First Results for a 2.5 THz Schottky Diode Waveguide Mixer

B.N. Ellison, ,B.J. Maddison, C.M. Mann, D.N. Matheson, M.L. Oldfield[†]
S. Marazita,[††] T. W. Crowe,[††] P. Maaskant,[†††] W. M. Kelly.[†††]

Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, UK.
University of Kent at Canterbury, Canterbury, Kent, CT2 7NT, UK.[†]
University of Virginia, Charlottesville VA 22903.[††]
University College, Cork, Ireland.[†††]

Abstract

A Schottky diode mixer has been realised at 2.5 THz in a waveguide configuration. Measured RF performance is comparable to that obtained using the conventional corner reflector mount and the waveguide mixer has the added benefits of excellent beam efficiency and circuit tuning capability. In addition, the structure has been demonstrated to be reliable and rugged. The mixer design and construction is briefly described and first RF performance results are presented.

Introduction

At millimetre and sub-millimetre wavelengths single ended waveguide mixers are invariably preferred for applications in which sensitivity and efficient antenna coupling are required. Such mixers commonly incorporate a wire whisker contacted dot-matrix diode mounted in a single moded waveguide, and coaxial or microstrip filtering to separate the signal and IF. At terahertz frquencies, however, where simple scaling indicates that circuit structures need to be less than 100 μm in size, waveguide mixers are generally perceived to be too difficult to build, and open structure mounts are favoured. In this paper we demonstrate that not only is it realistic to build waveguide mixers similar to those at lower frequencies, but that they have similar advantages; excellent antenna coupling, good performance and ruggedness.

Our mixer consists of single moded waveguide and a corrugated feedhorn structure to couple the incident signal into the waveguide. A dot-matrix diode is used as the non-linear circuit element. In order to avoid fabrication and fragility problems associated with scaling miniature wire whiskers, we have developed a novel planar whisker which incorporates RF and IF filtering and is fabricated entirely lithographically. The mixer is straightforward to assemble, and has good potential for further improvement.

Mixer Design

As far as possible, we have followed a conventional single ended mixer design. A corrugate feedhorn is used to couple signal and LO through a transformer into a single moded reduced height waveguide. The diode is mounted adjacent to the signal waveguide wall, and is contacted by a whisker which spans the waveguide. The diode embedding circuit is completed by a tuneable contacting backshort, and a stripline filter, which isolates the RF and allows down converted power from the IF to be passed to an external amplifier. The mixer circuit is illustrated in Figure 1.

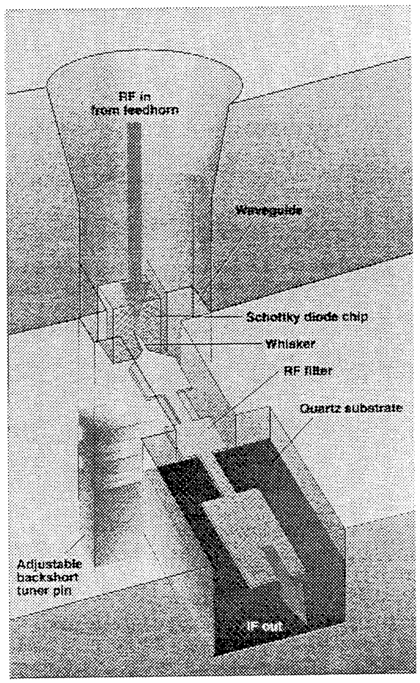

Figure 1: Schematic illustration of the 2.5 THz waveguide mixer block

Three points should be noted. First, because it is difficult at terahertz wavelengths to fabricate a wire whisker which has suitably low circuit inductance and is adequately strong, we have developed a planar whisker (1), which is fabricated and pointed lithographically. This structure has a number of advantages; it is mechanically strong, does not require "pre-bending" (since it naturally bends along its length when used to contact a diode), and can be made arbitrarily short. Second, in order to avoid the presence of dielectric (which would complicate circuit analysis and increase the possibility of unwanted waveguide propagation in the RF filter channel), the RF/IF filter is implemented in stripline with an air dielectric, and is integrated with the planar whisker. Third, because a diode mounting post would be difficult to build and inconvenient to integrate at this frequency, we have soldered the notch front diode directly into a channel adjacent to the waveguide, and opposite the filter..

The mixer circuit is therefore straightforward. The RF filter is a simple five section quarter wavelength design, and a large scale model of the mixer (420:1) was built in order to confirm the electrical characteristics of the filter and diode embedding structure at low frequencies.. Theoretical circuit modelling suggests that a larger diode with smaller resistance might be optimum, provided that a high quality backshort and low loss cavity is available; since this was difficult to quantify two different diode types were specified, primarily differing in anode capacitance.

References [1,2] describe in more detail the critical elements of the waveguide mount i.e., the whisker structure, mechanical cavity and corrugated feedhorn, and their performance. The feedhorn exhibited symmetric E and H antenna patterns with low sidelobe levels (< -18 dB) as shown in figure 2. Further, using the feedhorns in a back-to-back configuration allowed the loss of a section of waveguide, inserted between the feedhorns, to be tested [3]. The attenuation at 2.5 THz of a representative section of reduced height waveguide was measured to be ~1 dB/mm, compared with an estimated theoretical loss of 0.3 dB/mm.

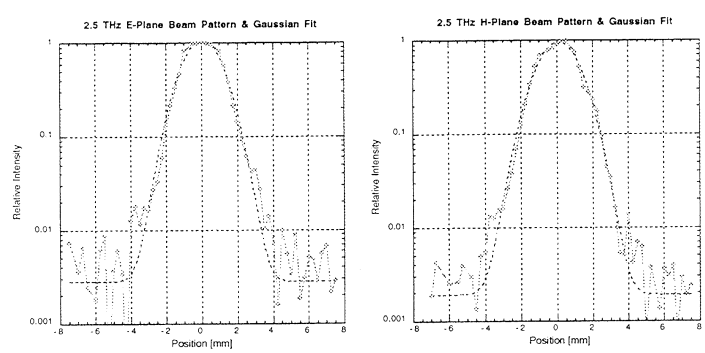

Figure 2: Corrugated feedhorn 2.5 THz radiation patterns

Assembly of the Mixer

Construction and integration of the waveguide cavity is straightforward. Optical and mechanical alignment fixtures can be used to ensure correct alignment of the mixer block feedhorn and backshort waveguide sections and to allow insertion of the tuneable backshort into the waveguide channel. The backshort tuner was fabricated from a 24 μm thick gold ribbon and a high precision micrometer drive was used to vary its position inside the waveguide

Positioning and integrating the small and delicate electrical components i.e., the Schottky diode and RF filter structure, is also straightforward provided that handling jigs and micro-manipulators are used . Despite the small scale of the components, (as an example the diode chip is typically 40 μm in dimension), our assembly techniques allowed repeated successful contacts of diode chip anodes. Two different diode types (with different anode diameters) have been assembled, and both were mechanically rugged. No special precautions were taken during handling of the mixer. Electrically, the mixer diode was fairly sensitive to static, and it was necessary to take reasonable care to avoid damage. This is not surprising, bearing in mind the small area diodes used.

A photograph of the assembled block is shown in figure 3, and figure 4 illustrates a diode chip mounted within the mixer cavity.

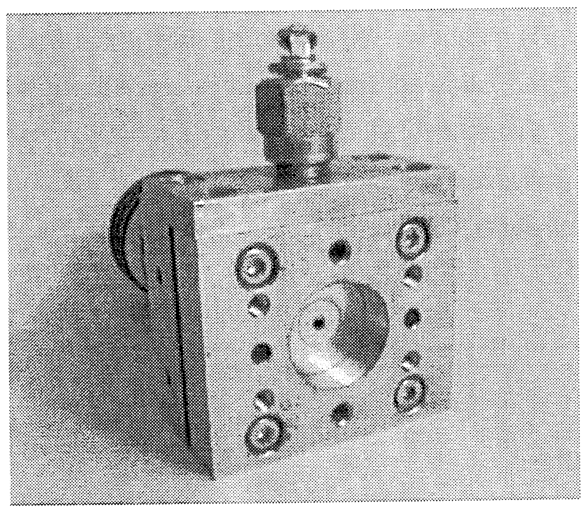

Figure 3: Photograph of 2.5 THz waveguide block

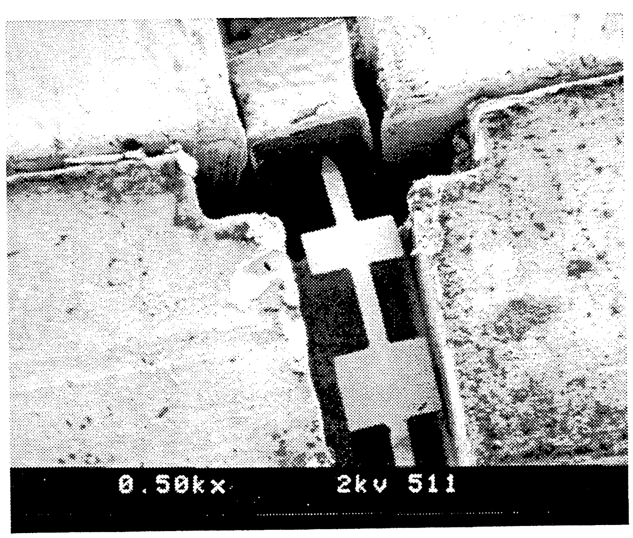

Figure 4: Whisker contacted UVA NF1T2 diode

Test Arrangement

Mixer tests were carried out using a laboratory based CO_2 pumped far infrared (FIR) laser as the local oscillator (LO) source. The FIR laser provides sufficient output power (> 25 mW at 2.5 THz) to allow the use of a single wire grid for LO injection as shown in figure 5. This significantly simplified the optical arrangement and eased alignment requirements. During the measurements the grid was set to an angle that allowed 50% (-3 dB) of the available LO power to be injected into the mixer. Unfortunately, this arrangement also introduces a corresponding 3 dB insertion loss in the signal path which significantly degrades the measurement signal to noise ratio. The mixer and receiver noise and conversion loss measurements presented here are corrected for this insertion loss. To check the validity of this correction we have measured the LO power transmitted and reflected from the grid using a disk calorimeter. The measurements indicated a 3 dB power division by the grid, as expected.

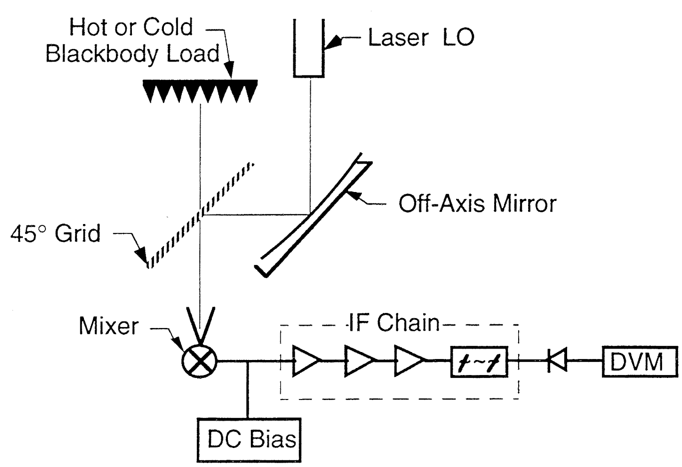

Figure 5: Schematic of RAL system test set-up

Sensitivity tests on the mixer were performed at room temperature by introducing two blackbody sources (Eccosorb AN72) of different physical temperatures (300 K and 80 K) into the signal path in a manner shown in figure 5. The corresponding change in the system total power output for each load was recorded and the system noise temperature, Tsys, determined from the relationship:

$$Tsys = \frac{Th - Y.Tc}{Y - 1}$$

where Th and Tc are blackbody hot and cold load temperatures respectively and Y is the corresponding ratio of the total power output. Calibration of the room temperature intermediate frequency (IF) chain using an IF reference standard enabled the mixer noise and conversion loss to be deduced from the system noise measurements. The IF was centred at 4 GHz with an instantaneous bandwidth of 500 MHz. Planck blackbody corrections have not been applied to the results.

Mixer Performance

Two different diode types have been initially tested, with different anode capacitances; one type, X106, was manufactured by Farran Technology Ltd (FTL) with relative large capacitance (~2 fF), and the second, NF1T2, manufactured by UVA which had lower capacitance (~0.5 fF). These latter diodes were similar in characteristic to diodes known to work well at terahertz frequencies in open structure mounts. Both diodes were manufactured in a notch front configuration using novel manufacturing techniques.

Both diode types showed modulation of the mixer current when pumped by the FIR laser, thereby demonstrating that the backshort is varying the embedding impedance presented to the diode and confirming the general validity of the mixer concept. For example, figure 6 shows a plot of LO induced mixer current as a function of backshort position for a constant mixer bias voltage.

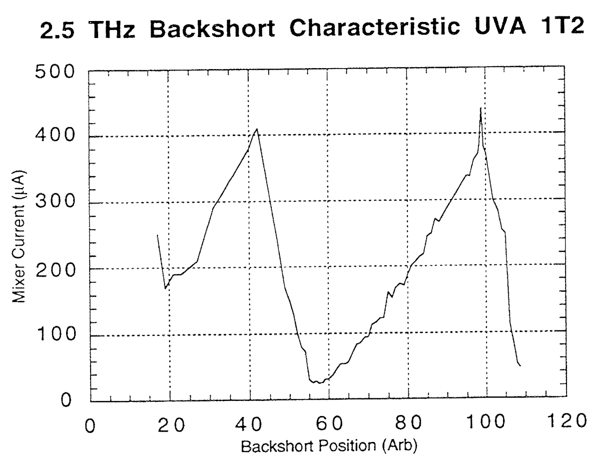

Figure 6: Local oscillator induced mixer current vs. mixer backshort position

However, better mixing performance has been demonstrated by the smaller capacitance diode, with the following characteristics.

$Rs = 23.3\ \Omega$

$\eta = 1.27$

$\Delta V = 74.5$ mV (1-10μA)

With this diode the backshort was able to modulate the current through the diode from near zero to over 400 μamps, and a series of system noise and mixer noise and conversion loss measurements were made at an LO frequency of 2.5 THz, for different LO power and DC bias conditions. Figure 7 shows the system noise measured at different LO power levels, with the minimum noise at a power level of ~ 8 mW. (This value may well be an overestimate. The LO has been measured with a disk calorimeter, and therefore includes all radiation modes from the laser. Our FIR laser is known to generate at least three modes, only one of which is coupled into the mixer, and the relative power content of these is unknown). Figure 8 shows the corresponding mixer noise and conversion loss. Finally, in figure 9, we show the minimum mixer noise and conversion loss as a function of varying mixer DC bias. All results have been corrected for the presence of the wire grid which was set to 3 dB.

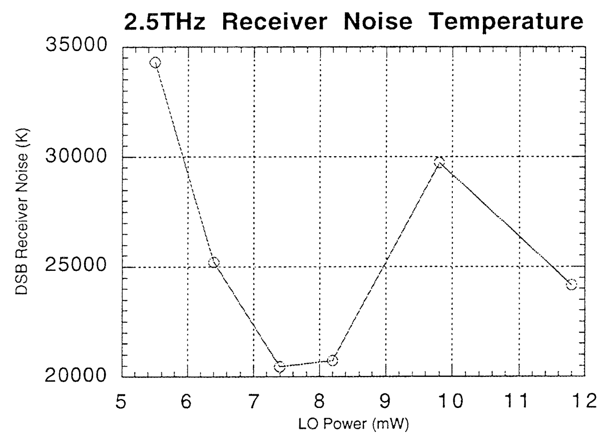

Figure 7: Variation of applied LO power

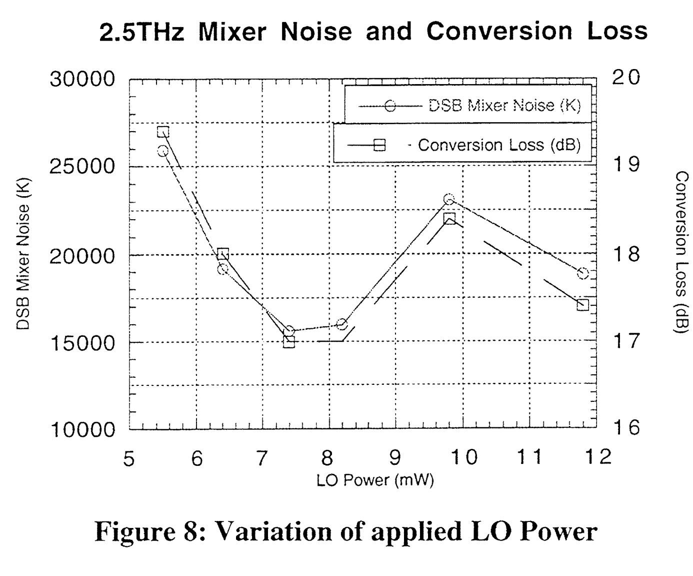

Figure 8: Variation of applied LO Power

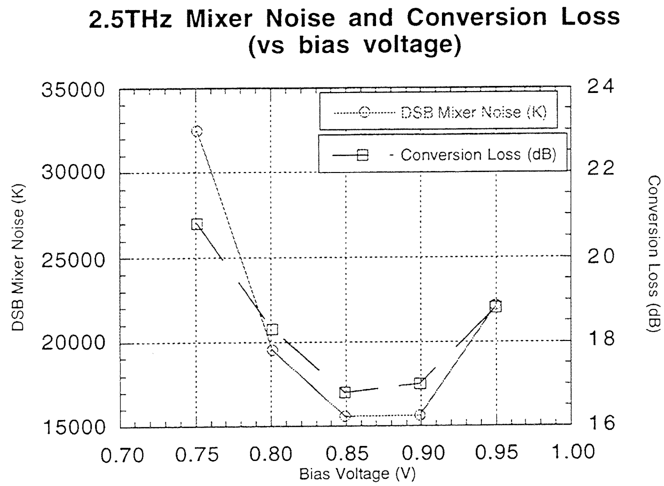

Figure 9: Varying Mixer Bias Voltage

Conclusions

We have demonstrated the feasibility of a waveguide mixer structure at 2.5 THz. Preliminary measurements indicate that the measured mixer noise performance is comparable to that of more mature corner cube devices. The waveguide structure offers additional advantages of excellent antenna characteristics and ruggedness. Further, it is likely that improvements in mixer noise could be obtained by, for example, further of tuning the mount embedding impedance, improvements in the cavity construction (suggested by the better RF performance of the smaller capacitance diode) and an iterative optimisation of the diode parameters.

Acknowledgements

This work would not have been possible without the machining skills of J.J. Spencer, M.J. Culver and D.S. Wilsher of the RAL Precision Microwave Workshop. We also thank A. Jones for his efforts on the mixer block design and A.F. Smith and P.H. Spurrett for their valuable support and assistance with the FIR laser.

This work was supported by the EU Environmental Programme Contract No. EV5V-CT92-0081.

References

[1] Mann, C.M., Maddison, B.J., Matheson, D.N., Oldfield, M. L. and Ellison, B.N. "Towards the Realisation of Space Borne Terahertz Waveguide Devices", Fifth Int. Symp. on Space Terahertz Technology, Ann Arbor, 1994.

[2] Ellison, B.N., Oldfield, M. L, Matheson, D.N., Maddison, B.J., Mann, C.M. and Smith A.F. "Corrugated Feedhorn at Terahertz Frequencies", Fifth Int. Symp. on Space Terahertz Technology, Ann Arbor, 1994.

[3] Ellison, B.N., Oldfield, M. L, Maddison, B.J., Mann, C.M., Matheson, D.N. "Waveguide attenuation measurements at 2.5 THz", In preparation.

[4] Kelly, W.M., Mackenzie, S. and Maaskant, P. "Novel Chip Geometries for THz Schottky Diodes", Proc. 5th Int. Symp. on Space THz Technology, pp. 404–408, May 1994.

[5] Mackenzie, S., Kelly, W.M., Maaskant, P., Maddison, B., Matheson, D.N., Ellison, B. "A New Schottky Barrier Diode Structure", Proc. Progress in Electromagnetics Research Symp., ESTEC, July 1994.