Up-dating of the Columbia - U. de Chile receiver

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***Abstract*—The up-grade of the Columbia - U. de Chile receiver is described in this paper. The main goals were to increase its sensitivity and its band of operation. To achieve this objective we included a HEMT amplifier as a front end component, getting a reduction in noise temperature of about 30%. To increase the frequency range of work we replaced the old Klystron oscillator with a Gunn device. We tested the new receiver at the lab and showed that the receiver works in the complete range of frecuencies between 85 and 115 GHz with a noise temperature better than 800ºK.**

***Index Terms*—HEMT amplifier, Gunn oscillator, Microwave engineering.**

I. Introduction

THE University of Chile, in cooperation with Harvard University, owns a radio-telescope, called Columbia - U. de Chile, which operates in the 3 mm band (115 GHZ). This instrument was built in the early 80's and is located in the Inter American Observatory of Cerro Tololo. The telescope has been used for different investigations, leading to the first map of our galaxy in the 12CO line [?].

After more than 15 years of operation it was decided that the technology of the receiver has to be modernized. The main goal of this work is to improve the sensitivity of the instrument and to increase its frequency range of work, allowing the study of different molecular species with the same instrument. The receiver was dismounted and moved to the RF Laboratory of Cerro Calán, where the updating work has been done.

The first task was replacing the old Klystron local oscillator with a new Gunn oscillator, which shows better features and is easier to use.

The second task was incorporating a HEMT (High Electron Mobility Transistor) amplifier at the front end of the receiver. In this way the noise of the instrument is dominated by the noise of the amplifier, which is less than the old system noise. As result we improved the sensitivity of the receiver. The HEMT amplifier was designed and built by the Jet propulsion Laboratory at Pasadena CA [?], and was obtained through a co-operative program between the Universidad de Chile and California Institute of Technology (CalTech).

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Figure 1. The radio-telescope Columbia - U. de Chile

II. Construction of the new Local Oscillator

The old Local Oscillator (LO) generator was a Klystron, a microwave tube which could generate a 53 - 60 GHz signal with 200 mW of power. This signal was doubled by a passive multiplier to get the 106 - 120 GHz signal which drove the mixer [?]. This frequency range only allowed it to perform observations in a narrow band, where only 3 CO transitions could be observed. Another problem of the old LO system was its operability. The Klystron tube needs two bias signals of 1600 V and 350 V and had to be cooled by water. Therefore the control system was quite hard to use.

The new Gunn oscillator, built by J.E.Carlstrom, generates a variable signal between 85 GHz and 115 GHz, allowing the observations of different molecular transitions for eight different molecules. The Gunn oscillator needs only a 10 V bias signal, and slight variation in this value allows adjusting the operational frequency.

This kind of oscillator is based on a semiconductor which exhibits a negative impedance region. The device is biased to work in the negative impedance regime, and is coupled to a resonant cavity. As a result the device starts to oscillate with a frequency determined by the size of the resonant cavity. To determine the frequency of operation the size of the resonant cavity is modified by a micro-metric screw. A fine tuning of the frequency is performed by small variations in the bias voltage. This feature is used by a PLL (Phase Lock Loop) circuit to lock the oscillator in the desired frequency.

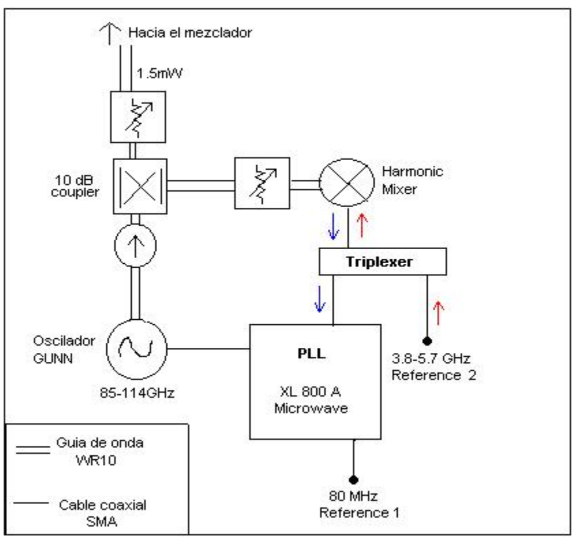

Figure 2. Esquemático propuesto para el oscilador local

In Figure **??** the control circuit for the Gunn oscillator is shown. To get a good match between the Gunn oscillator and further stages we used an isolator (10/5000 Aerowave[**?**]).

The LO signal generated at the Gunn is coupled by a 10dB directional coupler (10/3000/10 Aerowave) [**?**] to a harmonic mixer (Pacific Millimeter Products) [**?**]. This device mixes the LO signal with the N^{a} harmonic of a reference signal of 4-6 GHz. A triplexer allows separating the incoming 4-6[GHz] from the low-frequency resultant signal.

The reference signal is chosen to obtain a mixed frequency around 80 MHz. This signal is selected by the triplexer and sent to a PLL circuit (XL 800A, Microwave [**?**]). This component compares the signal from the harmonic mixer with an absolute 80 MHz reference signal, and corrects the bias voltage of the Gunn to lock this device at the desired frequency.

When the Gunn oscillator is properly controlled the LO signal exhibits excellent noise features and stability. To characterize the new LO system we measured the power delivered by this system, (Figure **??**). The LO oscillator system generates a frequency between 85 and 114 GHz with a power from 3 mW to 32 mW.

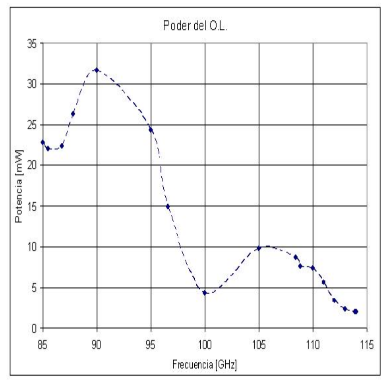

Figure 3. Poder generado por el oscilador local

The Schottky mixer needs 1 mW of power of and would be completely destroyed with power above 3 mW. So we can conclude that the new LO system generates enough power to drive the mixer in the complete range of frequency, and the user has to take care of the attenuator located between the mixer and the LO to avoid an excessive amount of power burning the mixer [**?**].

III. Installing a HEMT amplifier

The second stage in the updating of the telescope was integrating a HEMT amplifier as a front-end. In a chain of electronic devices the total noise of the system is (**??**),

$$T_{receiver} = T_1 + \frac{T_2}{G_1} + \frac{T_2}{G_1 G_2} + ... + \frac{T_n}{\prod G_i} \quad (1)$$

where T_i and G_i are the noise and gain of the stage 'i'. If an amplifier is used as the first component, the total noise corresponds to the amplifier noise plus the noise of the further stage divided by the amplifier gain. If the amplifier gain is enough (more than 20dB) the contribution of the further stages could be neglected.

The HEMT amplifier we used was designed and built at JPL [**?**], and is an experimental prototype developed for radioastronomy purposes. This kind of amplifier was successfully used in the SEQUOIA instrument [**?**].

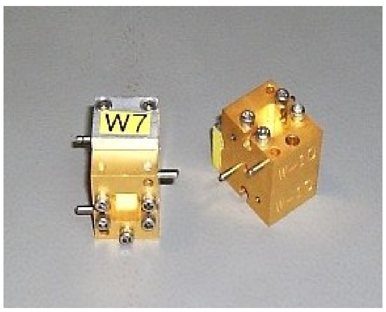

Figure 4. The W7 and W10 HEMT

To decrease the receiver temperature the HEMT amplifier was installed as the first component after the horn and the vacuum window. An isolator was used between the HEMT and the rest of the circuit. This component avoids the existence of standing waves, which could affect the stability of the amplifier and, in the worst case, cause oscillatory behavior in the amplifier. The isolator also protects the amplifier from power from the LO system which could be coupled to the HEMT in a reverse direction, damaging the component.

Figure **??** shows the new design of the receiver. A complete description of the other components present in the schematic can be found in [**?**] and [**?**].

The complete circuit operates at a cryogenic temperature of 77°K. Therefore the isolator has to be capable of working at this temperature. The Millitech isolator [**?**] used was especially designed to be used in these environmental conditions.

Using the information from [**?**] [**?**], the estimated noise temperature of the HEMT amplifier and the

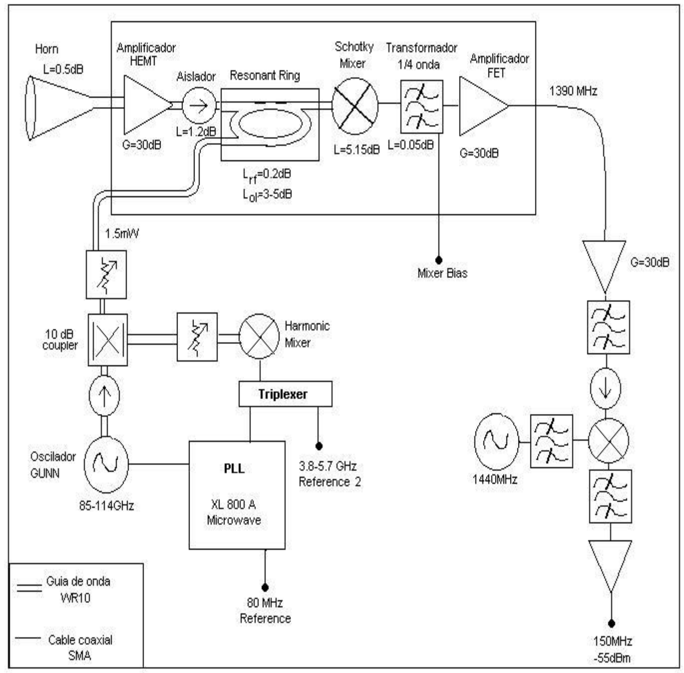

Figure 5. The new design of the receiver

isolator, the final noise temperature of the new receiver, was estimated to be 200°K operating at 77°K. The temperature of the old system was 350°K, therefore we achieved an improvement of 150°K.

IV. Results

When the updating work was finished, the values of the gain and noise were measured. To perform these measurement the Hold-Cold test, known also as the Y factor test was used [**?**].

To perform this test we measured the output power of the receiver when a cold load was put in front of the horn. This value was recorded as P_{Cold}. The cold load consist of an absorber embedded in Liquid Nitrogen, so the temperature of the load is known and corresponds to T_{Cold}=77°K.

After this procedure we measured the output power, P_{Hot}, when an ambient temperature load is put in front of the horn. Both quantities P_{Hot} and P_{Cold} are related to the Noise temperature and T_{Cold} T_{Cold} by (**??**) (**??**).

$$P_{Cold} = kT_{Cold} + kT_{Ruido} \tag{2}$$

$$P_{Hot} = kT_{Hot} + kT_{Ruido} \tag{3}$$

From these equations it's possible to get out an expression for the noise temperature (**??**) as a function of the Y factor, which is defined as $Y = \frac{P_{Hot}}{P_{Cold}}$.

$$T_{Ruido} = \frac{T_{Hot} - YT_{cold}}{Y - 1} \quad (4)$$

Once the new LO was installed, the performance of the receiver working in the new range of frequency was measured,(Figure **??** traced in blue). It was observed that the noise of the receiver was quite flat, but it increased at the lower frequency range.

After installing the HEMT amplifier the noise of the new receiver was measured, (Figure **??** points in red). A reduction in noise of about a 30% was observed. This procedure was performed with the receiver working at ambient temperatures. After cooling down the receiver the noise temperature was about 200ºK in the band between 100 and 115 GHz and more in the low part of the band.

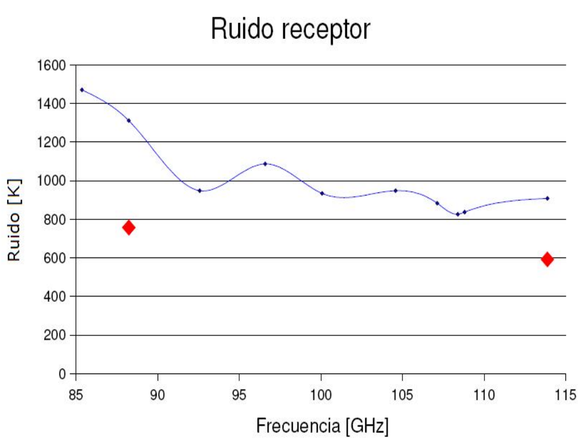

Figure 6. Noise temperature of the receiver

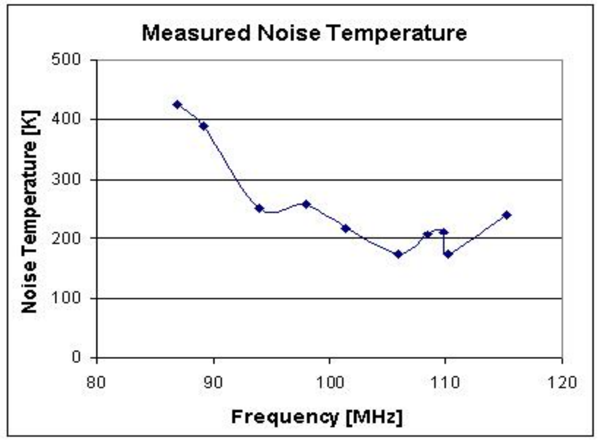

Figure 7. Noise temperature of the receiver

V. Conclusions

A new Local Oscillator system was built. It's based on a Gunn oscillator and puts out more power than 3 mW in the 85-115 GHz frequency range. The Gunn is controlled by a PLL circuit. The reference signal could be generated by the control system. This new LO was successfully integrated to the receiver.

After the integration of the new LO system the receiver was tested. The modified receiver could work without problems in the frequency range between 85 GHz and 115GHz. The noise temperature is 1500ºK for the low frequency range and 900ºK for the high frequencies.

The HEMT amplifier was incorporated as the front end of the receiver. The noise temperature of the whole system was diminished by 30%.

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