High Power Frequency Multipliers to 330 GHz

Byron Alderman[1], Manju Henry[1], Alain Maestrini[2], Jesús Grajal[3], Ralph Zimmermann[4], Hosh Sanghera[1], Hui Wang[1], Paul Wilkinson[1], and David Matheson[1]

[1]*Rutherford Appleton Laboratory, Chilton, Oxfordshire, OX11 0QX, UK*

[2]*Observatoire de Paris, LERMA, 75014 Paris, France*

[3]*Universidad Politécnica de Madrid, Ciudad Universitaria s/n, 28040 Madrid, Spain*

[4]*Radiometer Physics GmbH, 53340 Meckenheim, Germany*

Byron.Alderman@stfc.ac.uk

***Abstract*— The development of GaAs Schottky diodes using substrate transfer techniques is presented. It is argued that these devices are limited in power handling by the choice of substrate material. To mitigate against these thermal effects, the migration to CVD diamond substrates is a logical progression. A significant programme aimed at developing this technology is presented.**

I. Introduction

The terahertz (THz) spectral region between microwaves and infrared is of crucial importance to current and future space science, Earth observation and astronomy missions. As well as major international astronomy instruments currently under development or awaiting deployment (e.g., the ground based ALMA array) a number of cosmological and planetary science proposals have been submitted to the ESA Cosmic Vision 2015-2025 programme. In Earth observation, passive remote sensing of the atmosphere from space at millimetre and sub-millimetre wavelengths is expected to play a key role in the evolving EU/ESA GMES Sentinel and Eumetsat post-EPS programmes; terahertz radio measurements will be directed towards processes linking atmospheric composition and climate, notably including the GCOS-designated essential climate variables water vapour and ozone.

Despite these, and other potential applications that span the physical, biological, and medical sciences, the terahertz spectrum has yet to be fully exploited. In part this is because it remains difficult to generate conveniently useful amounts of power at THz frequencies.

In general, a low noise Schottky mixer radiometer requires of order 1 mW of LO power if a fundamental pump frequency is used, and perhaps two or three times this amount if a sub-harmonic mixing architecture is chosen. It is relatively straightforward to achieve 1-2 mW by harmonic multiplication of a fundamental source at ~100 GHz (derived historically from a Gunn diode oscillator or and more recently a power amplifier) at frequencies up to ~300 GHz using standard components. Producing power at higher frequencies requires higher orders of multiplication, either in a single device or by cascading multipliers, with consequently reduced efficiency and output. In fact, any high order terahertz multiplier requires custom Schottky circuits that are not readily available from commercial houses. A similar problem exists if output power greater than a few milliwatts is required at lower frequencies, since this requires both high power fundamental sources and optimised custom multiplier circuits that are able to handle large amounts of RF power.

For these and other reasons, most terahertz instruments use single radiometers rather than focal plane imaging arrays, and solid state Schottky diode receivers operating above a few hundred GHz are difficult and expensive to deploy.

ESA has long recognised the importance of Schottky technology and the terahertz spectrum to its programmes, and has supported a number of projects aimed at source and detector technology development. Historically, however, the requirement for terahertz components has been based on niche applications in astronomy and remote sensing, and European companies have focussed on the design and manufacture of terahertz components, rather than the underlying device technology.

Consequently they have relied on Schottky diodes and circuits developed in the US and supplied by the two world leaders, NASA's Jet Propulsion Laboratory (JPL) and Virginia Diodes Inc. (VDI). VDI has long been a leading international supplier of Schottky diodes, and together with JPL, has pioneered sub-millimetre integrated diode circuit development.

This paper gives an example of varactor multiplier technology from the Rutherford Appleton Laboratory (RAL), UK and outlines the future direction of this work. Specifically, a consortium led by RAL and involving the authors of this paper has recently been awarded a significant EU contract to develop high power multiplier technology. The principle goals of this work are outlined in this paper.

II. Transferred Diode Technology

The fabrication of Schottky varactor diodes transferred to quartz has been previously reported [1]. In these devices the anodes are in an anti-series configuration with a central contact pad and two anodes in series in each of two arms towards outer contact pads [2,3]. The devices have also been transferred to a 50 μm thick quartz substrate and therefore exists as five islands of GaAs on a quartz substrate with gold bridges between them. An SEM micrograph of the full chip is shown in Fig. 2. These discrete chips have dimensions 300 x 60 x 50 μm^3 (L x W x H) and they have been fabricated with values of junction capacitance between 32 and 52 fF, defined by alterations to the anode areas. Initial studies have shown that the transfer process does not degrade the diode characteristics and that they can be heated to at least 150 C for a short time typical of soldering without either degradation to the junction or the GaAs pads delaminating.

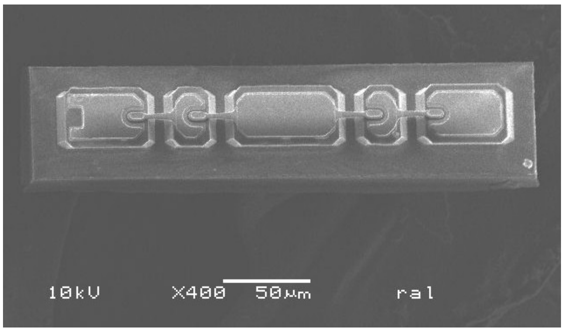

Fig. 1 SEM micrograph of a doubler circuit that has been transferred to a quartz substrate.

These devices have demonstrated a flange to flange conversion efficiency of 29% with an input power of 50mW. The limit is reached due to the poor thermal conductivity of the underlying quartz substrate. An alternative substrate would significantly improve the power handling of this circuit. Discrete diodes have been successfully transferred to aluminium-nitride and are awaiting testing.

RAL has also designed a 300 GHz integrated frequency doubler based on an aluminium-nitride substrate. This device is shown schematically in Fig. 2 with fabrication and measurement results expected shortly.

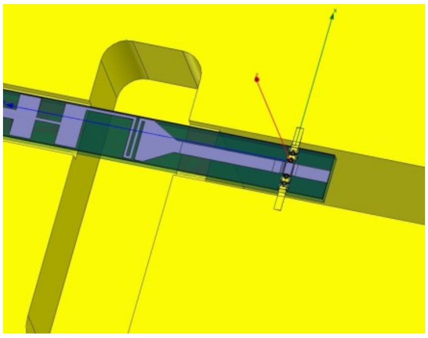

Fig. 2 Schematic of an integrated frequency doubler at 300 GHz.

III. MIDAS

MIDAS (**M**illimetre-wave **I**ntegrated **D**iode and **A**mplifier **S**ources) is a three year EU FP7 programme co-ordinated by STFC - Rutherford Appleton Laboratory and involving Observatoire de Paris, Universidad Politécnica de Madrid and Radiometer Physics GmbH. Within MIDAS, Schottky varactor diodes and the simulation tools for fabricating and designing state-of-the-art sub-millimetre wave components and sources will be developed. Using these, a demonstrator terahertz source will be fabricated, with the aim of generating levels of RF power previously unavailable within Europe. European amplifier technology, combined with optimised Schottky varactors fabricated on diamond substrates, will demonstrate a novel, generic, terahertz source technology, enabling planned sub-millimetre wave space science and Earth observation instrumentation to use European technology.

The primary objective of the proposed work is to demonstrate a 125 mW source operating from 270 - 300 GHz, using European device technology (MMIC power amplifiers and Schottky varactor diode circuits), in conjunction with power combining technology. Secondary objectives include the following

- Investigate and develop novel power combining amplifier techniques, with the aim of initially realising up to 400 mW, and later 1 W, at ~100 GHz.
- Investigate and develop novel thermo-electric design models of Schottky circuits.
- Integrate thermal models into the electromagnetic design suite.
- Transfer GaAs varactor diodes to CVD diamond substrates.

IV. Conclusions

GaAs Schottky varactor diodes have been successfully fabricated and transferred to alternative substrates of quartz and aluminum-nitride with impressive results. These devices are limited by the thermal power handling of the substrate material. A new EU FP7 project has been awarded to develop an electro-thermal model of these devices with the ultimate aim of demonstrating in excess of 100 mW in frequency bands to 330 GHz.

References

[1] B. Alderman, M. Henry, H. Sanghera, D. Wilby, and D. N. Matheson, "A frequency doubler to 170 GHz, using Schottky diodes transferred to a quartz substrate, with a power conversion efficiency of 29%", 5th ESA Workshop on Millimetre Wave Technology and Applications, ESA/ESTEC, Noordwijk, The Netherlands, 18-20 May 2009.

[2] N.R. Erickson and B.J. Rizzi, "A High Power Doubler for 174 GHz Using a Planar Diode Array," *in Proc. 4th International Symposium on Space Terahertz Technology*, pp. 287-295, 1993.

[3] D. Porterfield, T. Crowe, W. Bishop, D. Kurtz, E. Grossman, "A High-Pulsed-Power Frequency Doubler to 190 GHz", Proc. of the 30th Intl. Conf. on Infrared and mm-Waves, pp. 78-79, September 19-23, 2005, Williamsburg, Virginia, USA.