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# THERMAL DRIFT COMPENSATION WITH ON-CHIP MEMS PIEZOELECTRIC CAPACITIVE ACCELEROMETER

**Dr. Vijay Prakash Singh**
Research Guide, Department of Electronics & Communication Engineering, School of Engineering, Sri Satya Sai University of Technology & Medical Sciences, Sehore, MP, India

**Dr. Suneeta Kintali**
Research Co-Guide, Department of Computer Science & Engineering, JB Institute of Engineering and Technology

**Jupudi Vamsikrishna**
Research Scholar, Department of Electronics & Communication Engineering, School of Engineering, Sri Satya Sai University of Technology & Medical Sciences, Sehore, MP, India

## 1. ABSTRACT

The new advances in microelectronics innovation and the enormous development of the remote correspondence market have brought a lot of revenue into micro electro mechanical framework (MEMS) gadgets such as channels, oscillators, and switches. A scientific examination and a remuneration structure for temperature floats of predisposition and scale factor of a mass silicon MEMS capacitive accelerometer are introduced. The insightful model for the temperature float of inclination and temperature float of scale factor is set up dependent on the investigation results of warm twisting and firmness temperature reliance. Temperature drift is a key boundary influencing the general exhibition of high exactness and high security MEMS accelerometer. A three-dimensional design model of sandwich MEMS accelerometer made out of three distinct materials was set up utilizing limited component technique. At that point, warm mechanical coupling field investigation was performed dependent on the construction model, and the temperature float was quantitatively portrayed through separating the accelerometer's differential capacitance variety and its pace of progress. The accelerometers with various degrees of flood are displayed by chip cement substrate models to examine the deformity of touchy segment actuated by temperature change.

**Keywords:** Micro Electro Mechanical Systems (MEMS), temperature drift, capacitive accelerometer.

## 2. INTRODUCTION

Micro Electro Mechanical Systems (MEMS) have become exceptionally encouraging systems in the 21st century. Because of their scaling down, assortment, and soundness, MEMS creation is generally utilized in the production of accelerometers, gyrators, pressure nano-meters, and so on In MEMS sensor systems, micro accelerometers assume significant parts in items such as auto systems and route systems and are bit by bit being utilized in aviation and other cutting edge fields. Especially, the capacitive accelerometer has the remarkable benefits of straightforward handling, high return, a low temperature coefficient, low clamor, and high

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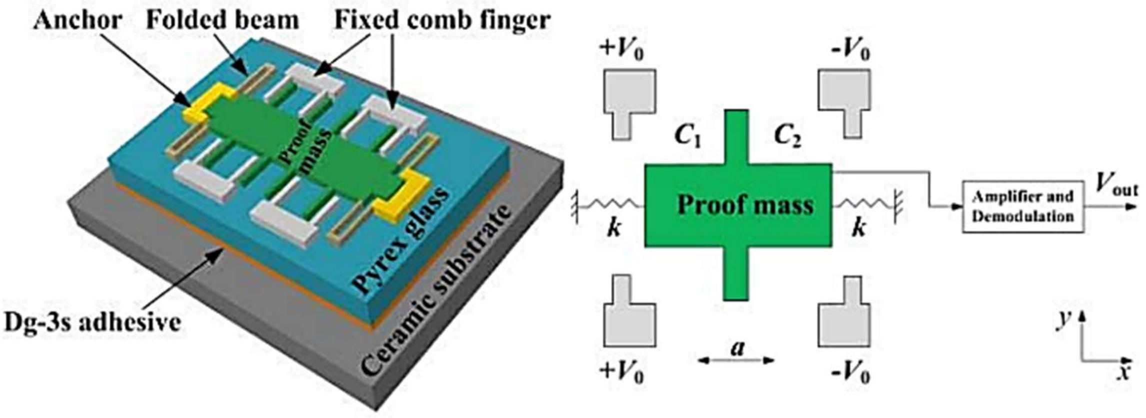
affectability. In this manner, the improvement of capacitive accelerometers has become a key exploration object, both at home and abroad. Through the improvement of handling innovation, circuit coordinating, and streamlining of foundational layout, the impact of warm commotion of the capacitive accelerometer can be decreased, and the affectability of the gadget can be improved. In any case, the exactness of the speeding up sensor is enormously influenced by the temperature. At the point when the temperature conditions are poor, a high temperature coefficient, low linearity, and temperature float are incredibly normal. Subsequently, research on high-accuracy, low-temperature affectability MEMS accelerometers has gotten incredible consideration.

The temperature drift of bias (TDB) and temperature drift of scale factor (TDSF) are the two principle pointers that portray the impacts of warm marvels on accelerometers. The logical recipes for the TDB and TDSF of the symmetric search capacitive accelerometer were acquired over a hypothetical investigation and the temperature pay structure was intended to lessen the TDB and TDSF of the accelerometer. It got a low temperature coefficient and high linearity by improving the sensor structure and investigated the hypothetical connection between the construction and linearity of the devices. Execution shifts brought about by temperature varieties have gotten increasingly problematic. To precisely show the conduct of MEMS, it is important to precisely register the coupling. Warm, underlying, and ecological activities ought to be considered in the displaying, recreation and plan of the gadgets. Multiphysics displaying and reenactment are progressively received in uncovering and taking care of coupled multiphysics issues of MEMS. The presentation of an accelerometer is worried about deviations in gadget execution because of natural temperature varieties. It is significant that an accelerometer's presentation is sufficiently powerful to temperature varieties. An ideal and powerful plan is profoundly attractive with respect to gadget plan. Subsequent to deciding the particular construction, measurement, and pressing technique, the estimations of TDB and TDSF were gotten, so these two boundaries can be utilized to direct the hypothetical plan of the gadget. A TDB of 179 µg/°C and a TDSF of −9.8 ppm/°C through the plan of the construction. They utilized a two-sided wire bond technique to kill the first pressure and improved the dependability of the gadget. It received a four-point support technique to lessen the contact region and got a linearity of 0.435% and a TDB of 0.02%/°C. It utilized a concentrated situating technique to get great linearity and a TDSF in the scope of −40 to 125 ◦C with a float of 0.3%. The estimation of the same extension proportion in the current logical equation is examined and brought into the model of the unbalanced design.

### 2.1 Principle of the Capacitive Accelerometer

The worked on model of the capacitive accelerometer worried in this paper is appeared in Figure 2.1. The touchy part is a silicon-based design supported flexibly by four collapsed radiates and is clung to a Pyrex glass substrate, which is joined to a ceramic substrate with the Dg-3s glue [Figure 2.1(a)]. The detecting part is an open-circle circuit to distinguish the differential capacitance framed by the brush finger capacitors of touchy part [Figure 2.1(b)]. The yield voltage is corresponding to the capacitive contrast of capacitors C1 and C2.



(a) (b)

**Figure 2.1. Brief structure and principle view of capacitive accelerometer. (a) Structure view. (b) Principle view of open-loop capacitive accelerometer.**

The mathematical boundaries of the created accelerometers are not the same as the plan format due to the drawing mistake. The plan width of the collapsed radiates is 5 μm, yet the genuine manufactured boundary is ~4.5 μm. Also, the normal width contrast of two shafts is ~0.2 μm. The short perspective on 1/2 of the accelerometer delicate design is appeared in Figure 2.2. At the point when quickening is applied, the verification mass will move the touchy way and create the capacitive distinction, which can be determined as follows:

$$\begin{aligned}\Delta C &= C_1 - C_2 \\ &= \varepsilon_0 \varepsilon_r S \left( \frac{2}{d_2 + x_m} + \frac{1}{d_1 - x_m} - \frac{1}{d_1 + x_m} - \frac{2}{d_2 - x_m} \right)\end{aligned} \quad (2.1)$$

where ε0 is the dielectric consistent of the vacuum, εr is the overall dielectric steady, xm is the removal of the evidence mass, and S and d are the confronting zone and hole between the capacitor plates, individually.

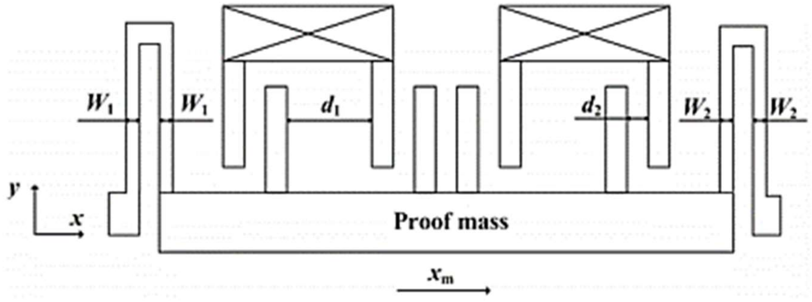


**Figure 2.2 Brief view of 1/2 of the accelerometer sensitive structure.**

## 2.2 Effects of Temperature Variations on the Accelerometer

### 2.2.1 The Material Properties

At the point when the accelerometer works in a wide temperature range, the temperature varieties will result in thermal deformation, thermal stresses and changes in Young's modulus of the material, and at last reason yield deviations of the accelerometer. As the accelerometer is intended to work in applications where critical temperature varieties are normal, the impact of temperature on the gadget execution is a significant concern. Accordingly, the impact of warm mechanical coupling to the yield capacitance should be resolved for the advancement or temperature remuneration of the accelerometer. The impacts of temperature minor departure from the accelerometer can be decoupled into three unique impacts: changes in the Young's modulus, thermal deformation and thermally incited stresses. The impact of temperature on the Young's modulus of the material changes can be approximated as

$E(t) = E(t_0) + E(t_0)TC_E\Delta t$ (2.2)

where E(t) is the Young's modulus under temperature t; E(to) is the Young's modulus under reference temperature t0 ; TCE is the temperature coefficient of Young's modulus; Δt is the adjustment in temperature.

### 2.2.2 Output Capacitance

Temperature varieties result in yield deviation because of warm twisting and changes in material properties. The yield capacitance of the accelerometer at various temperatures is appeared in Figure 2.3. The yield capacitance at reference temperature 20 °C is set to a unitary worth, and the yield capacitance at different temperatures is a relative incentive to the one at 20 °C.

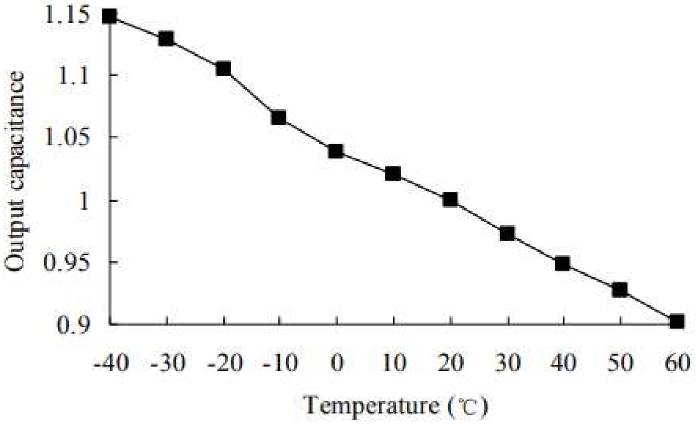


**Figure 2.3. Output capacitance at different temperatures**

It is seen that from −40°C to 60°C, the yield capacitance has a straight change pattern. The yield capacitance diminishes with the expanding of temperature. The greatest yield deviation can be 14.7%, which is found at −40°C. The yield deviation is essentially brought about by warm misshapening and changes in Young's modulus. The temperature varieties cause in the presentation float of the accelerometer, and in the long run lead to measurement mistakes. Hence, thinking about the natural temperature varieties and temperature-actuated warm mechanical coupling is essential in the plan of an accelerometer. Temperature remuneration technique or a hearty construction considering vulnerabilities for the plan could be created. Figure 2.3 gives a reference to temperature remuneration and a plan objective for strong plan by limiting the impact of temperature varieties comparable to the yield execution of the accelerometer.

### 2.2.3 Resonance Frequency

As the volume of the accelerometer is exceptionally little and the material (silicon) of the accelerometer has an extremely high coefficient of warm conductivity, it is assumed that the temperature of the accelerometer approaches the ecological temperature. The accelerometer is assumed to be a versatile body in its working temperature −40 to – 60°C. At that point inertial loads and uniform temperature loads are applied to the limited component model of the accelerometer and a modular investigation and warm mechanical coupling examination are performed. The difference in the first reverberation recurrence with temperature is appeared in Figure 2.4.

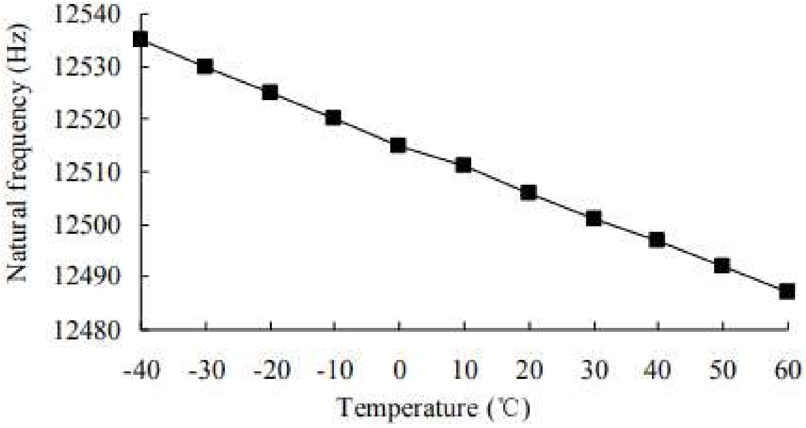


**Figure 2.4. 1st resonance frequency vs. temperature.**

## 3. LITERATURE REVIEW

**Eurico Esteves Moreira et al (2020):** This paper clarifies about the single-pivot thunderous MEMS accelerometer is introduced here. The objective is to accomplish the greatest affectability on a bunch of predefined imperatives: little impression of 500 m × 500 m, vacuum activity under 150 Pa (prerequisite for a solitary chip IMU) and creation utilizing a Bosch silicon surface micromachining measure. The sensor is formed by twofold finished tuning fork resonators in differential engineering and a power enhancement system to expand its affectability. A total portrayal of the gadget was performed including shut circle activity. A corresponding basic subsidiary shut circle regulator engineering refreshes continuously the excitation recurrence to a large portion of the reverberation recurrence of the resonators. A scale-factor of 170 Hz/g and a non-linearity of 0.63 %FS (activity scope of ±1 g) were tentatively measured. The general sensitivities of 0.08 %Hz/g/nkg and 0.48 %Hz/g are among the most noteworthy announced for DETF-based gadgets. Long haul (700 g/√Hz commotion floor measured), dynamic and warm float measurements are additionally revealed. The differential activity improved the warm execution by 77 %. Nonetheless, the steady requirement for better execution, lower creation costs and higher integrability is as yet driving enhancements for the accelerometer cutting edge and the look for options in contrast to the notable open-circle capacitive methodologies.

**Peng Peng et al (2020):** In this paper the creator clarifies about the Investigation of the Thermal Drift of MEMS Capacitive Accelerometers. Bundling pressure has critical impact on the warm strength of micro electromechanical framework (MEMS) gadgets, which use the bite the dust on-substrate bundling technique to interface the chips and the bundle shell. A specific cement, during the bundling cycle, is kept on the bundle shell by hands or machines to shape a transitional layer for sticking pass on and substrate. Because of the wildness of statement sum, the cement consistently stream out to shape flood structure in favor of kick the bucket chip. The glue flood will change the dispersion of warm pressure initiated by the changed temperature and further effect the warm soundness of gadgets, which is portrayed by the amount of warm float. This paper examines the commitment of cement flood to the warm float of brush MEMS capacitive accelerometers. The accelerometers with various degrees of flood are displayed by chip–cement substrate models to examine the twisting of delicate segment actuated by temperature change. The warm float is procured by a scientific strategy utilizing the construction twisting and the figuring of the differential capacitance. The warm float hypothesis for accelerometers with glue flood is checked by a progression of analyses. The results show that the cement flood can prompt 10% expansion of warm float contrasted and accelerometers without cement flood. What's more, this expansion can be stretched out by the lopsidedness of supporting light emissions. Subsequently, the flood marvel ought to be deliberately viewed as in the bundling cycle for exceptionally precise MEMS accelerometers.

## 4. PROPOSED METHODOLOGY

### 4.1 High-temperature Piezoelectric Accelerometer

A high-temperature accelerometer is generally utilized for recognizing the ignition motors' unusual conduct such as a thump impact. For thump identifying applications, accelerometers ought to have high operational temperature and high inflexibility because of the unreasonably unforgiving working states of the burning motor including high pressure (80 bars) and high-temperature (1,227°C) just as high climate. The high-temperature piezoelectric accelerometer is perhaps the most appealing accelerometer types for this application due to its high affectability, steadiness over a wide scope of temperatures, high inflexibility, basic and modest assembling measure. A pressure mode piezoelectric accelerometer utilizing YCOB single precious stones for ultrahigh-temperature applications. Thickness mode YCOB gems ($15 \times 7 \times 2$ mm$^2$) with the (XYlw)- 15°/45° cut were arranged and utilized for piezoelectric detecting precious stones. Inconel and high immaculateness alumina were mostly utilized for the materials of HT sensor get together and a platinum foil was utilized for electrical association. A schematic outline of the solid pressure mode accelerometer get together was appeared in Figure 4.1. A screw (7) was utilized to pack the piezoelectric component (4) between the seismic mass (2) and the base plate (1). A high immaculateness alumina (3) was picked for electrical insulation and the top and base electrodes (5) are made of platinum foil. The accelerometer execution was checked by exploratory results as an element of temperature up to 1,000 °C with a recurrence scope of 100–600 Hz. The steady affectability of the prototyped accelerometer was discovered to be 2.4 ± 0.4 pC/g across the measured temperature and recurrence range.

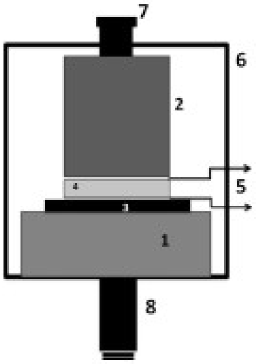


**Figure 4.1. Schematic diagram of the monolithic compression mode accelerometer**

The affectability as an element of abide time at 900 °C for 3 h was appeared in the little inset and the affectability was discovered to be 2.4 ± 0.4 pC/g. These results suggest the chance of utilizing YCOB single gems as PE sensors and acoustic sensors for ultrahigh-temperature applications. As of late a shear mode piezoelectric accelerometer with upgraded structure plan for high-temperature applications utilizing YCOB single gems. For high-temperature applications, shear mode sensors can offer higher temperature strength with decreased warm impacts from the sensor base, contrasted with the pressure mode sensor. Platinum electrodes were not utilized for this sensor to maintain a strategic distance from sensor disappointments because of flimsy film electrode corruption at high-temperatures. Also, the get together was cultivated by fixing the nut and screw to make up for the warm extension impact of every segment.

### 4.2 Performance metrics of MEMS Piezoelectric Capacitive Accelerometers

The improvement in execution attributes of the Piezoelectric Capacitive accelerometers is a significant focal point of examination for quite a while. The parameters that determine the performance of accelerometer are Prime axis Sensitivity, Cross axis Sensitivity, Temperature coefficient of offset (TCO) etc. Different boundaries are wide operation range, high resolution, shock survival ability, frequency response and structural simplicity, high Signal to Noise Ratio (SNR), ease, high exactness and high accuracy.

#### 4.2.1 Prime axis sensitivity

Accomplishing high affectability in micro-machined gadgets is a significant interest in the business as it satisfies the necessities of seismometers for oil investigation, quake expectations, microgravity measurement in vehicle air sacks and airplane applications. The numerical condition (4.1) alludes dislodging and decides the affectability of the accelerometer. The affectability relies upon (I) the size of the piezoresistive coefficients in silicon (ii) the thickness of the mass (iii) the crack pressure of silicon and (iv) the calculation of the accelerometer. Regularly prime pivot affectability above 0.5mV/V/g is called high affectability. The affectability can be expanded by utilizing high-esteem check materials and through novel plans

$$\Delta Z = - (MA_Z/K_Z) \qquad (4.1)$$

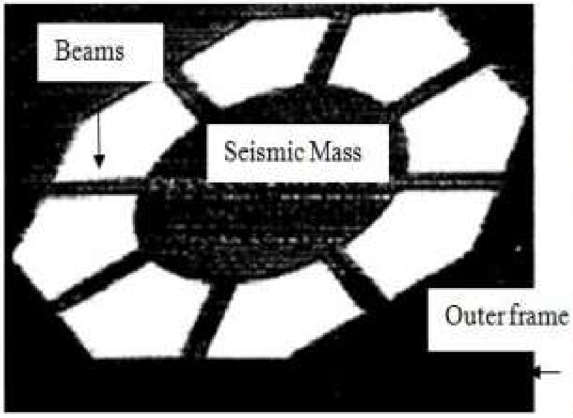
The sensitivity can be increased by

- Optimizing the mathematical plan of the accelerometer
- Increasing the mass of the device

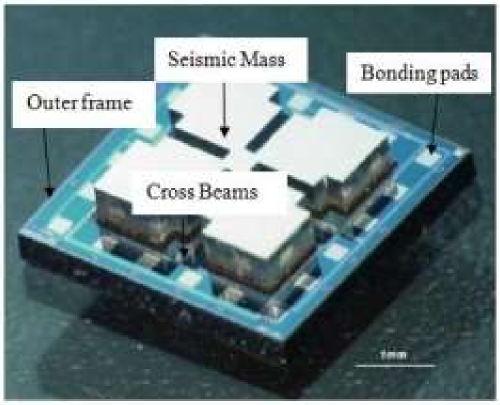
- Varying the doping concentrations in the piezoelectric coefficients.
- The electrical affectability execution is expanded by the utilization of silicon nanowire (SiNW) piezoresistance. SiNW shows a higher estimation of piezoelectric coefficients resulting in better (a) electrical affectability, (b) sign to noise proportion and (c) resolution. There is an increment of 2.51 times electrical affectability when silicon nanowires sensors are utilized than ordinary piezoelectric.

### 4.2.2 Cross axis sensitivity

Accomplishing low cross-pivot affectability in piezoelectric accelerometers is a basic issue for elite applications. In a sensor plan, the cross hub affectability is hypothetically anticipated to be zero and the cross pivot reaction is self-dropped when a suitable Wheatstone bridge is utilized. This is attainable just when all resistor esteems in the Wheatstone bridge are in a perfect world the equivalent and when the pressure prompted because of cross pivot speeding up is equivalent and inverse in nature. These conditions are hard to accomplish because of the varieties in the manufacture cycle. The cross pivot affectability decrease is accomplished by (i) lessening the distance between the focal point of the mass along the hub of quickening (ii) expanding the firmness consistent and (iii) diminishing the mass of the accelerometer. Changing the distance between the focal point of the mass along the bar length. In slant symmetric model the distance between the plane of the pillar and the focal point of the confirmation mass is decreased to limit the off-pivot affectability. An eight-beam piezoelectric accelerometer as demonstrated in figure 4.2 (a), gives cross hub affectability be that as it may, it is hard to shape the microstructure precisely without undermining issue contrasted with two bar and four bar accelerometer. In a solitary bar connect accelerometer, the cross pivot impact is suppressed by four fitting cross over piezoelectric to keep up similar proportion of malleable and compressive weight on the two sides of the extension. Anyway such course of action requires equity on front side circuits and rear engravings veils. Along these lines the piezoelectric are situated in focus to the beam width. Twenty 'p' type two terminal gadget as demonstrated in figure 4.2 (b), is set to frame six Wheatstone connects taking all things together six levels of opportunity; to accomplish relative cross hub sensitivities altogether the six axes.



(a)



(b)

**Figure 4.2 Structures to improve cross axis sensitivity (a) Eight beam accelerometer (b) Cross beam accelerometer**

### 4.2.3 Temperature sensitivity

The best test in utilizing piezoelectric accelerometer is the affectability to surrounding temperature. This is because of the great temperature subordinate piezoelectric impact and confuse in warm extension of composite materials during manufacture. At steady quickening, the yield of the accelerometer differs with temperature. Temperature affectability in a piezoresistive silicon accelerometer can be ascribed to three reasons specifically (i) Temperature dependency of diffused resistors in silicon because of dimensional changes (ii) Temperature dependency of piezoelectric coefficients and (iii) Temperature dependency of the flexible coefficient of glasslike silicon. This results in (i) Temperature Coefficient of Offset (TCO) and (ii) Temperature Coefficient of Sensitivity (TCS). Wheatstone bridge is successful in decreasing the TCO and for the most part, this impact can be disregarded. TCS impacts affectability due to the temperature reliance of the piezoelectric coefficients. In a solitary translucent silicon type piezoresistive accelerometer gadget, high-temperature activity is restricted as the spillage flow is available at the p-n intersection among piezoelectric and substrate. Expansion in spillage current expands the temperature twofold the occasions which again supplements the spillage current harming the gadget. Spillage flow decrease in Silicon on Insulator Structure is accomplished by building up a solitary photograph veil in the covered oxide and segregating the piezoelectric from mass silicon without p-n intersections. This veil diminishes the quantity of manufacture steps contrasted with traditional piezoelectric accelerometers and can describe high heaps of about 500g at various temperatures.

### 4.3 Effects of temperature changes on-chip MEMS piezoelectric capacitive accelerometer

As temperature changes, the actual properties of the construction, the holding layer, and the PZT sensor will likewise change. Among the temperature subordinate property constants of piezoelectric materials, the dielectric consistent which shows most huge impact on electrical impedance. The capacitive permission, causing a move in the nonexistent induction measurements which will force troubles in the utilization of the sensor demonstrative interaction for certifiable designs. To make the sensor analysis methodology reasonable in a certifiable setting, temperature impacts on the susceptance should be perceived, and the degree of these impacts is analyzed in this segment. Both broken and debonded patches were inspected for the impact of temperature on the susceptance for every disappointment mode. The essential concern was that the slant of the susceptance would fluctuate diversely among various holding and sensor conditions, making it more hard to evaluate the holding condition through the assessment of the permission slant. The results of the temperature test on debonded patches. It tends to be considered that to be temperature expands, the capacitance estimation of the piezoelectric increments. On account of the equal idea of the slant changes, a sensor symptomatic calculation that is invariant of temperature changes can be created. In the event that the calculation utilizes a framework to discover distant piezoelectric sensors, the methodology can be temperature free, on the grounds that an anomaly will stay an exception at any temperature.

The impacts of temperature on the susceptance measurements of broken patches were likewise inspected. The strategy was equivalent to the debonding temperature test, however utilizing the wrecked patches from the past segment. The result of the messed up sensor temperature. Similarly as with the debonded sensors, the wrecked sensors carry on in an anticipated way as all the sensor measurements will move by a similar rate for some random temperature change. The change in both the debonded and broken sensor's susceptance signals demonstrates anyway that temperature impacts should be taken out in a sensor analytic calculation, since sensor disappointment and temperature changes modify the susceptance signal likewise. The uniform change in different breakage rates would take into consideration temperature impacts to be taken out if a technique for exception identification is utilized.

## 5. RESULTS

Electrical portrayal of the scaffold formed resonator has been performed utilizing an organization analyzer. Two distinctive electrical portrayals of the extension recurrence reaction around the reverberation have been done 1) with an on-chip incorporated CMOS speaker and 2) straightforwardly with the organization analyzer (with no additional circuitry). The standard of activity of the on-chip readout circuit utilized depends on the incorporation of the capacitive current created by the vibrational development of the resonator by utilizing the inborn capacitance of a CMOS speaker. MEMS with on-chip intensification is because of the minimization of the Q- loading impact inalienable to the electrical identification technique utilized. The utilization of the on-chip readout circuit diminishes the estimation of the coupling capacitance between the excitation and readout electrodes (C0) on the grounds that no electrical associations with any test cushion for the readout electrode are utilized. Along these lines, the Q-factor is expanded because of the decrease of the parasitic current (across the coupling capacitance) that covers the motional current. Higher Q-factors (a factor of 10) are normal with low-pressure measurements, as it has been exhibited in past works dependent on cantilevers.

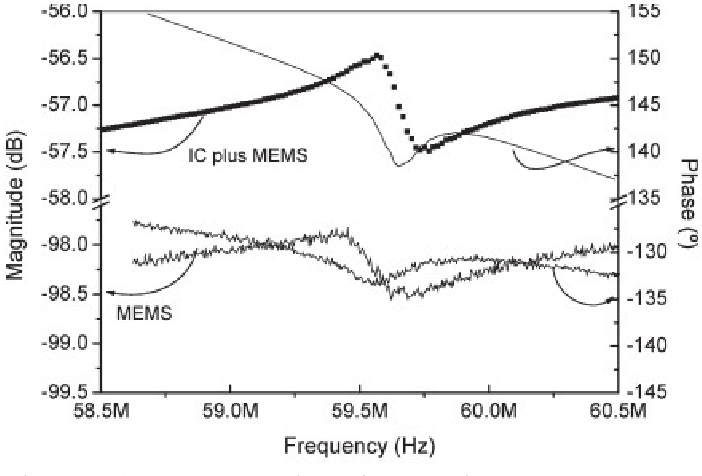


**Figure 5.1 Results obtained from a direct measurement of the MEMS (bottom graph) and using the on-chip amplifier (top graph).**

Figure 5.2 shows the transmission range S21 for various dc polarizations of the extension to show the springs oftening impact because of the electrostatic excitation of the mechanical design. An expansion of the applied voltage gives, as a result, a move in the resounding recurrence to bring down qualities.

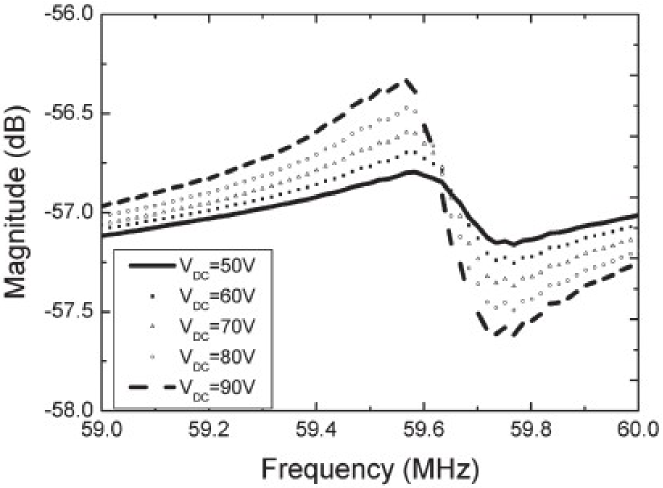


**Figure 5.2 Results obtained with the onchip accelerometer for different dc-applied voltages**

## 6. CONCLUSION

A piezoelectric sensor self-symptomatic cycle that acts in situ checking of the operational status of piezoelectric sensors and actuators was introduced. It was affirmed that both corruption of the mechanical/electrical properties of a piezoelectric and holding abandons between a piezoelectric and its host design could be distinguished utilizing the proposed method. piezoelectric accelerometer is one of the MEMS accelerometers used to detect speeding up dependent on the rule of piezoelectric. . To show the procedure, a resounding micro electro mechanical extension at 60 MHz with CMOS on-chip readout hardware has been actualized. The on-chip speaker diminishes the addition misfortunes of the MEMS gadget just as the Q-loading impact. For acquiring an eventual outcome utilizing this philosophy of CMOS–MEMS manufacture, it will be important to marginally alter the incorporated circuit bundling measure. The CMOS–MEMS post process can be performed, at the wafer level, to deliver the versatile constructions. From that point onward, the utilization of a microcap gadget at the wafer level permits a standard bundling.

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