

A novel feed network for microstrip patch antenna at THz frequency band

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Abstract – *In this paper, a novel feed network for patch antenna with star shape has been presented. This antenna works at THz band having important. Designed antenna at 200GHz with new feed network increased bandwidth and compared with reported similar antennas has capability that bandwidth changes from 10% up to 53%. Proposed antenna has engineered capability between bandwidth and gain of antenna.*

Keywords: THz frequency, gain, feed network, bandwidth, star patch antenna, PBG substrate.

1. Introduction

Terahertz regime of the electromagnetic spectrum extends from millimeter through micrometer in wavelength encompassing frequency approximately 0.1 to 10 THz [1]. Due to unique feature of less hazardous effect on human being, the experimentation on surveillance system with terahertz devices are in progress. [2]. The atmospheric path loss is the main obstacle to the realization of the commercial THz wireless communication system. It is necessary to increase the gain of the antenna in the terahertz system to cover the longer distance. The substrate loss is an obstacle to the millimeter and sub-millimeter wave microstrip antenna [3]. Microstrip antennas have low gain about 5-6dB. The substrate plays important role in achieving desirable antenna characteristics. With the increase in dielectric permittivity the antenna directivity is increased but surface wave loss increases and leading to degradation of the gain and directivity because power couple into substrate modes. Reduction of surface waves improves antenna performance. Photonic Band Gap (PBG) substrate can offer a real solution to this problem when it is used as antenna substrate [4]. In this paper used PBG substrate for proposed antenna. The very large bandwidth provided by the THz Band opens the door to a variety of applications which demand ultra-high data rates and allows the development of a plethora of novel applications in classical networking scenarios as well as in new nanoscale communication paradigms [5]. G-band frequencies (140-220 GHz) have been experiencing resurgence recently as many systems have been allocated or

are proposing to us frequencies within this operating band. Such applications include high-data rate wireless indoor communication systems, direct detection radiometers for remote atmospheric sensing, high-resolution passive and active mm-wave imaging applications, systems for detection of concealed weapons, and aircraft navigation in zero visibility conditions [6]. These applications have raised the demand for integrated mm-wave antennas with large bandwidth, high gain, and small size. Traditionally, horn antennas would be considered to achieve high gain solutions; however, their overall size and associated losses resulting from routing signals off-chip to a transition from the active MMICs to the horn make these antennas unattractive [7, 8].

2. Related Work

Adel S. Emhemmed, Ian McGregor, Khaled Elgaid [6] design 200GHz broadband proximity coupled patch antenna. Their results achieve show that the bandwidth is 13GHz from 190.8GHz to 203.8GHz, determined from 10dB return loss and the gain is about 2.98dB at G-band frequencies. Bernhard Klein, Michael Jennings, Patrick Seiler, Dirk Plettemeier [9] design Wideband Half-Cloverleaf Shaped Antenna On-chip for 160-200GHz Applications. Simulation results show maximum absolute gain of 2.2dBi at 200GHz. B. Benakaprasad, A. Eblabla, X. Li, and K. Elgaid and D.J. Wallis, I. Guiney, and C. Humphreys [10] design Terahertz Microstrip Elevated Stack Antenna Technology on GaN-On-Low Resistivity Silicon Substrates for TMIC. Resonance

frequency in agreement with the modelling at 0.27 THz and a measured S11 as low as -18 dB was obtained. A directivity, gain and radiation efficiency of 8.3 dB, 3.4 dB, and 32% respectively was exhibited from the 3D EM model. Z. Jiang, S. M. Rahman, P. Fay, J. L. Hesler and L. Liu [11] design Tunable 200 GHz lens-coupled annular-slot antennas using Schottky varactor diodes for all-electronic reconfigurable terahertz circuits. They present a frequency tunable lens coupled annular-slot antenna (ASA) using a Schottky varactor diode operating at ~200 GHz. This type of tunable lens-coupled ASA is very promising for use as the detector elements in tunable/reconfigurable THz circuits, such as FPAs. We have designed an ASA on a silicon substrate for operation in G-band (140–220 GHz) with an unloaded resonant frequency of ~200 GHz. Michael Jennings, Bernhard Klein, Ronny Hahnel, Dirk Plettemeier [12] design On-Chip Integrated Antennas for 200 GHz Applications. All antenna elements are designed for an operational frequency of 200 GHz for wireless computer board-to-board and chip-to-chip communication. The gain of the antenna elements is above 0 dBi and all elements achieve a bandwidth larger than 10 GHz.

3. Patch antenna basic structure

The proposed antenna in this paper has two layers. Upper layer is PBG structure and bottom layer is homogeneous substrate. Shape of patch is star with 8 edges. This patch obtained by combining two same dimensions' squares located 45° relative to each other. The host material of the PBG material is Teflon ($\epsilon_r=2.1$) whose length and width are 1000 μm and 1000 μm , respectively. In the host material, cylindrical air defects of radius $r = 30 \mu\text{m}$ and center-to-center inter-cylinder spacing $a = 100 \mu\text{m}$, have been used. The PBG substrate thickness and the length of air cylinders are equal. The radiating patch, feed-line and ground plane are made of copper of thickness 20 μm . Proposed new feed network is shown in Fig.1a, b. To excite the antenna, the wave port has been employed.

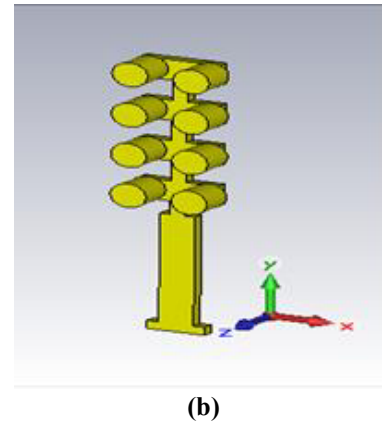
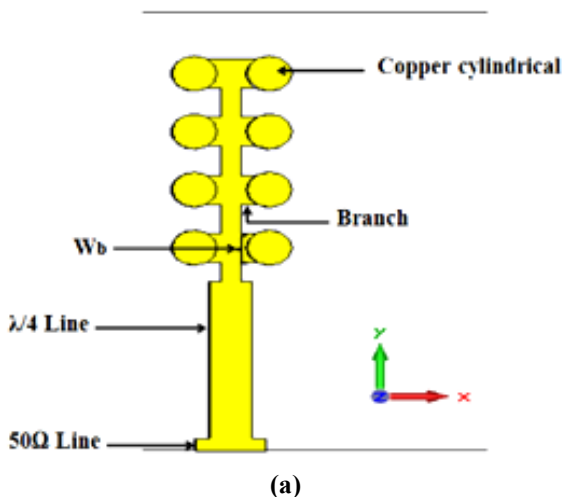


Figure 1. New feed network (a) front view (b) side view

4. simulation and results

A. PATCH ANTENNA WITH USING MICROSTRIP FEED LINE

Initially, star patch antenna fed by commercial method microstrip feed line. Structure of antenna is shown in Fig.2. Dimension of patch is 476.3 μm . width and length of feed line is 32 μm and 210 μm respectively. Thickness of PBG substrate (h) is 60 μm . The width and height of the port is equal to 200 and 120 μm , along x- and z-axis, respectively. The port is placed at ymin position equal to -500 μm .

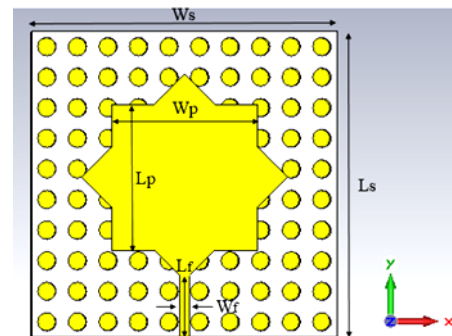


Figure 2. patch antenna with feed line

Antenna simulated by CST STUDIO SUITE. Simulation results of this antenna is shown in Table.1. Bandwidth determined from -10dB return loss.

Table.1 Simulation results of antenna with using feed line

W_p (μm)	476.3
L_p (μm)	476.3
W_f (μm)	32
h (μm)	60
Frequency (GHz)	200
S_{11} (dB)	-43.10
Bandwidth (GHz)	7.68
Bandwidth (%)	3.84
Gain (dB)	6.83
Radiation efficiency (%)	92.69
Z_{11} (Ω)	49.13

B. PATCH ANTENNA WITH USING NEW FEED NETWORK

In this segment, we simulated star patch antenna with using feed network that is shown in Fig.1. This feed network includes a 50Ω line, a $\lambda/4$ transformer for impedance matching between patch antenna and the 50Ω line and also the copper cylinders connected to patch. This antenna is shown in Fig.3 a, b. Thickness of homogeneous substrate (h_1) is $40\ \mu\text{m}$. The width and height of the port is equal to 300 and $130\ \mu\text{m}$, along x- and z-axis, respectively. The material of bottom substrate is Teflon ($\epsilon_r=2.1$). Distance between two substrates is equivalent $20\ \mu\text{m}$. Simulation results this antenna is shown in Table.2.

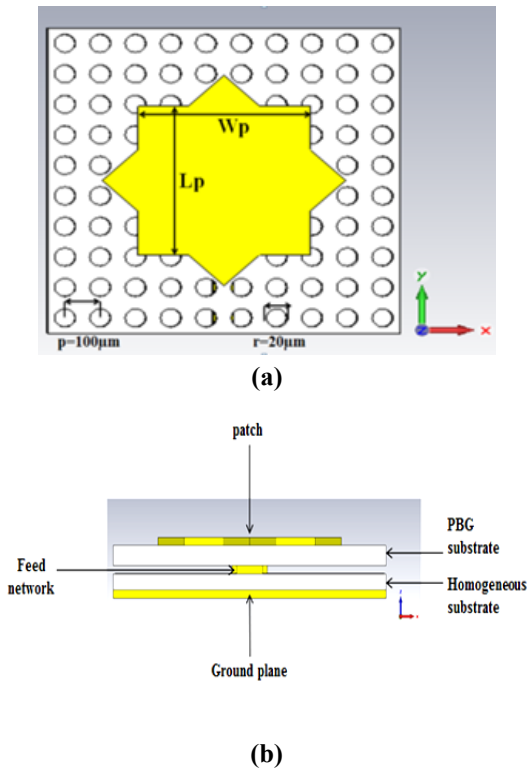


Figure 3. Star patch antenna with new feed network (a) antenna with feed network on bottom layer (b) side view of patch antenna with two layers

Table.2 Simulation results of patch antenna with using new feed network

W_p (μm)	481.5
L_p (μm)	481.5
h (μm)	60
h_1 (Thickness of bottom sub) μm	40
W_b (μm)	50
Frequency (GHz)	200
S_{11} (dB)	-23.47
Bandwidth (GHz)	25.79
Bandwidth (%)	12.89
Gain(dB)	7.71
Radiation efficiency (%)	94.19
Z_{11} (Ω)	46.10

Fig.4 has shown new feed network increased -10dB bandwidth from 3.84% to 12.89%. Table 1 and 2 indicate that gain of antenna for new feed network increased. Cartesian plots of gain of antenna shown in Fig.5 and Fig.6.



Figure 4. Return loss (dB), star patch antenna with feed line(blue) and new feed network(red)

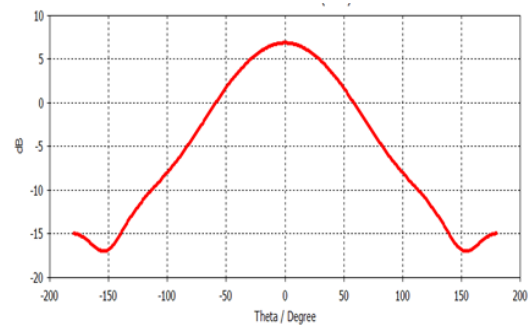


Figure 5. Gain of antenna for feed line

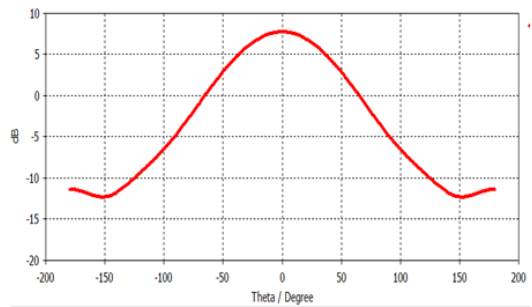


Figure 6. Gain of antenna for new feed network

Fig.7 and Fig.8 indicate radiation efficiency and gain vs frequency respectively. Radiation efficiency and gain vs frequency plots are more smoothly for patch antenna with new feed network compared to feed line.

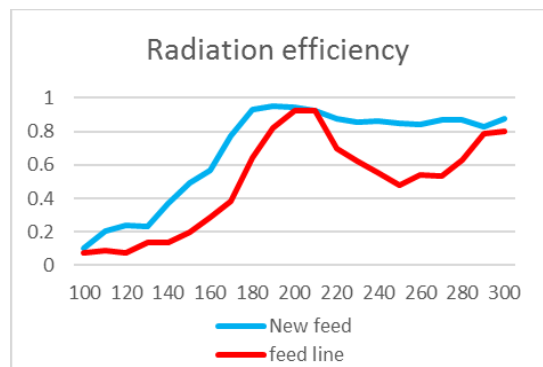


Figure 7. Radiation efficiency

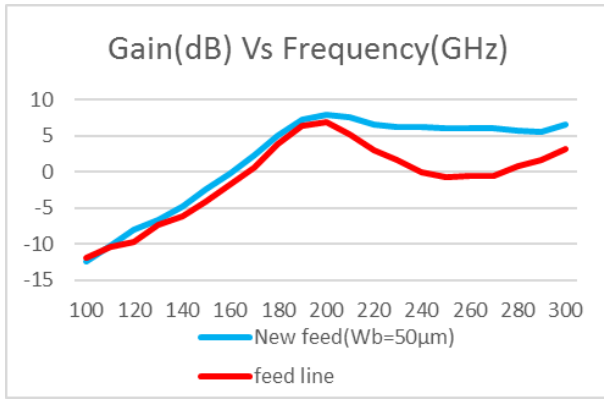


Figure 8. Gain vs Frequency

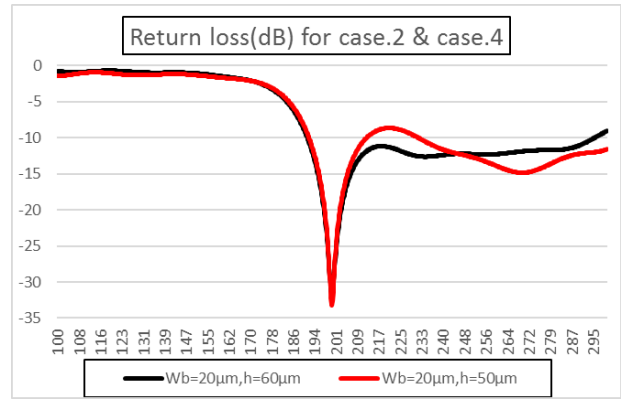


Figure 10. effect change of W_b on Gain of antenna

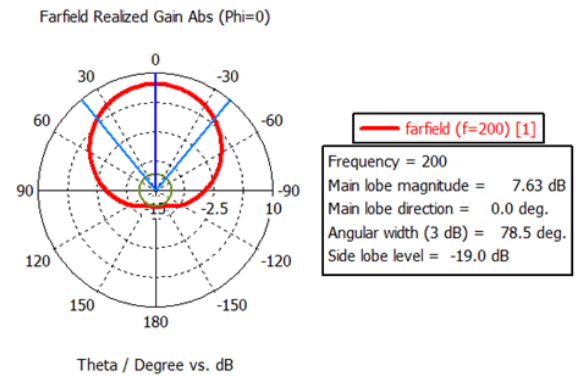
C. EFFECT OF NEW FEED NETWORK ON ELECTRICAL PERFORMANCE

In previous section, we have considered a star patch that fed by new feed network. In this section we investigated effect of change new feed network parameters on antenna performance. The simulated results show the electrical parameters like return loss, gain and bandwidth of proposed models. These electrical performances of parameters are compared between conversional feed line and new feed network on Table.3.

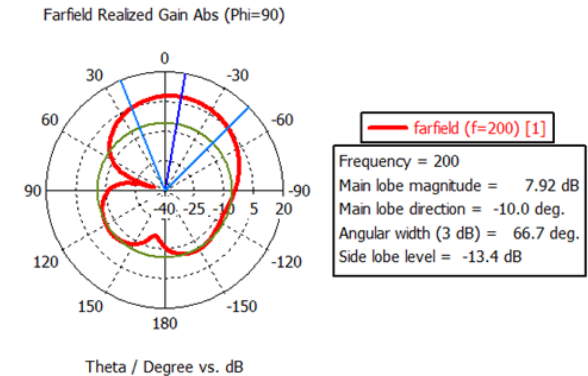
Table.3 Results of change new feed network on antenna electrical performance (Gain is at $\phi=0^\circ$)

	Case1	Case2	Case3	Case4
$W_p(\mu\text{m})$	489	488.5	487	489
$L_p(\mu\text{m})$	489	488.5	487	489
$h(\mu\text{m})$	60	60	60	50
$h_1(\mu\text{m})$	40	40	40	40
$W_b(\mu\text{m})$	30	20	10	20
Frequency (GHz)	200	200	200	200
Bandwidth (GHz)	80	104.6	106.9	20.89
Bandwidth (%)	40	52.3	53.45	10.44
Return loss(dB)	-38.91	-31.83	-27.3	-33.09
Gain (dB)	7.67	7.48	7.63	7.85
Radiation eff. (%)	54.61	91.30	94.39	93.54
$Z_{11}(\Omega)$	49.76	50.94	51.42	49.02

The simulated results in Table.3 show with decrease width of branches in new feed structure (W_b), bandwidth of antenna increase up to 53%. For case.4 in Table.3 thickness of PBG substrate selected $50\mu\text{m}$. In this case bandwidth decreased to 10.44% but gain of antenna increased. Fig.9. show return loss for case.2 & case.4 in Table.3. Fig.10 show plots of gain vs frequency for each four cases in Table.3. This figure indicates gain of antenna with change W_b , not change much. Fig.11 show radiation pattern (gain) of antenna in case.3. Radiation pattern in E-plane is along broad-side direction and in H-plane main lobe is at -10° direction. Co-polarization and cross-polarization plots in E-plane for case.3 has shown in fig.12.

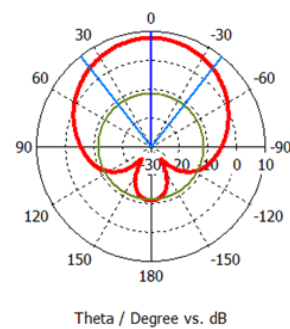


(a)



(b)

Figure11. radiation pattern of antenna for $W_b=10\mu\text{m}$ (a) E-plane (b) H-plane



(a)

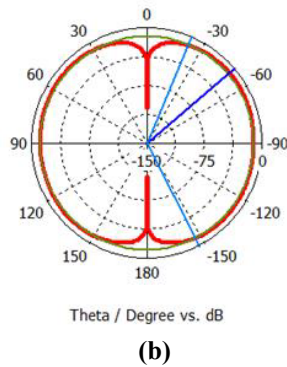


Figure 12. (a) co-polarization (b) cross-polarization

5. conclusion

In this paper, we presented and simulated a star patch antenna with new feed network at 200 GHz. We have shown this feed network offers larger bandwidth compared to patch antenna fed by feed line method. We also investigated effect of changing width of feed network branches (W_b) and thickness of substrates; bandwidth of antenna between 10-53% is available. According to simulation results, we can engineer between bandwidth and gain of proposed antenna.

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