A 600GHz High Power Tripler for Space Applications

Hugh J Gibson[1*], Oleg Cojocari[3], Ion Oprea[3], Bertrand Thomas[2], Tapani Narhi[4]
[1]*Gibson Microwave Design, Antony, France*
[2]*Radiometer Physics GmbH (RPG), Meckenheim Germany*
[3]*Advanced Compound Semiconductor Technologies (ACST) GmbH, Darmstadt Germany*
[4]*European Space Agency ESTEC Netherlands*
*Contact:gibson@radiometer-physics.de

Abstract— **Several recent space missions have required un-cooled receivers for radiometer use above 500GHz for atmosphere probing. These include MetOP 2nd generation meteorological satellites and Jupiter Moons JUICE spacecraft. The preferred technology for these missions is high performance (uncooled) Schottky balanced mixer but producing the necessary Local Oscillator (LO) pump power is a formidable challenge. This paper outlines the design of a 600GHz tripler, capable of providing in excess of 5mW, capable of driving a sub-harmonic Schottky mixer for 1.2THz. The project is part of ESA initiative AO-6649 to develop key technologies for high power, high frequency Local Oscillator sources for future space missions.**

I. INTRODUCTION

Schottky varactor multiplier technology has been the principle method of generating reliable power at millimeter wavelength for many decades. Several competing technologies have been developed, but have so far failed to replace varactor multipliers at frequencies over 300GHz. Schottky varactors at these frequencies are not without its own problems: the size of the varactor diodes becomes very small, causing severe problems of current crowding and overheating, limiting both the efficiency of the varactor multiplier and the maximum input power possible. A performance 'wall' is hit which has long been recognised by many groups in the field, as far back as 1991 [1] [2]. Despite much research, output power performance of even the best THz varactor multipliers is still relatively poor (< 0.5mW from a single multiplier device at close to 1THz) but is still significantly better than other competing technologies.

While power-combining technology is being pursued to ameliorate this problem, it is still understandably beneficial to obtain as much power as possible from a single device before resorting to power combining.

This paper outlines work undertaken to design a narrow-band tripler at 600GHz with excellent output power (without power combination), for space missions. The difficulties which cause reduced efficiency and limit output power are discussed.

Providing the high power 100mW 200GHz input pump-power for this tripler is also a major challenge. This 200GHz doubler work is presented separately at this symposium by Bertrand Thomas.

The design of the 600GHz tripler film-MMIC is based on a previous 440GHz film-MMIC doubler, but has some significant improvements, notably an integrated CVD-diamond heat-spreader. Results from this 440GHz doubler test device were previously presented by ACST [3]. Over 12mW output power was achieved from a 2-anode doubler at 440GHz, with over 25% efficiency, which we view as an excellent preliminary result. This doubler was also valuable in providing information about the correct GaAs doping concentration.

The ACST varactor implementation provides exceptional quality Schottky contacts with very high reverse breakdown voltages. A separate paper highlighting the key varactor device technologies will be published by Ion Oprea of ACST GmbH.

II. TRIPLER LAYOUT

The 600GHz tripler uses a standard, series-connected varactor, balanced configuration with DC bias. The THz-MIC is fabricated on a low-dielectric film membrane substrate. This structure allows several innovative features, including very thin (but large area) isolated mesa islands, front-side and back-side metallization forming a sandwich-wrap around the varactor mesas and a direct thermal path to a thin diamond layer.

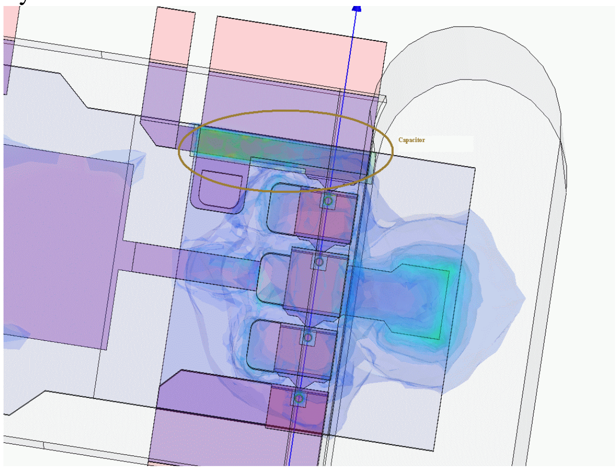

Fig. 1 The varactors of the tripler shown with the thick gold straps to the CVD diamond. The area circled is a single-layer capacitor for DC bias.

Very thin MESAs have three major advantages: a) they allow a quasi-vertical structure with a small RF current path to the back-side gold, b) the GaAs layer is thin enough to largely suppress RF eddy current skin effects, which plays a major role in extra resistance [4][5], and c) there is a very short thermal path from the anode to the gold metallization.

The mesa pad construction appears extremely large compared to a typical GaAs MMIC tripler, but does not pose problems because of the low dielectric constant of the thin film membrane. The large pads greatly assist thermal transfer (see Fig 1).

The MMIC design outlined is quite elaborate with many processing steps. A doubler, based on very similar technology at 332GHz is already being tested in an ESA reliability programme for use as a 664GHz mixer LO for currently under development PostEPS/MetOp2 satellites.

We are hoping to simplify the design in the future, keeping the key features but to make the technology accessible to mass-manufactured devices.

III. TRIPLER DESIGN AND SIMULATIONS

To achieve the design goal of 5mW output power, we pessimistically assume we require about 100mW input power at 200GHz. 4 anodes can handle this power with ease (from a voltage breakdown perspective). We estimate a maximum input power of 140mW for 4 anodes. Dissipating heat from the multiple small anodes however is a major problem. It is necessary to situate the anodes close to a low-dielectric but high thermally conductive material, acting as a heat-spreader. Vapour-deposited (CVD) diamond is an ideal material which has been successfully tried by several groups [6] including ourselves but the attachment of the diamond to the GaAs device with a very thin layer of glue has always been the thermal “bottleneck” [4]. A new technology has been developed within this activity for the monolithic integration of a CVD diamond heatspreader into the tripler THz-MIC. This allowed us to avoid a problematic intermediate adhesive layer.

The design of the tripler follows previous design strategies, using a combination of HFSS simulation for the structure plus a non-linear harmonic-balance simulator for the diodes (AWR Microwave Office). The device is swept in frequency and simulated either in pieces or as a whole, without filtering out harmonic components. The harmonic balance analysis therefore includes all the complex interactions of the harmonics. The final whole simulation also includes all excited internal waveguide and substrate modes.

RF simulations show that this geometry can still achieve high RF performance while still simultaneously offering excellent thermal performance.

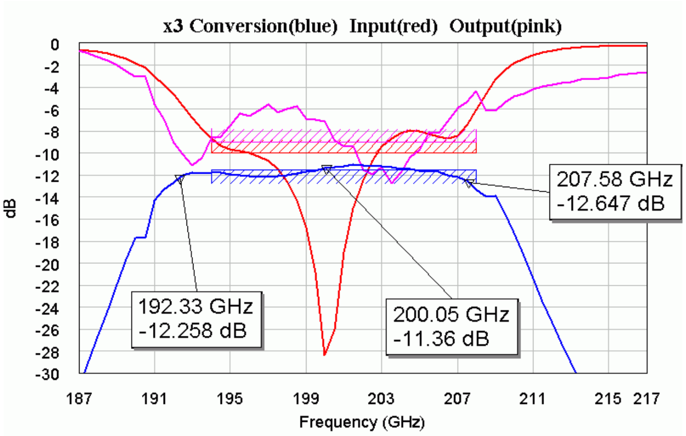

Fig. 2 Conversion efficiency and input and output match (dB scale) for an input power of 100mW and 10V bias

At these high frequencies, it is imperative to keep the varactor anode area as large as possible because the expected effective series resistance (caused by current crowding and velocity saturation) scales with the junction area [6]. This design uses 4 anodes each with Cj0 of 14fF. The large capacitance of the varactors is a challenge for wideband design. This design has nearly 11mm of various waveguide input matching transformer sections (extremely large for a 600GHz device). The bandwidth achieved is in excess of 8% and the efficiency is good (6%) see Fig 2. A series resistance value of 80 Ohms/Cj0 (fF) is used (Erickson [7]) in the simulation, which is consistent with other measured ACST varactors at comparable frequencies. The thin mesa and vertical varactor ACST structure may be the reason for the lower series resistance, compared to the usual 120 Ohms.

Using the optimal GaAs doping concentration to match the input power is also critical to reduce velocity saturation effects. Unfortunately, increasing doping concentration causes several major detrimental effects: a similar value of Cj0 will have a smaller anode diameter for a higher doping density and the varactor will also have reduced reverse breakdown voltage. A careful balance is therefore required to give the best compromise between anode size and saturation effects for any particular frequency and input power. This has been studied in depth by several other groups [8] which include, fortuitously a 400GHz doubler and a 600GHz tripler.

IV. EXTENDED BANDWIDTH DESIGN

A special requirement for the JUICE spacecraft is that the 1200GHz receiver must cover nearly 19% bandwidth.

Work is underway to attempt to extend our existing tripler design to allow even wider bandwidths, compatible with the JUICE requirements. This work has concentrated initially just on the problems of high power, with narrow bandwidth. Once this step has been achieved, a wider band version, using the same technology, and probably the same MMIC (with lower efficiency and therefore higher input power) will be attempted.

V. CONCLUSIONS

A new method of creating a high power, high frequency tripler THz-MIC is presented. The design seeks to reach high efficiency by minimising the effects of current crowding and velocity saturation. A high input power is possible through the use of an integrated diamond heat-spreader. The ACST varactor implementation allows reverse breakdown voltages close to the theoretical maximum -15V. The combination of these features is expected to allow output power levels in excess of 5mW to be achieved at 600GHz from a single device. Testing of the multiplier is expected in early 2015.

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