Non-contact Radiative Temperature Monitoring of Blood Plasma and Packed Red Blood Cells in a Powerful Microwave Environment

Dawei Xu(1)(2), Dirk Rüter(1), and Daniel Erni(2)

(1) Institute of Measurement Engineering and Sensor Technology,
University of Applied Sciences Ruhr West,
D- 45479 Mülheim an der Ruhr, Germany

E-Mail: dawei.xu@hs-ruhrwest.de, dirk.rueter@hs-ruhrwest.de

(2) General and Theoretical Electrical Engineering (ATE),
Faculty of Engineering, University of Duisburg-Essen,
D-47048 Duisburg, Germany

E-Mail: daniel.erni@uni-due.de

Abstract – Local overheating is a hazard in the microwave warming of packed red blood cells (PRBC) and fresh frozen plasma (FFP) [1]. Therefore, accurate and non-contact temperature monitoring would be helpful for the microwave heating process [2], especially if it provides the interior temperature. A radio frequency (RF) method for measuring the global temperature of the blood products is presented herein.

The blood products emit thermal noise (Planck's radiation) in the microwave band. By measuring this thermal radiation, the temperature of the PRBC and FFP can be obtained. Since different frequency bands penetrate the blood products at different depths, the temperature of various depths can be selected by choosing suitable frequencies.

Microwave warming takes place in an electromagnetically closed cavity. The 2.45 GHz microwave radiation for heating has power levels on the order of 1 kW, while the emitted thermal radiation is on the order of 4 fW at 300 K (27 °C, or around room temperature) and 1 MHz resolution bandwidth. Thus, the ratio between active RF heating and passive RF emission spans more than 18 orders of magnitude. Selective filter elements are required for this problem.

Two experimental setups were designed to examine the thermal radiation from the surface regions at high frequencies (about 10 GHz) and the thermal radiation within the fluid at frequencies below 1 GHz. As shown in Fig. 1, a low noise block converter (LNB) was applied to detect the thermal noise from the surface of the PRBCs in the high frequency range (10.7–12.7 GHz). The LNB had a low inherent noise factor (NF) of < 0.5 dB, and its gain was optimized for weak satellite signals. To avoid damage in this amplifier stage, a waveguide, acting as a selective high-pass filter, was connected directly to the front of the LNB. The high power microwave energy (2.45 GHz) did not pass the LNB.

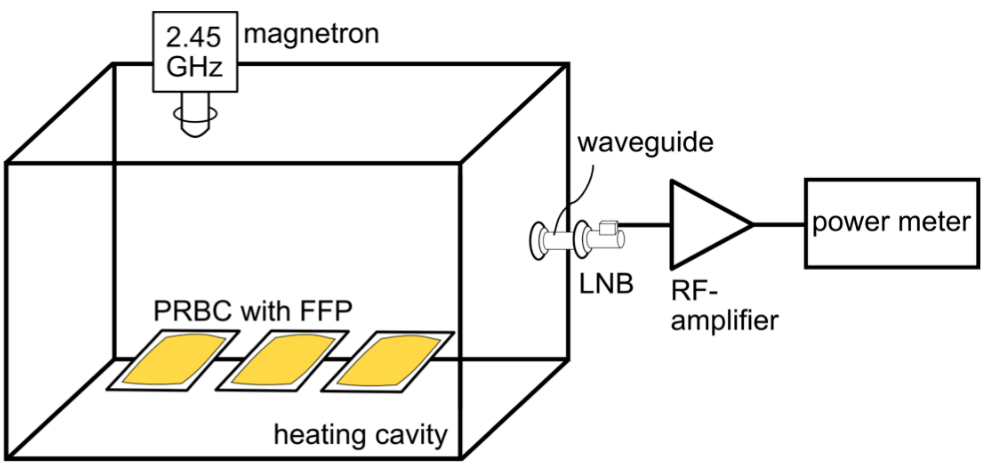

Fig.1: Experimental setup with LNB

The wavelength of the thermal noise in the 10 GHz range was much smaller than the dimensions of the heating cavity. The electromagnetic (EM) mode distribution in the cavity was in a homogeneous manner (quasi optical), which was used for the coupling between the LNB and the measured fluid. A stable coupling was important for the evaluation of the radiation from the antenna. The influence of the cavity wall temperature in this application can be offset by a mathematical algorithm and the known wall temperature.

Fig.2 shows the experimental setup using an ultra-wideband (UWB) antenna with a center frequency of about 0.9 GHz for receiving the low frequency thermal radiation. The penetration depth was about 3.5 times higher than at 10 GHz. The interior thermal radiation of the fluid passed through the surface and was collected by the antenna. The gain of the low noise amplifier (LNA) was about 60 dB. A low-pass filter was required to protect the sensitive input stage of the LNA from the high power 2.45 GHz microwave. Filter structures on the PCB could be easily destroyed by such high power. Therefore, an elliptic low-pass filter was designed, based on the strip line theory. This high quality filter used air as the insulating media. The useful radiation at 0.9 GHz passed over the filter with insertion loss of 0.1 dB, and the high power microwave radiation was attenuated by about 75 dB by reflection.
A variance in EM mode caused by the similar dimensions of wavelength and cavity size can greatly influence the coupling between the antenna and the measured fluid. This variance can be offset by measuring the reflection parameters of the antenna.

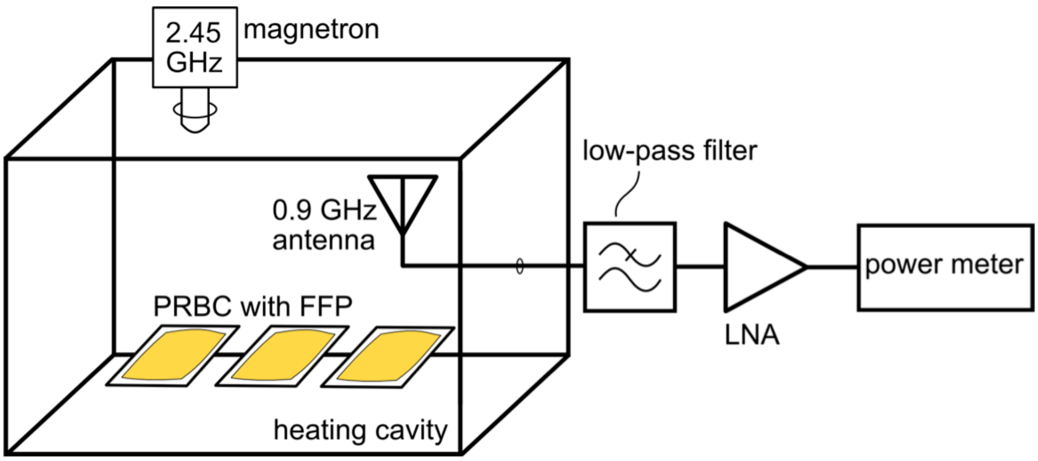

Fig.2: Experiment setup with 900MHz UWB antenna

Compared to the traditional off-line measurement, the on-line measurement which can be realized by this non-contact radiative method is safer and much more flexible. It could avoid some of the hemolysis damage from local overheating [1], and may improve the quality of the warmed plasma.

References

[1] P. L. Leaman and G. G. Martyak, “Microwave warming of resuscitation fluids,” *Annals of emergency medicine*, vol. 14, no. 9, pp. 876–879, 1985.

[2] R. S. Grabowy and K. L. Carr, “In-line microwave warmer for blood and intravenous fluids,” Defense Technical Information Center, Technical Report, 1989.