Phase and Amplitude Antenna Measurements on an SIS Mixer Fitted with a Double Slot Antenna for ALMA Band 9

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Introduction

Phase and amplitude antenna measurements are required to give a complete and comprehensive antenna beam pattern of receiver systems. Radio astronomical receivers in the past years have been becoming more complex and/or increasing in frequency. There are a number of multichannel receivers on telescopes now that are either multi-frequency, or multi-beam, with or without polarization diversity. These receivers, with the advent of projects like FIRST or ALMA, now go into the terahertz frequency bands.

The reason for phase and amplitude measurements over simple amplitude measurements is so that the entire antenna system can be properly measured in the laboratory environment

IRAM with its 2 radio astronomical sights at Pico Veleta and The Plateau du Bure have had for many years a phase and amplitude antenna test facility, which has worked up to frequencies of 350 GHz. This system has been upgraded to make measurements to the top of the ALMA frequency bands, of 1 THz for band 10

In this paper we show the schematic layout of the new system. Then we will proceed to show its properties at frequencies up to 700 GHz.

This will be followed by the measurements on crossed slot antenna fitted with an SIS junction in the ALMA band 9 frequency range 600-720 GHz.

Reasons for Phase and Amplitude Measurements.

There are a number of reasons to have a phase and amplitude antenna measurement facility over a simple amplitude measurement system. These can be listed as follows:

1. To measure all of the quasi-optical parameters of an antenna structure or system. These include the following:
    - The waist size and its position in the X, Y and Z directions with respect to a known reference.
    - To measure the angle of the beam from a known plane of reference.
2. To measure the efficiencies of the optical system, i.e. The side lobe levels the gains and the phase, and then be able to relate this to the theoretical models.
3. To find the efficiencies of coupling to further optical trains and telescopes

4. To be able to pre-align quasi-optical systems with optical systems such as laser alignment in order to be able to improve system efficiency.

The IRAM antenna facility

The antenna measurement facility was designed to work up to frequencies of 350 GHz, which are the maximum frequencies that the IRAM telescopes at Pico Veleta and the Plateau de Bure can reach. There are 2 different systems of taking the antenna beam patterns;

1. A far field antenna beam pattern system with an elevation over azimuth rotation stages.
2. An X and Y raster scan quasi-near field measurement system

The former system is mainly used for horn and horn lens systems, and the latter is for the more complex systems that would be difficult to rotate, due to size or complexity. It is possible to do a raster scan of about 450mm x 450mm. This latter was used for the measurements to be described. Both of these systems have a positional accuracy of about 0.5μm. The schematic diagram of the system is shown in figure 1 below. The receiver system for frequencies up to 350GHz is a homodyne system as described in reference 1. This system was not able to be increased in frequency for 2 main reasons;

1. The power from the harmonic mixer driving it from frequencies up to 36GHz was not enough to give enough dynamic range.
2. The system of multiplication of the reference level did not give a stable reference above a multiplication factor of 4.

This system has been modified to improve its performance at frequency ranges up to 1 Terahertz. The system shown in figure 1 has two phase locked Gunn and 6X multiplier sources. One as the local oscillator, Gunn2, which is directed onto the antenna under test and the mixer located in the dewar by means of a horn lens combination followed by a mylar beam splitter. The other is put on to the translation table. The horn used for the transmitter is an open-ended piece of waveguide of cross section 0.46 x 0.23 mm machined to a point. The signal is mixed with the LO to give an intermediary frequency, IF, of 4, or 1.5 GHz, depending which mixer is used for the experiments. This is amplified and filtered and bought into the mixing box A.

On each of the 2 oscillator chains before they are multiplied by 6, we have 2 directional couplers; 1 about-20dB used to phase lock the 2 Gunn oscillators from the 2 synthesizers 1 and 2. The other about –15dB, where there are 2 harmonic mixers. The signals are down-converted, filtered and amplified and then mixed together to have a reference signal which equals IF/6. This reference is multiplied by 6 and then, amplified, filtered and put into the other input port of the mixer box A.

In this mixer box a 3rd input from a 4th synthesizer at 1.5 GHz enters. This is split in 2. One part goes through a band pass filter to the reference port of the vector voltmeter, an HP8508A. The rest of the signal is mixed with the multiplied reference to a frequency of 2.5 GHz . This is filtered and amplified and mixed with the IF signal to give an input signal on the vector voltmeter of 1.5GHz. The 2 inputs to the vector voltmeter are phase coherent.

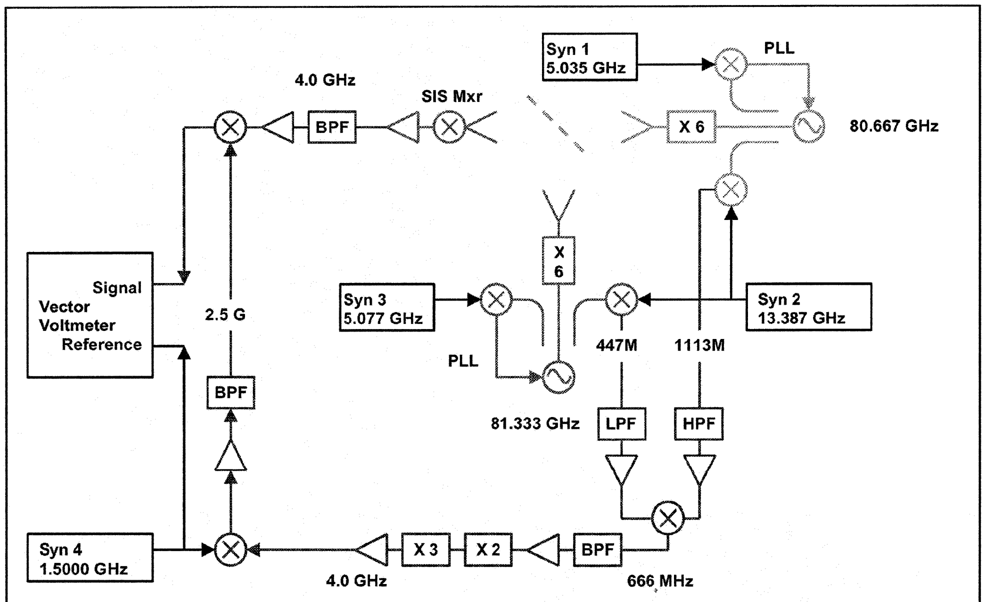


Figure 1.

This system has been modified from the lower frequency case in 2 major aspects:

1. The use of 2 Gunn oscillator / multiplier chains, one for the local oscillator (LO) and the other as the transmitter. At the lower frequencies a harmonic mixer could be used as a transmitting source. This has also meant the use of a first down converter on the reference.
2. The reference has to undergo the same number of multiplications as the transmitter. In this case a factor 6 was used. This has meant that the reference signal's signal to noise ratio was too low to lock the vector voltmeter. To get over this problem a further mixing scheme was required.

The equipment set up can be seen in the photographs in figures 2 and 3.

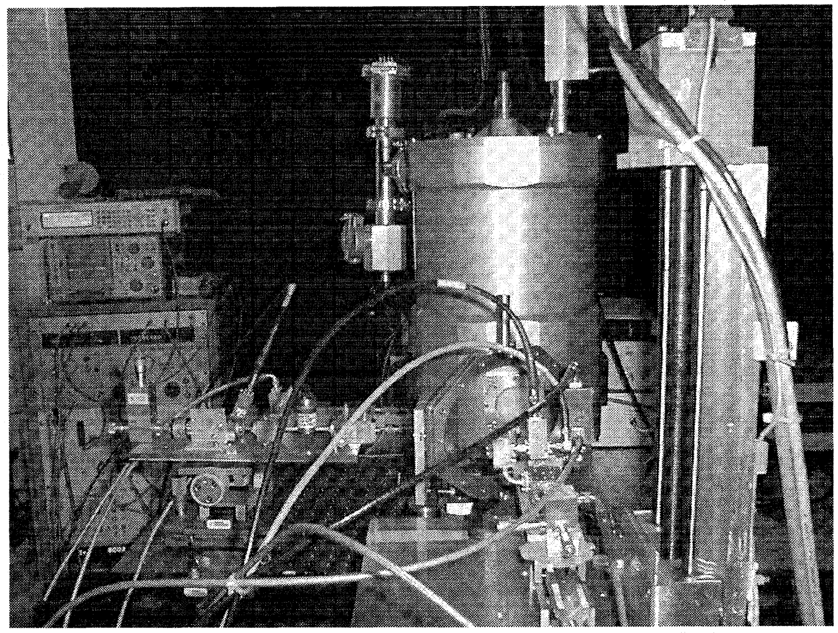


Figure 2 shows the view behind the transmitter with the Gunn and multiplier fitted onto the XY table. On the left can be seen the LO with the mylar beamsplitter in front of the Infrared Instruments dewar. Behind and to the left can be seen the rack of equipment holding the electronics, consisting of 2 of the synthesizers, The vector voltmeter and the reference multipliers, filters and amplifiers

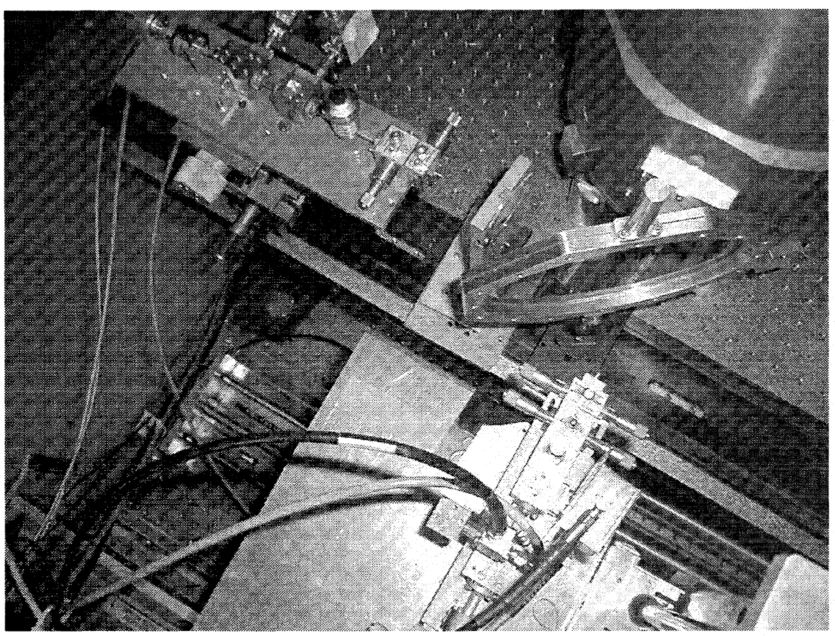


Figure 3 Shows a top view of the 2 Gunn multiplier chains. In the fore ground the transmitter on the XY table, and on the left the LO with the lens and the mylar beam splitter.

Performance

The system at present has been taken up to a frequency of 700GHz. The dynamic range as can be seen in fig 4 at a frequency of 630GHz is greater than 60dB.

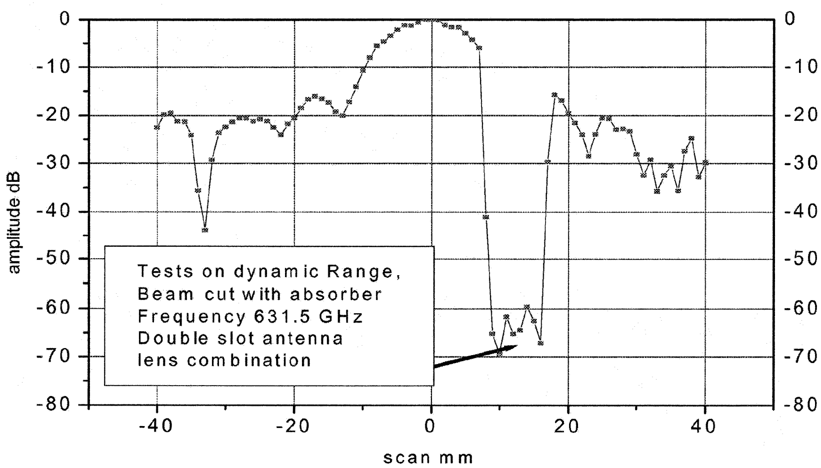


Figure 4 System dynamic range

The phase measurement shows that there is no loss of phase throughout its amplitude dynamic range. Figure 5 shows a plot of a diagonal horn at 634 GHz. The amplitude signal is to a level of –40 dB, but the phase can be unfolded all the way out to this level.

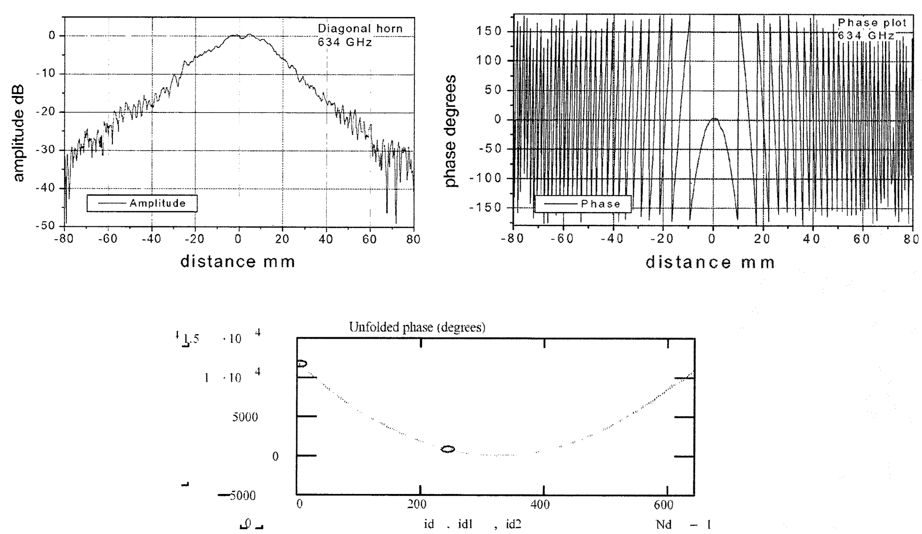


Figure 5 A measurement of a Diagonal horn at 634 GHz, showing the amplitude and phase plots, with the unfolded phase

One of the main problems encountered was the saturation of the SIS junction. Before each set of measurements checks had to be made to put the system into a linear measurement area. This was done by decreasing the transmitted signal in steps to see the effect on the polar pattern and then coming back to a level about 5 dB below the last point where there was not any change. This can be seen in figure 6.

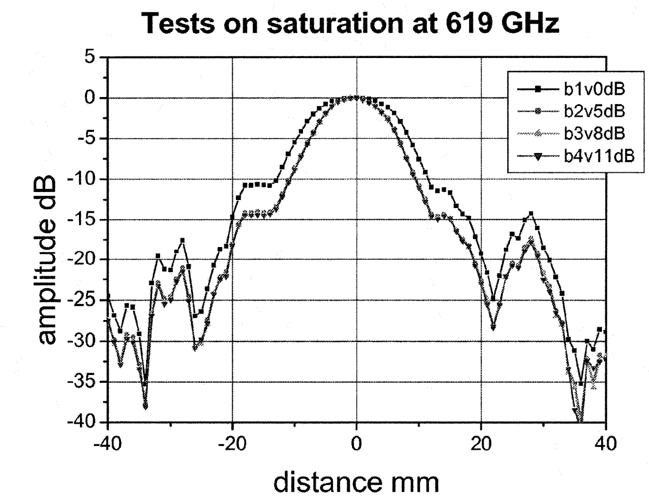


Figure 6 Saturation Experiments 0 dB,-5,-8,-11 transmitted power

Results

This equipment has been used to measure a double slot antenna mounted onto elliptical silicon lens, reference 2. The lens surface was matched with a stycast matching layer to reduce the reflection from the lens surface.

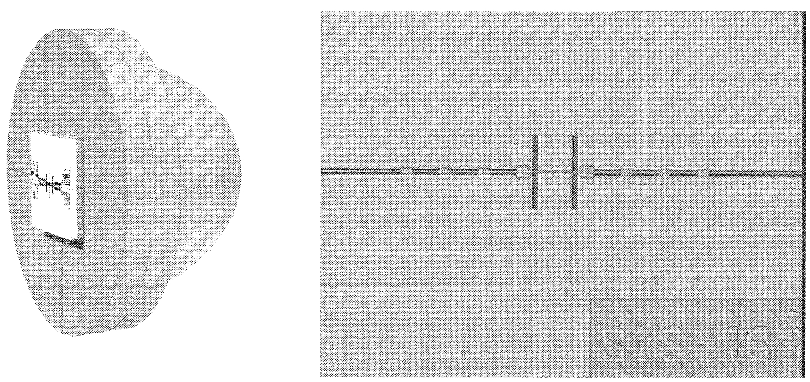
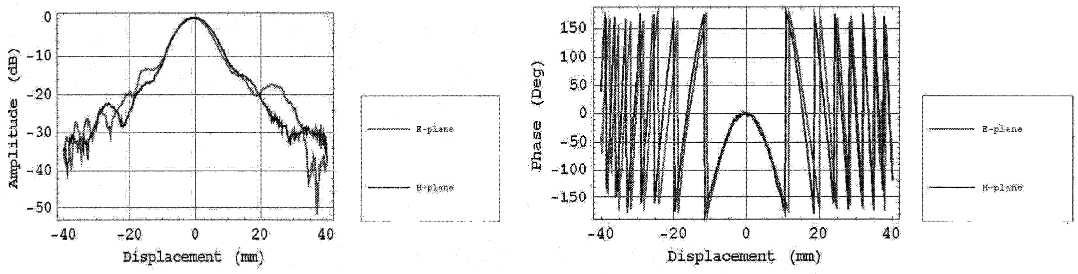


Figure 7 On the left a sketch of the antenna, and on the right a photograph

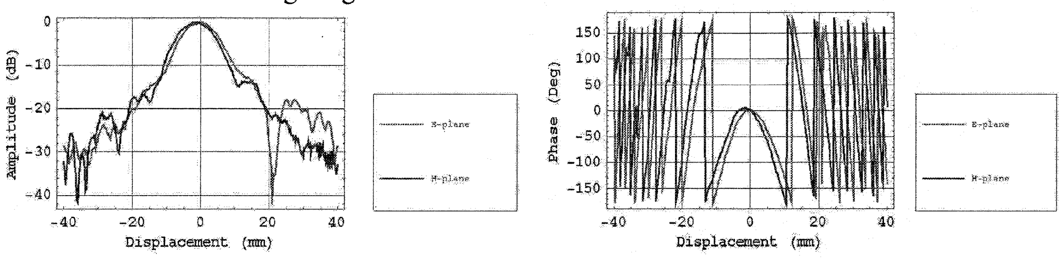
The measurements were made as described earlier, with the local oscillator injected through a mylar beam splitter. This meant that the transmitter had to be at the relatively large distance of 160 mm from the dewar.

Initial measurements in the 2 principle planes were made to align the antenna against the X-Y table, and to center the beam. This position was unfortunately lost during these measurements when the transmitter chains had to be changed.

The measurements were made in the quasi-near field of the elliptical lens. Cuts of +/- 40 mm distance with a step size of 0.25 mm were made in the 2 principal planes. These results are shown for 2 frequencies below at 604 GHz and 696 GHz.



696 GHz measurements giving Woh = 3.78 and Wov =3.86



604 GHz measurements giving Who = 3.8 and Wov = 3.86

Figure 9 Crosscut measurements of the E-vertical and horizontal at 696 and 604 GHz

A series of these measurements were made over the frequency range. From the results of these measurements they were recalculated and put into the far field. These results can be seen below in figure 10. The results of these measurement show that there is a unique phase center for this antenna structure. The waist of this antenna structure is 3.9 +/- 0.2mm over the frequency measured and in both polarizations. The side lobe properties of this antenna have the first side lobes between –18 and -20 dB across the frequency range. The amplitude as the phase is perfectly symmetric and frequency independent. The 1-D Guassisity (overlapping integral with gaussian beam in Cartesian coordinate system) of this antenna was calculated over the frequency rang and found to be about 95-97%. However, the waist size Wv and distance |Zv for vertical direction are different from Wh and Zh in horizontal direction. This leads to slight degradation in 2-D Gaussitity which is about 89% across the measured frequency range.

A series of 2 dimensional scans were made at each frequency over an area of +/- 40 mm. To reduce the length of these measurements, the separation of the measurement points was increased to 2.5 mm x 2.5 mm, which has meant there is a reduction in the phase accuracy. An example of these measurements can be seen in figure 11.

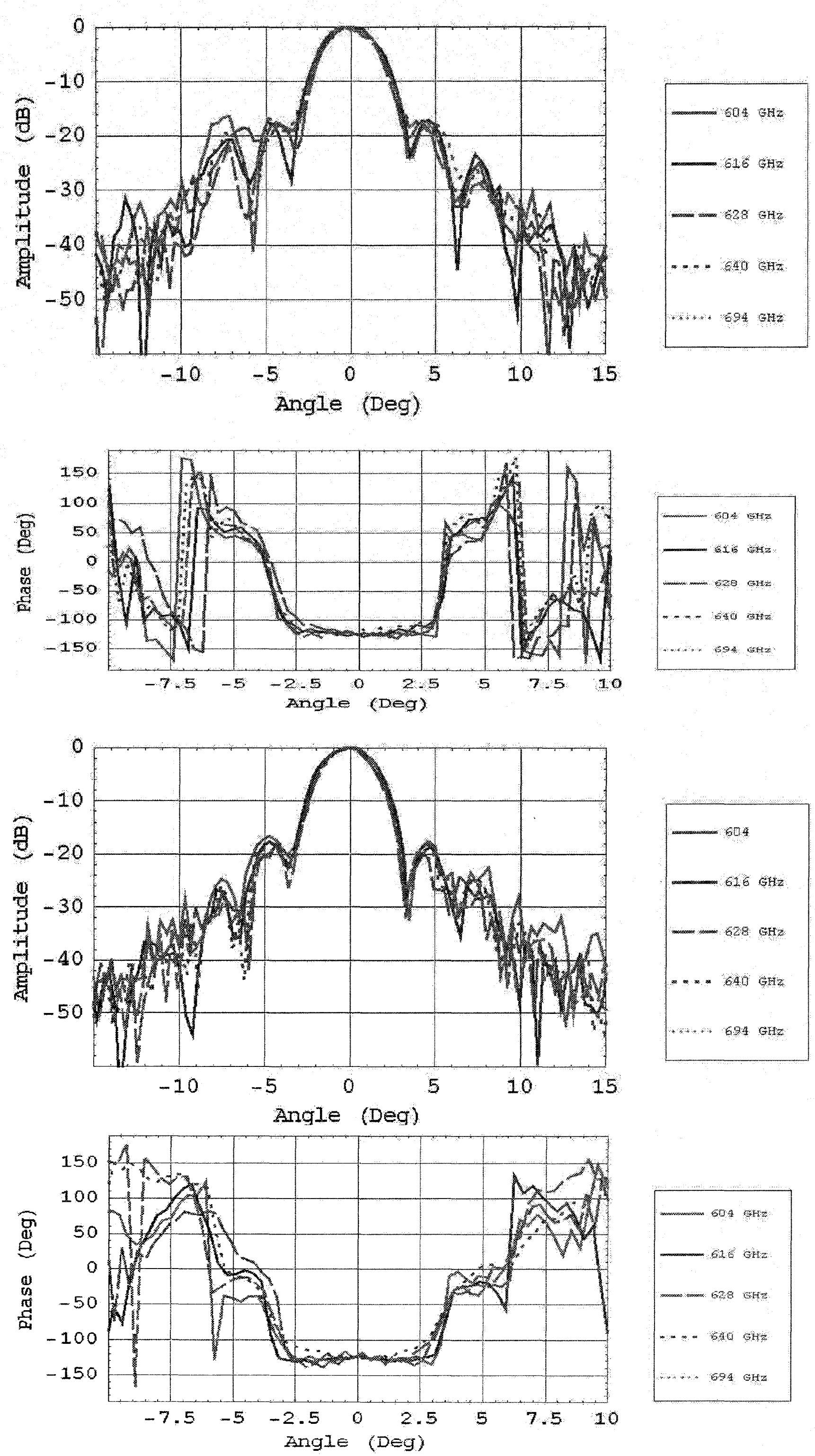


Figure 10 Far field results of the double slot antenna on a matched ellipsoidal lens above E-Vertical and below E-Horizontal

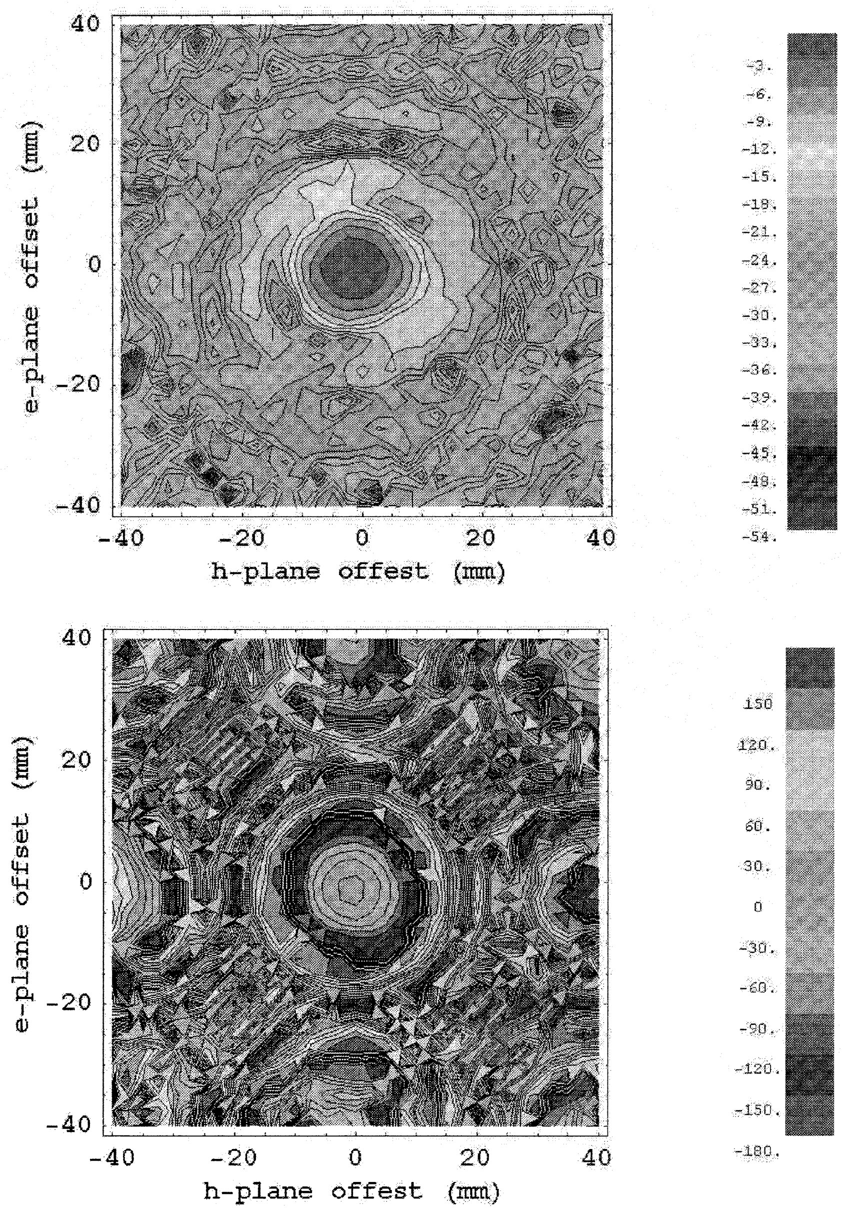


Figure 11 A 2 dimensional measurement pattern of the twinned slot antenna at 604GHz above the amplitude scale in 3dB steps, and below phase with the scale in 30-degree steps

Conclusion

In this paper we have shown a means of accurately measuring antenna and systems I the sub-millimeter wavelengths. The measurements shown were made at frequencies between 600 and 700 GHz. These measurements had a dynamic range of greater than 60dB, with a phase coherence over the entire dynamic range. With the measurement technique shown, this can easily be taken up into the Terahertz frequency ranges, without a degradation of performance.

With this equipment we have successfully measured in phase and amplitude a double slot antenna structure mounted on to a matched silicon ellipsoidal lens and fitted with an SIS mixer. This antenna is a possible candidate for the ALMA band 9 receiver. These measurements were made over a frequency range of 600 – 700GHz. The side lobe level was found to be at –18 to –20 dB over the frequency range. The beam was symmetrical and frequency independent. There was found to be a unique phase center for both major planes and a waist of 3.9mm. The Guassisty of the antenna was of the order of 89 % over the frequency range.

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Reference;

1. M.Carter, S.Halleguen, B.Fouilleux, IRAM Antenna Test System Proceedings of the 5th International Workshop on Terahertz Electronics, Sept 1997, Grenoble France.
2. Van der Vorst, M.J.M.; De Maagt, P; Herben, M.H.A.J.; On the Design of Integrated Lens Antennas. 20th ESREC Antenna Workshop on Millimeter Wave Antenna Technology and Antenna Measurement; ESTEC, Noordwijk, The Netherlands; June 1997