Design and Verification of a Novel Crossed Dipole Structure for Quasi-Optical Frequency Doublers

S. Helbing, M. Cryan, F. Alimenti, P. Mezzanotte, L. Roselli, and R. Sorrentino

***Abstract*—A novel structure suitable for quasi-optical frequency doublers is presented. It is based on the crossed dipole structure, but uses four diodes in a bridge configuration to form a balanced multiplier layout and incorporates the necessary dc path in a simple way within the structure. The entire structure is analyzed using the lumped element (LE)-FDTD method. To allow a comparison of the results, the concept of *quasi-optical effective aperture* is introduced. Simulated as well as measured quasi-optical results are presented and a good agreement is achieved.**

***Index Terms*—Crossed dipoles, quasi-optic frequency multiplier.**

I. INTRODUCTION

TODAY, quasi-optical devices are gaining interest for use in millimeter and submillimeter wave frequency ranges [1]. The main idea behind the quasi-optical approach is to avoid lossy transmission lines and to reduce the power handled by one device by spreading it over an array of many low-power devices.

For the simulations presented here the lumped element (LE)-FDTD method [2], [3] is used which is an extension of the traditional FDTD approach [4], [5]. LE-FDTD allows the incorporation of lumped-element models of passive, active, and nonlinear devices. Additionally, plane-wave excitation using the total-field/scattered-field formulation [6] and radiation pattern determination of the scattered field [7] is implemented in the code, making it ideally suited to simulate quasi-optical structures as a whole.

Compared with structures based on a single radiating element such as single slots or dipoles, the crossed dipole approach offers an interesting advantage: the incoming and outgoing waves are orthogonally polarized and thus can be easily separated by polarization grids. This concept was shown by Steup *et al.* [8], where the multiplier is formed by a single diode per array element which is biased by an external dc network. With this unbalanced layout power is lost due to the creation of all even and odd harmonics of the incident signal. To overcome this problem, a quasi-optical multiplier based on an arrangement of four slot antennas was proposed by Kim *et al.* [9], which uses four diodes in a bridge configuration to form a fully balanced layout. This leads to a more efficient device because only even harmonics are created and the input and output ports are isolated.

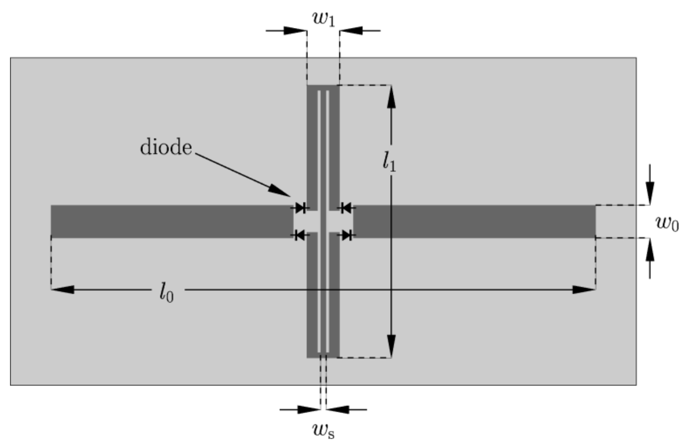

Fig. 1. Layout of the proposed structure. $l_0 = 2l_1 =$ 32.0 mm, $w_0 =$ 1.6 mm, $w_1 =$ 2.0 mm, and $w_s =$ 0.2 mm. The substrate has a thickness of $h =$ 0.813 mm and a dielectric constant of $\epsilon_r = 3.38$.

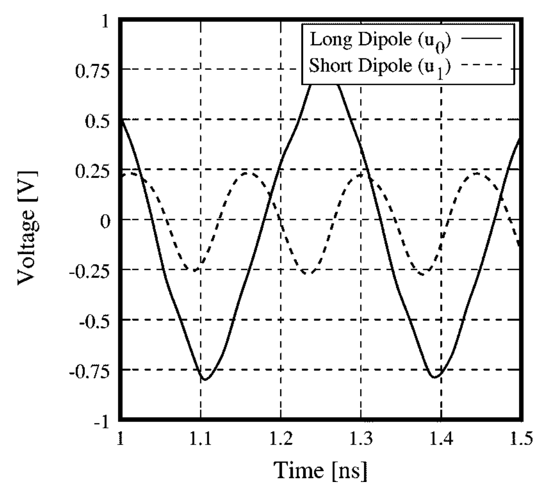

Fig. 2. Voltages probed in the gaps of the long (u_0) and short (u_1) dipole for an input frequency of $f_0 =$ 3.5 GHz after steady state has been reached.

In this letter, a structure suitable for quasi-optical multipliers is proposed which combines the simplicity of crossed dipoles with the advantages of a fully balanced diode configuration.

For the simulations and measurements, a scaled model of the structure is used which operates with an input frequency of about 3.5 GHz. But due to its simple planar layout, a monolithic integrated version for the millimeter-wave range is feasible.

Manuscript received November 23, 1999; revised February 1, 2000. This work was supported by the European Commission under the TMR Network Program ERBFMRXCT960050.

The authors are with the DIEI, University of Perugia, I-06125 Perugia, Italy.

Publisher Item Identifier S 1051-8207(00)03348-1.

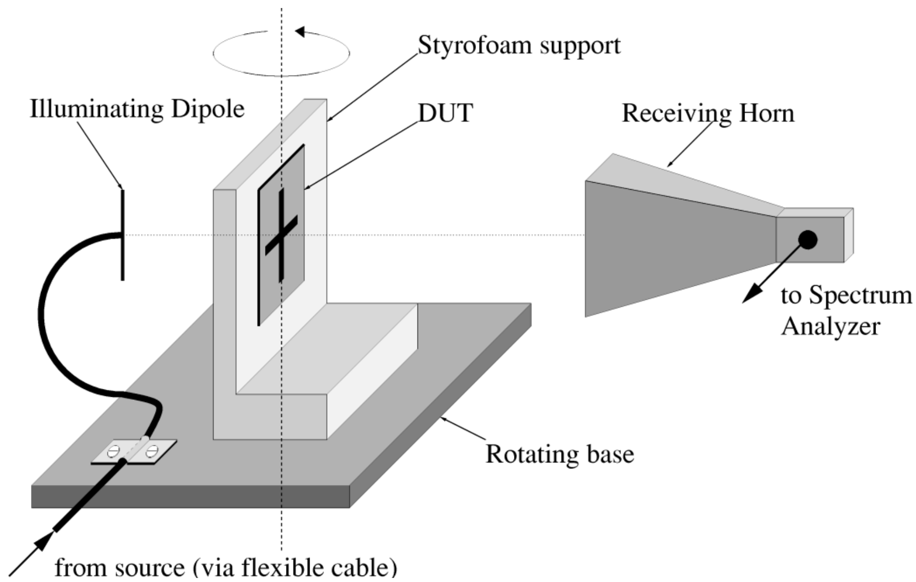

Fig. 3. Brief sketch of the measurement setup. To reduce multipath propagation the measurements were performed in an anechoic chamber.

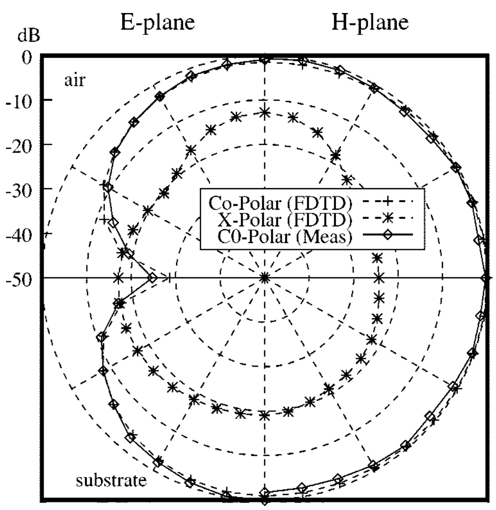

Fig. 4. Simulated and measured radiation pattern at the doubled frequency of $f_1 = 7$ GHz. For the measurement only the copolar component is shown. The planes are referred to the short dipole.

II. The Proposed Structure

The layout of the proposed structure of the quasi-optical frequency doubler is shown in Fig. 1. It consists of two crossed $\lambda/2$-dipoles. The long dipole receives the incoming power at the fundamental frequency, and the short dipole transmits the generated power at the doubled frequency in an orthogonally polarized orientation.

The multiplication is achieved by four diodes in a bridge configuration, thus forming a fully balanced multiplier layout. Although the diodes are operating self-biased and no external dc supply is necessary, a dc path for the generated dc component must be provided for proper operation of the multiplier. This is done with a thin metal strip which is embedded in the short dipole connecting its outer ends. Thus, a sufficient amount of inductance is provided to avoid a major disturbance of the RF performance. This approach leads to a very compact quasi-optical multiplier element suitable for large arrays.

III. Simulated and Measured Results

The structure was simulated under sinusoidal plane wave excitation with the incident electric field vector parallel to the long dipole. A field strength of $E_{\rm inc} = 50$ V/m was chosen. At the input frequency of $f_0 = 3.5$ GHz this leads to a peak-to-peak voltage of $u_{0,\rm pp} \approx 1.5$ V at the input ports of the diode quad as seen in Fig. 2. Also the full-wave rectification is visible, as well as the effectiveness of the dc path shorting the dc component of the voltage u_1 in the gap of the short dipole.

To allow a comparison between simulated and measured results in terms of conversion efficency, the concept of *quasi-optical effective aperture* $(A_{\rm qe})$ is introduced. $A_{\rm qe}$ is defined as the ratio of the isotropic radiated power $P_{\rm 1irp}$ at the multiplied frequency to the fundamental incident power density S_0 at the device

$$A_{\rm qe} = \frac{P_{\rm 1irp}}{S_0}. \tag{1}$$

This definition already includes both focusing effects of the device at fundamental and multiplied frequency and does not depend on the type or distance of the antennas used to illuminate the multiplier and to extract the power.

The measurement setup is shown in Fig. 3. The multiplier is placed in the far field of a dipole antenna, thus a plane-wave excitation can be assumed. The illuminating antenna is placed on the rotating base to provide a constant excitation. The power fed to this dipole was chosen to produce the same field strength of $E_{\rm inc} = 50$ V/m as used in the simulation. The radiated power at the doubled frequency is picked up with a waveguide horn which has a cutoff frequency above the fundamental frequency. Thus, any disturbance of the result due to received power at the fundamental frequency is voided.

The simulated and measured results for the copolar component of the radiation pattern at the doubled frequency of $f_1 = 7$ GHz are presented in Fig. 4 and show very good agreement. For the cross-polar component, only the simulated result is shown due to difficulties in the measurement setup: although the input

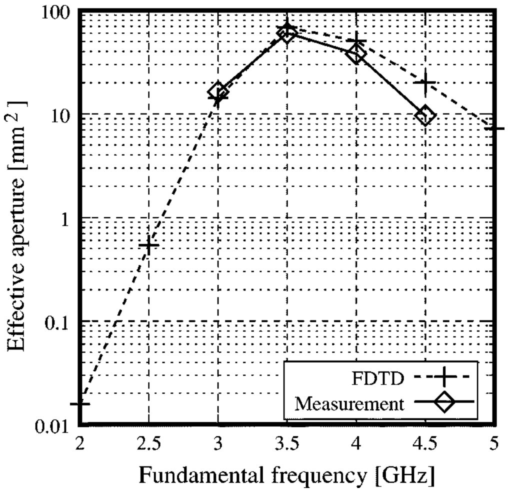

Fig. 5. Simulated and measured quasi-optical effective aperture $A_{\rm qe}$ for an input field strength of $E_{\rm inc} = 50$ V/m.

signal is filtered a small amount of power at the doubled frequency is leaking through the low pass and is radiated from the exciting antenna in the same polarization as the cross-polar component. Thus, only the interference of these two signals is measurable.

The quasi-optical effective aperture $A_{\rm qe}$ was measured from 3 to 4.5 GHz and the point of best performance ($A_{\rm qe} = 60.4$ mm^2) was found to be at 3.5 GHz. As seen in Fig. 5, the behavior was very well predicted by the LE-FDTD simulation in terms of absolute values as well as the frequency of best performance.

These results suggest that the LE-FDTD method can be successfully used for further optimizations of the structure.

IV. Conclusion

A novel fully balanced crossed dipole structure for quasi-optical frequency multipliers was proposed. A good level of agreement between LE-FDTD simulations and measurements was achieved. The method will be used for further optimizations of the structure.

References

[1] J. A. Navarro and K. Chang, *Integrated Active Antennas and Spatial Power Combining*. New York: Wiley, 1996.

[2] W. Sui, D. Christensen, and C. Durney, “Extending the two-dimensional FD–TD method to hybrid electromagnetic systems with active and passive lumped elements,” *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 724–730, 1992.

[3] P. Ciampolini, P. Mezzanotte, L. Roselli, and R. Sorrentino, “Accurate and efficient circuit simulation with lumped-element FDTD technique,” *IEEE Trans. Microwave Theory Tech.*, vol. 44, pp. 2207–2215, Dec. 1996.

[4] K. S. Yee, “Numerical solution of initial boundary value problems involving Maxwell's equation in isotropic media,” *IEEE Trans. Antennas Propagat.*, vol. AP-14, pp. 302–307, 1966.

[5] A. Taflove and M. E. Brodwin, “Numerical solution of steady-state electromagnetic scattering problems using the time-dependent Maxwell's equations,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, no. 8, pp. 623–630, 1975.

[6] A. Taflove, *Computational Electrodynamics*. Norwood, MA: Artech, 1995.

[7] R. J. Luebbers, K. S. Kunz, and M. Schneider, “A finite-difference time-domain near zone to far zone transformation,” *IEEE Trans. Antennas Propagat.*, vol. 39, pp. 429–433, Apr. 1991.

[8] D. Steup, A. Simon, M. Shaalan, A. Grüb, and I. Lin, “A quasi-optical doubler array,” *Int. J. Inf. Millim. Waves*, vol. 17, pp. 843–856, May 1996.

[9] M. Kim, V. M. Lubecke, S. C. Martin, R. P. Smith, and P. H. Siegel, “A planar parabola-feed frequency multiplier,” *IEEE Microwave Guided Wave Lett.*, vol. 7, pp. 60–62, Mar. 1997.