

A High-Gain Ka-Band Microstrip Patch Antenna with Simple Slot Structure

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Abstract-A high gain Ka-band microstrip patch antenna with simple slot structure is presented. The structure uses two patches and each patch has four slots on it. An open-loop is used to feed the two patches. The bandwidth of $S_{11}<-10$ dB is from 33.0 GHz to 37.1 GHz, equivalent to a relative bandwidth of 11.7% centered at 35 GHz. With a dimension of 7.9mm×8.4mm×0.508mm(equal to $0.92\lambda_0\times0.98\lambda_0\times0.06\lambda_0$ at 35 GHz), the peak gain in the band is high up to 11.5 dBi, and the gain in the band is higher than 10.6 dBi. The antenna has the advantages of high gain and simple structure, so it is a good choice for the small equipment.

Keywords-Ka-band, microstrip patch antenna, high gain, simple slot structure

I. INTRODUCTION

The microstrip patch antenna has been widely used for its advantages of low profile and low cost. But it usually has a low gain for its wide beam-width and narrow band for its high quality factor. Especially at millimeter-wave band, there is a high pass loss in the air, so high-gain antenna is needed to get a longer propagation distance. With the development of 5G, the amount of smaller equipment is increasing, and the design of planar antenna with wide band and planar simple structure is one of the concerns to ensure the communication between devices and keep a low cost.

To get a high gain, some technologies, such as multilayer structure, antenna array [1], parasitical cell [2], can be adopted. To the problem of narrow band of microstrip antenna, slot, parasitical cell, and aperture-coupled feeding can be used. These methods can be effective for the gain enhancement or bandwidth extension, but some of them at the cost of high profile or process complexity. In [3], a high gain grid array antenna is designed, keeping the low profile. In [4], a kind of high gain antenna working at 60 GHz is designed. The radiation is based on the discontinuity of open-ended stubs, and a square loop is used to feed the stubs.

In this article, a kind of Ka-band microstrip patch antenna fed with an open-loop is proposed. Two patches, with four slots on each patch, are used. It realizes a gain higher than 10.6 dBi, with the $S_{11}<-10$ dB bandwidth from 33 to 37.1 GHz. This kind of structure simplifies the feeding and keep the advantages of low profile and low cost.

II. ANTENNA DESIGN

Fig.1 illustrates the geometry of the proposed high-gain antenna, which consists of a ground plane layer, one substrate layer of Rogers5880, with the thickness of 0.508mm, and the

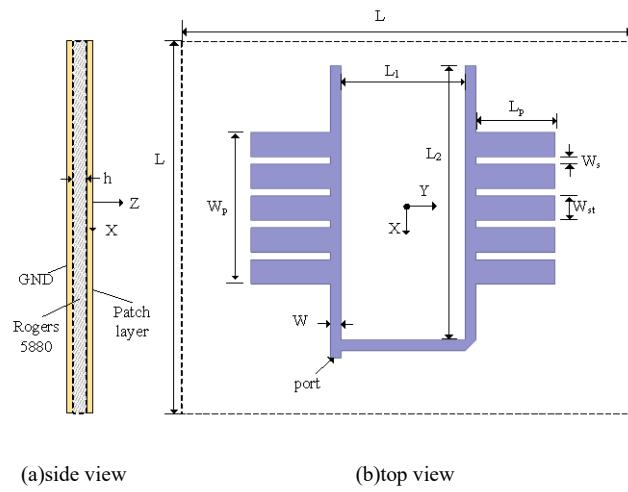


Figure 1. Geometry of the proposed antenna

Table 1. The antenna parameters. (Unit: mm)

L ₁	L ₂	W	W _p	L _p	W _s	W _{st}	h	L
3.4	7.6	0.3	4.6	2.2	0.2	0.76	0.508	16

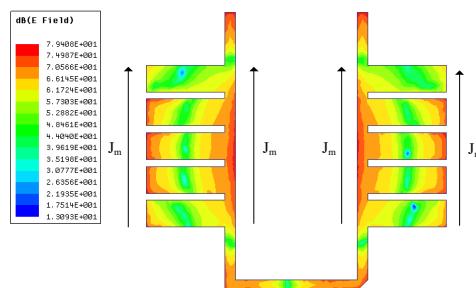


Figure 2. Electric field distribution at 35 GHz and the equivalent magnetic currents

patch layer. The patch layer is composed of two patches with slots and the feeding loop. The optimized parameters of the antenna are shown in the Table1.

To get a high gain, the proposed antenna uses two patches to obtain main radiation. At the open-end of the patch, the discontinuity caused by the open-end produces efficient radiation field. And the radiation field can be equivalent to be produced by the magnetic currents located on the open-end, as shown in Fig.2. There are four same-width slots on each patch,

dividing the patch into five stubs with same width W_{st} . The value of W_{st} changes according to the values of W_p and W_s . The slots help to widen the bandwidth and improve the field distribution.

An open loop is designed to feed the two patches. The feeding point is at one angle of the loop. The open loop consists of two long lines and one short line. At the open-end of the long line, the maximum electric field intensity is obtained. The length of the long line is about one guide wavelength, and the short line is about half guide wavelength. Therefore, at the other end of the long line, it also gets the maximum electric field intensity. and the electric field is out of phase at the corresponding position of the two long lines. The electric field distribution is shown in Fig.2.

The two patches are placed on the two sides of the open loop mirror-symmetrically. With a 180° phase difference of long lines, the two patches can radiate in phase. It is worth noting that the radiation from the long lines cancel out in the principal direction for their opposite phase of electric field. Compared with the patches, the short line of the loop has in-phase electric field distribution, as shown in Fig2, so the short line also helps to increase the radiation.

III. SIMULATED RESULTS

In the patch antenna, resonant frequency is mostly determined by L_p . Based on the parameters in Table1, the influence of L_p is shown in Fig.3. It can be seen that the resonant frequency increases when the L_p decreases. Finally, 2.2mm is chosen as the value of L_p . The simulated bandwidth

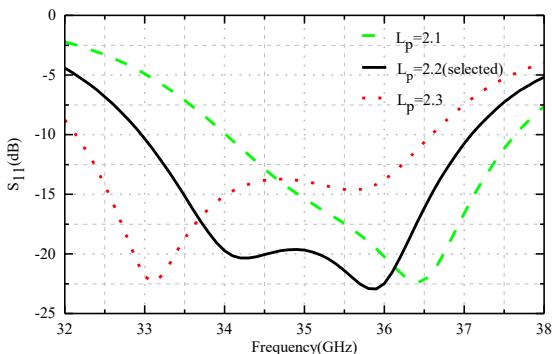


Figure 3. the S_{11} at different L_p

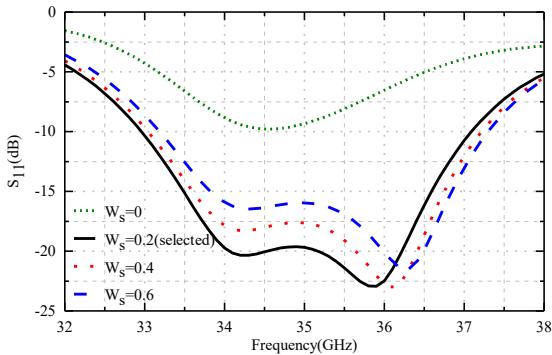
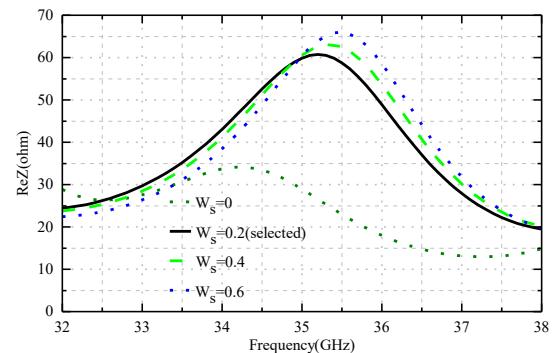
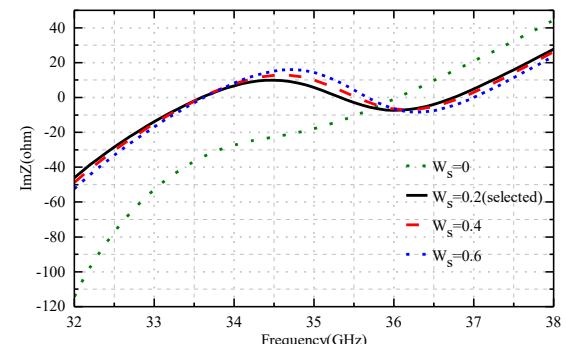


Figure 4. the S_{11} at different W_s



(a) the real part of Z_{in}



(b) the imaginary part of Z_{in}

Figure 5. the input impedance (Z_{in}) at different W_s

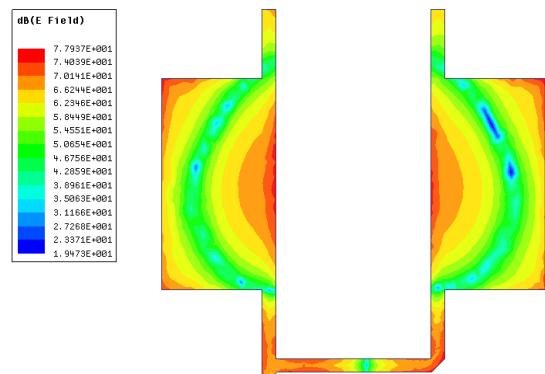


Figure 6. Electric field distribution at 35GHz when $W_s=0$ mm

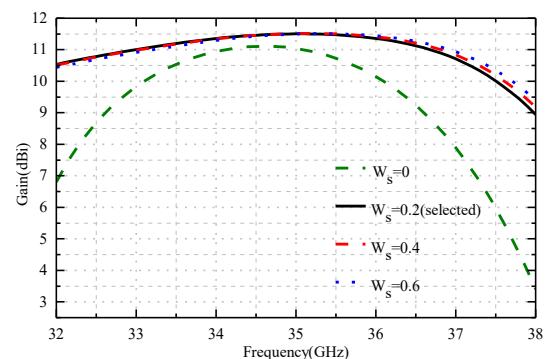


Figure 7.the simulated gain at different W_s

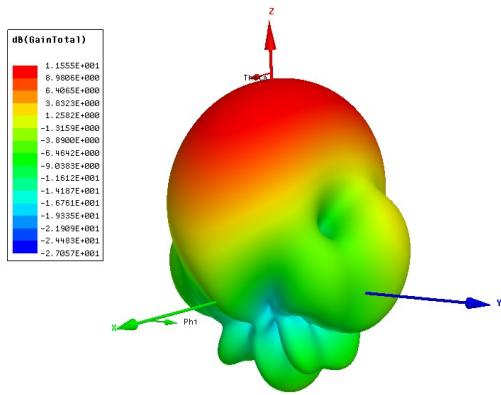


Figure 8. Simulated 3D pattern at 35 GHz

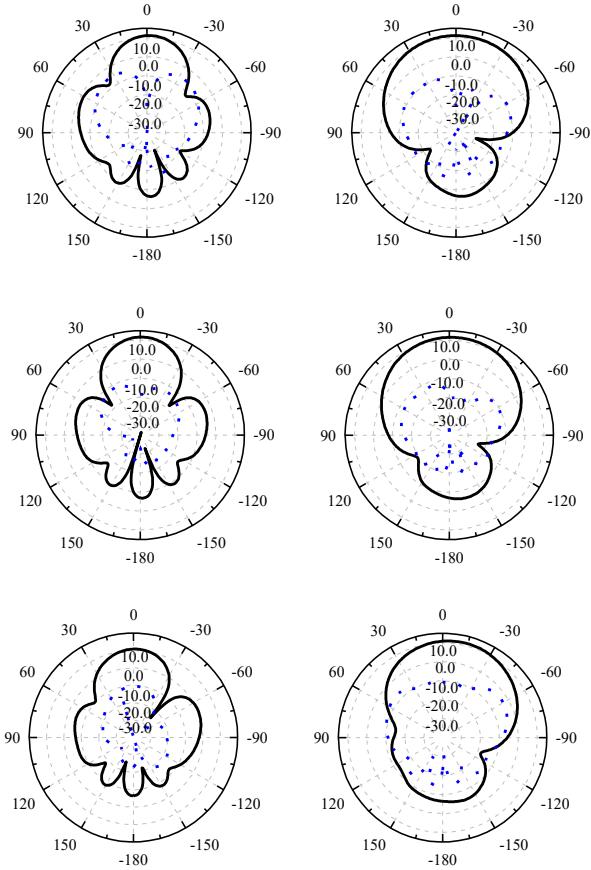


Figure 9. Simulated radiation patterns of E-plane(left) and H-plane(right) at 33,35,37 GHz (from top to bottom), co-polar component (black solid line) and cross-polar component (blue dot line)

with $S_{11} < -10$ dB is from 33.0-37.1 GHz, equivalent to a relative bandwidth of 11.7% centered at 35 GHz.

The slots help to widen the bandwidth and improve the uniformity of the field distribution. The S parameter and input impedance at different W_s are shown in Fig.4 and Fig.5. The line of $W_s=0$ mm means there are no slots on the patch. Obviously, by adding the slot, multi-mode resonances are introduced and the bandwidth of the antenna is expanded.

When $W_s=0$ mm, which means there are no slots on the patches, the electric field distribution is as shown in Fig.6. Compared with Fig.2, it can be seen that when there are no slots, the uniformity of electric field distribution decreases, especially at the edge of the patches. The comparison of the gain at different W_s is shown in Fig.7. It can be seen that the gain is higher when the slots exist. Based on the parameters in Table1, the gain in the band is higher than 10.6 dBi. And the maximum gain of 11.5 dBi is obtained at 35.1 GHz.

Fig.8 shows the 3D pattern at 35 GHz. And the radiation patterns of principle plane at 33,35,37 GHz are shown in Fig.9. It can be seen that the patterns tilt a little in the E-plane at 33 and 37 GHz. It means that the feeding phase difference of the two patches deviates from 180° . For this reason, the gain declines when the frequency is far from 35 GHz, as shown in Fig.7. In general, the radiation pattern is stable in the impedance bandwidth.

IV. CONCLUSION

A design of Ka-band high gain microstrip patch antenna with simple slot structure is proposed. It consists of two patches with slots and an open-loop for feeding. The simulated -10 dB impedance bandwidth is from 33.0 to 37.1 GHz, and the peak gain is 11.5 dBi. The slots help to realize wider bandwidth and higher gain. The antenna uses an open-loop to feed the two patches, simplifying the design of feeding. This structure also has the potential to be extended for a larger array. The antenna enjoys the advantages of high gain and simple structure, and it can be used in communication of the small equipment, such as automotive anti-collision radar and unmanned aerial vehicle.

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