Study on Coplanar Fed CPW Patch Antennas

K. Li, C. H. Cheng, T. Matsui and M. Izutsu

Photonic Tech. Div., Communications Research Laboratory (CRL), MPT of Japan
4-2-1 Nukui-Kitamachi, Koganei-shi, Tokyo 184-8795, Japan.
E-mail: keren@crl.go.jp, Tel: +81-42-327-6883, Fax: +81-42-327-6106

1. INTRODUCTION

Coplanar waveguide (CPW) fed antennas have been increasingly studied in recent years [1-6]. The coplanar waveguide, compared with the microstrip line, has advantages such as low radiation loss, less dispersion, uniplanar configuration and easy mounting of shunt lumped elements or active devices without via hole as for the microstrip line [2, 7]. In our previous paper, we have employed CPW fed slot antennas to the direct connection with a photodetector operating at microwave and millimeter-wave frequencies in radio on fiber system [8]. The photodetector has a CPW transmission line for output and then requires a CPW feed line for direct connection to the antenna. From the system side, high efficiency antenna is required. One objective of this work is to find an antenna with high radiation efficiency and a CPW feeding structure for easy connection to the photodetector or some microwave photonic devices. Both slot antenna and loop slot antenna are suitable to the CPW feeding structure [3, 5]. During the investigation of various kinds of planar antenna structures including the slot and loop slot antenna, we found an antenna which consists of a patch surrounded by closely spaced ground conductor and a CPW feed line, as shown in Fig. 1, and can meet our above requirements. The antenna looks very similar to the loop slot antenna as given in [3, 5]. After many simulations by changing different dimensions of the patch and slots, we discovered that the antenna behaves more like a microstrip patch antenna than a loop slot antenna. Particularly, the resonant frequency of the antenna is primarily determined by the patch length L of about a half guided wavelength instead of the loop size. Electromagnetic simulation demonstrated the similar distribution of the electric fields around the slots as that of microstrip patch. The input impedance variation versus the length of patch L has also the similar tendency and we can then realize a impedance matching by only adjust the width W of the patch. These simulation results lead us to consider the antenna shown in Fig. 1 as a patch antenna, not a loop slot antenna. Furthermore, we introduce a new concept of “CPW patch antenna” here in order to exploit the similarities between the CPW and microstrip patch antennas and many techniques developed for the microstrip patch antennas [9, 10].

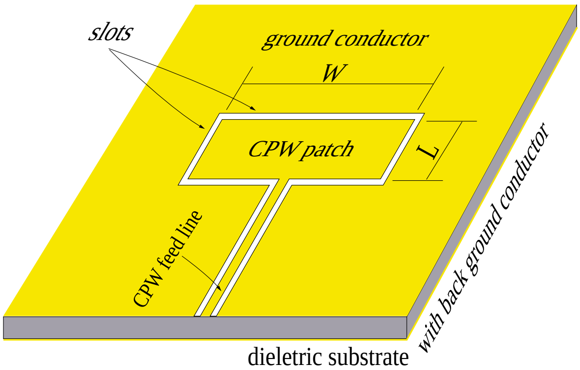

Fig. 1 Configuration of coplanar fed CPW patch antenna

In this paper, we first present simulation results for the CPW patch antenna. From electromagnetic simulation, we can see the similarities of the field distribution around the patch between the CPW patch antenna and the conventional microstrip patch antenna. Based on the simulation results we then design and fabricate a prototype of CPW patch antenna at a central frequency of 10 GHz on a conductor backed dielectric substrate with relative dielectric constants 2.17. The measured results including return loss, radiation pattern and gain, as well as the comparison with the simulation results, will be presented.

2. SIMULATION AND ANTENNA DESIGN

Simulation has been carried out by using IE3D, a commercial electromagnetic simulator based on the integral equation method and the method of moment. As a prototype for the CPW patch antenna operating around 10 GHz, a low material loss dielectric substrate (DICLAD®880, ARLON) is used in this work. Back ground conductor is introduced here to obtain an unidirectional radiation pattern. Following is a list of the parameters.

Relative dielectric constant $\varepsilon_r = 2.17$
Thickness of the substrate $h = 0.508$ mm
Metal film: Cu, with thickness of 18 μm
$\tan\delta = 0.00085$ at 10GHz

The geometric dimensions for the antenna shown in Fig. 1 are denoted in Fig. 2. The CPW feed line is designed to be of 50 ohm in order to match the measurement system. Dimensions of the CPW are calculated by close-form formulas given in [7] as following.

Dimensions of CPW, *s*-*w*-*s* = 1.0mm-1.6mm-1.0mm

Length of CPW feed line L_{fed} = 10 mm

From simulation around 10 GHz, we found a set of dimensions as following that can achieve the resonant frequency at 10GHz and at the same time a good matching with the 50 ohm CPW feed line.

Length of the patch L = 9.55 mm

Width of the patch W = 31.0 mm

Width of the slots S = 1.0 mm.

The simulation software IE3D supports both electric current model and magnetic current model for the analysis of printed planar antennas. We used the current model in our intensive simulations, though a magnetic current model is far more efficient and suitable in principle to the analysis of the CPW structure than using an electric current. This is from the comparison of our simulated results and our later describing measured results of the resonant frequency and input impedance matching. The electric current model gives more accurate results than the magnetic current model in IE3D.

Figure 3 shows the simulated reflection coefficient S_{11} at the input point of a 10 mm CPW feed line of the CPW patch antenna. The simulated frequency range is from 8 GHz to 12 GHz. A resonant and impedance matching point is near a point of 10 GHz.

Figure 4 shows the magnetic current (i.e., the electric field) distribution along the slots at the resonant frequency point of 10 GHz. The fields along the feed side slot and outer side slot are in phase and almost a uniform distribution in the horizontal direction. No field changes to be out phase along the input side and outer side slots though an equivalent total length of the slot $W + S$ at outer side is about $1.6\lambda_0/\sqrt{\varepsilon_r}$, where λ_0 is the wavelength in free space at 10 GHz, is longer than one and a half guided wavelength, while the fields along the left and right side slots show a out phase variation where the equivalent length of the slots $S/2 + L +$

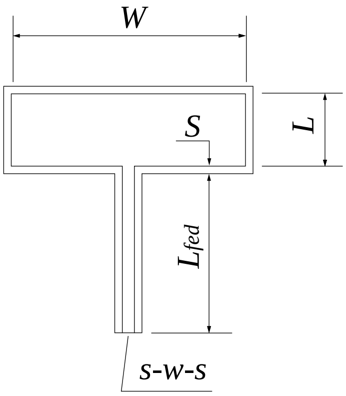

Fig. 2 Geometric Dimensions of the CPW patch antenna with a CPW feed line.

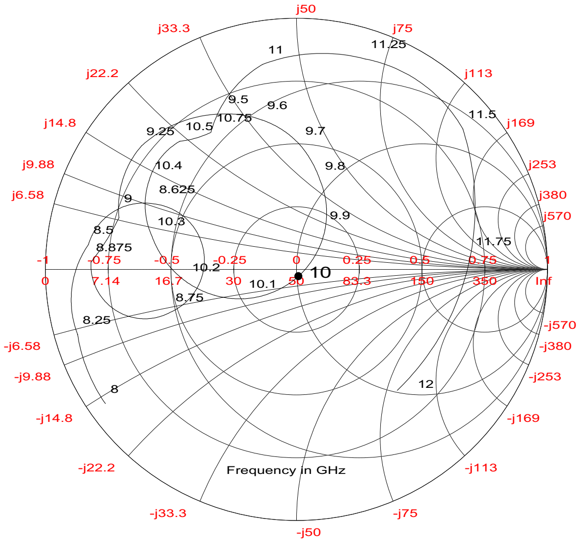

Fig. 3 Smith Chart of the simulated scattering parameter S11 of the CPW patch antenna with a 10 mm CPW feed line.

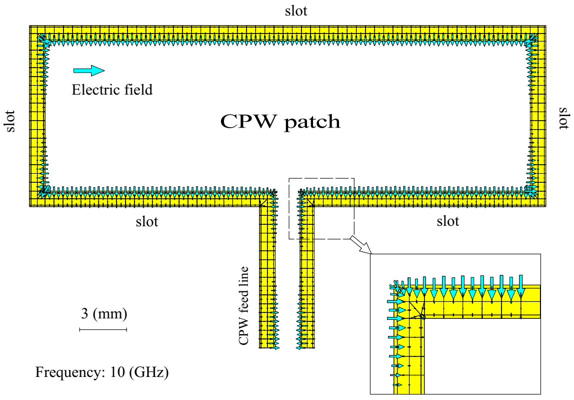

Fig. 4 Electric field distribution at 10 GHz along the slots surrounding the patch of the CPW patch antenna with a CPW feed line.

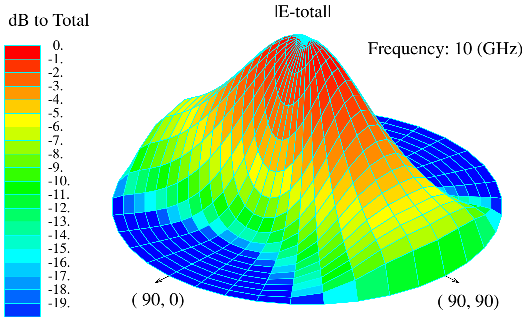

Fig. 5 Simulated 3D radiation pattern of the CPW patch antenna at 10 GHz.

$S/2$ is about $0.52\lambda_0/\sqrt{\varepsilon_r}$, close to a half of guided wavelength. This field distribution clearly demonstrates that, with the field distribution of the microstrip patch in the mind, the CPW patch antenna at the resonant point is much more like a "patch" than a "loop slot". The resonant length of CPW patch $L \approx 0.47\lambda_0/\sqrt{\varepsilon_r} \approx 1/2\lambda_0/\sqrt{\varepsilon_r}$ also follows the same rule as for the microstrip patch antenna [9, 10]. This is why we call the antenna shown in Fig.1 a "CPW patch" antenna not a "loop slot" antenna.

A 3D radiation pattern at the resonant frequency is shown in Fig. 5. The radiation beam is relatively broad in E-plane. The 2D patterns will be given later together with the measured patterns.

Figure 6 is the simulation results of radiation directivity and gain versus the operating frequency. At 10 GHz, the gain is about 8.9 dBi, which is a relative large value compared with a conventional microstrip patch for the larger width $W = 31.0$ mm which results in a narrower beam in H-plane, while a typical size of the microstrip patch is about 19 mm at the same frequency and on the same substrate.

Simulation results of radiation efficiency and antenna efficiency are shown in Fig. 7. We can see that antenna efficiency changes sharply and reaches maximum at resonant and matching point of 10 GHz, while the radiation efficiency keeps flat variation and almost higher than 80% over the whole interested frequency range.

3. Fabrication and Measurement

The antenna pattern is fabricated by using a wet etching process. DICLAD®880 substrate is used in our fabrication. Antenna dimensions are the same as these for simulation. Less than 50 micrometer tolerance in dimension may be introduced during the fabrication process.

Reflection coefficient S_{11} is measured on a vector network analyzer (HP 8510C). Coaxial-to-CPW test fixture is used to mount the CPW patch antenna.

Figure 8 shows the measured return loss of the CPW patch antenna as well as simulation result. We can see a good agreement between the two results. The antenna has a bandwidth of 3.4% at -10 dB return loss, which is comparable to that of the microstrip patch antenna.

Radiation pattern measurement is done in a chamber. A standard pyramidal horn is used as a feed antenna. CPW patch antenna is mounted on a positioner which is controlled by a computer. A coaxial connector is soldered to the CPW feed line to output the signal from the CPW patch antenna to a spectrum analyzer (HP 8565E).

Figure 9 shows measured radiation pattern in E-plane, H-plane and cross polarizations in each planes

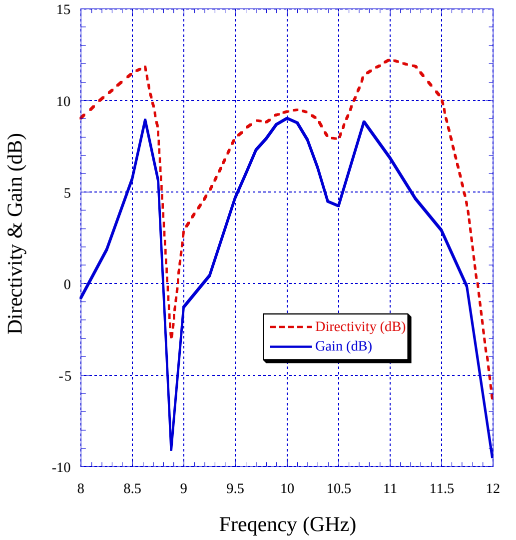

Fig. 6 Simulation results of radiation directivity and gain.

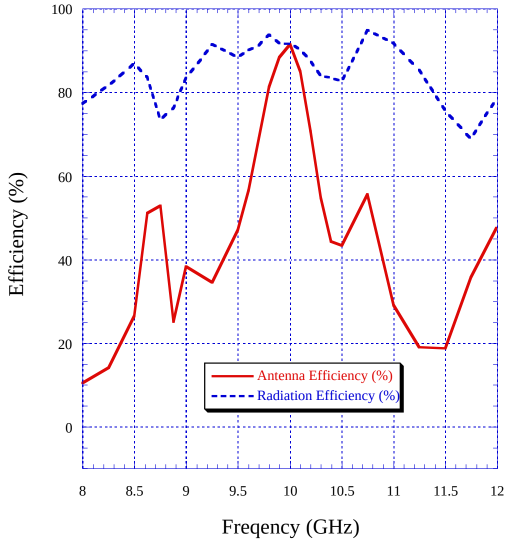

Fig. 7 Simulation results of radiation efficiency and antenna efficiency.

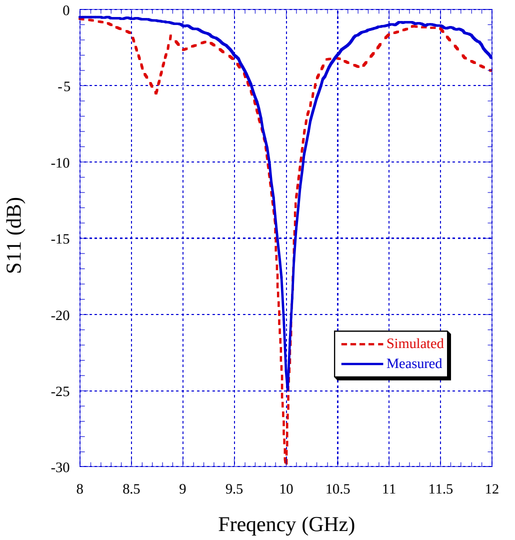

Fig. 8 Measured and simulation results of return loss of the CPW patch antenna.

of the CPW patch antenna. H-plane has a narrower radiation beam than E-plane. Small variation rips along the E-plane curve are due to the diffraction of the limited size of the ground conductor (about 20 mm long apart from the patch). In E-plane the antenna has a 3 dB beam angle of about 77 degrees that is much broader than that in H-plane (about 45 degrees). Cross polarization is under -23 dB in E-plane while there is a maximum value -17 dB in H-plane.

Figure 10 shows the comparison of the radiation pattern in E-plane and H-plane between the measured and simulated results.

Absolute gain is measured by using another standard pyramidal horn antenna as a receiving antenna which is the same as the feed one and has a gain of 11.2 dB at 10 GHz. The CPW patch antenna has a gain of about 7.8 dB which is 1.1 dB lower than the simulated gain.

4. Discussions and Conclusion

We have presented both simulation and experimental results for the CPW patch antenna proposed in this paper. These results demonstrated the similarities between the proposed CPW patch antenna and the microstrip patch antenna. Introducing the concept of the “CPW patch” and using the knowledge and techniques [9, 10] developed for the microstrip patch greatly helps us to simulate and design such antennas. Design rules for microstrip patch antenna such as half wavelength patch length hold for the CPW patch antenna. There are also many differences between the two patch antennas, including the radiation pattern, gain. The CPW patch antenna has more free parameters to design, not only the patch dimensions but also slots. A comprehensive comparison of these two antennas will be presented in our future paper.

The CPW patch antenna with a coplanar feed line can be easily applied to millimeter-wave systems. Ground conductor backed CPW patch antenna presented in this paper has also some advantages to provide unidirectional radiation pattern and easy mounting, packaging and integration with other microwave circuits and devices. Surface mode, which lowers the radiation efficiency can be eliminated by using a thin and ground conductor backed dielectric substrate where the higher mode can be excited is the parallel plate waveguide modes which have much higher cutoff frequencies than the operating frequencies.

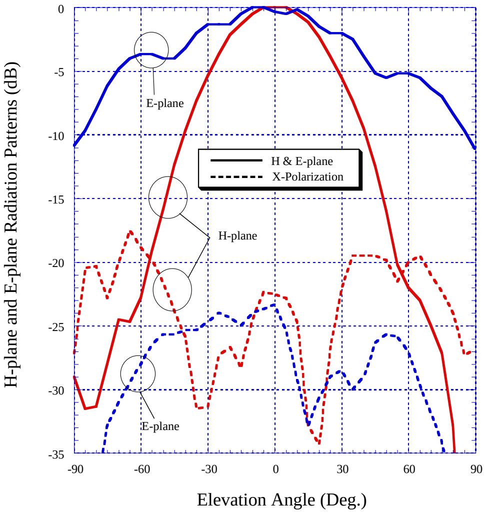

Fig. 9 Measured radiation pattern in E-plane, H-plane and cross polarizations in each planes of the CPW patch antenna.

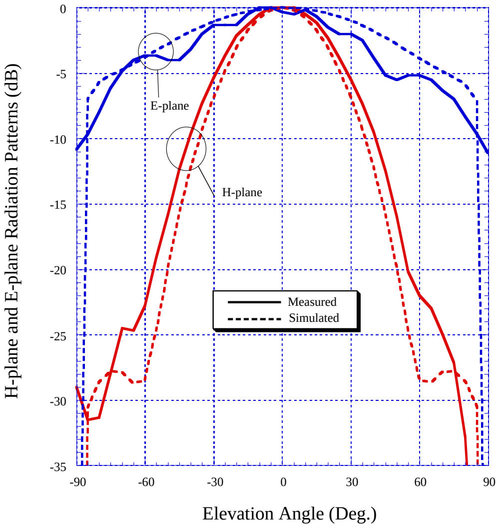

Fig. 10 Measured and simulated radiation patterns in E-plane and H-plane at 10 GHz.

References

[1] W. Menzel, et. al., IEEE Microwave and Guide letters, vol. 1, no. 11, pp. 340-342, Nov. 1991.

[2] B. K. Kormanyos, et. al., IEEE Trans. on Microwave Theory and Techniques, vol. 42, no. 4, pp. 541-545, Apr. 1994.

[3] H-C. Liu, et. al., IEEE Trans. Antennas and Propagat., vol. 43, no. 10, pp. 1143-1148, Oct. 1995.

[4] L. Giauffret, et. al., IEEE Trans. Antenna Propagat., vol.45, no.4, April 1997

[5] P. Otero, et. al., IEEE Trans. Antenna Propagat. vol.46, no.10, Oct. 1998

[6] S. Sierra-Garcia, et. al., IEEE Trans. on Antennas and Propagat., vol. 47, no. 1, pp. 58-64, Jan. 1999.

[7] K, C. Gupta, R. Garg, I. Bahl, and P. Bhartia, “Microstrip lines and slotlines,” Second Edition, Artech House, Norwood, MA, 1996.

[8] K. Li, et. al., 1999 IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting, Orlando, Florida, USA, July 11-16, 1999.

[9] D. R. Jackson, et. al., IEEE Trans. Antennas and Propagat., vol. 39, no. 3, pp. 407-410, Mar. 1991.

[10] K. F. Lee, and W. Chen, ed., “Advances in microstripo and printed antennas,” John Wiley & Sons, New York, 1997.