

A novel configuration of THz photonic transmitter

I. Moumane¹, J. Zbitou², M. Latrach³, A. Errkik⁴, O.Chakkor⁵

^{1,2,4}Laboratory of Mechanics, Energetics, Electronics and Telecommunications LMEET,

FSTS Hassan 1St University of Settat, Morocco

³Microwave group ESEO, Angers, France

⁵ENSA of Tetuan, Morocco

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ABSTRACT

In this paper we present a new design of a photonic transmitter based on multi-layers substrate GaAs and using for generation of THz waves. The proposed circuit is composed from a photodetector (PD) “which converts the light to the electrical signal”, THz Antenna, low-pass filter and DC probe. Firstly we have optimized the THz antenna using an EM solver which is Momentum integrated in ADS “Advanced Design System”. Then we have optimized the low pass filter which plays the role of inductance that is an RF choke permitting to separate the RF signal from the DC one. Finally, we have associated the different components, add the DC probe and simulate the whole proposed system. The dimensions of the final circuit are $400.317 \times 167.16 \mu\text{m}^2$. The obtain results permit to validate the final circuit at THz and make it suitable for THz applications.

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Corresponding Author:

I. Moumane,

Laboratory of Mechanics, Energetics, Electronics and Telecommunications LMEET,

FSTS Hassan 1St University of Settat, Morocco.

Email: moumaneibt@gmail.com

1. INTRODUCTION

Recently we remark the fast growing of the THz applications due to a lot of factories related to the development of the modern Femtosecond Lasers and High-Speed Photodetectors. Many researchers in different domains such as biomedical imaging, spectroscopy, Security and telecommunications are focusing now their searchers on THz waves which presented several advantages based on interactivity with the material where it spreads and fast absorption by the atmosphere [1].

Before the difficulties of the THz domain reside in the generation and detection. But the situation are changed now, for the generation of the THz waves as an exemple many methods are proposed but the most used is the one that relays on the coplanar waveguide (CPW) photonic transmitters [2]. The CPW technology offers in fact several advantages due to its features, like low radiation, low dispersion, easy of shunts and series connections [3].

In this paper we present a compact photonic transmitter composed from a photodetector associated to the THz antenna, low pass filter and DC probe Bias. The following sections will study and discuss the design of the different components.

2. PHOTONIC TRANSMITTER SYSTEM

2.1. Photodetector “PD”

Photodetectors are semiconductor devices that can detect optical signals through electronic processes. The extension of wavelength of coherent and incoherent light sources into the far-infrared region on one hand and the ultraviolet region on the other has increased the need for high-speed, sensitive photodetectors. The operation of a general photodetector includes basically three processes:

(1) carrier generation by incident light, (2) carrier transport and multiplication by current-gain mechanism if present, and (3) extraction of carriers as terminal current to provide the output signal [4].

There exist many types of photodetectors. They are divided into two classes; thermal detectors and photon detectors. Thermal detectors detect light by sensing the temperature rise when the light energy is absorbed at their dark surface. These are more suitable for far-infrared wavelengths. Technically they are more like thermal sensors and will be discussed to a larger extent in the next chapter. The photon detectors are based on the quantum photoelectric effect: a photon excites a carrier which contributes to the photocurrent [4].

The photoelectric effect is based on the photon energy $h\nu$, the wavelength of interest is related to energy transition ΔE in the device operation, with the obvious but important relationship [4].

$$\lambda [\mu\text{m}] = \frac{hc}{\Delta E} = \frac{1.24}{\Delta E(\text{eV})} \tag{1}$$

Where λ is the wavelength, c is the speed of light, and ΔE is the transition of energy levels. A PD has different properties such as:

Sensitivity: The ability of the photodiode to transform light absorbed into an electrical current in other terms the number of charge carrier pairs generated per incident photon [5].

$$\eta_{\text{ext}} = \frac{I_{\text{pd}}}{q} \cdot \frac{h\nu}{P_{\text{opt}}} \tag{2}$$

Responsivity: Where I_{pd} is the photogenerated current by the absorption of the optical input power P_{opt} at a frequency ν mentioned in (2). A common figure of merit is the external responsivity R , defined as the ratio of photocurrent to the input optical power [5]:

$$R = \frac{I_{\text{pd}}}{P_{\text{opt}}} = \frac{\eta_{\text{ext}}\lambda[\mu\text{m}]}{1.24} \text{ A/W} \tag{3}$$

Where R depends on the state of polarization of the incoming light, the definition of the polarization dependent loss (PDL) is useful [5]:

$$\text{PDL} = 10 \cdot \log\left(\frac{R_{\text{max}}}{R_{\text{min}}}\right) \text{ dB} \tag{4}$$

With R_{max} and R_{min} are the maximum and minimum responsivities for all states of polarization.

In order to evaluate the high-speed photodiode, the electrical 3dB bandwidth is used. It specifies the frequency range from DC to the cut-off frequency $f_{3\text{dB}}$. The bandwidth of a lumped element photodiode, at which the device length is much shorter than the electrical signal wavelength, might be limited mainly by the RC-time constant and the carrier drift times in the depletion region. These bandwidth constraints lead to a 3dB bandwidth which can be approximated by [5]:

$$f_{3\text{dB}} \approx \frac{1}{\sqrt{\frac{1}{f_{\text{RC}}^2} + \frac{1}{f_{\text{t}}^2}}} \tag{5}$$

With the RC limited bandwidth [5].

$$f_{\text{RC}} = \frac{1}{2\pi R_{\text{tot}} C_{\text{pd}}} \tag{6}$$

And the carrier transit time limited bandwidth [5].

$$f_{\text{t}} = \frac{3.5\bar{v}}{2\pi d_{\text{abs}}} \tag{7}$$

R_{tot} stands for the photodiodes' total resistance including series and load resistances [5].

C_{pd} is the junction capacitance [5].

$\bar{v} = \sqrt[4]{2\left(\frac{1}{v_e^4} + \frac{1}{v_h^4}\right)^{-1}}$ is the averaged carrier drift velocity with the electron and hole velocities v_e and v_h [5].

d_{abs} : The absorber thickness [5].

In this work we have chosen the Metal Semiconductor-Metal Traveling wave Photodetector (MSM-TPD) by reason of its high power-bandwidth and coplanar-waveguide fed slot owing to its easy connection with planar devices [6]. The PD based on GaAs substrate which characterized by a succession of layers as mentioned in the Figure 1 [7]:

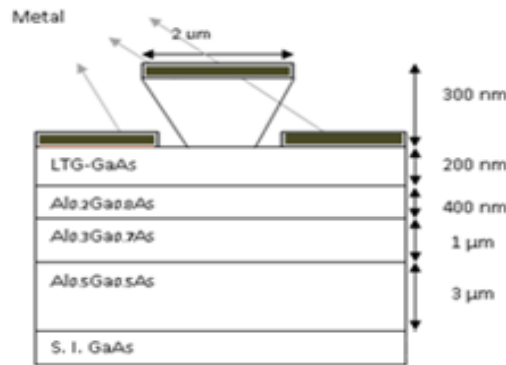


Figure 1. Structure of the photodetector based on GaAs substrate [7]

2.2. THz Wideband Antenna

The integration of the antenna into the CW photonic transmitter circuit is mandatory. It's role focuses on the transmission of the RF signal providing from the PD.

In the Figure in below we present the design of THz Antenna based on the multilayer substrate presented in Figure 1. The final dimensions are obtained after many series of optimization using different methods integrated in ADS as Random and gradient techniques. The bowtie antenna structure as shown in Figure 2 and final optimized parameters in Table 1.

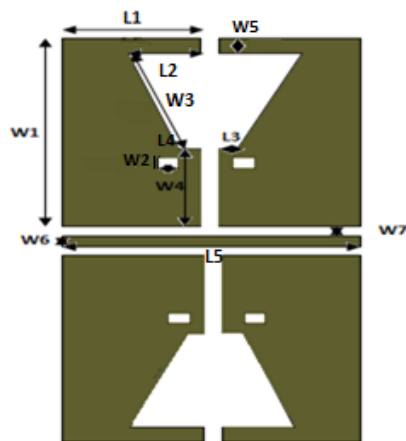


Table 1. The Final Optimized Parameters of the Proposed CPW THz Antenna

Parameter	Value (μm)
L1	55.09
L2	26.39
L3	6.93
L4	8.24
L5	116.77
W1	79.17
W2	5
W3	48.10
W4	29.35
W5	6.27
W6	4
W7	5

Figure 2. The bowtie antenna structure

Figure 3 presents the reflection coefficient S11 of the validated antenna with a good matching impedance below -10dB in the bandwidth between 1THz and 1.28THz.

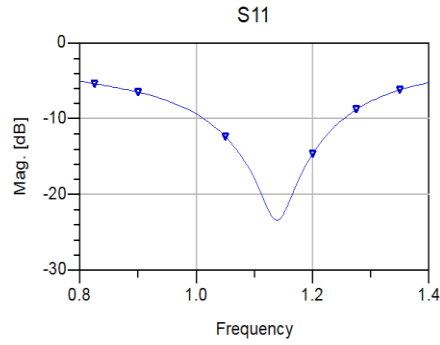


Figure 3. Reflection coefficient versus frequency

To have an idea about the behavior of the antenna we have launched a 3D simulation at 1.14 THz in ADS, we obtain the radiation diagram which shows that the antenna is bidirectional. The radiation pattern at 1.14 THz as shown in Figure 4.

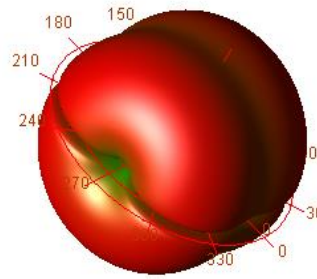


Figure 4. The radiation pattern at 1.14 THz

We have done a comparison between the proposed antenna and another THz antennas validated in literature to give an idea about the performances of the final validated THz antenna. The Table 2 presents the difference in term of (dimensions, frequency bandwidth) between the proposed antenna and others structures:

Table 2. Comparison of the Antenna structures

Antenna Structure	Length	Frequency Bandwidth
Proposed Antenna	117 μm	[1THz,1.28THz]
Antenna[8]	330 μm	[1THz,1.25THz]
Antenna [9]	200 μm	Narrow band at 645 Ghz
Antenna [10]	1040 μm	Narrow bandat 850 Ghz

As shown in this table, the proposed antenna presents good performances in term of bandwidth and length.

2.3. Low-Pass Filter “LPF”

After the optimization of THz Antenna we pass to the second step the validation of the LPF [11], which is responsible of in blocking the RF signal providing from PD and transmitting via antenna to reach the DC probe Bias.

In this study we have chosen a a stepped impedance LPF structure presenting in the study [12] with the aim to increase the rejection band. The proposed LPF composed from three unit cells as shown in Figure 5 and dimensions are presented in Table 3.

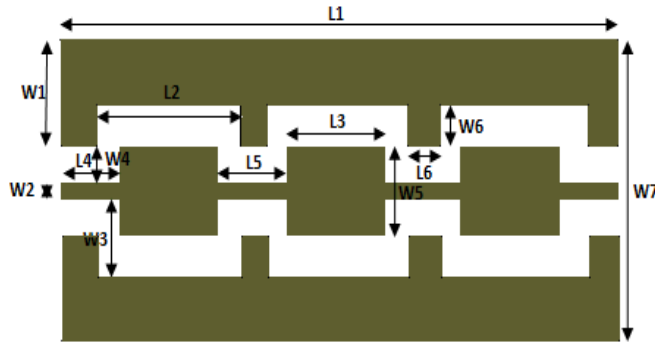


Figure 5. The layout of the periodic LPF THz structure

Table 3. Values of the LPF Parameters

Parameter	Value (μm)
L1	171
L2	45.78
L3	32.74
L4	16.97
L5	19.40
L6	6.67
W1	37.29
W2	7
W3	19.40
W4	10.91
W5	32.44
W6	9.09
W7	97.62

The Figure 6 presents a good low insertion loss, with a cutoff frequency of 0.88 THz and a wide rejection band until 1.1 THz, which makes the proposed “LPF” suitable for THz applications.

To form an idea about the function of the proposed “LPF” structure we have launched a 3D simulation in ADS at 0.75 THz in the frequency passband and at 1 THz in the rejection frequency band. As a result, we can see from Figure 7 (a) that we have a flow of energy from port 1 to port 2 and for Figure 9 (b) the energy is stopped to reach the port 2.

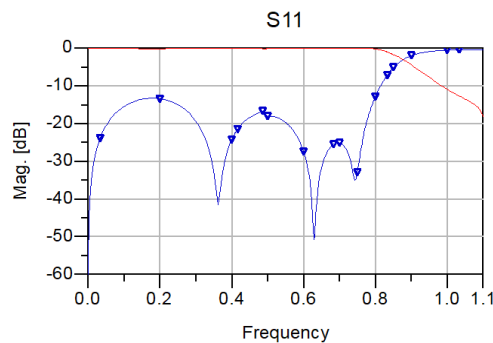


Figure 6. Simulation S-Parameters results versus frequency

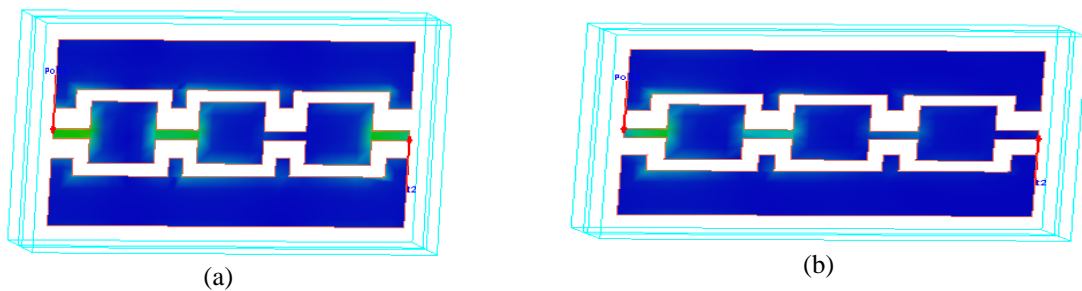


Figure 7. The current density @ 0.75 THz (a) THz and (b) 1THz

2.4. CW Photonic Transmitter Simulation

After the validation of the THz antenna and the LPF, we have connected the different components to the photodetector MSM-TWPD and added the DC probe responsible for the Bias of the PD to obtain the final circuit CW photonic transmitter presented in Figure 8 and values of DC probe parameters in Table 4.

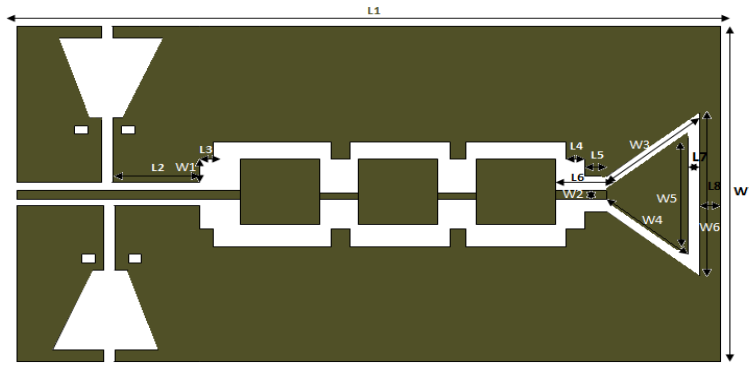


Figure 8. The proposed CW photonic transmitter

Table 4. Values of DC Probe Parameters

Parameter	Value (μm)
L1	400
L2	54.75
L3	9.42
L4	10.15
L5	19.58
L6	35.17
L7	6.16
L8	7.61
W1	6.52
W2	5
W3	98.06
W4	89.92
W5	96.46
W6	118.21
W7	167.52

The Figure 9 presents the simulation result of the CW THz photonic transmitter which permits to validate this circuit between 1.26 THz and 1.32 THz.

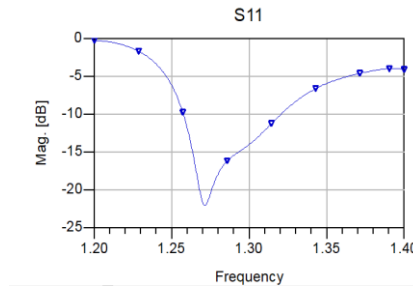


Figure 9. Simulation S-Parameters results versus frequency

3. CONCLUSION

The objectif of this paper is the validation of CW photonic transmitter using for generation of THz waves. As mentioned before the system is composed from photodetector, THz antenna, Low pass filter and DC probe. In the first step we have chosen the photodetector MSM-TPD. Then we pass to the optimization of the THz antenna which transmits the RF signal providing from the PD. After we move to the design of the low pass filter which blocks the RF signal to reach the DC probe Bias. And in the final step we have associated and simulated the whole system using an electromagnetic solver Momentum integrated in ADS until obtain the validate results. The final circuit is mounted on a multilayers GaAs substrate and having an area around $400.317 \times 167.16 \mu\text{m}^2$.

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BIOGRAPHIES OF AUTHORS

	<p>Ibtissame Moumane: was born in Morocco in 1989, She received the degree of engineering in telecommunication and network from National School of Applied Sciences of Khouribga, Morocco in 2012. Currently, She is preparing the Ph.D. in University of Hassan 1st in Settat. Her interests include THz communication, antennas, low-pass filters, photodetectors and CW Photonic Transmitter.</p>
	<p>Jamal Zbitou was born in Fes, Morocco, in June 1976. He received the Ph.D. degree in electronics from Polytech of Nantes, the University of Nantes, Nantes, France, in 2005. He is currently an associate Professor of Electronics in FST University Hassan 1st, Settat, Morocco. He is involved in the design of hybrid, monolithic active and passive microwave electronic circuits.</p>
	<p>Mohamed Latrach and the was born in Douar Ksiba, Sless, Morocco, in 1958. He received the Ph.D. degree in electronics from the University of Limoges, Limoges, France, in 1990. He is currently a Professor of microwave engineering with the Ecole Suprieure d'Electronique de l'Ouest (ESEO), Angers, France, where his research involves RF and microwaves. His field of interest is the design of hybrid, monolithic active, and passive microwave circuits, metamaterials, LH materials, antennas and their applications in wireless Communications.</p>
	<p>Ahmed Errkik was born in July 1960 in Morocco. He received the Ph.D. degree in physics from the University of Technology Compiegne (UTC), Compiegne, France. He is currently an associate Professor of physics in FST University Hassan 1st, Settat, Morocco. He is involved in the design of hybrid, monolithic active and passive microwave electronic circuits.</p>
	<p>Otman Chakkor was born in November 1977 in Tangier, Morocco. He is a Professor (Head of Telecommunication Departement) at Abdelmalek Essaadi University, in National School of Applied Sciences ENSA in Tetuan, Morocco and member of the RSAID Laboratory. He received his PhD-Thesis from the University of Granada (Spain), Department of Architecture and Technologies of Computers; Area: Signal processing, He obtained his degree of Electric Engineering IEEA from Abdelmalek Essaadi University (Morocco) in 1999.</p>