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Monolithic Microwave Integrated Circuit Water Vapor Radiometer

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Abstract

A proof-of-concept Monolithic Microwave Integrated Circuit (MMIC) Water Vapor Radiometer (WVR) is under development at Jet Propulsion Laboratory. WVRs are used to remotely sense water vapor and cloud liquid water in the atmosphere and are valuable for meteorological applications as well as the determination of signal path delays due to water vapor in the atmosphere. The high cost and large size of existing WVR instruments motivate the development of miniature MMIC WVRs, which have great potential for low cost mass production. The miniaturization of WVR components allows large-scale deployment of WVRs for Earth-environment and meteorological applications. Small WVRs can also result in improved thermal stability, resulting in improved calibration stability. This paper describes the design and fabrication of a 31.4 GHz MMIC radiometer as one channel of a thermally stable WVR, to assess the MMIC technology feasibility.

Introduction

A WVR is "... a device for measuring sky brightness temperature at two frequencies on and near the emission line at 22.2 GHz."[1] A typical WVR consists of two independent radiometers, or channels, tuned at 20.7 GHz and 31.4 GHz. The development effort described here concentrated on the design and fabrication of the 31.4 GHz channel alone, with the idea that the second (e.g. 20.7 GHz) channel could be constructed in the same way.

A primary motivation for this research is to build a thermally stable WVR through the minimization of the WVR components. Improved WVR thermal stability should lead to increased system calibration stability. Dual channel radiometers, at 20.7 GHz and 31.4 GHz, sense sky brightness temperatures which respond to both water vapor and liquid water. The 20.7 GHz channel is more affected by water vapor, while the 31.4 GHz channel by liquid water. Two independent and simultaneous measurements of sky brightness temperatures at these frequencies allow the extractions of water vapor and liquid water content in the atmosphere.[2] Measurement accuracy can be increased with improved system calibration stability.

A thermally stable WVR is therefore desirable. By miniaturizing the WVR instrument, thermal stability can be improved.

System Design

The system design approach was to integrate MMIC chips from commercial and research foundries onto carriers built at JPL, and also to develop a modular package design which allows individual modules to be tested. The WVR receives a Radio Frequency (RF) signal with a 400 MHz bandwidth centered at 31.4 GHz, amplifies the signal, downconverts it to an Intermediate Frequency (IF) of 9.4 GHz, detects the IF signal, then processes it to give an output frequency between 0-100 KHz. This output frequency is proportional to the measured sky temperature.

A system block diagram is shown in Figure 1. The radiometer MMIC assembly consists of a noise source module, a Low Noise Amplifier (LNA) module, a mixer module, an IF amplifier and bandpass filter module, and a detector/voltage-to-frequency converter module. The noise source module is used for system calibration. The LNA module amplifies the RF signal and determines the system noise figure. Frequency downconversion is done through the mixer. The IF amplifier and bandpass filter module serves as a gain block and determines the system bandwidth. The detector/voltage-to-frequency converter module detects the IF signal then converts it to a frequency pulse between 0-100 KHz which is proportional to the amplitude of the IF signal. A photograph of the radiometer MMIC assembly is shown in Figure 2 and the individual MMIC modules are shown in Figure 3. These MMIC modules along with a Dielectric Resonator Oscillator (DRO) for the mixer Local Oscillator (LO) supply and an antenna will be integrated onto a heat sink carrier, as illustrated in Figure 4. The LNAs and IF amplifier chips were procured from commercial foundries (Varian and Pacific Monolithics), and the mixer was developed and fabricated at Honeywell. The DRO was purchased from Varian.

Among the challenges of this effort are the package design, the electrical performance characterization of the MMIC chips, and the fabrication and assembly of the modules. MMIC modular testing, minimization of size and thermal analysis are major considerations in the package design. The MMIC chips were mounted on their module carriers for testing. Module carriers were machined from Molybdenum. The rest of the WVR package was made from brass. Package fabrication and module assembly were done at JPL.

Module testing is currently in progress. Preliminary tests on the LNA module, mixer, IF amplifier module and the detector/ voltage-to-frequency module have been performed, and system integration and test will follow.

Applications

The potential commercial applications of WVRs are promising. The National Oceanic and Atmospheric Administration's (NOAA) ground based dual-wavelength WVRs have shown the ability to monitor aircraft icing conditions by measuring supercooled liquid water in clouds. Such radiometers, if they could be made small and at low cost, could be deployed at small and medium sized airports. NOAA has a related application in which measurements of precipitable water vapor can be used by numerical weather prediction models; such data could be used to improve the calibration of polar orbiting and geostationary satellites. The Department of Energy (DOE) is investigating the implementation of numerous WVRs at several global study sites over the next two years for their Atmospheric Radiation Monitoring (ARM) project. The ARM project seeks to improve the capability of general circulation models so that global effects, such as global warming, can be predicted.

Conclusions

This proof-of-concept 31.4 GHz MMIC WVR demonstrates the technological feasibility of a miniature radiometer instrument. The cost of large-scale production of this MMIC WVR is potentially low, which is essential in commercial applications.

Acknowledgements

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References

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[2] D.C. Hogg, *et al.* "Measurement of Excess Radio Transmission Length on Earth-space Paths" *Astronomy and Astrophysics*, 95, 1981, pp. 304, 305.

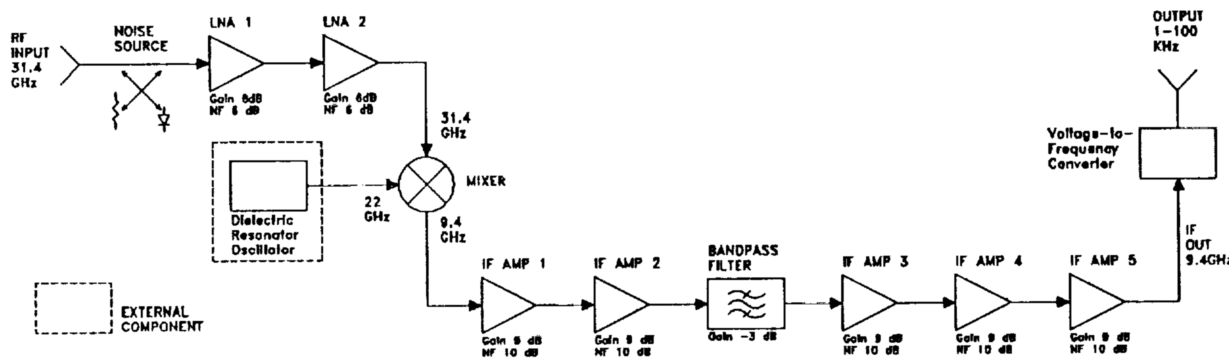


Figure 1. System Block Diagram

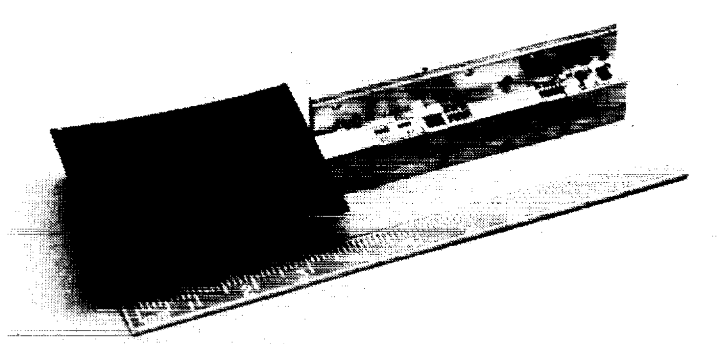
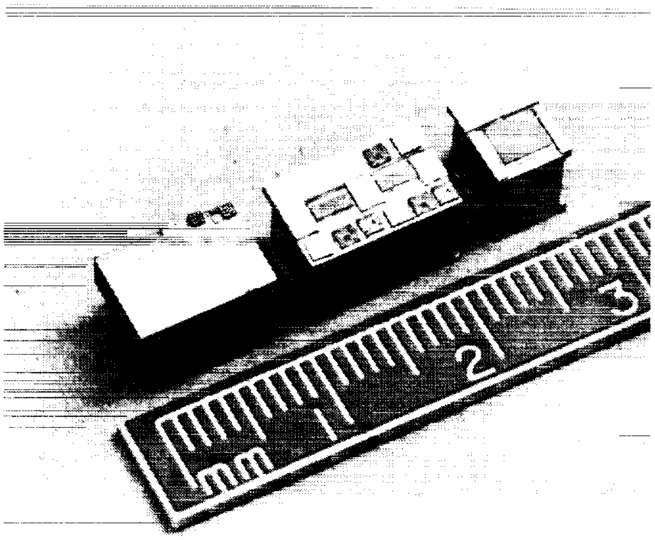
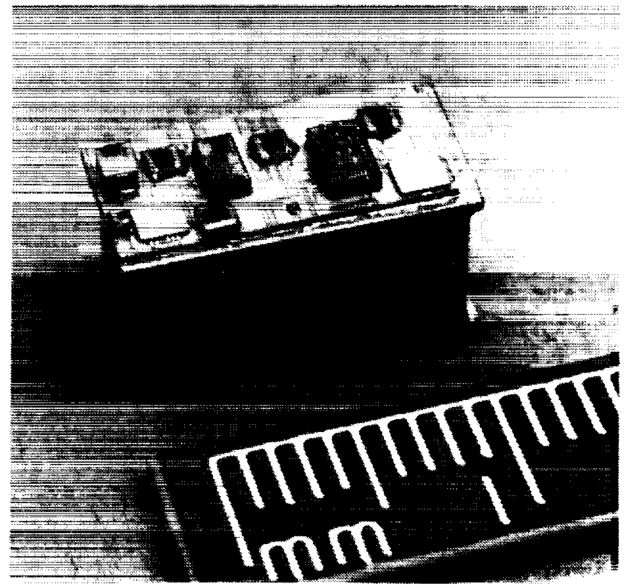


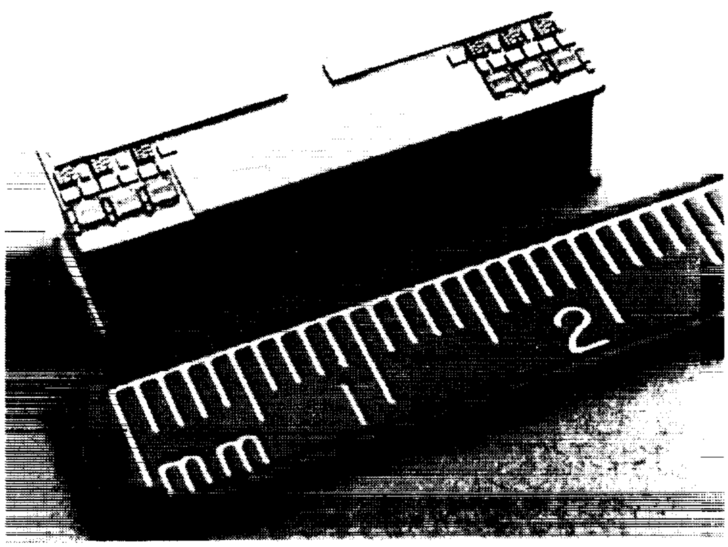
Figure 2. MMIC Radiometer Assembly



Noise Source,Low Noise Amplifier and Mixer Module



Detector/Voltage-to-Frequency Converter Module



IF Amplifier and Bandpass Filter Module
Figure 3. MMIC Modules

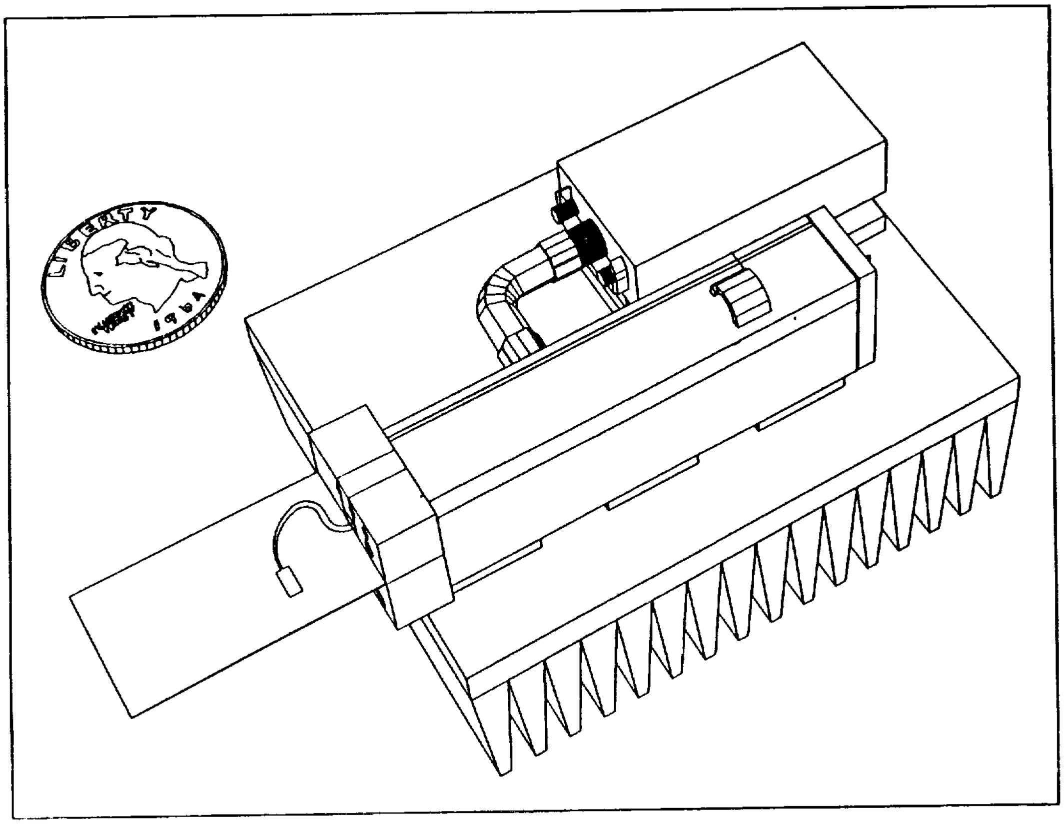


Figure 4. MMIC Radiometer Integrated System Layout