Harmonics Suppression for Circular Microstrip Antenna with Slits and Open Stubs

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1. Introduction

To develop Super Solar Power System, receive antennas (rectennas) have been investigated to get high conversion efficiency by suppressing re-radiation of harmonics excited in diode of rectifying circuit. For high conversion efficiency circular microstrip patch antennas (CMA), with slits [1] [2] or stub loadings have been proposed. However, the combination of slits and stubs are not examined to suppress the re-radiation of harmonics.

This paper presents the input characteristic of CMA with slits and stubs to suppress the harmonics radiation.

2. The way to suppress harmonics

A conventional microstrip square-patch antenna with the side length of a has resonant frequencies determined by the equation of $a/2=n\lambda$, where n is integer and λ is resonant wavenumber. If such an antenna is applied for the rectenna, the use of filters is necessary to prevent radiation of harmonics generated by nonlinear characteristics of diode because the higher order mode resonant frequencies of the antenna coincide with the harmonics. On the other hand, the numbers of higher mode resonances of CMA are not integers when we assume a pill box cavity with magnetic wall to evaluate the resonant frequency of CMA. The eigenvalues to determine the resonant condition of this model are given by the roots of Bessel functions, which is an advantage of CMA to use as rectennas. To eliminate the use of filters for the CMA rectennas, modified CMAs were proposed. The technique to suppress the resonances at the second and third higher order modes are given by inserting slits in CMA by controlling the current flows on the top patch [1]. The ideal shape of slit is parallel to the dominant current flow and is perpendicular to higher order mode currents, however, the current distributions on the CMA are complex and the harmonics re-radiation are not completely suppressed by this technique. Another harmonics suppression method is to add open stubs for the feeding stripline. The length of open stub is quarter guide wavelength in resonant frequency of higher order modes. Two or more stubs are required to suppress the second and third modes completely.

This paper investigates the characteristics of higher order modes suppression by both methods in detail and examines their combination to suppress the harmonic radiation effectively.

3. Suppressing higher order modes by slits and stubs

First, we confirm reflection characteristics of microstrip square-patch antenna and CMA. We design them to resonant at 2.45 GHz by adjusting the size of patch and feeding position of stripline. The dielectric substrate of relative constant $\varepsilon r=2.6$ with the thickness of 1.6 mm.

Fig. 1 shows S11 of an original CMA structure. Three higher order mode resonances are appeared in the frequency range less than 7GHz. These higher order mode resonances do not coincide with the second and third harmonic frequencies of the dominant mode resonance, however the bandwidth of higher order modes is overlapped with the harmonic frequencies. First, we add an open stub S1 with the length of λg/4 at 6.7GHz, where λg is the guide wavelength. As shown in Fig. 2, the deep resonance at 6.7GHz is reduced, while another resonance at 6.1 GHz is excited. To eliminate these resonances, we add another stub S2 and adjust the spacing between two stubs to optimize the suppression of higher order modes. As a result, the S11 at the second and third harmonics are improved to -0.63dB and -0.13dB. As shown in Fig.2, the open stubs are very effective to suppress the resonances at the second and third harmonic frequencies. Next, we examine the slits as another harmonic suppression technique.

Fig. 3 shows the current distribution of the original CMA at the second mode frequency. To reduce these current flows, the slits are cut across these currents. These slits should be cut not to disturb the current flow of the dominant mode. An example of slit cut is shown in Fig.3 and its S11 is shown in Fig. 4. The slit width is 0.5 mm and the length is 5.6 mm. The resonance at 4.05GHz is well suppressed, while the resonance at 6.7 GHz is not changed. Fig. 5 shows the current distributions at 6.7 GHz, where the blue arrows are the directions of current flow. We add arch shaped slits across the current distributions at 6.7 GHz. Fig. 6 shows optimized slits arrangement and its S11 of CMA to suppress the resonances at higher order mode frequencies. The diameter of CMA and slit parameters suppressing the resonance at 4.05 GHz are changed for the fine tuning. The S11 of the second order mode suppressed from -11.4 dB to -6.77 dB. However, that of the third harmonics is -4.92 dB at 6.4 GHz.

Then, we examine the CMA with slits and stubs. As shown in Fig. 7, the CMA with two kinds of slits has the resonances at 3.6 GHz, 4.45 GHz and 6.4 GHz. To suppress the resonance at 4.45 GHz, the open stub S11 added to the feeding stripline of the CMA with two kinds of slits. The resonance at 4.45 GHz is suppressed, while it causes the resonance at 6.3 GHz. We add the open stub S2 to suppress this resonance and adjust the spacing between two stubs to optimize the input characteristics. This optimization reduces these resonant frequencies. The S11 of higher order modes is suppressed to -6.77 dB at 4.45 GHz and -1.76 dB at 3.6GHz. Furthermore, that of the third mode is suppressed to -1.84 dB at 6.4GHz.

Finally, Fig. 8 summarizes the S11 of four types of CMA, where the antenna elements are without slits and stubs, with slits and without stubs, with stubs and without slits, and with slits and stubs. The CMA with slits and stubs is the best choice to suppress the higher order mode resonances for the CMA. The S11 of the second and third harmonics frequencies is suppressed to -0.26 dB at 4.9 GHz and -0.17 dB at 7.35 GHz

4. Conclusion

In this paper, we designed CMA in order to suppress re-radiation of harmonics arise from diode in rectifying circuit. We examined the input characteristic of the CMA by the slits, stubs and their combinations. Considering entire frequency, we showed that the CMA with slits and stubs suppressed harmonics more than the CMA with stubs. And we showed that harmonics are suppressed by using CMA instead of square microstrip patch antenna

References

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[3] F. L. Hsiao, T. W Chiou and K. L. Wong, ”Harmonic Control of A Square Microstrip Antenna Operated at 1.8 GHz Band”, 2001 Asia-Pacific Microwave Conference., p1052-1055, Dec. 2001.

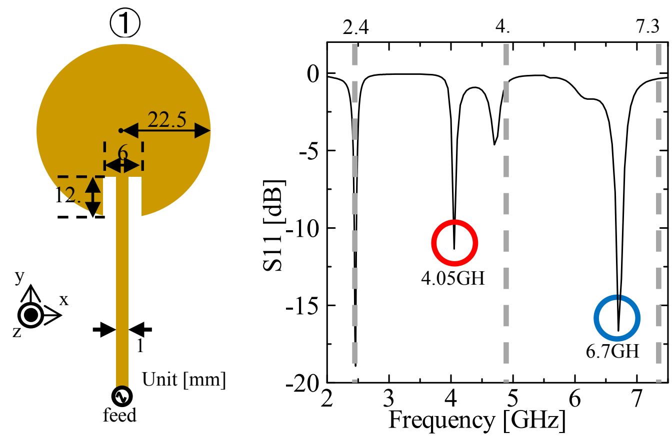

Figure 1: Early CMA structure and S11

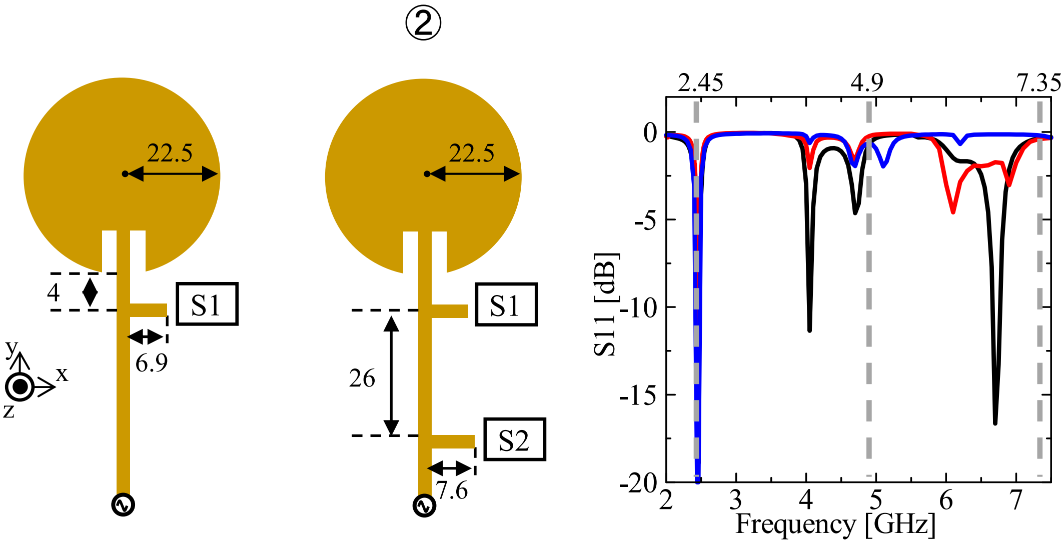

Figure 2 : Structures of CMA with stubs and S11
Black : w/o stub, red : w/ S1, blue : w/ S1 and S2

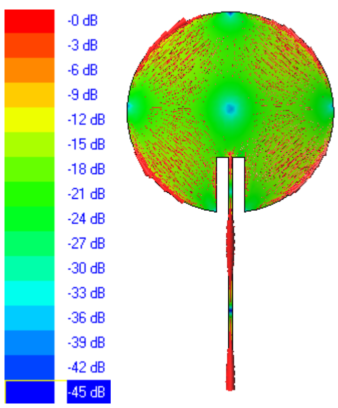

Figure 3: Current distribution at 4.05 GHz

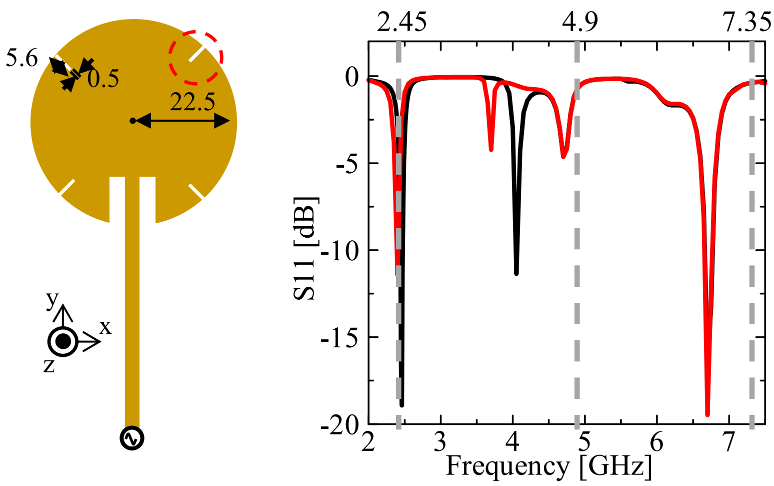

Figure 4: Structure of CMA with slits and S11

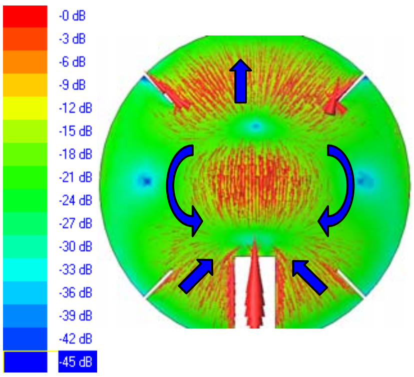

Figure 5: Current distribution at 6.7 GHz

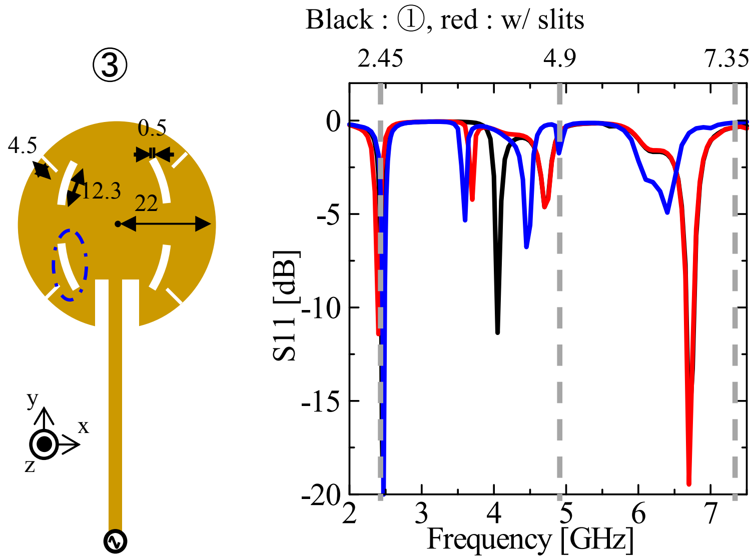

Figure 6: Structure of CMA with two types slits and S11

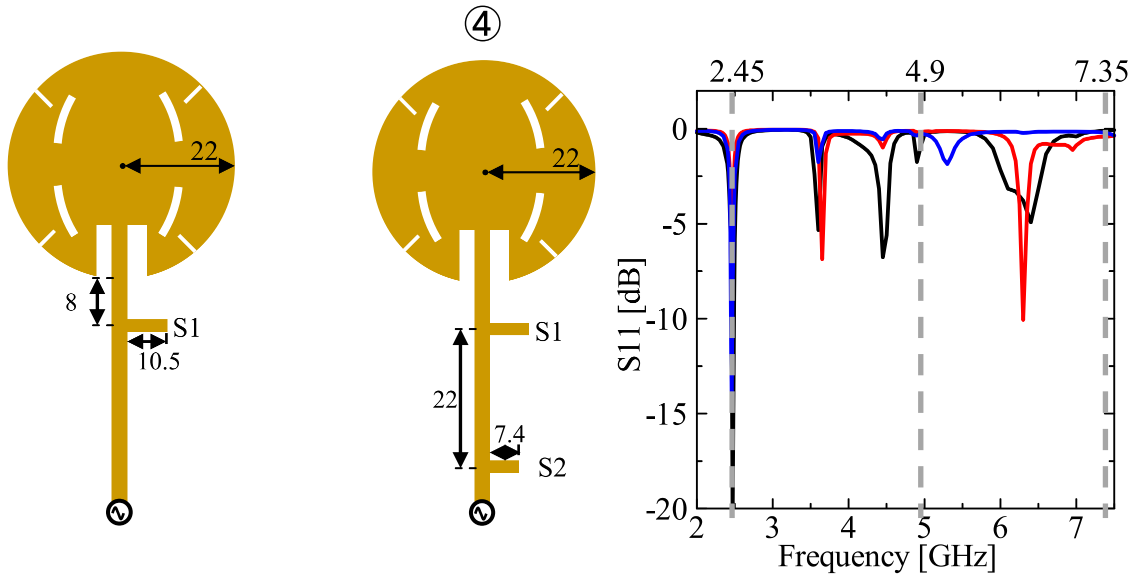

Figure 7 : Structures and S11 of CMA with slits and with stubs or without stubs
Black : w/o stub, red : w/ S1, blue : w/ S1 and S2

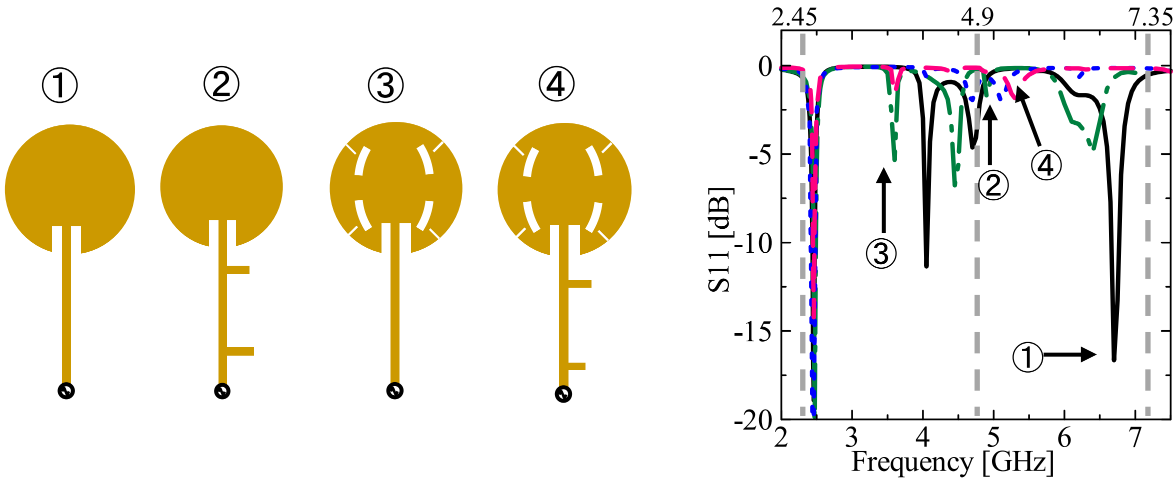

Figure 8 : S11 of four types of CMA; without slits and stubs, with slits and without stubs, with stubs and without slits.