Fabrication tolerance and gain improvements of microstrip patch antenna at terahertz frequencies

Rabbani, Muhammad; Ghafouri-Shiraz, Hooshang

DOI:
10.1002/mop.29920

Fabrication Tolerance and Gain Improvements of Microstrip Patch Antenna at Terahertz Frequencies

M. S. Rabbani* and H. Ghafouri-Shiraz†

School of Electronic Electrical and System Engineering

University of Birmingham, 52 Pritchatts Road

Edgbaston, B15 2TT, UK

*saqibrabbani05@hotmail.com and †ghafourh@bham.ac.uk

ABSRACT: In this paper, a technique has been proposed to design microstrip antenna arrays at terahertz (THz) frequencies with improved gain and fabrication tolerance. The antenna is designed at 100GHz frequency and fabricated with simple laboratory based PCB etching process. The gain is improved to 13.4dBi with the help of only three patch elements. The measured -10dB return loss bandwidth (BW) is 5.55% of the central frequency. The measured and the simulation results are all in good agreement.

Key words: THz microstrip antenna, 100GHz antenna, terahertz antenna, THz array, THz antenna fabrication

1. INTRODUCTION

Terahertz frequency spectrum (100GHz-10THz) is envisioned to be the essential host for future wireless services offering wide spectral bandwidth and fine resolution [1]. However, in order to attain an effective link budget for a THz wireless radio link, high gain antennas are vital to compensate the enormously high free space path loss [2]. Moreover, since the wavelength is very small (0.03mm-3mm) at THz frequencies hence, enlargement of the antenna's size, which is a fraction of the operating wavelength, is crucial to reimburse the fabrication cost and tolerance [3]. Also, integrability of the antenna with the other THz components is another obligation to acquire the overall device compactness [4]. Amongst the

other contender, microstrip antenna is one of the attractive candidates for THz wireless systems because of its potential robustness to encounter the aforementioned constraints [5].

In the recent years, some work has been reported on THz microstrip antenna designs [3]-[9]. However, in the reported THz microstrip antennas, the patch and the associated dimensions are calculated based on the conventional design equations and the overall antenna structure remained far below than the ordinary PCB etching limit of 152 μm line width/gap [10]. Moreover, only the simulation based results have been presented and there is a lack of experimental measurements to support the design concepts. To the best of the authors' knowledge, no particular work has been reported to improve the microstrip antenna size for THz frequencies in combination with the improved performance and ordinary fabrication and practical measurements.

In the present paper, we have demonstrated a procedure to design microstrip patch array at THz frequencies. The proposed method is verified by designing and testing a prototype at 100GHz frequency. The tested antennas' attributes are compared with a microstrip patch antenna designed at 100GHz with the traditional method. The proposed antenna gain has enhanced to a few folds while the antenna size has considerably improved to satisfy the conventional PCB etching restrictions as mentioned earlier. The return loss (S_{11}) is measured with the help of Anritsu's 145GHz VNA Apparatus 'ME7838D' incorporated with MA25300A module. The far-field pattern was measured with Agilent Technologies' 110GHz PNA Network Analyzer "E8361C" in combined with the extension module "N5260-60003".

2. MICROSTRIP ANTENNA DESIGN PROCEDURE

Conventional rectangular microstrip patch antenna is half-wavelength resonator in which the patch length and width determine the operating frequency and the antenna's input impedance, respectively [10]. Traditionally, for the low microwave frequency designs, the width of the

patch is set to be comparatively equal to the patch length to keep the antenna size small and to avoid the excitation of unwanted resonance modes [10]. In this way, an ordinary patch antenna gives a high input impedance of above 200Ω which is matched with the standard 50Ω impedance, in one way, by employing an impedance transformer (IT) of over 100Ω microstrip transmission line (MTL). Such a high impedance MTL is usually wide enough to be etched on a dielectric material of above 0.5mm substrate thickness which is commonly used for low microwave frequencies. However, for THz microstrip antennas, a very thin dielectric material is required to satisfy the limit: $h < \lambda_0 / (4\sqrt{\varepsilon_r})$ [11] where h is substrate thickness, λ_0 is the wavelength in free space and ε_r is relative dielectric constant of the substrate material. Etching of the aforementioned high impedance microstrip line on such a thin material is challenging because the line width falls far below the PCB etching limit of 152 μm [10]. In order to overcome this problem, we have reduced the overall antenna's input impedance (Z_{in}) much lower than 50Ω (i) by extending the patch width beyond the ordinary size, and (ii) by making an array of multiple patches fed in series. The total input impedance of an array of 'n' identical patch elements appropriately fed in series is expressed as [10]:

$$Z_{in} = \frac{Z_p}{n} \qquad (1)$$

where Z_p is the input impedance of the individual patch element. Subsequently, such a low antenna input impedance is matched with the standard 50Ω impedance through the corresponding microstrip line IT of low impedance which is wide enough to convince the conventional fabrication limits.

The geometry of the proposed microstrip array is illustrated in Fig. 1. The array consists of three wide patches of the same size which are fed in series. The patch width (W) and length (L) are calculated from the following expressions [12]:

$$W = \frac{\lambda_0 (2M+1)}{\sqrt{2(\varepsilon_r + 1)}} \qquad (2)$$

$$L = \frac{\lambda_0 (2N+1)}{2\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (3)$$

where M and N are non-negative integers (in our present design we chose $M = 1$ and $N = 0$), ε_r and ε_{eff} are the relative and the effective dielectric constants, respectively, and ΔL is patch length extension due to the fringing filed effect [10]. The input impedance of the individual patch is given as [12]:

$$Z_p = \frac{59.81\lambda_0}{W} \qquad (4)$$

By substituting Eq .(4) into Eq.(1), we can obtain the total array's input impedance as:

$$Z_{in} = \frac{59.81\lambda_0}{nW} \qquad (5)$$

Ultimately, 'Z_{in}' is matched with the standard 50Ω impedance through the MTL used as quarter-wavelength impedance transformer. The characteristic impedance 'Z_0' and the width 'W_T' of the microstrip TL are given as [13]:

$$Z_0 = \sqrt{50 Z_{in}} \qquad (6)$$

$$W_T = \frac{376.99h}{Z_0\sqrt{\varepsilon_r}} \qquad (7)$$

Substituting Eq. (5) into Eq. (6) and Eq. (6) into Eq. (7) give the following final expression for the width of the MTL in terms of the 'W' and 'n':

$$W_T = 6.89h\sqrt{\frac{nW}{\varepsilon_r \lambda_0}} \qquad (8)$$

Equation (8) explains the motive of increasing 'n' and 'W' to widen the transmission line width 'W_T'. Since the transmission lengths 'L_{T1}' and 'L_{T2}' provide impedance transformation

and phase matching on the patches, respectively, they can be computed by the following expressions [12]:

$$L_{T1} = (2P+1)\lambda/4 \qquad (9)$$

$$L_{T2} = (2Q+1)\lambda/2 + 2\Delta L \qquad (10)$$

where P and Q are non-negative integers (in our design we used P=1 and Q=0) and λ is the operating wavelength. The array's final dimensions are acquired through the simulation based optimization process by using CST microwave studio.

3. RESULTS AND DISCUSSIONS

For the comparison purpose, initially, a conventional single patch microstrip antenna is designed at 100GHz frequency on a low loss dielectric material 'RT/Duroid5880' with $\varepsilon_r = 2.2$ and substrate thickness $h = 127\,\mu\text{m}$ based on the traditional method as described in the literature [10]. Figure 2 shows the structure of the patch antenna and its dimensions are given in Table I. From Table 1, it can be seen that the overall antenna size is quite small and the transmission line width 'W_T' is $100\,\mu\text{m}$ which is far below the fabrication limit $(152\,\mu\text{m})$ of the conventional cost-effective etching process.

Figure 3 depicts the simulated return loss (S_{11}) and far-field radiation patterns (FRP) of the designed patch antenna. Figure 3(a) indicates that the -10dB return loss BW is 6% whereas the antenna gain and efficiency at 100GHz are 7.56dBi and 66.7%, respectively.

Subsequently, by using the proposed method as described in section II, a microstrip array of 3 patches is designed at 100GHz frequency on the same Duroid substrate as that used for the conventional antenna shown in Fig. 2. Table 2 shows the optimized dimensions of the array structure (see Fig. 1) where it is clear that all PCB dimensions are fabricable with the ordinary etching process. The fabricated prototype and the experimental set up are demonstrated in Fig. 4. A W-band flange launcher (also called 1-mm connector) is employed

to connect the antenna with the VNA module. The far-field radiation pattern is measured in the lab room assuming free space conditions considering negligible reflections from the surroundings because of the high signal attenuation (72.44dB/m) at 100GHz frequency.

Figure 5 shows the simulated and measured return loss and FRP of the 100GHz microstrip array designed using the proposed method. From Fig. 5 (a), it is clear that the minimum measured return loss is -17.97dB at 99.27GHz and the simulated and measured BWs are 8.87 % and 5.55%, respectively. Both the simulated and measured antenna gains at the resonant frequency of 99.5GHz are, respectively, 13.4dB and 12.2dBi where the former is obtained by applying the two –identical antenna method explained in [14]. The antenna simulated efficiency is about 94%.

Figure 5(c) indicates that the main radiation beam is focused at around 0^0 in both planes. The simulated and measured 3dB beam widths in H planes are 40.2^0 and 48.28^0, respectively, and that in E plane is 26.1^0. Figure 6 shows the gain frequency plot of the designed antenna. The result shows that the gain is maximum at the resonant frequency of 99.5GHz and it remains above 11.5dB in the whole operating band (98GHz-103GHz). Table-3 compares, BW, gain and efficiencies of the two designed antennas (i.e. the conventional single patch antenna and the proposed 3-patch array). From Table 3 we can conclude that the performance of the proposed 3-patch array antenna is considerably enhanced as compared with the conventional patch antenna.

4. CONCLUSION

A method has been developed to design THz microstrip antenna arrays with improved gain and geometrical dimensions to ease the fabrication reluctance when conventional PCB etching method is used. The design concept was verified through both simulation and measurement on a proposed 100GHz 3-patch array which was exited through a series feeding

networks. The overall antenna performance is enhanced as compared with the microstrip patch antenna designed using the conventional etching method. In order to design microstrip antenna arrays at further higher THz frequencies, higher values of integers ‘M’, ‘N’, ‘P’ and ‘Q’ should be chosen in Eqs. (2) to (6) and (9) to (10) so that the antenna dimensions remain conventionally fabricable. However, much higher values of these constants may cause some unwanted resonances at undesired frequencies which may limit the antenna size extension and hence, the design frequency to go far beyond 1THz as discussed in [12].

References:

[1] K. Huang, and Z. Wang, Terahertz terabit wireless communication, Microwave Magazine, IEEE 12, no. 4 (2011): 108-116.

[2] F. I. Akyildiz, J. M. Jornet, and C. Han, Terahertz band: Next frontier for wireless communications, Physical Communication 12 (2014): 16- 32.

[3] K.R. Jha, G. Singh, Improved Performance Analysis of Square Patch Microstrip Antenna at Terahertz Frequency, Advances in Recent Technologies in Communication and Computing, 2009. ARTCom '09. International Conference on, vol., no., pp.676, 679, 27-28 Oct. 2009

[4] E. Seok, C. Cao, D. Shim, D. J. Arenas, D. B. Tanner, and C. Hung, A 410GHz CMOS push-push oscillator with an on-chip patch antenna. In Solid-State Circuits Conference, 2008. ISSCC 2008. Digest of Technical Papers. IEEE International, pp. 472-629. IEEE, 2008.

[5] K.R. Jha, G. Singh, Terahertz planar antennas for future wireless communication: A technical review. *Infrared Physics & Technology* 60 (2013): 71-80.

[6] K.R. Jha, G. Singh, Terahertz planar antennas for future wireless communication: A technical review. *Infrared Physics & Technology* 60 (2013): 71-80.

[7] K. R. Jha, and G. Singh, Dual-band rectangular microstrip patch antenna at terahertz frequency for surveillance system. Journal of computational electronics 9, no. 1 (2010): 31-41.

[8] M. Younssi, J. Achraf, M. H. Yaccoub, E-M. Ahmed El, and A. Noura, Study of a Microstrip Antenna with and Without Superstrate for Terahertz Frequency, *International Journal of Innovation and Applied Studies* 2, no. 4 (2013): 369-371.

[9] G. Singh, Design considerations for rectangular microstrip patch antenna on electromagnetic crystal substrate at terahertz frequency, *Infrared Physics & Technology* 53, no. 1 (2010): 17-22.

[10] R. Bancroft, (2009). Microstrip and printed antenna design [electronic resource]. Raleigh, NC, SciTech Pub.

[11] James, J. R., and A. Henderson. High-frequency behaviour of microstrip open-circuit terminations, *IEE Journal on Microwaves, Optics and Acoustics* 3, no. 5 (1979): 205-218.

[12] M. S. Rabbani, and H. Ghafouri-Shiraz, Size improvement of rectangular microstrip patch antenna at MM-wave and terahertz frequencies, Microwave and Optical Technology Letters 57, no. 11 (2015): 2585-2589.

[13] G. Bianchi, and R. Sorrentino, *Electronic filter simulation & design*, New York: McGraw-Hill, 2007.

[14] McMaster University, Basic methods in Antenna Measurements, Online: accessed on Oct. 26th, 2015 at:

http://www.ece.mcmaster.ca/faculty/nikolova/antenna_dload/current_lectures/L08_Measure.pdf