DEFENCE RESEARCH & DEVELOPMENT ORGANISATION

SOLID STATE PHYISCS LABORATORY , DELHI

Summer Internship Project Report

On

Modelling Microbolometer Using Matlab/SIMULINK

&

Microbolometer analysis Using Conventor

Duration – 8 Weeks

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Under the Supervision of

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DECLARATION

I would like to express my sincere gratitude to DRDO – Solid State Physics Laboratory (SSPL) for providing me the opportunity to work on a meaningful and enriching internship project.

I hereby declare that the internship report titled 'Modelling Microbolometer Using Matlab/SIMULINK & Microbolometer analysis Using Conventor' submitted by me for the fulfillment of the requirements of the internship completion is a record of original work carried out by me during my internship at DRDO – Solid State Physics Laboratory (SSPL), under the guidance of Mr. Amit Kumar Vishwakarma sir (Scientist,SSPL)

This report has not been submitted previously, in part or full, to any other university or institute for any purpose.

I have duly acknowledged all the sources and references used in the preparation of this report.

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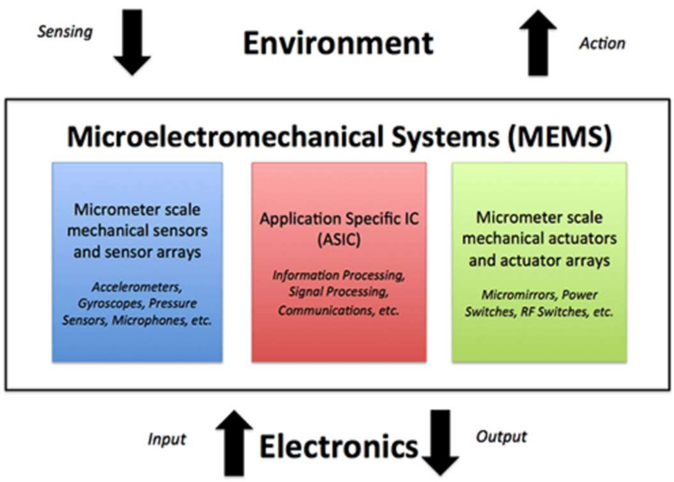
1.INTRODUCTION TO MEMS

Micro-Electro-Mechanical Systems (MEMS) are miniaturized mechanical and electro-mechanical elements that are fabricated using the principles of microfabrication. These systems integrate sensors, actuators, electronics, and mechanical structures on a single silicon substrate or chip. MEMS devices are typically measured in micrometers (µm), with components ranging in size from 1 µm to 1000 µm (1 mm). MEMS can perform functions such as sensing, signal processing, and actuation, often in real-time and with high precision. The interdisciplinary nature of MEMS combines mechanical engineering, electrical engineering, materials science, and semiconductor technology.



Functionality of a MEMS device. (Image: ITRS)

1.1 Fabrication and Technology –

MEMS devices are primarily fabricated using CMOS-compatible microfabrication techniques, such as:

- Photolithography
- Etching (wet and dry)
- Thin-film deposition (CVD, PVD)
- Doping (ion implantation, diffusion)
- Surface and bulk micromachining
- Wafer bonding and packaging

1.2 Examples of MEMS Devices–

- *MEMS Accelerometers* – Measure acceleration and motion; used in smartphones, airbags, and wearable devices.
- *MEMS Gyroscopes* – Detect angular velocity; used in navigation systems, drones, and gaming controllers.
- *MEMS Pressure Sensors* – Monitor air or fluid pressure; used in automotive and biomedical fields.
- *MEMS Microphones* – Tiny microphones used in smartphones, hearing aids, and smart speakers.
- *MEMS Mirrors* – Used in projection systems and LIDAR for beam steering.
- *MEMS Microbolometers* – Thermal infrared sensors used in night vision and thermal cameras.

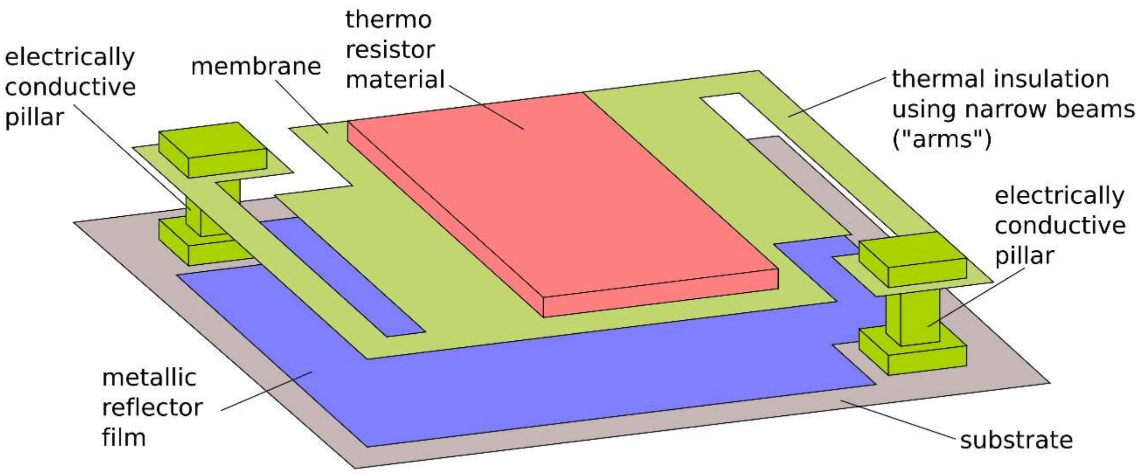
Future advancements in MEMS will be driven by continued innovation in materials science, fabrication methods, and system-level integration. These developments will not only enhance the performance and reliability of existing devices but also enable entirely new classes of applications.

In conclusion, MEMS technology stands at the forefront of modern engineering and is poised to be a foundational component in the next generation of intelligent and adaptive systems.

MICROBOLOMETER

Microbolometers play a crucial role in various modern civil and military applications. One of their key advantages is their compact size, which makes them ideal for integration into advanced and innovative electronic devices. Given the rapid advancements in this field, infrared radiation microdetectors have become a prominent area of research in academic institutions and scientific organizations worldwide. Many of these institutions actively collaborate with commercial companies in the field of research and development, leading to the continuous improvement of existing technologies and the creation of new products.

Microbolometers represent a promising class of resistive detectors with significant potential for the future. Their compatibility with CMOS fabrication technology adds a major economic advantage, as these devices can be manufactured using the same production lines and processes as standard CMOS integrated circuits.

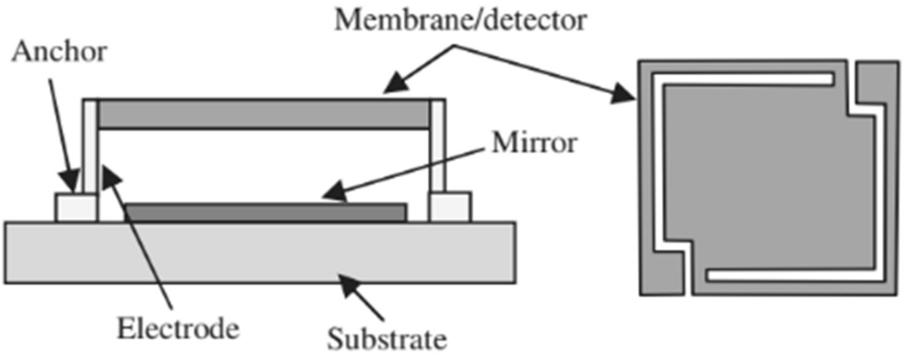


Simplified representation of a bolometric pixel

Source-wikipedia.org/wiki/Microbolometer

Microbolometer Structure

A microbolometer typically consists of three main components: the membrane, anchors (supporting legs), and the substrate. The membrane is suspended above the substrate and is connected to it via thin supporting legs, which serve to thermally isolate the membrane from its surroundings. This thermal isolation is critical for accurate infrared detection. On the substrate, a Readout Integrated Circuit (ROIC) is integrated, which is responsible for signal processing—converting the electrical signals generated by the sensing layer into usable output data, such as temperature or intensity values. To maximize the detector's efficiency, the entire structure is typically enclosed in a vacuum package, which eliminates thermal losses due to air convection, thereby enhancing sensitivity. The membrane itself is the key sensing element of the microbolometer. It comprises a top and bottom protective layer, with an active sensing material (commonly vanadium oxide or amorphous silicon) sandwiched in between. The membrane is carefully designed to withstand operational stresses and avoid structural failure, while maintaining excellent mechanical and thermal properties for radiation detection. The supporting legs not only provide structural integrity but also serve as electrical pathways to the ROIC. They enable biasing of the sensing material and allow current flow, which is used to detect changes in resistance caused by incident infrared radiation. To enhance performance, a reflective mirror is typically placed beneath the membrane. This mirror reflects unabsorbed infrared radiation back into the sensing layer, effectively increasing absorption and improving the overall sensitivity of the detector.



Cross sectional view of microbolometer

MICROBOLOMETER OPERATION

The operation of a microbolometer is very simple. Absorbed incident IR radiation on thermo-sensing material brings about temperature rise. This in turn causes temperature change and simultaneously electrical resistance and voltage change, which can be measured by ROIC(ReadOut Integrated Circuit) . This quantity can be finally transformed by external circuit to temperature. The thermal sensor is very attractive because of temperature and ambient light under which it can work (room temperature and complete darkness). Its other advantage is low weight, low power, large spectral response and long term operation compared to photon-based detectors

Microbolometer operation is based on heat flow equation :

This equation takes into consideration the temperature change dependency on the radiant p ower . The equation relation includes a heat (thermal) capacity C of microbolometer

$$C\frac{d(\Delta T)}{dt} + G(\Delta T) = \eta P e^{j\omega t}$$

where P0 is the amplitude of absorbing IR radiation power, η is the absorbance of the sensitive layer, ω is the angular frequency of IR radiation modulation and ΔT is the temperature difference of the detecting layer.

Because microbolometer operation is based on resistance change and high responsivity , resistivity growth current bias consequently causes emerging self-heating effect (Joule heating effect). Solving the heat-balance equation (1) gives the temperature rise in the detector :

$$\Delta T = \frac{\eta P_0}{G\sqrt{1+\omega^2\tau^2}}$$

where, **τ** =C/G is the time constant (thermal response time).

NOISE THEORY BACKGROUND :

The detection capability of microbolometer is limited by various noises. Four main types of noises in microbolometer devices: Johnson noise, 1/f noise, temperature fluctuation noise and background fluctuation noise.

A. *Johnson Noise*

The Johnson noise is caused by random motions of the charge carriers. Microbolometers are resistors indeed, this is why the phenomena takes place there

$$V_j = \sqrt{4kT_m R_m \Delta f}$$

The Johnson noise component

where k is the Boltzmann constant, Tm is the bolometer temperature, Rm is the bolometer resistance and Δf is the bandwidth of the integration time.

B. *1/f Noise*
1/f is a meaningful noise source of semiconductors at low frequencies. It is caused by quasi-random moving photons comes from the surrounding of the detector.

C. *Temperature Fluctuation Noise*
A thermal detector, which is in contact with its environment (by conduction and radiation), exhibits random fluctuations in temperature, since the interchange of heat with its surrounding has a statistical nature; this is known as temperature fluctuation noise.

$$T_{TF} = \sqrt{\frac{4kT_m^2\Delta f}{G(1+\omega^2\tau_{TH}^2)}}$$

Temperature fluctuation expression

D. *Background Radiation Noise*

During the heat exchange between the detector and its surroundings is negligible, in reference to the radiation exchange, background fluctuation noise is temperature fluctuation noise.

E. *Responsivity and Detectivity*

linear dependency between resistance and temperature :

$$R = R_0\left[1+\alpha(T-T_0)\right] = R_0(1+\alpha\Delta T)$$

Where α is temperature coefficient of resistance (TCR), (TCR), R_0 is the resistance at the temperature T_0.

output voltage signal Vout :

$$V_{out} = I_{bias}\Delta R = \frac{\eta I_{bias}\alpha R_0 P_0}{G\sqrt{1+\omega^2\tau^2}}$$

where I_{bias} is the bias current of microbolometer.

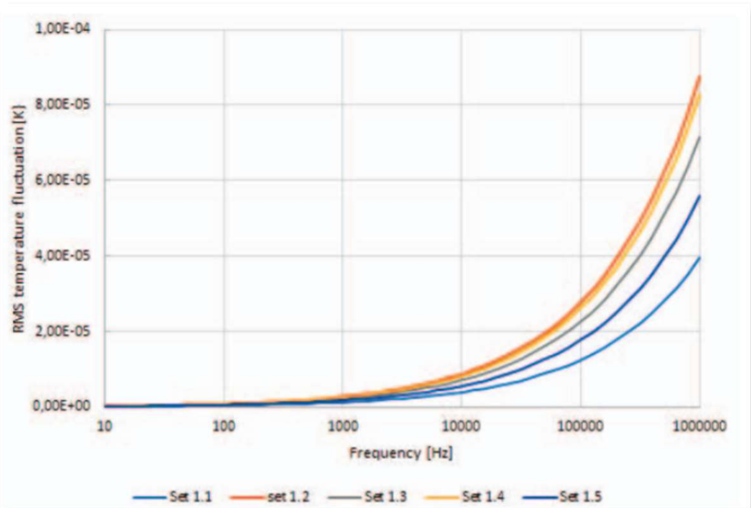
Having V_{out} we can get responsivity $\Re$ defined by the following equation:

$$\Re = \frac{V_{out}}{P_0} = \frac{\eta I_{bias}\alpha R_0}{G\sqrt{1+\omega^2\tau^2}}$$

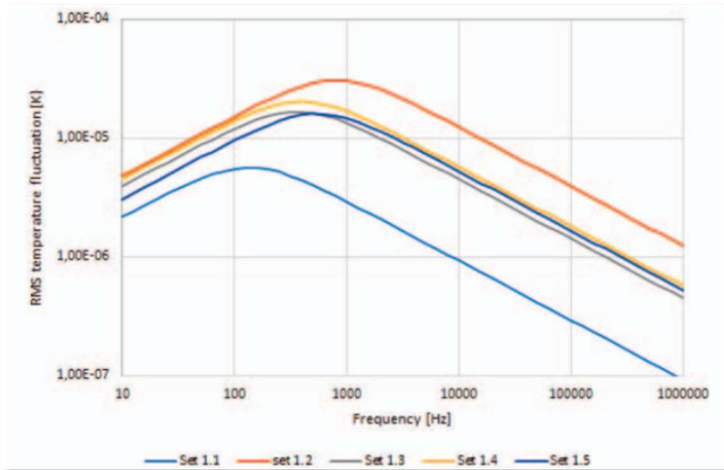
DATA SETS AND CHARACTERISTIC CURVES FOR MICROBOLOMETER CIRCUIT ANALYSIS

	Set 1.1	set 1.2	Set 1.3	Set 1.4
R_{TH}	9,44E+04	4,64E+05	3,09E+05	4,14E+05
G_{TH}	1,06E-05	2,16E-06	3,24E-06	2,42E-06
C_{TH}	1,25E-08	4,21E-10	1,42E-09	9,70E-10
τ_{TH}	1,18E-03	1,95E-04	4,40E-04	4,01E-04

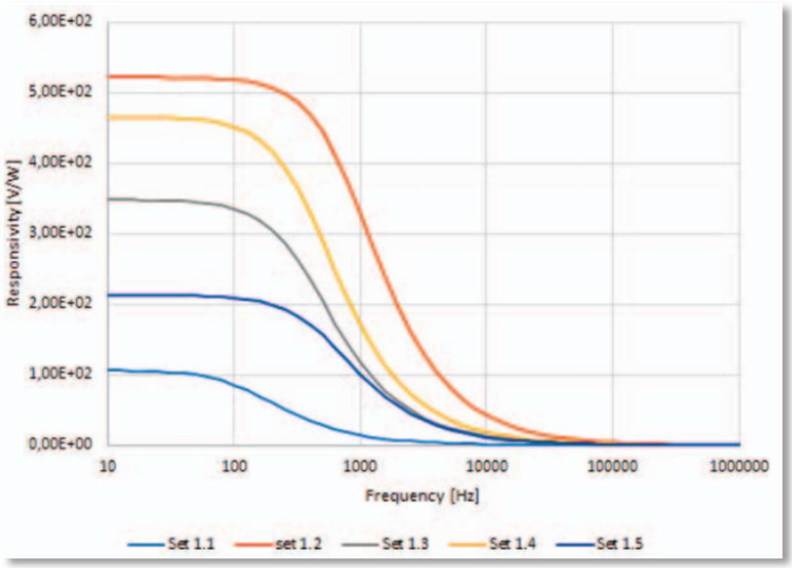
SETS OF DATA USED IN CALCULATION AND SIMUATION



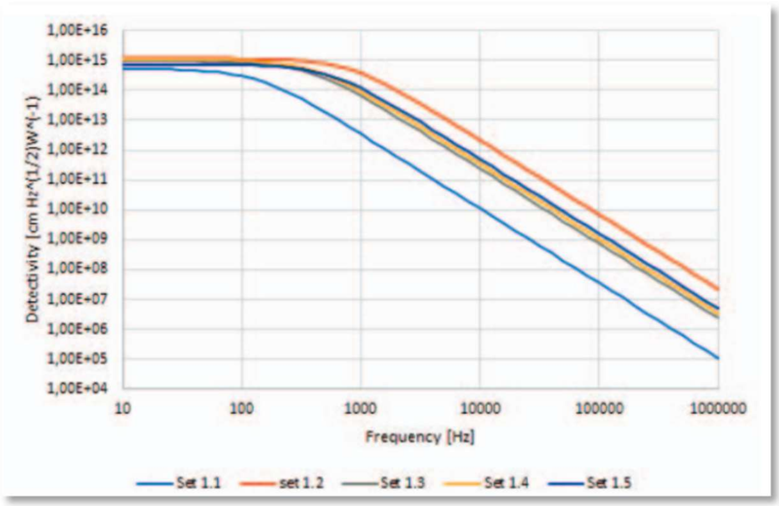
- Spectral density of Johnson noise for various C,G, τ parameters used in microbolometer electrical circuit model.



- Spectral density of temperature fluctuation noise (rms temperature fluctuation for various C,G,τ parameters used in microbolometer electrical circuit model.



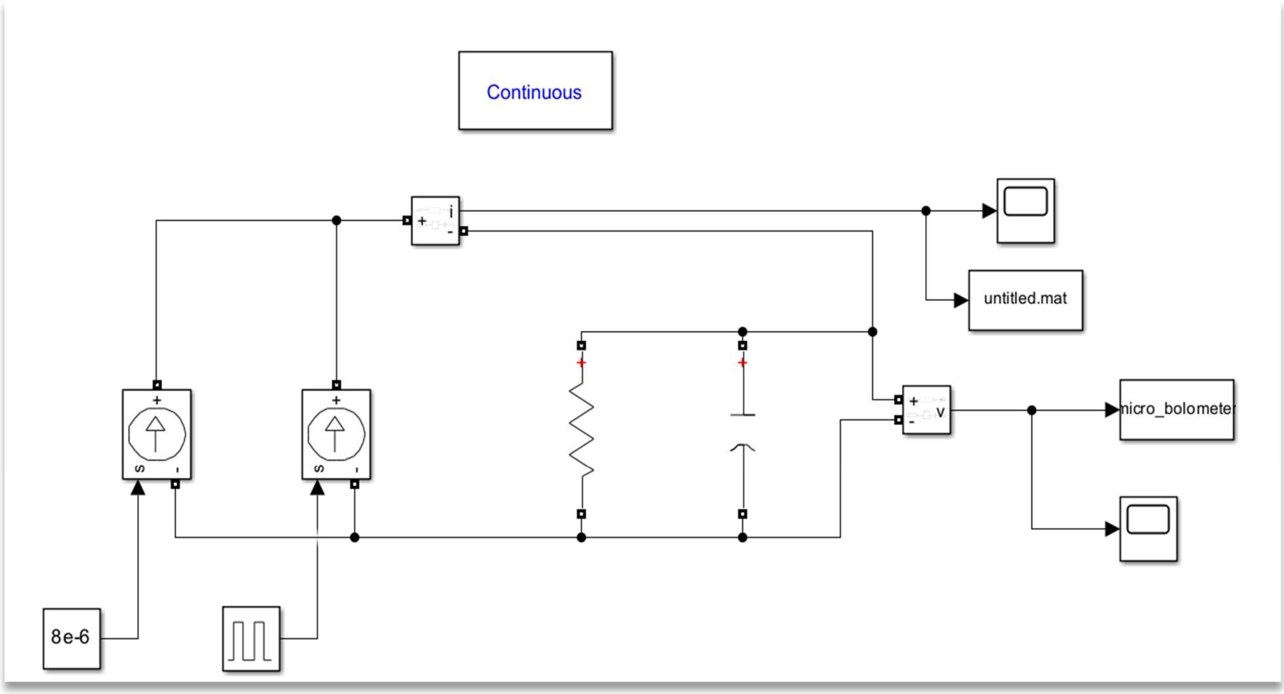
Responsivity for various C,G, τ parameters used in microbolometer electrical circuit model.

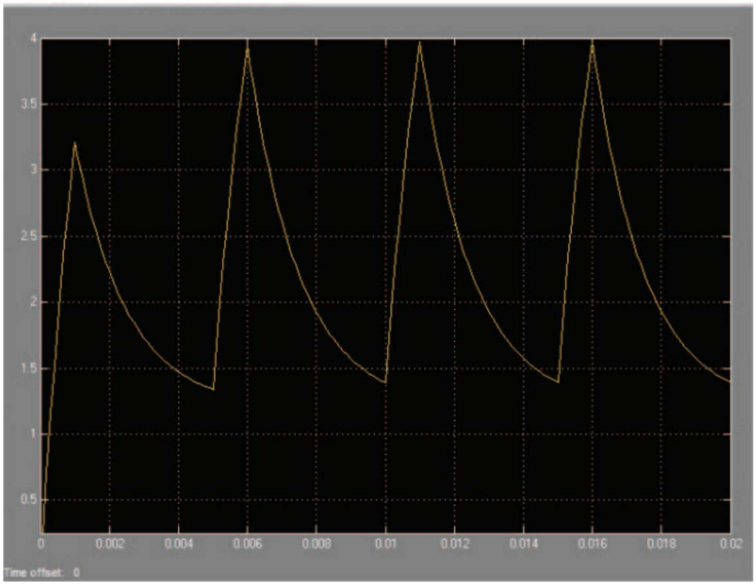


Detectivity of Johnson noise (for various C,G, τ parameters used in microbolometer electrical circuit model.

CIRCUIT MODEL OF MICROBOLOMETER USING SIMULINK / MATLAB

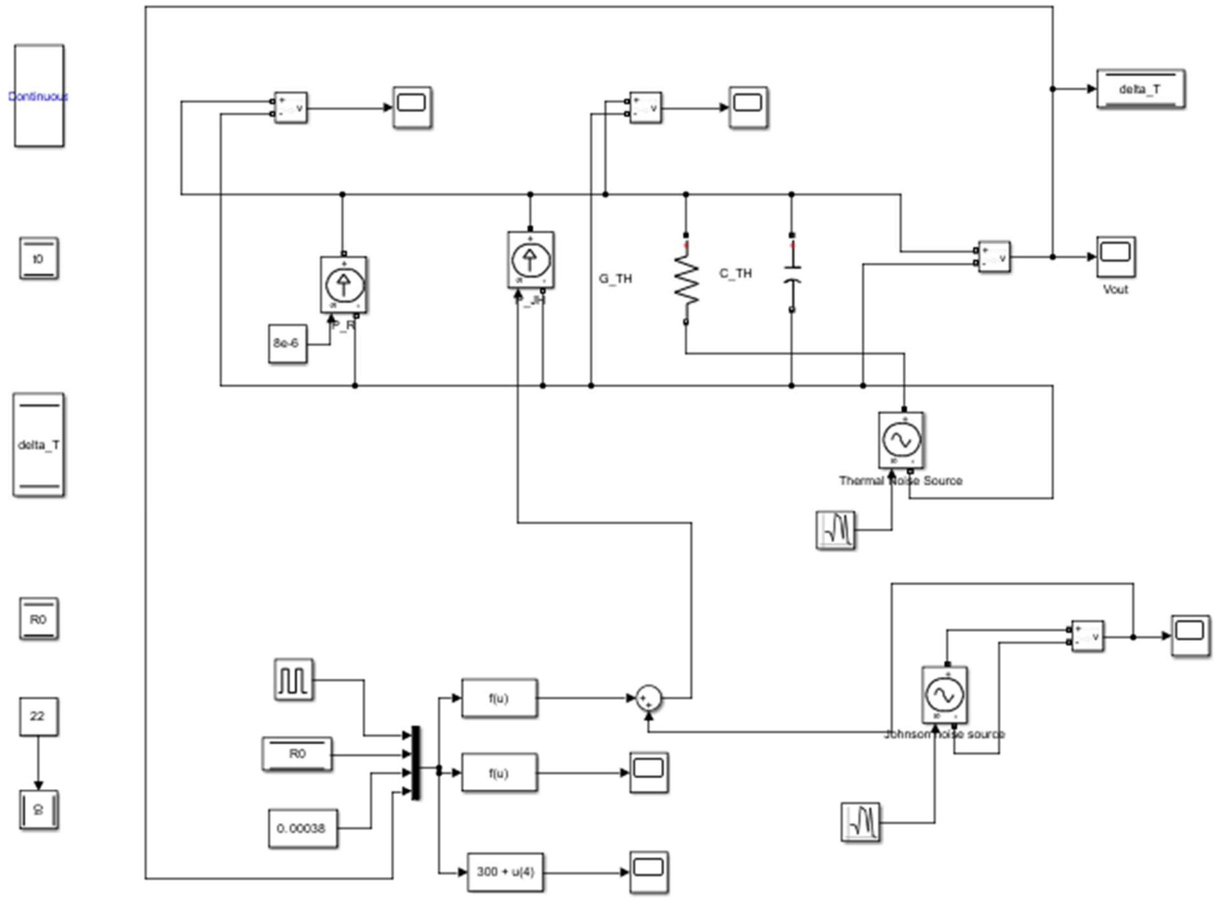
A.MICROBOLOMETER CIRCUIT MODEL WITHOUT NOISES IN SIMULINK





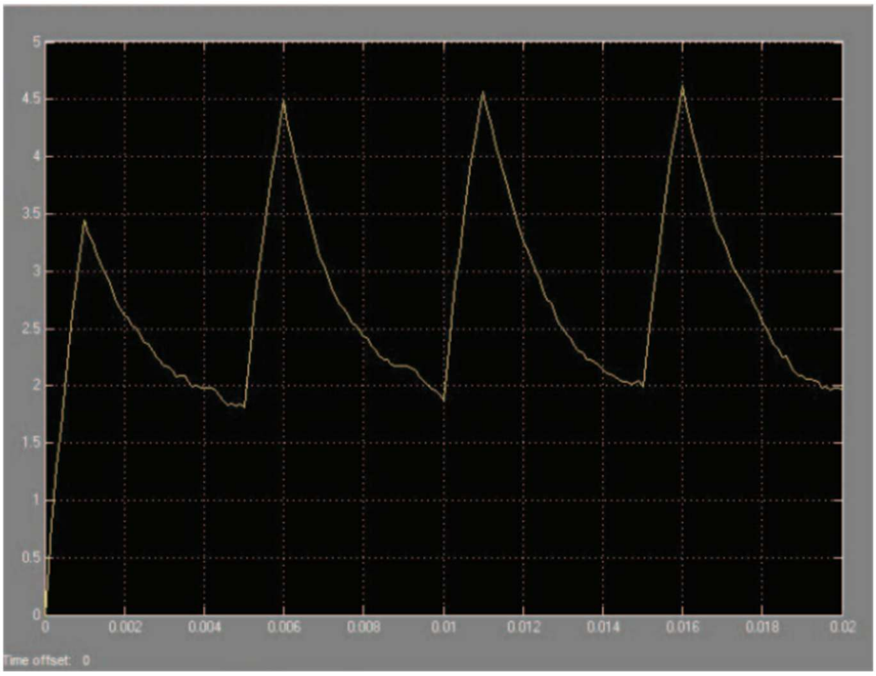
Temperature rise characteristic without application noise sources.

B. MICROBOLMETER COMPLEX CIRCUIT WITH NOISES



Implementation complex circuit model of microbolometer in SIMULINK.

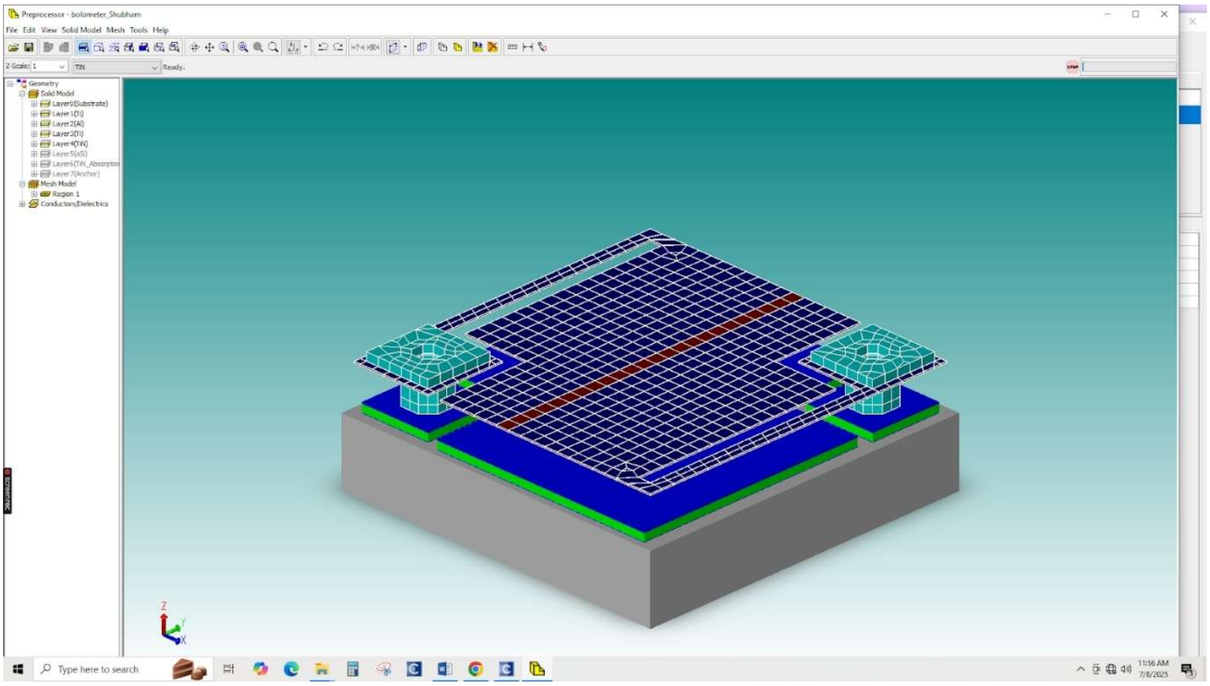
The random sources generated values in ranges calculated in whole range of frequencies 10Hz – 1MHz.



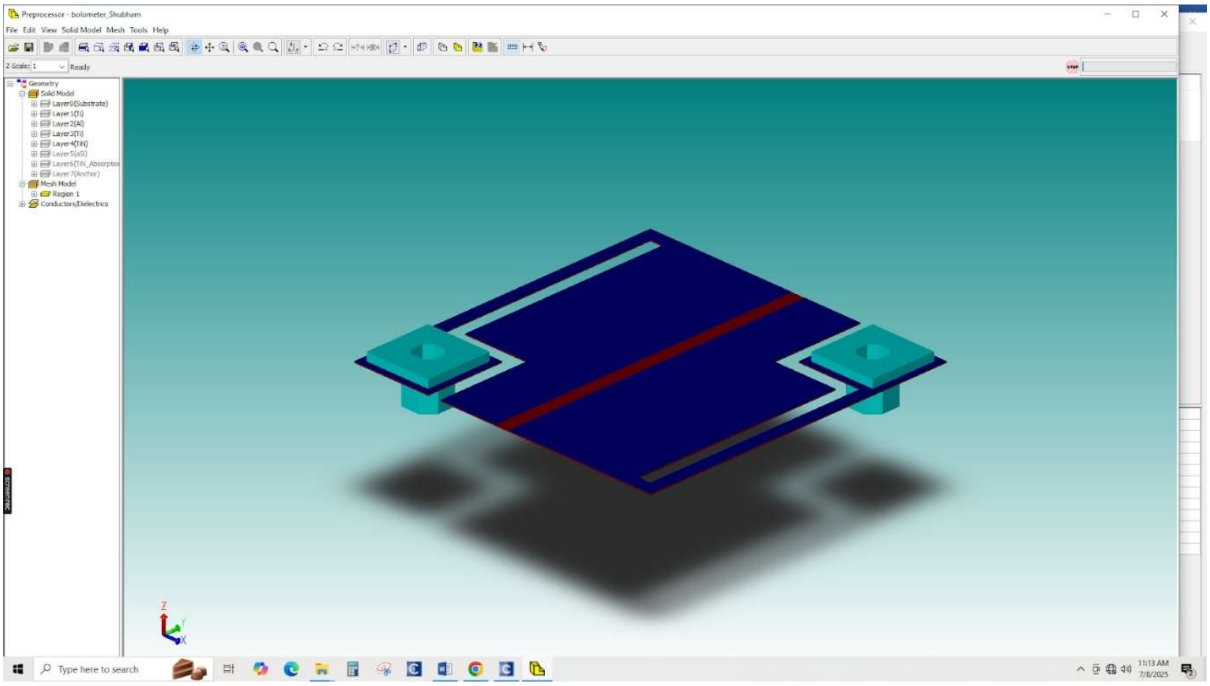
Temperature rise characteristic with application noise sources.

MICROBOLMETER ANALYSIS USING CONVENTOR

Microbolometer 3D model in Conventor :



Microbolometer cross sectional view :



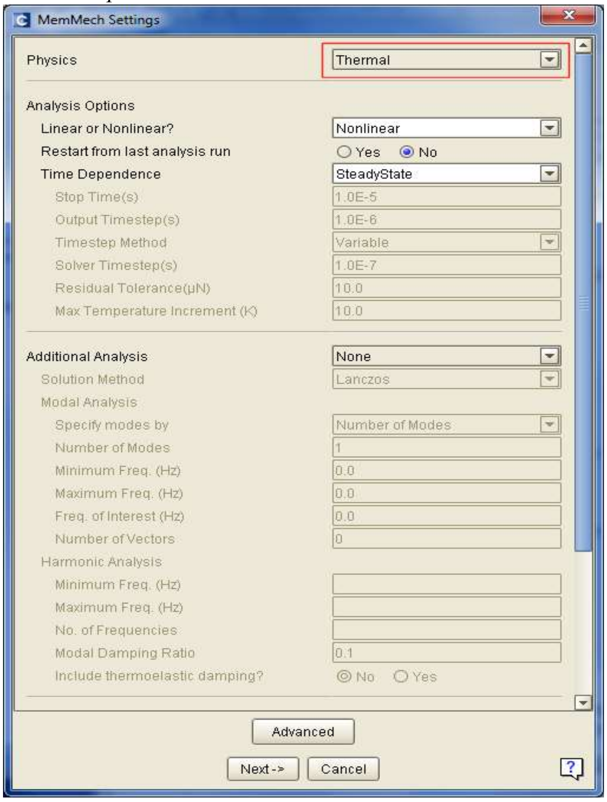
Fundamental Design Parameters :

- steady-state thermal analysis to determine the total thermal conductance, G
- transient thermal analysis to determine the thermal time constant, τ, and total heat capacity, C
- steady-state electrothermal analysis to generate a voltage-temperature curve
- steady-state electrothermal analysis to determine the electrical resistance, R, from a static current-voltage curve
- steady-state thermomechanical analysis to resolve pre-stress and thermal

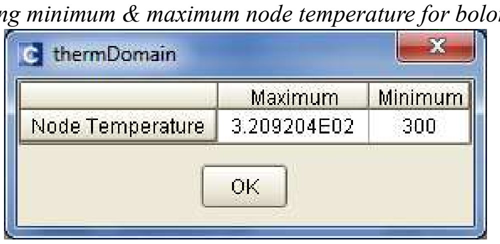
1 .steady-state thermal analysis to determine the total thermal conductance, G

1.1) setting parameters for thermal analysis

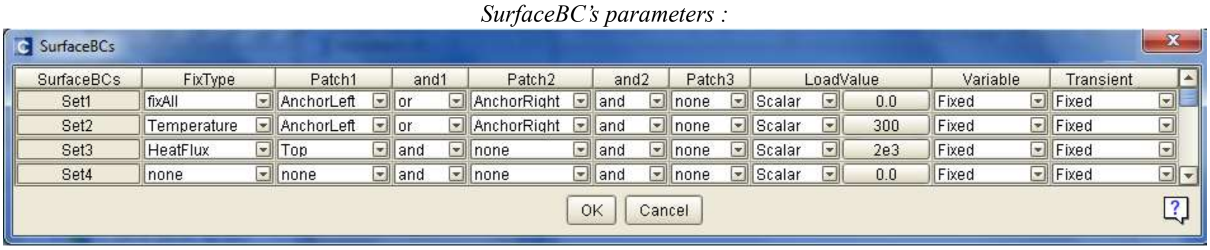
MemMech parameters :



setting minimum & maximum node temperature for bolometer

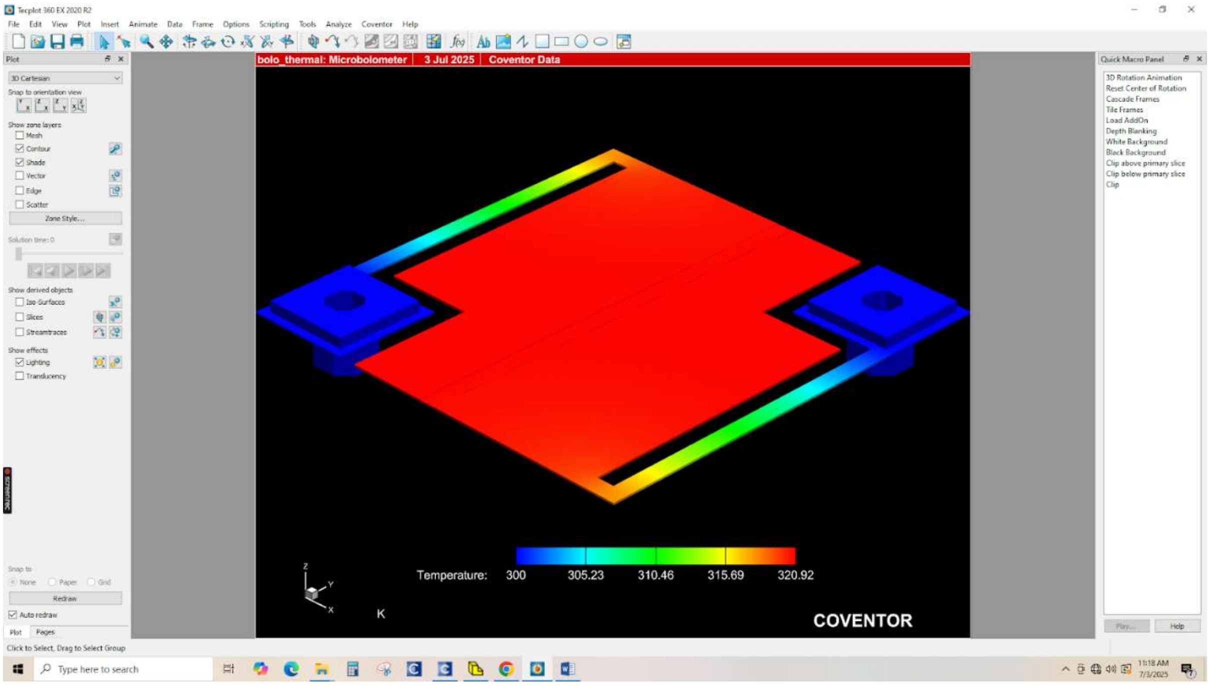


SurfaceBC's parameters :

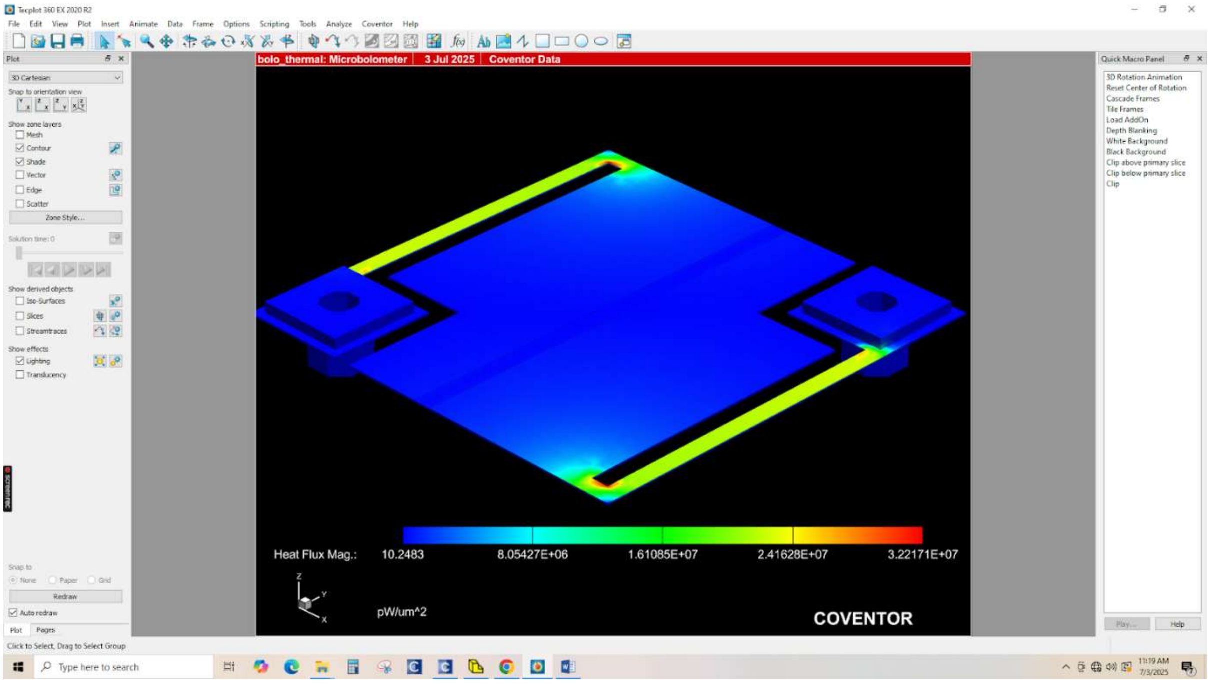


Results :

Temperature Analysis Result in 3D model :

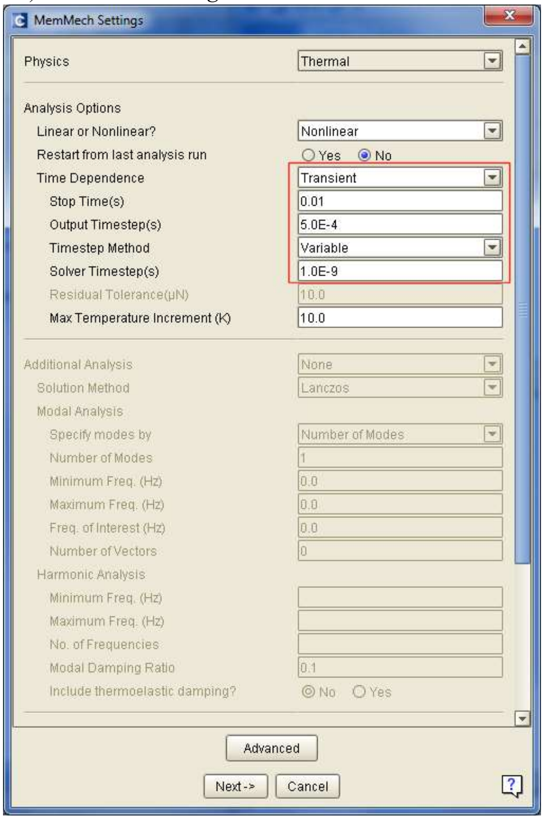


HeatFlux Result in 3D model :

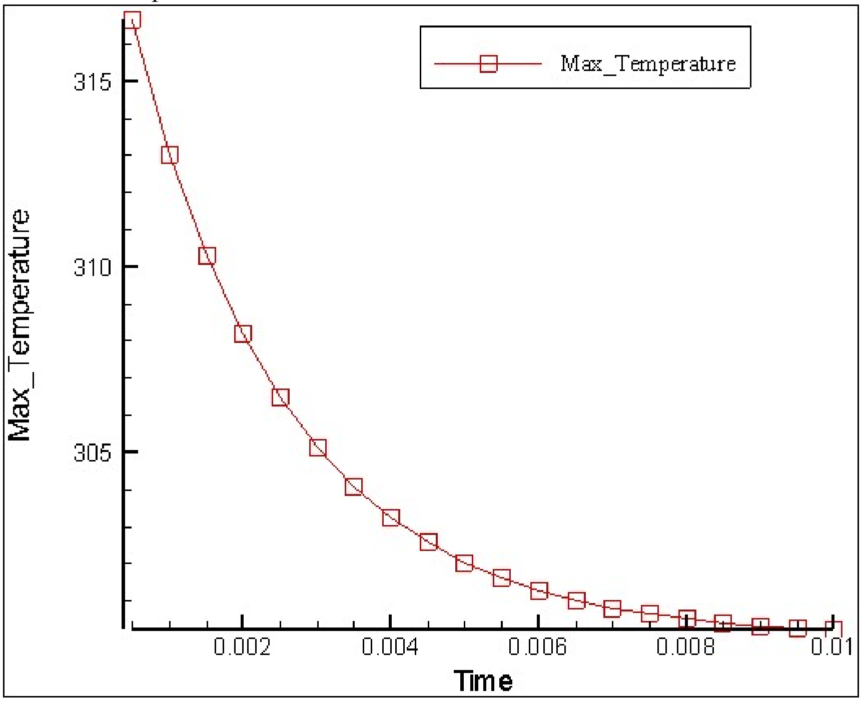


2. transient thermal analysis to determine the thermal time constant, τ, and total heat capacity, C

2.1) MemMech Settings

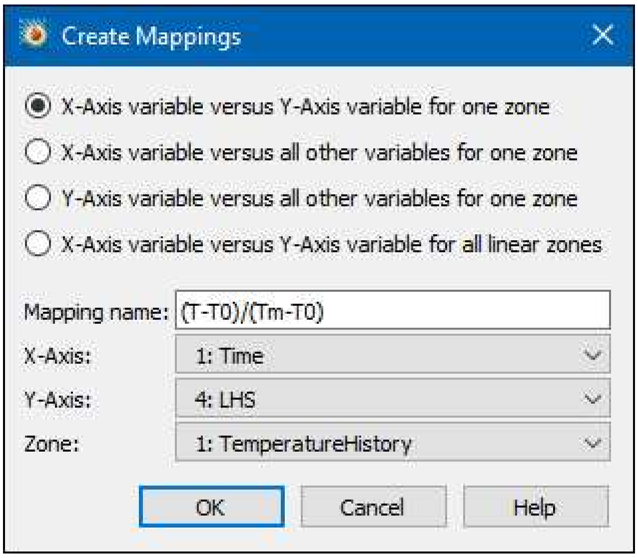


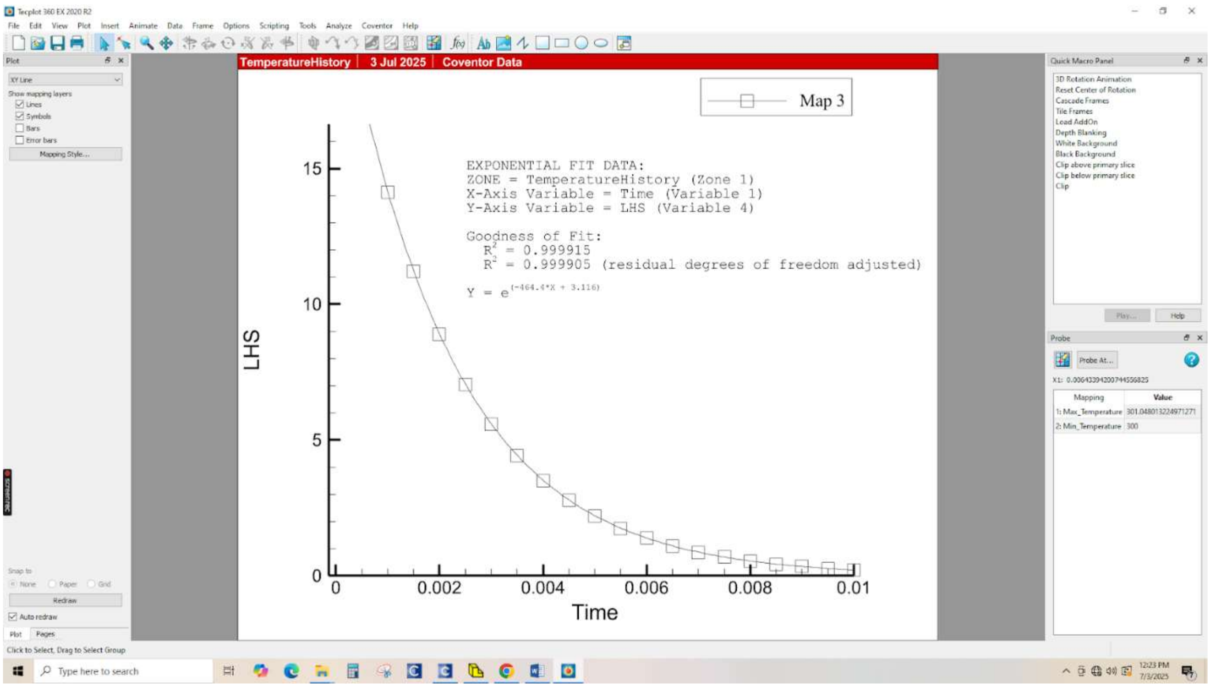
Maximum Temperature Curve



Equation : (t-t0)/(tm-t0)

here
LHS = ({MAX_TEMEPRATURE} – 300)/(300.92-300)



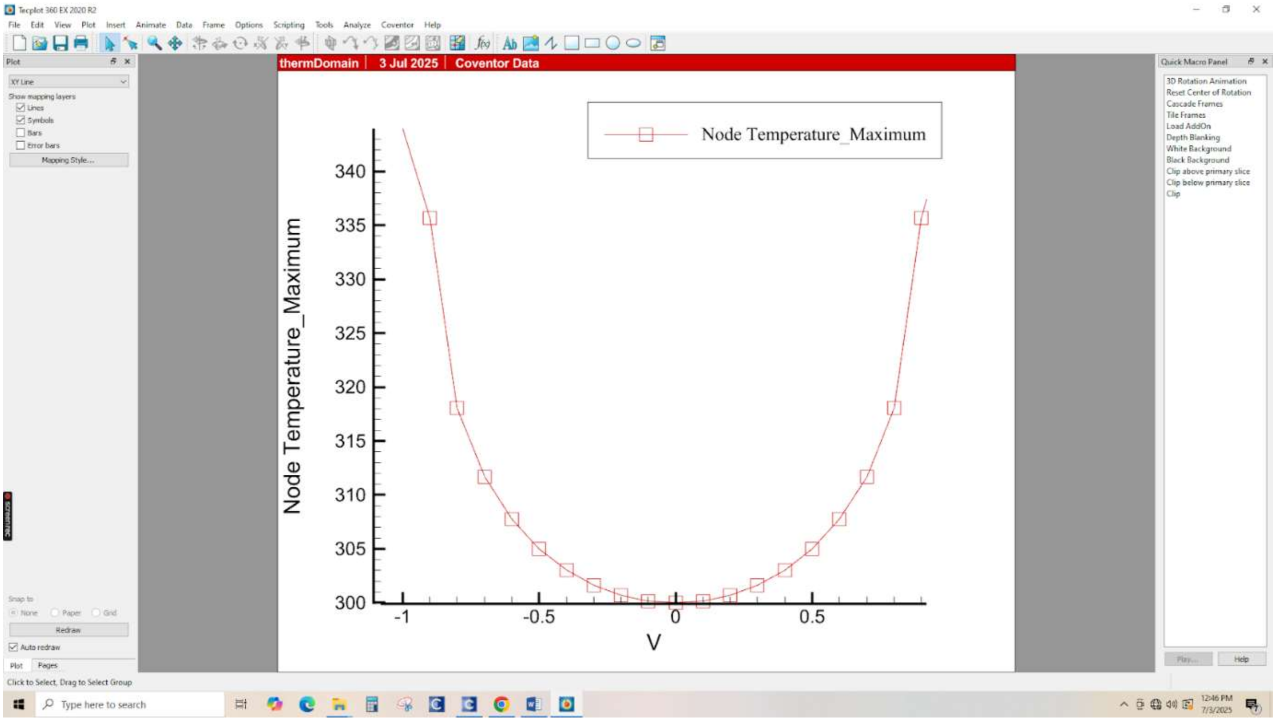


- The A coefficient is the reciprocal of the time constant, so τ is 2.15E-03 seconds. With both *G* and τ known, *C*, the total heat capacity, can be calculated using Equation: $C = G * \tau$ = 9.7E-11 J/K.

3. steady-state electrothermal analysis to generate a voltage-temperature curve :

Results:

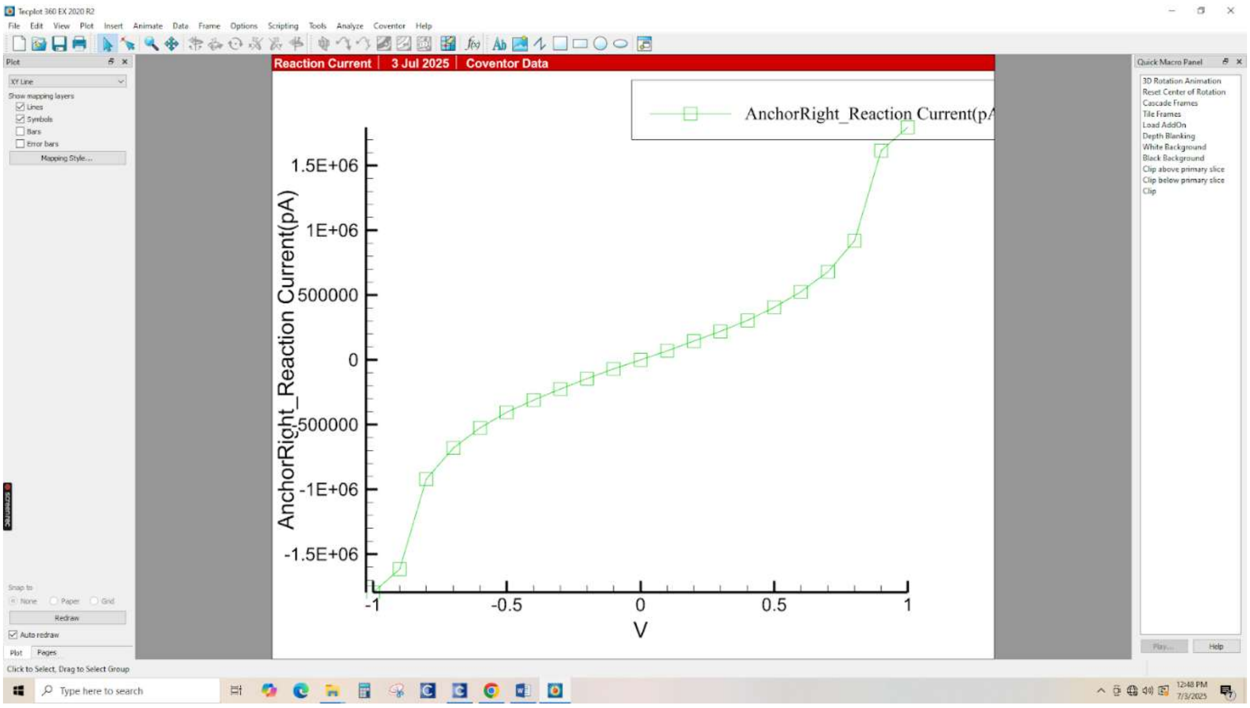
V vs Max_node temp curve



4. steady-state electrothermal analysis to determine the electrical resistance, R, from a static current-voltage curve

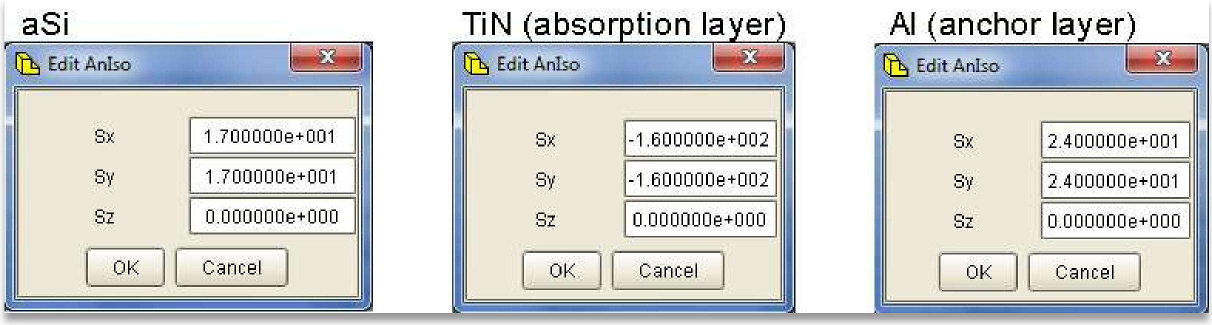
Results:

IV-Curve :



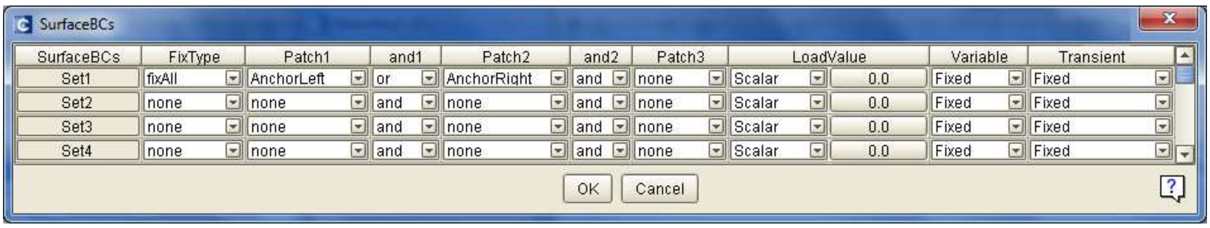
5. Steady-state thermomechanical analysis to resolve pre-stress and thermal

Pre stress value for model materials :



MemMech setting :

SurfaceBC's settings



VolumeBC's settings

VolumeBCs

VolumeBCs	BCType	Part	LoadValue		Variable	Transient
Set1	T-Fixed	ALL	Scalar	300	Fixed	Fixed
Set2	none	none	Scalar	0.0	Fixed	Fixed
Set3	none	none	Scalar	0.0	Fixed	Fixed

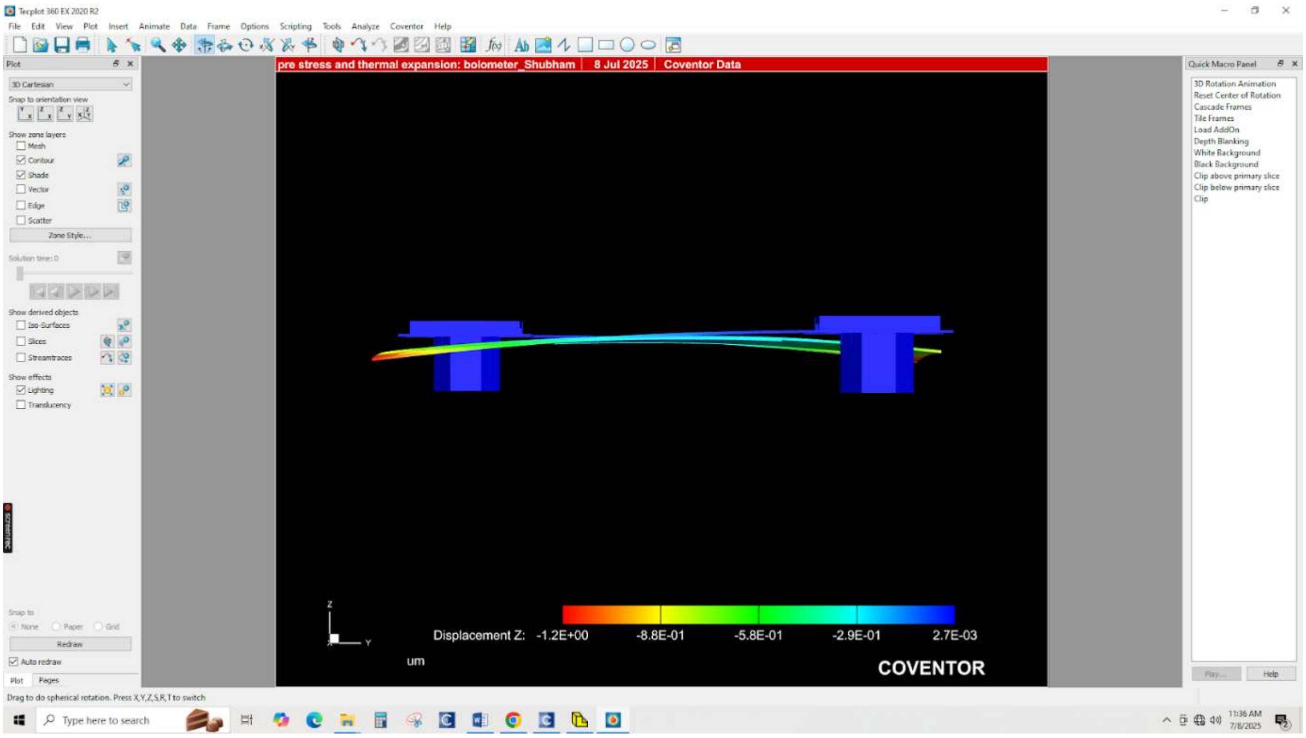
OK Cancel

RESULT :

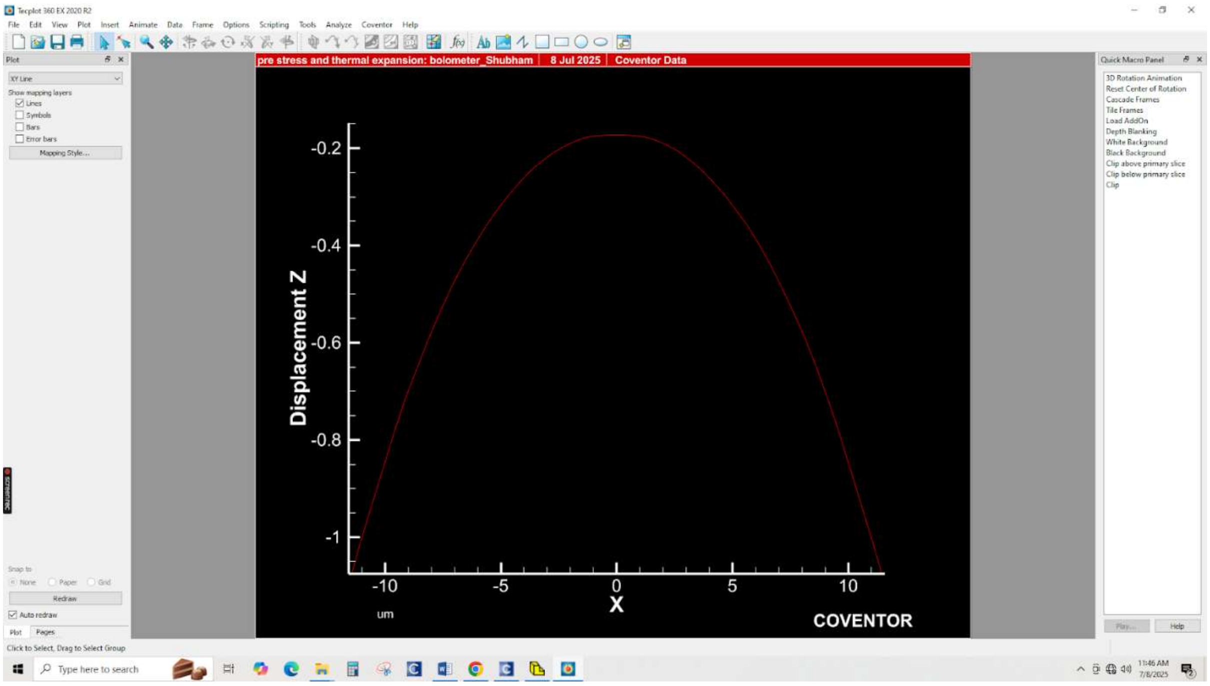
mechDomain

	Maximum	Minimum
Node Displacement	1.172449E00	2.312978E-43
Node X Displacement	1.377499E-02	-1.387677E-02
Node Y Displacement	5.268204E-02	-5.271924E-02
Node Z Displacement	2.710105E-03	-1.171798E00

OK



The results show that the highest and lowest elevations of the IR absorber layer differ by nearly 1.2µm across the pixel. Understanding the influence of both the pre-stress due to fabrication and the temperature change due to device operation is essential to assessing the flatness of the sensor and maximizing absorption of incident radiation.



Summary Of Design Parameters

Design Parameters	Value
G (Thermal Conductance) (W/K)	4.5E-08
τ , Thermal Time Constant (sec)	2.15E-03
C , Specific heat (J/K)	9.7E-11
R , Resistance @ 300K (ohms)	1.40E 06
TCR(thermal coefficient of Resistance) 1/K	0.02622
Responsivity(V/W)	3.90E05
Maximum Deflection @ 300K (μm)	1.176

The preceding table summarizes the fundamental design parameters for this microbolometer. **G was determined by a steady-state thermal analysis; τ was derived from a curve fit of the temperature response from a transient thermal analysis**. **C was calculated from known G and τ values**. **The resistance value was taken from the steady-state electrothermal analysis at the reference temperature of 300K**. This corresponds to the resistance associated with 0.1V bias, which is within the regime wherein resistance varies linearly with temperature. Other assumed values required of Equation 4 to determine responsivity include

Bias Current = 1E -06 A

ω , angular frequency of modulation of radiation (assumed) = 30Hz

η , the absorbance of the IR sensitive layer is the product of the absorption of the Tin layer & the fill factor of the sensor , taken as 0.9 and 0.53 respectively.

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- Yanan Xu yxu@desu.edu · Mukti Rana mrana@desu.edu · Kevin Díaz-Aponte