A Channelized 2nd IF/LO Downconverter for the EOS Microwave Limb Sounder

Remi LaBelle

Jet Propulsion Laboratory (JPL), California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA, (818) 354-1615

Abstract — **The Earth Observing System (EOS) Microwave Limb Sounder (MLS) is scheduled for launch in 2004 on the EOS Aura spacecraft. The design, assembly and test of the flight 2nd Intermediate Frequency/Local Oscillator (2nd IF/LO) subsystem for this instrument has been completed and is presented here. The 2nd IF/LO subsystem consists of 5 separate microwave assemblies, 1 for each of the 5 millimeter wave radiometer front ends, providing a total of 33 separate IF channels. Some key requirements of the subsystem are as follows: provide frequency multiplexing of overlapping or closely spaced 1st IF channels while maintaining low ripple in the passbands; generate 19 different 2nd LO frequencies, in the range of 4–20 GHz, with low phase noise and a placement resolution of 400 KHz; downconvert the 1st IF's to a common 2nd IF frequency centered at 900 MHz; minimize cost and schedule by using common designs for the 5 different assemblies wherever possible.**

I. Introduction

The Earth Observing System (EOS) Microwave Limb Sounder (MLS) instrument is scheduled for launch in 2004 on the EOS Aura spacecraft. Aura is the third in the EOS series of low earth orbit (LEO) satellites, managed by the NASA Goddard Spaceflight Center (GSFC), to study the earth, oceans, and atmosphere. The MLS experiment is a collaboration between the United States and the United Kingdom [1]. The Jet Propulsion Laboratory (JPL) has overall responsibility for its development and implementation. The University of Edinburgh (UE) Meteorology Department has responsibility for aspects of data processing algorithm development, data validation, and scientific studies. The overall scientific objectives of MLS are to measure temperature, pressure, and several chemical species in the upper troposphere and stratosphere. These measurements will increase understanding of ozone chemistry in the atmosphere and improve knowledge of processes that affect climate variability.

A simplified block diagram of the overall instrument is shown in Fig. 1. The 5 different radiometer front ends cover roughly 15 GHz bands, ranging from 118 GHz to 2.5 THz [2]. The channelizations required in the 5 1st IF bands are shown in Fig. 2. The placement of the 2nd local oscillator frequencies is also shown, for either high- or low-side downconversion. It can be seen that these are broadband IF's, with bandwidths up to 2.7:1. While the radiometer front ends were the most technically challenging portion of the instrument, in terms of qualifying the millimeter wave devices for space, the 2nd IF/LO subsystem presented many challenges of its own. This paper describes the 2nd IF/LO (SIF) design and how some key technologies were employed to meet the subsystem performance requirements. Test results for the various subsystem assemblies are also presented, along with photos of the finished flight hardware.

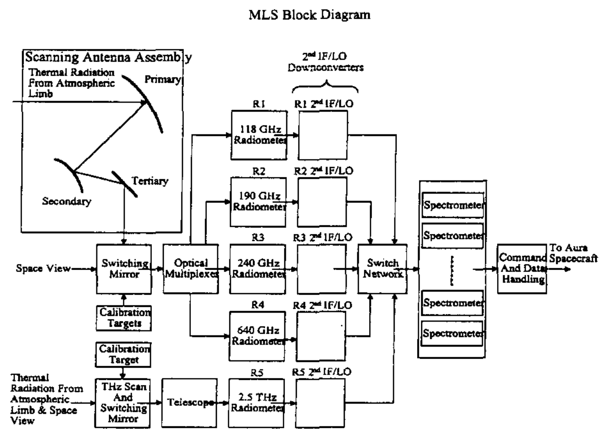

Fig. 1. Simplified MLS Block Diagram

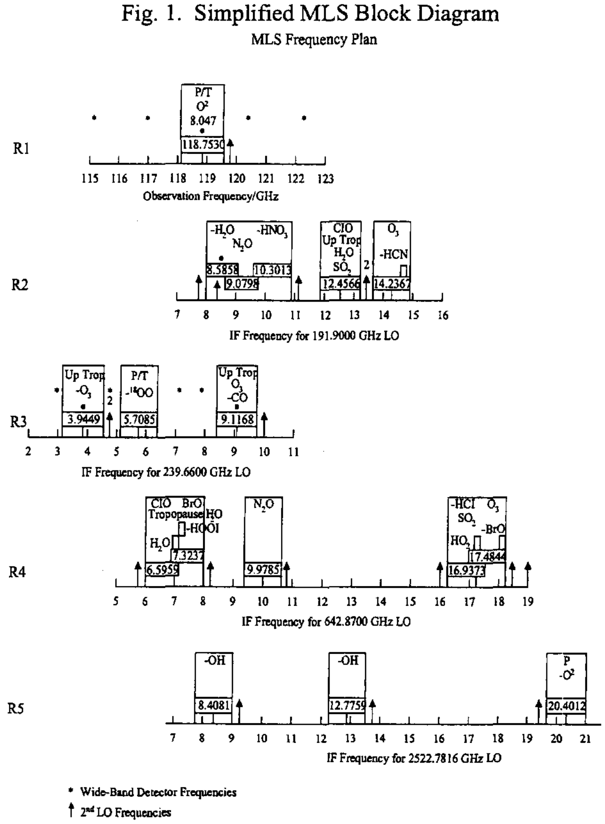

Fig. 2. 1st IF Frequency Bands

II. Subsystem Design

The SIF subsystem consists of 5 separate microwave assemblies, 1 for each of the 5 millimeter and submillimeter wave radiometer front ends, providing a total of 33 separate IF channels. Some key requirements of the subsystem are as follows: provide frequency multiplexing of overlapping or closely spaced 1st IF channels while maintaining low ripple in the passbands; generate 19 different 2nd LO frequencies, in the range of 4–20 GHz, with low phase noise and a placement resolution of 400 KHz; downconvert the 1st IF's to a common 2nd IF frequency centered at 900 MHz for processing by the filterbank spectrometers; maintain a noise figure <6 dB while varying the "back-end" gain over a 15 dB range to accommodate different signal paths to the filterbank spectrometers; minimize cost and schedule by using common designs for the 5 different assemblies wherever possible.

The RF portion of each SIF assembly consists of 1 to 6 phase-locked oscillators, a frequency multiplexer (MUX) module, and 1 or 2 3-channel 2nd IF downconverter modules. In addition, each SIF assembly has on-board power conversion and a monitor and control interface. The DC-DC converter provides +12 and ±5V from the spacecraft 29V bus voltage. A custom FPGA-based data acquisition card performs control of DC power to each channel, step attenuator settings, PLO frequency programming, and monitoring of engineering telemetry. The overall SIF assemblies are packaged as 2-sided plates, with a nominal RF side and a DC and monitor and control side. These plates slide into slots in an electronics bay on the MLS instrument, and are secured by wedgelocks on 1 side and fasteners on the other 3 sides. A block diagram of a typical assembly (R2 SIF) is shown in Fig. 3. Photos of the top and bottom sides of the R2 SIF assembly (while mounted in a handling fixture) are shown in Figs. 4 and 5 respectively.

A. Frequency Multiplexers

The MUX modules for the 5 different SIF assemblies all have similar low-noise balanced amplifier stages to cover some portion of the 3–21 GHz 1st IF range. They are similar functionally, but contain unique 1300 MHz (1 dB) wide channel filters, with up to 38% bandwidth. Each filter is realized as a balanced pair of "wiggly line" microstrip filters [3]. The filters are grouped as traveling loop channelizers, with groups of 2 or 3 filters in a balanced configuration. In the cases where there are overlapping 1st IF bands, these filters are in separate groups. The groups are isolated by separate gain stages and a Wilkinson divider. This optimizes the isolation between bands (>45 dB) and minimizes passband ripple (<2 dB peak-peak) due to input and output mismatch. A block diagram for the MUX2 module is shown in Fig. 6 and a photo of the RF side is in Fig. 7.

B. 2nd IF Downconverters

The 2nd IF Downconverter modules use the different 2nd LO frequencies to downconvert each of the bands to a center frequency of 900 MHz. These 2nd IF's are then routed to the instrument spectrometers for spectral analysis. At the input of these modules is a broadband, triple-balanced mixer, which covers the 3–21 GHz RF input range. The overall channel gain is set by a 6-bit, 31.5-dB attenuator on the 900 MHz output. This attenuator also allows for an "OFF" state during injection of calibration tones in the "back end" of the modules. The assemblies are thermally compensated, using thermo-pads, to provide an overall positive gain versus temperature coefficient. This provides compensation for the negative gain coefficient in the MUX modules. To minimize "floor

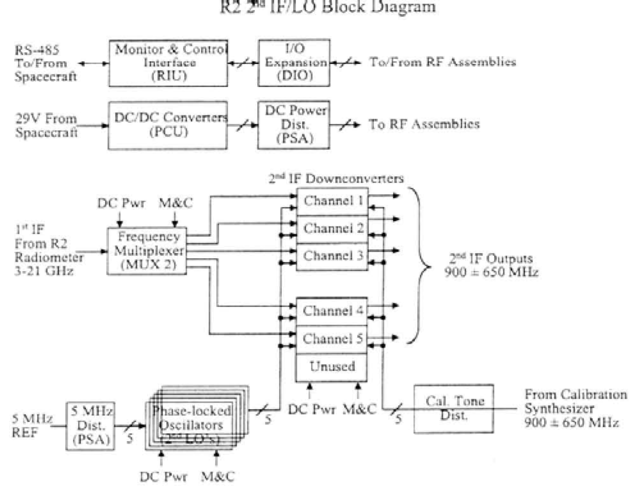

Fig. 3. R2 2nd IF/LO Block Diagram

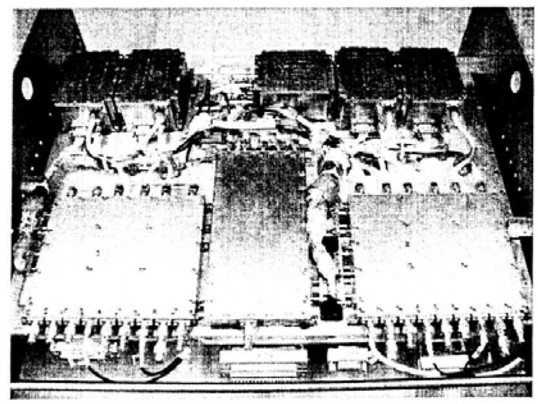

Fig. 4. R2 2nd IF/LO Assembly — RF side.

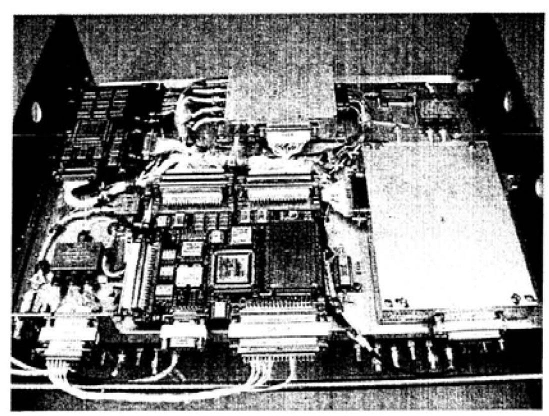

Fig. 5. R2 2nd IF/LO Assembly — DC side.

space" required on the plate assemblies, the modules are packaged as 3-channel downconverters, with separate power and gain control for each channel. A block diagram of a 2nd IF Downconverter single channel is shown in Fig. 8 and a photo of the RF side is in Fig. 9.

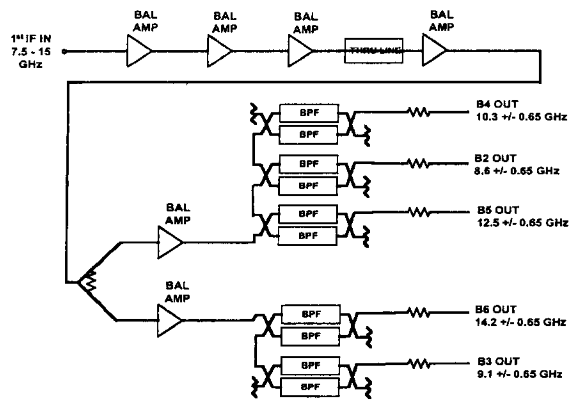

Fig. 6. MUX 2 Block Diagram

FPO

Fig. 7. MUX 2 — RF side

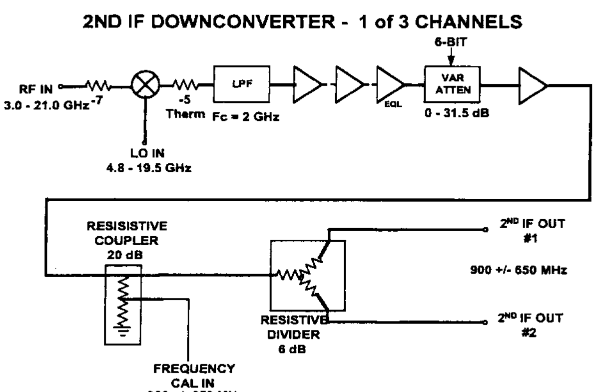

Fig. 8. 2nd IF D/C Block Diagram

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Fig. 9. 3-Channel 2nd IF D/C – RF Side

C. Phase-locked Oscillators (PLO)

The 2nd LO's were chosen as the point in the signal chain to do fine tuning for the exact millimeter-wave frequencies of the various chemical species being measured. Although fix-tuned during operation, they are required to have a step size (settability) as small as 400 kHz. This capability was achieved using a National LMX-2325 phase-locked loop (PLL) chip locked to a 5 MHz master reference for long-term stability. A common architecture was used for the 19 different 2nd LO frequencies, using a coaxial resonator oscillator (CRO) in the range of 2–2.5 GHz. Active multipliers were then used to scale up to the required frequencies between 4 and 20 GHz. For PLO's with reference divide ratios ≥ 7, 100 MHz clean-up loops were used between the PLL and CRO to reduce phase noise and spurious.

III. Design and Qualification for Space

The SIF subsystem is subject to the normal constraints placed on space hardware of limited mass and DC power. However, the most challenging aspect of designing for space was finding an acceptable compromise between component reliability, for a 5-year mission, and cost. The general MLS parts approach was to use NPSL (NASA Parts Selection List) Level 2 parts (equivalent to MIL-STD-975, Grade 2). For the components with no previous flight history, customized screening and qualification tests were developed in order to meet the intent of NPSL Level 2 as closely as possible. This included radiation testing of the National LMX-2325 PLL chips for both high- and low-dose rates. In addition, all semiconductors used were hermetically sealed, either in individual ceramic packages or overall sealed hybrid assemblies.

IV. Flight Subsystem Test Results

Much of the flight subsystem testing was automated, in order to facilitate monitoring of the large number of channels over the environmental test conditions. There was also a complex wiring harness and cable package to verify, due to the large amount of I/O for attenuator control, power on/off, etc. An example of the measured passband responses, from a scalar network analyzer, is shown for SIF2 in Fig. 10. Gain versus temperature testing was done using a broadband noise source for the 1st IF inputs in order to simulate the expected broadband inputs from the radiometer front ends. A typical temperature cycle output for SIF2 is in Fig. 11, showing the channel gains to be stable to within ±0.5 dB over the –5 to +40 C flight acceptance range.

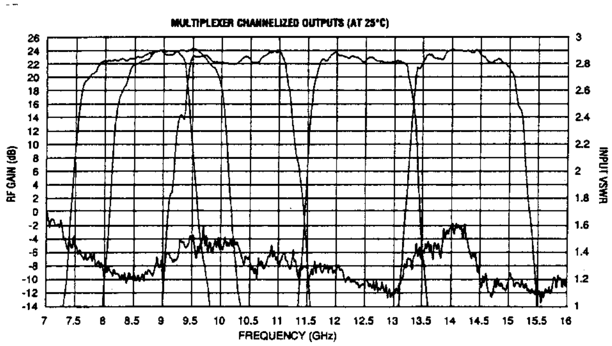

Fig. 10. MUX 2 Passband Responses

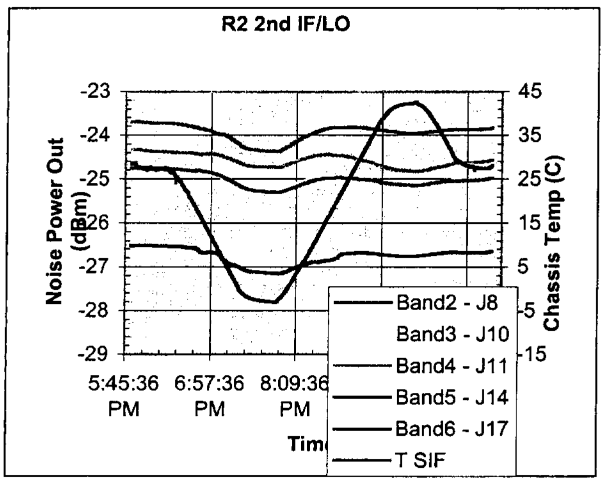

Fig. 11. S IF2 Channel Gains vs Temperature.

V. Conclusion

This paper has described some of the design challenges and test results for the MLS 2nd IF/LO Subsystem. Testing of the various flight assemblies within the SIF subsystem is complete and the units have been delivered to the MLS instrument for system testing. The MLS instrument has now been delivered to the EOS Aura spacecraft at Northrop Grumman Space Technology (NGST) where the spacecraft is undergoing acceptance and environmental testing in preparation for launch in January 2004.

Acknowledgement

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