SIDEBAND RATIO IN DOUBLE SIDEBAND RECEIVERS WITH A MICHELSON INTERFEROMETER

M. Romanini, A. M. Baryshev, R. Hesper, F. P. Mena, W. Wild

Abstract—Terahertz heterodyne receivers typically use double sideband (DSB) mixers. The precise knowledge of the receiver sideband ratio (SBR) is a fundamental requirement for the calibration of the data taken with this type of receivers. At the moment the spectroscopic techniques developed for submillimeter analysis, such as Martin Pupplet interferometry[1] and Gas cell technique[2] rely on a calibrated filter system and suffer from inaccuracies caused by standing waves. Here, we present sideband ratio measurements of a submillimeter receiver in the 600-720 GHz band (ALMA Band 9) using a Michelson interferometer as input filter. The main requirement for this method is that the resolution must be high enough to allow distinguishing between the two side bands of the DSB receiver. The advantages of this method are, first, the simplicity of the experimental setup, and, second, the possibility to identify and calibrate out standing waves in the signal and local oscillator paths. In our procedure we use, in fact, exactly the same receiver configuration for both direct and heterodyne detections. Although the results are still preliminary, we have found a good agreement in the SBR measured with both configurations.

***Index Terms*—Double sideband mixer, Michelson interferometer, sideband ratio.**

I. INTRODUCTION

The millimeter and submillimeter regions of the electromagnetic spectrum are the most important ones for radio astronomy and for measurement of atmospheric molecules[3]. For the detection of these wavelengths, one of the most common methods is heterodyne detection. The purpose of a heterodyne receiver is to translate a signal at higher frequency to a lower frequency where it can be amplified more effectively. In a heterodyne receiver the incoming reference signal (RF) is combined, or “mixed”, with a local oscillator (LO) signal at a frequency close to the reference signal frequency. The RF signal can be either above or below the LO frequency. These bands are called upper (USB) and lower (LSB) bands. The output of the receiver is the intermediate frequency (IF) corresponding to $f_{USB}-f_{LO}$ or $f_{LO}-f_{LSB}$. A double-sideband receiver has only one IF port and both signals are received in the same channel.

The accurate calibration of a heterodyne receiver requires knowledge of the sideband ratio (SBR), which is, the gain ratio between the upper and lower sideband frequencies. For an ideal double-sideband receiver the SBR is equal to one, but in practice the receiver response in the upper sideband may be different from that in the lower sideband. Hence it is very important to know the SBR at different LO frequencies to be able to recover, from a measured spectrum, the correct relative intensity of the various spectral lines.

Here we propose a new method to measure the SBR based on a Michelson interferometer. We investigate the relation between the direct and heterodyne mode to determine if the simple direct detection method is a reliable predictor of the SBR, and whether it can be used for the calibration of actual observations.

II. EXPERIMENTAL SETUP

A block diagram of the instrumental setup is shown in Fig.1. The source consists of a glowbar lamp with a chopper in front of it for lock-in measurements. The first part of the setup consists of a Michelson interferometer. A beamsplitter (BS1) at the entrance of the Michelson interferometer is used to separate the light from the source into two beams. One beam is reflected off a fixed mirror and one off the moving mirror, whose motion is computer-controlled. Varying the position of the moving mirror changes the optical path of the second beam, thus introducing a time delay between the two beams. After the reflection from the mirrors, the beams are recombined, again through the beamsplitter BS1. The intensity of the recombined beam as a function of the path difference is the Fourier transform of the product of the spectral distribution of the source, the transmission of the optical medium and the spectral response of the detector. The maximum spectral resolution is defined as $\Delta\nu=c/2\Delta l$, where c is the light velocity and Δl is the difference length path of the movable mirror. Since the resolution of a Michelson interferometer increases with increasing optical path difference, the maximum spectral resolution is achieved by using the entire distance over which the movable mirror can be displaced to measure only one side of the interferogram. If

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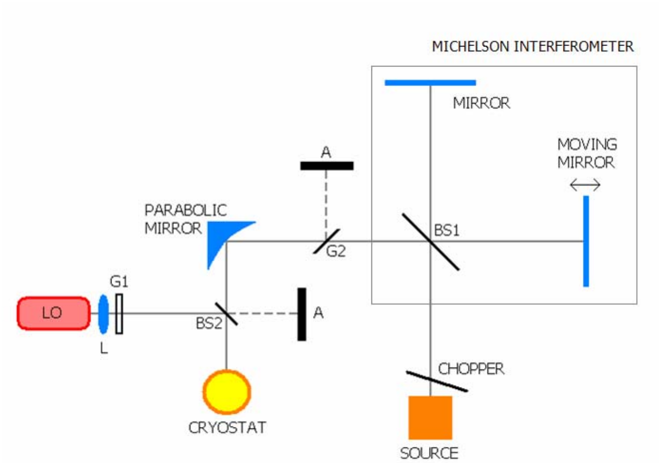

Fig. 1. Scheme of the heterodyne detection setup. *BS1* is the beamsplitter of the Michelson interferometer. The beam from *BS1* is coupled with the signal from the LO through beamsplitter *BS2*. *L* and *G1* are respectively a lens and a grid used to focalize and change the amplitude of the LO signal. The grid *G2* is used to reduce the standing waves from the LO as discussed in the text. The rejected beams are sent to absorber plates, *A*.

both sides of the interferogram are measured, the achieved resolution is half of the maximum resolution. In our Michelson interferometer the maximum spectral resolution achievable is 1 GHz, corresponding to a difference in path length of 150 mm.

When the receiver is used in direct detection mode, the recombined beam is sent to a parabolic mirror which focuses it into the cryostat where the receiver is located. In this way it is possible to obtain the frequency response of the receiver. In heterodyne detection mode, the beam from the parabolic mirror is coupled with the signal from the local oscillator using the beamsplitter BS2. We have performed the experiment in both detection modes using two different superconductor-insulator-superconductor (SIS) junctions, hereafter called mixer 1 and mixer 2. Both junctions are designed to operate in the 600–720 GHz band. Due to imperfections in the coupling between the incoming signal and the horn receiver, some LO signal can be reflected back into the Michelson interferometer forming standing waves. Since the LO signal is polarized, introducing a new grid (G2) can reduce these standing waves. We have done so during the heterodyne detection with mixer 2. By rotating G2 we can diminish the intensity of the standing waves.

III. RESULTS AND DISCUSSION

We start presenting the data taken with mixer 1 which were obtained without the insertion of grid G2. First, we have measured the response of the mixer over the entire frequency range using the direct detection mode. This corresponds to the thick grey curve in Fig. 2a. The resolution in this mode is 18.75 GHz corresponding to a difference in path length of 8 mm. We have then characterized the mixer in heterodyne mode. This is achieved by coupling the LO signal at different LO frequencies to the RF signal. During heterodyne detection the LO frequency is varied from 597.6 GHz to 720 GHz in steps of 3.6 GHz. The LO signal power was kept constant over the whole frequency range. For these measurements we have used the entire path length of the Michelson interferometer in order to have the maximum spectral resolution (1 GHz). Examples of heterodyne spectra, acquired with different LO frequencies, are shown in the thin lines of Fig. 2a. In each spectrum two peaks can be clearly distinguished around the LO frequency, they correspond the LSB and USB bands. A third peak is visible between the two main features at exactly the LO frequency. These peak is originated by the standing waves from the LO that are reflected back in the interferometer.

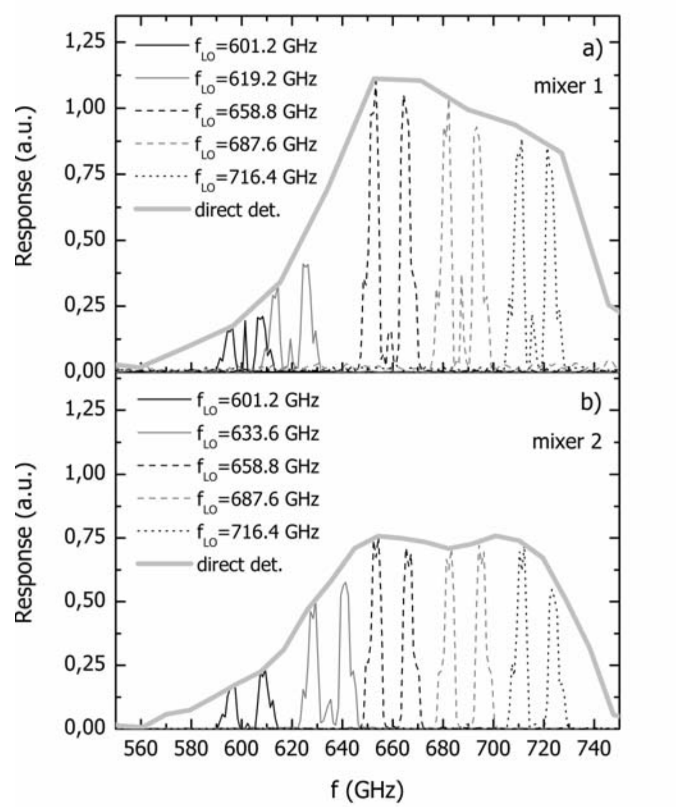

Fig. 2. Comparison between the direct response spectrum (thick grey line) and some heterodyne detection spectra at different LO frequencies (thin lines): a) with mixer 1 and without grid G2, b) with mixer 2 and the insertion of grid G2.

Since the gain of the mixer is not constant for all measurements at different LO frequencies, each of the heterodyne spectra was normalized so that the intensity of one of the two sideband peaks coincides with the intensity of the direct response at the same frequency. With this procedure we can directly compare the full spectrum obtained with the direct detection mode and the heterodyne spectra at different LO frequencies. As it can be seen in Fig. 2a, the intensity ratio between the upper and lower sideband peaks follows closely the intensity profile of the direct spectrum.

The sideband ratio (SBR) is calculated for each LO frequency as the ratio between the integrals of the USB and LSB peaks. This is then compared with the SBR estimated from the direct detection response, defined as the ratio between the integrals of the direct-detection curve in the same frequency ranges of the USB and LSB peaks, respectively. The result of this comparison is reported in Fig. 3a. Each estimate is accompanied by the appropriate error bar. It can be seen that

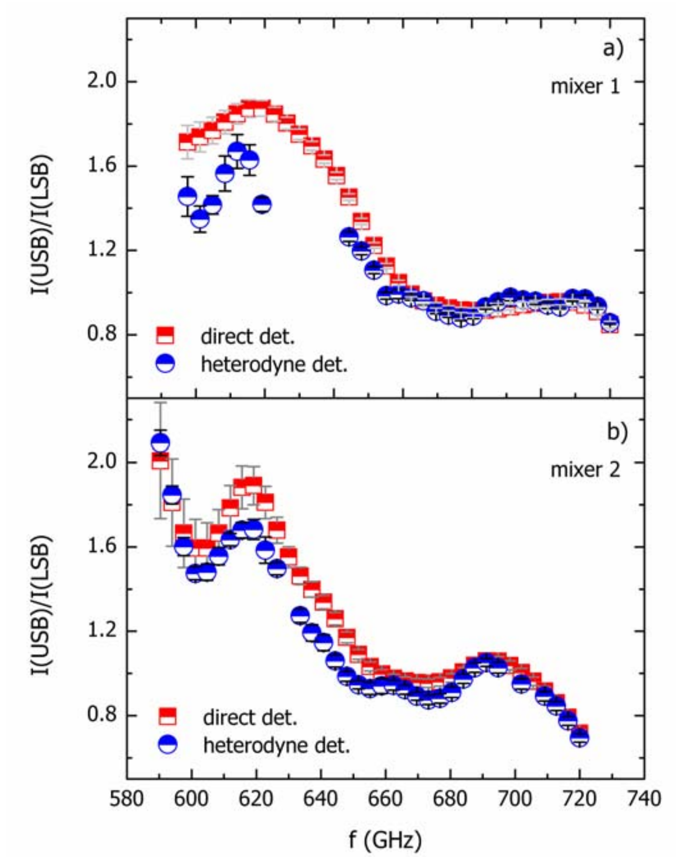

Fig. 3. Comparison between the measured SBR in heterodyne mode (ratio between the integrals of the USB and LSB peaks) and the estimated SBR from the direct detection response (ratio between the integrals of the direct detection curve in the same frequencies range of the USB and LSB peaks) a) with mixer 1 and without the grid G2, b) with mixer 2 and the insertion of the grid G2.

for both detection modes the SBR is in the expected range, *i.e.*, between 1.0 and 2.0[4] (corresponding to less than 3 dB), over the whole frequency spectrum.

From this first set of measurements it is seen that there are some differences between the SBR in the two different detections modes at frequencies below 640 GHz. The main reason is the presence of standing waves coming from the LO source as the pumping level changes with the position of the moving mirror in the Michelson interferometer. This effect is more pronounced at low frequencies since the coupling horn-incoming signal is also lower at these frequencies. The insertion of G2 solves almost completely this problem as discussed in Section II. Another problem is the low pumping level of the LO at some frequencies. An example of that is the lack of results between 620 and 640 GHz: the pumping level was not enough to generate a signal response at these frequencies. To overcome this difficulty, we have split the frequency range in two subranges, a low-frequency range from 590.4 GHz to 662.4 GHz and a high-frequency range from 666.0 GHz to 720 GHz. For each range we realigned the LO signal in order to optimize the pumping level. The heterodyne spectra were taken separately in these two frequency ranges, again in steps of 3.6 GHz. We performed a second set of measurements, with mixer 2, where these two changes were implemented. The results are shown in Fig. 2b. It is evident that the intensity of the central peak in each heterodyne spectrum has decreased. For mixer 2 we have also acquired a complete spectrum in direct mode. For this measurement we have increased the resolution to 9 GHz corresponding to a length path of 16 mm. This allows to increase the number of points in the direct spectrum and thus achieve a better estimate of the area under the curve for the evaluation of the SBR in direct mode. The spectra taken in these two configurations follow also quite well each other (Fig. 2b). What is more important, we found an almost perfect agreement between the SBR calculated from the two different detection modes (Fig. 3b).

IV. CONCLUSIONS

We have presented a new simple experimental set up to measure directly the sideband ratio in heterodyne receivers. This set up uses a Michelson interferometer and a grid to filter out standing waves. We have applied this method to investigate the sideband ratio of two different double-sideband mixers when used in direct and heterodyne detection modes. A good agreement between these two modes has been found. However, a more thorough investigation of the relation between the direct and heterodyne mode is necessary, especially at low frequencies. We plan also to apply this method to the calibration of the sideband-separating mixer for Band 9 of ALMA recently developed at SRON.

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