A 350 GHZ FINLINE MIXER FED BY A HORN-REFLECTOR ANTENNA

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ABSTRACT

In this paper we describe the design and preliminary results of testing a tunerless finline mixer over the frequency range of 330-360 GHz. The mixer is fed by a conical horn-reflector antenna, machined into an aluminium split block to ensure that the mixer has low sidelobe level and high aperture efficiency, without the employment of a phase correcting lens. The mixer chip itself comprises an antipodal finline taper and a miniature microstrip line, which contains an Nb/Al-oxide/Nb junction. Our preliminary test of the mixer at 4.7 K yielded receiver noise temperature of about 90 K DSB which includes some IF and RF losses. The measured beam pattern of the conical horn reflector antenna was in excellent agreement with the computed results.

INTRODUCTION

We have already reported the successful operation of an antipodal finline mixer at 230 GHz. We showed that the mixer is easy to use and has a noise temperature which is comparable to best waveguide mixers, despite that it does not have any mechanical tuning (Yassin *et al*, 1997a). Another feature of the finline mixer is that it operates over a remarkably wide band. We have already demonstrated that the finline mixer can operate well over one octave provided the junction tuning remains effective. In this paper we shall describe an improved design and test results of a tunerless finline mixer which is designed to cover the frequency range of 320-390 GHz. The mixer is fed by a horn-reflector antenna, machined into an aluminium split block to ensure that the mixer has low sidelobe level and high aperture efficiency, without the employment of a phase correcting lens. The mixer chip itself comprises an antipodal finline taper and a miniature microstrip line, which contains an Nb/Al-oxide/Nb junction. The two superconducting films are deposited on one side of a 90 μm thick quartz substrate and are separated by 400 nm thick oxide layer. The antipodal finline taper is then transformed into a microstrip line of characteristic impedance of 20-30 ohms which is ideal for SIS junctions. The inductive tuning stub was fabricated as part of the IF microstrip transmission line rather than at right

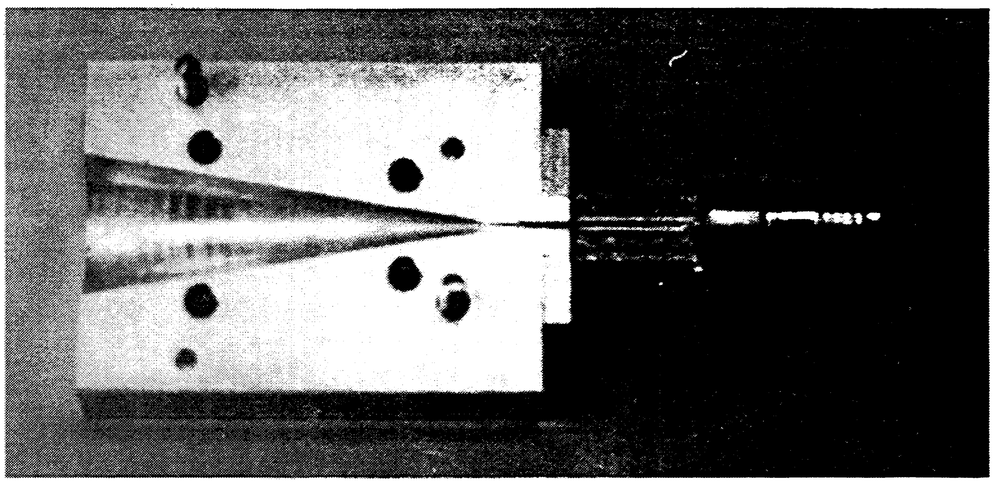

FIGURE I   A photograph of the split Aluminium block

angles to it, as in our previous designs. In this way, the stub both tunes out the junction capacitance and also acts as an RF choke.

MIXER DESIGN

The mixer block and antenna: The mixer block comprised a horn-reflector antenna, machined into an Aluminium split block. We have chosen wave guide dimensions of a= 700μm and b= 350μm, a horn semiflare angle of 9.46°, a horn diameter of 10.0 mm and a parabolic reflector of focal length of 17.7 mm. This gave a -3 dB beamwidth of about 4.5 degrees depending on polarisation and plane of observation. A photograph of the lower part of the split block including the IF bias board carrier is shown if Fig. 1.

We have chosen to start our first tests employing a horn-reflector antenna which is fed by a smooth-wall (rather than a corrugated) conical horn, keeping in mind that the horn will be corrugated at a later stage. This antenna has four principal copolar radiation patterns of different beamwidths and sidelobe levels, since the field distribution over the aperture of a smooth-wall (unlike the corrugated)horn depends on the input polarisation, and since the radiation pattern of the horn-reflector antenna can be observed either in the longitudinal plane (the plane of symmetry, which includes the horn axis) or in the transverse plane (which is perpendicular to the horn axis). This choice therefore gives us the opportunity to verify the accuracy of our design and the precision of our machining techniques by comparing several computed and measured beam patterns of similar yet distributions. We have computed the far field pattern of the antenna in the usual manner by first projecting the field over the horn aperture into the projected aperture, using conformal mapping (Withington *et al,* 1997) . The field distribution of the horn aperture was assumed to be that of a TE11 circular waveguide and the far field of the projected aperture was calculated using either

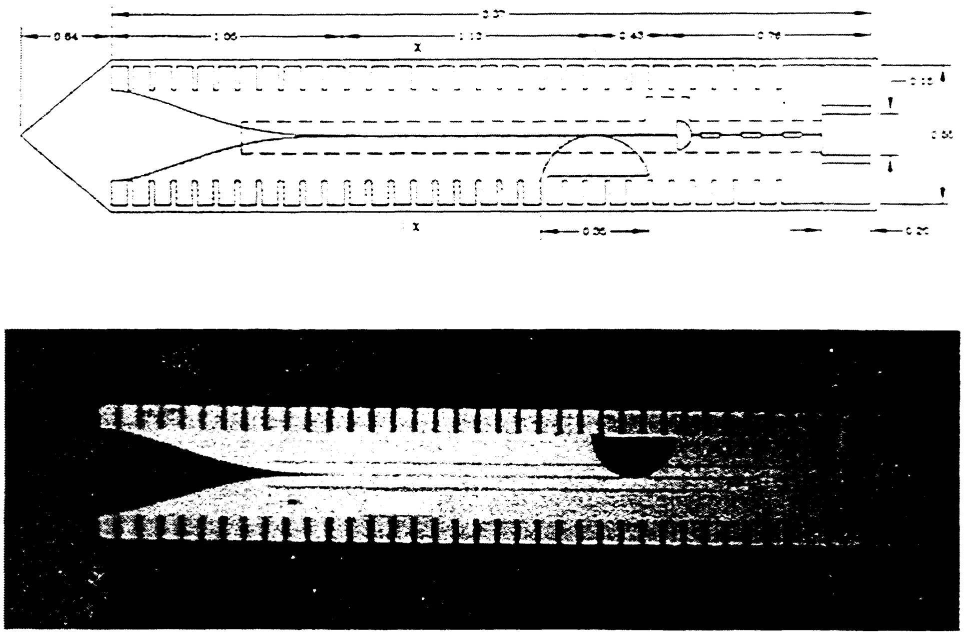

FIGURE II A magnified view and a photograph of the finline mixer chip

the Kirchoff scalar integral or Gaussian modes.
The mixer chip and IF assembly: A magnified view and a photograph of the mixer chip are shown in Fig. 2.
The finline taper and mixer circuits were deposited on a quartz substrate of thickness d=90 μm. The transmission-line tapers were designed using quasi-TEM techniques, and the electrical properties of the finline and microstrip were calculated using methods which we have described previously (Yassin *et al*, 1997b). As was mentioned above the tuning radial stub was fabricated as part of the main microstrip transmission line rather than at right angles to it, as in our previous designs. The main reason for this choice is to eliminate the effect of the IF circuit on the junction tuning, and to make the radial stub act as an RF choke. This means that the old RF choke structure (three inductive and three capacitive pads) may now be removed, resulting in a significant decrease in the chip capacitance at IF frequencies. The mixer chip was manufactured at KOSMA, university of Cologne, using four mask layers. The first forms the base finline electrode and the ground plane for the microstrip, the second defines the tunnel junction and a 200 μm of SiO, the third allows the addition of of an additional 200 μm layer of SiO and the forth forms the wiring finline layer, the microstrip, the RF choke and the tuning stub. The area of the the junction which was employed in our tests (w1s3) is 0.6μm^2, current density of 14000 A/cm^2 and a normal resistance of 25 Ω. The IF signal is extracted by bonding 30μm wires to the three pads on the chip and connecting those wires to the bias

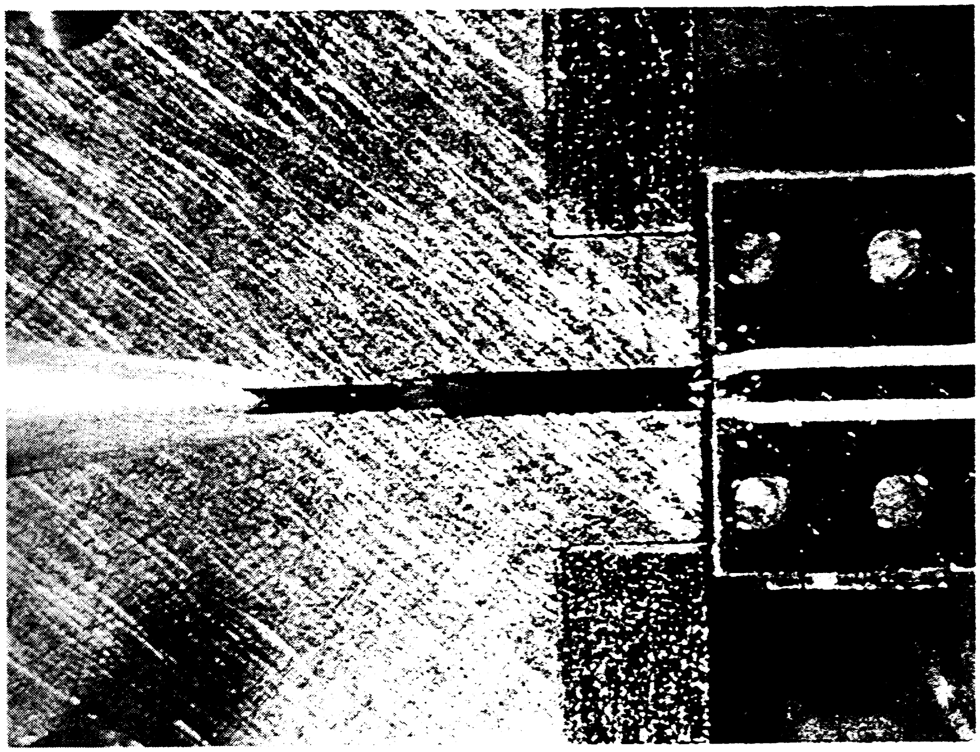

FIGURE III A photograph of the IF assembly

board as shown in Fig. 3.
The bias board itself was a ground plane backed coplanar waveguide which was preferred to the more commonly used microstrip in order to make the bonding pads on the chip level with the IF board metallisation. We designed the coplanar waveguide using the electromagnetic modelling software "Sonnet" in order to take into account the finite width of the ground planes which was made relatively small so that the IF board could be fitted within the coil former. Fig. 4 shows that the measured transmission and return loss of the coplanar waveguide are remarkably good over a wide range of IF frequencies.

EXPERIMENTAL RESULTS

We started our mixer tests by investigating the far field pattern of the horn-reflector antenna. The local oscillator horn was used as a transmitter and its output power was modulated electronically. A radiation pattern was taken by placing the Dewar on a rotary table and rotating the table about a vertical axis which passed through the apex of the horn. Since at this stage we were only interested in measuring the main beam, no special effort was made to increase the dynamic range or to eliminate wide-angle reflections. In Fig. 5 we show a measured pattern when the input polarisation was longitudinal and the observation was made in the longitudinal plane. This configuration yields

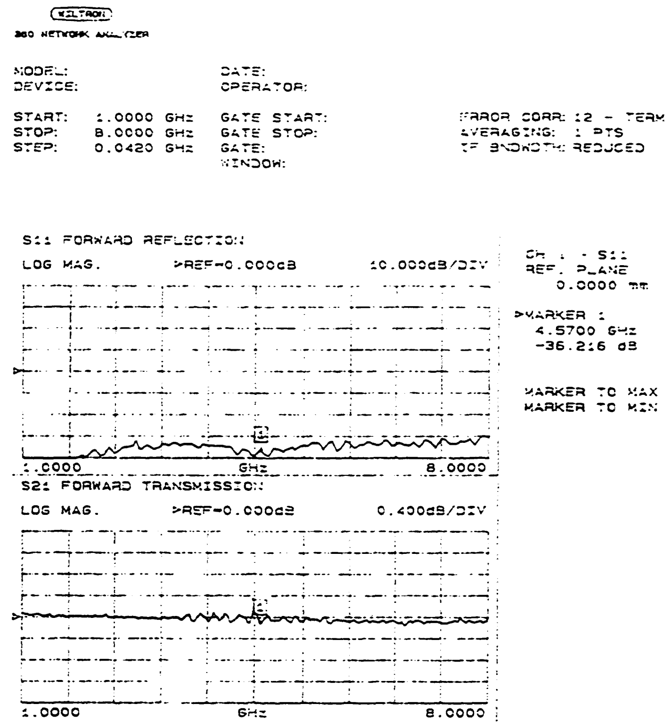

FIGURE IV The measured transmission and return loss of the coplanar waveguide

relatively high sidelobes since the electric field is not truncated. This can clearly be seen in Fig. 5 which also shows excellent agreement between the computed and measured main beams. Work is in progress to measure the other copolar and cross- polar radiation pattern configurations, and the far out sidelobes. We would like to emphasize yet again that in the final design, the horn will be corrugated so that the antenna will have a circular beam and low sidelobes.

To test the noise temperature of the mixer we injected power into the signal path using a 30 μm thick Mylar splitter. In the first attempt the temperature of the mixer block was 5.5 K and in Fig. 6 we show three unpumped curves corresponding to three different temperatures (the 4.2 K curve was measured on the dip-stick with zero magnetic field). In addition to the expected change in the energy gap we clearly notice the increased sloping of the high temperature curve.

In Fig. 7 we show the pumped I-V curve and the hot/cold IF response of the mixer at a temperature of 5.5 K and a frequency of 338 GHz. The receiver noise temperature measured in this case was 130 K (DSB).

In Fig. 8 we demonstrate the efficient tuning of the junction capacitance by the radial stub by plotting pumped I-V curves at two different frequencies. The

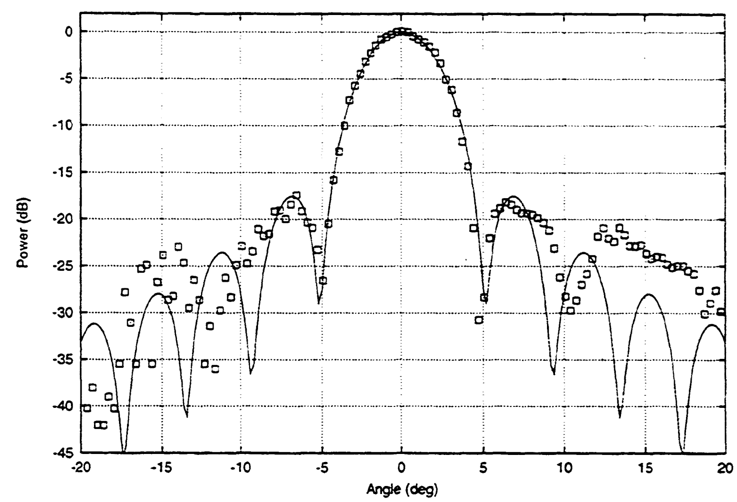

FIGURE V 350GHz conical horn-reflector beam pattern

Josephson effect could easily be suppressed at the first null with a coil current of 88 mA. Although the slope of the photon step at 344 GHz appears to be slightly negative, we did not observe any instabilities in the IF output. Instabilities however may still exist at frequencies below 330 GHz and we shall investigate this later.

We show the IF response of the mixer at 356 GHz in Fig. 9 which gives a noise temperature value of 90 K. Similar values were obtained at all frequencies between 333-360 GHz range which was determined by the availability of local oscillator power. The above quoted values of noise temperature, which are higher than expected at those frequencies, include the losses of the IF amplifier, the Mylar splitter and the cryostat window whose width was in fact designed to test a 500 GHz mixer. In addition, these results represent our first attempt to test the mixer and we expect them to improve on them by modifying the experimental setup and trying different devices.

Finally we intend to modify the finline chip in order to design an image separating mixer. The design will be based on two back-to-back finline tapers, where the signal is fed through one side, and the LO through the other. The IF can be taken from the side, through the waveguide wall without affecting the electrical properties of the transmission line since the electromagnetic field is well confined in the microstrip (Kerr, A. R., and Pan, S-K., 1996). An obvious advantage of this design is that the RF signals are fed to the device without using highly inductive probes. Moreover, there will be enough space on the chip to design the required integrated circuits.

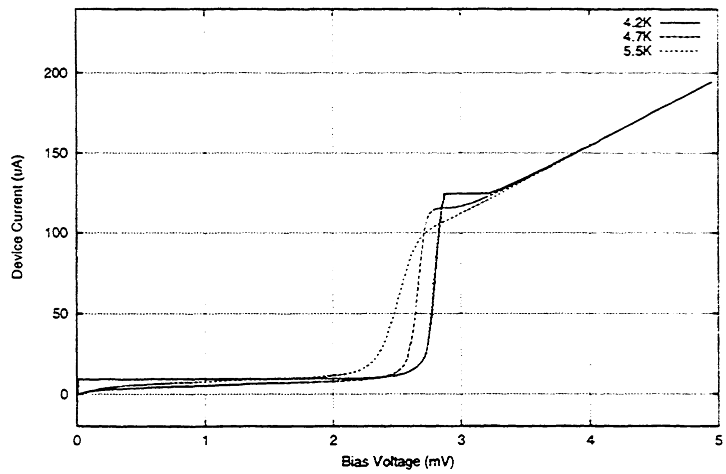

FIGURE VI I-V curves at 3 different temperatures

CONCLUSIONS

We reported the successful operation of an antipodal finline mixer in the frequency range of 330-360 GHz. The preliminary measured results of DSB receiver noise temperature are 90 K which include IF and RF losses in the test system. The measured beam pattern of the horn reflector antenna are in excellent agreement with computed results which illustrates the integrity of both our design and manufacturing techniques of these antennas.

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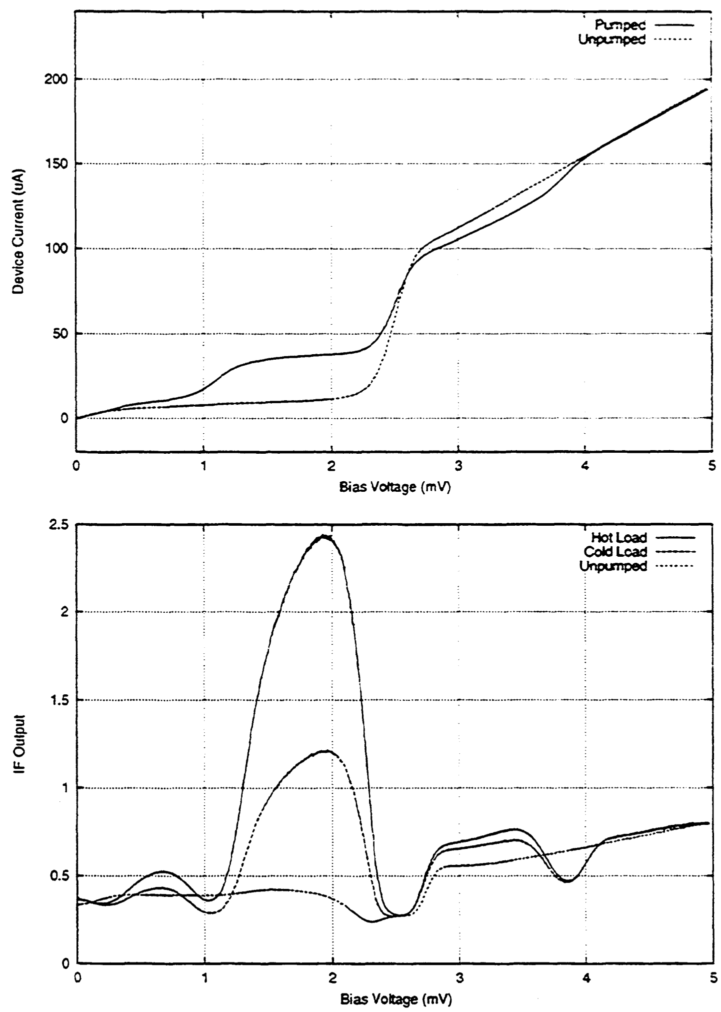

FIGURE VII   Pumped I-V curves and the hot/cold IF response at 5.5K

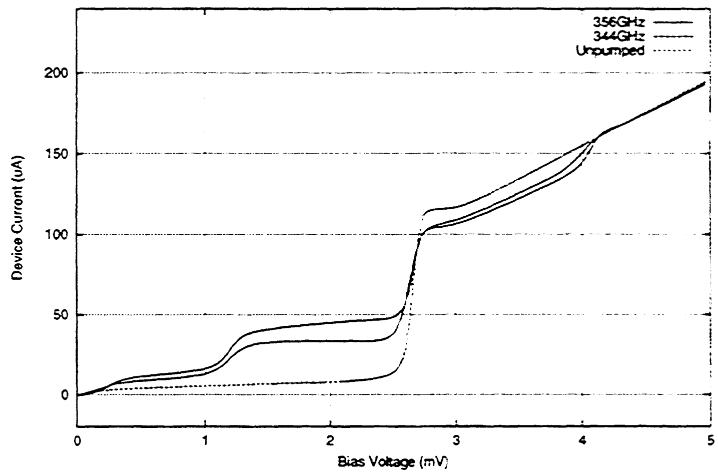

FIGURE VIII Pumped I-V at two different frequencies

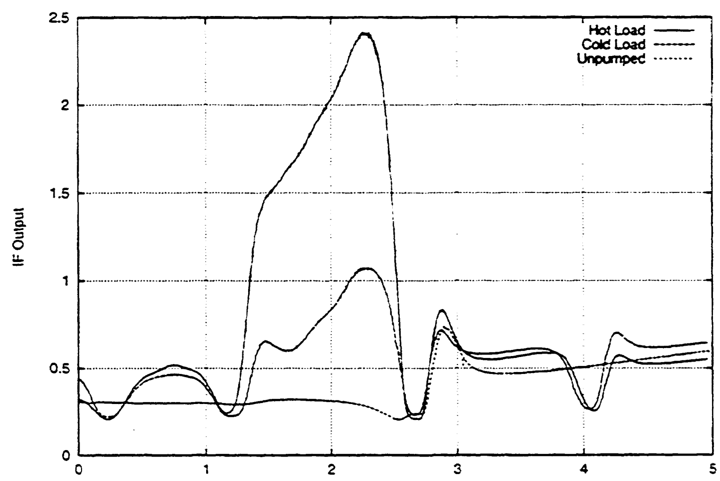

FIGURE IX The IF response at 356GHz