18EE8732:Micro and Nano Scale Sensors and Transducers

MODULE – 5: Integrated Sensor/Actuator Units and Special Purpose Sensors

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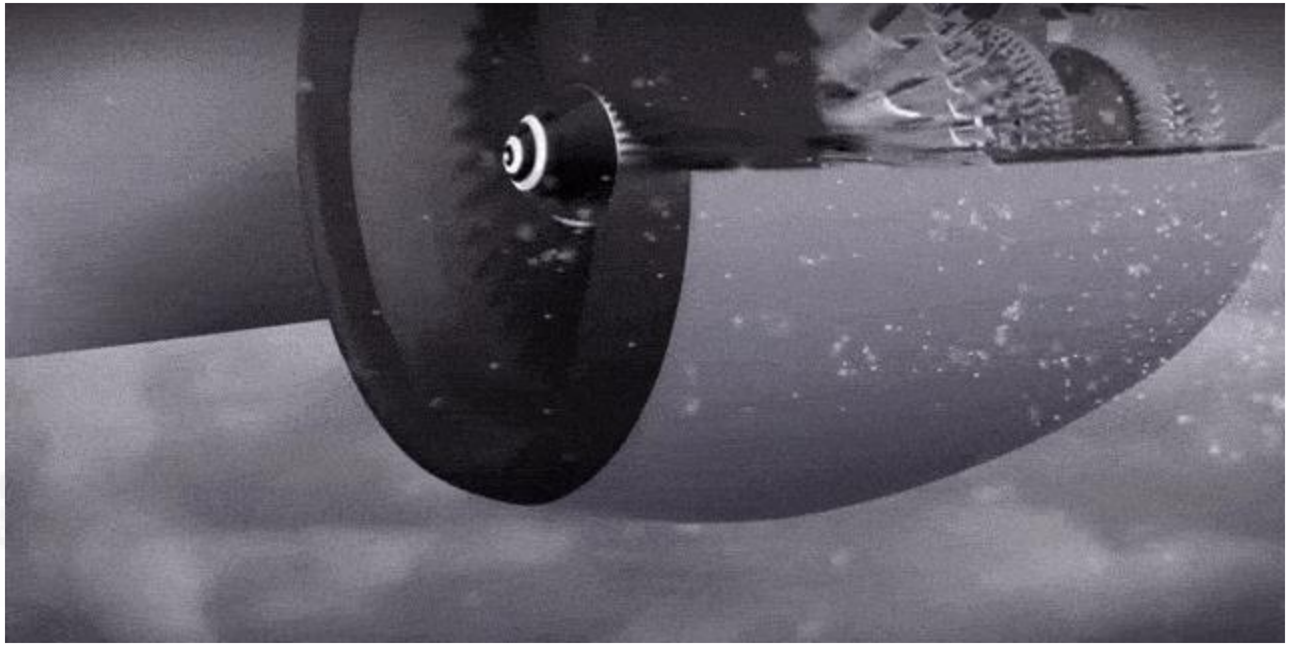
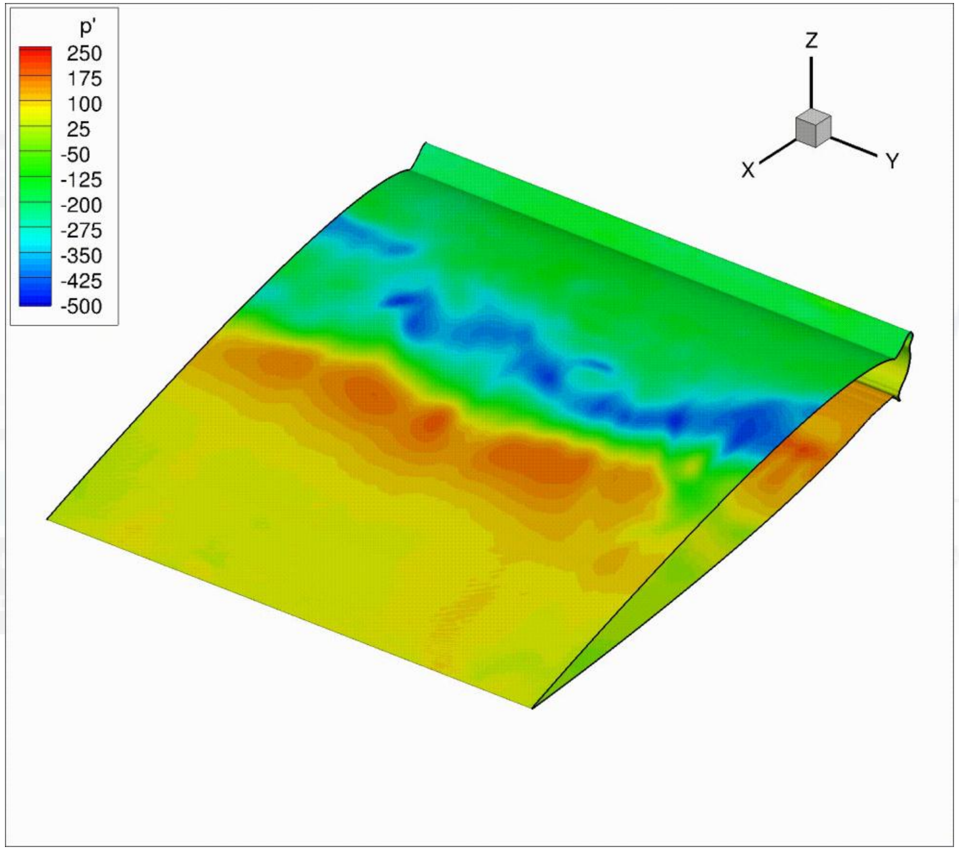
Aircraft Icing Detectors



Aircraft Icing Detectors



Aircraft Icing Detectors

This section introduces a new type of icing detector for aircraft applications.

Unlike the well-known icing detectors that are based on **optics**, the new detector utilizes **α particles**.

An **α -particle source** is attached to the wing of the aircraft, and a detector that mainly depends on a MOSFET transistor is placed a few centimeters away from the source.

Aircraft Icing Detectors

As the **α -particle source** strike the detector, they deposit their positive charges on the gate of the MOSFET (n-channel), and the **transistor turns ON**.

If, however, a **layer of ice builds up on the wing** and prevents the α particles from reaching the detector, the **MOSFET shuts OFF**.

Inference: The new detector is more reliable than optics based detectors because it is an integral part of the wing and hence cannot miss the formation of ice.

Principle of Operation

The formation of ice on an airplane wing during flight can be **catastrophic**. Investigation of numerous icing-related accidents has shown that ice deposits alter the perfect aerodynamic shape of the wing

Principle of Operation

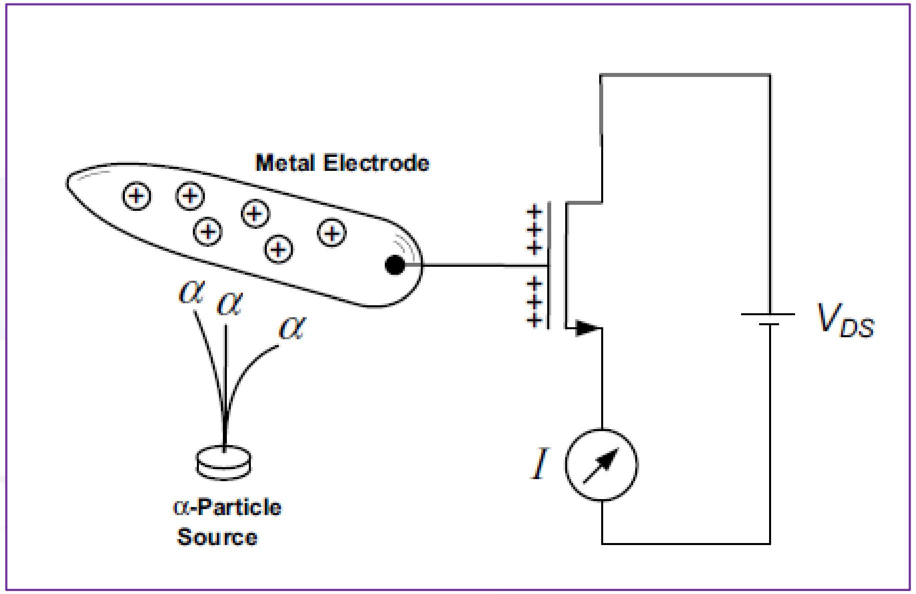
NEED: An optical detector can quickly and reliably detect the formation of ice, it is **usually not an integral part of the wing structure**.

One potential problem with such an approach is that ice may form on the wing but not the detector

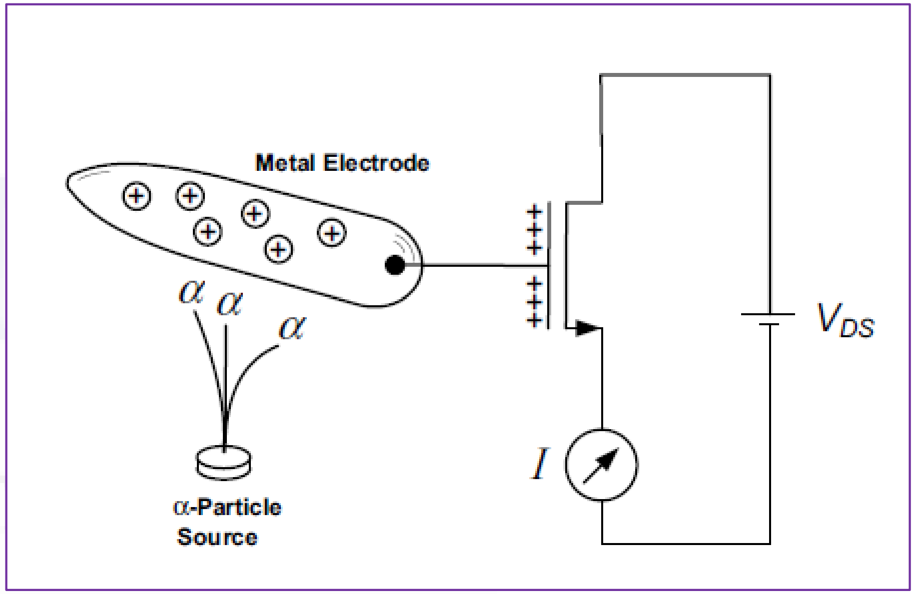
Principle of Operation

Step-1: a thin **α -particle** source is attached to or embedded in the surface of the wing.

The amount of **radioactive isotope that is used in the present application is only slightly more than the amount used in a conventional household smoke detector**, and therefore does not constitute an environmental or safety hazard

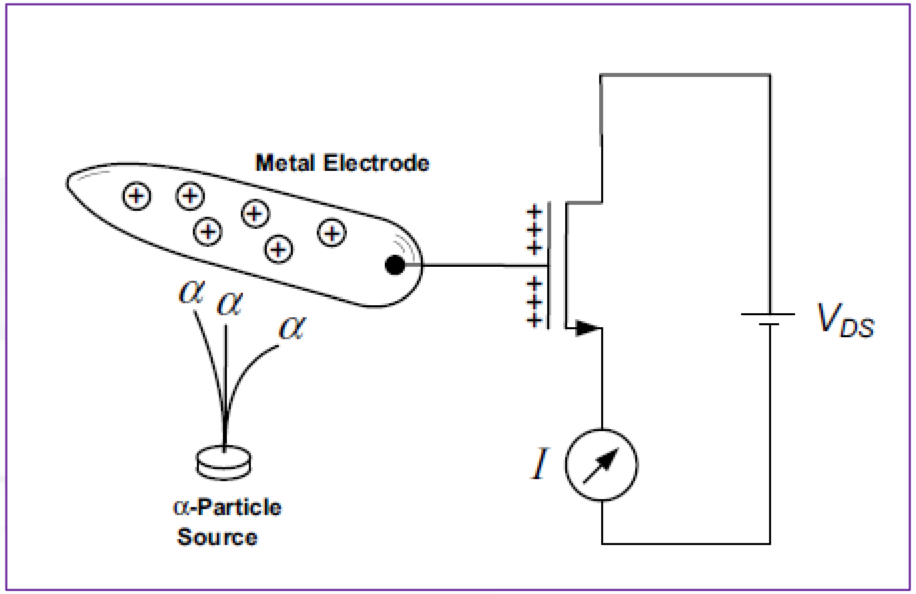


Step-2: The emitted **α** particles strike a small metallic electrode that is aerodynamically shaped and positioned a few centimeters above the source, as shown.



Step-3: The positive charge of the **α** particles is therefore transferred to the electrode upon impact, and the a particles are neutralized

Step-4: electrode is directly connected to the gate of an n-channel MOSFET transistor, as shown in the figure. The MOSFET is known to be highly sensitive to a charge on the gate and will be in an ON state as long as the a particles continue to reach the electrode.

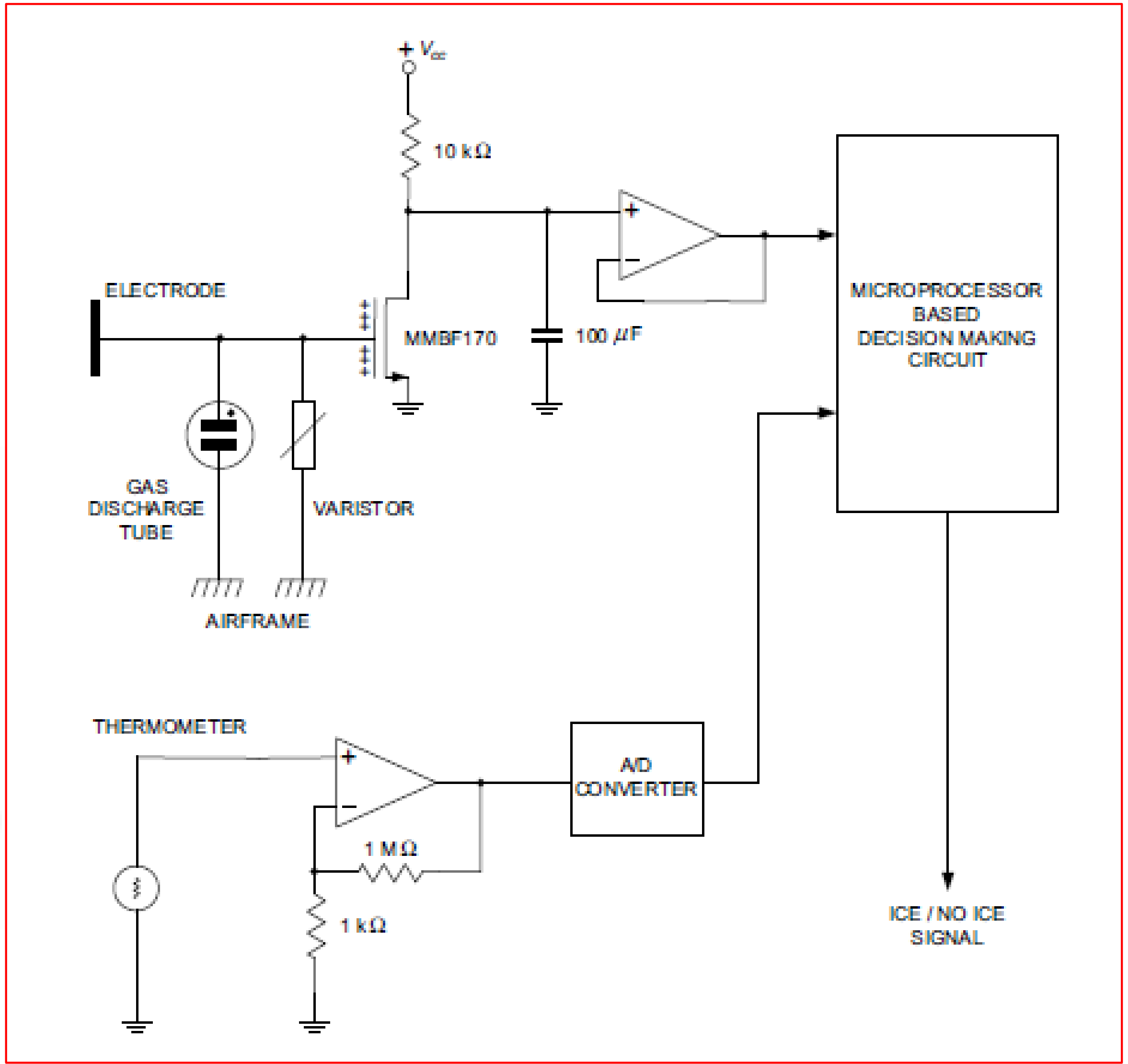


Step-5:If a layer of ice forms on the wing and covers the **α** -particle source, the a particles will be stopped by such a layer, will fail to reach the electrode, and hence theMOSFET will turn OFF. This results in a current $I = 0$ through the device, which can be used to trigger an alarm.

Photograph of the detector, mounted on a model airplane with an aluminum fuselage and aluminum wings. **<u>The length of the detector is 10 cm.</u>**

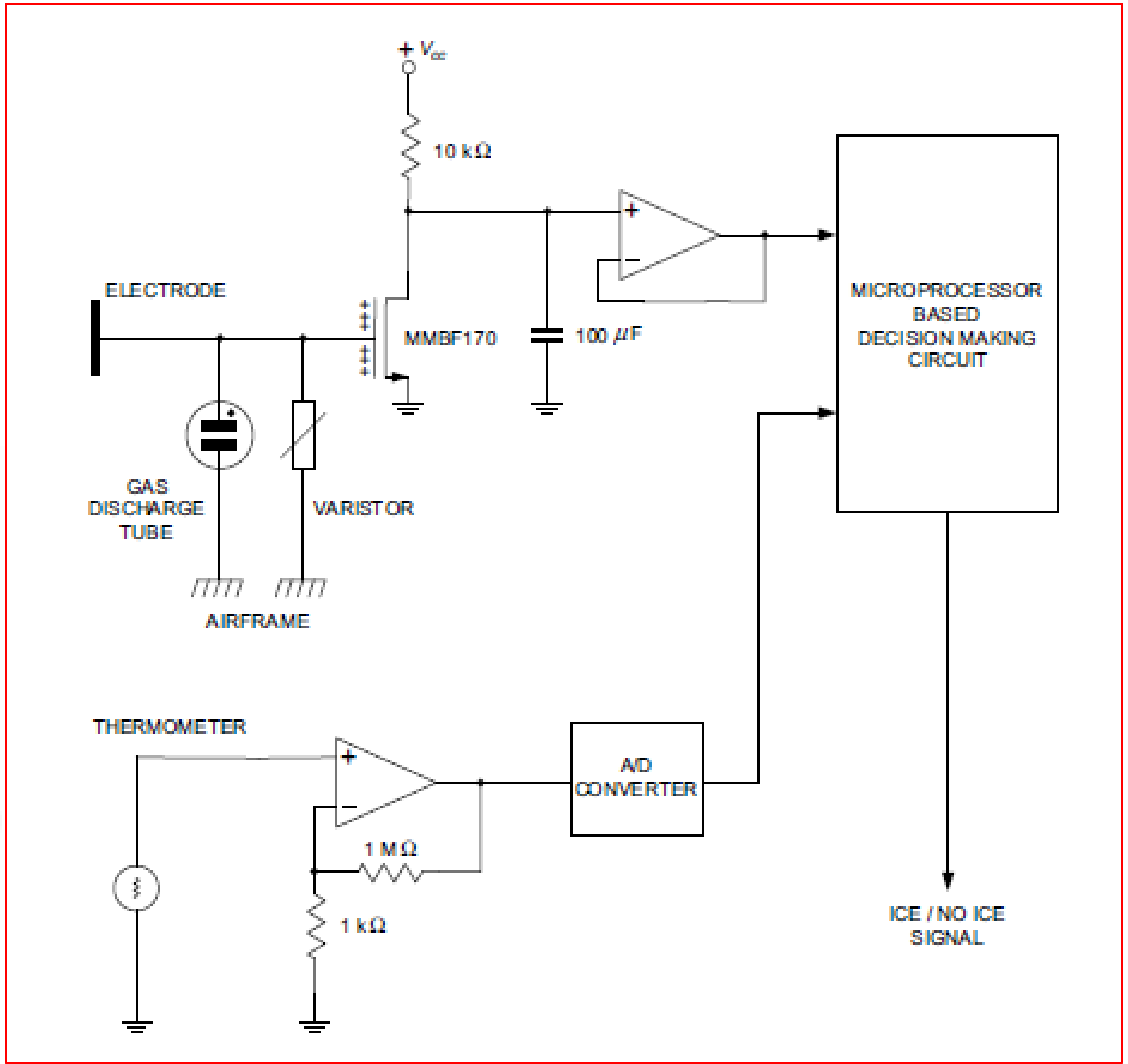
Figure shows the interface circuit that is used in the present prototype.

This is a very basic circuit for sensing the state of the MOSFET under various operating conditions



Step-1:In the circuit, the electrode, which acquires the positive charge, is directly connected to the **gate of an n-channel, enhancement mode MOSFET.**

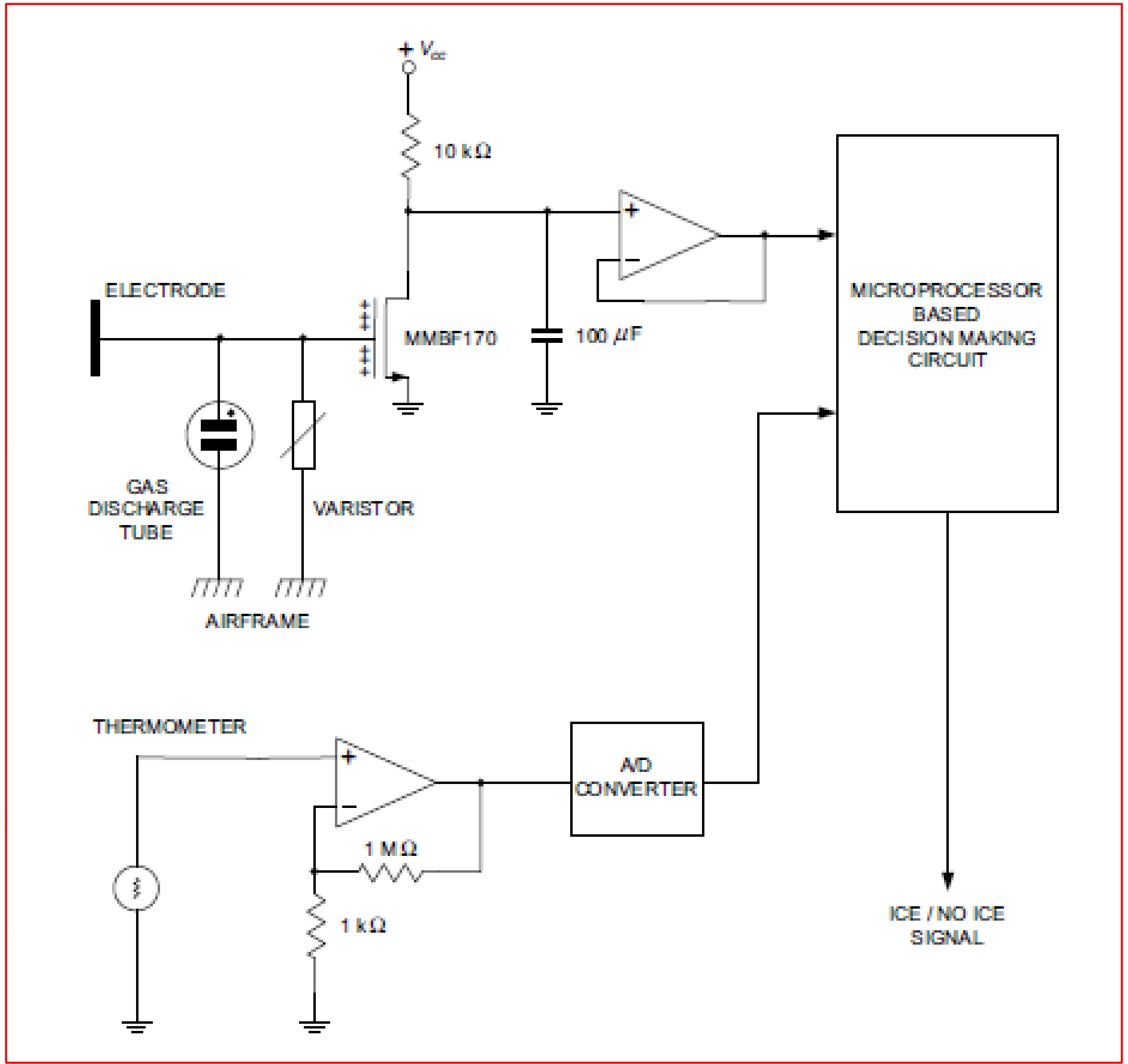
Step-2: Two surge protection components are also connected to the gate: **a gas discharge tube for protection against lightning**, and a **varistor for dissipating any voltage build-up above 20 V**



Step-3:Both components are directly connected to the airframe, as shown, and help **to eliminate transients in addition to the main function of protecting the MOSFET**

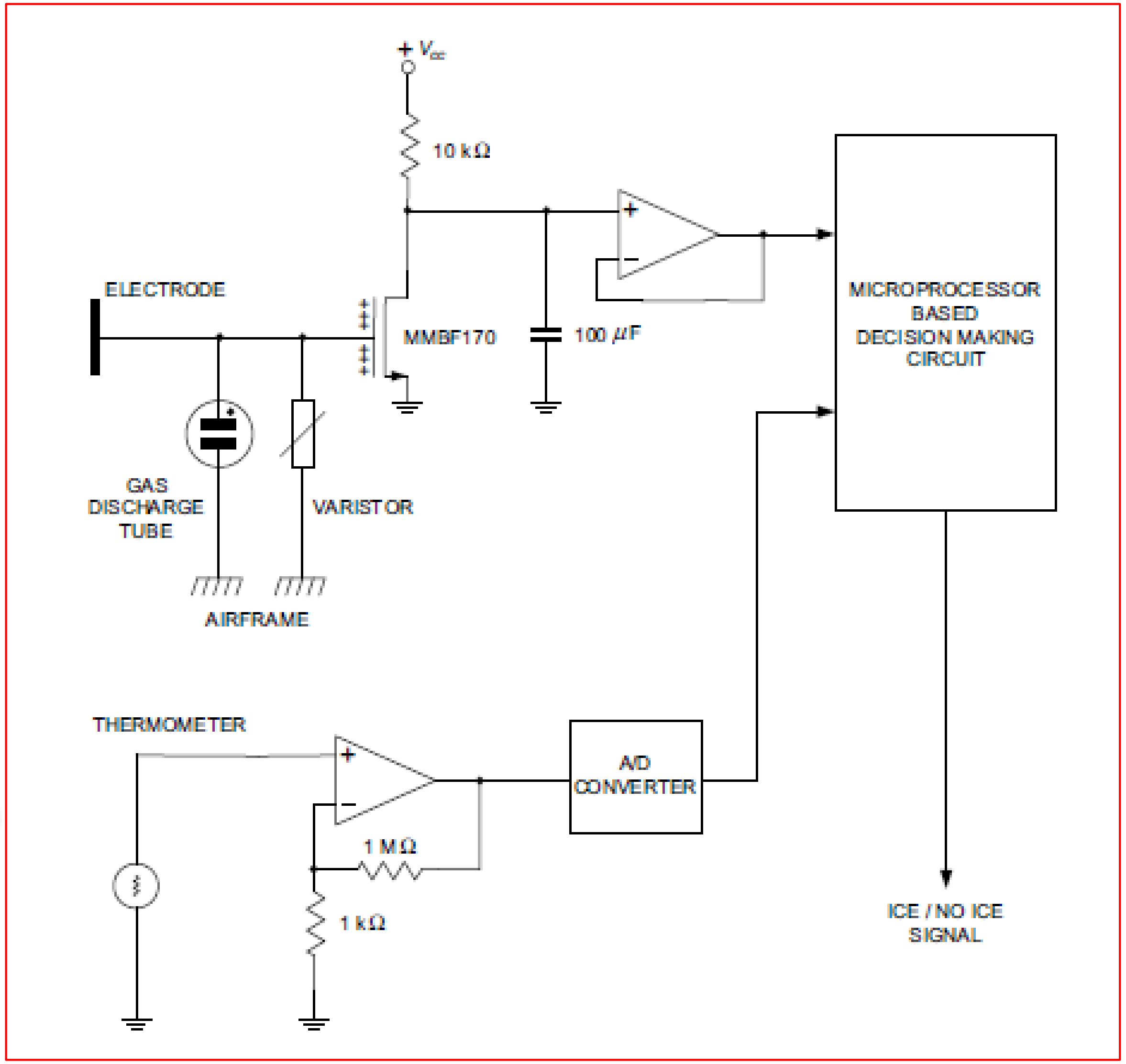
Step-4: When the positive charge is present on the gate of the MOSFET, the device is ON, and hence the output voltage (which is fed to a microprocessor circuit) is **low**.

Step-5: If the charge is not present, however, the device is OFF, and hence the output voltage will be **high**—indicating an alarm.



Step-6: The “alarm” signal is **filtered with a low-pass filter** for further suppressing the transients.

A microprocessor circuit is used for making a decision about the **validity of any alarm signal from the MOSFET**.



The presence of ice on the wing is asserted if two conditions are present:

First, the alarm signal (or high-voltage signal) from the MOSFET must hold steady for several seconds; hence any transients are ignored.

Second, the thermometer interface circuit, which is shown in the lower part of Figure , must indicate a below-freezing temperature while the alarm signal from the MOSFET is present.

The presence of ice on the wing is asserted if two conditions are present:

If the above two conditions are satisfied simultaneously, the microprocessor circuit issues a **valid warning signal** about the presence of ice on the wing.

The microprocessor circuit board that is used in the present application is a small footprint board that is based on an **8-bit PIC microprocessor**. The board was programmed in C.

Theory

Determination of the turn ON condition of the MOSFET:

For **turning ON a MOSFET transistor** by means of a flow of positively charged particles.
The charges that reach the gate of the MOSFET will be used to charge the input capacitance C_{iss} of the device

The deposited charge *Q* will therefore be given by

$$Q = \int C_{iss}\, dV$$

Theory

For small MOSFET devices, C_{iss} is usually represented by a straight line with negative slope as a function of V_{DS}. The above integral can be therefore written as follows:

$$Q = \int_{V_{DD}-V_{GS}}^{V_{DD}} (C_0 + mV)\, dV$$

Where, **C_0 is the initial capacitance** (at $V_{DS} \approx 0$),

***m* is the slope of the straight line**, and the limits of integration are due to the fact that the gate-drain voltage changes from

V_{DD} to $V_{DD} - V_{GS}$ as the input capacitance is charged

Theory

By carrying out the simple integration and rearranging the terms, the following quadratic equation is obtained:

$$V_{GS}^2 - 2V_{GS}\left(V_{DD} + \frac{C_0}{m}\right) + \frac{2Q}{m} = 0$$

Solving the above equation for V_{GS} gives

$$V_{GS} = \left(V_{DD} + \frac{C_0}{m}\right) \pm \sqrt{\left(V_{DD} + \frac{C_0}{m}\right)^2 - \frac{2Q}{m}}$$

Theory

The **leakage current density** ***J*** **through the SiO_2 layer** will be related to the **electric field intensity** ***E*** between the gate and the source terminals

$$J = \sigma E$$

where σ is the conductivity of SiO_2

$$\frac{I}{A} = \sigma \frac{V_{GS}}{\Delta x}$$

where *A* is the surface area of the gate electrode and D*x* is the distance,

Theory

$$V_{GS} = \frac{I\Delta x}{\sigma A} = \left(V_{DD} + \frac{C_0}{m}\right) \pm \sqrt{\left(V_{DD} + \frac{C_0}{m}\right)^2 - \frac{2Q}{m}}$$

The current I is equal to the ratio $\Delta Q/\Delta t$, where Δt is the time taken to reach the steady state. By replacing Q by ΔQ, the above equation can be written as

$$\begin{aligned} V_{GS} &= \frac{\Delta Q}{\Delta t}\left(\frac{\Delta x}{\sigma A}\right) \\ &= \left(V_{DD} + \frac{C_0}{m}\right) \pm \sqrt{\left(V_{DD} + \frac{C_0}{m}\right)^2 - \frac{2\Delta Q}{m}} \end{aligned}$$

By solving the above equation for ΔQ,

$$\Delta Q = 2\left(V_{DD} + \frac{C_0}{m}\right)\frac{\sigma A}{\Delta x}\Delta t - \frac{2}{m}\left(\frac{\sigma A}{\Delta x}\Delta t\right)^2$$

Because of the very small value of σ, the second term in the above equation is negligible in comparison with the first term; hence we can conclude that

$$\frac{\Delta Q}{\Delta t} = I \approx 2\left(V_{DD} + \frac{C_0}{m}\right)\frac{\sigma A}{\Delta x}$$

From the well-known equation

$$C = \varepsilon_0 \varepsilon_r \frac{A}{\Delta x}$$

where ε_0 is the permittivity of free space, and ε_r is the relative permittivity of the insulating material ($\varepsilon_r = 3.9$ for SiO_2), the ratio $\Delta x / A$ is calculated to be

$$\frac{\Delta x}{A} = \frac{\varepsilon_0 \varepsilon_r}{C} \approx 1.438 \quad \mathrm{m}^{-1}$$

The minimum steady-state current that is expected to reach the gate of the MOSFE
will be therefore given by

$$\boxed{I = \frac{\Delta Q}{\Delta t}}$$

The load line and the operating points of the MOSFET:

Because the load is large, the MOSFET will be operating in the ohmic region, where the drain current is given by

$$I_D = \frac{V_{DS}}{R_{on}}$$

where R_{on} is the ON resistance of the MOSFET

I_D is related to the load by the well-known load line equation

$$I_D = \frac{V_{DD}}{R} - \frac{1}{R} V_{DS}$$

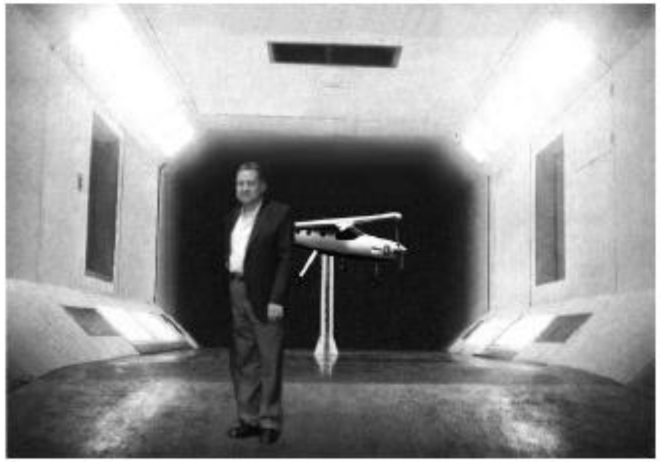
$$V_{DS} = \frac{V_{DD}}{1 + R/R_{on}}$$

With the MOSFET resistance R_{on} being typically equal to 1 W, it is clear that $V_{DS} \approx 0$ when the MOSFET is fully ON

Performance Data and Experimental Results

The model airplane to which the detector was attached was tested in a wind tunnel that provides air speeds of up to **1000 km/h** (620 mi/h).

A number of substances were injected into the air flow to test the response of the detector to different air compositions.

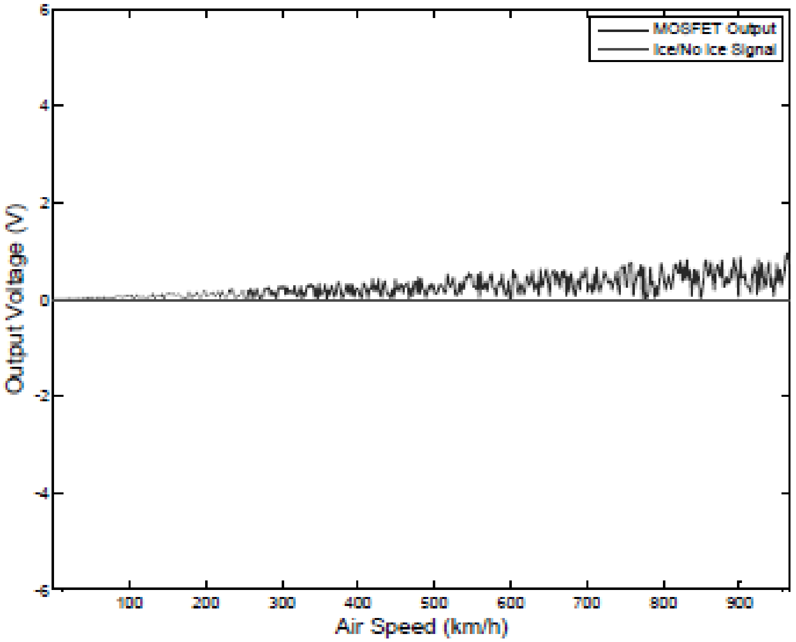


The following were the compositions/ conditions under which the detector was tested:

- Clean, dry air.
- Air with up to 80% relative humidity (moisture).
- Super-saturated water vapor (clouds).
- Air mixed with large, condensed water particles (rain).
- Air mixed with small crystals of ice.
- Air mixed with dust particles.
- Artificial lightning.

Results of testing with dry air, moist air, or super-saturated water vapor:

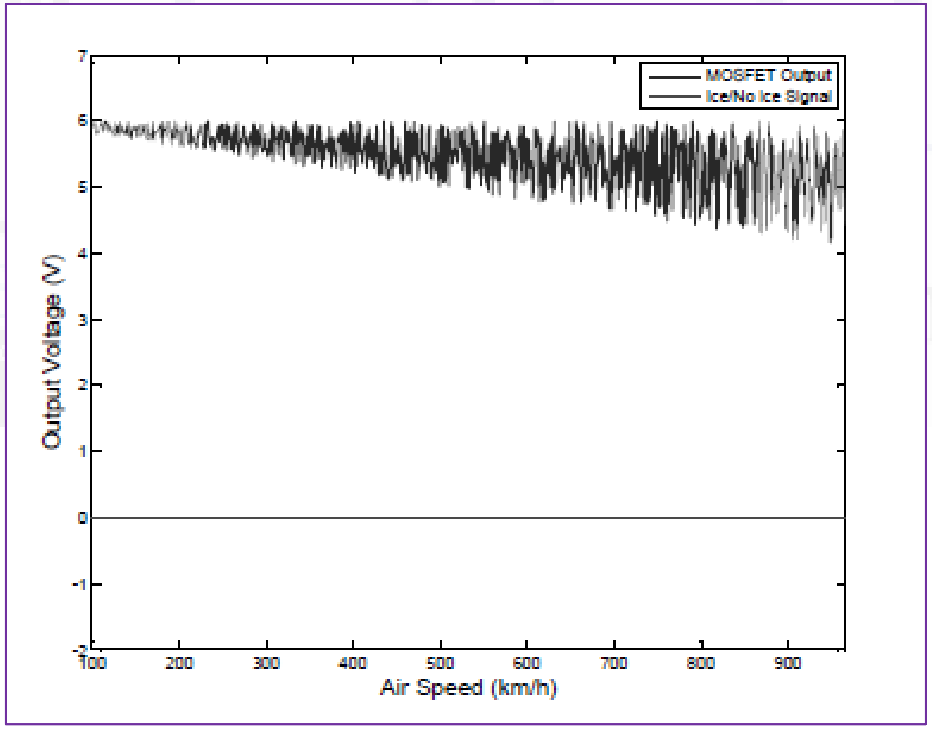
Output voltage of the MOSFET, and the ice/no ice signal provided by the decision making microprocessor, as a function of the air speed.



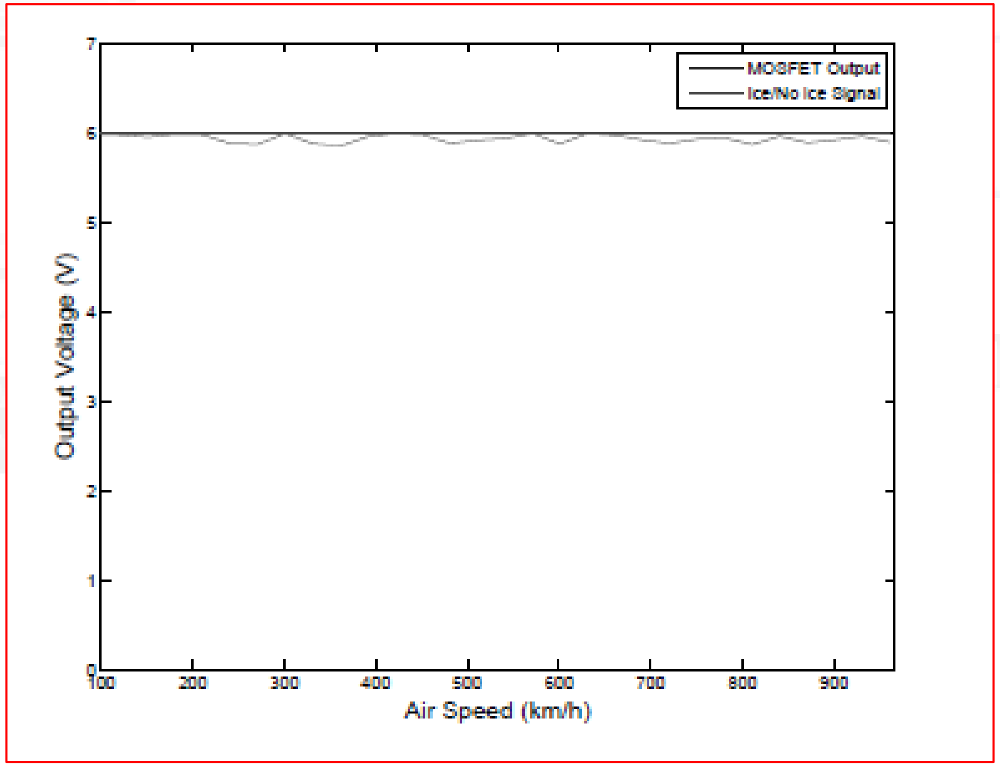
In the experiments reported here, the following were the atmospheric conditions inside the tunnel:

- Stagnation pressure (or total pressure): **approximately 100 kPa.**
- Temperature: **15^{o}C** (except in one experiment in which ice was injected into the air flow)
- Dynamic pressure: the dynamic pressure is given by the well-known quantity $1/2\ \rho V^2$
  where ρ is the density of air and v is the velocity.

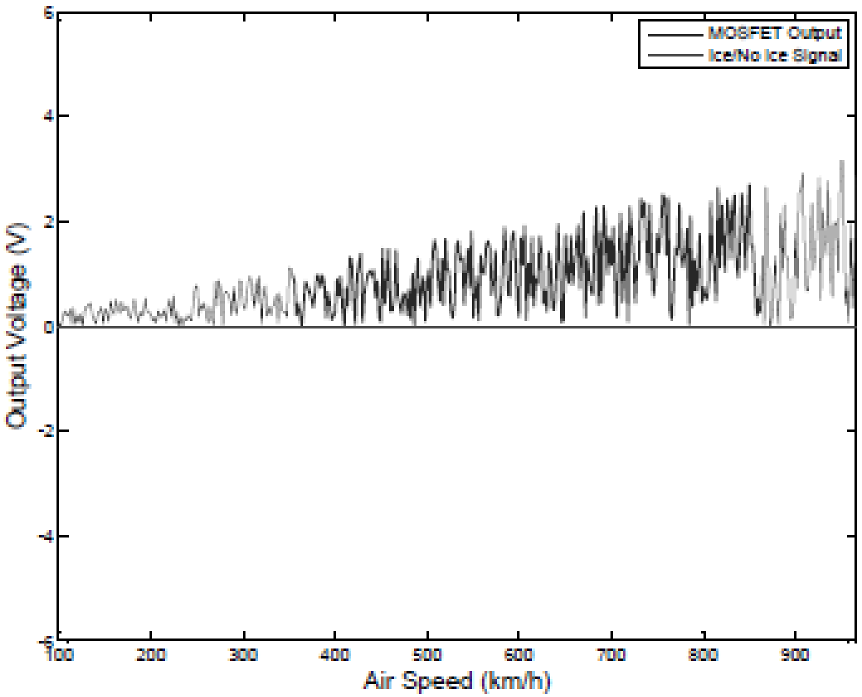
Results of testing with simulated rain: output voltage of the MOSFET, and the ice/no ice signal provided by the decision-making microprocessor, as a function of the air speed.



Results of testing with ice crystals: output voltage of the MOSFET, and the ice/no ice signal provided by the decision-making microprocessor, as a function of the air speed.



Results of testing with dust particles: output voltage of the MOSFET, and the ice/no ice signal provided by the decision-making microprocessor, as a function of the air speed.



The slight increase in the output voltage of the MOSFET at high air speeds is due to the fact that a very small fraction of the alpha particles are swept away from the detector at such speeds.

Testing under lightning strikes:

In this test, lightning was simulated by grounding the airframe and discharging an electrode that was raised to a potential of **2 million volts**[5] directly through the detector.

As expected, the lightning protection devices included in the detector quickly dissipated the excess charge within a fraction of a second, and, although the output voltage of the MOSFET swung substantially for a fraction of a second, the transient did not affect the operation of the detector and no false alarm was observed.

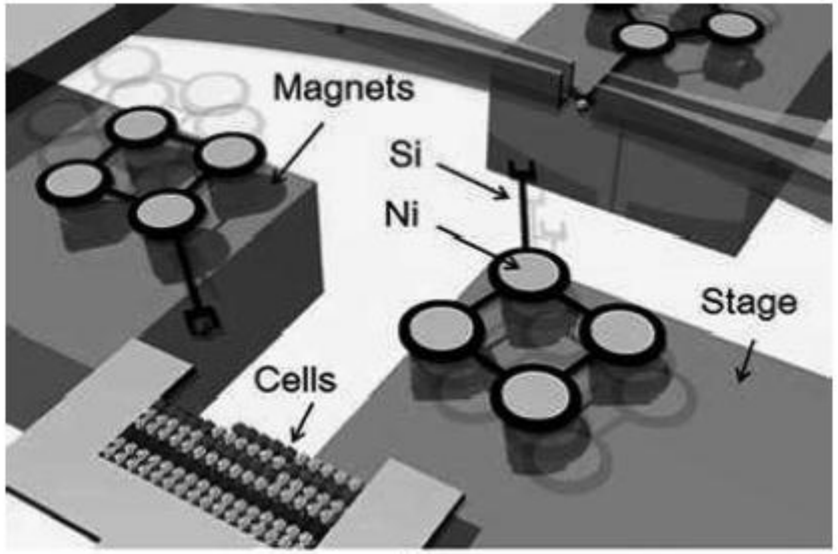
Results of testing with dust particles:

Airplanes sometimes encounter dust storms. The concentration of dust in such storms typically ranges between 5 and 15 mg per cubic meter of air . The size of the dust particles is typically found to be between several micrometers and 0.1 mm .

Dust with such specifications was injected into the air flow in order to test the response of the sensor in the presence of dust.

As can be concluded, the output of the **MOSFET is generally low and intermittent,**

Microfluidic, Microactuators, and Other Special Purpose Small-Scale Devices



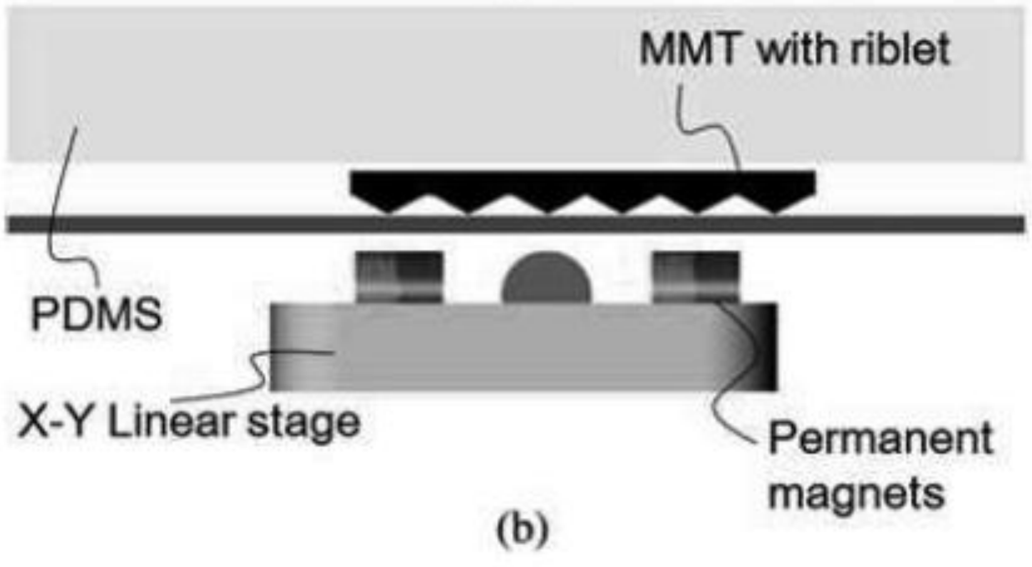


Figure shows a novel, recently introduced concept for a magnetic microrobot actuation in a microfluidic chip

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Inkjet-printed microfluidic RFID-enabled platform for wireless Lab-on-Chip applications

The purpose of the sensor is to identify various fluids such as water, alcohol, ethanol, etc

Quiz

1) True or false: All aircraft icing detectors depend on optics for tracking the formation of ice.

Ans:

False. The newest aircraft icing detectors use an a-particle source and an Alpha-particle detector

2) True or false: Aircraft icing detectors that depend on electromagnetic principles are the most accurate.

Ans: False. These types of detectors are the least accurate.