Journal of Nano- and Electronic Physics
Vol. **15** No 3, 03028(5pp) (2023)

Журнал нано- та електронної фізики
Том **15** № 3, 03028(5cc) (2023)

A Wideband Microstrip 1 × 2 Array Antenna Fed by Coupler for Beam Steering Terahertz (THz) Band Applications

Abdelaaziz El Ansari[1], V. Jayaprakasan[2], K. Duraisamy[3], Sudipta Das[4,*], Tarik El-Arrouch[1],
Najiba El Amrani El Idrissi[1]

[1] *Signal System and component Laboratory, Sidi Mohamed Ben Abdellah University – FST Fez, Morocco.*
[2] *Department of Electronics and Communication Engineering, Sreenidhi Institute of Science and Technology, Hyderabad*
[3] *Department of Biomedical Engineering, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, Tamil Nadu, India*
[4] *Department of Electronics and Communication Engineering, IMPS College of Engineering and Technology, Malda, W.B India*

(Received 20 May 2023; revised manuscript received 15 June 2023; published online 30 June 2023)

Terahertz band gap is the range of frequency lying between the microwave band and the optical band, its range spectrum starts from 0.1 THz to 10 THz. This band provides unallocated wide bandwidth as well as very high-speed communication in the futuristic applications. This article presents a broadband microstrip 1 × 2 array antenna powered by hybrid coupler in terahertz band (around 2.45 THz). To reach this Broadband antenna, at first, a wideband 3 dB hybrid coupler is designed and optimized. After that, two basic elements of square shaped with slots are fed by the two output ports of the coupler. The results obtained reports that the suggested antenna offers – 10 dB wide bandwidth equals to 846 GHz (from 1.91 to 2.77 THz) with good impedance matching, maximum directivity equals to 8.86 dBi at the operating frequency 2.45 THz. Additionally, it offers the capability of beam steering which can be obtained by switching of the input ports of the coupler. Thus, the antenna can produce two beams at ±30°. The structure and simulation results of the proposed antenna have been done on Rogers RT/duroid 5880 substrate. The total size of the proposed microstrip array antenna is 110 × 112 × 1.56 μm³. Due to its capability of beam steering and broadband characteristic, the proposed antenna is a potential candidate for Terahertz band applications such as materials characterization in the THz band, medical imaging and future high-speed wireless communication.

Keywords: Array antenna, Beam steering, Broadband, Microstrip patch antenna, Terahertz band, Coupler.

DOI: 10.21272/jnep.15(3).03028 PACS numbers: 83.40.Ba

1. INTRODUCTION

In the past decade, the wireless communication systems undergone a significant evolution in the outdoor and indoor communications. This evolution needs high-speed communication systems for the establishment of faster communication link. However, the available microwave spectrum band are totally allocated and utilized by many wireless communication applications. This limitation has motivated many researchers all around the world to search other unallocated bands. Thus, the terahertz band gap is a potential choice to allow whole wireless applications thanks to its unallocated spectrum as well as its high speed communication which can be up to 10 Gbits per second [1-2]. The terahertz band is the range of frequencies located between the microwave and optical band; its range spectrum starts from 0.1 THz to 10 THz.

To have a true transmission and reception of data, an antenna is an unavoidable part of wireless communication systems. The most common antennas have used in wireless communication are the patch antennas thanks to its low cost, profile, and weight as well as its simplicity of integration with wireless systems [3]. However, this kind of antennas have some weakness' such as, narrow bandwidth [4], weak gain [5], and inflexibility in radiation beams [6]. These limitations motivate many scientists and researchers all around the world to suggest some solutions. The array antenna [7] is one of solutions to get up the gain and directivity. Moreover, the feed by hybrid coupler [8] or Wilkinson power divider [9] are potential solutions to resolve the inflexibility problem as well as to widen its bandwidth.

So far, most available terahertz antennas are simple and having fixed beam as per best of authors knowledge. In the most of the cases, for wireless communication system, the transmitter and the receiver are moving. The available THz antennas [10-15] as reported in literature could not be not able to track electromagnetic waves in steerable directions. To overcome this problem, a steerable antenna is necessary. In addition, due to the increase of customers, the progress in internet of things as well as the giant growth of wireless systems, compact, wideband antenna is essentially required.

Hence, in this paper, we have suggested a new broadband, beam steerable microstrip 1 × 2 array antenna in the THz band operation. This antenna is able to direct

---

[*] sudipta.das1985@gmail.com

© 2023 Sumy State University

the radiation in two different directions with good performance. The proposed antenna is dedicated to operate in terahertz band, it has – 10dB impedance bandwidth of 846 GHz with a maximum directivity of 8.861 dBi and beam switching capability in two different directions covering a scanning beam angle of 60 degree.

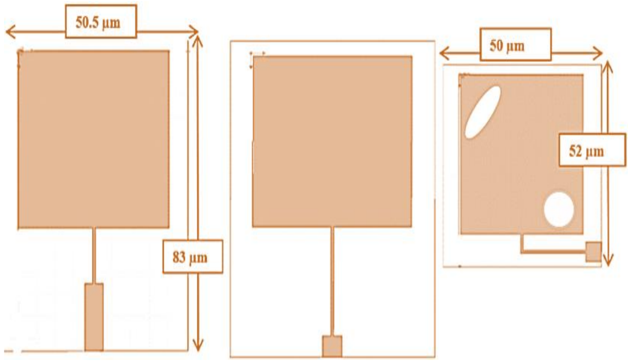
This paper is presented into four essential parts as follows: after this introduction, Section 2 discusses the investigated design method. Section 3 is dedicated to results and discussion. Finally, section 4 is the conclusion of this article.

2. INVESTIGATED DESIGN METHOD

In this section, we have presented the design methodology that has been used in order to achieve a wideband steerable antenna using microstrip technology. First of all, a microstip rectangular patch antenna is designed as well as optimized. After that, a wideband coupler is optimized. Finally, the broadband steerable antenna is reached by feeding two same basic elements by the optimized coupler. The design has been conducted on substrate Rogers RT/duroid 5880 with the total size of 110 × 112 × 1.56 μm^3.

2.1 Study and Design of The Basic Element

The proposed basic radiating element is a planar antenna having a rectangular shape. At first, it was fed by 50 Ω feed line and the impedance matching is insured by a quarter-wave impedance transformer (see Case 1 in Fig. 1). After that a parametric scan have been conducted on the dimensions of the quarter-wave impedance transformer and the feed line (see Case 2 in Fig. 1). Finally, in order to miniaturize space, the optimal length of the quarter-wave impedance transformer is folded (Case 3 in Fig. 1). In this case, circular and elliptical slots are added on two opposite corners of the patch. These slots helped to attain the resonance at the desired frequency. The basic element has been designed using HFSS simulator. It is conducted on substrate (Rogers RT/duroid 5880). The overall size of this optimized basic element is 50 × 52 × 1.56 μm^3.



Case 1 Case 2 Case 3

Fig. 1 – Optimization steps of the proposed basic element

2.2 Study and Design of the Proposed 3 dB Hybrid Coupler

A hybrid coupler is a power divider that contains two input ports and two output ports. It has the ability to divide the input signal in two equal quantities making a 90 degrees phase shift between them. It can be used for power combining or power division. The proposed 3 dB hybrid coupler is illustrated in Fig. 2. It is made of eight transmission microstrip lines and their impedances are related to the input impedance which equals to 50 Ω in their shunt arm, so the characteristic impedance of series arm is $\frac{Z_{50}}{\sqrt{2}} = 35.35\ \Omega$.

The analytical equations that allowed to calculate the lengths and widths of shunt arms as well as series arms of the proposed coupler can be calculated from ref [3].

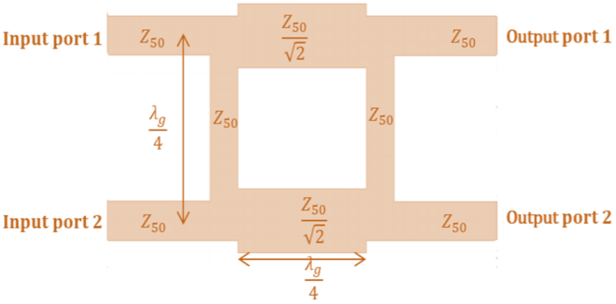


Fig. 2 – Proposed microstrip 3 dB hybrid coupler

The scattering matrix is given as [3]:

$$[S] = \frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 1 & e^{j90^\circ} & 0 \\ 1 & 0 & 0 & e^{j90^\circ} \\ e^{j90^\circ} & 0 & 0 & 1 \\ 0 & e^{j90^\circ} & 1 & 0 \end{bmatrix} \quad (1)$$

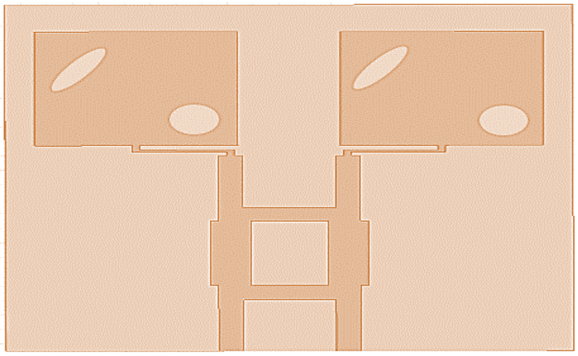
In this scattering matrix, it's clear that it equals to its transpose. So, the designed antenna is symmetrical. Thus, any port can be used as input port.

In this work, the designed coupler will be utilized to design a beam-steering and broadband antenna. Indeed, as result of the available 90 degrees phase shift between the two output signals, the power divider can be able to steer two beams in two directions ±30° by switching the input signal between two input ports. The other non-fed port should be matched to its impedance that helps to convert the narrow bandwidth to a wide operating bandwidth for the designed antenna.

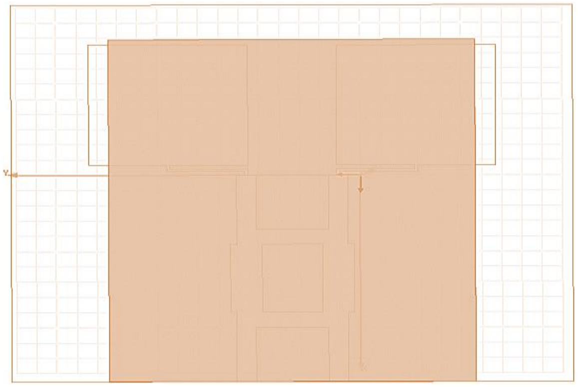
2.3 Study and Design of the Proposed Broadband Beam-Steerable 1 × 2 Array

In order to increase radiation and impedance performance of the basic radiating element, the optimized coupler is used to feed two identical basic elements by a separation distance *d*. So, the two patches are supplied by two signals having the same amplitude with 90° phase shift between them. Thus, the proposed array antennas will be flexible in beam directions and beam steerable.

Fig. 3 shows the proposed design of the beam steerable antenna with top side indicating patches and back side, indicating a partial ground plane of this antenna.



(a)



(b)

Fig. 3 – Design of the proposed microstrip broadband steerable antenna. (a) Top view. (b) Rear view

Due to the 90 degrees phase shift made by the designed hybrid coupler, the radiation pattern will move in two different directions creating an angle θ with the normal to the antenna. This angle can be expressed by the equation:

$$\sin\theta = \pm\frac{\varphi\lambda}{2\pi d} \qquad (2)$$

λ = The wavelength in air.
φ = The phase shift made by the coupler.
d = The distance that separates two patches, in which d should respect the condition $d \leq \frac{\lambda}{2}$ for reducing the mutual coupling between patches.

In equation (2), the angle θ is expressed as a function of d, λ, and φ. Since d is fixed ($d = \frac{\lambda}{2}$). Also, knowing that φ is fixed by hybrid coupler ($\varphi = 90°$). Thus, the angle θ will be controlled by one parameter λ. Consequently, for each operating frequency corresponds to a direction θ. In this work, the operating frequency is selected as 2.45 THz. So, its corresponding direction θ will be ±30°. This θ value is theoretical, in the next section, simulation results are presented.

3. SIMULATION RESULTS AND DISCUSSION

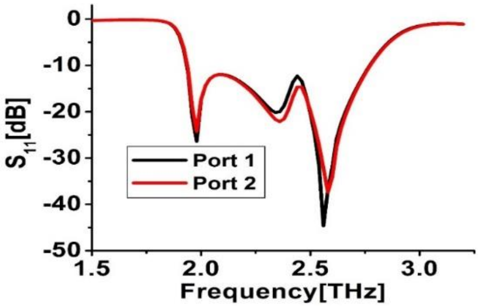
The simulation studies have been performed using HFSS EM software and the obtained results are discussed in this section. The results are obtained through two studied scenarios:

i) 1st step: when and port 1 is fed and port2 is adapted to 50 Ω.

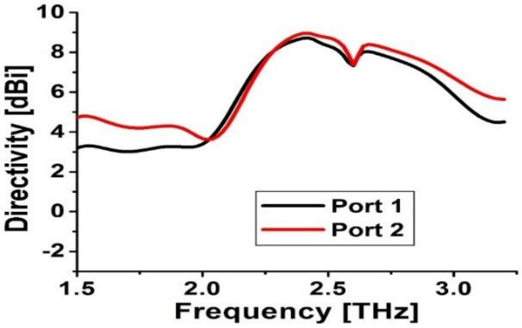
ii) 2nd step: when and port 2 is fed and port1 is adapted to 50 Ω

Fig. 4 displays the port 1 results versus port 2 results. Thus, it can be seen that there is a good agreement between these two cases.

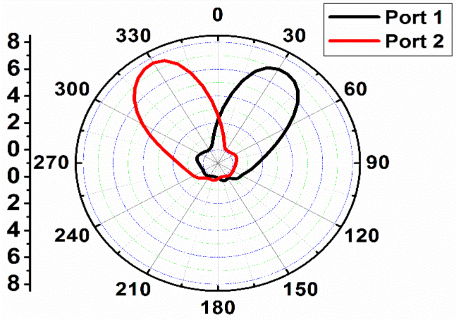
Fig. 4(a) illustrates the simulation results of the reflection coefficient S_{11} when port 1 is ON against when port 2 is ON. So, it can be noted that in both scenarios, a wide bandwidth of about 846 GHz (from 1.91 to 2.77 THz) can be obtained.



(a)



(b)



(c)

Fig. 4 – Simulation results (a) reflection coefficient S_{11}, (b) directivity, (c) direction of maximum beam of radiation pattern

Table 1 – Comparison of proposed beam-steerable THz antenna with other previous references

References	– 10 dB Impedance bandwidth (GHz)	Operating frequency (THz)	Peak Directivity (dBi)	beam steering capability
[10]	340	[0.535-0.84]	–	No
[11]	67	[4.062-4.129]	3.81	No
[12]	60	–	5	No
[13]	269	[0.445-0.714]	5.7	No
[14]	385	[6.8-7.186]	7.28	No
[15]	350	[3.3688-3.723]	8	No
This work	846	[1.91-2.77]	8.86	Yes

Fig. 4(b) indicates the simulation results of the directivity when port 1 is ON against when port 2 is ON. So, it's clear that in both scenarios that the peak directivity is achieved exactly at the chosen frequency (2.45 THz) and equals about 8.86 dBi.

Fig. 4(c) illustrates the simulation results of the maximum beams' directions obtained in both studied scenarios. So, it is clear that when port 1 is fed, the beam is oriented to the right by angle θ equals about 30°. However, when port 2 is fed, the beam is oriented to the left by angle θ equals about – 30°. Consequently, the theoretical values of the angles $\theta = \pm 30°$ are now proved by the obtained simulation results.

The performance comparison of proposed broadband steerable antenna with some previous reported works [10-15] has been performed. As depicted in Table1, the proposed planar array antenna offers the broadest bandwidth of 846 GHz, highest directivity of 8.86 dBi with beam switching capability.

4. CONCLUSION

In this article, we have studied and designed a broadband beam-steering planar 1 × 2 array antenna for terahertz band applications that operates within the band [1.91-2.77 THz]. Our main design goal addressed in this work is to control the radiation pattern in two different directions with good performance. The suggested array antenna offers a broadband – 10 dB impedance bandwidth of 846 GHz (1.91 to 2.77 THz), and a peak directivity of 8.86 dBi at the operating frequency 2.45 THz. Furthermore, it offers two beams radiation patterns in two directions $\theta = \pm 30°$. Thus, this antenna is very suitable for future terahertz band applications, particularly in the future high-speed wireless communication, and material characterization in the THz band, medical imaging, arms and explosive detections.

REFERENCES

1. R.K. Kushwaha, P. Karuppanan, L.D. Malviya, *Phys. B Condens. Matter.* **545**, 107 (2018).
2. B. Choudhury, B. Danana, R.M. Jha, *PBG Based Terahertz Antenna for Aerospace Applications* (Springer: Singapore: 2015).
3. A. El Ansari, S. Das, N.E.A. El Idrissi, T. El-Arrouch, A. Bendali, *E3S Web Conf.* **351**, 01056 (2022).
4. S. Das, A. Karmakar, P.P. Sarkar, S.K. Chowdhury, *Microwave Opt. Technol. Lett.* **56** No 2, 316 (2014).
5. Ahmed Boutejdar, Mohammad A. Salamin, Mouloud Challal, Sudipta Das, Soumia El Hani, Saad S. Bennani, P.P Sarkar, Telkomnika **16** No 5, 2023 (2018).
6. Hicham Medkour, Mohamed Cheniti, Adam Narbudowicz, Sudipta Das, Erika Vandelle, Tan P. Vuong, *Microwave Opt. Technol. Lett.* **62** No 6, 2398 (2020).
7. A. El Alami, S. Das, B.T.P. Madhav, S. Dosse Bennani, *J. Instrum.* **14** No 5, P05002 (2019).
8. A. El Ansari, S. Das, T. El-Arrouch, N. El Amrani El Idrissi, *2022 9th Int. Conf. Wirel. Networks Mob. Commun. WINCOM 2022* (2022).
9. S. Lakrit, H. Medkour, S. Das, B.T.P. Madhav, W.A.E. Ali, R.P. Dwivedi, *J. Circuits, Syst. Comput.* **30** No 08, 2150133 (2021).
10. S.M. Shamim, M.S. Uddin, M.R. Hasan, M. Samad, *J. Comput. Electron.* **20** No 1, 604 (2021).
11. G. Varshney, *Silicon* **13** No 6, 1907 (2021).
12. K. Vijayalakshmi, C.S.K. Selvi, B. Sapna, *Opt. Quantum Electron.* **53** No 7, 395 (2021).
13. C.M. Krishna, S. Das, A. Nella, S. Lakrit, B.T.P. Madhav, *Plasmonics* **16** No 6, 2167 (2021).
14. M.A.K. Khan, M.I. Ullah, R. Kabir, M.A. Alim, *Plasmonics* **15**, No 6, 1719 (2020).
15. E. Thakur, N. Jaglan, S.D. Gupta, *Wirel. Pers. Commun.* **123** No 1, 407 (2022).

Широкосмугова мікросмугова антенна решітка 1 × 2 із зв'язувачем для керування променем: застосування в діапазоні терагерц (ТГц)

Abdelaaziz El Ansari[1], V. Jayaprakasan[2], K. Duraisamy[3], Sudipta Das[4], Tarik El-Arrouch[1], Najiba El Amrani El Idrissi[1]

[1] *Signal System and component Laboratory, Sidi Mohamed Ben Abdellah University – FST Fez, Morocco.*
[2] *Department of Electronics and Communication Engineering, Sreenidhi Institute of Science and Technology, Hyderabad*
[3] *Department of Biomedical Engineering, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, Tamil Nadu, India*
[4] *Department of Electronics and Communication Engineering, IMPS College of Engineering and Technology, Malda, W.B India*

Ширина забороненої зони терагерцового діапазону – це діапазон частот, що лежить між мікрохвильовим діапазоном і оптичним діапазоном, його спектр діапазону починається від 0,1 ТГц до 10 ТГц. Цей діапазон забезпечує нерозподілену широку смугу пропускання, а також дуже високошвидкісний зв'язок у футуристичних програмах. У цій статті представлено широкосмугову мікросмужкову антенну решітку 1 × 2, що живиться від гібридного зв'язувача в терагерцовому діапазоні (близько 2,45 ТГц). Для досягнення цієї широкосмугової антени спочатку розроблено та оптимізовано широкосмуговий гібридний роз'ем 3 дБ. Після цього два основних елемента квадратної форми з прорізами подаються через два вихідних порти з'єднувача. Отримані результати повідомляють, що запропонована антена пропонує ширину смуги – 10 дБ, що дорівнює 846 ГГц (від 1,91 до 2,77 ТГц) з хорошим узгодженням імпедансу, максимальна спрямованість дорівнює 8,86 дБ на робочій частоті 2,45 ТГц. Крім того, він пропонує можливість керувати променем, яку можна отримати шляхом перемикання вхідних портів з'єднувача. Таким чином, антена може створювати два промені під кутом ± 30°. Структура та результати моделювання запропонованої антени були виконані на підкладці Rogers RT/duroid 5880. Загальний розмір запропонованої мікросмужкової антенної решітки становить 110 × 112 × 1,56 мкм^3. Завдяки своїй здатності керувати променем і широкосмуговим характеристикам запропонована антена є потенційним кандидатом для застосувань у діапазоні терагерц, таких як характеристика матеріалів у діапазоні ТГц, медичне зображення та майбутній високошвидкісний бездротовий зв'язок.

Ключові слова: Антенна решітка, Керування променем, Широкосмуговий зв'язок, Ммікросмугова патч-антена, Трагерцовий діапазон, Відгалужувач.