# Design and evaluation of medical microwave radiometer for measuring tissue temperature

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## Abstract

Medical microwave radiometry is a passive non-invasive technique for measuring tissue temperature gradient in the human body. Design and evaluation of a medical microwave radiometer centered at 1.3 GHz with 330 MHz bandwidth is presented here. An active noise source with noise equivalent temperature of 303 K is used for temperature calibration. Radiometer characterization results are presented for matched load maintained at thermal steady state and hot spot in a tissue phantom. Radiometer measurements recorded using a dielectric loaded waveguide and substrate integrated waveguide (SIW) antenna with a slot demonstrated the ability to measure the temperature gradient at depth.

**Keywords -** microwave, radiometry, thermometry, tissue

## 1. Introduction

Microwave radiometry is a widely used remote sensing technique in astronomy and meteorology [1]. However, its application in medicine has not been fully explored due to the challenges associated with receiving and processing the ultra low power thermal radiation from biological tissues in the presence of stray electromagnetic interference (EMI), and designing compact body contacting antennas with good impedance matching to the human body to receive thermal radiation in the microwave regime. Medical microwave radiometers employ a near field antenna either in contact or non-contact mode connected to a radiometer. Microwave radiometers proposed for medical applications typically operate over the frequency range of 1-6 GHz due to the trade-off between penetration depth and spatial resolution [2], and the frequency of operation is decided by the application at hand. The early work on medical microwave radiometry was reported for detection of breast cancer [3]. Other applications investigated include monitoring of brain temperature [4-6], urinary tract infection [7] and body core temperature [8].

In this paper we present a summary of the design and assessment of our medical microwave radiometer operating at 1.3 GHz. The device design and experimental setup for evaluation are briefly presented in Section 2. Section 3 presents the results and discussion. Section 4 concludes ths work.

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## 2. Methodology

### 2.1 Radiometer design

Fig. 1 shows the Dicke configuration achieved using an antenna, active reference noise source, single pole double throw switch, total power radiometer and power detector. The active reference noise source was designed for the operating bandwidth (BW) with return loss more than 20 dB. The total power radiometer consists of cascaded low noise amplifiers (LNAs) and filters. The LNA was designed using Si-GE HBT for un-conditional stability and noise figure less than 1 dB in the operating BW. Band pass filters were designed for selective processing of in band signals with defected ground structure to suppress out of band EMI from mobile and wireless communication devices. The active and passive microwave components were designed on 1.58 mm thick RT-Duroid 5880 using circuit simulation software (ADS, Keysight Technology, USA). The fabricated circuits were assembled inside an aluminium enclosure to improve immunity to ambient EMI and minimize internal coupling between the circuits. The device was battery operated to avoid conducted susceptibility.

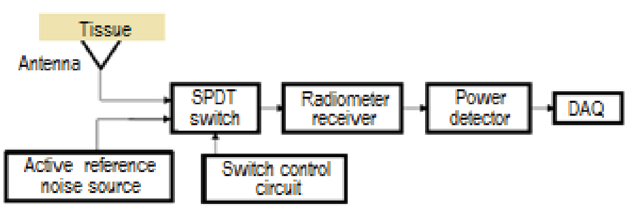
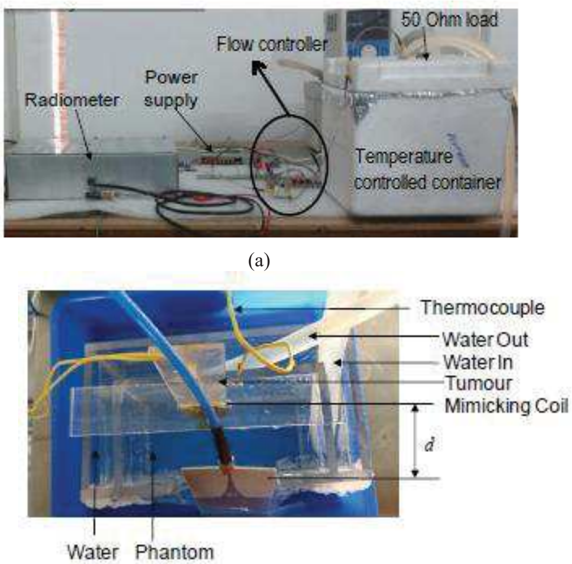



Figure 1. Block diagram of medical microwave radiometer.

### 2.4 System characterization on phantom

Fig. 2(a) shows the experimental setup for gathering the amplified band limited noise spectrum for a matched input termination (50 Ω) maintained at thermal steady state. The temperature of the water bath was varied over 20-40 ℃ and the corresponding noise voltage was recorded at thermal steady state. As noise gathered by the radiometer has contributions from system electronics, the integration time for gathering thermal noise was determined using Allan deviation calculated for varying integration time. A 10 mm diameter hot spot immersed in a liquid tissue phantom mimicking the human body tissue was used to assess the radiometer's ability to measure temperature gradient at depth. Fig. 2(b) shows the phantom setup. Measurements were repeated for loaded waveguide and SIW slot antennas.




(b)

Figure 2 System characterization setup. (a) 50 Ω load, (b) antenna and phantom setup with the 10 mm diameter hot spot.

## 3. Results and discussion

### 3.1 Radiometer characterization

The noise figure of the radiometer is less than 3 dB in the operating BW. Radiometer spectrum indicated 30 dB suppression in mobile phone and wireless device bands. Figure 3 shows the calibrated brightness temperature measurements for the 50 Ω load for 2 ms integration time. The brightness temperature is linearly proportional to the load temperature.

### 3.2 Antenna brightness temperature measurements

Table I shows the antenna brightness temperature difference, $\Delta T_B$ with and without the hot spot at depth. Measurements are shown for two antennas. It can be observed that the visibility of the hot spot is higher for the substrate integrated waveguide slot compared to the dielectric loaded waveguide. This is because the interrogation volume of the waveguide antenna is smaller than the slot antenna.

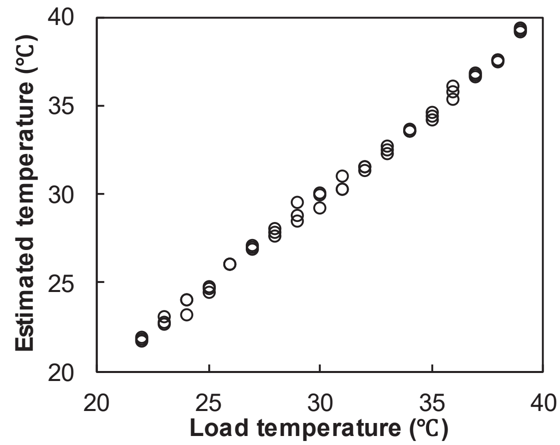



Figure 3 Radiometer characterization results for 50 Ω load maintained at thermal steady state (Fig. 2(a)).

TABLE I – ANTENNA BRIGHTNESS TEMPERATURE MEASUREMENTS

| Hotspot depth, $d$ (mm) | Antenna brightness temperature gradient, $\Delta T_B$ (℃) | |
|---|---|---|
| | Dielectric loaded waveguide | SIW slot |
| 20 | 1.07 | 1.88 |
| 30 | 0.68 | 1.00 |
| 40 | *Nil | 0.64 |

Note: * No appreciable contrast was present between the measurements.

## 4. Conclusion

Design and assessment of a medical microwave radiometer were presented for measuing tissue temperature gradients in the human body using dielectric loaded waveguide and SWI slot antennas. Device characterization results indicated linear relationship between the measured noise power and the load temperature. Phantom measurements demonstrated the ability to detect temperature gradient at depth using a medical microwave radiometer.

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