A PATCH - SLOT ANTENNA STRUCTURE FOR QUASIOPTICAL MULTIPLIERS

F. Tiezzi*, W. Menzel*, F. Alimenti+, P. Mezzanotte+, L. Roselli+, R. Sorrentino+, M. Shaalan#

* Microwave Techniques, University of Ulm, D-89069 Ulm, Germany
E-mail: menzel@mwt.e-technik.uni-ulm.de
\+ Istituto di Elettronica, University of Perugia, Via G. Duranti 93 , I-06125 Perugia, Italy
E-mail: sorrent@unipg.it
\# Institute for High Frequency Electronics, Techn. University of Darmstadt, Merckstr. 25,
D-64283 Darmstadt, Germany

ABSTRACT

An antenna structure based on the combination of one or two slots and a patch is investigated as the basic structure for a millimeter-wave quasi-optical multiplier. This arrangement, on the one hand, is receiving and reradiating the RF, and on the other hand, is acting as a simple frequency and direction filter. Radiation diagrams at both fundamental and harmonic frequencies are presented in a scaled frequency range, showing the potential of this structure for quasi-optical doubler and tripler applications.

INTRODUCTION

A number of efforts recently have been made to realize quasi-optical amplifiers, power combiners, or frequency multipliers [1] - [3]. A typical frequency doubler arrangement as presented in [3] is sketched in Fig. 1. A Gaussian beam is focussed on an array of planar doubler circuits, each doubler element consisting of a printed slot with one Schottky or varactor diode. These slot structures are bidirectional antenna elements. Quasi-optical filters, e.g. [4], have thus to be added to reject the incident wave and the wave excited at the harmonic frequency at the respective opposite side of the doubler circuit.

This contribution presents a dual frequency antenna approach for quasi-optical frequency multipliers using a patch-slot combination (Fig. 2) similar to the coplanar fed patch antenna reported in [5]. For a frequency multiplier, one diode is placed across each slot. Coplanar or slotline matching elements are intended for matching the diodes at input and output frequency and, if possible, to act as idler circuits. The patch and one or two slots are designed in such a way that at the fundamental frequency, power is received from the patch side only, while at the first or second harmonic frequency, power is reradiated on the side of the slot(s) only – or at least to the greater extent. In this way, a much simpler arrangement for mm-wave and submillimeter-wave frequency multipliers seems to be possible.

DESIGN OF THE ANTENNA STRUCTURE

A calculation of the antenna properties as well as some optimization is done using an extended FTDT method [6] - [8]. Results partly are compared to a commercial simulator based on the method of moments [9]. The “natural” resonance of the patch mainly determines the forward radiation at the fundamental frequency [10], [11], the geometry of the slot and the thickness of the substrate are used to optimize the backward radiation at the desired harmonic frequency. For the final application, GaAs will be used as substrate material integrating both the diodes and the antenna structures. In a first step, the antenna is investigated in a scaled frequency range. With respect to available substrate materials, a thickness of 1.27 mm and a dielectric constant of 10.8 have proven as a suitable compromise for the frequency range of interest here.

Investigations with a single and a double slot showed that the latter provides a better back-to-forward ratio. In addition, it is possible to arrange the two slots in about half a wavelength (surface wave) distance from each other at the harmonic frequency to reduce the excitation of surface waves. These typically result in severe difficulties as they affect mutual coupling of the radiating elements and lead to circuit losses. Thus, radiation properties and the conversion loss of a multiplier are affected, especially in combination with a relatively thick substrate and high dielectric constant as used in this application.

RESULTS

Radiation diagrams for the fundamental as well as for the harmonic frequency were calculated with FDTD assuming a finite substrate size and for comparison, with the method of moments; the latter is based on an infinite substrate size. The fields were integrated over the entire space, and a back-to front ratio as shown in Fig. 3 could be achieved as a function of frequency.

For initial measurement of the antenna diagrams, a thin Duroid substrate (h = 0.127 mm) with two microstrip feed lines was added to the antenna substrate (Fig. 4); the ends of the lines were bonded across the slots. Two different feed substrates were necessary to excite the slots with the proper phases at the two frequencies. Fig. 5 shows measured and computed input return loss at 14 GHz, Fig. 6 the experimental input reflection coefficient at 28 GHz. The original measurement curve shows a high number of loops. To check their origin, the edges of the antenna substrate were covered with absorbing material. The result – a rather smooth curve – indicated a strong influence of surface wave resonances. Fig. 7 shows theoretical and experimental radiation diagrams of the arrangement at the fundamental and the harmonic frequency. The experimental results were strongly affected by the small size of the substrate, leading both to a considerable ripple on the curve as well as an increased backward radiation [12]. In an array of multipliers, this effect is expected to be much less pronounced. To reduce the effects of surface waves, the individual antennas can be spaced to partly cancel the excitation of surface waves. In addition, holes may be etched or machined into the antenna substrate to provide stop bands for the surface waves [13].

With respect to tripler applications, an antenna structure of this type seems to be even better suited, as the computed radiation diagrams for frequencies of 10.5 and 31.5 GHz indicate (Fig. 8).

In a subsequent step, the frequency doubler antenna structure was modified including two multiplier diodes, matching the diodes ($Z_D \approx (5+j100)\ \Omega$ at 14 GHz, $Z_D \approx (5+j50)\ \Omega$ at 28 GHz) by a suitable inclusion of coplanar stubs. Fig. 9 shows the antenna input impedances at the diode positions with and without matching stubs. Injecting a 14 GHz signal to the arrangement, doubler performance clearly could be stated. The doubler conversion loss, however, could not yet be determined; work towards this are going on including a small doubler array.

CONCLUSION

An radiating structure based on a patch-slot configuration has been proposed and optimized as a potential antenna element for mm- and submillimeter-wave frequency multipliers. It includes the necessary space and frequency diplexing functions which, up to now, have to be performed by additional quasi-optical filters. Scaled models of this antenna have been built and tested together with a first multiplier arrangement, showing the principal function of the antenna.

ACKNOWLEGEMENT

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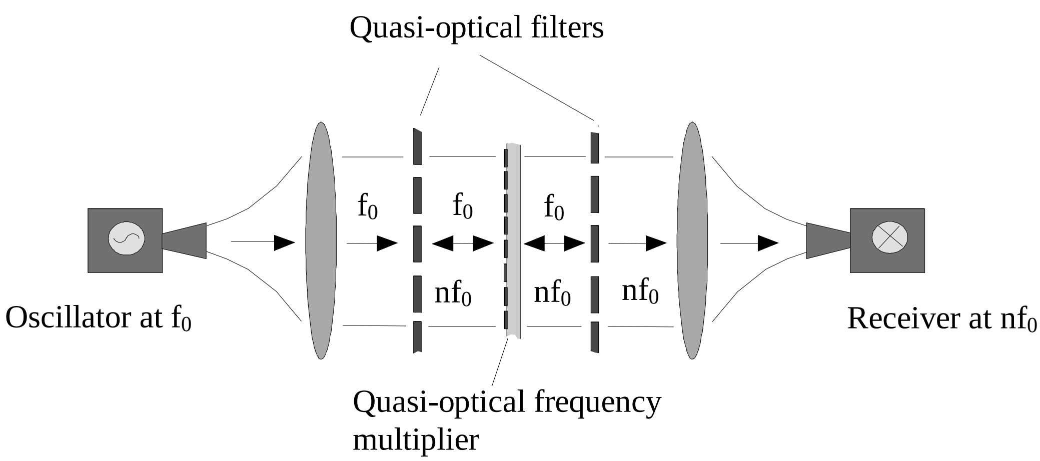

Fig. 1: Basic setup of quasi-optical frequency multiplier arrangement.

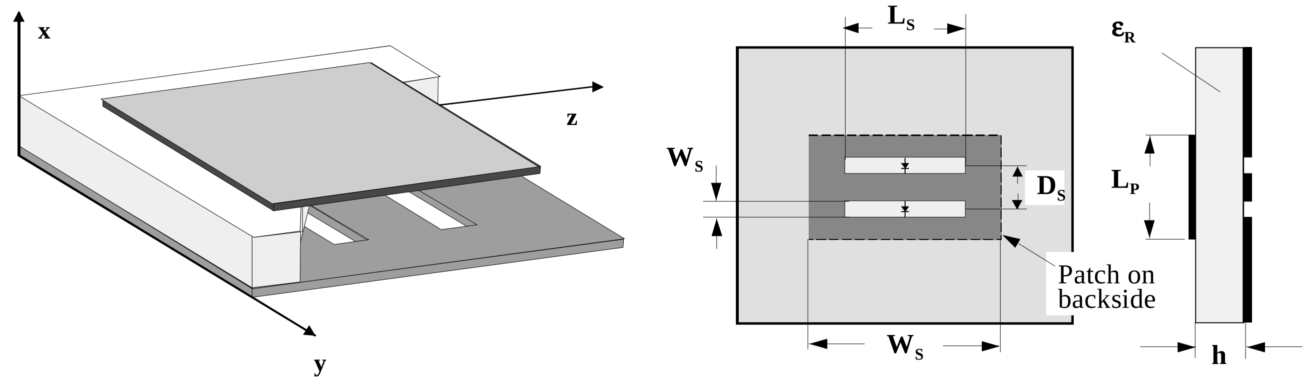

Fig. 2: Basic setup of the patch – slot antenna structure (L_P = 2.2 mm, W_P = 3 mm, L_S = 1.8 mm, W_S = 0.3 mm, D_S = 1.25 mm).

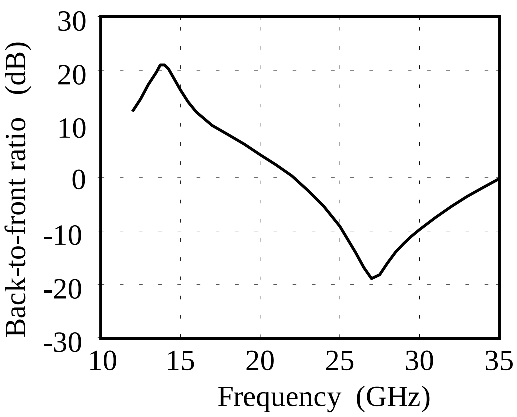

Fig. 3: Back-to-front ration calculated with FDTD.

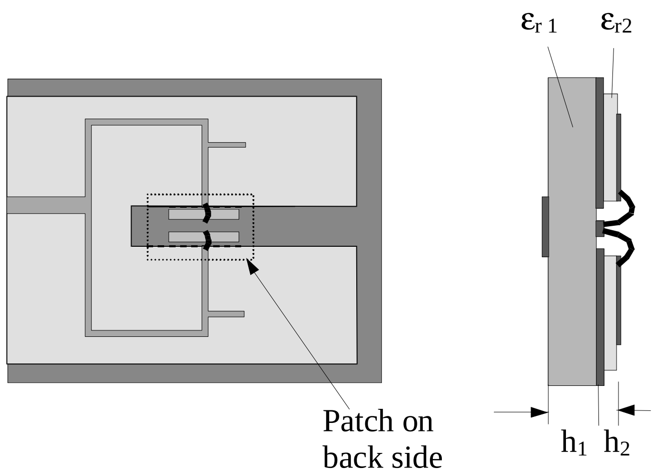

Fig. 4: Arrangement for feeding the antenna structure.

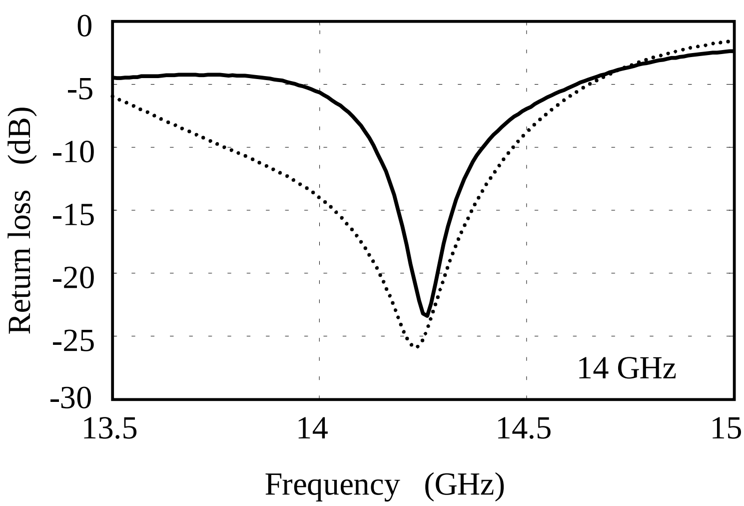

Fig. 5: Return loss of the structure at 14 GHz (── experiment, ······ theory).

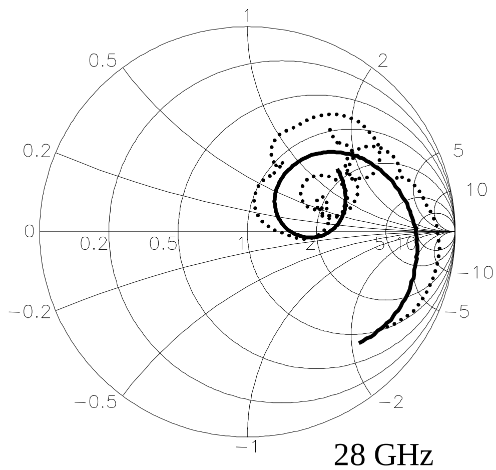

Fig. 6: Input reflection coefficient of the structure from 27 to 29 GHz (······ without, ── with absorbing material at the edge of the substrate

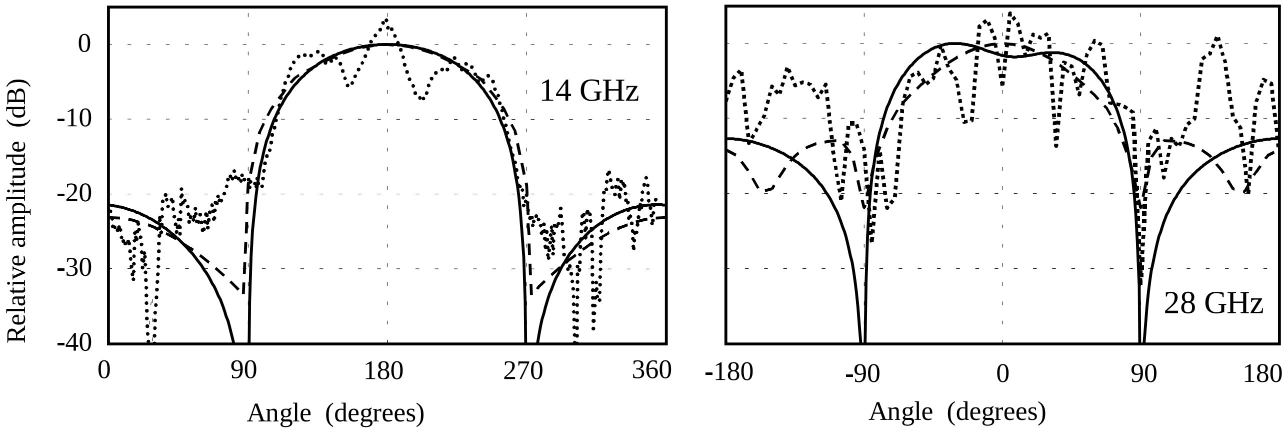

Fig. 7: H-plane radiation diagram of the structure at 14 and 28 GHz. (see the different angle axis references; ······ experiment, --- computed with FDTD, — computed with the method of moments)

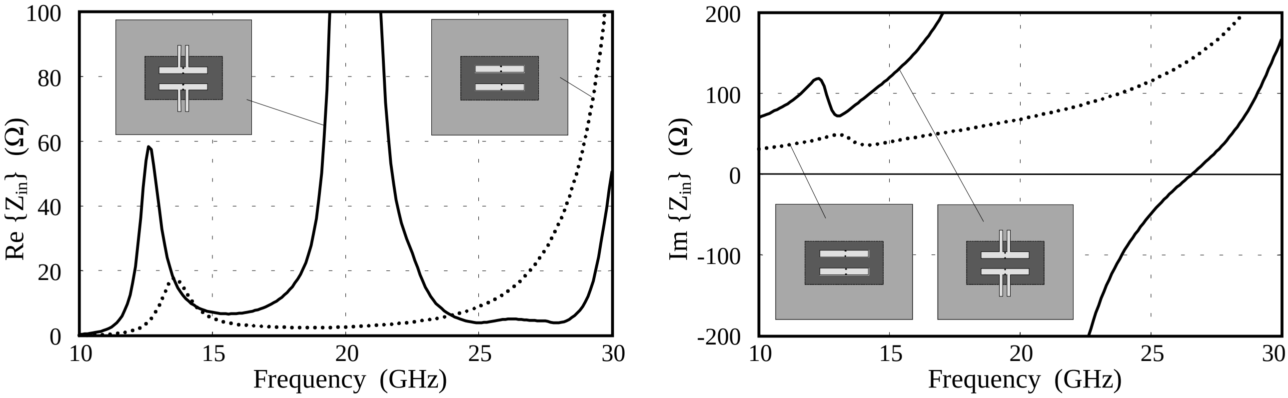

Fig. 8: Computed input impedance of unmatched and matched antenna structure for the frequency doubler (stub dimensions: W = 0.2 mm, S= 0.15 mm, L = 1.315 mm).

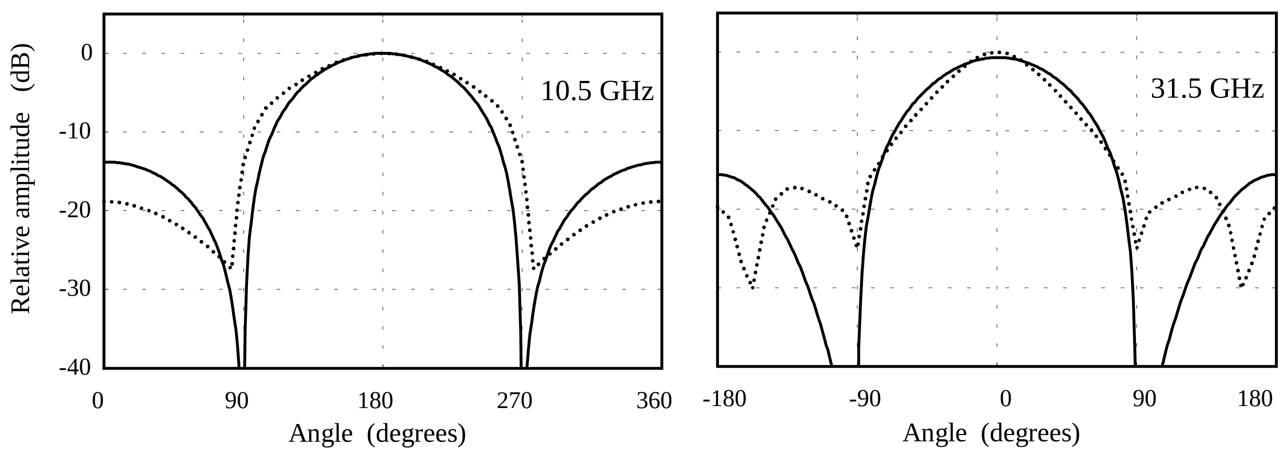

Fig. 9: H-plane radiation diagram of a antenna structure for tripler applications at 10.5 and 31.5 GHz computed with ···· FDTD and — method of moments (see modified angle axis,
L_P = 3.75 mm, W_P = 4.5 mm, L_S = 3.0 mm, W_S = 0.3 mm, D_S = 1.25 mm).