A Dual Polarization Sideband Separation SIS Receiver for the Large Millimeter Telescope

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Abstract

A dual polarization SIS heterodyne receiver is being built for use on the Large Millimeter Telescope (LMT). The LMT is a 50 m diameter millimeter-wavelength telescope being built in Mexico as a joint project between UMass and Instituto Nacional de Astrofisica, Óptica, y Electrónica (INAOE) in Mexico. The receiver is designed to operate in the 210 – 275 GHz atmospheric window, and will provide state-of-the-art sensitivity using a sideband separation scheme to separate the upper and lower sidebands. In each polarization, 8 GHz of effective bandwidth per sideband (16 GHz total) will be available without the use of cumbersome mechanical tuners. Due to the prevailing physical conditions in the interstellar medium of galactic and extra-galactic sources, the 1 mm band is expected to be the workhorse scientific band for the LMT. The SIS receiver will also handle the necessary requirements of a commissioning receiver.

The receiver will be mounted at the Cassegrain focus of the LMT, and will employ a waveguide-based OMT. Each polarization output of the OMT will enter a split-block waveguide mixer block, which will contain the passive in-phase and quadrature hybrids for the LO signal and RF signals respectively. Two single-ended SIS junctions of the same design as that used in the ALMA Band 6 mixers will be used. The IF outputs of the two mixers are amplified using 4–12 GHz IF amplifiers, and then passed through a quadrature IF hybrid to separate out the sidebands. The entire receiver system will be housed in a cryostat equipped with a closed-cycle 4 K refrigerator. A new generation of bias electronics has been designed, which is interfaced to the control computer using a simple 2-wire I^2C communication protocol. The design of the entire receiver system has been optimized to allow the individual subsystems to be scaled up to an eventual large-format focal-plane array receiver system at 1 mm wavelength for the LMT.

1 Introduction

The Large Millimeter Telescope (LMT) is a 50m diameter millimeter-wavelength telescope being built atop Sierra Negra, a volcanic peak near Mexico City (see Figure1a) [1]. The LMT will have a wavelength coverage of 4 mm to 1 mm (75 - 300 GHz). The telescope is being built in a collaboration between the University of Massachusetts, Amherst (UMass), and the Institito Nacional de Astrofisica, Óptica, y Electrónica (INAOE) in Mexico. Due to the prevailing physical conditions in the interstellar medium of galactic and extragalactic sources, the 1 mm band is expected to provide the most interesting science for the LMT/GTM. Figure 1b shows the transmission plot and some molecular lines of significant astrophysical interest for the Sierra Negra site, assuming a rather pessimistic water vapor column of 2 mm of PWV. The excellent atmospheric transmission provided by the site, coupled with a sensitive wideband 1 mm heterodyne receiver system will provide new perspectives on stellar, chemical, and galaxy evolution in present and past epochs. The proposed instrument will also handle the necessary requirements of a commissioning receiver.

The receiver is designed to provide state-of-the-art sensitivity using a novel sideband separation scheme to separate the upper and lower sidebands. In each polarization, 8 GHz of effective bandwidth per sideband (16 GHz total) will be available without the use of cumbersome mechanical tuners. The polarization diplexing will be performed using a novel waveguide orthomode transducer (OMT) [2,3]. The technology development of the initial 1 mm commissioning receiver is geared to serve as a stepping stone for a future 1mm focal plane array on the LMT.

2 Overview of the Receiver Architecture

The 1 mm SIS commissioning receiver will be mounted at the Cassegrain focus of the LMT with simple coupling optics. See Figure 2 for details of the system architecture. Figure 3 shows the schematic details of a single balanced sideband separation mixer (BSSM).

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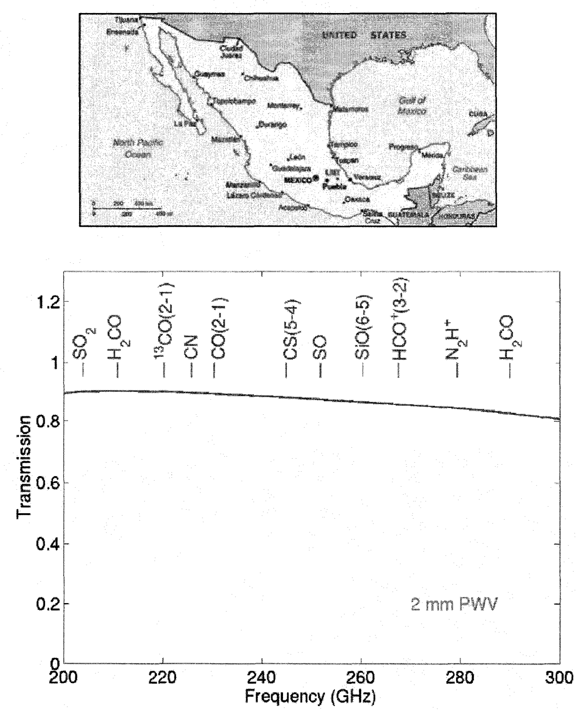

Figure 1: (a) Location of LMT in Mexico (b) Transmission plot for LMT site assuming 2 mm of precipitable water vapor. Also shown are the frequencies of important molecular lines in the 1 mm band.

The incoming dual-polarized signal is coupled into a corrugated feedhorn. A waveguide orthomode transducer (OMT) splits the signal into two orthogonal components, each of which is processed by a balanced sideband separation mixer (BSSM). Two sidebands of each polarization is amplified by 4 - 12 GHz low-noise IF amplifiers. The local oscillator signal is derived from a computer controlled frequency synthesizer, which is frequency multiplied by a chain of multipliers. The LO signal is split by a waveguide power divider and feeds each BSSM mixer block. Details of the BSSM are shown in Figure 3.

3 Design of Waveguide Hybrids

The entire BSSM will be assembled in one single split-block machined block, and will house the waveguide hybrids. Figure 4 shows the appearance of the split-block. The RF 90° coupler uses a branchline coupler. The design details and expected performances of the 4-section branchline coupler is presented in Figure 5. The design was performed with CST Microwave Studio and Ansoft HFSS. The optimized 4-branch line coupler shows good performance, and is easily machinable (and scalable to THz frequencies). The LO power divider design is based on a 3 dB 0° power combiner that was used in the OMT design described in [2]. This design was scaled, and then optimized for the 1mm band.

4 Prototype Single-Ended Mixer

Before building the full BSSM, a prototype single-ended mixer block has been constructed to test SIS junction mounting methods, characterize double-sideband noise performance, and new generation of bias electronics. The design of the LMT 1 mm SIS receiver employs the NRAO Band 6 low parasitic (with low output ca-

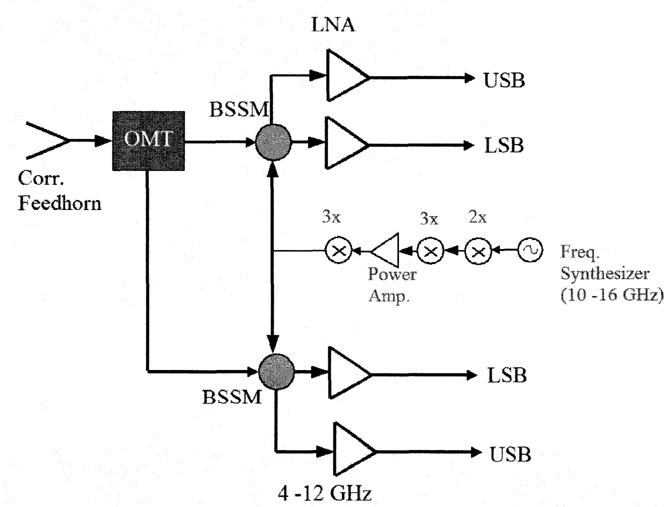

Figure 2: Schematic Block Diagram of 1mm SIS Receiver. See text for details of the receiver

pacitance and inductance) SIS junctions [4]. The mixer block (see Figure 6) was fabricated at UMass using a numerically-controlled NC micromachine [5]. The junction is mounted in suspended stripline channel cut orthogonal to the waveguide. The SIS junction has a coplanar waveguide section which needs to be grounded to the block. Two 20 mil (0.5 mm) long, 1 mil (25.4 μm) diameter gold wires are glued carefully to the shelves in the channel, after which the junction is mounted into channel. The gold wires are then crushed to provide a good ground return. A custom jig with glass-slides was constructed to crush the gold wires when mounting the SIS junction. A 0.5 mil (12 μm) goldwire is used to connect hot-side of junction to a 50 Ohm IF microstrip line. The IF line connects to a field-replaceable SMA connector at the top end of the block. A DC bias network (with a 100:1 voltage divider) consisting of chip resistors and chip capacitors is mounted on the mixer block, and a 4-wire bias network connector is soldered directly to the mixer block. Room temperature DC resistance tests show that SIS junction has the correct normal state resistance. Cryogenic DC IV test results are shown in Figure 7. RF Cryogenic tests will be performed soon. The single-ended mixer will be tested with a 4 – 8 GHz isolator mounted to the IF SMA, followed by a WBA13 type 4 – 12 GHz IF Low Noise Amplifier. A Sumitomo SRDK 415DE closed-cycle 4 K refrigerator system, with integral helium pot (for temperature stabilization of the 4 K stage) is being used. A custom square dewar will house the receiver.

5 Bias Electronics Systems With I^{2}C Control

A new generation of bias electronics for SIS/HEB receivers has been designed and built. Computer control of SIS, IF LNA, magnet, and IF total power is achieved by a two-wire serial bus called the I^{2}C (Inter-IC) bus [6]. Most of the bias cards are VME 6U based cards which will be housed in a VME chassis.

The SIS mixer bias control is divided into two circuit cards - an SIS bias card, and a SIS bias preamp card (which is mounted right outside the dewar in an RFI tight box). The SIS bias card has I^{2}C Xicor digital potentiometers with which bias voltage can be set. The bias cards contain 12-bit I^{2}C analog-to-digital converters to digitize the current and voltage sense outputs which originate from the bias preamp card. An I^{2}C general purpose IO chip is used to select between constant voltage mode or open-loop mode (for IV sweeps). Each SIS bias card and preamp card can bias 8 independent mixers. For laboratory testing, a Linux PC running a GTK+ based graphical user interface (GUI) with a MySQL database backend is used. Low-

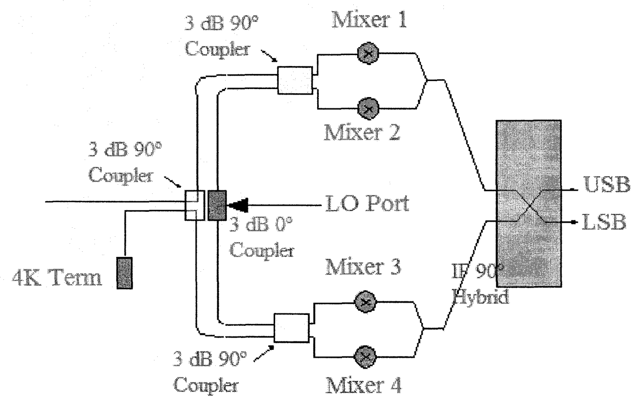

Figure 3: Schematic Block Diagram of a Balanced Sideband Separation Mixer (BSSM). The incoming RF signal is split by a 3 dB 90° coupler, while the LO goes through a 3 dB 0° coupler. The LO and RF couplers are implemented in waveguide hybrids (see §3). The top and bottom halves each contain a balanced mixer, implemented with two SIS mixers (biased with opposite polarity with respect to each other). The IF signals are amplified and combined with a IF 90° hybrid to separate out the upper sideband (USB) and lower sideband (LSB) signals.

level I^2C commands are encapsulated in user-callable libraries with a simple API (Application Programming Interface).

6 Wideband IF Amplifier

A connectorized 4 - 12 GHz WBA13 IF amplifier has been fabricated and tested (see Figure 8). These IF amplifiers have a noise temperature $\leq$ 6 K through most of the 4 - 12 GHz band. However, we find that for optimum noise, the power dissipation in these amplifiers can be rather high ($\sim$ 20 mW). NRAO has developed very low dissipation, low noise IF amplifiers which are well-matched with the SIS junctions, and require no isolators between it and the mixer [7]. The NRAO design uses a 3-stage design based on discrete InP HFET amplifiers (which are available at UMass from a previous TRW wafer run). Assembly of the amplifier can be somewhat complex. For the future 1mm focal plane array for the LMT, it might be desirable to design an IF amplifier with simpler assembly requirements. We are designing a new hybrid IF amplifier, which employs a single InP HFET amplifier in the first stage, and a TRW InP WBA5 MMIC amplifier (a 2-stage design) immediately following it. A preliminary design shows good noise performance with 30 dB gain (see Figure 8c).

7 Summary and Acknowledgements

- A dual-polarization, balanced, sideband separation SIS receiver for the 1mm wavelength band is being built for the LMT.
- The mixer block employs waveguide hybrids to perform the appropriate phasing to accomplish balanced, sideband separation.
- Wideband 4 – 12 GHz IF amplifiers will be used.
- The receiver will be fully computer controlled using I^2C 2-wire interfaces.

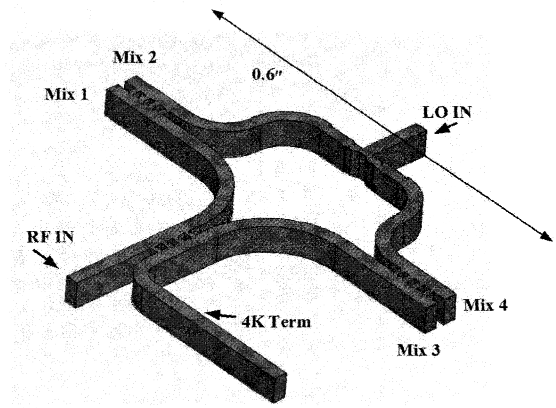

Figure 4: Waveguide Hybrid design for the BSSM. The block can be machined in split-block fashion, and measures $0.9 \times 0.9 \times 0.75$ inches in size.

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8 References

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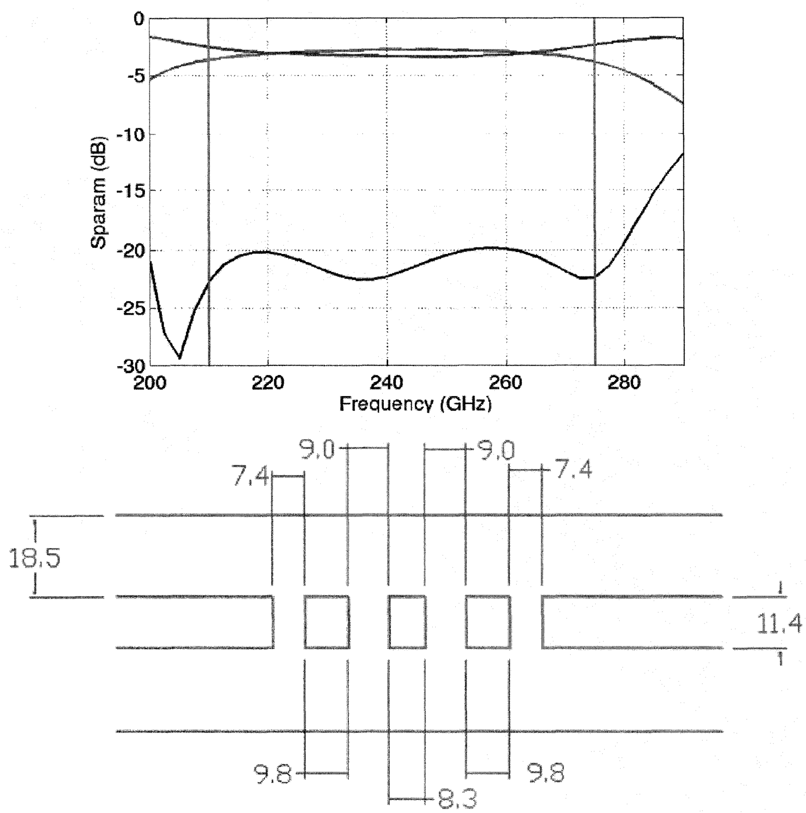

Figure 5: (a) Expected performance of the designed 4-branch line coupler. The designed band is 210 - 275 GHz. The red and blue curves show the coupling to the two output 3 dB ports, and the black curve shows the input match to the branchline coupler. (b) Details of the 4-branch line coupler. All dimensions are in mils. The width of the waveguides is 37 mils.

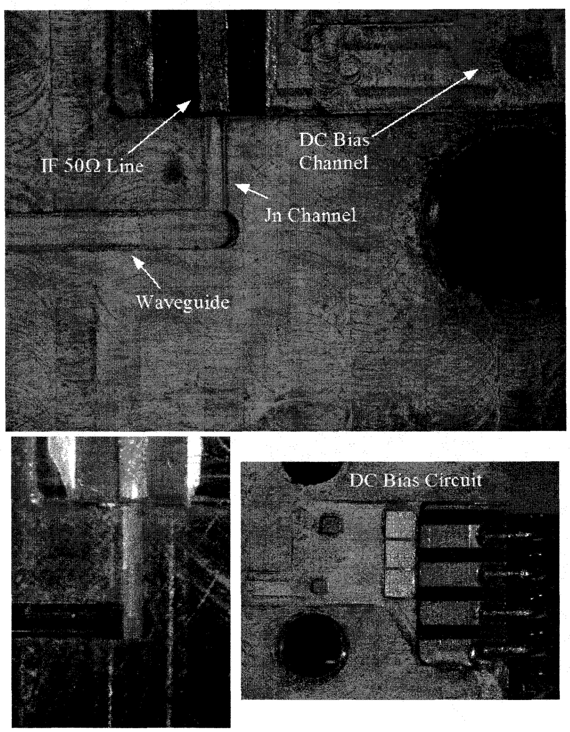

Figure 6: Single-ended SIS mixer block assembly details. Top picture: View of the waveguide, suspended stripline channel, and IF line before placing SIS junction. Bottom left: SIS junction in channel (with ground plane facing above). Bottom right: View of the DC bias circuit that includes, pins for current and voltage sense outputs.

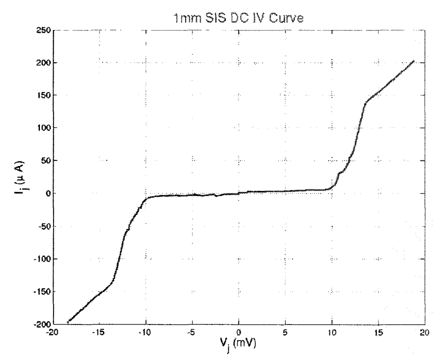

Figure 7: Single-ended SIS mixer Cryogenic I-V tests at $\sim$ 4 K. The measured I-V response of the single-ended SIS mixer showing low-leakage current.

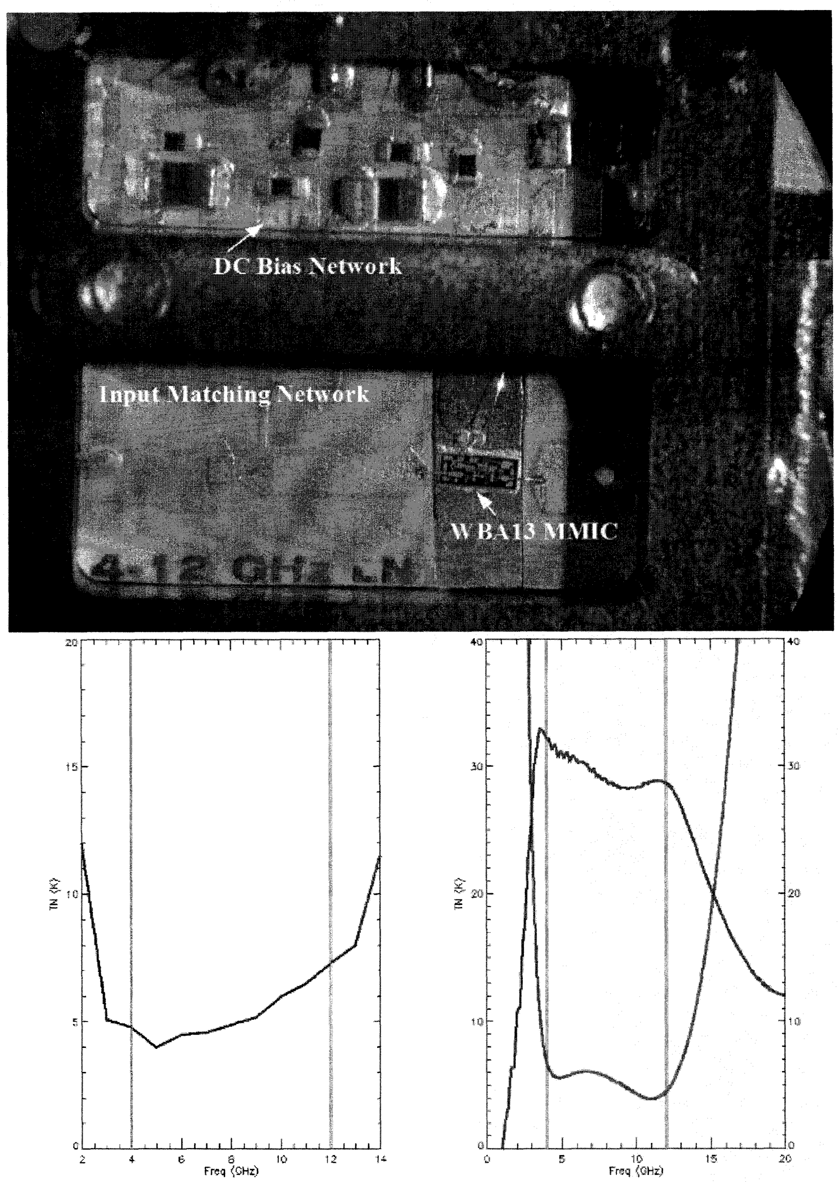

Figure 8: (a) Top: Photograph of the WBA13 IF amplifier built and assembled at UMass. A metal bridge provides isolation between the DC bias networks and the high frequency RF side of the amplifier. (b) Bottom Left: Measured Noise temperature of the WBA13 amplifier. Noise tests were done at 20 K in a test dewar equipped with a Variable Temperature 50Ω load (VTL). The plot shows an upper limit to the noise temperature as mismatch losses in the VTL have not been factored out. (c) Bottom Right: Simulated performance of a newly designed hybrid HFET/MMIC IF amplifier. The blue curve shows the gain in dB, and the red curve shows the anticipated noise temperature. Green lines denote the design bandwidth of the IF amplifier.