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Comments on "Numerical investigation and circuit analysis of interdigitated photoconductive antenna for terahertz applications"

Octavio A. Castañeda-Uribe[1] · **Carlos A. Criollo**[2] · **Alba Avila**[3]

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Abstract

The work "Numerical investigation and circuit analysis of interdigitated photo-conductive antenna for therahertz applications" presents an equivalent circuit model for terahertz antennas with an interdigitated topology. In this work, the proposed model is used to enhance the antenna efficiency by optimizing the structural parameters of the interdigitated topology. However, several equations used in the model presents inconsistencies that directly affects the presented results of circuit model. In the present communication we discusses the inconsistencies in the proposed model assumptions and respectfully suggest possible corrections.

Keywords Interdigitated photo-conductive antenna · Equivalent circuit model · Terahertz applications

1 Introduction

Recently, it has been published an equivalent circuit model (ECM) for terahertz photoconductive antennas with interdigitated topology (Rathinasamy et al. 2022), which has been implemented to study the effect of the antenna width, length, and interdigitated-elements periodicity in the THz pulse generation. However, the reported ECM equations present

Carlos A. Criollo and Alba Avila have contributed equally to this work.

✉ Octavio A. Castañeda-Uribe
octavio.castaneda@urosario.edu.co

Carlos A. Criollo
ca.criollo99@uniandes.edu.co

Alba Avila
a-avila@uniandes.edu.co

[1] School of Engineering, Science and Technology, Universidad del Rosario, Bogotá, Colombia

[2] Department of Electronics Engineering, Universidad CESMAG, Pasto, Colombia

[3] Department of Electrical and Electronic Engineering and Centro De Microelectrónica (CMUA), Universidad de los Andes, Bogotá, Colombia

several inconsistencies, which raises a concern about the accuracy and repeatability of the results. In order to avoid a possible misleading in the THz community, we report the following inconsistencies: (i) the definition of active volume in equation 3, (ii) the definition of the active area of the interdigitated photoconductive antenna (IPCA) in equation 4, Kirchhoff's voltage law in equation 5, (iii) Kirchhoff's current law in equation 6, and (iv) the variable definitions in equation 5.

2 Definition of active volume in equation 3

According to the authors, the average carrier density expression considers the active area and volume of the antenna as $A_a = (L \times W) - N_e L_e W_e$ and $V_a = L \cdot W \cdot d$, respectively. In our opinion, the expression used for the active volume is inconsistent with the standard definition reported elsewhere (Prajapati et al. 2017; Castañeda-Uribe et al. 2018), in which the active volume is defined as the product of the laser-illuminated surface area times the penetration skin depth. Considering the interdigitated topology of the antenna, the active volume should be, in this case, defined as $V_a = (L \times W - N_e L_e W_e) \cdot d$.

Using $V_a = L \cdot W \cdot d$ instead of $V_a = (L \times W - N_e L_e W_e) \cdot d$ affects significantly the magnitude of the average carrier density $n(t)$ in equation 3, which completely impacts the curves in the result section.

3 Definition of the active area of the IPCA in equation 4

The expression for the equivalent gap conductance reported in equation 4 includes an incorrect definition of the active area. At this point in the article, two different definitions for the active area have been defined (A_a, A), which is confusing and misleading to the readers. Furthermore, the latest definition denoted by the authors as (A) does not correspond to a canonical definition of area. Specifically, the authors defined it by adding two different widths (W_g) and (W_e). his definition needs at least a length term, which must be multiplied by the width. This error in estimating the active area directly impacts the magnitude and units of the time-dependent conductance in equation 4, thus affecting the results of the message in the article.

We suggest adding a figure with the antenna geometry to clarify all the antenna dimensions referred to in the equations (W_g, W_e, L_g, L_e). For example, assuming that the antenna presents the geometry in Fig. 1, the active area could be approximately defined as $A = N_g(W_g L_e) + N_e(W_e L_g)$. Note that this definition includes width and length dimensions, which agree with a canonical area definition.

4 Kirchhoff's voltage law in equation 5

The authors present in equation 5 a Kirchhoff's voltage law for the ECM in figure 2c. However, this equation does not belong to the presented circuit diagram; therefore, we do not understand the origin of this equation. In addition, equation 5 introduces: V_{geq}, V_d terms that are not defined or specified in any of the circuits presented in Rathinasamy et al. (2022). Therefore, it is impossible to establish Kirchhoff's voltage law without knowing the position and polarization of all voltages in the circuit.

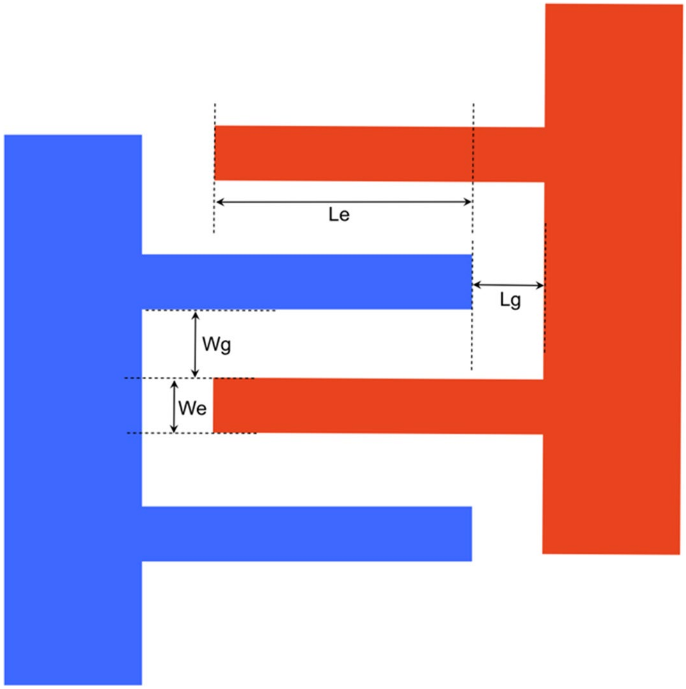

Fig. 1 Antenna geometry with fingers and gap dimensions

On the other hand, the proposed circuit in figure 2C locates in parallel with the bias voltage the elements that represent the interdigitated antenna (G_g, R_g, C_g), which means that the voltage on the capacitor ($V_c(t)$) is equal to the bias voltage (V_{bias}). This is a significant inconsistency given that the bias voltage is time-independent, but the capacitor's voltage is time-dependent. Finally, it is unknown the position of the elements (G_{geq}, R_{eq}) in the circuits, which also impedes the understanding of equation 5.

We suggest modifying the proposed circuit in figure 2C. The modification must include: (i) drawing the voltages with the corresponding polarization on each element, (ii) clarifying the name of the circuit elements, and (iii) modifying the position of some elements in the circuit. It is essential that all the circuit variables used in equation 5 must appear in the circuit.

5 Kirchhoff's current law in equation 6

The authors present in equation 6 a Kirchhoff's current law that does not correspond to any circuit in the article. Assuming that equation 6 comes from the circuit in figure 2c, there is an inconsistency, given that the Kirchhoff law in this circuit should includes the currents of all 6 branches in parallel: Bias voltage source, dark resistance, dark capacitance, equivalent conductance, equivalent capacitance, and antenna impedance. Unfortunately, the equation presented by the authors takes into account only 4 of 6 branches and additionally, it is omitted the position of the following variables: $I_{tot}, V_{geq}, G_{geq}, I_{Ceq}$. In this case, we suggest the authors introduce the same actions mentioned in Sect. 4.

6 Variables definition in equation 5

The authors define in the paragraph below equation 5 several variables as follows:

"where, V_{bias} is the bias voltage across the antenna electrodes, V_d is voltage due to dark resistance R_d, $V_s(t)$ represents the time-dependent screening voltage. $V_{geq}(t) = V_{g1}(t) + V_{g2}(t) + ... + V_{gn}(t)$, $n = 1, 2, 3, ...$ is the voltage across each interdigitated antenna element in the active region, $R_eq = R_1 + R_2 + ... + R_n$,$n = 1, 2, 3, ...$ is the electrode loss resistance, $I(t)$ is the optical pulse intensity, Z_a is the antenna impedance. The interdigitated electrode elements act as a parallel plate capacitor and contribute to the enhancement of THz radiation."

We identify in the above-cited paragraph at least three main errors: i) the voltage across each interdigitated antenna element (V_{geq})is defined as a sum of voltages, thus indicating that the elements are connected in series. This condition is not in agreement with the proposed circuit in figure 2C, in which the antenna elements are connected in parallel; ii) similarly, the electrode lost resistance (R_{eq}) is presented as a sum of resistances ($R_1, R_2, ...$) indicating a series connection, which is not consistent with the proposed circuit; iii) finally, the authors define $I(t)$ as the optical pulse intensity instead of defining it as a current (given that is a voltage law equation). In this case, we suggest to the authors the same actions mentioned in Sect. 4.

Author contributions All the authors contributed equally to this work.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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