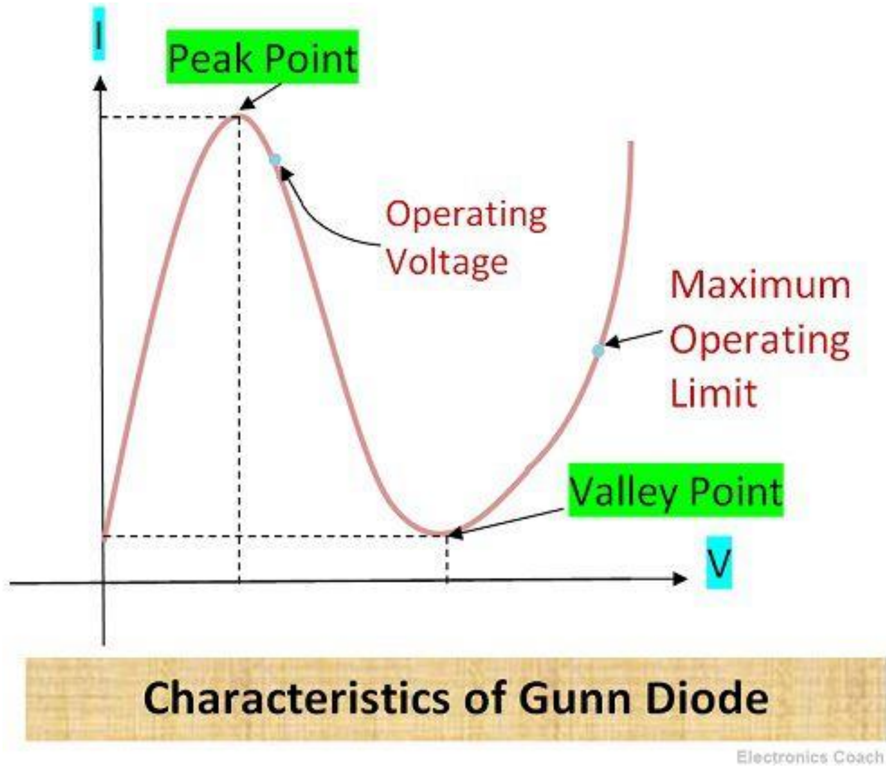
Courtesy: Reference Link: [1]

G.5 Why does current through a Gunn diode increase when voltage is applied across the anode and cathode?

Sol.

When biasing is applied to Gunn diode, the entire voltage appears across the active region. In Gunn diode, there is valence band, conduction band and one more band near conduction band. Thus, on initial DC bias the current through the device increases because electrons move from valence band to conduction band.

The Current in Gunn diode starts increasing initially with the applied DC voltage. At a particular point, the current starts decreasing this point is called threshold point or peak point.



After crossing threshold point the current starts decreasing and this creates negative resistance region in the diode. Due to this negative resistance region, the diode acts as amplifier and oscillator. In this negative resistance region, the Gunn diode is able to amplify the signals.

Courtesy: Reference Link: [1] [2]

G.6 What is the region of the Gunn diode I-V curve between the Peak Point and the Valley Point called? What happens operationally in this region?

Sol.

The region of the Gunn diode I-V curve between the Peak point and the Valley point is called negative resistance region. During this region, the current actually decreases with the increase in the supply voltage.

Courtesy: Reference Link: [1]

G.7 How would you calculate the dynamic resistance of a Gunn diode in series with the resonator load?

Sol.

The dynamic resistance of a Gunn diode is calculated by taking the differential voltage over the differential current. In other words, the dynamic resistance can be defined as the change in the voltage input to the change in the current output for a Gunn diode.

The dynamic resistance will thus showcase a value that is both positive and negative since it is true for the I-V characteristics of a Gunn diode during the negative resistance region that the current will actually decrease with the increase in temperature and the reverse takes place later.

Lastly, the Gunn diode dynamic resistance value is found such that the average negative resistance of the Gunn diode becomes equal to the resistance of the resonator. This is when sustained oscillations are obtained.

Courtesy: Reference Link: [1]

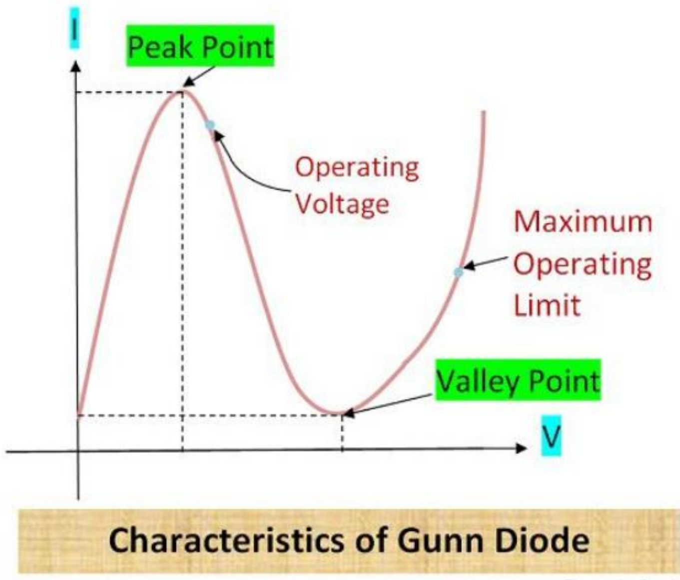
G.8 The negative dynamic resistance characteristic of the Gunn diode is admittedly odd. Why does it not violate the principle of Conservation of Energy?

Sol.

The oscillations in a Gunn diode are initiated when the loading of the resonator is slightly higher than the maximum negative resistance of the device. Next, these oscillations grow in terms of amplitude until the average negative resistance of the Gunn diode becomes equal to the resistance of the resonator after which one can get sustained oscillations.

Moreover, the oscillatory power P_o 'generated' by the negative resistance oscillator comes from the D.C. bias power, $P_{in} = IV_{bias}$, which we have to provide to maintain an average diode voltage in the negative resistance region. As the principle of conservation of energy requires that $P_{in} \geqslant P_o$ it follows that the negative resistance region can never include zero volts.

This in fact true that the negative resistance region never includes zero volts but includes the lowest point called the valley point which is above zero volts. Thus, the principle of conservation of energy is not violated.



Courtesy: Reference Link: [1]

G.9 How are the current oscillations initiated in a Gunn diode?

Sol.

The oscillations are initiated when the loading of the resonator is slightly higher than the maximum negative resistance of the device. Next, these oscillations grow in terms of amplitude until the average negative resistance of the Gunn diode becomes equal to the resistance of the resonator after which one can get sustained oscillations.

Courtesy: Reference Link: [1]

G.10 How does a Gunn oscillator work to obtain the velocity of the target?

Sol.

The Gunn oscillators generate high microwave frequencies that are used for microwave motion detectors from 10 GHz to a few THz. These microwave frequencies are used by the microwave motion detector transducer. Initially, when a microwave signal strikes an object, the reflected signal is changed because of the motion of the target and therefore the change in the frequency of the reflected signal is characterized by the Doppler frequency shift.

This amount of Doppler frequency shift is directly proportional to the velocity of the target's velocity relative to the transmitter. Thus, based on a simple equation, the velocity of the target can be calculated using the known frequency shift in the echoed microwave signal.

$$F_D = 2V\frac{(F_0)}{C}\cos\varnothing$$

where
F_0 = transmitter frequency in hertz
C = velocity of light (3×10^8 meters per second)
V = velocity of the target (meters per second)
$\varnothing$ = angle between microwave beam and target's path

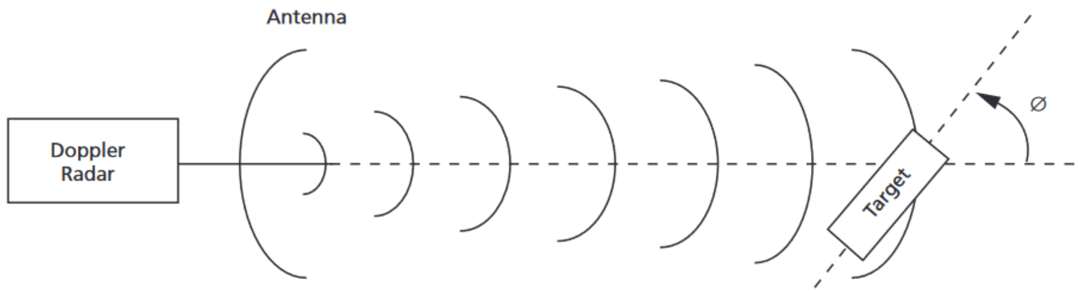


Figure 1. Doppler Shift Caused by Relative Motion of the Target

Courtesy: Reference Link: [1]

G.11 Why do you need to run the signal for the doppler shift frequency through both an amplifier and a notch filter in a commercial microwave detector?

Sol.

The signal for the Doppler frequency shift is run through an amplifier because the frequency shift can be very small which can be hard to detect without an amplified value. Secondly, with amplification, noise present in the frequency shift which is prevalent because of the stray particles moving randomly in the atmosphere will also be amplified. The notch filter therefore nullifies this noise by filtering the Doppler frequency shift in order to provide a signal of high fidelity.

G.12 Why is bi-directional sensitivity an important feature in commercial microwave motion detectors? How is it implemented?

Sol.

Bi-directional microwave motion detectors are able to sense the motion in both directions: towards and away from the sensor. This is a very important feature in the commercial microwave motion detectors because the bi-directional microwave motion detection enables detection of motion in all the directions. This is possible by using the transceivers that have antennas with two-sided high-gain lobes for microwave detection and this transceiver will able to move with a degree of freedom of 180°. But, since the antenna will be bi-directional, the sensor will be able to detect motion in all the directions efficiently.

G.13 What microwave band is used in the commercial microwave detector shown in slide deck C3M4V5.pdf?

Sol.

The commercial microwave detector given in the slide is operating at 24.15 GHz which falls into the K-band.

H. A microwave detector is being used as an automatic door opener for the front lobby of a hotel. The following information is known about the detector when sensing a person about to enter the hotel.

Time for diode to increase or decrease voltage, t_d =	0.0207	nanoseconds
Doppler frequency shift, Δf =	45	Hz

How fast is the person moving in m / s? (Type in a two-decimal number)

Sol. $\boxed{\mathbf{0.5590\ ms^{-1}}}$

Based on the information provided in the class slide, the following equation can be used to find the speed of the moving person:

$$\Delta f = f_0 - f_r = f_0 \frac{1}{1 + \frac{c_0}{v}} = f_0 \frac{v}{v + c_0},$$

Here,

$\Delta f = f_0 \times (v / (v + c_0))$ and $\Delta f = 45$ Hz, $f_0 = 24.15$ GHz (based on the class slide) and $c_0 = 3 \times 10^8\ ms^{-1}$ (speed of light)

Thus,

$45 = 24.15\ G\ (v / (v + 3 \times 10^8))$

$\therefore (v / (v + 3 \times 10^8)) = 1.863354 \times 10^{-9}$

$\therefore (v + 3 \times 10^8) / v = 0.5366\ G$

$\therefore 1 + ((3 \times 10^8) / v) = 0.5366\ G$

$\therefore$ ((0.3 G) / v) = 0.5366 G

$\therefore$ v = 0.3 G / 0.5366 G = $\boxed{\mathbf{0.5590\ ms^{-1}}}$

I. A security company would like to use a microwave detector to help protect the home of their billionaire client. He lives reclusively in a villa on top of a mountain, where only one road leads to the top.

The company wants to point the detector at an open point on the road, where they are guaranteed to spot a moving vehicle moving ahead. They want this open point to be sufficiently far away, so that they can have time to alert their security guards to the possibility of an incoming threat.

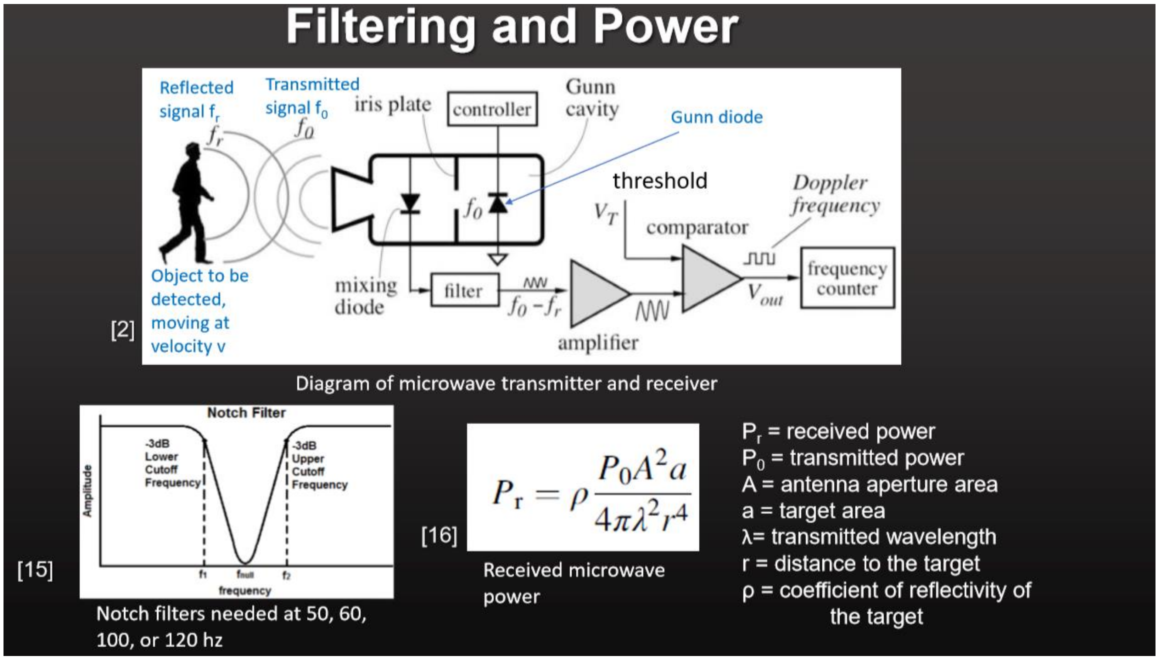
The following information is specified about the detector when sensing a vehicle on the open point on the road. The security company wants your firm to design the microwave detector.

Transmitted power, P_0 =	5000	watts
Antenna aperture area, A =	50	mm^2
Target area, a =	35	m^2
Transmitted frequency, f =	86	GHz
Distance to the target, r =	0.60	km
Coefficient of Reflectivity of target, ρ =	0.19	

What is the reflected power, Pr from the vehicle in milliwatts. (Type in a 3-decimal number). Do you think this will be a difficult electronics design to implement in the detector?

Sol. $\boxed{\mathbf{4.1944\ pW}}$

Based on the information provided in the class slide as shown below, the reflected power can be calculated.



Thus, the calculation is as shown below:

$$P_r = \frac{\rho \cdot P_0 A^2 a}{4\pi \lambda^2 r^4}$$

since, $C_0 = f \cdot \lambda$, we can replace the equation as below:-

$$\therefore P_r = \frac{\rho \cdot P_0 A^2 a}{4 \cdot \pi \cdot \left(\frac{C_0}{f}\right)^2 \cdot r^4}$$

$$= \frac{0.19 \times 5000 \times (50 \times 10^{-6})^2 \times 35}{4 \times \pi \times \left(\frac{3 \times 10^8}{86 \times 10^9}\right)^2 \times (0.6 \times 10^3)^4}$$

$$= \frac{8.3125 \times 10^{-5}}{0.0198 \times 109}$$

$$= 419.44 \times 10^{-14} = \boxed{0.0041944\,nW}$$

Here, it is concluded that if the transmitted power is 5000 W then the received power will be only **0.0041944 nW** or $\boxed{\textbf{4.1944 pW}}$.

It can be thus said that the received power is only 0.0838 x 10^{-12} % of the transmitted power. Such a design will not only be difficult to design but will also be very susceptible to errors (due to undesired sensor noise) which can lead the sensor detection system to provide false results. To conclude, it is very difficult to design a sensor system with the above characteristics.

J. Answer the following questions about humidity sensors.

J.1 What is the difference between P_s and RH?

Sol.

P_s stands for the pressure of the saturated water vapour which is defined as the equilibrium point of water vapor pressure in a closed container of water and air.

RH stands for relative humidity which is defined as ratio of the partial pressure of water vapor in air at a given temperature, to the maximum of saturation vapor pressure at that temperature.

P_s is given in Pascal or atm (units of pressure) whereas RH is normally stated in terms of % and since it is unitless.

J.2 What is the difference between P_{atm} and P_a?

Sol.

P_{atm} stands for the atmospheric pressure which is defined as the pressure of open air in the atmosphere, which varies by elevation. It is stated in terms of Pascal or atm (units of pressure).

P_a stands for partial pressure of dry air which is defined as the pressure of only the dry air present in the atmosphere. This pressure excludes the pressure built in the atmosphere due to the pressure of water vapour. It is stated in terms of Pascal or atm (units of pressure).

To conclude, $P_{atm} = P_w + P_a$ where P_w = partial pressure of water vapour and P_a = partial pressure of dry air. Thus, the P_{atm} (atmospheric pressure) consists of both the individual pressures created by the presence of water vapour and dry air in the atmosphere.

Courtesy: Reference Link: [1]

J.3 Suppose you cool moist air to the dewpoint. What is the relationship between P_w and P_S?

Sol.

If the moist air is cooled to the dewpoint then the P_w (partial pressure of water vapour) will reduce to zero and P_s will therefore be more or less constant (since $P_w \rightarrow$ tends to zero) and will consist only of partial pressure of dry air inside the saturated environment consisting of moist air.

Courtesy: Reference Link: [1]

J.4 How does relative humidity relate to absolute temperature?

Sol.

Relative humidity is the ratio (expressed as a percentage) of the amount of moisture actually in the air to the maximum amount that can be present at that temperature. It is inversely proportional to the absolute temperature given that the moisture remains constant throughout the change. Thus, for a given amount of moisture, the relative humidity will vary inversely with respect to the absolute temperature – i.e. If the absolute temperature increases, RH decreases and vice versa.

J.5 What is one common method of calibrating humidity sensors? How does this method work?

Sol.

A dish of saturated salt solution in a sealed box generates moisture in the air over the dish. The relative humidity depends on the salt, but is only slightly dependent on temperature. This is helpful in calibrating the humidity sensors.

Courtesy: Reference Link: [1] and class slide

J.6 How does a capacitive humidity sensor work? What are the advantages and disadvantages of this design?

Sol.

Capacitive humidity sensors consist of a substrate on which a thin film of polymer or metal oxide is deposited between two conductive electrodes. The sensing surface is coated with a porous metal electrode to protect it from contamination and exposure to condensation. The substrate is typically glass, ceramic, or silicon. The incremental change in the dielectric constant of a capacitive humidity sensor is nearly directly proportional to the relative humidity of the surrounding environment. The change in capacitance is typically 0.2–0.5 pF for a 1% RH change, while the bulk capacitance is between 100 and 500 pF at 50% RH at 25°C.

Capacitive sensors are characterized by low temperature coefficient, ability to function at high temperatures (up to 200°C), full recovery from condensation, and reasonable resistance to chemical vapors. The response time ranges from 30 to 60 s for a 63% RH step change.

Advantages:

State-of-the-art techniques for producing capacitive sensors take advantage of many of the principles used in semiconductor manufacturing to yield sensors with minimal long-term drift and hysteresis. Thin film capacitive sensors may include monolithic signal conditioning circuitry integrated onto the substrate. The most widely used signal conditioner incorporates a CMOS timer to pulse the sensor and to produce a near-linear voltage output (see Figure 1).

Disadvantages:

Capacitive sensors are limited by the distance the sensing element can be located from the signal conditioning circuitry, due to the capacitive effect of the connecting cable with respect to the relatively small capacitance changes of the sensor. A practical limit is <10 ft.

Direct field interchangeability can be a problem unless the sensor is laser trimmed to reduce variance to ±2% or a computer-based recalibration method is provided. These calibration programs can compensate sensor capacitance from 100 to 500 pF.

Courtesy: Reference Link: [1]

J.7 How does a resisitive humidity sensor work? What are the advantages and disadvantages of this design?

Sol.

Resistive humidity sensors measure the change in electrical impedance of a hygroscopic medium such as a conductive polymer, salt, or treated substrate. The impedance change is typically an inverse exponential relationship to humidity.

Resistive sensors usually consist of noble metal electrodes either deposited on a substrate by photoresist techniques or wire-wound electrodes on a plastic or glass cylinder. The substrate is coated with a salt or conductive polymer. When it is dissolved or suspended in a liquid binder it functions as a vehicle to evenly coat the sensor. Alternatively, the substrate may be treated with activating chemicals such as acid. The sensor absorbs the water vapor and ionic functional groups are dissociated, resulting in an increase in electrical conductivity.

Advantages:

The "resistive" sensor is not purely resistive in that capacitive effects >10–100 MΩ makes the response an impedance measurement. A distinct advantage of resistive RH sensors is their interchangeability, usually within ±2% RH, which allows the electronic signal conditioning circuitry to be calibrated by a resistor at a fixed RH point. This eliminates the need for humidity calibration standards, so resistive humidity sensors are generally field replaceable. The small size, low cost, interchangeability, and long-term stability make these resistive sensors suitable for use in control and display products for industrial, commercial, and residential applications.

Disadvantages:

In residential and commercial environments, the life expectancy of these sensors is >>5 yr., but exposure to chemical vapors and other contaminants such as oil mist may lead to premature failure. Another drawback of some resistive sensors is their tendency to shift values when exposed to condensation if a water-soluble coating is used. Resistive humidity sensors have significant temperature dependencies when installed in an environment with large (>10°F) temperature fluctuations.

Courtesy: Reference Link: [1]

J.8 Why did air filled capacitive humidity sensors never gain commercial acceptance?

Sol.

The typical uncertainty of capacitive sensors is ±2% RH from 5% to 95% RH with two-point calibration. Capacitive sensors are limited by the distance the sensing element can be located from the signal conditioning circuitry, due to the capacitive effect of the connecting cable with respect to the relatively small capacitance changes of the sensor. A practical limit is <10 ft. Thus, these are some of the reasons why air filled capacitive humidity sensors never gained commercial acceptance.

Courtesy: Reference Link: [1]

J.9 What is the relationship between the capacitance of a capacitive humidity sensor and relatively humidity?

Sol.

The dielectric constant of air is affected by humidity. With the change in the humidity, the dielectric constant of air will change. The capacitance of the capacitive humidity sensor is given by the equation as under:

$$C = \varepsilon_r \cdot C_0$$

Here, C is the capacitance in farads at a given humidity level, er is the dielectric constant and C0 is the capacitance in the absence of dielectric constant.

Also, the dielectric constant is directly proportional to the humidity in the air and the capacitance of the capacitive humidity sensor is directly proportional to the dielectric constant.

Thus, the capacitance of the capacitive humidity sensor is directly proportional to the relative humidity in the atmosphere it is present in.

J.10 What is the relationship between the impedance of a resistance humidity sensor and relatively humidity?

Sol.

The impedance of the resistive humidity sensor decreases with the increase in the relative humidity. Therefore, the impedance of the resistive humidity sensor is inversely proportional to the change in the relative humidity.

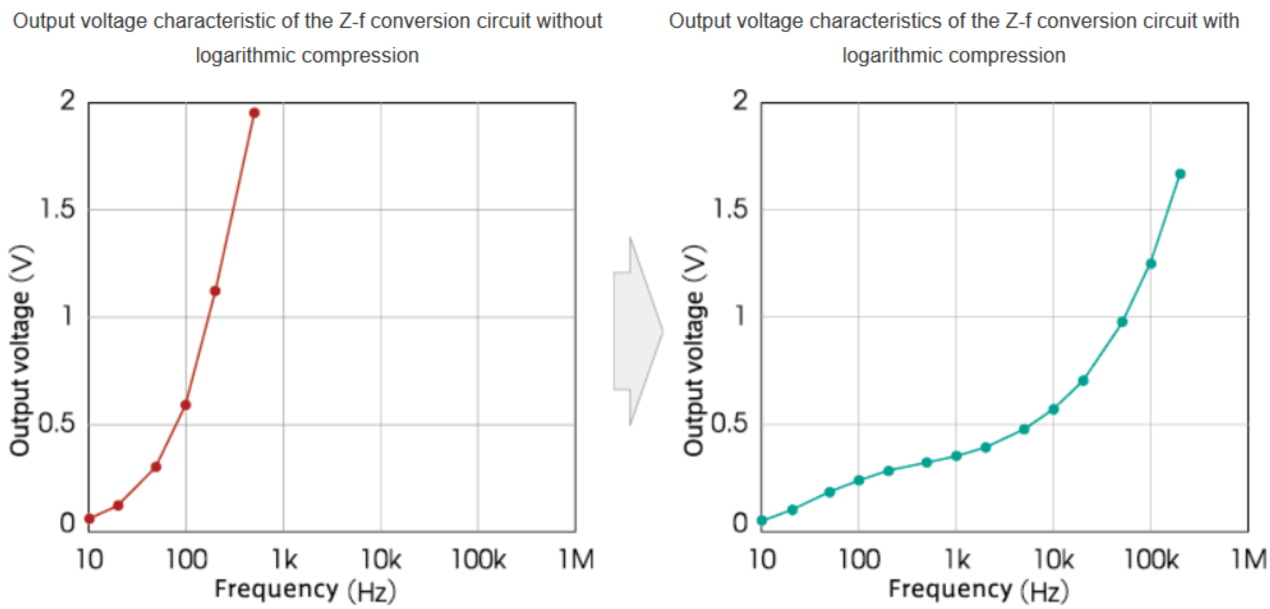
J.11 How is linearization performed for the CHS series of resistive humidity sensors?

Sol.

A variable resistance humidity sensor requires logarithmic compression because impedance variations in response to humidity become exponential. Normally, this logarithmic compression is performed by a log amplifier.

In the CHS Series humidity sensor units, a frequency that changes according to the humidity obtained by the Z-f conversion circuit is converted into a pulse wave with the pulse width τ. When doing so, control of the negative feedback time constant is performed using a nonlinear element to make the pulse width τ large at low humidity or small at high humidity. As a result, the exponential characteristic as shown in the graph of Figure 6 (left) is logarithmically compressed and becomes an output voltage characteristic as described in the graph of Figure 6 (right).

Figure 6 Logarithmic compression of the output voltage characteristic of the Z-f conversion circuit

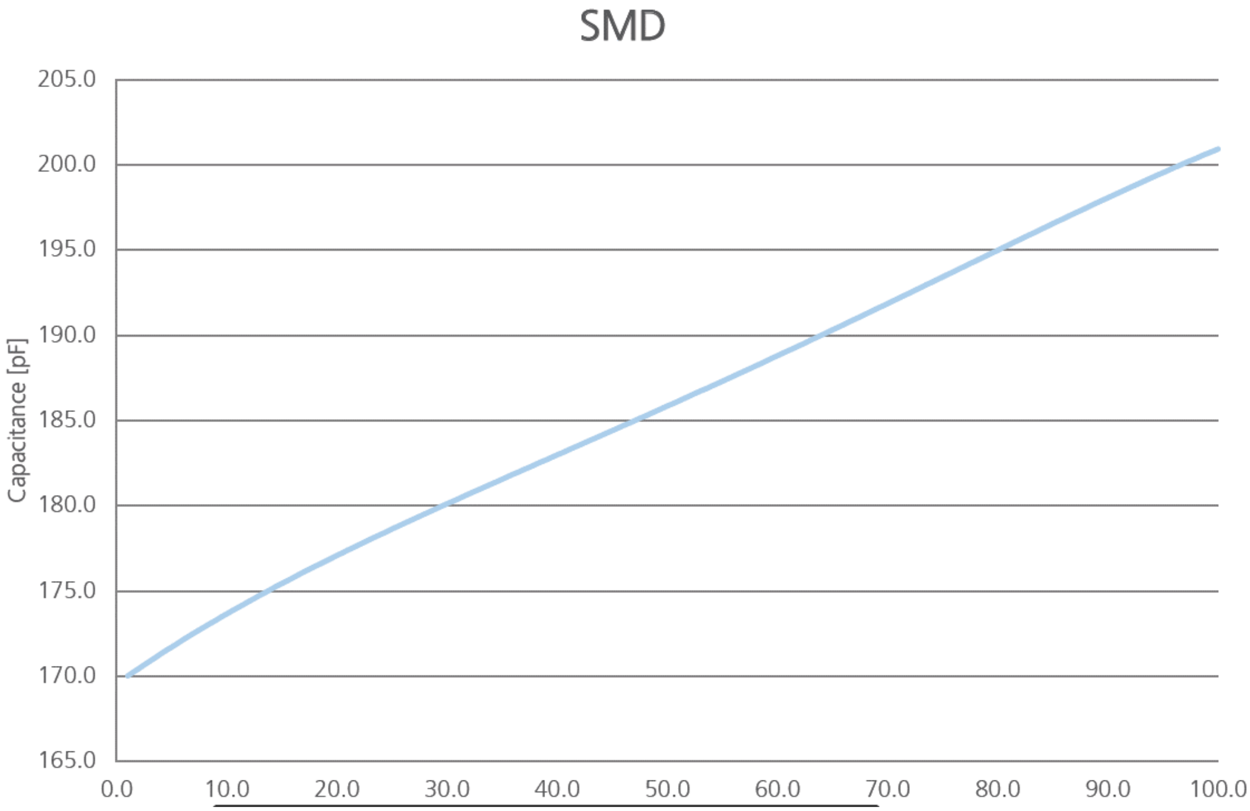


Courtesy: Reference Link: [1]

K. You are using the SMD version (surface mount) of the P14-W capacitive humidity sensor from Innovative Sensor Technology Inc. The relevant specs are shown in the screen shots below. Other relevant information is given in the table below

Capacitance, C =	186	pF
Ambient Temperature, T =	29	°C

Including the errors associated with linearity, hysteresis, and temperature dependence of the humidity reading, what is the highest humidity reading that you could get? Assume that you sum the errors. (Type in a 1-decimal number).


SMD
Capacitance [pF]
205.0
200.0
195.0
190.0
185.0
180.0
175.0
170.0
165.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0

Technical Data

	Wired	SMD
Dimensions (L x W x H / H2 in mm):	5 x 3.81 x 0.4 / 0.8	6.35 x 2.54 x 0.4
Capacitance at 30 % RH and +23 °C (C_{30}):*	150 pF ±50 pF	180 pF ±50 pF
Sensitivity at C_{30} = 150 pF/ 180 pF (15 % RH to 90 % RH):	0.25 pF/% RH	0.3 pF/% RH

Operating humidity range:	0 % RH to 100 % RH (maximal dew point +85 °C)	
Operating temperature range:	-50 °C to +150 °C	
Loss factor:	< 0.01 (at +23 °C, at 10 kHz, at 90 % RH)	
Linearity error:	< 1.5 % RH (15 % RH to 90 % RH at +23 °C after one point calibration)	
Hysteresis:	< 1.5 % RH	
Response time t_{63}:	< 5 s (50 % RH to 0 % RH at +23 °C)	
Temperature dependence (nominal):	Δ % RH = (B1 x % RH + B2) x T [°C] + (B3 x % RH + B4)	
	B1 = 0.0014 [1/ °C]	B2 = 0.1325 [% RH/ °C]
	B3 = -0.0317	B4 = -3.0876 [% RH]
Measurement frequency:	1 kHz to 100 kHz (recommended 10 kHz)	
Maximal supply voltage:	< 12 V_{pp} AC	
Signal form:	alternating signal without DC bias	
Connections:*	CuP-SIL-wire post-plated with Sn, 10 mm or Au/Cu-wire, Ø 0.4 mm, 10 mm, or SMD, automatic assembly compatible	

Sol. $\boxed{\textbf{54.2 \% RH}}$

To solve this problem, we will first assume that the approximate value of relative humidity (RH) in % at 186°C will be around 50 % RH based on the graph provided for the SMD.

Considering the same, the errors can be calculated based on the spec sheet as shown under:

- Linearity error: Max error value will be approximately 1.5 % RH
- Hysteresis error: Max error value will be approximately 1.5 % RH
- Temperature dependence error:

  This can be calculated as under using the equation given in the spec sheet: (given that T [°C] = 29°C)

  Δ % RH = (0.0014 x 50 + 0.1325) x 29 + (-0.0317 x 50 – 3.0876)
  = 1.1999
  == 1.2 (approx.)

Based on the above error values, the total error will be the sum of the three errors and therefore, the total error will be:

Total error
= 1.5 % RH + 1.5 % RH + 1.2 % RH
= 4.2 % RH

Finally, the highest humidity can be obtained by adding those errors to it.

Thus, the highest relative humidity reading is:

= 50 % RH + Total error
= 50 % RH + 4.2 % RH
= $\boxed{\textbf{54.2 \% RH}}$