# Characterization of a Martin-Puplett interferometer of a 2.6THz heterodyne receiver

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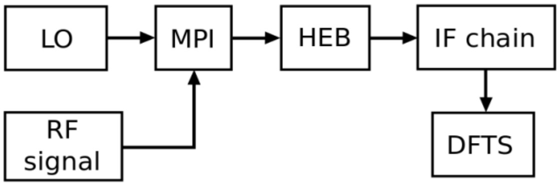
***Abstract*—In this proceeding we characterize the Martin-Puplett interferometer (MPI) of a 2.6 THz heterodyne receiver. It it is used to overlay the sky and the local oscillator signal before the mixer. By measuring each component of the MPI and by calculating the atmospheric losses, we could attribute the largest losses in the MPI to the atmospheric transmission and irregular spacings of the wires in a wire grid.**

***Index Terms*— heterodyne receiver, optics, stability, THz**

## I. INTRODUCTION

Several recent projects in radio astronomy are dedicated to heterodyne measurements in the THz field. For example, the GREAT instrument [1], on SOFIA, which is designed to observe some spectral lines between 1.5THz and 4.7 THz, or Millimetron [2], which is an ambitious project for a future space telescope mission aiming to observe between 0.1THz and 5THz. In order to prepare a receiver for such projects, we built a test receiver at 2.6 THz and characterized it. This heterodyne receiver is composed of a local oscillator (LO), a Martin Puplett interferometer (MPI), a Hot Electron Bolometer (HEB) mixer, an intermediate frequency (IF) chain and a digital Fourier transform spectrometer (DFTS) (see figure).



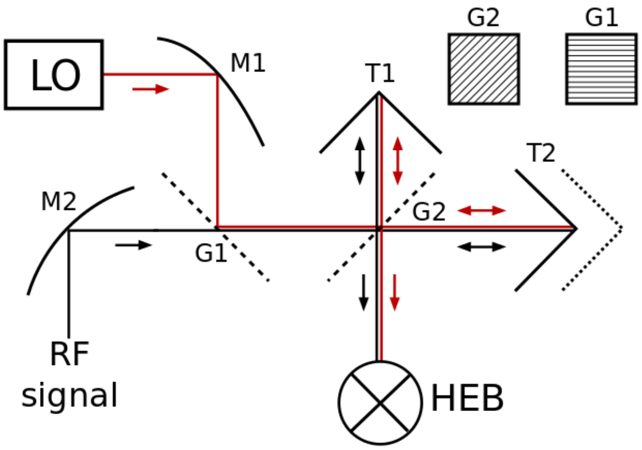
Our local oscillator is a 2.6THz multiplier-amplifier chain from VDI (Virginia Diodes, Inc) which emits a maximum of about 2µW at 2.6THz. The HEB, using a twin slot antenna and a silicon lens, was designed and produced at LERMA (Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique et Atmosphère) and LPN (Laboratoire de Photonique et de Nanostructures) and it is optimized for 2.6THz [3]. It uses a NbN (niobium nitride) bridge on a silicon substrate and is phonon cooled. The IF chain includes one cryogenic amplifier from Caltech, two commercial warm amplifiers and a 1.5GHz low pass filter. The DFTS (Digital Fourier Transform Spectrometer), from RPG (Radiometer Physics GmbH), has 8192 channels and a bandwidth of 1.5GHz.

To characterize our receiver, we focused on two major points. The Martin-Puplett interferometer that assures the coupling between the local oscillator and the observed radio frequency signal (RF signal), and the stability of the receiver. Here we will describe our investigations of the Martin-Puplett interferometer.

## II. MARTIN PUPLETT INTERFEROMETER

### A. *Presentation of the Martin Puplett Interferometer*

In heterodyne receivers the signal of the sky is mixed with the LO signal. If the mixer has only one port, the signals need to be superimposed optically before the mixer. Usually a beam splitter is used to superimpose the LO signal and the RF signal. However, 80% or 90% of the LO power is lost by the beam splitter. As we don't have a lot of LO power, we couldn't afford to lose that much power, so we decided to use a MPI instead. A MPI is a polarization rotating interferometer. An MPI has theoretically very little loss, but is a lot more difficult to align than a beam splitter, because it is composed of several elements.



MPIs have previously been used in heterodyne receivers, such as the SMART receiver for KOSMA [4], the CONDOR P.I. receiver for APEX [5] and the GREAT receiver on SOFIA [1] besides others.

Our MPI is composed of two ellipsoidal mirrors, M1 and M2, two wire grids, G1 and G2, and two roof top mirrors, T1 and T2 (see figure). The arrows indicate the propagation of the beams in the MPI. The two squares at the top right of the schematic show the orientation of the wires for both grids. The

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mirror T2 can be translated to adjust its distance to G2. A detailed description of the principles of a Martin-Puplett interferometer can be found in Martin and Puplett [6] or Goldsmith [7].

To characterize our MPI we measured the LO power at the output of the MPI with a Golay cell detector. As the measured power was below 1.0µW, the Golay cell was near its detection limit. However, this experiment revealed that the MPI was losing about 40% of the LO power, without taking into account the atmospheric losses. In order to improve the MPI, we studied all the MPI's elements and characterized their losses.

### *B. Ellipsoidal mirrors*

The two ellipsoidal mirrors were designed at LERMA and fabricated by RPG (Radiometer Physics GmbH). They were specifically designed to match the (simulated) beam pattern of the HEB at 2.6THz. As the reflection losses of an ellipsoidal mirror are not very easily measurable (the beam changes its waist and hence the coupling to the detector changes), we started by verifying the mechanical properties of the ellipsoidal mirrors. We used a profilometer to measure the rms roughness of the mirrors' surface and found 400nm rms. The roughness of the mirrors is responsible for the scattering of the beam. According to Ruze's formula [8], the corresponding directed reflection for a 115µm wavelength signal is

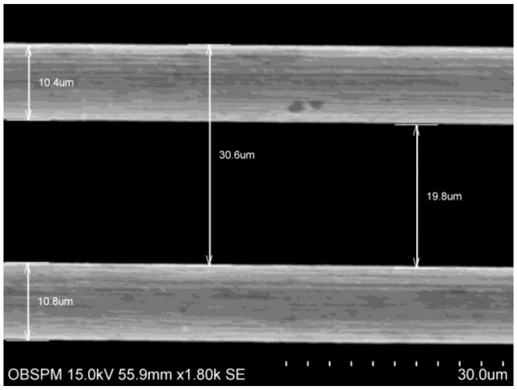
$$R = e^{-\left(4\pi\, s_{rms}/\lambda\right)^2} = 0.998$$

Where $s_{rms}$ is the rms roughness.

The losses due to the mirrors' roughness can be considered as negligible. We also studied the shape of the mirrors and characterized it by measuring the depth profile along their major axis. There was less than 2.5% difference between the theoretical and experimental one. In summary, the mirror fabrication is good and the mirrors are in accordance with our requirements.

### *C. Wire grids*

The two wire grids have been manufactured by the university of Erlangen. After measuring them with a scanning electron microscope, we could confirm that the wires' thickness was 10µm, as requested (see figure).



The average spacing measured between the wires was 37µm very close to the specification of 35 µm. We used the formulas from P.Goldsmith's book [7] to calculate the reflection and transmission efficiencies expected for perfect grids with these parameters.

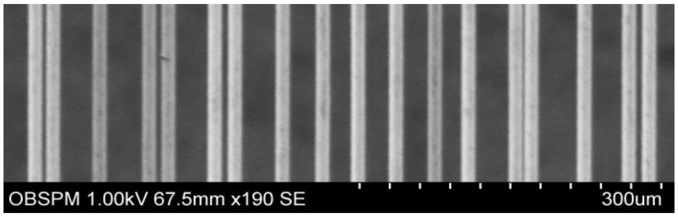
$$R = \left(\frac{1}{1 + 2Z_g/Z_{fs}}\right)^2 \quad \text{and} \quad T = \left(\frac{1}{1 + Z_{fs}/\left(2Z_g\right)}\right)^2$$

Where $Z_g$ is the grid impedance and $Z_{fs}$ the characteristic transmission line impedance.

$$\frac{Z_g}{Z_{fs}} = -j\omega_0 \ln\left(\frac{g}{2\pi a}\right)\left(\frac{g}{\lambda\omega_0} - \frac{\lambda\omega_0}{g}\right)^{-1}$$

Where g is the wire spacing and a, the radius of the wires, $\omega_0 \approx 0.85$ is a dimensionless number, based on measurements. It defines the location of the resonance that occurs when g is close to λ [9]. We calculated that our grids should have an efficiency of 99% for both reflection and transmission.

However, with the scanning electron microscope, we observed some important irregularities in the wire spacing (see Figure).



According to J.B. Shapiro [10], the reflection efficiency of the grids also depends on the grid spacing regularity. Shapiro defines the irregularity σ as the standard deviation of the spacings/notch. Their study showed that a value of $\sigma/\lambda = 0.085$ resulted in a reflexion efficiency of 95% (the other 5% were transmitted) and a value of $\sigma/\lambda = 0.06$ in 2% losses. Their study was carried out at lower frequencies (< 600 GHz) and for thicker wires and larger spacings, but the effects are expected to scale with wavelength. A value of $\sigma/\lambda < 0.05$ is necessary to approach the efficiency of an ideal grid [7]. From the figure above we calculated an rms variation σ of 8.2µm. This corresponds to $\sigma/\lambda = 0.07$ and we would expect losses of a few percent.

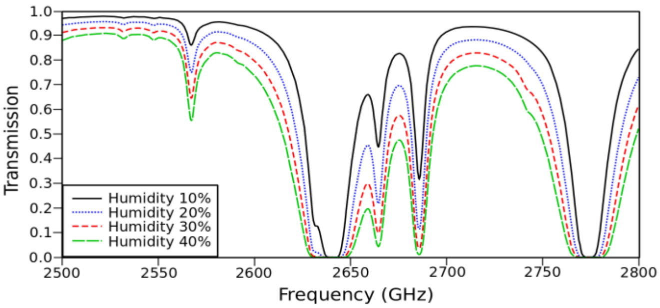
To confirm these theoretical calculations, we used the simulation software HFSS to calculate the reflection and transmission expected for the grids. Perfect grids as well as irregular grids were simulated and the results show that irregularities in the grids can cause noticeable losses (table below).

| | Measured | Calculated (HFSS) | |
|---|---|---|---|
| | Real grid | Regular grid | Irregular grid |
| Transmission | 96% | 98% | 98% |
| Reflection | 80% | 98% | 88% |

In order to measure precisely the transmission and reflection efficiency of our grids, the measurement has been performed with a set of two grids. The first grid was used to eliminate the cross polarization of the LO and the second grid was the one we wanted to characterize. The power was measured by an IR bolometer cooled with liquid helium (from IR labs). We found a transmission of 96% and a reflection of 80%. It also enabled us to measure the cross polarization of the LO, which we found to be 8%. The difference between the simulated losses and the measured losses, are due to 3 factors: 1) The simulations cannot take into account an exact copy of the grid, but works with a typical grid cell that is repeated to make up the grid. This technique is used to reduce the calculation time to less than a day. 2) A reflection angle of 90 degree has not been taken into account. 3) Misalignments of the detector can cause additional losses.

### D. *Air absorption*

At 2.6THz, the water vapor contained in the air absorbs a part of the signal. We used the software am (atmospheric model) developed by Scott Paine [11]. For our optical path length (50cm) and ambient temperature (20°C). It gave us different values of transmission depending on the relative humidity of the air (see figure below).



As we see in the figure, for a relative humidity of 30%, which is the average value for our laboratory, we have a transmission of 80% through 0.5m of air.

## III. CONCLUSION

In summary, along with the grids, the water vapor in the air seems to cause the biggest losses in our MPI. Let's estimate the total losses of the MPI. The first grid is seen in transmission for the RF signal and in reflection for the LO signal. Then, the second grid is seen in reflection and in transmission by both signals. The atmospheric absorption is the same for both signals. It gives 49% transmission for the LO signal and 59% transmission for the RF signal (or 61% and 73% not including the atmospheric absorption). It is consistent with our primary measurement, with the Golay cell detector, which was 60% transmission without taking the atmosphere into account. If we add the water vapor absorption, we find a transmission of 48% for the LO signal.

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