A Prototype 150 GHz Heterodyne Receiver Module for Large-Format Astronomical Instruments
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Abstract: The atmospheric window centered around 150 GHz is an important frequency band for many astronomical measurements using ground-based instruments. Science applications include spectral line studies, separating the cosmic microwave background (CMB) radiation from foregrounds, and detecting the hot gas around galaxy clusters using the Sunyaev-Zel’dovich effect (see Figure 2). Receiver arrays utilizing High Electron Mobility Transistor (HEMT) technology with excellent noise and scalability have been manufactured up to around 100 GHz. Due to recent improvements in bandwidth and noise temperature, it is now feasible to consider higher frequency receivers with this technology. A compact, wide-band, heterodyne receiver module has been designed to operate in the 140-180 GHz band using HEMT Monolithic Microwave Integrated Circuit (MMIC) InP Low Noise Amplifiers. These amplifiers, along with a second harmonic mixer, bias circuitry, filter, and connectors, are integrated into a single, split-block housing approximately one inch cubed in size (see Figure 1). Preliminary cryogenic tests have measured an average system noise temperature of 97 K and average gain of 22 dB over a band from 140 to 180 GHz (see Figures 3 and 4). A spot noise temperature of 58 K has been measured at 166 GHz. Development of a 4-element array to demonstrate the scalability of these receivers is currently underway, and will serve as a proof-of-concept for much larger, 100-element arrays for astrophysical applications.

Module Design: The heterodyne amplifier module was designed to collect radiation in the 150 GHz atmospheric window (about 140-170 GHz RF) and mix it down to 0-30 GHz Intermediate Frequency (IF) for processing. Incident radiation is collected by a feedhorn antenna and fed through WR-05 waveguide to a waveguide-to-microstrip probe transition. The planar signal is then amplified by a series of Low Noise Amplifiers (LNAs) and input into the second-harmonic mixer for downconversion to the IF band and extraction from the module through a coaxial connector. The Local Oscillator (LO) for the mixer is provided by a WR-10 waveguide input. Bandpass filters are provided between the mixer and the LNAs to protect the amplifiers from LO leakage through the mixer (see Figure 1). Preliminary gain and noise data were collected with only two LNAs in the module. For the second phase of testing, a third LNA and a second bandpass filter were added to the module housing to increase the gain of the module and reduce the noise temperature (see Figures 3 and 4). The design and testing of the individual components is discussed elsewhere [1].

Design Features:
- Compact: the outer dimensions of the assembled module are: 1.000” x 1.000” x 1.126”.
- Rapid Production: The split block design allows easy access to the MMIC channel, enabling automated assembly and mass-production.
- Biasing: LNA bias circuits inside the MMIC channel ensure that protective biasing is as close to the chips as possible.
- Flexibility: Extra space for additional filters and amplifiers ensures that different component configurations can be tested using the same module housing.

Figure 1: Top: Block diagram of the module design. Middle Left: Photograph with dimensions of the assembled module. Middle Right: Photograph of the module top showing the split waveguide cavities. Bottom Left: Photograph of the top of the main module block with the MMIC channel exposed. Bottom Right: Photograph of the bottom of the module with the cover removed so that the routing board and protective circuitry are exposed.

Future Work: The prototype module demonstrates cryogenic noise temperatures that average 87 K over a 40 GHz band from 140 to 180 GHz. Currently, the bias conditions for the first LNA cannot be set to the full value for maximum gain without causing instabilities. Modifications to the module, including an LED added to the first LNA cavity to reduce photon trapping, are expected to fix this issue. Future measurements with full packaging of the module noise temperature of the module for both the two LNA population phase (blue) and three LNA phase (red). With three LNAs, the module noise temperature is about the same as the measured noise of a single packaged LNA, which is also plotted. The minimum measured noise temperature is 58 K at 166 GHz. Room temperature noise measurements were approximately six times greater than cryogenic measurements.

Figure 2: Above: Schematic of the Sunyaev-Zel’dovich Effect (SZE). Left: Graph of the change in the intensity of the CMB spectrum caused by the SZE. There is a decrement at 150 GHz (blue) and no change at ∼217 GHz (red).

Figure 3: Graph of the measured cryogenic noise temperature of the module for both the two LNA population phase (green) and three LNA phase (red). With three LNAs, the module noise temperature is about the same as the measured noise of a single packaged LNA, which is also plotted. The minimum measured noise temperature is 58 K at 166 GHz. Room temperature noise measurements were approximately six times greater than cryogenic measurements.

Figure 4: Graph of the gain of the three LNA module both at room temperature (green) and at 22 K (red). When the module is cooled to 22 K, the average gain is 22 dB over the 40 GHz band from 140 to 180 GHz, which is about 10 dB greater than the gain at room temperature.

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