THE DEVELOPMENT OF AIRBORNE COSSIR FOR ICE CLOUD MEASUREMENTS

Zhaonan Zhang, Bryan Monosmith
Microwave Instruments & Technology Branch
NASA, Goddard Space Flight Center

1. INTRODUCTION

Ice clouds are a key atmospheric entity that couple the global hydrologic and energy cycles and modulate the climate system response to changes in global forcing. Most ice cloud measurements conducted in the past by aircraft or satellite sensors have been limited to the visible and infrared regions of the spectrum. Retrievals of cloud parameters from these sensors are generally limited to regions near the top of the ice clouds. To probe denser ice clouds and study their microphysical properties requires sensors at longer wavelengths. Theoretical analyses have shown that millimeter and sub-millimeter wave radiometric measurements with broad spectral coverage can provide reliable estimations of ice cloud parameters [1], [2]. To realize this potential, an airborne Compact Scanning Sub-millimeter wave Imaging Radiometer, CoSSIR, was developed.

2. NEW FREQUENCY BANDS

The primary version of CoSSIR was composed of six total power sub-millimeter wave radiometers at the frequencies of 183, 220, 380, 487 (V & H), & 640 GHz. The 487 GHz (V & H) channels were dual-polarized and the remaining channels were horizontally polarized. The instrument was first flown on board the NASA ER-2 aircraft during CRYSTAL-FACE in July 2002. After some improvement, the instrument was flown again on board the NASA WB-57 aircraft during the first phase of the CR-AVE in January 2006. During these field campaigns, the instrument could provide water vapor profiling capability up to an altitude of about 15 km.

Studies have shown that water vapor absorption reduces sensitivity to lower clouds for frequencies above 500 GHz. Lower frequencies, 183, 220, & 380 GHz, in sub-millimeter wave range have less water vapor absorption and can thus sense lower altitude ice clouds, which tend to have large particles.

Studies have also shown that two highest water vapor absorption windows with acceptable transmission in sub-millimeter wave range are around 643 GHz and 874 GHz. Simulations demonstrate that the higher frequencies, particularly at 874 GHz, are highly sensitivity to scattering by ice particles. Simulating the polarization ratios of 640 GHz brightness temperature demonstrates greater sensitivity to particle size.

Consequently, multiple sub-millimeter wave frequency, 183 GHz ~ 874 GHz, measurements on water vapor lines provide humidity profile and cloud height information, thereby providing a unique measurement of ice clouds. In order to extend the frequency range from 643 GHz to 874 GHz, a dual-polarization 643 GHz and a single-polarization 874 GHz radiometer were recently developed. The design and development of these radiometers will be described in the next two sections.

The latest version of CoSSIR that measured radiation at the frequencies of 183, 220, 380, 643 (V & H) and 874GHz was flown for the TC4 field campaign in July ~ August, 2007.

3. DESIGN OF RADIOMETERS

The descriptions of the radiometer design are going to focus on the recent developed radiometers, the dual-pol 643 GHz and single-pol 874 GHz radiometers.

The dual 643 GHz radiometers were driven by two independent Gunn oscillators with operating frequencies at 80.375 GHz. Each source signal was fed into a cascade of two varactor doublers and its frequency was multiplied up to 321.5 GHz with a 4 mW power level to provide a LO power for 643 GHz sub-harmonic mixer.

Due to considerations of frequency stability, a DRO, Dielectric Resonator Oscillator, output frequency of 36.417 GHz was selected for the driving source of the 874 GHz receiver. After the source power was amplified by an RF amplifier, the signal frequency was multiplied by 12 with a cascade chain composed of a frequency quadrupler and tripler. Consequently, a signal at frequency of 437 GHz with a 2.5 mW power level was produced to be used for a LO power of 874 GHz sub-harmonic mixer.

The frequency stability of the LO was degraded with the multiplication of the fundamental frequency. For the dual-pol 643 GHz receivers, the frequency stability of Gunn oscillators was typically at 8 MHz/^{0}C. But the stability of the LO was reduced to 32 MHz/^{0}C. In order to keep the down converted IF signal within the IF band a frequency band of 0.1 ~ 6.0 GHz was chosen.

The DRO chosen was of high quality with frequency stability of 3.5 MHz/^{0}C for the 874 GHz LO chain. Since the fundamental frequency was multiplied by 12 and there were other frequency stability issues in the 874 GHz channel, an IF bandwidth of 0.5 ~ 8.0 GHz was selected.

4. DEVELOPMENT OF RADIOMETERS

In the CoSSIR radiometers, stages of multipliers were employed to multiply frequencies up to the LO frequencies. The forwards biases of the multipliers induced by the input RF powers were sensitive to the input power levels and physical temperature. During the development, heat sinking was properly mounted on the multipliers to keep temperatures at a certain range; thermal control chips were attached on the Gunn oscillators to control operating temperatures; and layouts were carefully considered to avoid interference among the channels.

Some innovations were implemented during the development of the 874 GHz radiometer. In the primary version, a DRO was operating at a frequency of 12.140 GHz. A tripler & RF amplifier output frequency of 36.420 GHz was connected to the next stage with a WR-22 flange. In the latest version, a DRO frequency of 36.417 GHz was selected and a K-connector to replace the WR-22 flange in the Trip & RF amplifier. These approaches significantly reduced DC power supply and volume allowing the entire radiometers to be integrated into the original drum.

5. THE COSSIR DRUM

The CoSSIR drum, a cylinder 8.5” diameter and 11” length, with the control unit is shown in Figure 1.

Fig. 1 The CoSSIR drum with the control unit.

The calibration references of the drum were composed of two close coupled external blackbodies at the temperatures of ~250 K and ~300 K. The external blackbody measured to an accuracy of +/- 0.1 K provided a calibration accuracy of about +/- 0.7 K in the brightness temperature range of 200 ~ 300 K.

The scan geometry of CoSSIR was software programmable with versatile scan modes. It can be programmed to perform a conical scan with incidence angles between 0^0 ~ 54^0, or an across track scan, or a combination of both. The details of the scan pattern can be found in Wang et al. [3].

6. LABORATORY CALIBRATION

A few series of laboratory calibration tests of the instrument were conducted with a liquid nitrogen (LN_2) calibration load to verify and enhance radiometry performance. An across track scan mode was programmed in these tests, with the antenna beams pointing at three fixed scenes of cold, hot, and LN_2 loads for one second each in every cycle. The calibration run normally lasted 1~2 hours, after the initial instrument warm up of about 30 minutes. A blower was used to apply cold air at the scan head continually to keep the Gunn oscillators from overheating.

Calibration data was used to adjust bias voltages and video-amps gains to balance the performance of the 643 GHz dual channels. After several testing cycles, the measured brightness temperatures of the 643 GHz dual channels were within 1.0 K during laboratory calibrations.

House keeping data was used to improve the performance of the 874 GHz receiver. The test data showed that the temperature variations of the DRO were less than expected. But the temperature changes of the RF amplifier were still un-controllable, which seriously affected the LO power level and performance sensitivity.

The laboratory calibrations provided unique information about how to adjust bias voltages on each stage and balance the entire operations. The adjustments enhanced performance of radiometers, resulting in a system noise temperature, T_{sys}, of 4000 K for the 643 GHz radiometer and 8000 K for the 874 GHz radiometer.

7. TC4 FIELD CAMPAIGN

The TC4 field campaign was in Costa Rica during July 15 ~ August 10, 2007. CoSSIR was on board the NASA ER-2 aircraft with a cruising altitude of about 20 km. The measurements were therefore above all cloud systems. Previous measurements of ice clouds by CoSSIR (Evans et al., 2005) were limited to the frequency range of 183~640 GHz. The measurements during the TC4 extended the frequency coverage over 183~874 GHz. Additionally, CoSSIR had a dual-polarization measurement capability at 640 GHz during TC4.

A segment of brightness temperature map acquired by the CoSSIR is shown in Figure 2.

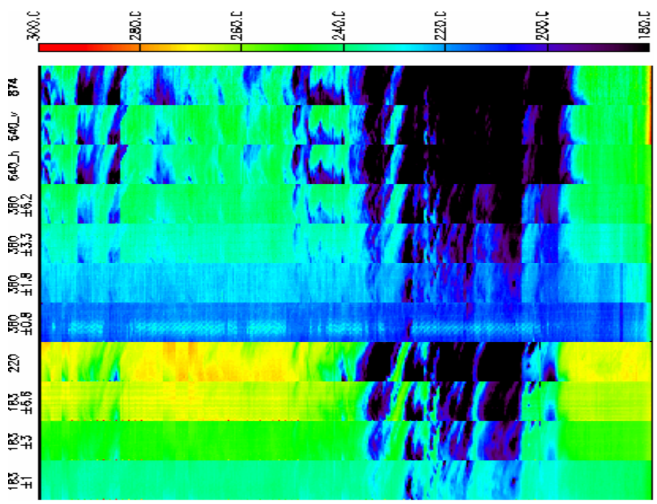

Fig. 2. The brightness temperature maps acquired by the CoSSIR during a flight segment on July 17, 2007 over ocean areas south of San Jose, Costa Rica.

Brightness temperature variations along the flight path obtained at an observation angle of 53.6^0 in the forward direction during a flight on July 17, 2007 over ocean areas south of San Jose, Costa Rica.

The brightness temperature map shows that the regions of low brightness temperatures are a result of millimeter wave and sub-millimeter wave scattering by ice particles in the clouds. The scattering is strongly frequency dependent, the higher the frequency the larger the scattering. The dispersion in the scattering signatures near the water vapor lines of 183 and 380 GHz are caused by water vapor absorption.

For light to moderate ice clouds, the high-frequency channels, particularly at 874 GHz, show a much higher sensitivity to scattering by ice particles. In the cloud-free regions, the polarization ratios of 643 GHz brightness temperature are close to unity as expected; while in the region of ice clouds these ratios are varied from unity, clearly indicating non-spherical features of the ice particles.

8. SCIENTIFIC SIGNIFICANCE

The brightness temperature map presented above clearly demonstrates the recent advance in sub-millimeter wave radiometry for ice cloud sensing. The new 874 GHz radiometer greatly improves the CoSSIR sensitivity to small ice particles. This implies that CoSSIR is able to pick up the measurements of ice clouds where the visible/IR approaches left behind, i.e. saturated. The new polarization measurement capability at 643 GHz can provide information on particle shapes, as well as improve the accuracy of the ice cloud parameter retrievals, e.g., ice water path and particle size.

9. ACKNOWLEDGE

The authors would like to acknowledge Gerald Heymsfield and the Principal Investigator, James Wang for their assistance in preparing and editing this presentation. Ed Means and Eric Simon also contributed to the mechanical, electrical and software modifications to CoSSIR in preparation for the TC4 campaign. Virginia Diodes Inc. is largely responsible for developing sub-millimeter technologies used in CoSSIR, especially the 874 GHz radiometer components.

10. REFERENCES

[1] K.F. Evans, J.R. Wang, P.E. Racette, G. Heymsfield, L. Li, "Ice Cloud Retrievals and Analysis with Data from the Conical Scanning Submillimeter Imaging Radiometer and the Cloud Radar System during CRYSTAL-FACE," J. Appl. Meter., 44, 839-859, June 2005.

[2] J.R. Wang, L.A. Chang, B. Monosmith, Z. Zhang, "Water Vapor Profiling From CoSSIR Radiometric Measurements," IEEE Trans. Geosci. Remote Sens., vol. 46. no. 1. pp. 137-145, Jan. 2008.

[3] J.R. Wang, P.E. Racette, J.E. Piepmeier, B. Monosmith, and W. Manning, "Airborne CoSMIR Observations Between 50 and 183 GHz over Snow-covered Sierra Mountains," IEEE Trans. Geosci. Remote Sens., 45(10), pp. 55-61, 2007.