A Compact 500 GHz Planar Schottky Diode Receiver with a Wide Instantaneous Bandwidth

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Abstract

Microwave Limb Sounding has proved to be an important technique for probing the Earth's atmosphere. Studies of proposed atmospheric chemistry instruments have shown a requirement for single sideband heterodyne radiometers which operate at frequencies up to ~900 GHz, with wide instantaneous bandwidth (up to 20 GHz), good sensitivity and high beam efficiency.

Here we report results from a very compact, solid state sub-harmonically pumped planar diode mixer receiver operating in a broad frequency band around 500 GHz. LO power is supplied by an ~87 GHz fundamental Gunn diode oscillator multiplied by a whisker contacted Schottky varactor diode tripler, and the signal band is selected by a low loss frequency selective surface (FSS) filter positioned in the signal path. The receiver has a simple configuration and good sensitivity over a wide instantaneous bandwidth; total SSB system noise is about 10,000K when measured in a band from 498.5 - 505 GHz.

Introduction

The need to measure atmospheric processes involved in ozone depletion and global climate change has highlighted the potential of microwave limb sounding in the lower stratosphere and upper troposphere. Successful measurements in the stratosphere can be made with receivers which have instantaneous bandwidths similar to those generally employed in radio astronomy receivers, typically ~1 GHz (e.g., UARS MLS [1]). However, because of pressure broadening, at lower altitudes an instantaneous bandwidth of several GHz may be needed to properly establish the line shape of even a single emission feature. Further receiver design constraints include the requirement for very high efficiency optical coupling to the detector (to avoid confusing signals from directions away from the intended field-of-view) and a simple, reliable design (because of the remote, often hostile environment encountered in aircraft and satellite operation).

For these reasons the design of sub-millimetre receivers most commonly encountered in ground based telescopes may not be appropriate. Specifically, it is difficult to inject signal and Local Oscillator (LO) power into a single ended fundamental mixer whilst maintaining a wide bandwidth. Here we describe a receiver based on a planar double diode mixing structure, pumped by a Schottky varactor diode tripler. Designs of this type have been specified for a number of instruments at millimetre wavelengths (e.g., MAS, AMSU-B, MHS) and have been demonstrated at frequencies up to 300 GHz. This paper describes preliminary results from a receiver designed to operate in the band 498.5 to 505 GHz, a region of the atmospheric spectrum which includes ClO and a potentially accessible transition of BrO.

Receiver Design

Heterodyne receivers utilising waveguide sub-harmonic mixers (that is, double diode mixers pumped at half the signal frequency) have a number of attractive features from a system design point of view. First, signal and LO frequencies are well separated and can be isolated by simple filters within the waveguide cavity, thus avoiding the requirement for a low loss LO injection network. Not only does this remove an important bandwidth limiting element, it also simplifies the receiver optics and removes a potential cause of baseline instability (that is, lack of spectral flatness across the band when viewing thermal noise of uniform power density). Second, it allows a simpler LO configuration (since power need only be generated at half the signal frequency). Third, and most important, sub-harmonic mixers utilise double diode mixer structures in which two diodes are seen in parallel at the IF. This considerably simplifies IF matching problems, and allows the simple implementation of receivers with wide instantaneous bandwidths; at frequencies up to 300 GHz, sub-harmonic receivers are well known to demonstrate both good sensitivity (approaching that of a good fundamental mixer receiver) and signal bandwidths in excess of 10 GHz.

Consequently, the receiver described here is based on a sub-harmonic pump architecture. Recent improvements in planar diode technology indicate that "flip-chip" diodes can be used at frequencies approaching one terahertz: we have therefore chosen planar diode technology (because of its obvious benefits), and waveguide cavities for both mixer and frequency tripler.

In order to avoid possible confusion from unwanted emission lines it is highly desirable to filter the image sideband. Following a systematic study of optional filtering methods, a frequency selective surface filter (FSS) has been chosen on grounds of performance (insertion loss and filtering characteristics) and mechanical convenience. This is simply positioned in the mixer field of view, in front of a focusing mirror. However, in order to obtain adequate isolation between the signal and image sidebands, it is necessary to operate the mixer at a high IF frequency; a frequency of 19.0 to 25.5 GHz has been selected.

Mixer

The mixer is based on a design developed at RAL for millimetre wavelengths [2] and extended to higher frequencies for the present application. The mixer utilises a crossed waveguide cavity with a reduced height signal waveguide coupled to the optical field of view by a waveguide transformer and a corrugated feedhorn. An anti-parallel "flip-chip" planar diode pair (type SD1T7 manufactured by the University of Virginia) is soldered onto a quartz substrate which spans the signal waveguide and incorporates necessary signal filtering: LO power (at half the signal frequency) is introduced into the diodes through a waveguide transformer at one end of the filter, and from the opposite end the down converted signal is passed to the IF pre-amplifier.

In order to ensure that signal is coupled to the IF in the 19 to 26 GHz band, a 'K' connector has been implemented which efficiently transforms the 50 Ω microstrip filter to a coaxial line with good return loss. Filtering between the LO and signal frequency is achieved with a simple $\lambda/4$ high-low impedance transmission line filter, whilst the IF filter is an empirical hammerhead design, scaled from lower frequencies. Non-contacting, fixed position waveguide backshorts are used to optimise performance. The mixer design has been verified by extensive modelling.

Multiplier

The tripler incorporates a crossed waveguide cavity and is based on a design reported by Archer [3], in which the output waveguide supports both the second and third harmonic of the pump at the diode, before transforming to single moded waveguide supporting the third harmonic at the multiplier output. An optimum embedding circuit for the dot-matrix Schottky varactor type (University of Virginia type 5M4) has been calculated using a non-linear analysis programme [4] and realised through a simple stripline filter in a rectangular enclosure designed to present a near short circuit to the second and third harmonic frequencies at the wall of the output waveguide, and a novel planar probe which straddles the waveguide and includes an integral whisker for contacting the diode. This "planar whisker" technology [5] is simpler to analyse than a wire whisker, and, by varying its width, can be used a as convenient circuit tuning element. Minimal time has been spent characterising the multiplier on its own; rather, performance of the receiver (including the multiplier) has been optimised.

Receiver

Mixer and multiplier have been designed mechanically to fit neatly together with minimal lengths of waveguide, and a custom designed waveguide coupler allows the Gunn source to be phase locked (results presented here, however have been made with a free running Gunn). Waveguide blocks, with other receiver components (focusing mirror, FSS filter and IF amplifiers) are mounted directly to a simple receiver plate.

Although the mixer and frequency multiplier have adjustable tuning shims for receiver optimisation, their drive mechanisms are removable. Consequently, the receiver has been mounted on a plate to which the backshort drive mechanisms are fixed; the waveguide shims are glued to these. Once optimised, the tuning shims can be locked in position, and the adjusters removed.

Results

Receiver performance has been measured at a number of IF frequencies, including 1, 8 and 19 - 25.5 GHz. Allowing for the effect of IF amplifier chains with differing noise characteristics, receiver performance is encouragingly uniform across the complete 1 to 26 GHz frequency band. Near optimum zero biased mixing performance is noted when a Gunn power of ~70 - 100 mW is applied to the multiplier through a variable attenuator; the varactor diode is typically biased at 5.5 volts and draws a current of 3 to 7 milliamps at these drive levels. Mixer IF return loss is typically greater than ~7 dB.

Noise performance has been characterised by measuring the receiver Y factor, using simple CV3 thermal loads (assumed to be at hot and cold temperatures of 295 and 80`K respectively) in the receiver field of view.

Figure 1 illustrates DSB receiver performance measured in a 1 GHz bandwidth at an IF of 8 GHz. In this example, the receiver was optimised with the FSS optical filter removed. A total receiver noise of ~4,800 K is measured, in spite of an IF amplifier chain of noise temperature ~200 K. De-embedded mixer noise performance and conversion loss (including an IF mismatch loss of ~0.7 dB) are estimated to be ~2,300 K and 9.6 dB respectively.

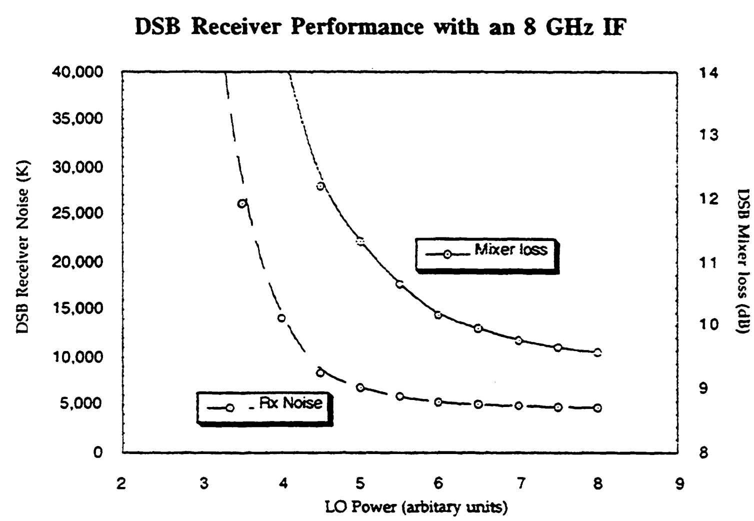

Figure 1: Plot of receiver noise and mixer loss as a function of LO power

Figure 2 illustrates the SSB receiver performance, including the FSS sideband filter, across an integrated IF band 19 to 25 5 GHz (that is, a signal band extending from 498.5 to 505 GHz). In this case the receiver has been tuned to minimise receiver noise in the signal band; we have used an interferometer to investigate the mixer sideband ratio in this configuration and at the optimum backshort tuning point a gain ratio of 2 to 3 was observed. The FSS has been separately characterised using a Fourier transform spectrometer (FTS), which indicated a signal insertion loss of 0.8 dB and sideband rejection of >20 dB. This is consistent with a radiometric measurement of its loss, though this measurement is potentially confused by uncertainties in the mixer sideband ratio.

Equivalent SSB receiver performance, mixer performance and conversion loss in the 19 to 25.5 GHz band is calculated to be 10,800K, ~3,700 K and 12.8 dB respectively. As in the 8 GHz case, mixer conversion loss includes an IF mismatch loss of ~0.7 dB.

As can be noted from the illustrations, the receiver behaves in a similar manner to sub-harmonic receivers measured at lower frequencies. That is, as LO pump power increases, noise and conversion loss drop rapidly. Further increasing LO power has little effect on performance, until eventually diode noise begins to slowly increase.

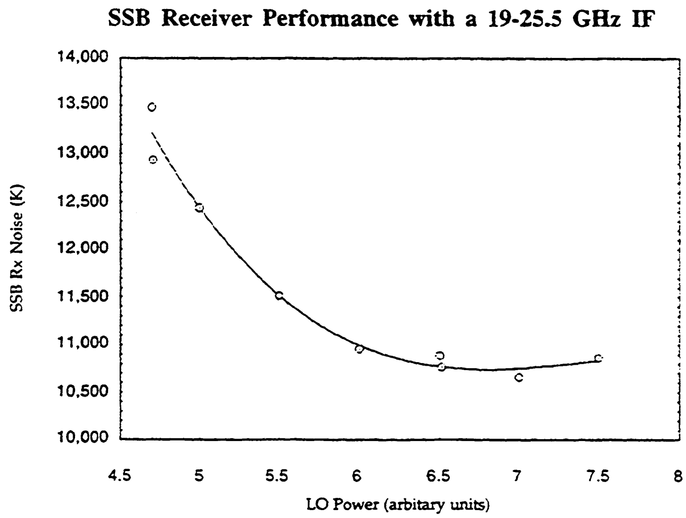

Figure 2: Plot of receiver noise as a function of LO power

The complete front end receiver, including Gunn oscillator, mixer, frequency multiplier and other waveguide and IF amplifier components is very compact, and can easily be accommodated within a volume of approximately 20 x 12 x 10 cm^3.

Conclusions

A very compact, 500 GHz sub-harmonic diode mixer receiver pumped by a Gunn diode oscillator and varactor frequency tripler has been demonstrated to have good sensitivity, and a well matched IF which spans ~0.5 to 26 GHz. A DSB mixer noise temperature and conversion loss of 2,300 K and 9.6 dB respectively has been measured at an IF of 8 GHz, and a SSB mixer noise temperature and conversion loss of 3,700 K and 12.8 dB respectively has been measured in an IF band from 19 - 25.5 GHz. An SSB receiver system with greater than 20 dB sideband rejection and total system noise ~10,800 K has been demonstrated for an instantaneous signal band extending from 498.5 - 505`GHz.

Since it is clearly possible to scale the waveguide and diode circuitry by a further factor of at least 1.5, it is likely that this technology will be applicable to receivers operating at frequencies up to one terahertz.

References

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