DUAL FREQUENCY MULTI-CHANNEL MILLIMETER WAVE RADIOMETERS FOR HIGH ALTITUDE OBSERVATION OF ATMOSPHERIC WATER VAPOR

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ABSTRACT

This paper describes three generations of a millimeter wave radiometer operating at 94 and 183 GHz designed for airborne atmospheric measurements on-board NASA Convair 990 and RB-57 aircraft. Airborne measurements in 1977 and 1978 have substantiated theoretical conclusions on millimeter wave atmospheric properties.

Introduction

The technique of mapping atmospheric weather phenomenon by measuring the magnitude of the water vapor absorption line at 183.3 GHz from a satellite platform has shown promise as an aid in locating and understanding storms. Two radiometers have been constructed and flown on the NASA Convair 990 research aircraft in various atmospheric and geophysical measurement programs[1,2] in 1977 and 1978. A third radiometer with a mechanically scanned beam incorporating techniques gained from the previous instruments is currently under construction to make brightness temperature images of atmospheric phenomenon from 60,000 feet on-board a NASA RB-57 aircraft in the Spring of 1979. The two most recent instruments also contain a 94 GHz radiometer to measure surface reflectivity. All three systems incorporate recent advances in Schottky barrier mixers, solid state millimeter wave local oscillator components and automatic, unattended operation, calibration, and data collection by means of a microcomputer control and data acquisition system.[3,4]

System Descriptions

The first radiometer employed two IF channels near 183 GHz. A close-in channel at 183 $\pm$ 1 GHz was used to make measurements near the peak of the water vapor absorption line and a second channel at 183 $\pm$ 5 GHz was used to aid in determining the relative shape of the line. The second radiometer utilized a third channel at 183 $\pm$ 8.75 GHz to further increase the line resolution plus a 94 GHz channel to measure ground reflectivity. Figure 1 illustrates the relative arrangements of the various channels.

Both Convair radiometers were fixed beam systems using a corrugated horn-lens antenna. The front-end was mounted in a modified window port as shown in Figure 2 with a movable external reflector allowing a downlooking angle of 45° or up-looking at 14° above the horizon. Aircraft maneuvers also allowed zenith viewing.

First System

The first 183 GHz radiometer employed a single-ended mixer with a Schottky barrier diode in a Sharpless wafer mount. Local oscillator power was provided by a 91.65 GHz klystron driving a solid state varacter doubler developed by AIL. LO energy was coupled into the mixer via a cavity type diplexer. This assembly along with a rotating Dicke chopper, a calibration load assembly, IF and video amplifiers was mounted on an aluminum plate which was attached to a modified window of the Convair. The phase sensitive detectors and microcomputer controlled data collection system were contained in a separate rack-mounted unit along with a computer terminal through which the operator communicated with the control programs. Radiometer calibration was achieved by a rotating reflector which periodically allowed the radiometer to view alternately a heated hot load at 336°K, a cold load referenced to the aircraft skin (about 250°K in flight) or the outside environment. The calibration sequence was under the control of a microcomputer. Calibration data along with the physical load temperatures as measured by embedded thermistors were recorded on magnetic tape.

Over 90 flight hours of data were taken by this system on the NASA Convair 990 during the Winter and Spring of 1977. Flights ranged from the Southern California Coast, Northwestern U.S., Canada, Alaska, and Greenland. Early results indicate that ice particles in the upper atmosphere can be detected by reflection of millimeter wave energy at 183 GHz.[5]

Second System

In order to gather more data on the shape of the water vapor absorption line at 183 GHz a third IF channel was added to the original system at 8.75 GHz. A second RF channel at 94 GHz was also added to provide data on surface reflectivity and low altitude rain. A unique beam combining Dicke chopper design allowed both antennas to share the same calibration loads and lens antenna. A block diagram of the improved system is shown in Figure 3. Additional improvements were made in the data collection system to allow longer unattended operation and to incorporate a real-time display of calibrated brightness temperatures.

An improved 183 GHz mixer was incorporated into this radiometer containing a wideband IF matching network to allow low noise operation at the 8.75 GHz IF frequency. The three IF channels were distributed to the IF amplifiers by a strip-line triplexer specially designed for this application. Figure 4 shows the window mounted RF components. The data collection and control electronics are shown in Figure 5.

This radiometer was involved in several NASA atmospheric measurements programs in 1978 including hurricane monitoring in Project Storm Fury, in the Carribean and Pacific, SEASAT ground truth measurements in Alaska and NIMBUS 7 sea surface and polar ice measurements in Greenland, Norway, Alaska and Hawaii.

Flight Test Data

Observations made at 94 GHz during a penetration of tropical storm Cora in the Lesser Antilles have yielded positive results in the correlation between low-level rainfall and a sharp decrease in the 94 GHz brightness temperature. While looking down on the storm from 30,000 feet simultaneous indications of precipitation were noted on both the NASA GSFC Electronically Scanned Microwave Radiometer (ESMR) and the Georgia Tech 94 GHz radiometer. Figure 6 shows a plot of brightness temperatures for the 94 and 183 GHz channels along with aircraft altitude and IR surface temperature. Note the sharp drop in temperature as the Convair entered an area of overcast. Results from these and other flights with this instrument suggest the potential usefulness of 94 GHz radiometry in mapping rain over land and sea.[6] Several times during the Convair 990 flight series, a controlled spiral descent at a constant bank angle was used to allow all sensors on-board the Convair 990 to obtain atmospheric temperature profiles. Figure 7 shows a plot of the 183 GHz and 94 GHz brightness temperatures while the radiometer was up-looking at an angle of 44°. Note the rapid warming in the 183 GHz channels and the more gradual change at 94 GHz. The noise on channel 2 (183 GHz, 8.75 GHz IF) was due to ground based X-band radar interference. The lower two plots are pressure altitude and aircraft roll angle.

Third System

The third generation of the airborne millimeter wave radiometer system is currently under construction in preparation for a measurement program beginning in May, 1979. The RF portion of the radiometer will be an improved version of the last Convair system. The 183 GHz front-end will be upgraded to an all solid state configuration.

A digitally controlled, rotating, metal reflector mounted on a foam structure will be used to image a ± 22° angular swath with a 1° beamwidth at 183 GHz. The entire radiometer will be packaged in sealed temperature controlled enclosures mounted in a special RB-57 experiment pallet. The operation of the radiometer will be controlled by three microcomputers and will operate automatically for up to 7 hours under control of an internally stored program. Radiometric data will be recorded on magnetic tape cartridges for post flight analysis by a special ground support data processing system.

Summary

A summary of the important characteristics of the three systems described above is shown in Table 1. Rapid improvements in millimeter wave component technology coupled with advances in microprocessor hardware have made such improvements in system performance and complexity possible. The experience gained from these systems has greatly reduced the normal delay between laboratory and field in millimeter wave radiometry.

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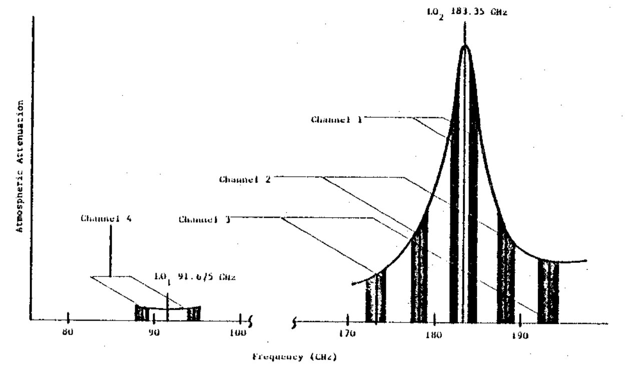

Figure 1. 94/183 GHz Radiometer Frequency Allocation.

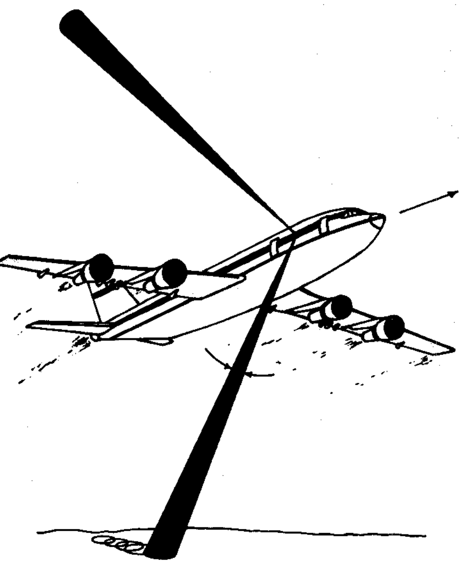

Figure 2. Radiometer Viewing Angles.

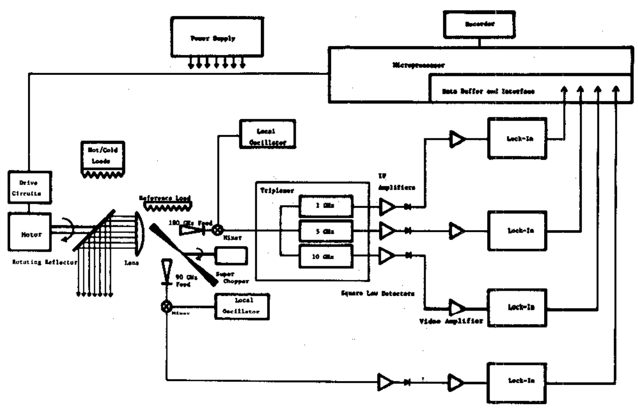

Figure 3. 94/183 GHz Radiometer Block Diagram.

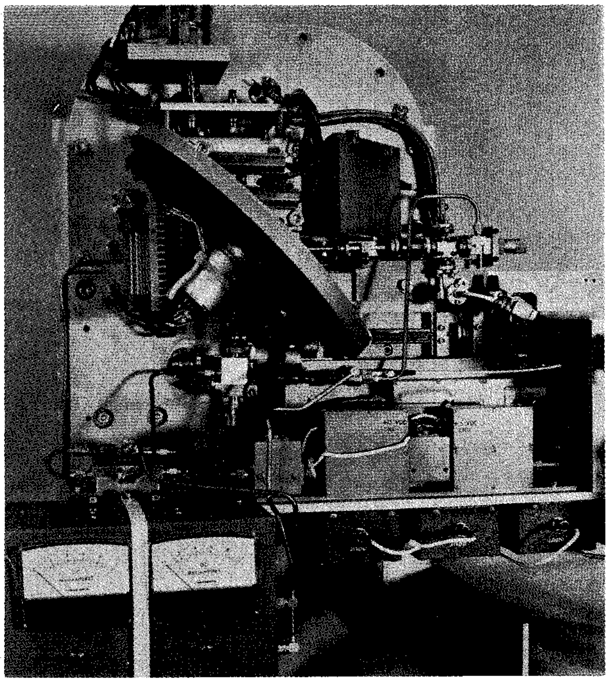

Figure 4. Radiometer Front-end.

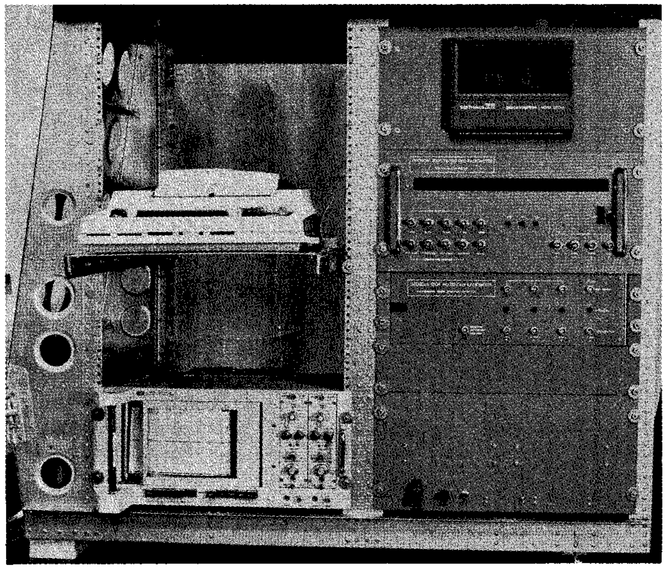

Figure 5. Data Collection and Control System.

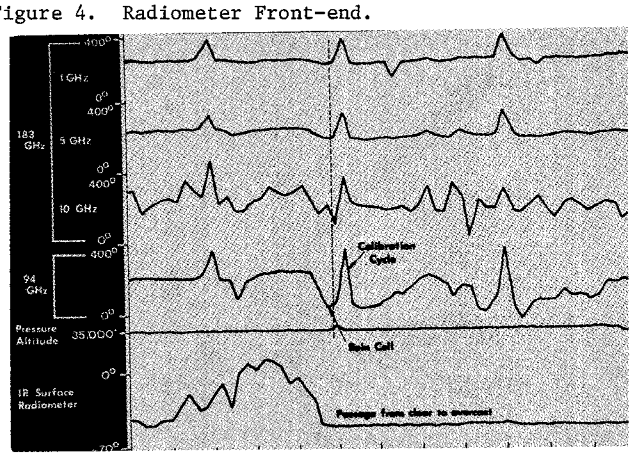

Figure 6. Brightness Temperatures Versus Time Showing Rain Detection(Down-looking).

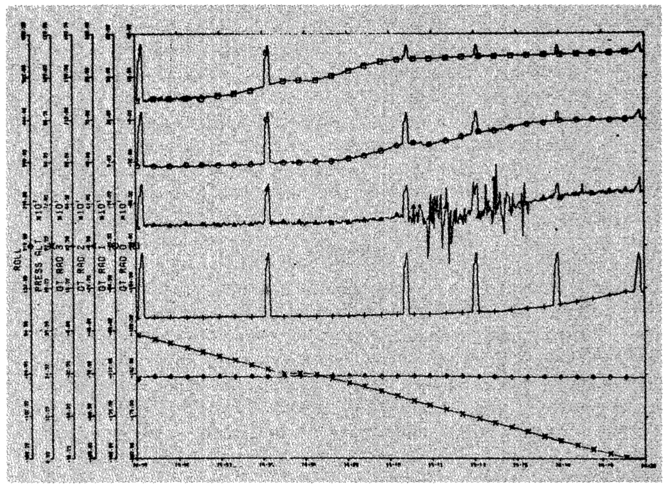

Figure 7. Brightness Temperatures Versus Time During Spiral Descent (Up-looking).

Table 1. Operational Comparisons of the Georgia Tech Millimeter Wave Radiometers.

	1ST GENERATION	2ND GENERATION	3RD GENERATION
PLATFORM	NASA AMES CONVAIR 990	NASA AMES CONVAIR 990	NASA HOUSTON RB-57
DATES	MARCH - APRIL 1977	JUNE - NOVEMBER 1978	APRIL - SEPTEMBER 1979
LOCATIONS	WESTERN U.S., ALASKA, GREENLAND	WESTERN U.S., ALASKA, HAWAII, GREENLAND, NORWAY	U.S.
RF CHANNELS	183.3 GHZ	183.3 AND 94 GHZ	183.3 AND 94 GHZ
IF CHANNELS	1 AND 5 GHZ	1,2, 5 AND 8.75 GHZ	1, 2, 5, 8.75 GHZ
LOCAL OSCILLATOR	KLYSTRON/VARACTOR DOUBLER	KLYSTRON/VARACTOR DOUBLER	GUNN/DOUBLER
MIXER(S)	SCHOTTKY BARRIER-SHARPLESS WAFER	SCHOTTKY BARRIER-SHARPLESS WAFER (94 GHZ) SCHOTTKY BARRIER-IMPEDANCE MATCHED (183 GHZ)	SCHOTTKY BARRIER-SHARPLESS WAFER (94 GHZ) SCHOTTKY BARRIER-SUBHARMONIC PUMPED (183 GHZ)
SYSTEM NOISE FIGURES (DSB)	12.1 DB (1 GHZ IF) 18.5 DB (5 GHZ IF)	183 GHZ: 10 DB (1 GHZ IF) 94 GHZ: 9.5 DB 16 DB (5 GHZ IF) 22 DB (8.75 GHZ IF)	183 GHZ: 9.0 DB (1 GHZ IF) 94 GHZ: 9.5 DB 12.0 DB (5 GHZ IF) 18.0 DB (8.75 GHZ IF)
DICKE SWITCH	LOADED ROTATING METAL BLADE, 30 HZ	BEAM COMBINING REFLECTIVE BLADE, 250 HZ	BEAM COMBINING REFLECTIVE BLADE, 500 HZ
VIEWING ANGLES	45° FROM NADIR AND 14° ABOVE HORIZON	SAME	SCANNING ± 22°
BEAM WIDTH	2.5°	2.5° (183 GHZ) 5° (94 GHZ)	1° (183 GHZ) 2° (94 GHZ)
ANTENNA	CORRUGATED HORN - 2" REXOLITE LENS	SAME	CORRUGATED HORN - 6" REXOLITE LENS
CALIBRATION TECHNIQUE	GRAPHITE-EPOXY COATED ALUMINUM LOADS AND MOTOR DRIVEN REFLECTOR	SAME	LARGE GRAPHITE-EPOXY LOADS VIEWED DURING SCAN RETRACE
DATA COLLECTION	MICROCOMPUTER CONTROLLED CARTRIDGE TAPE SYSTEM. SIMPLE SINGLE PROCESSOR SYSTEM REQUIRING FREQUENT OPERATOR ATTENTION	SIMILAR TO 1ST GENERATION BUT WITH ADDITION OF AN ALPHANUMERIC PLASMA DISPLAY AND HIGH SPEED FLOATING POINT PROCESSOR FOR REAL-TIME DISPLAY OF CALIBRATED BRIGHTNESS TEMPERATURES	MULTI-PROCESSOR SYSTEM WITH SEPARATE MICRO-COMPUTERS FOR TAPE DRIVE CONTROL, SCANNER OPERATION AND MASTER CONTROL. GROUND SUPPORT HARDWARE WILL ALLOW TRANSFER OF DATA FROM CARTRIDGE TO REEL-TO-REEL TAPE AND COLOR DISPLAY OF RADIOMETER DATA.
INTEGRATION TIME	2 SEC	200 MS	15 MS
SYSTEM SENSITIVITY/ °K (ΔTmin)	0.3°K (1 GHZ IF) 1.0°K (5 GHZ IF)	183 GHZ: 0.6°K (1 GHZ IF) 94 GHZ: .4°K 2.4°K (5 GHZ IF) 7.1°K (8.75 GHZ IF)	183 GHZ: 1.8°K 94 GHZ: 1.4°K 2.6°K 10.0°K