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Development of Calibration Set-up for ECE Radiometer Systems at Institute for Plasma Research

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Abstract: For the absolute measurement of temperature using Radiometer system, Radiometer must be calibrated with known incident power. Calibration setup is indigenously developed to calibrate the various (E, Ka AND F-Band) ECE Radiometer systems available at IPR. “Hot and Cold technique” is used with blackbody sources, one at room temperature and another at Liquid Nitrogen temperature.

New calibration technique using DSP, as well as the conventional technique using Lock-in amplifier, are implemented to remove the noise of system. The blackbody sources are chopped with high accuracy DC motor to generate the temperature difference. Calibration coefficients for individual channels are determined. Inherent noise and losses are calculated by analytical way as well as experimental measurements.

Theoretical and experimental measurement has shown necessitate for High temperature black body target. Prototype is generated for High temperature blackbody calibration source. Various materials are analyzed for thermal and dielectric properties.

1. Introduction:
Electron Cyclotron Radiation is very powerful technique as plasma diagnostics tool in fusion research system like tokamak [1]. We can effectively measure the plasma parameters like the plasma electron temperature or the plasma electron density[2] . This measurement is very useful in study of the phenomena like Magneto Hydro Dynamic (MHD) activity, energy confinement and electron thermal energy transport[3]. Understandings of these physical phenomena are necessary to get successful in controlled nuclear fusion.

At Institute for Plasma Research we have developed Super heterodyne radiometer in frequency range of 60-90GHz and 90 -140GHz, and homodyne radiometer in 26-40GHz[3]. Now to calculate the plasma temperature from radiometer data, radiometer should be calibrated. Radiometer can be cross calibrated using other well established diagnostics like Thomson scattering . In absence of well established diagnostics, radiometer needs to be calibrated absolutely. Absolute calibration is obtained by exposing the radiometer to Hot and Cold black body source of known temperature. Alternatively the system can be calibrated with the well calibrated antenna and source with known power.
2. **Hot and cold technique:**
Radiometer can be calibrated by comparing the reading of blackbody source with known temperature. But the usually the inherent noise of the radiometer is much higher than power of available blackbody source. To eliminate this noise, the hot and cold technique applied in which radiometer readings for the sequence of antenna views of hot and cold blackbody sources are recorded and then averaged over same view.

This reduces the effect of noise inversely with number of sequences.

The intensity of radiation from black body is governed by Plank’s Law [1].

\[
I_{BB} = \frac{h\omega^3}{8\pi^3 c^3} \left( \frac{1}{e^{\frac{h\omega}{kT}} - 1} \right)
\]

The temperature of the black body decides the output power and it should be detectable at the detector end. Plasma is black body and possesses temperature of several thousand Kelvin. But blackbody source of that much temperature is practically not feasible.

3. **Black body calibration setup:**

Figure 1. Depicts various components of the calibration setup. Microwave absorbing Ecosorb is used as black body material which gives the reflection coefficient up to -60dB. Ecosorb at Room temperature is kept as hot body source. The Ecosorb is cooled to LN₂ temperature in cryogenic Diwar which serves the purpose of cold blackbody. Chopper technique is applied to generate the sequence of hot and cold blackbody view.

![Figure 1. The calibration Setup for Radiometer.](image)
DC-motor gives stable rpm up to 4000 with 0.25 torque. But at the higher speed the Ecosorb on top of fan fly off, hence the calibration is done at lower speed only.

![Figure 2. Block diagram of calibration system](image)

same point of opposite blade while the antenna is looking at fan blade. The reference TTL generated corresponds to the source that the antenna is looking at. Lock-in amplifier matches the phase of reference and average the data sample for high and low state for given time. But the requirement is that the reference frequency should not vary more than 1% during the averaging time. Otherwise the Lock-in amplifier gets unlocked. Using Lock-in amplifier the calibration is performed with planner ecosorb.

4. Replacing Lock-in amplifier with DAQ:
With bigger block of conical ecosorb, generating constant frequency square was getting difficult. And hence the new analysis technique is implemented. The reading of the reference and radiometer channels is recorded on continuous DAQ system for more than 45 minutes. With this we could overcome the problem of unlocking of lock-in amplifier.
The code is generated to identify the state at which antenna is looking at and to remove the noise by averaging the subsequent cycle. The data acquisition rate is adjusted such that the nyquist condition is well satisfied. The calibration coefficient is determined for Ka-band radiometer and is shown Figure 4.

Fig 3. Data from Reference and Radiometer channel

Fig 4. Calibration coefficient of Ka-band radiometer and ECE Radiometer data on Aditya tokamak
5. Characterization of Radiometer Systems:

The required temperature of the black body is highly dependent on the internal noise and losses of the radiometer system. Higher losses demand the higher source temperature to increase the signal to noise ratio and to make the signal detectable at detector. Radiometer systems are characterized for noise temperature and losses up to detector end are calculated. The detector is sensitive up to the power of -52dBm but with time the sensitivity decreases. The power at the detector input after all losses and gain of E-Band Super heterodyne Radiometer [3] comes to be -48 and -52 dBm for room and LN2 temperature. Hence the Hot body source must be utilized to improve the calibration results. Fig 5. Shows the noise temperature of F-Band Radiometer[4,5]. It also expresses the necessity of high temperature blackbody calibration source.

![Figure 5. Calibration Coefficient of Ka-Band ECE Radiometer](image)

6. High temperature Blackbody Calibration Source:

The black body calibration source is under the designing procedure. Ideal black body material which can withstand high temperature is not yet evaluated. The target of emissivity equal to Unity is achieved by internally reflecting the incident power and makes it loss. Macor and Silicon-carbide are the two major candidates for this study the choice is finally made on SiC due to its high thermal conductivity compared to Macor, though it has drawback of high reflection coefficient difficult machining.

The reflection coefficient of macor and SiC is determined using reflection technique[6] for various incident angle. These measurement shows that SiC has reflection as bad as 0.6, compare to very low 0.21 of Macor. But Thermal conductivity of macor is quite low and maintaining constant temperature over surface with macor becomes quite difficult.
The reflection coefficient for SiC and Macor is analytically calculated for various angle of incident and also for different cone angle. Figure 6 show the total power reduction after each internal reflection from surface for cone angle of 45°.

Figure 6. Ray tracing for 45° base plate grooves, and Reflection Coefficient of Macor and Silicon-Carbide block with 45° wedge.
With less reflection coefficient, the macor seems to be a better candidate. But SiC also gives reflection coefficient better than 0.01, showing 98% emissivity, ideally. The proposed diagram of Hot-Blackbody source is shown in Fig 7. Various heating mechanism can be implemented depending on best performance. Hot air must be exhausted to prevent the effect on fan and viewing antenna.

7. Area of attention:
For temperature uniformity even convective heat exchange can be implemented with high boiling liquid like oil, but wave reflection from surface of oil deteriorates the result. Better exhaustion mechanism design is under process. Technique using well calibrated transmitting antenna system over full frequency range is under development.

8. Conclusion:
Calibration setup is indigenously designed and fabricated for various radiometer systems. Chopper setup is used to generate the hot-cold signal sequences. Calibration of various radiometer systems are carried out and temperature of plasma is determined based on calibration coefficient obtained. New calibration technique using DSP, as well as the conventional technique using Lock-in amplifier, are implemented to remove the noise of system. Inherent noise and losses are calculated by analytical ways as well as experimental measurements which reveals the necessity of High temperature calibration source. High temperature blackbody calibration source designed is generated and various materials are analyzed for their thermal and dielectric properties.

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