Power Measurements of THz Radiation from Photoconductive Antennas for Validating a Norton Equivalent Circuit

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***Abstract*—A validation of a recently proposed equivalent circuit model for describing the radiation of photoconductive antennas is shown in this work. The validation is obtained by comparing the power estimated by the model against radiated power measurements of a manufactured prototype. The model describes the feeding mechanism of an antenna provided via a photoconductor gap, when it is optically pumped by a laser, taking into account for the electrical proprieties of the material, for the geometrical sizes of the gap, and for the laser power excitation. Two different measurement setup have been used, in order to verify the accuracy of the measurements. In order to compare the estimation of the power predicted by the model and the measurements, an evaluation of the efficiencies involved in the THz measurement quasi-optical system has been performed for both the setups. A good agreement is achieved between the measurements and the power estimated with the model.**

Keywords— Photoconductive antennas, power measurements.

I. Introduction

THz technology has aroused a growing interest in the recent years for its variety of applications [1], [2]. In particular, large attention has been focused on photoconductive antennas, since these devices are able to radiate a broadband electromagnetic radiation, which covers the spectrum from the millimeter waves up to the THz waves, at relatively low cost [1]–[3]. Although there is a growing interest about such devices, the lack of a clear model from an engineering point of view, which can be used to improve the performances, has meant that the range of applications has been always limited to short range applications, mainly spectroscopy, due to the very low power level emitted by such devices.

The mechanism able to make possible the THz power generation on a broadband spectrum in photoconductive antennas resorts to optical pumping of a photoconductor material (e.g. Low Temperature Grown GaAs or InGaAs). The optical energy, provided by a pulsed femtosecond laser with an appropriate wavelength, creates free electron-hole pairs in the crystal lattice of the material, since the electrons move from the valence band to the conduction band. This phenomenon leads to a change of the conductivity as a function of the time of the illuminated area of the photoconductor material, showing a periodically pulsed behavior. These behavior depends on the pulsed laser rate and the recombination time of the carriers in the lattice of the material [1]–[3]. The change of the carriers density leads to a time varying conductivity in the area of the feeding gap of an antenna. Applying a bias voltage at the antenna gap, a short current pulse is generated, since free carriers are accelerated by the electric field induced by the bias voltage. Such pulse current feeds the antenna, which radiates an electromagnetic pulse on a very large bandwidth. In order to describe such optical pumped THz power generation and coupling of the photoconductor gap with the antenna, a Norton equivalent circuit model has been recently proposed [3].

In this work, a validation of the proposed Norton equivalent circuit model for photoconductive antennas by means of measurements of the radiated power is shown. Two measurement setups have been employed to measure the same device. Such measurements were found in a good agreement with the theoretical model.

II. Measurements and Validation of the Model

A photoconductive bow-tie antenna, which is one of the most used geometries in current commercial THz time domain systems, was manufactured. The photoconductor chip is composed by a layer of LTG-GaAs. On top of the chip, on the opposite side where the antenna metallization is patterned, a silicon lens is placed. All the geometrical and electrical details will be given during the conference. The power measurements have been carried out by using two different measurements setups, which are composed by the same QO system and two different power detectors as in Fig. 1. The QO system was composed by two 90° off-axis parabolic reflectors. The first detector used to perform the measurements was a cryo-cooled bolometer operating at a temperature of 4K. The second detector was a room temperature termocouple based power meter, where the sensor was coupled with the QO sytem via an Horn antenna WR-10.

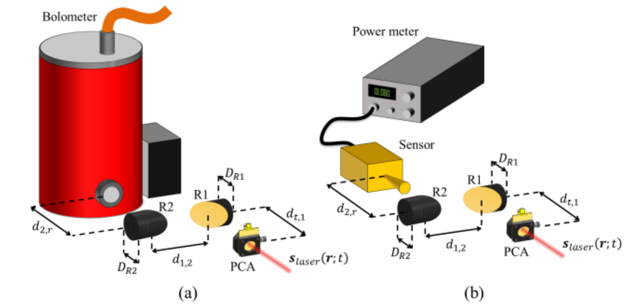

Fig. 1. Power measurements setup: a) Bolometer setup and b) Power meter setup.

The bolometer detector was also used to perform the alignement of the antenna with the laser beam, because of the faster response of the bolometer than the response of the power meter. The device was biased with a voltage of 40V, The antenna was excited with a pulsed laser with optical power P_{opt} = 30mW; pulse duration τ_{pulse} = 100fs; and repetition frequency f_{pulse} = 80MHz. The measurements are listed in the second column of TABLE I. The power detected by the two setups are different because of the different efficiencies involved in the two setups.

In order to validate the model discussed in [3], the comparison between the power estimated by the model and the measured one has been performed. To have a fair comparison between the measurements and the theoretical model, both the setups have been characterized in term of their efficiency in the operative frequency bandwidth. The antenna and the relevant electromagnetic coupling with the QO system and the detectors have been simulated on the entire pulse bandwidth. From the simulations, it was possible to extract the various efficiencies involved in the two measurement setups (antenna radiation efficiency, QO system spillover efficiency, detectors coupling efficiency, etc.). By using such efficiencies, it was possible to obtain a theoretical estimation of the power detected by the two detectors. The power detected was computed using three different spot sizes of the laser beam, as it is shown in Table 1. The reason is due to the uncertainty about the positioning of the antenna with respect to the focusing lens of the laser beam, which is intrinsic in the alignement procedure. Indeed, to maximize the readout of the bolometer, the antenna and the focusing lens of the laser have to be slightly moved from the starting position using a three-axis manual translation stage within a range of about 1mm.

For this reason, before of the alignment procedure, the focused laser spot size, was measured using an edge knife procedure, along the laser beam axis, in a range of 1mm around the optimal position of the antenna. The measured spot size of the laser at -3dB power level is shown in Fig. 2. The power calculated are in fair agreement inside the uncertainty range of the laser spot size in the 1mm range. Note that the power radiated by the photoconductive antenna is strongly dependent on the size of the focused laser spot on the gap, as it is shown in Table 1.

TABLE I.

Setup	**Power Measured**	**Power Calculated**		
		D_1=16μm	D_2=28μm	D_3=41μm
Bolometer	0.11μW	6.18μW	0.65μW	0.10μW
Power Meter	0.66μW	15.21μW	1.60μW	0.24μW

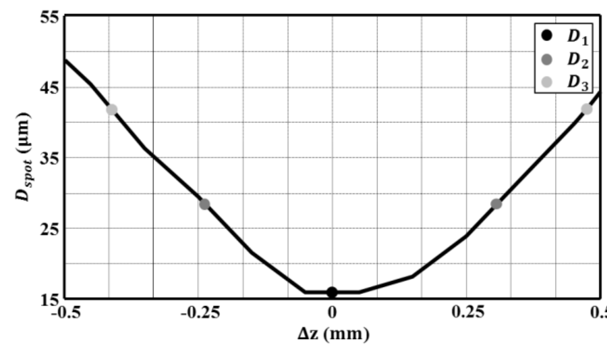

Fig. 2. Measurements of the -3dB laser spot size with respect to the position Δz along the laser beam axis in a range of 1mm centered at the focal point of the focusing lens of the laser beam.

III. Concluding Remarks

In this work, a prototype of a photoconductive antenna has been manufactured and the power emitted by the prototype has been measured using two different power detectors. The measurements have been compared with the power calculated using a theoretical model, proposed recently, after evaluating the various efficiencies involved in the entire measurement setups. The results of the proposed model show a fair agreement inside the range of the uncertainty of the measurement setups about the laser spot size on the photoconductor gap. The power radiated by the photoconductive antenna is strongly dependent on the position of the antenna gap respect with the focused spot of the laser. Further measurements and details will be discussed during the conference. The validation of the model suggests that such model can provide an effective tool to design and analyze photoconductive antennas, in order to improve the performance of such devices.

References

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