92 GHz Radiometer System for Remote Sensing Applications

Yong-Hoon Kim, Sunghyun Kim, Gum-Sil Kang, Han-Sik Kim, Ki-Seok Yang

Kwangju Institute of Science and Technology (K-JIST)
1 Oryong-dong, Puk-gu, Kwangju, 500-712, Korea
Tel: +82-62-970-2387, Fax: +82-62-970-2384, E-mail: yhkim@kjist.ac.kr

Abstract

In this paper, very high performance millimeter-wave radiometer of 92 GHz is presented. Radiometer system design, brightness temperature measurement and calibration methods are described. The architecture of radiometer including data acquisition, storage and digital signal processing using a notebook computer are explained and some experimental data in the laboratory are introduced. The system noise figure and total gain of implemented radiometer are 12 dB and 56 dB, respectively. The system stability is evaluated from the experiment. The difference of the detector output voltage for two targets, whose brightness temperature are 80 K and 300K, is 4 mV. The mechanical scanning method is considered to get a brightness temperature image of the earth surface scene.

I. Introduction

Millimeter-wave radiometer is a monitoring sensor system in the field of atmospheric gas detection, water vapor, measurement and wet/dry type snow detection. The radiometer plays an important role more and more in the research of earth environment presently. Depending on various applications, the center frequency of radiometer is chosen in the frequency band range of 20 GHz to over 300 GHz. In designing radiometer system, the most important parameters in many considerations are the stability and sensitivity of radiometer system. The accuracy of measured data has been affected by these parameters. In general, it is very difficult to implement a millimeter-wave radiometer system with a low noise figure because of the difficulty in designing low noise amplifier in this band. Therefore all of the RF components should be designed to achieve a low noise figure. In this paper, we present radiometer system implementation with low noise figure and measured parameters of the system performance. We also describe calibration method, brightness temperature measurement and data acquisition for getting high accuracy result.

II. Radiometer Overview

In case of lossless antenna, the emitted power from target is collected by antenna, and this power is converted to antenna temperature (T_A) directly related to brightness temperature of the target through output terminal. Therefore brightness temperature of the target is obtained by measuring antenna temperature. The total noise output power is related to the sum of system noise temperature and antenna noise temperature[1]. The total noise power, P_{out}, is given by

$$P_{out} = k \cdot B \cdot G \cdot (T_A + T_N) \quad \text{(watt)} \qquad (1)$$

where k is a Boltzman's constant and B, G and T_N are the system bandwidth, the system gain and receiver noise temperature, respectively. The sensitivity of radiometer system (ΔT) is defined as follows;

$$\Delta T = \frac{(T_A + T_N)}{\sqrt{B \cdot \tau}} \qquad (2)$$

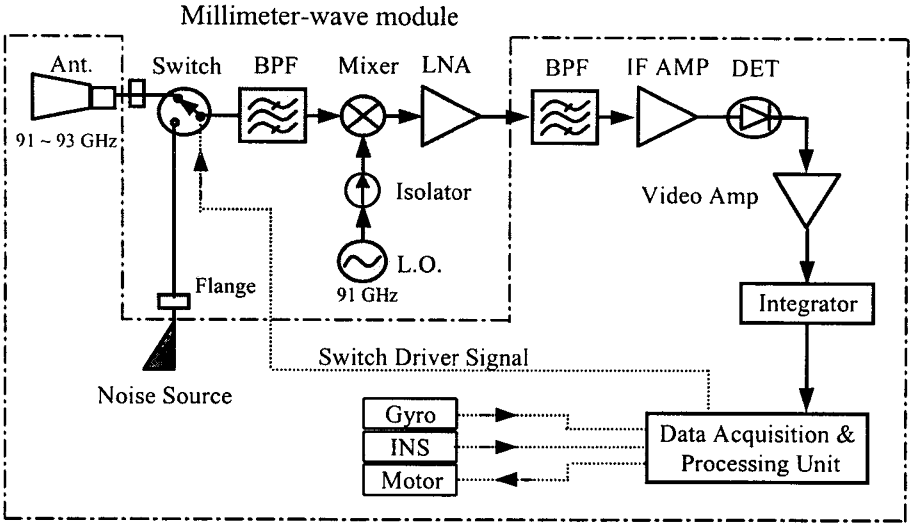


Fig. 1 System block diagram of 92 GHz Radiometer

$$T_N = 290\cdot(NF - 1) \qquad (3)$$

where τ is the integration time and NF is the total noise figure of radiometer system.

III. Radiometer System Design

In general, a type of radiometer is divided into dicke radiometer, noise injection radiometer and total power radiometer[2]. In this paper, the total power radiometer with gain calibration after measuring signal through antenna, shown in Fig. 1, was designed to get high sensitivity with simple structure. The specification of radiometer is shown in TABLE I. The system noise figure including RF switch is 12 dB and the dynamic range of input brightness temperature is from 80 K to 320 K. The temperature and angular resolution are 0.5 K and 2°, respectively. The noise temperature of the system is 4306 K and integration time is set to 75 ms for achieving 0.5 K sensitivity.

TABLE I
Specification of 92 GHz Radiometer System

Radiometric observation angle	2 °
System noise temperature	4306 K
Sensitivity	$\Delta T < 0.5$ K
Dynamic range	80 ~ 320 K
Absolute radiometric accuracy	$\delta T < 2$ K
Center frequency	92 GHz
Bandwidth	2 GHz
System type	Single channel Total power

A. Antenna

To get brightness temperature from antenna temperature, the antenna characteristics must be known and evaluated. In this radiometer, the reflector antenna with low side-lobe and high main-beam efficiency was used for high performance. The specification of antenna is shown in TABLE II.

B. Down Converter

Down converter consists of BPF, oscillator and mixer.

TABLE II
Specification of Antenna

Center frequency	92 GHz
3 dB Beamwidth	2 °
Bandwidth	2 GHz
Main-lobe efficiency	> 0.9
Fist side-lobe level	< -25 dB

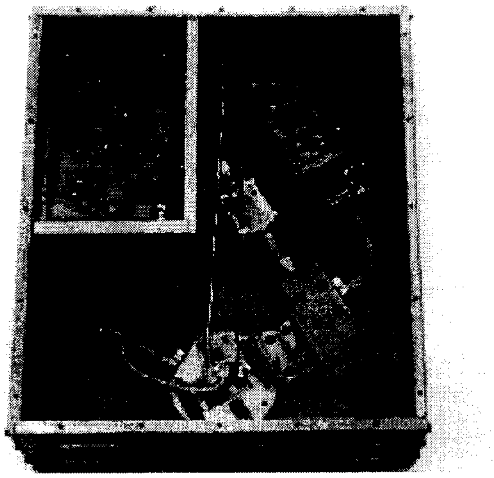


Fig. 2 The millimeter-wave module of 92 GHz radiometer

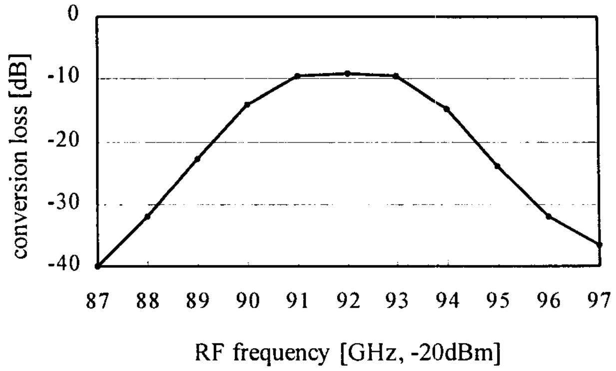


Fig. 3 Performance of 92 GHz down-converter

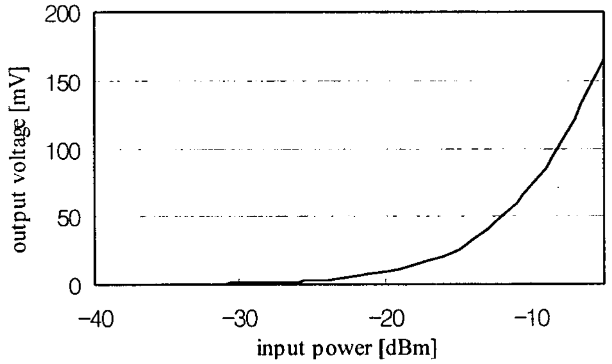


Fig. 4 Detector output voltage according to input power

The band pass filter was designed with low insertion loss and high Q. The optimum structure for getting a good performance is fin line configuration. Generally, metal inserts in fin-line structure are printed on a dielectric substrate which bridges the broad walls of a rectangular waveguide[3]. The implemented BPF was designed using a grounded fin-line structure with alternating metallic bridges ('fin') and large gap over the total height of the rectangular waveguide. A quarter wave-length transformer was also used for the efficient transition waveguide-to-fin-line. As a result, the return loss of filter improved about 5 dB using this transformer. The experimental data of BPF is 0.8 dB insertion loss, 16.8 dB return loss, 3 GHz bandwidth at 92 GHz. In a radiometer system, local oscillator should have the characteristics of low phase noise, good frequency and amplitude stability. So the local oscillator is designed using the gunn diode which satisfies these considerations[4]. The oscillator is composed of Gunn diode, radial resonator, backshort, bias filter and impedance transformer. The output power of oscillator is +12 dBm, and the phase noise is -105 dBc/Hz at 100 kHz offset. Also the designed Gunn diode oscillator has good amplitude stability and frequency stability. To convert RF signal to IF signal, the 92 GHz waveguide mixer was designed and implemented using beam-lead shottky diode. The implemented mixer is single balanced crossbar type with good isolation between LO port and RF port[5]. This mixer is made up of LPF, BPF, suspended stripline-to-wavguide transition, and matching network. The measured data of mixer is 8.5 dB conversion loss, 5 dB bandwidth, 1.3 RF VSWR. The millimeter-wave module of 92 GHz radiometer is shown in Fig. 2 and the performance of down-converter is also shown in Fig. 3.

C. IF Unit

IF Unit consists of IF LNA, BPF, detector and integrator. IF LNA was used to reduce system noise figure. The total gain of amplifiers is adjusted to a suitable level because detector must be operated in square-law detection region. The noise signal down-converted from RF module is transmitted to IF LNA, BPF and detector in turn. The total input power of detector is adjusted to

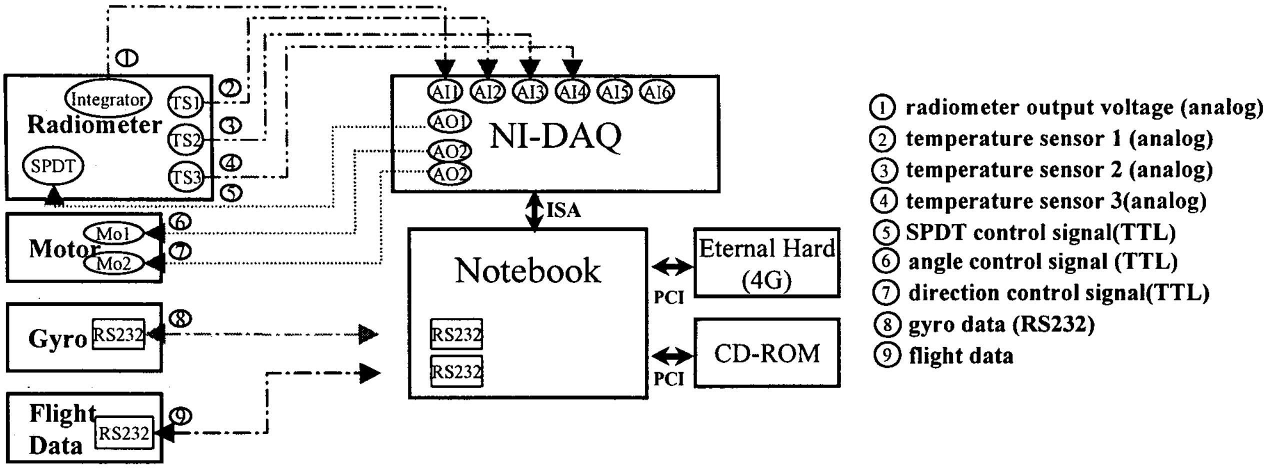


Fig. 5 Data acquisition unit for 92 GHz radiometer system.

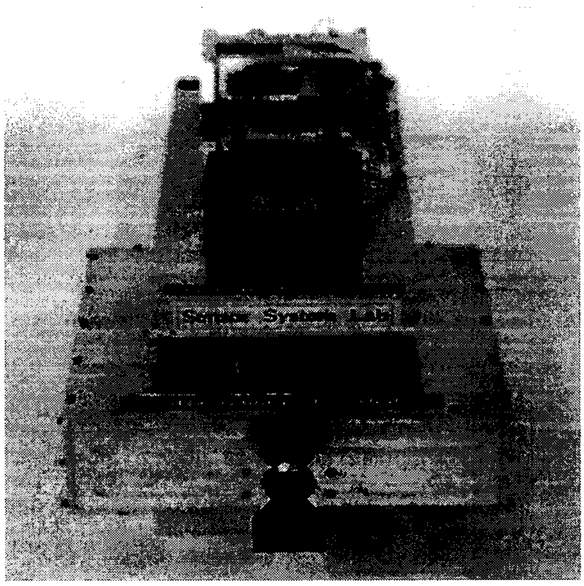


Fig. 6 Scanning radiometer

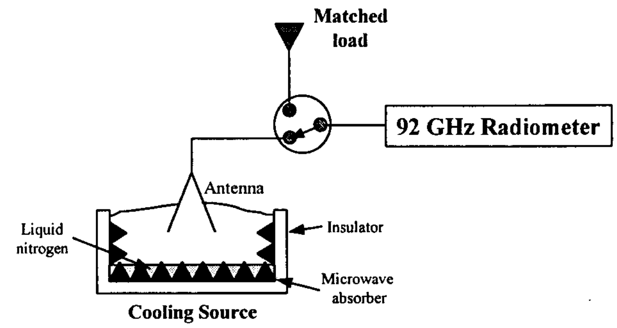


Fig. 7 Calibration procedure of 92 GHz radiometer

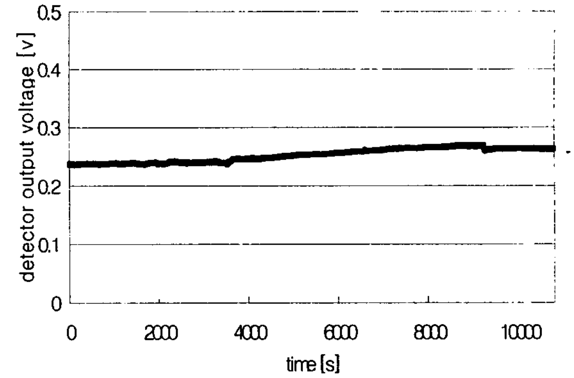
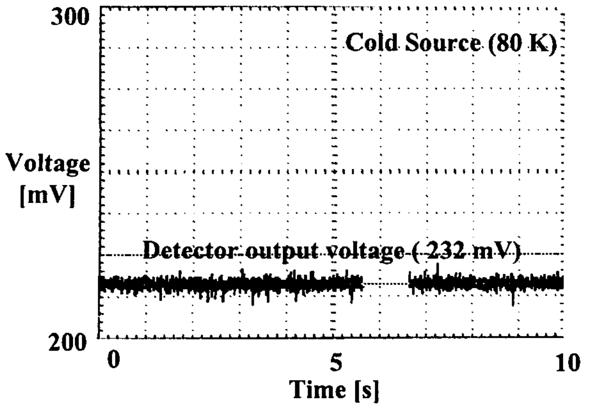


Fig. 8 The stability of implemented radiometer

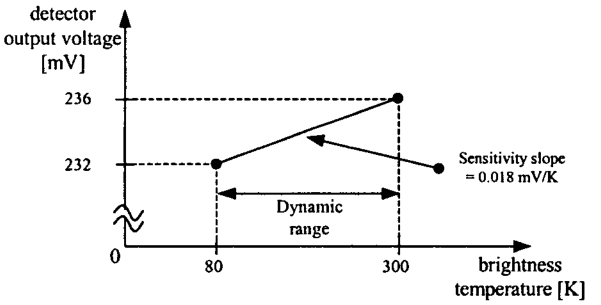
below - 20 dBm for the square-law operation. And total power noise signal is converted to voltage signal by detector with voltage sensitivity of 1.7 mV/μW. The output voltage of detector is shown in Fig. 4.

D. Data Acquisition Unit and Scanning

To achieve the meaningful data during experiment, a well designed data acquisition unit is necessary. If the scanning of antenna is required to achieve the real aperture image, sampling of output signal of radiometer should be synchronized with the control signal of a motor. Fig. 5 shows the data acquisition and processing module. The NI-DAQ (National Instrument Data Acquisition board) is used to sample the analog output of radiometer and the signal of temperature sensors. Also the SPDT switch and the motor are controlled by the NI-DAQ board. The motor control parameters such as a scan angle and an angular velocity are decided by height and velocity of the platform and 3 dB beamwidth of antenna. During the experiment physical temperature of the



(a) The cold source data



(b) Relation of output voltage and brightness temperature

Fig. 9 Perfomance of 92 GHz radiometer

matched load showed in Fig. 5 is measured by a temperature sensor. The measured temperature is used to compute the drift of system gain and the gain variation is compensated by data processing after the experiment. The flight parameters of platform such as height, velocity, and position can be obtained through GPS(Global Positioning System), altimeter and INS (Inertial Navigation System) data. To acquire the exact positioning data of antenna, the angular information is obtained by using the 6-axis gyro sensor. The antenna must scan with constant velocity for getting image from brightness temperature of target. In our system, as shown in Fig. 6, full radiometer system rotates using a step motor.

IV. Calibration and Experimental Results

Since the radiometer is operated in an unexpected environment, it is very important to maintain a reliable calibration. When square law detector is used, it is assumed that the radiometer output voltage is linearly proportional to the input noise power. Then two reliable sources of known brightness temperature are required for calibration purpose. One is cold source using liquid nitrogen whose temperature is about 80 K. A matched load is used as hot calibration source because a well matched load generates a noise temperature equal to its physical temperature. Radiometer system measures each source by changing switch position in turn. The calibration method is shown in Fig. 7. Fig. 8 shows the measured stability of 92 GHz radiometer system. Noise signal is generated from matched load and the measured data is obtained from detector output. For the purpose of radiometer calibration, it is very important to maintain the stable output of detector about same target during short interval. The maximum drift of detector output voltage is about 30 mV for 3 hours. Therefore it can be said that the designed radiometer system is very stable. The performance of 92 GHz radiometer is shown in Fig. 9. The output voltage of detector is measured using oscilloscope. The experimental environment is divided into the cold source and hot source, the measured data of cold source is shown in Fig. 9(a). The brightness temperature of cold source is 80 K and 300 K that of hot source. The output voltage difference in two sources is 4 mV. Therefore the detected output voltage is changed in terms of brightness temperature of input noise with ratio of 0.018 mV/K in the dynamic range.

V. Conclusion

The millimeter-wave radiometer system of 92 GHz has been designed and implemented. The brightness temperature measurement, calibration method and data acquisition are also described. From the experimental result, it can be concluded that the implemented radiometer system is very stable because the detected voltage variation is small. Also the detected output voltage is changed in proportional to brightness temperature of input noise with the ratio of 0.018 mV/K in the dynamic range. To obtain better performance of radiometer system, noise figure and stability of the system must be adjusted.

VI. Acknowledgement

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VII. References

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