DOI 10.5162/sensor2015/P9.1

Low Cost Microwave Total Power Radiometer Sensor for Industrial Applications

R. J. Hadi [1], C. Sandhagen [1], B. Jungstand [2], A. Göller [2], A. Bangert [1]
[1] Microwave Electronics Lab, University of Kassel
Wilhelmshöher Allee 73, D-34121 Kassel, Gemany,
micel@uni-kassel.de
[2] hf sensor GmbH
Weißenfelser Straße 67, D-04229 Leipzig, Germany

Abstract:
A simple design, low cost, fast response, microwave total power radiometer sensor is proposed for industrial applications in X-band frequency range (10.7 - 11.7 GHz or 11.7 - 12.75 GHz). The sensor has been tested to detect hot spots behind thermal isolation materials in a laboratory setup, as a single sensor in a production line and as an array in a production line providing 2D-measurement results.

Keywords: Total power radiometer, X-band, industrial applications, low cost, isolation material.

Introduction

The microwave radiometry in general is a method of detecting the radiation of matter which has temperature higher than absolute zero (0 K). All material bodies and substances radiate energy in the form of electromagnetic waves according to Planck's law [1]. Microwave radiometry sensors offer a non-invasive, non-destructive method for monitoring the environment [2] or measuring remotely the process temperatures in several industrial applications [3, 4, 5]. Infrared (IR) remote sensors are sensitive only to the surface temperatures with few microns penetration depth inside the observed target, whereas the microwave radiometry sensors can provide information about the temperature profile inside the target within several decimeters. In this paper, a low cost microwave total power radiometer sensor is proposed to detect hot spots inside thermal isolation material or to measure the temperature inside an isolating container.

Design and Realization of the Total Power Radiometer Sensor

The basic configuration of radiometer systems is the total power radiometer. Consider the total power radiometer sensor shown in Fig. 1. As shown, an antenna is delivering the noise signal (black body radiation) of the observed object to a commercially low-cost, low-noise block (Single LNB/ FLS9901, Schwaiger) with a low noise figure (< 0.8 dB) and a high total gain (> 55 dB). The input frequency ranges of the LNB are 10.7-11.7 GHz low band and 11.7 - 12.75 GHz high band respectively. The output frequency range is 0.95 - 2.15 GHz. In order to apply DC voltage to the LNB, a bias

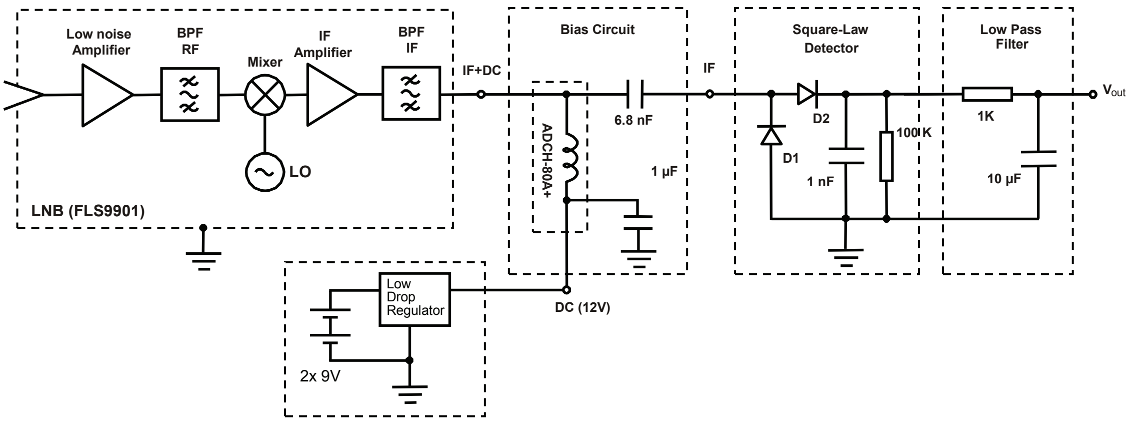

Fig. 1:Block diagram of microwave total power radiometer sensor

DOI 10.5162/sensor2015/P9.1

circuit is used. The envelope signal of the RF output is obtained by a square-law detector. This is using two Schottky diodes (HSMS 2852) connected in anti-parallel from the RF signal's perspective to reduce the RF impedance of the circuit and for doubling the output voltage. The bias circuit and the detector are fabricated and printed on Rogers 4003C substrate material, which it has dielectric constant of 3.55 and a thickness of 0.813 mm. Due to the nature of the signal from the object being noise, a low-pass filter (f-3dB = 16Hz) is used to smooth the output signal. To isolate the sensor from external interferences it is shielded by an aluminum box as shown in Fig. 2.

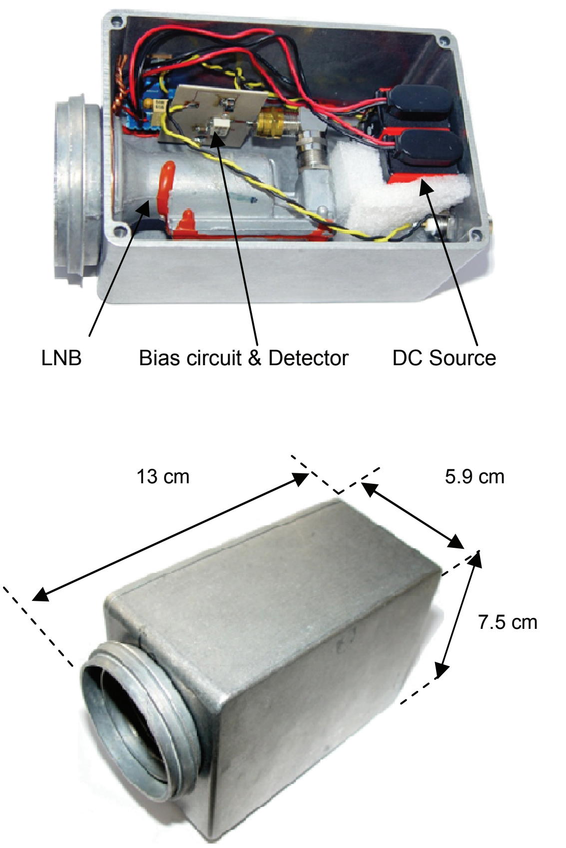

Fig. 2: Photographs of microwave total power radiometer sensor

Testing Results

The microwave radiometer sensor is tested using an artificial target or phantom simulating a hot spot. The measurement setup is shown in the Fig. 3. The microwave radiometer sensor is placed in 20 cm away from the thermal isolation material and the artificial target is placed behind the thermal isolation material to demonstrate the advantage of microwave over infrared remote sensors. The artificial target consists of two concrete resistors (2cm*2cm*1cm) whose temperature is controlled by a PID temperature controller (XMT 7100, Pohltechnik) supplied by a low voltage DC source.

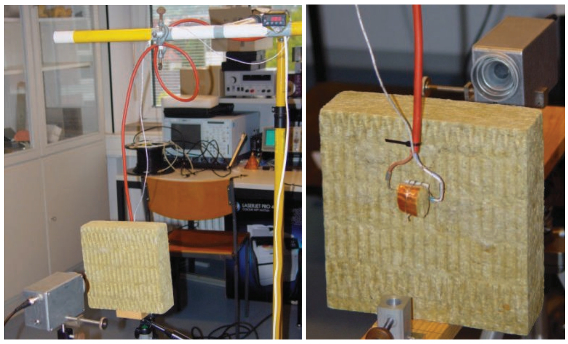

Fig. 3: Photographs of measurement setup with phantom, left) front view, right) back view

The output of the microwave radiometer sensor is recorded by a digital storage oscilloscope (54641A, Agilent). The measured output voltage at different target temperatures without isolating material is shown in Fig. 4.

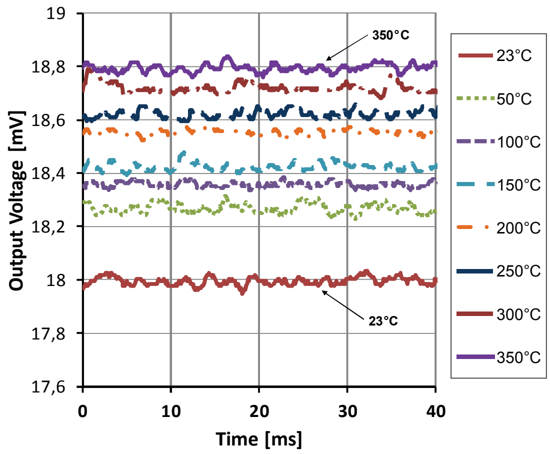

Fig. 4: Output voltage for different temperatures

The output voltages measured with a digital multimeter are given in Tab. 1.

	Output signal 1s average [mV]	
Temperature of target [°C]	with isolation material	without isolation material
30	18.44	18.43
50	18.51	18.45
100	18.56	18.51
150	18.62	18.57
200	18.71	18.61
250	18.78	18.67
300	18.85	18.72
350	18.92	18.78

Tab. 1: Measured output signal

DOI 10.5162/sensor2015/P9.1

They are obtained with and without isolating material. It can clearly be seen that the received signal i.e. the temperature dependent radiation is penetrating the isolation material giving a sight through isolating material yet for small objects.

Measurements of Single Sensor

In one possible application the task is to find hot inclusions (e.g. glowing pieces of coal) in slabs of a thermal insulating material with a single total power radiometer shown in Fig. 5 provided with an industrial bus interface.

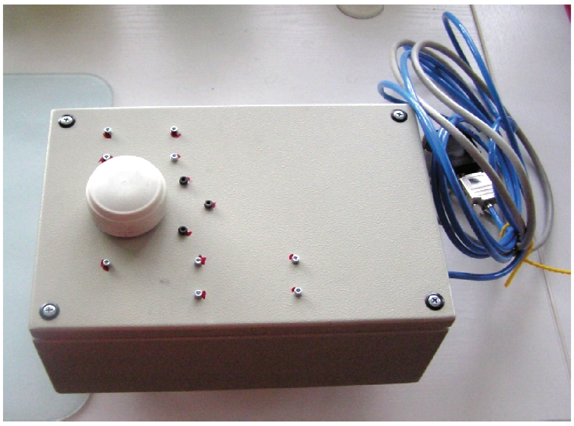

Fig. 5: Single sensor

The hot inclusions are inserted in the slabs 20 mm or 60 mm under the surface. These prepared slabs are placed on the running production line on top of the currently produced material.

The radiometer is positioned over the material and the output value (digitized output power of the radiometer) is recorded over time.

The following Fig. 6 shows the result of such a measurement.

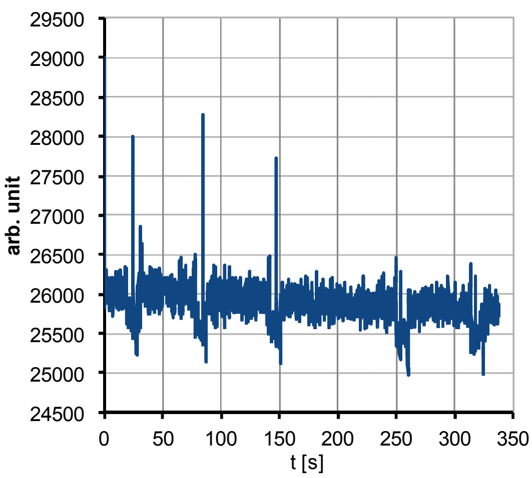

Fig. 6: Single sensor measurement signal

The first three slabs contained hot coal inclusions positioned 20 mm under the surface. In the two following slabs the inclusion were positioned 60 mm beneath the surface. Since the prepared slabs had time to cool down and are colder then the fresh product, the beginning and the end of the slabs are visible in the data. The hot inclusions are visible as peaks. At the time of the measurement no rise of the surface temperature was measurable.

Measurements of Sensor Array

To measure the temperature distribution in the same application, a module, consisting of eight total power radiometers was built, shown in Fig. 7.

Fig. 7: Sensor array module

With this module measurements were made on the production line with the hot inclusions placed directly in the material between 20 and 40 mm beneath the surface. The measurements can be visualized in a false-color plot (green = normal temperature; red = hot). The plots in Fig. 8 on the next page show two measurements. The inserted hot inclusions are visible as red spots consisting of single or multiple (up to three) individual measurement points. Other areas of increased temperature are visible, but the hot inclusions have a much higher radiometer output than the surrounding parts of the material.

Conclusion

A commercial low-cost, low-noise block, a bias circuit, a square-law detector, and a low-pass filter are used to build a total power radiometer sensor, which has abilities of detecting hot spots and sensing the temperature profile inside several decimeters depth of the thermal isolation materials. Due to fast response of measurements, the sensor can detect hot spots under real time conditions. The utilization of an array of total power radiometer sensors visualizes the temperature profile inside the thermal isolation material during the production process.

DOI 10.5162/sensor2015/P9.1

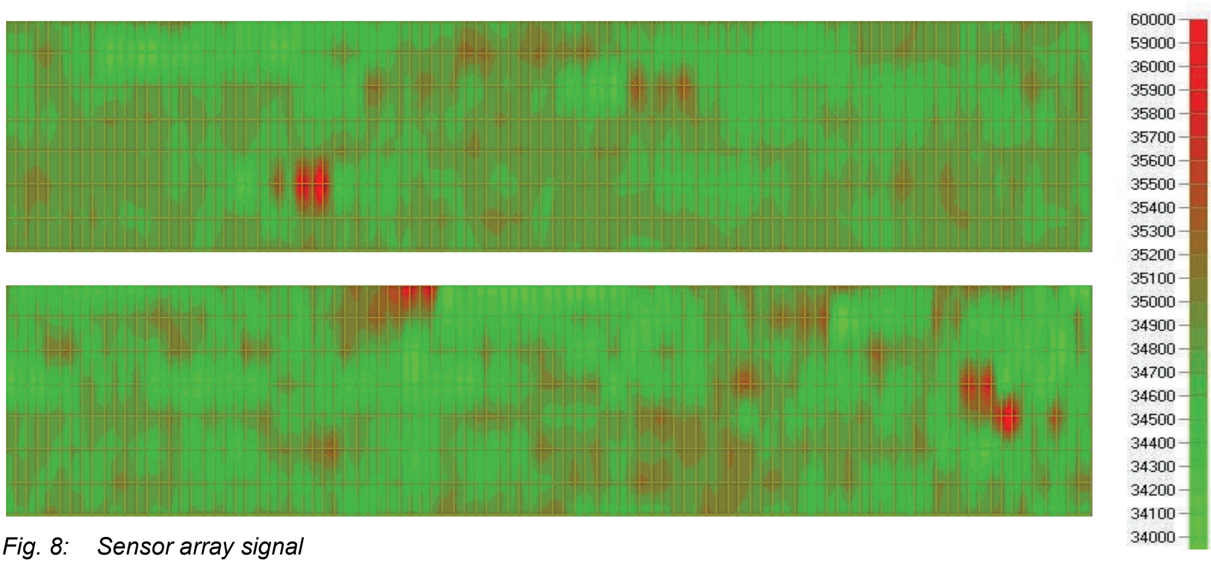

Fig. 8: Sensor array signal

References

[1] F. T. Ulaby, R. K. Moore, and A. K. Fung, “Microwave Remote Sensing.” Vol. 1, MA: Artech H., 1981.

[2] F.Alimenti, S. Bonafoni, S. Leone, G. Tasselli, P. Basili, L. Roselli, K. Solbach, “A Low-Cost Microwave Radiometer for the Detection of Fire in Forest Environments”, IEEE TGRS, 2008, pp 2632-2643

[3] K. D. Stephan, J. A. Pearce, L. Wang, and E. Ryza, "Prospects for industrial remote temperature sensing using microwave radiometry," in IEEE MTT-S Int. Symp., vol. 2, Jun. 6-11, 2004, pp. 651-654.

[4] E. Nyfors and P. Vainikainen, “Industrial Microwave Sensors.” Norwood, MA: Artech House, 1989.

[5] W. D. Rawle and W. P. Lonc, “A small microwave total power radiometer,” IEEE Antennas Propag. Mag., vol. 34, no. 2, pp. 53–54, Apr. 1992.