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On the Experimental Characterization of Generated and Received Pulses of Photoconductive Antennas

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Abstract—**Photoconductive antennas (PCAs) are promising candidates for sensing and imaging systems. We have investigated their properties under pulsed laser illumination both in transmission and reception. First, a transmitting PCA has been characterized including a power measurement. Then, a Quasi-Optical (QO) link between a transmitter and a receiver was modelled and analyzed. In this work, we characterize this link with measurement. We use bow-tie based PCAs as examples, and measure the radiated power of the transmitter and the detected current of the receiver. The measurement shows very good agreement with the simulation.**

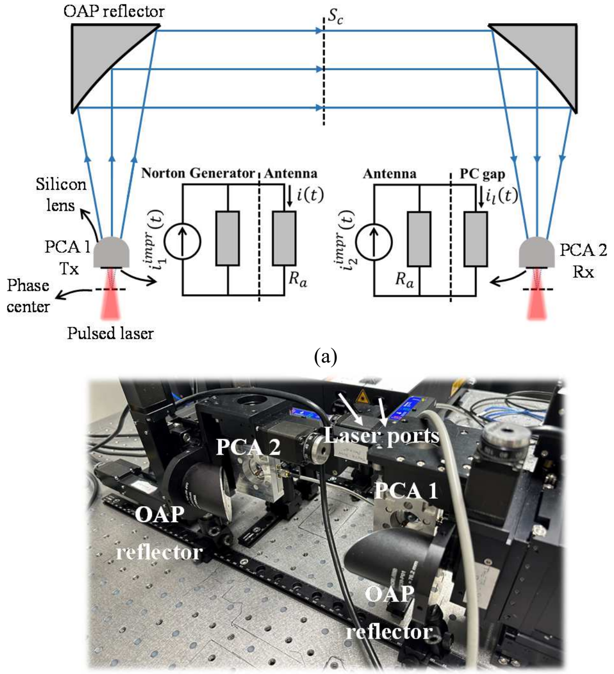
I. INTRODUCTION

Photoconductive antennas (PCAs) are promising candidates for sensing and imaging applications [1], [2] since they can radiate wide-bandwidth THz signals under pulsed laser illumination. A transmitting PCA has been well characterized in [3], [4]. To characterize a receiving PCA, a Quasi-Optical (QO) link between two pulsed PCAs was modelled to evaluate the propagation loss, and a Norton circuit in reception (Rx) was proposed to analyze the receiver performance [5]. However, the proposed QO link included two lossy plano-convex lenses and the simulated receiver performance was not validated. In this work, we move to a reflector-based setup (no dielectric loss) and we focus more on the measurement of the received currents.

II. ANALYSIS OF THE QO LINK AND THE RECEIVER

A schematic representation of the considered QO link is provided in Fig. 1(a) and the corresponding experimental setup is shown in Fig. 1(b). The transmitter, PCA 1, radiates towards an off-axis parabolic (OAP) reflector. The reflected fields are then focused by the other reflector on the receiver, PCA 2. Both PCAs are printed on extended hemispherical silicon lenses and the phase centers of the lenses are aligned with the focuses of the reflectors. This QO link can be analyzed resorting to the field matching technique discussed in [5]. By correlating the Physical Optics (PO) fields radiated by PCA 1 and 2 on the middle plane S_c shown in Fig. 1(a), we can obtain the propagation loss of this link and the impressed current in the equivalent circuit in Rx, i.e. $i_2^{impr}(t)$ in the right circuit in Fig. 1(a). We can then use it to solve the circuit and calculate the current flowing across the load of the circuit, $i_l(t)$.

The amplitude of $i_l(t)$ is highly dependent on the synchronization between the transmitter and the receiver. The transmitted THz signals impinge on the receiving PCA periodically with a repetition time of T, and then induce the periodic impressed currents $i_2^{impr}(t)$ on the antenna. For each replica of $i_2^{impr}(t)$, we can change the time delay t_i of the laser pulses in Rx to synchronize with different portions of the time base of $i_2^{impr}(t)$. For each delay t_i, we first calculate $i_l(t, t_i)$ by solving the Rx circuit in Fig. 1(a). We then integrate and average $i_l(t, t_i)$ over the time T to obtain a single value of the received current $i_d(t, t_i)$. Finally, to obtain the complete time evolution of $i_d(t)$, we need to sweep the time delay of the laser pulses in Rx so that $i_2^{impr}(t)$ can be completely synchronized with the pulses.



(a)

(b)

Fig. 1. (a) Schematic representation of the QO link between two PCAs. Equivalent Norton circuits for the transmitter and the receiver are also shown. (b) Photograph of the corresponding experimental setup.

III. MEASURED PERFORMANCE OF THE BOW-TIE PCAS

Here we use two identical bow-tie based PCAs as the transmitter and the receiver and follow the setup in Fig. 1 to conduct the measurement. These antennas have the same gap size of 10 μm × 10 μm and are printed on LT GaAs substrates. The detailed antenna geometry is discussed in [4]. The pulsed laser source is the TERA K15 from Menlo Systems, with ad-hoc modifications. It operates at $f = 384.6$ THz (780 nm) and has a repetition time of $T = 12.5$ ns. It has two free-space laser ports to illuminate both PCAs with the same optical power of $\tilde{P}_{opt} \approx 30$ mW. This power term includes the spillover and reflection of the laser on the PC gap. The transmitter is biased by an external voltage of $V_b = 30\ V$ while the receiver is biased by the induced voltage calculated from $i_2^{impr}(t)$.

The output laser beam is focused by a plano-convex lens on the gap of the PCA to obtain a waist of 8.5 μm. This corresponds to the full width at half maximum of 10 μm (same as the gap size) and can achieve the ideal illumination. The spot size of the focused laser beam was measured along two orthogonal axes using the knife-edge technique with two metal blades [6]. Due to extensive alignment procedures, the profiles have excellent Gaussian shapes and their FWHM are 9.3 μm (y axis) and 10 μm (z axis), which leads to an average spillover efficiency of $\eta_{so} = 0.608$. By considering also the absorption of the LT GaAs substrate, the optical efficiency is $\eta_{opt} = \tilde{P}_{opt}/\tilde{P}_L \approx 0.358$, where $\tilde{P}_L$ is the power of the measured profiles.

A. Power Measurement

We first measure the radiated power of the transmitter. We replace the receiver in Fig. 1 by a PM5 power meter which is connected to a conical WR-10 horn antenna to capture the THz signals. Then we replace the blade by the transmitting PCA for the power measurement. The position of the PCA is fine tuned to obtain the maximum DC current flowing on the PC gap, which corresponds to the best laser illumination. Moreover, to maximize the detected power, the position of the reflectors and the horn are well aligned.

The power radiated by the transmitter and measured by the power meter is plotted in Fig. 2 as the function of the optical power $\tilde{P}_{opt}$ when $V_b = 30$ V. This setup is also simulated in TICRA GRASP [7] where the sources are the secondary fields radiated by the silicon lens. This measured power is lower than the previously measured bow-tie antenna in [4]. Therefore, we use different recombination time $\tau_c = 700$ fs and scattering time $\tau_s = 2.8$ fs in the simulation to fit the measurement and the resulting agreement is quite good.

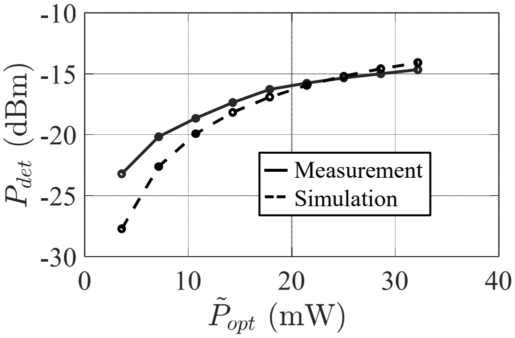


Fig. 2. Measured detected power compared to the simulation when the biasing voltage is $V_b = 30$ V.

B. Current Measurement

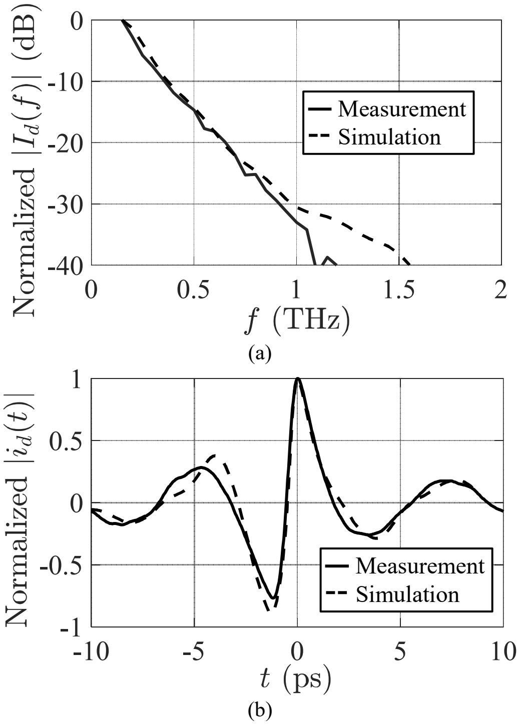
Once the transmitter side is fine-tuned and well aligned, we move to the receiver side and use the setup in Fig. 1(b) to measure the received currents. We use the same procedures to align and measure the laser profiles and replace the blade by the receiving PCA. After fine tuning the position of the receiver, we connect it to a current meter to read the received current $i_d(t)$. To obtain the complete time evolution of $i_d(t)$, we need to synchronize the transmitter with the receiver with different time delay. This can be achieved by changing the optical delay of the receiver. We fix the optical path of the transmitter, and change the Optical Delay Unit (ODU) of the laser port in Rx. This ODU can electronically control the optical delay in a wide range. Therefore, we can sweep it back and forth to synchronize the receiver with the THz signals emitted by the transmitter, and then construct the current $i_d(t)$.

The challenging part is the alignment of the OAP reflectors to obtain the optimal current amplitude. This is because each reflector has 4 degrees of freedom and the receiving PCA is more sensitive to such alignment than the power meter. After elaborate alignment, we obtain the optimal current spectrum $I_d(f)$ which is shown in Fig. 3(a) and compared to simulation. Because our analysis method is not accurate at low frequencies, here we truncate the measured spectrum for $f < 150$ GHz. The agreement is very good from 150 GHz to 1 THz. It is worth mentioning that this measured spectrum decreases quite fast since the measured antenna has a long recombination time of $\tau_c = 700$ fs. We then perform the inverse Fourier transform for $I_d(f)$ to obtain the corresponding time signal $i_d(t)$ which is shown in Fig. 3(b). Again, the simulation matches well with the measurement, with slightly higher side lobes.

IV. CONCLUSION

In this work, we presented a reflector-based QO link between two PCAs for the measurement of the radiated power and the received currents. The analysis of the link and the receiver was briefly discussed.

Bow-tie based PCAs were used for the measurement. The extensive alignment between the PCAs and the laser sources led to excellent laser profiles to illuminate both PCAs. For the transmitter, the measured detected power showed quite good agreement with the simulation. For the receiver, we compared the received currents in time- and frequency-domains. The agreement is also very good.



(a)

(b)

Fig. 3. Measured received current compared to the simulation: normalized (a) spectrum $I_d(f)$ and (b) time signal $i_d(t)$.

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