HIGH EFFICIENCY PLANAR FREQUENCY MULTIPLIER AT MILLIMETRE WAVES AND QUASI-OPTICAL INVESTIGATIONS FOR (SUB) MILLIMETRE APPLICATIONS

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***Abstract* - This paper presents the design and measurement of a hybrid varactor frequency multiplier in the millimetre wave range and the first investigations on a quasi-optical frequency doubler. For the planar circuit, a multilayer technology was used for the synthesis of the source and load impedances of the varactor. The conversion losses are about 12 dB at 62 GHz with an output power of 10.8 dBm.**

The measurement test bench and results on passive circuits in quasi-optical technology are presented. A quasi-optical doubler has also been investigated and designed and the first results are presented.

I. INTRODUCTION

For sub-millimetre wave applications, like FIRST and SOFIA programs [1], local oscillators at very high frequencies (up to 1 THz) are required for heterodyne receivers. A solution for providing power with low phase noise at sub-millimetre waves associates a low frequency oscillator with one - or more - frequency multipliers. This high frequency oscillator must have sufficient power for efficient driving of the down converter. Waveguide techniques are still widely used for millimetre and sub-millimetre radiometers, but planar circuits (hybrid or MMIC) could allow the drawbacks of waveguide whisker contacted diode multipliers (losses, fragility ...) to be overcome. However, no tuning can be done on planar multipliers and accurate modelling of the circuit is required. Quasi-optical solutions could be an interesting choice in the near future.

II. PLANAR CIRCUIT DESIGN

The source and load impedances and the working conditions of the multiplier are initialised with the Penfield and Rafuse equations [2]. Non-linear simulations are then used to optimise the results and calculate the output power at fundamental and harmonic frequencies (figure 1).

Realisations at lower frequencies and sensitivity simulations give important information to control each step in the design procedure such as impedance terminations at fundamental and second harmonic frequencies (for a doubler). For the 28/56 GHz doubler, radial stubs are used to short-circuit the second harmonic at the input and the fundamental frequency at the output in a large frequency band. These stubs are positioned very close to the diode : this is very important to improve the conversion efficiency.

Classical planar technologies such as microstrip or coplanar technologies lead to very low and very high impedance transmission line sections for the diode matching, inducing high losses and then reducing the efficiency. A technology [3] with microstrip and multilayer coplanar lines (figure 2) was adopted to combine the advantages of each one. To obtain very low characteristic impedances, a small substrate thickness is used. But at the same time, high values are required. The multilayer technology detailed in figures 2 and 3 allows us to approximately retain the same central conductor width throughout the circuit, cutting the ground plane under the inductive transmission line sections. Classical coplanar lines are used at the accesses for coaxial probe measurements. The doubler circuit is fabricated on a 635 μm Alumina substrate with two metal layers and one dielectric layer. The surface is 6.7 mm x 9.7 mm.

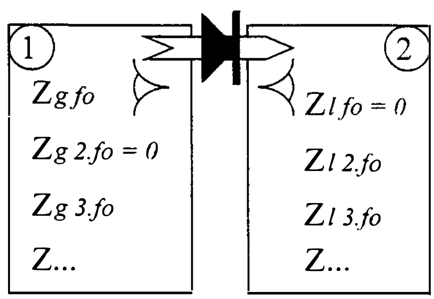

Fig. 1. Impedance optimization at each port.

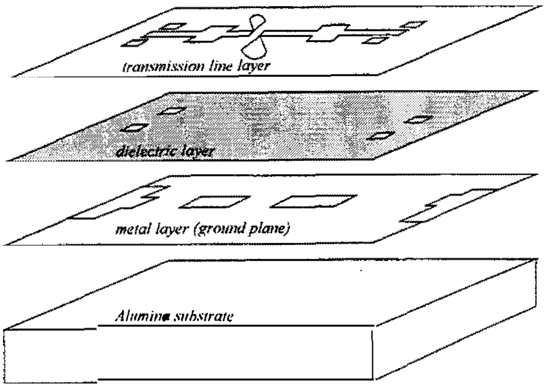

Fig. 2. Multilayer technology process on an Alumina substrate with two metal layers and one dielectric layer.

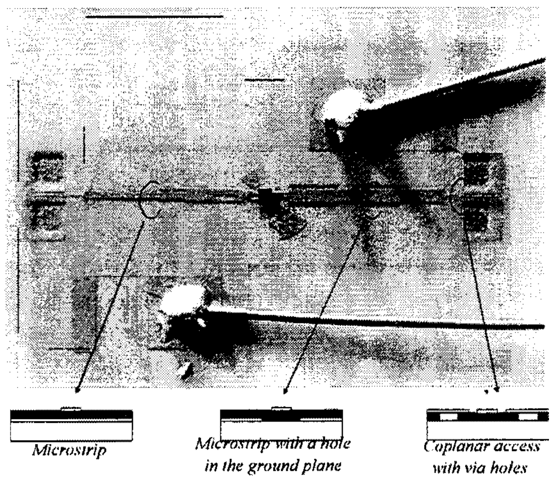

Fig. 3. Photograph of the multilayer frequency doubler. The surface is 6.7 mm x 9.7 mm.

III. RESULTS FOR THE PLANAR DOUBLER

Experimental results (figure 4) show that the optimal input frequency is 30.8 GHz for maximum output power (10.8 dBm) and efficiency (10.3 dB). The fundamental rejection is 25 dB. But at the 28.25 GHz input frequency, the fundamental rejection is optimal (-48 dB) as expected in simulations.

The electromagnetic simulation (2D and 3D) of the matching circuits was compared with HP-MDS library models used for the multiplier design. Differences in the computed S parameters, that is, the source and load impedances, can explain the frequency shift of the optimal output power. The dielectric permittivity of the thin layer should also be extracted for better accuracy.

No instabilities are observed at any frequency or power sweep. To have a good stability forecast many simulations and tests were performed.

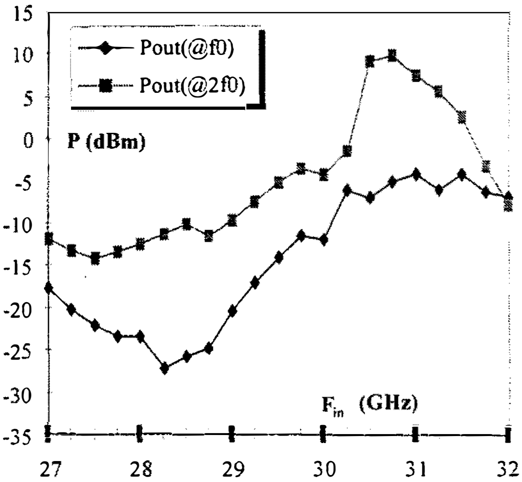

Fig. 4. Output power at fundamental and second harmonic for P_{in}=20 dBm and V=-9 V.

IV. QUASI-OPTICAL TECHNIQUE

Recent developments give a solid state response for power capabilities at millimetre and sub-millimetre waves [4]. Fig. 5 illustrates an example of a quasi-optical circuit. Passive components were studied for accurate modelling [5]. The grid array can be an amplifier (output at f0) or a multiplier (output at n.f0).

Active planar arrays allow high level output power by recombination in free space with increased reliability. The matching of the active device (diode, transistor) can be done on the active grid, or can be carried out by external components such as a polarizer which works like a tuning short circuit and a dielectric slab like an adaptator. For a better input and output isolation, the electric fields at the two ports are cross-polarized. It is also important for a multiplier to shunt the second harmonic at the input and the fundamental at the output with two separate circuits.

To design a millimetre doubler, the hybrid active grid of figures 6 and 7 with 69 cells, was chosen because of its simplicity ([4]). The unit cell consists of two quarter-wave dipole antennas in quadrature polarisation at the fundamental (38 GHz) and at the second harmonic (76 GHz). These antennas are connected via a Varactor diode which is the non-linear component. The active grid (i.e. the multiplier) is externally matched with tuning slabs and polarizers which can be shifted during the measurement for optimal performances (output power, conversion efficiency,...). The multiplier grid is printed on 210 µm substrate (ε_r=3.5).

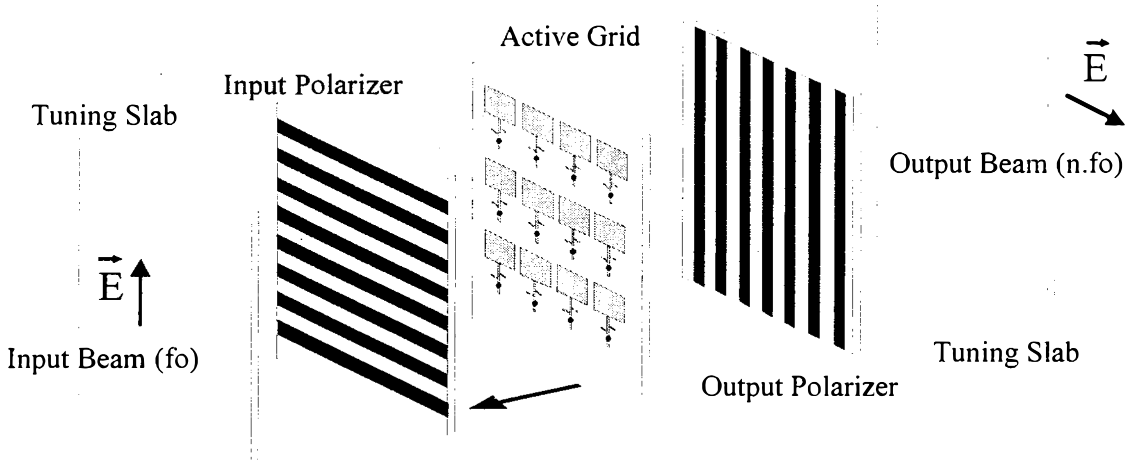

Fig. 5. Quasi-optical frequency multiplier.

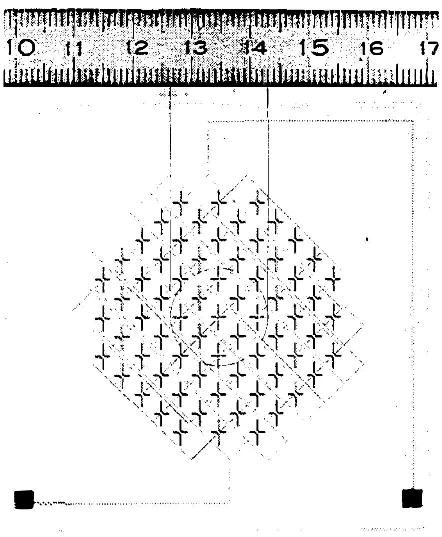

Fig. 6. Photograph of the active grid (dimension in cm).

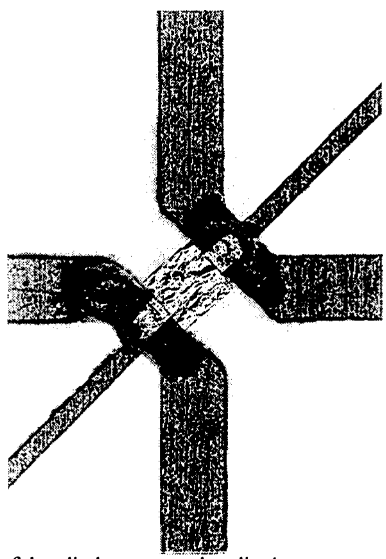

Fig. 7. Detail of the diode connected to dipole antennas.

V. QUASI-OPTICAL MEASUREMENTS

A. Quasi-Optical test bench and modelling

For quasi-optical element characterisation and modelling, two test benches were carried out with Gaussian Optic Lens Antennas (GOLA) in the Ka band and in the W band. These benches were validated for S parameter measurements of passive quasi-optical elements such as polarizer, filter and dielectric slab. Simulated and measured S parameters show very good agreement. The complex permittivity of dielectric slabs is also extracted with high precision [7].

Using models or measured S parameters, simulations of simple quasi-optical functions (cascaded polarizer and slab for example) in classical CAD software (such as HP-MDS) were carried out [5]. Non-linear simulations of the whole quasi-optical frequency multiplier were investigated and are still under study. The precise modelling of the component access through the antenna (dipole,...) is very important and rather difficult because it has to take into account all the modes in the structure, the cross-polarisation and the multiple accesses (quasi-optical and active components).

B. Quasi-Optical multiplier measurement

With a Ka band GOLA, a W band GOLA and a Ka band power amplifier (10W), the active array with input and output polarizers was tested with a 38 GHz input frequency.

In a first experiment, only 9 diodes were mounted on the array. But with so few diodes, the performances are not very attractive. The conversion efficiency is less than -40dB at the 76 GHz output frequency. To explain these poor results, it must be pointed out that the 1.7 cm active area diameter with 9 diodes on the grid is too small in comparison with the 8 cm waist diameter of the input

Gaussian beam. So, too little power is intercepted by the active area that is, by the 9 dipole antennas connected to the diodes. Most of the incident power is not transferred to the active device and the efficiency is very low.

The second harmonic output power was measured for different positions of the input polarizer in relation to the active grid. Fig. 8 gives the normalised output power evolution and shows some periodicity. This result is very important because the positioning of the tuning elements must be very precise : there is only 700 µm between the maximal output power position and the minimal output power position. However, this behaviour was observed in preliminary non-linear simulations of the whole multiplier with very simple modelling (an inductance) of the dipole antenna.

VI. CONCLUSION

The design and measurement of a planar hybrid frequency doubler have been presented. The diode matching circuits make use of a coplanar and microstrip multilayer technology for high and low impedance synthesis without discontinuity of the central strip. With a 9.3 % (-10.3 dB) maximum conversion efficiency, it is a candidate for a state of the art of hybrid diode multipliers at this frequency. However, frequency shift was observed.

Quasi-optical technology is very attractive for combining solid state components, tuning circuits and power. Unlike passive circuits, the simulation of an active grid is quite difficult to achieve. Developments are in progress and a W band quasi-optical doubler will be tested in the near future.

ACKNOWLEDGEMENTS

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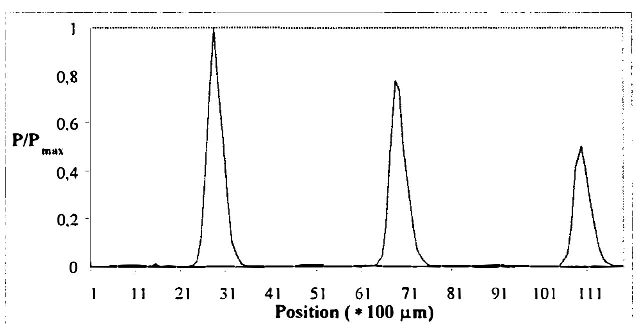

Fig. 8. Normalized output power measurement of the quasi-optical multiplier for different positions of the input polarizer in relation to the active grid.

VII. REFERENCES

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