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Design of Planar Slot Yagi-Uda Array Antenna

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1. Introduction

Yagi-Uda array antennas are well recognized to have high directivity and end-fire radiation patterns. Most planar Yagi-Uda antennas are constructed in microstrip configurations for various applications [1-3]. Only a few studies have been published on designing the complementary slot Yagi-Uda antennas [4-6]. The currents on the array elements were investigated experimentally in [4]. The slot antenna was designed to excite the surface wave of a dielectric slab for power combining purposes [5]. In [6], Simba *et al* present a type of X band planar sectored antennas based on the slot Yagi-Uda array. This study intends to investigate the design of Simba *et al* carefully. The influences of each geometrical parameter on the impedance matching are first investigated. An S band antenna is then designed on a thinner substrate using these investigations.

2. Simulation Model of Slot Yagi-Uda Antenna

Figure 1 depicts a three elements slot Yagi-Uda array, originally proposed in [6], on the top of a double-face grounded substrate with a thickness hsub and dielectric constant ε_r=2.1. The width and length of this substrate are represented by the symbols Wsub and Lsub respectively. This antenna basically consists of a rectangular (director) and two U-shaped (driven and reflector) slots cut in the upper ground plane. In order to ease the setup of simulation model, the grounded posts in the original paper are replaced by the perfect electric conductor (PEC) walls connected to the two ground planes to prevent the coupling of these slots through waveguide modes in the substrate. These slots have the same width wslot. The other physical dimensions of these slots are characterized by Ldrv, drvb, Lref, refb and Ldir respectively. The distance of the reflector from the driven is denoted as dref, and ddir is the distance of the director from the driven. The physical dimensions of the PEC walls and their relative positions to the three slots are characterized by the symbols Wpps, osup1, osup2, osup3 and osup4 respectively. The antenna is probed by the centre conductor of a coaxial cable (characteristic impedance 50 Ω, inner diameter 0.5 mm and outer diameter 2.1 mm). The coordinates of the probe are xp and yp.

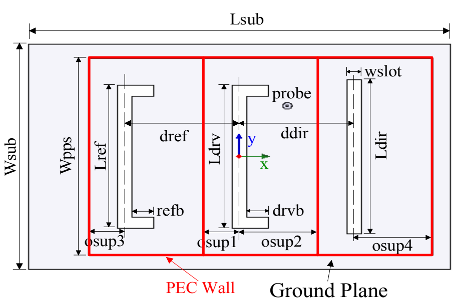

Figure 1 The Slot Yagi-Uda Antenna

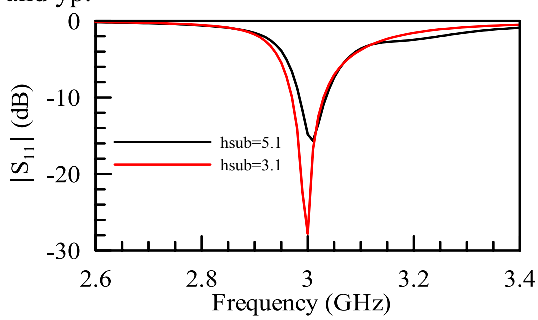

Figure 2 The Simulated Return Loss

The antenna designed in [6] has a centre frequency 10.2 GHz. In this work, the centre frequency is intended shifting to 3 GHz by multiplying the physical dimensions in [6] by a factor 3.4 (=10.2/3). The width and length of the substrate are reduced to appropriated values and the probe position is fine adjusted for better return loss. The scaled physical dimensions of this array are listed in Table 1, and the return loss simulated by Ansoft HFSS [7] is the black curve in Fig. 2. From the simulated result, it is clear that the antenna in [6] can be simply scaled to other operating

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frequency by multiplying an appropriated factor. However, the substrate thickness (hsub=5.1 mm in this example) may prevent the scaled antenna for practical applications. Therefore, this study aims to find a method for designing the scaled antenna with practical substrate thickness. Investigating the influences of the physical sizes relating to the driven can help us achieving this goal.

Table 1: The Physical Sizes of the Scaled Antenna

Ldrv	44.2	yp	15.8
drvb	5.1	osup1	8.5
Ldir	47.6	osup2	18.7
ddir	27.2	osup3	8.5
Lref	44.2	osup4	18.7
refb	5.1	Wpps	61.2
dref	27.2	Wsub	70
wslot	3.4	Lsub	100
xp	11.35	hsub	5.1

Unit : mm

3. The Influences of Adjusting the Sizes Relating to the Driven

As shown in Fig. 1, the driven is a slot on the broad wall of a dielectric loaded rectangular waveguide cavity. The probe excites the TE_{10} waveguide mode in the cavity and the energy is transferred from the cavity mode to the radiating wave through the slot. Therefore, the size and shape of the driven slot (wslot, Ldrv, drvb) and its position (osup1 and osup2) relative to the cavity can affect the impedance matching of the antenna. The influences of varying the probe position (xp, yp) must also be investigated because it affects the excitation of the waveguide mode. In the following figures, the effects of varying these dimensions on the reflection coefficient are presented in the polar charts. Except those shown in the figures, the dimensions of the simulated antennas are the same as those shown in Table 1. Fig. 3 presents the effects of varying xp and yp, in the step of 2 mm, respectively. The solid triangular symbols mark the reflection coefficients at the centre frequency (3GHz) for various xp_s and yp_s. From this figure, the arc length of the reflection curve swept from 2 to 4 GHz is reduced when increasing the values of xp or yp. The reduction of varying xp is more apparent than that of varying yp. The reflection coefficient of the centre frequency rotates in a clockwise sense in this reduction process.

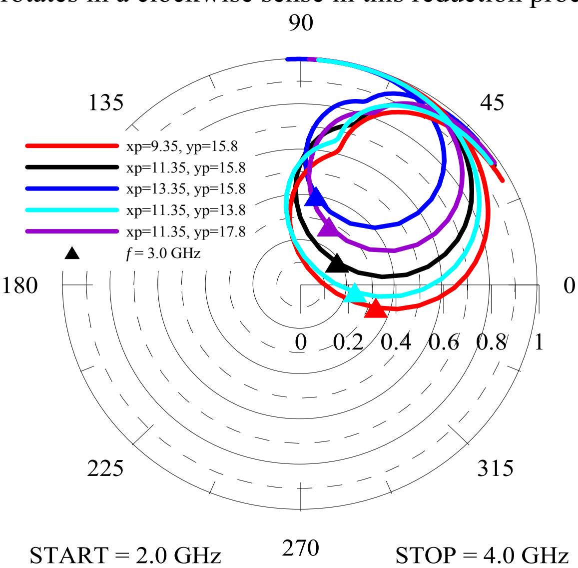

Figure 3 The Effects of Varying xp and yp

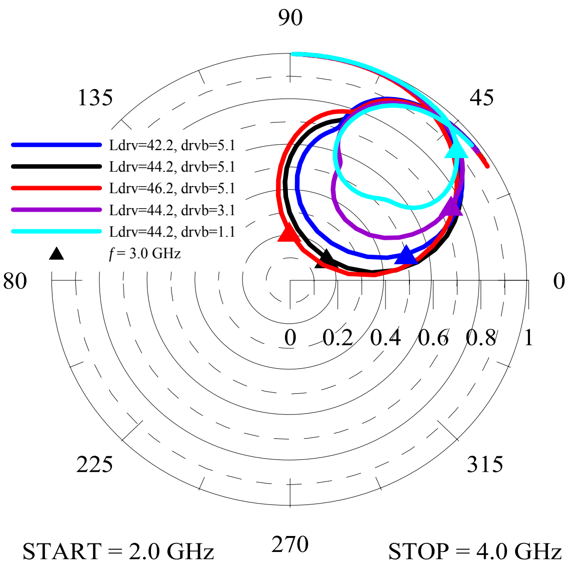

Figure 4 The Effects of Varying Ldrv and drvb

Fig. 4 examines the effects of varying Ldrv and drvb in the step of 2 mm. Increasing Ldrv from 42.2 mm to 46.2 mm slightly increases the arc length of the reflection coefficient curve, while decreasing drvb from 5.1 mm to 3.1 mm can greatly decrease the corresponding arc length. This means the parameter drvb has great effects on the impedance matching of the antenna. The reflection coefficient of centre frequency also rotates in a clockwise sense when increasing the values of these parameters.

The effects of varying the slot width (wslot) and the position (osup) of PEC walls relative to the slots are presented in Fig. 5. Increasing wslot from 1.4 mm to 5.4 mm has no great effect on the reflection coefficient curves, but the reflection coefficient of centre frequency (mark symbols) rotate quickly in a counter-clockwise sense. As shown in Fig. 1, the positions of the PEC walls relative to the three slots are controlled by the parameters osup$i_{i=1,2,3,4}$. In Fig.5, the curves denoted by osup mean the osup*i* in Table 1 are adopted in the simulations. In obtaining the curve denoted by "osup-2", the value of osup1 and osup3 are decreased by 2 mm, while the value of osup2 and osup4 are increased by 2mm. That is the PEC walls are moved in the positive x direction by 2mm relative to the three slots. On the other hand, in obtaining the curve denoted by "osup+2", the PEC walls are moved in the negative x direction by 2mm relative to the three slots. The PEC walls (or slot) position has great effect on the reflection coefficient curve. The arc length is greatly reduced when moving the PEC walls from right to left in Fig. 1. The reflection coefficient of centre frequency also rotates quickly in a counter-clockwise sense.

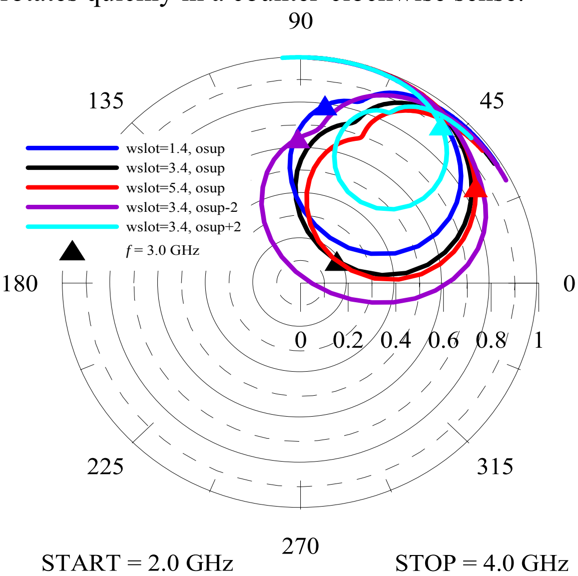

Figure 5 The Effects of Varying wslot and osup

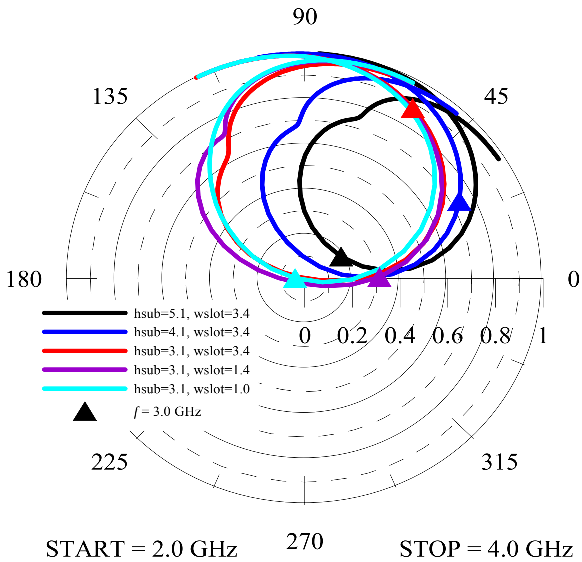

Figure 6 The Effects of Varying hsub

4. Design the Antenna Using a Thinner Substrate

Instead of using the thick substrate (hsub=5.1mm) in Table 1, this work aims to design the scaled antenna in a thinner substrate. The effects of reducing the thickness, from 5.1 to 3.1 mm, of the substrate on the reflection coefficient are presented in Fig. 6. The arc length of the reflection coefficient curve is increased and the reflection coefficient of centre frequency rotates in a counter-clockwise sense as the thickness is reduced. It is clearly shown that the impedance matching bandwidth is reduced as the thickness is reduced. As the substrate is reduced to 3.1 mm, the reflection (red) curve passes the origin (zero reflection) at a frequency higher than the centre frequency 3.0 GHz. However, the reflection coefficient (red mark) of centre frequency is rotated to have magnitude closed to 0.9. In other words, the driven radiate at a higher frequency. To make the driven radiate at the derided frequency, the red mark has to rotate clockwise to the centre of polar chart without greatly altering the shape and position of the reflection (red) curve. Carefully examining the effects of varying the parameters in the previous section, it can find that reducing the width of slot (wslot) may have the possibility to achieve this target (Fig. 5). Therefore, the width is decreased from 3.4 mm to 1.4 and 1.0 mm respectively. The reflection coefficient curves for these two decreased widths are also plotted in Fig. 6 for comparison. It can clearly observe that the triangular mark rotates clockwise to the neighbourhood of origin and the reflection curve dose not alter greatly as the width is decreasing. Therefore, the design of antenna using this thinner substrate can be completed by simply decreasing wslot. The return loss of the well design antenna is also plotted in Fig. 2.

Fig. 7 and 8 compare respectively the x-z and conical planes radiation patterns (E_θ) of the two scaled antennas (hsub=3.1 and 5.1 mm) at the centre frequency. For the Yagi-Uda antenna designed on the thinner substrate (hsub=3.1 mm), the maximum radiation occurs at $\theta=42^o$ and $\varphi=0^o$. The maximum directivity is 6.95 dBi. The maximum radiation for the antenna designed on the thick substrate (hsub=5.1 mm) occurs at $\theta=49^o$ and $\varphi=0^o$. The maximum directivity is 6.82 dBi. The radiation patterns of these two antennas are similar to the pattern of the antenna in [6] where they are scaled from.

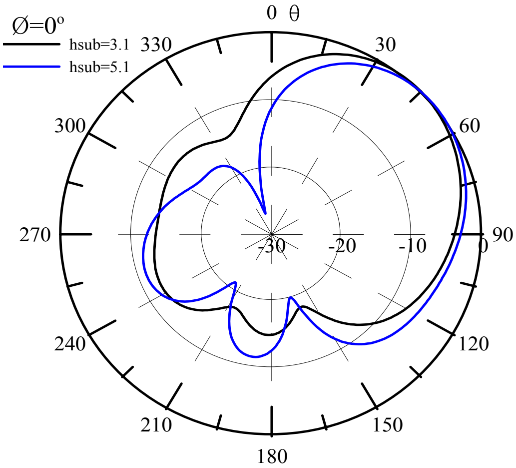

Figure 7 The Radiation Pattern (x-z plane)

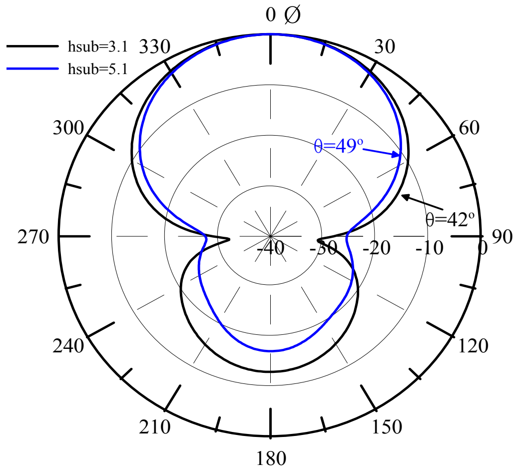

Figure 8 The Radiation Pattern (conical plane)

5. Conclusions

This work presents a simple and systematic method to design a new antenna from previous designs. A scaled antenna of the desired centre frequency can be easily obtained by multiplying the physical sizes of the original antenna by an appropriated factor. For the specific examples shown here, the design of planar Yagi-Uda antenna on a thick substrate can be applied to the design of the same antenna on a thinner substrate by simply modifying the slot width. Careful examining and using the influences investigated in Section 3, the same principle can be applied to design the antenna on a substrate of another thickness only by modifying a few physical sizes. The scaled antenna turns out to have the similar performances as the original antenna.

References

[1]J. Huang, A.C. Densmore, “Microstrip Yagi array antenna for mobile satellite vehicle application”, IEEE Trans. Antennas Propag., vol. 39, No. 7, pp. 1024-1030, 1991.

[2]W.R. Deal, N. Kaneda, J. Sor, Y. Qian, T. Itoh, “A new quasi-Yagi antenna for planar active antenna arrays”, IEEE Trans. Microw. Theory Tech., vol. 48, No. 6, pp. 910-918, 2000.

[3]P.R. Grajek, B. Schoenlinner, G.M. Rebeiz, “A 24-GHz high gain Yagi-Uda antenna array”, IEEE Trans. Antennas Propag., vol. 52, No. 5, pp. 1257-1261, 2004.

[4]R.B. Burton, R.W.P. King, “An experimental investigation of currents on a Yagi array of slot antennas on planar and curved surfaces”, IEEE Trans. Antennas Propag., vol. 14, No. 4, pp. 451-454, 1966.

[5]Y. Qian, A.R. Perkons, T. Itoh, “Surface wave excitation of a dielectric slab by a Yagi-Uda slot array antenna – FDTD simulation and measurement,” Proc. Topical Symposium on Millimeter Waves, Kanagawa, Japan, pp. 137-140, 1997.

[6]A.Y. Simba, M. Yamamoto, T. Nojima, K. Itoh “Planar-type sectored antenna based on slot Yagi-Uda array”, IEE Proc.-Microw. Antennas Propag., vol. 152 No. 5, pp. 347-353, 2005.

[7]High Frequency Simulation Structure (HFSS), Ansoft Coporation.