HIGH SENSITIVITY, ACCURATE MMW RADIOMETERS FOR GROUND-MAPPING SYSTEMS

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ABSTRACT

AC coupled, periodically calibrated, total power radiometric sensors, covering the atmospheric windows from 10 to 220 GHz, are described. Modulated rf noise generators are used to provide pilot signals for gain stability.

Introduction

A series of radiometric sensors (Figure 1) is described in this paper. These units operate at rf ranges of 10, 35, 94, and 140 GHz.[1,2,3] In addition, a conceptual design of a similar unit at 220 GHz is described. All of these sensors are similar in concept; all employ a distinctive configuration which combines the high sensitivity of the total power technique with the accuracy and stability of the Dicke periodic calibration system.

These units were configured so that they could be mounted in a common airborne scanner, and were used by the Air Force to study radiometric area correlation techniques.

The accuracy of the system is based upon close control of the overall gain using a pilot signal as the reference, and periodic calibration using an rf termination at a known physical temperature. Three types of pilot signal generators have been used: noise-generating diodes, IMPATT-type oscillators, and barretters. These generators are discussed in more detail later.

System Operation

The detailed operation of the control and processing portion of the system can be seen in Figure 2. The rf power from the antenna ($2kB_{IF}T_S$) and the system noise generated in the mixer/IF amplifier are combined with a modulated noise-like signal from the pilot signal generator and both are simultaneously down-converted in the mixer. Since these signals are identical in their spectral characteristics over the rf band of interest, the overall gain of the pilot signal, as it is processed by the receiver, will be identical to that from the antenna or from the reference termination. This overall gain includes the mixer conversion loss, the IF amplifier gain, the detection efficiency of the second detector, and the video gain down to the band-defining video filters. A video AGC maintains a constant voltage level at the output of the synchronous detector, thereby providing an accurate calibration for the antenna temperature output signals.

Figure 1. Radiometric Sensors

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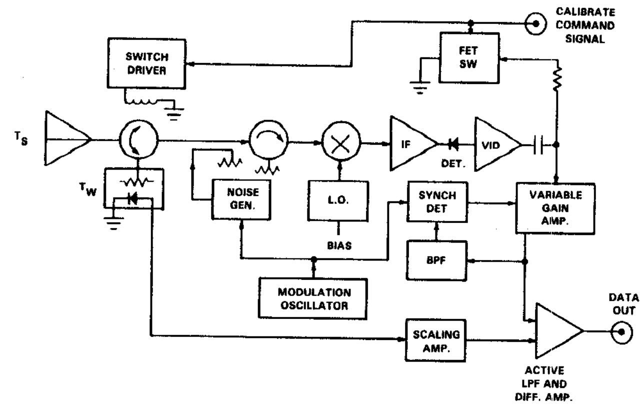

Figure 2. Basic Radiometer Block Diagram

Pilot Signal Generator

It is evident that the stability of the pilot signal is of critical importance to this system. However, the pilot signal generator must also be small in size and must respond to relatively high modulation frequencies. Moreover, the equivalent temperature of the pilot signal must be high enough to provide a detectable temperature change after passing through the directional coupler. Thus, conventional noise-tubes are eliminated because of their size; and passive terminations, because of insufficient output. However, an exception for the passive termination is the barretter, which has been used at 10 and 35 GHz. A barretter is a tiny platinum-wire bolometer which changes temperature and resistance upon the application of small amounts of rf or dc power. By embedding the wire across the waveguide and controlling its resistance with a switched bridge circuit, the physical temperature of the wire can be modulated between two precisely known values at fairly high rates. The highest usable temperature of the wire is limited to approximately 900K; therefore, the maximum differential temperature signal is approximately 400K. Since the wire is matched to the waveguide impedance by the embedding circuitry, the noise power supplied to the waveguide is directly proportional to the wire temperature. A 13 dB coupler is used, giving a pilot signal amplitude of approximately 20K at a modulation rate of 700 to 1,500 Hz. Although this device is probably the most accurate and stable of the pilot signal generators, the limited output and frequency characteristics have negated its use for many airborne systems.

Noise-generating diodes of two types have been used for pilot signal generators at 35, 94, and 140 GHz. A low-capacitance step-recovery diode (TI MD-631) in a beam-lead configuration has been quite successful at Ka-band. In this case, the diode was bonded across a gap in a microstrip circuit and the output coupled to the main line by means of a microstrip coupler as shown in Figure 3. When biased at 4 mA in the reverse breakdown region, this diode generated approximately 6,000K. Coupling through an 18 dB coupler provided 100K signals, modulated at 4,800 Hz. Although the output was a function of ambient temperature, it was repeatable, and a temperature compensation network was readily tailored to provide a video output reference which was nearly constant over an ambient temperature range from -20 to +70°C.

At 94 GHz and 140 GHz, IMPATT diodes, biased below the normal operating current level, have provided large amounts of noise power. At 94 GHz, for example, a 300 mA diode, when operated at 110 mA, produced a noise temperature of 17,000K. Coupling through a 19.2 dB coupler yielded a pilot signal with a 200K variation, modulated in this case at 1,907 Hz. A similar technique was used at 140 GHz, and noise levels of 2,000K were generated. In both cases, the noise level, though not constant with temperature, was repeatable, permitting thermal compensation to within the required accuracy.

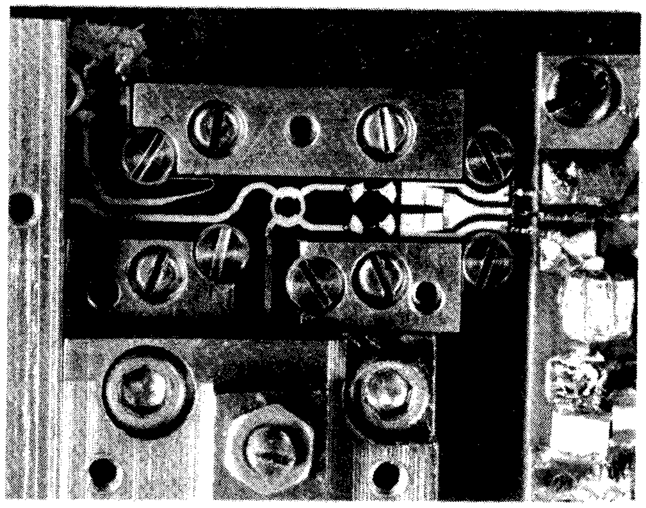

Figure 3. Microstrip Circuitry

Calibration

The periodic calibration of the output data makes use of a reference waveguide termination at a known physical temperature. This termination is connected to the receiver input periodically, usually at the end of each antenna sweep. Simultaneously, as shown in Figure 4, the input of the differential amplifier is grounded by the FET switch. Therefore, the data output signal displays only the physical temperature of the termination. During the scan, the FET switch is opened and the video voltage into the processor represents the difference between T_w and T_s. The differential output amplifier subtracts this from T_w, leaving only T_s as shown.

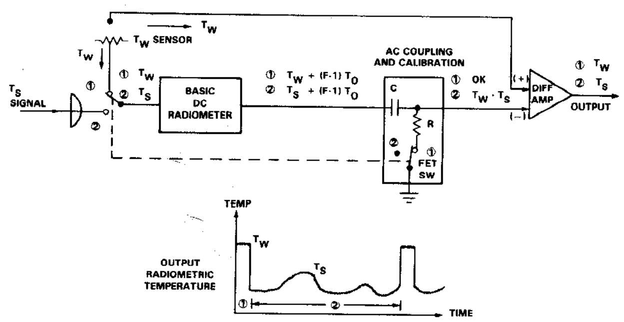

Figure 4. Periodic Calibration Technique

Figure 5 summarizes the performance characteristics of these radiometers at the various frequency ranges, including the estimated values for the proposed 220 GHz configuration shown in Figure 6. This design uses quasi-optical techniques in oversize waveguide to implement the required component characteristics for this type of radiometer. The estimated performance is based upon data published by Taub,[4] Erickson,[5] and others for components of this type.

Acknowledgements

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References

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f_o (GHz)	WG Size	RF Losses (dB)	Mixer NF (dB)	Overall NF (dB)	ΔT_{min} (Kelvins)	Output Data BW (Hz)
10	WR-90	1.2	5.3	6.65	0.4	30
35	WR-28	1.3	5.0	6.4	1.5	150
94	WR-10	2.9	9.4	12.5	3.5	150
140	WR-8	5.0	6.3	11.5	1.5	10
220	WR-10	2.5*	12*	15*	3.5*	10

*Estimated

Figure 5. Radiometer Performance Characteristics

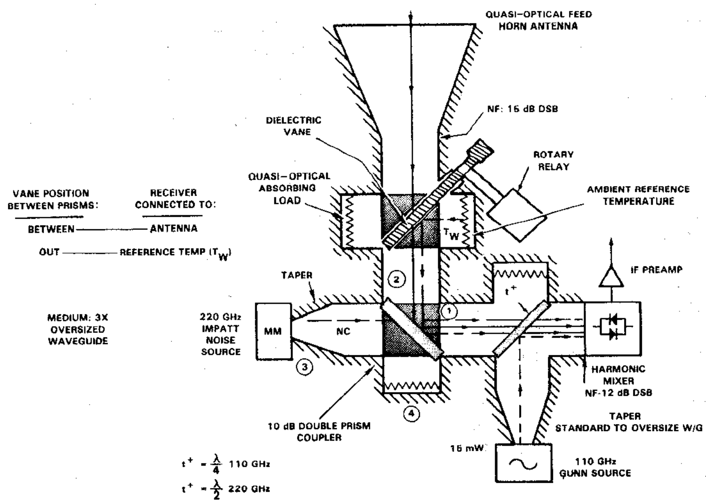

Figure 6. 220 GHz Quasi-Optical Radiometer Arrangement