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On the Power Radiated by Photo Conductive Sources

Arturo Fiorellini Bernardis, Huasheng Zhang, Paolo Sberna, Juan Bueno, Andrea Neto, *Fellow, IEEE*, Nuria Llombart, *Fellow, IEEE*

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***Abstract*— The time evolution of voltages and currents in a pulsed photo conductive antenna (PCA) source is evaluated resorting to a rigorous procedure that stems from semiconductor physics first, to define the phenomena involved in the generation of the photocurrent, and then relies on an equivalent circuit in time domain, providing a direct estimation of the power generated by the PCA as well as its spectral distribution. The circuit model is validated via a campaign of measurements of standard PC antenna sources. The saturation phenomena in the THz radiated power occurring at large optical excitation levels, previously observed by the scientific community and associated to different phenomena, are accurately predicted by the present method, which ascribe their main cause to the feedback from the antenna: indeed, the electromagnetic field generated by the device tend to reduce the strength of the forcing field used to accelerate the photo-carriers.**

***Index Terms*—Equivalent circuit, terahertz (THz), photoconductive antennas (PCAs), THz radiated power, THz sources, THz technology**

I. CONTENT

Photoconductive antennas (PCA's) consist of a metallization biased to a constant voltage level printed onto a photoconductive substrate excited by a pulsed laser and radiating into a dense dielectric lens. When a laser with the appropriate carrier frequency impinges on the device gap, the provided energy injects free electrons from the valence to the conduction band, carriers that are then rapidly reabsorbed by the material once the excitation is no longer active. The charges are accelerated by the applied forcing field, eventually producing a time-varying current flowing across the gap responsible for the radiation. For small area sources, a distinctive effect limiting their THz power output is the saturation emerging when larger and larger optical excitations are used to pump the photoconductive substrate. The majority of the authors have associated this saturation to screening effects introduced by the antenna radiation and\or space charge build-up, [1,2]. Obtaining an equivalent circuit representation of the physical phenomena involved in the photocurrent generation can thus lead to photoconductive source designs that are more efficient in terms of THz power. Several equivalent circuits have been proposed in the literature, but they all needed *a posteriori* fine tuning to make the predictions fit with the measurements, [3,4,5].

With this contribution, we present a rigorous procedure to construct a circuit model that predicts the power radiated by PCA's and its spectral distribution with high accuracy: starting from the analysis of the physical processes involved in the carrier generation, motion and recombination in a semiconductor, [6,7,8], we proceed building an equivalent circuit model in time domain that includes the antenna effect; the model is immediate to translate in the frequency domain in order to deal with electromagnetic entities such as the antenna radiation impedance and the quasi optical channel efficiency. An electromagnetic validation of the model is given in [9]. The procedure is applied to the analysis of a photoconductive device relying on a substrate of Low Temperature grown Gallium Arsenide (LT *GaAs*), excited by a pulsed femtosecond laser, fed by a constant bias voltage and radiating into a silicon lens.

The procedure is validated by comparison of the expected power and spectra with data collected from a measurement campaign. The results agree exceptionally well, without the need to tune any parameter in order to make the predictions fit with the measurements, as opposed to [3,4,5].

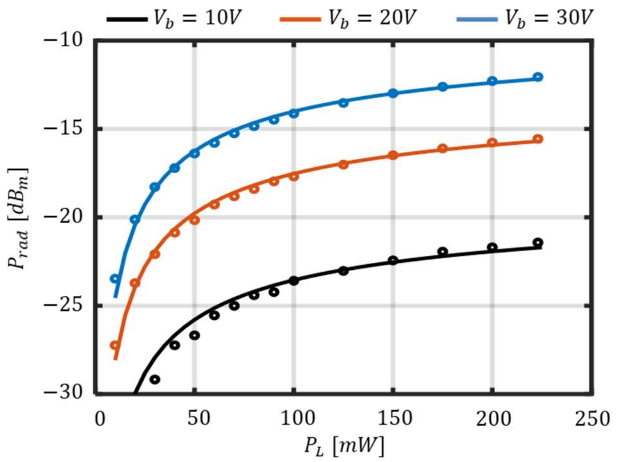

Fig.1 Power radiated by the PCA as function of the optical excitation level for three different bias points: predictions of the model hereby proposed (solid lines) against measurements (bullet points)

REFERENCES

[1] M. Tani, S. Matsuura, K. Sakai, and S. Nakashima, "Emission characteristics of photoconductive antennas based on low temperature grown GaAs and semi-insulating GaAs," Appl. Opt., vol. 36, no. 30, pp. 7853–7859, Oct. 1997.
[2] Zhisheng PIAO et al. "Carrier Dynamics and Terahertz Radiation in photoconductive Antennas" Jpn. J. Appl. Phys. Vol. 39 (2000) pp. 96–100 Part 1, No. 1, January 2000
[3] Loata, M. D. Thomson, T. Löffler, and H. G. Roskos, "Radiation field screening in photoconductive antennae studied via pulsed terahertz emission spectroscopy," Appl. Phys. Lett., vol. 91, p. 232506, Dec. 2007
[4] A. Garufo, G. Carluccio, N. Llombart, and A. Neto, "Norton equivalent circuit for pulsed photoconductive antennas—Part I: Theoretical model,"IEEE Trans. Antennas Propag., vol. 66, no. 4, pp. 1635–1645, Apr. 2018.
[5] A. Garufo et al., "A Connected Array of Coherent Photoconductive Pulsed Sources to Generate mW Average Power in the Submillimeter Wavelength Band," in IEEE Transactions on Terahertz Science and Technology, vol. 9, no. 3, pp. 221-236, May 2019
[6] P. Drude, "Zur Elektronentheorie der Metalle", Annalen der Physik, Vol. 306, pp. 566613, Mar. 1900
[7] D.R. Grischkowsky: "Nonlinear generation of sub-psec pulses of THz electromagnetic radiation by optoelectronics – Application to time-domain spectroscopy", in H.Walther, N. Koroteev, M.O. Scully (Eds.): Frontiers in Nonlinear Optics (Institute of Physics, Philadelphia 1993)].
[8] J. Shan and T. F. Heinz, "Terahertz radiation from semiconductors,"in Ultrafast Dynamical Processes in Semiconductors, vol. 92, K.-T. Tsen, Ed. Berlin, Germany: Springer-Verlag, 2004, pp. 1–59]
[9] A. Neto, A. Freni, N. Llombart, "On the Accurate Characterization of Pulsed Photo Conductive Sources: The Norton Circuit in Time Domain submitted to "Eucap 2021".