# Simulation and performance analysis of microwave sensor for high power stray radiation

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***Abstract*— High power microwave will be used in extensively in fusion research machine like Tokamak for variety of purpose such as plasma heating, control and diagnostic. Under certain plasma conditions all power is not fully absorbed and there is some stray radiation that leads to damage of microwave and millimeter wave components. Therefore, it is necessary to monitor the power level of the stray radiation. For monitoring the stray radiation, the detector based on the theory of bolometer is design and developed. The simulation is performed to design the detector. This paper gives the simulation results and method of the detector design.**

***Keywords*—bolometer, sensetivity, mircowave, thermocouple, silicon carbide.**

## I. Introduction

The two major contributors to the microwave power in the vacuum vessel are the Electron Cyclotron Heating (ECH) and the Collective Thomson Scattering (CTS) with frequencies of 170 GHz and 60 GHz respectively. This power can damage in-vessel components and diagnostics directly through electromagnetic overloading or indirectly through absorption of the power causing overheating. Microwave detectors distributed over the vacuum vessel are proposed to monitor this microwave power and give alerts in case the power density level reaches a critical threshold.

The primary goal of these detectors is protection against overheating and sensitive diagnostics.

## II. Mesurement Options

### *A.* Schottky-diode detector

The most common detector used for measuring microwave power is a Schottky-diode detector. This method has the advantage of having a very fast response time due to the direct conversion of the microwave power into a voltage in the diode but main disadvantage is that diodes are semiconductors which need to be shielded very well from neutrons [1].

### *B.* Pyroelectric sensors

Second possibility is to use far infrared pyroelectric sensor. However, this method will probably be difficult due to neutron irradiation which can damage the pyroelectric crystal and the electrical circuit and cause unresolvable heat disturbances in the crystal [1].

### *C.* Bolometer

This is the third option of bolometry. Sketch of the bolometer principle is given in fig 1.1. The working principle is that the microwave power is absorbed by a fluid or a solid whose temperature rise can be measured with an RTD (Resistance Temperature Detector) or a thermocouple. It have advantage of very stable output [1].

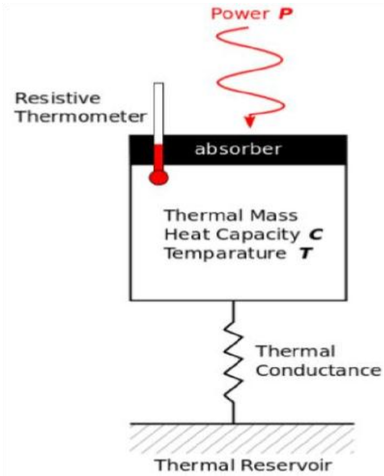


Figure 1. Sketch of the measurement principle of a bolometer. Conduction is used here for cooling

## III. Methodology for Detector

The Goal of the microwave detector is to measure the microwave power density. This must be deduced from the output of the detector which is a voltage. For a detector based on bolometry there is an intermediate quantity which the temperature. A relation between the temperature and the voltage can be found with the thermo-electric Seebeck effect.

The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.

### A. Seebeck equation

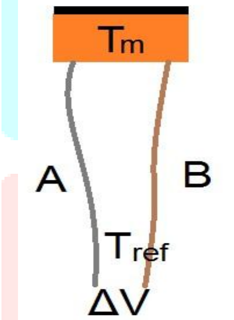


Figure 2. Equivalent Schematic representation of a thermocouple connected to a solid body. The thermocouple consists of two wires A and B with different Seebeck coefficients. This temperature $T_m$ can be determined by measuring the voltage $\Delta V$ at temperature $T_{ref}$ [2].

$$\Delta V = -\int dV = \int S dT. \qquad (1)$$

$$\Delta V = \int_{T_{ref}}^{T_m} S_A dT + \int_{T_m}^{T_{ref}} S_B dT = \int_{T_{ref}}^{T_m} (S_A - S_B)\, dT. \qquad (2)$$

### B. Detector criteria

For an analytical analysis of the microwave detector the lumped capacitance method, in which it is assumed that the body temperatures are uniform, is very useful. As a rule of thumb, this method can be used when the Biot number is smaller than 0.1 [3]

$$Bi = \frac{hL_c}{k_{int}} \qquad (3)$$

where Lc is the characteristic length which is defined as the ratio between the volume V of the body and its exposed surface S and where kint is the internal thermal conductivity. The heat transfer coe cient h is defined as

$$h = \frac{q}{T - T_{sur}}, \qquad (4)$$

in which q is the total heat flux through the body, T the temperature of the body and Tsur that of its surroundings. In the case of the bolometer bodies there is a net heat flux qμ - qr (i.e. microwave heating minus thermal radiation) coming in at the top surface while a heat flux qc is conducted away at the bottom. So for the bolometer bodies q is given by [3]

$$q = q_\mu - q_r + q_c = \alpha p - \epsilon\sigma(T^4 - T_{sur}^4) + U(T - T_{sur})/A, \quad (5)$$

Filling in equation 2.8 in equation 2.6 gives the first criterion for the detector

$$Bi = \frac{L_c}{k_{int}}\left|\frac{\alpha p}{T - T_{sur}} - \varepsilon\sigma(T_{max} + Tsur)(T_{max}^2 + T_{sur}^2) + \frac{U}{A}\right| < 0.1, \quad (6)$$

the second criterion is that the typical response time should be

$$\tau = \frac{\rho c L_c^2}{k_{int}} \ll t_{int} \quad (7)$$

And third criteria is sensitivity of the detector

$$\rho c V \frac{dT}{dt} = \alpha p S. \quad (8)$$

$$\frac{1}{p}\frac{d.\ T}{dt} \approx \frac{\alpha S}{\rho c V}. \quad (9)$$

*C.* Design of detector

The solid body is made from the copper for its good thermal conductivity and relatively high melting point. For ease of manufacturing and for a uniform temperature at a certain Hight, cylindrical bolometers are recommended. An SIC (silicon carbide) [4] can be used for absorbing body. This coating has high absorbed power fraction and its easily available in market.

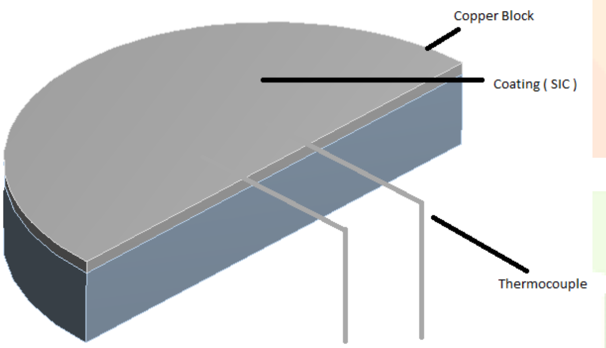


Figure 3. Schematic representation of design.

*D.* Thermocouple

Thermocouple is a temperature sensor that uses a junction formed by dissimilar metals

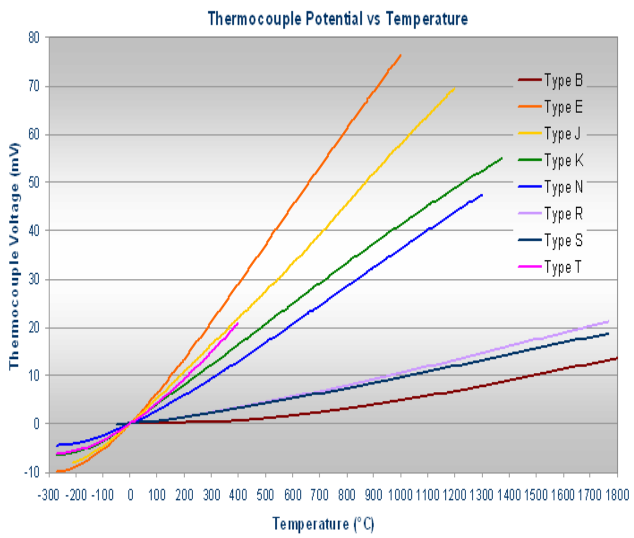


Figure 4. Schematic representation of thermocouple.

## IV. THEORETICAL CALCULATIONS AND RESULTS

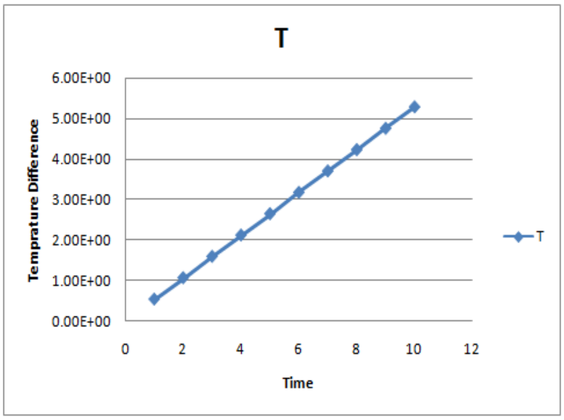


Figure 5.Schematic representation grah for Temperature Difference Vs Time

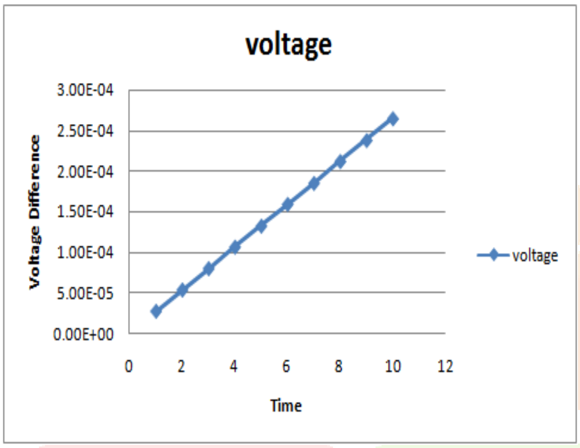


Figure 6.Schematic representation grah for Voltage Difference Vs Time

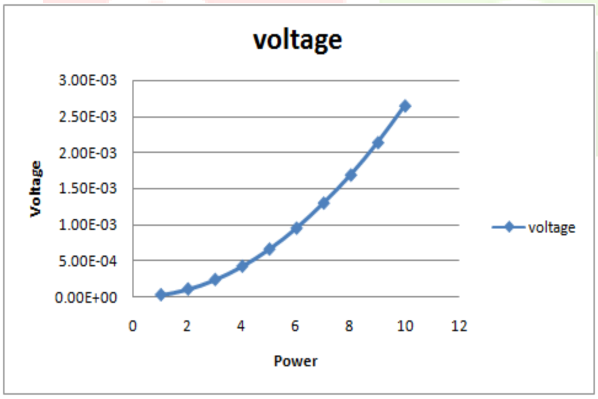


Figure 7.Schematic representation grah for Voltage difference Vs Time

## V. SIMULATION

Simulation is done in ansys workbanch software, in which the temperature of the copper plate is mesured.

Properties of Outline Row 3: Copper Alloy

| | A | B | C |
|---|---|---|---|
| 1 | Property | Value | Unit |
| 2 | Density | 8300 | kg m^-3 |
| 3 | Isotropic Thermal Conductivity | 401 | W m^-1... |
| 4 | Specific Heat | 385 | J kg^-1 ... |

Figure 8.Properies of copper

Properties of Outline Row 4: Silicon Carbide

| | A | B | C |
|---|---|---|---|
| 1 | Property | Value | Unit |
| 2 | Density | 3100 | kg m^-3 |
| 3 | Isotropic Thermal Conductivity | 120 | W m^-1... |
| 4 | Specific Heat | 750 | J kg^-1 ... |

Figure 9.Properies of Silicon Carbide

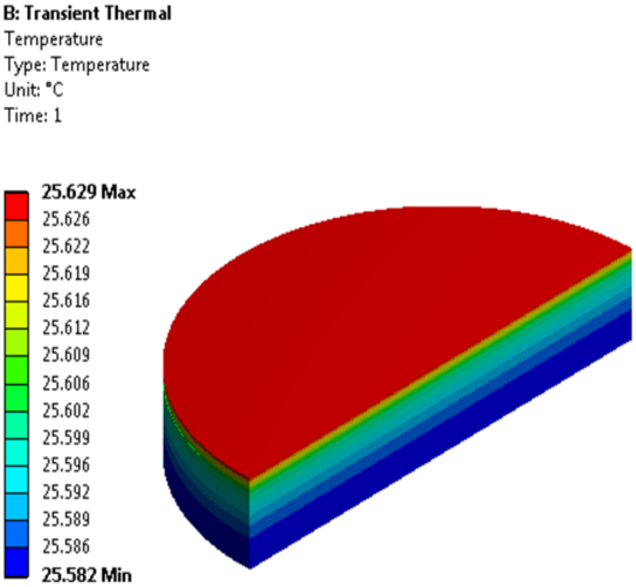


Figure 10.Temperature increase after 1sec for the detector

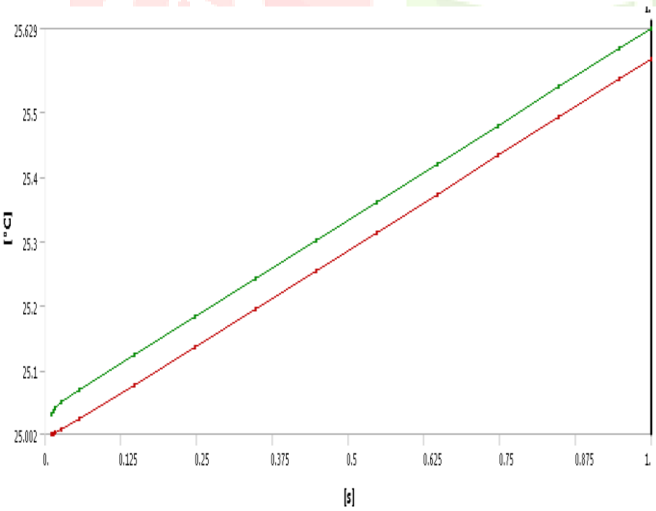


Figure 11.Temperature Vs Time for 1sec

Tabular Data

| | Time [s] | Minimum [°C] | Maximum [°C] |
|---|---|---|---|
| 1 | 1.e-002 | 25.002 | 25.032 |
| 2 | 1.3333e-002 | 25.002 | 25.038 |
| 3 | 1.6667e-002 | 25.003 | 25.042 |
| 4 | 2.6667e-002 | 25.007 | 25.051 |
| 5 | 5.6667e-002 | 25.024 | 25.07 |
| 6 | 0.14667 | 25.077 | 25.124 |
| 7 | 0.24667 | 25.136 | 25.183 |
| 8 | 0.34667 | 25.195 | 25.242 |
| 9 | 0.44667 | 25.255 | 25.301 |
| 10 | 0.54667 | 25.314 | 25.361 |
| 11 | 0.64667 | 25.373 | 25.42 |
| 12 | 0.74667 | 25.432 | 25.479 |
| 13 | 0.84667 | 25.491 | 25.538 |
| 14 | 0.94667 | 25.551 | 25.598 |
| 15 | 1. | 25.582 | 25.629 |

Figure 12.Table from of the data for 1 sec

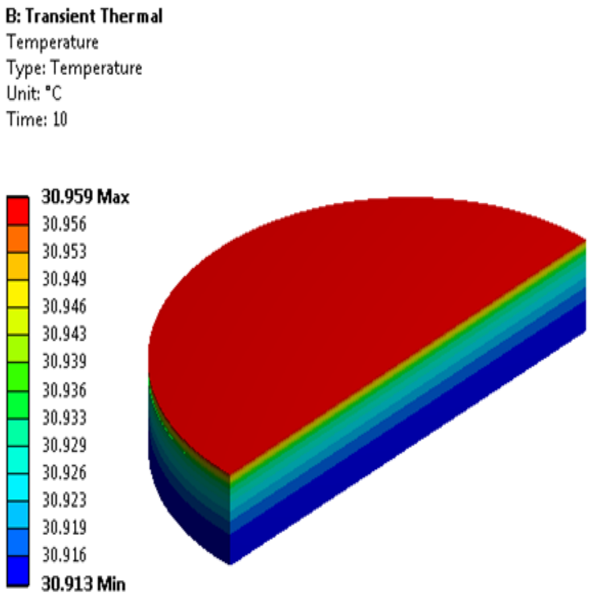


Figure 13.Temperature increased after 10sec

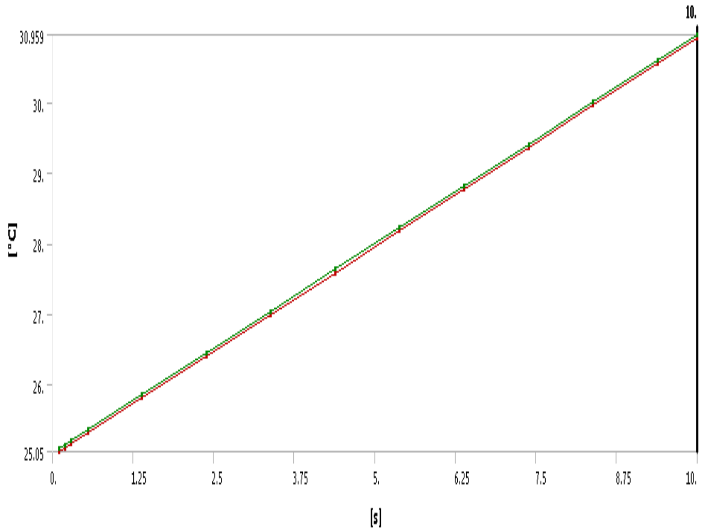


Figure 14.Temperature Vs Time for 10sec

| | Time [s] | Minimum [°C] | Maximum [°C] |
|---|---|---|---|
| 1 | 0.1 | 25.05 | 25.094 |
| 2 | 0.19179 | 25.104 | 25.15 |
| 3 | 0.28358 | 25.158 | 25.205 |
| 4 | 0.55895 | 25.321 | 25.368 |
| 5 | 1.385 | 25.81 | 25.857 |
| 6 | 2.385 | 26.403 | 26.449 |
| 7 | 3.385 | 26.995 | 27.042 |
| 8 | 4.385 | 27.587 | 27.634 |
| 9 | 5.385 | 28.179 | 28.226 |
| 10 | 6.385 | 28.772 | 28.819 |
| 11 | 7.385 | 29.364 | 29.411 |
| 12 | 8.385 | 29.956 | 30.003 |
| 13 | 9.385 | 30.548 | 30.595 |
| 14 | 10. | 30.913 | 30.959 |

Figure 15.Table from of the data for 10 sec

## VI. CONCLUSION

- Solid body is made from copper for its good thermal conductivity and relatively high melting point.
- SIC (Silicon Carbide) coating will be used for the absorbing body. This coating has high absorbed power [4].
- J-Type thermocouple is taken which have seebeck coefficients of 50 mV/C
- Microwave detector based on solid body bolometer which can measure up to 1w power having response time 0.1 sec is designed.
- When we give 1w power to the copper plate for 10 sec, then we will get 5 degree increasing temperature and 0.25 volt from seeback effect.
- After simulation we get the same degree of the temperature increase with the theoretical calculation.

## VII. ACKNOWLEDGEMENT

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