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A Compact Wideband 24 GHz End-Fire Helix Antenna with High Gain Turn Ratio in Planar Technology

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Abstract—A wideband end fire antenna architecture in planar technology with fewer turns: helix antenna in planar technology adopting thickness of quarter wavelength is suggested. A wideband 24 GHz helix antenna with 2.25 turns in Rogers compressed RT 4350 technology is presented. The antenna has a bandwidth of 6.2 GHz for S_{11}, gain of 9.3 dBi, half power width of 39.5° and 39°, respectively in X-Z and X-Y planes. This helix antenna is characterized by wide bandwidth, high gain, high half power width, compactness, and high gain turn ratio. It could also be utilized in antenna design for other frequency bands with compressed PCB technology, as well for on-chip THz antenna design.

1. INTRODUCTION

For an RF system, one difficult task is to design high output power transmitters. High gain antenna helps improve the EIRP of the transmitter. Reference [1] compares an isometric linear broadside array with an end fire array with the same N elements. Both directivity (D) and half power beam width (HP) of end fire array are twice of the broadside array according to [1]. Therefore, performance of an end fire array is much better than a broadside array. This is the reason that this paper focuses on an end fire array antenna and presents an end fire array antenna in planar technology.

Various researches have been carried out upon helix antennas in planar technology. In [2], a 5-turn X-band helix antenna with an additional reflective plane is fabricated on RO4003 dielectric substrates with gain of 11–12 dBi. In [3], a 5-turn helix 28 GHz antenna with 10 dBi gain is presented in RT5880 substrates for 5G application. In [4], an 8-turn S-band helix antenna with an additional reflective plane is given with gain of 10 dBi in RT 5880 technology. In [5], a 4-turn planar helix antenna at 10 GHz with gain of 8 dBi is demonstrated. In [6], an 8-turn planar helix antenna at 9.75 GHz with gain of 8.5 dB is demonstrated. In [7], fabricated in borosilicate glass substrate with a thickness of 350 μm, a 3.25-turn planar helix antenna at 58 GHz with gain of 6.3 dB is presented. In [8], a 15-turn planar helix antenna at 4 GHz with gain of 7.6 dB is presented in Roger 4003C technology. In this work, utilizing Roger RT 4350 compressed PCB technology, a high gain and compact planar helix antenna, whose reflective plane is included in the rogers PCB design, with fewer turns (only 2.25 turns) is designed.

2. A WIDEBAND END FIRE ANTENNA IN PLANAR TECHNOLOGY

This work tries to imitate the axial-mode helix antenna in planar technologies like PCB technology, or CMOS, BiCMOS technologies, etc. In [9], a helix antenna with turn radius of λ/π and turn distance of $\lambda/4$ is suggested. This work tries to mimic the original helix antenna design in planar technology. At 24 GHz, quarter wavelength is around 3 mm, which is very close to double of the thickness of roger 4350 PCB substrate: 1.524 mm; therefore in this work, a compressed rogers 4350 PCB technology is

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tried for the design of a 24 GHz end fire antenna. Two rogers 4350 PCBs with a thickness of 1.524 mm are compressed and adhered together to form an RF PCB with a thickness around 3 mm.

Figure 1 shows an imitated axial-mode helix antenna in planar rogers 4350 PCB technologies with 2.25 turns. Darker color indicates the metals and vias of the helix antenna, and the remainder is dielectric material of rogers 4350.

Compared with axial-mode helix antenna, in order to adapt to planar technology, this PCB antenna utilizes straight metal paths in the top and bottom planes, and vertical vias through the PCB to form the square coil, and realize a new end fire antenna in planar technology. Ground plane of the helix antenna is realized by arrays of vertical vias throughout the top, middle, and bottom metals as shown in Figure 1.

One turn is a typical repetition cycle of the structure in a helix antenna. In Figure 1, a turn is composed of a straight metal path in the top plane, a straight metal path in bottom plane, and two vertical vias throughout the RF PCB which connect the straight metal paths in top and bottom planes. Width of the metal path in this work is 0.28 mm.

Figure 2 shows the dimension estimation of an imitated axial-mode helix antenna in planar PCB technology. Height H, width W, and length L of the square coil are roughly quarter wavelength.

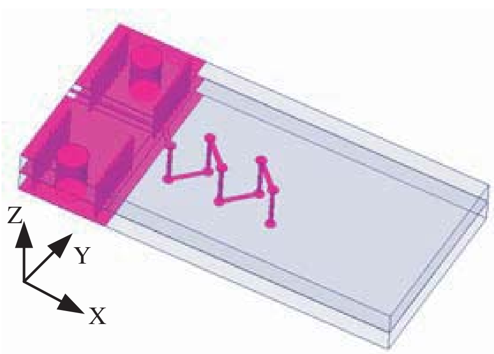


Figure 1. An imitated axial-mode helix antenna in planar PCB.

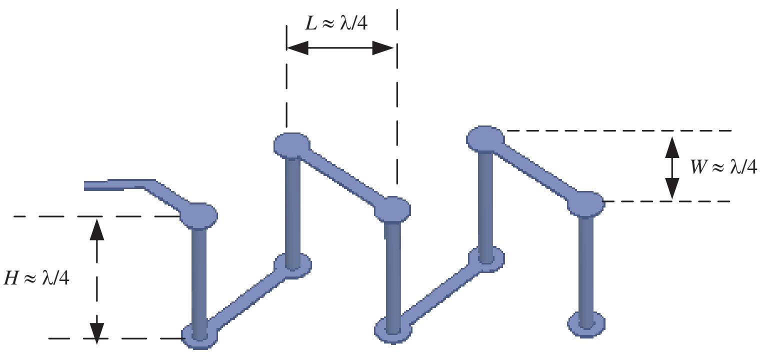


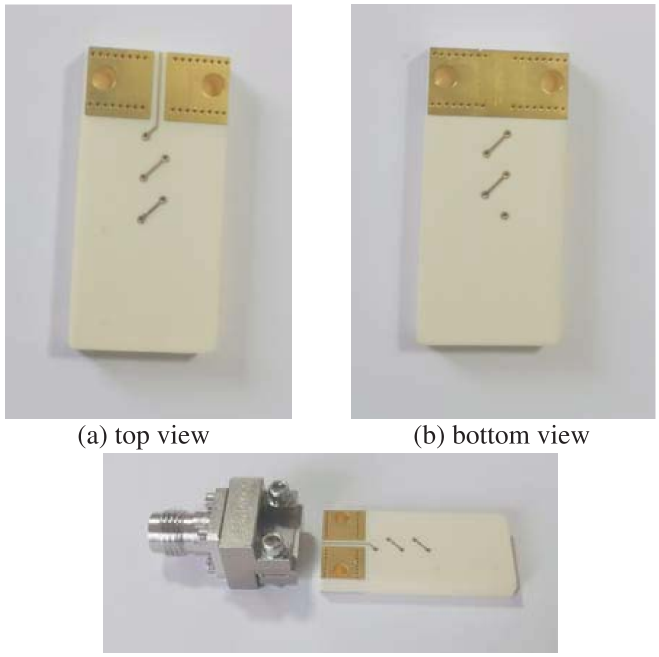
Figure 2. Dimension of an imitated axial-mode helix antenna in planar PCB.

Figure 3 shows the top view, bottom view, and side view of the antenna prototype. In Figure 3(c), side view, a Southwest 2.4 mm end launch connector 1492-04A-6 is also included to show the size of the antenna prototype.

3. SIMULATION AND MEASUREMENT RESULTS

After optimization of L, W, and H of the helix antenna, Figure 4 shows the simulation and measurement results of S parameter of the helix antenna with 2.25 turns. Measurement results agree well with the simulation ones. Helix antenna with 2.25 turns has a bandwidth ($S_{11} < -10$ dB) extending from 21.8 GHz till 26.5 GHz (26.5 GHz is the highest frequency of the network analyzer). Simulated bandwidth of the antenna is 6.2 GHz from 21.8 GHz to 28 GHz.

Figure 5 shows the simulated and measured antenna gains of the helix antenna with 2.25 turns in X-Z and X-Y planes. Measurement results agree with the simulation ones. The antenna achieves 9.3 dB maximum gain and a 39.5° half power width (from −34° to 5.5°) in X-Z plane. Beam is tilted in X-Z plane by 15° due to phase error of the two turns, and the authors will correct the phase error in the next version of the planar helix antenna. In X-Y plane, the antenna achieves 8 dB maximum gain and a 39° half power width (from −18° to 21°). Measured antenna efficiency is 0.86.



(a) top view (b) bottom view

(c) side view

Figure 3. (a) Top view, (b) bottom view and (c) side view of the antenna prototype.

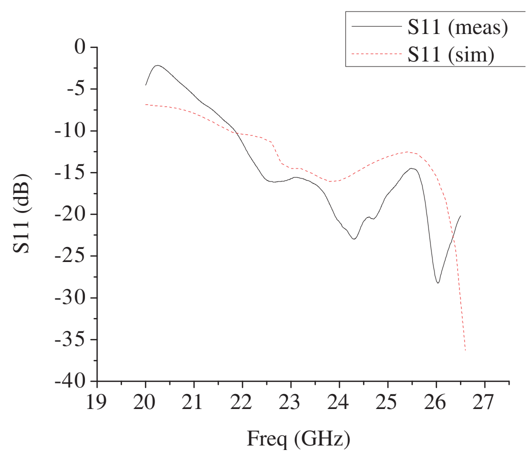


Figure 4. Simulation and measurement results of S parameter of the helix antenna with 2.25 turns.

4. MORE DISCUSSIONS ON HELIX ANTENNA

Table 1 gives a comparison of this work with state of the art. Antennas in [2, 4] require additional reflective plane; therefore, their compactness is low, while antennas of [3, 5–8] and in this work include reflective plane in PCB design, and compactness is high. Thicknesses of all antennas in [3–8] are much less than quarter wavelength; thickness of the antenna in [2] is comparable with quarter wavelength, but it is very uncompact in both PCB design and reflective plane design. Compared with the works in [2–8], the antenna in this work only requires 2.25 turns to achieve a gain of 9.3 dBi, because it adopts a thickness which is close to quarter wavelength. Therefore due to its mimicking original helix antenna, antenna topology in this work could achieve higher gain with fewer turns. Table 1 also compares the gain turn ratio (dB/turn) of various antennas, and the antenna in this work has a maximum gain turn ratio.

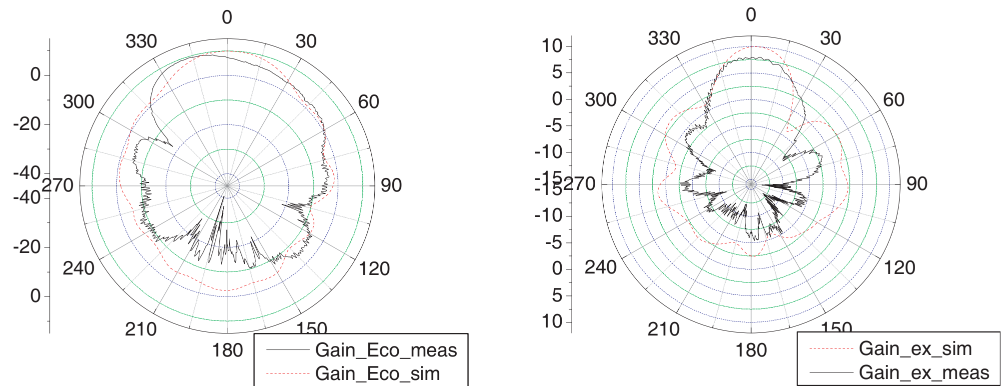


Figure 5. Simulation and measurement results of gain in X-Z and X-Y plane of the helix antenna with 2.25 turns.

Table 1. Comparison state of the art.

	Freq (GHz)	Gain (dBi)	Thickness (mm)	Turns	Compactness	Gain turn ratio (dB/turn)
[2]	$8 \sim 11$	$11 \sim 12$	8	5	low	2.4
[3]	28	10	1	5	high	2
[4]	2.4	10	0.254	8	low	1.13
[5]	$7 \sim 12$	8	3.175	4	high	2
[6]	9.75	8.5	3.175	8	high	1.06
[7]	58	6.3	0.35	3.25	high	1.9
[8]	1.8–5.8	7.6	0.508	15	high	0.51
This work	24	9.3	3	2.25	high	4.1

The helix antenna in this work is characterized by high gain, wide bandwidth, high half power width, compactness but with fewer turns. The antenna is neither linearly polarized, nor circularly polarized. The helix antenna in this work is close to circularly polarized, but it is not circularly polarized; therefore, its measured axial ratio is deteriorated and is below 8 dB in the range 23.5 GHz–24.5 GHz. In future, in planar technologies with more metal layers, on-chip helix antenna in planar technology which will mimic traditional helix antenna more could be designed, and it will be more close to circularlt polarized and achieve better axial ratio performance. With compressed PCB technology, this kind of helix antenna which adopts thickness of quarter wavelength could also be utilized in other frequency bands. Besides, for mm-wave and THz signals, quarter wavelength decreases with increase of frequency, and this kind of antenna is even applicable to on-chip THz antenna design.

5. CONCLUSION

A compact and wideband end fire antenna architecture in planar technology with fewer turns: helix antenna in planar architecture adopting thickness of quarter wavelength is suggested. A wideband 24 GHz helix antenna with 2.25 turns in compressed PCB rogers 4350 is presented. The antenna has a bandwidth of 6.2 GHz for S_{11}; gain of 9.3 dBi, half power width of 39.5° and 39° in X-Z and X-Y planes, respectively. This helix antenna is characterized by wide bandwidth, high gain, high half power width, compactness, and high gain turn ratio. It could also be utilized in antenna design for other frequency bands with compressed PCB technology, as well for on-chip THz antenna design.

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