U-7 CRYOGENIC ALL SOLID-STATE MILLIMETER-WAVE RECEIVERS FOR AIRBORNE RADIOMETRY

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Abstract

Cryogenic receiver modules for 90 and 140 GHz have been developed that are part of an airborne imaging system. They consist of Schottky-barrier mixers followed by GaAs-FET IF amplifiers. The DSB receiver noise temperatures are 210 K for the 90 GHz and 250 K for the 140 GHz system. The instantaneous bandwidth is 2.5 GHz for both front-ends. Results of some flight tests are presented.

Introduction

High resolution airborne microwave imaging is of great practical interest for the remote sensing of the earth´s surface. In particular the millimeter-wave region is very useful, because high angular resolution can be achieved with small antennas and at the same time contrast losses due to weather conditions and atmospheric attenuation are still small. In the past however, the resolution of millimeter-wave airborne imaging systems was very poor, because of the relatively high noise temperatures of the receivers used. This resulted in data rates on the order of only 100 samples per second for a temperature resolution of 1 K. In order to increase this value by at least one order of magnitude, cryogenic receiver front-ends for 90 and 140 GHz have been developed that have extremely low noise temperatures and very broad instantaneous bandwidths. [1]

Receiver Concept

In order to avoid the inherent resolution losses of a Dicke-system or a correlation-system, the simple total-power receiver concept was chosen. The disadvantage of the uncompensated gain fluctuations in a total-power system was found to be negligible in our case, because of the short integration times used (on the orderof milliseconds). In addition the short- and long-term stability of the receiver was improved by temperature control of all critical components (IF-amplifiers, detector etc.).

Fig.1 shows a block diagram of the receiver. Two exchangeable cryogenic front-end modules have been built, one for 90 GHz and the other one for 140 GHz. They consist of a Schottky-barrier mixer followed by a two-stage IF-amplifier. For the cooling to about 20 K, a closed-cycle refrigerator system (CTI 21) is used. The weight of the compressor is 39 kg and the power consumption is 1.1 kW. The cooled components are located in a vacuum chamber in order to prevent convection and condensation of the air.

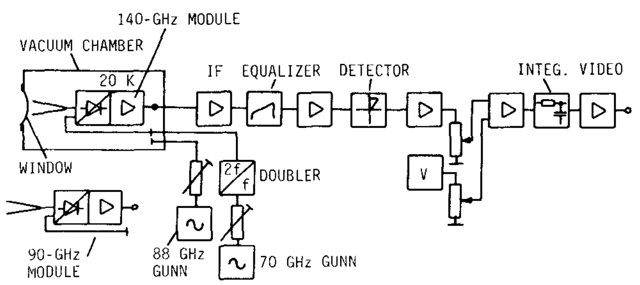

Fig.1: Block diagram of the receiver

The mixers are pumped by Gunn-oscillators. For the 140 GHz receiver module, a 70 GHz Gunn-oscillator followed by a frequency doubler is used. The efficiency of this doubler is about 10%, giving an available output power of 2 mW at 140 GHz. However the pump-power requierement of the mixer was only about 0.1 mW when cooled to 20 K. For the doubler, the same type of diode has been used as for the mixers.

The IF-signal coming from the cryogenic front-end is further amplified in uncooled amplifiers and then rectified in a back-diode detector. An equalizer is inserted to smooth the frequency response of the IF-amplifier chain. Fig.2 shows the remaining frequency response. The IF-band limits of 1.5 and 4 GHz respectively are defined by the gain drop-offs of the amplifiers. After the detector the signal is compensated and pre-integrated.

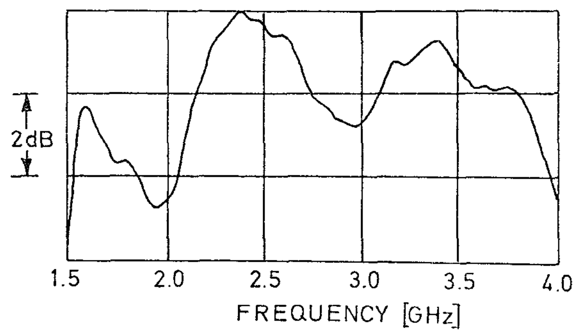

Fig.2: IF-gain response of the receiver

Front-end Modules

A cross-sectional view of the 90 GHz front-end module is shown in Fig.3. The 140 GHz module looks quite similar to this. The local oscillator is coupled via a TE_{111}-mode cavity filter into the signal waveguide, which is an electroformed transition to a reduced height (1/3) waveguide cross section. Due to the band-pass frequency response of the filter, the signals in both sidebands of the mixer are reflected at the filter. Therefore at the signal frequencies the filter acts as a backshort. The distance between filter and mixer diode was experimentally optimized for minimum noise figure.

The mixer diodes have been fabricated at the Institut für Angewandte Festkörperphysik in Freiburg F.R.G. The diameters of the Schottky-contacts are 2µm and the

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epilayer doping concentration is $2 \cdot 10^{16} cm^{-3}$. The parasitic series resistance is 7Ω and the ideality factor (characteristically inverse slope of V-logI curve) is 1.07 at room temperature. This type of diode is used for both front-end modules and also for the 70 to 140 GHz doubler. However special varactor diodes would be more suitable for the doubler.

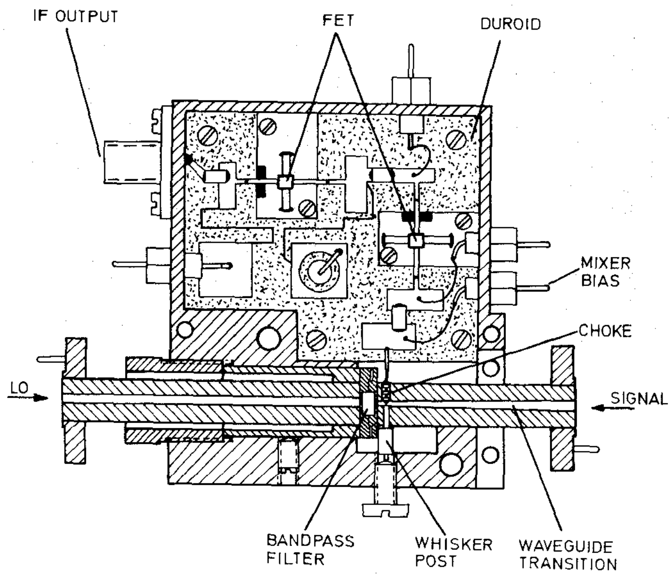

Fig.3: Cross-sectional view of the 90 GHz front-end module

The cryogenic IF amplifiers have been optimized for the frequency band from 1.5 to 4 GHz, resulting in a noise temperature of 35 K for the IF-amplifier chain. The gain is 12 dB per stage. In order to reduce the uncooled postamplifier noise contribution, two stages are mounted in each front-end module. The transistor type MGF 1412 (Mitsubishi) was used for all cryogenic amplifier stages. For the input and output matching networks, double-section matching transformers in microstrip technology have been chosen. In order to achieve a broad matching bandwidth, short (0.1 λ) matching elements were used[2]. The same technique was applied for the matching of the mixer IF-output port.

Table 1 gives a summary of the specifications of both front-end modules. The stated figures for the theoretical data rate are calculated for a temperature resolution of 1 K, assuming a mean value for the antenna temperature of 250 K. However the real values for the complete imaging system are about 40% lower because of the nonideal frequency response of the IF-amplifier chain (see Fig.2), radom losses and the limited main-beam efficiency.

Imaging System

The cryogenic receiver is part of an airborne imaging system. The two front-end modules can be exchanged within short time. However, the cryogenic part of the receiver has to be at room temperature for the exchange. The cool-down time is about 3.5 houres. At both frequencies, the same off-axis parabolic mirror antenna is used. The minor axis diameter is 20 cm, giving an angular resolution (HPBW) of about 1° at 90 GHz and 0.7° at 140 GHz. The antenna oscillates around an axis parallel to the flight direction so that the ground is scanned perpendicular to the flight path (see Fig.4). The maximum oscillation frequency is at present 35 Hz and the scan angle is ± 14.5°. It is hoped, that the oscillation frequency can be increased to about 50 Hz in the near future.

TABLE 1

specifications of the receiver front-ends

center frequency	88 GHz	140 GHz
intermediate frequency	1.5-4 GHz	1.5-4 GHz
IF bandwidth	2.5 GHz	2.5 GHz
receiver noise temp. (DSB) at room temp.	710 K	870 K
receiver noise temp. (DSB) at 20 K	210 K	250 K
theor. data rate (1 K)	11815 s^{-1}	10000 s^{-1}
stability, short term	$3 \cdot 10^{-5}$/min	$3 \cdot 10^{-5}$/min
stability, long term	$2 \cdot 10^{-4}$/h	$2 \cdot 10^{-4}$/h

For absolute temperature calibration, a rotating absorber is placed between the mirror and the receiver input. The dumbell-shaped absorber is synchronized with the mirror such that it covers the receiver input, when the mirror changes the direction of movement. The data are recorded on magnetic tape for further analysis on the ground and also displayed on a screen for quick-look evaluation.

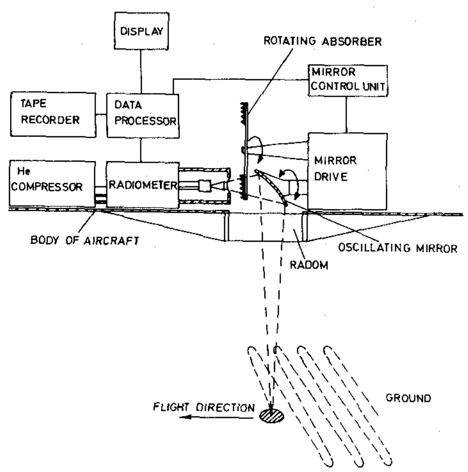

Fig.4: Block diagram of the imaging system

Results

The imaging system has been flown several times aboard a small twin-engine aircraft (Dornier Do 28). Fig.5 shows a 90 GHz image of the DFVLR area, taken from an altitude of 85m. A visual photograph of the same area is shown on the left for comparison. The shown area of 43 by 650 m was overflown within 13 seconds (aircraft speed: 50 m/s). This image exemplifies the capability of high-resolution airborne radiometry.

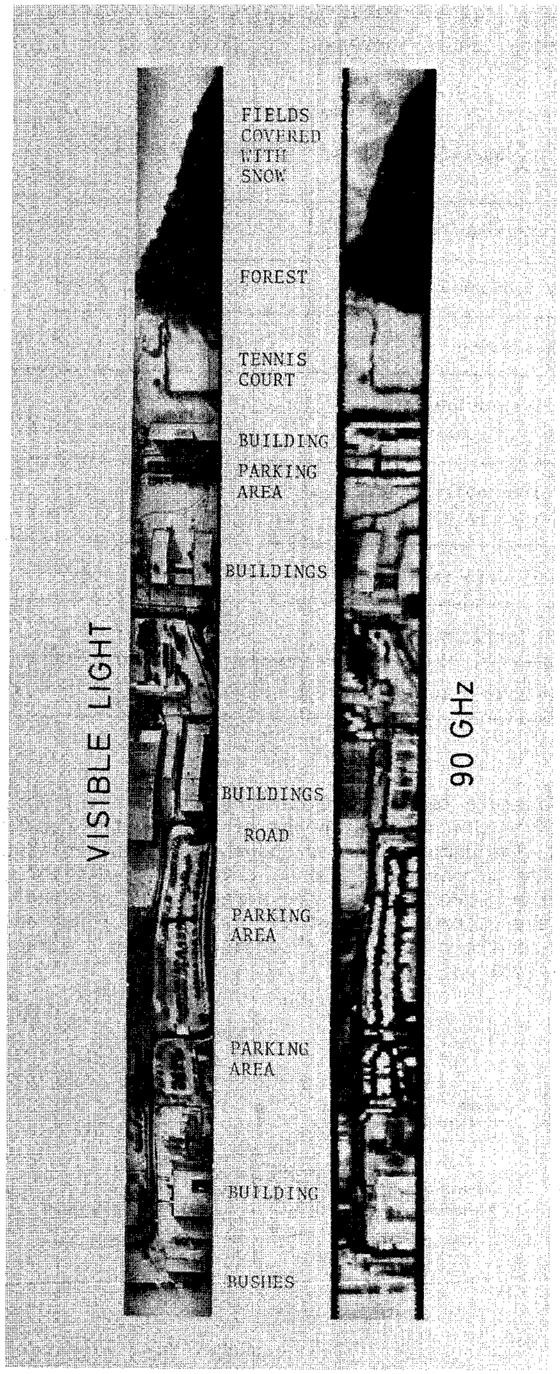

Fig.5: DFVLR area, altitude 85m, comparison: visible light (left) with 90-GHz image (right). Dark areas have a higher radiometric temperature in the 90-GHz image.

Fig.6 shows airplanes parked on a concret platform at 90 GHz (left) and 140 GHz (right). In both pictures small vehicles around the airplanes can also be detected. Furthermore radiometer resolution is sufficiently fine to display the substructure of the concrete platform. In general the images at 140 GHz have a lower contrast compared to images at 90 GHz because of the much higher radiometric temperature of the sky at 140 GHz. Further results have been published elsewhere.[3]

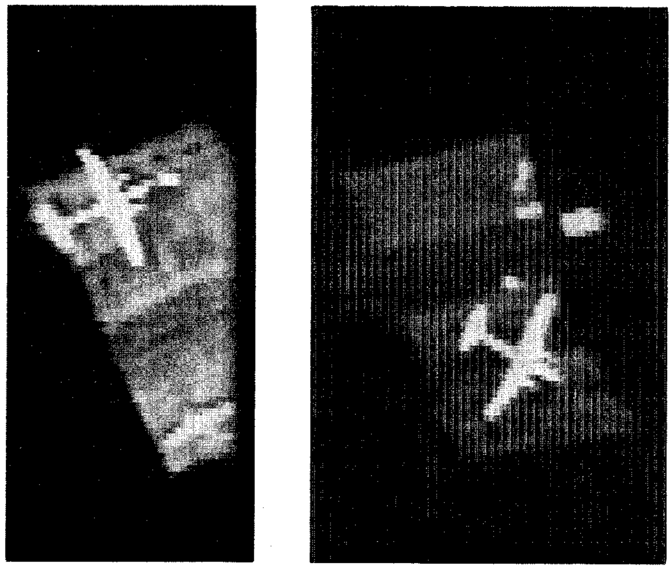

Fig.6: 90-GHz (left) and 140-GHz (right) images of airplanes. Altitude 85m, scanwidth 45m.

Conclusion

A cryogenic receiver system has been built which is small in size and reliable under flight conditions. The significant improvement in sensitivity compared to room-temperature receivers opens new fields of applications for airborne radiometry. Further resolution improvements are possible by increasing the number of receiver modules, i.e. using a multichannel system. It would also be desirable to replace the mechanically movable mirror by an electronically scanning antenna. Developments in these directions are under way.

References

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