Proposal and Basic Study of an Electromagnetically Fed Planar-Type Yagi-Uda Sectored Antenna

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1. Introduction

Variable antenna directivity is seen to be one of the keys to achieve multifunction terminals. For consumer terminals, the properties, such as small size, light weight, low price, and low power consumption, are also indispensable. An electronically steerable parasitic array radiator (ESPAR) antenna has been well researched and developed as an antenna satisfying such properties [1]. However, a high-gain ESPAR antenna, for example, an antenna with gain greater than 10 dBi, has not yet been developed. In order to achieve higher gain, the number of elements must be increased. Therefore, we proposed an antenna arrangement involving some Yagi-Uda antennas with a common feed dipole [2]; the beam direction of this antenna can be switched by transforming the dipole elements, except one Yagi-Uda antenna, to electrically invisible state. The advantage of this antenna is that the desired performance can be realized by appropriately designing the unit Ygi-Uda antenna. However, this antenna has drawbacks with regard to mechanical stability, mass production, and compactness. Therefore, a Yagi-Uda sectored antenna with a planar structure is proposed, and its basic performance is investigated.

2. Planar structure of stacked and electromagnetically fed antennas

If Yagi-Uda antennas are stacked in parallel to form a planar structure, it becomes difficult to set a common feed dipole. In this paper, we propose a method for arranging feed dipoles individually, as shown in Fig. 1(a). In this configuration, the feed dipoles are arranged close to each other. Therefore, the dipoles are excited by mutual coupling, even if the power of the antenna feed is switched by a circuit switch. In order to diminish the excitation due to the mutual coupling, the feed dipoles are transformed to electrically invisible state by switching to suitable inductive loading. Moreover, this operation is also used to switch the feed dipole. Hence, not only directors and reflectors but also feed elements are loaded with circuit switches for switching between an inductor port and a short-circuit port, as shown in Fig. 1(b). The dipoles of a Yagi-Uda antenna are switched to short-circuit ports, and the other dipoles are switched to inductor ports so that they are electrically invisible. Each feed dipole is electromagnetically fed by a probe, which is smaller than a quarter wavelength, as shown in Fig. 1(c), in order to prevent direct radiation. As this configuration allows the arrangement of Yagi-Uda antennas such that they are close to each other, the monopoly area for the stacked antenna and the length of feed circuit lines to each element antenna can be reduced.

3. Beam switching performance

The beam switching performance is calculated by using the moment method (IE3D), at a frequency of f_0 = 6 GHz. The dipoles are assumed to be planer-type dipoles, and the length *L*, width *W*, and interval *R* of each element are designed such that they have a high directive gain, as shown in Table 1. The directive gain G_d is 12.65 dBi and the input impedance Z_{in} is 24.34 – j58.89 [Ω]. The absolute gain pattern $G_a(90,\phi)$ (directivity – conductor loss) is shown in Fig. 2.

Four Yagi-Uda antenna units are used; the directions of the antenna units are varied in steps of 22.5° in the sequence %1, %2, %3, and %4, and they are stacked in the order %3, %1, feed probe, %4, and %2, as shown in Fig. 1(a). The characteristics are calculated when the dipoles except one Yagi-Uda antenna are loaded with the reactance values shown in Table 2. The working gain pattern $G_w(90,\phi)$ (directivity – conductor loss – miss-match loss) in the E-plane, and the directive gain and input impedance characteristics are shown in Fig. 3(a) and Table 3(a), respectively. As a comparison, the characteristic in the case that the inductor loadings are exchanged to the open-circuit are shown in Fig. 3(b) and Table 3(b), respectively. The results show that the beam direction can be switched by exchanging the Yagi-Uda antenna whose dipoles are short-circuited. When the dipoles other than the short-circuited Yagi-Uda antenna are open-circuited, the directivity gain is decreased to approximately 8 dBi, and the impedance matching deteriorates. On the other hand, when the other dipoles are subject to inductive loading, a directive gain similar in value to that of the dipole alone, i.e., >12 dBi, can be achieved. These results show that the electrical influence of an inductively loaded dipole vanishes more perfectly as compared to that of an open-circuited dipole; furthermore, the majority of the electric influence of the closely stacked feed elements vanishes. Moreover, the impedance matching (to 50 Ω) is improved such that the *vswr* is <2; however, the *vswr* is 2.39 in the case of the dipole alone. Consequently, for the antenna to cover angles ranging from –45° to 45°, a working gain greater than 10.7 dBi can be provided.

4. Importance of the Stacking order

The scheme adopted for the stacking order of the units %3, %1, %4, and %2 separates the units that are close to each other. The inner units %2 and %3 are located on the top and bottom layers, respectively, and the neighboring units, %2 and %1, and %3 and %4, are set such that they are not set on neighboring layers. To clarify the effect of the stacking order, the antenna characteristics are calculated for the stacking order %3, %4, feed probe, %1 and %2. The working gain patterns $G_w(90,\phi)$ in the E-plane and the directive gain G_d for the case in which the dipoles are subject to reactance loading (shown in Table 2) are shown in Fig. 4 and Table 4 respectively. The impedance matching becomes worse than the antenna of the stacking order %3, %1, %4, and %2, although the directivity is almost identical to it. As a result, the minimum working gain of the sectored beams for the angle range 0–90° decreases from 10.7 dBi to 9.2 dBi. This implies that the stacking order is important for the design of the proposed sectored antenna.

5. Effect of reducing switches

The proposed antenna requires a large number of switches, whereas the efficiency is not severely decreased due to loss of switches because no switch is loaded in the RF feed circuit [3]. It is examined whether or not the switch loading to the outer dipoles can be reduced. The directive gain G_d and impedance matching and the working gain pattern $G_w(90,\phi)$ when the switches of the dipoles of the fourth director #4 are reduced and short-circuited are shown in Table 5 and Fig. 5, respectively. In this case, both the radiation pattern and impedance matching are almost the same as in the case with the switch of #4. The reason for this is considered to be the weak mutual coupling between the four directors due to the dipole elements of #4 facing the neighboring elements along the axial direction along which the radiation is weak.

6. Conclusion

We proposed a planar antenna that comprises stacked Yagi-Uda antennas pointed along different directions. Sector beams can be formed by switching the feed Yagi-Uda antenna. In order to eliminate the disturbance due to the mutual, the dipoles of the unfed Yagi-Uda antennas are transformed to electrically invisible state. The feature of the antenna is that feed elements are fed electromagnetically and the feed element is switched by transforming the unfed elements to electrically invisible state.

The calculation results showed that the feed Yagi-Uda antenna can be switched and the influence of unfed Yagi-Uda antennas on the directivity can be suppressed by transforming the dipoles to electrically invisible state. It was shown that the input impedance is more sensitive to the stacking order than the directivity. Consequently, the input impedance matching of the sectored antenna can be improved beyond that of the Yagi-Uda antenna alone by appropriate design of the stacking order. The design of a four-sector antenna that can cover 90° with a working gain greater than 10.7 dBi was shown. It was shown that the switches of the four directors can be reduced without deteriorating the antenna performance.

References

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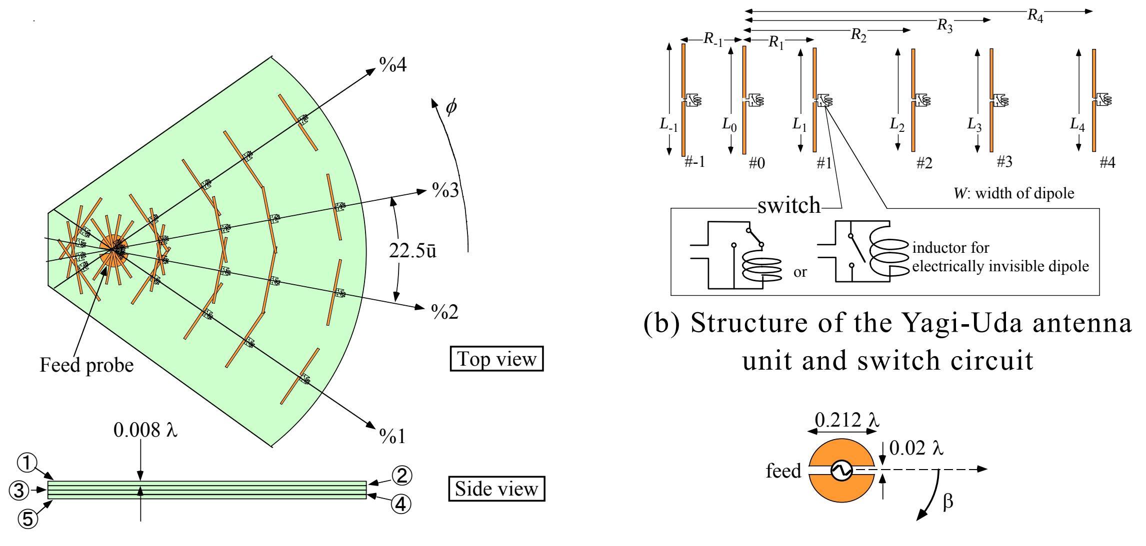


(a) Structure of the stacked units

(b) Structure of the Yagi-Uda antenna unit and switch circuit

(c) Structure of the feed probe

Figure 1: Structure of the proposed planar sector antenna.

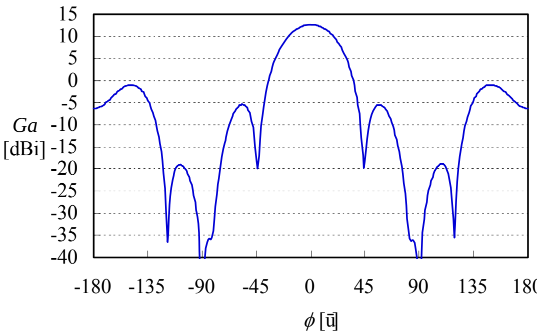


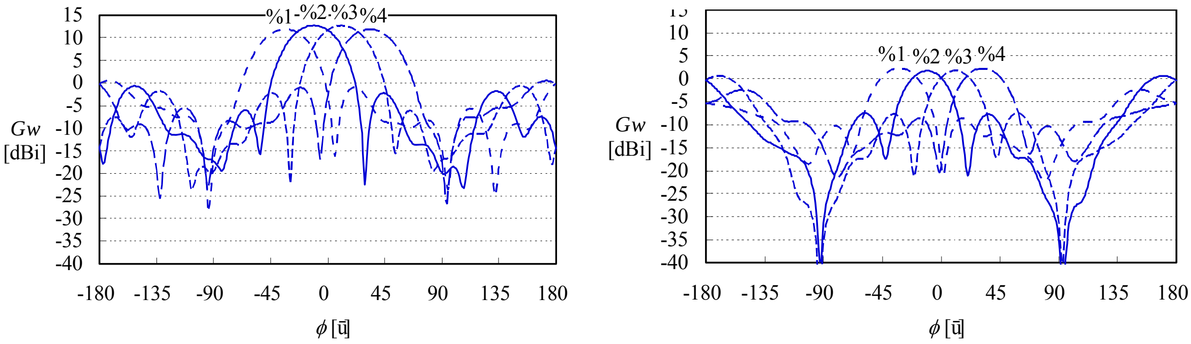
Figure 2: Absolute gain pattern in the E-plane of the Yagi-Uda antenna alone.

Table 1: Dimensions of the Yagi-Uda antenna unit employed for the calculations.

#	-1	0	1	2	3	4
L /*λ*	0.468	0.448	0.432	0.426	0.430	0.426
W /*λ*	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137
R /*λ*	0.248	0	0.248	0.690	1.010	1.428

Table 2: Inductance values for the electrically invisible transformation (6 GHz).

#	-1	0	1	2	3	4
Lx [nH]	26	26.3	28	28.2	28.2	28.2



(a) Inductive loading (b) Open-circuited loading

Figure 3: Beam switched working gain pattern in the E plane (in the order of %3, %1, %4, %2).

Table 3: Directive gain and impedance matching (in the order of %3, %1, %4, %2).

(a) Inductive loading

%	1	2	3	4
Gd [dBi]	12.33	12.89	12.89	12.35
Rin [Ω]	82.27	46.93	46.63	83.64
Xin [Ω]	1.368	1.680	1.759	-0.5719
vswr	1.65	1.08	1.08	1.67

(b) Open-circuited loading

%	1	2	3	4
Gd [dBi]	7.32	8.32	8.32	7.30
Rin [Ω]	19.58	16.32	16.48	18.96
Xin [Ω]	-84.18	-97.58	-97.88	-83.05
vswr	10.1	15.0	14.9	10.2

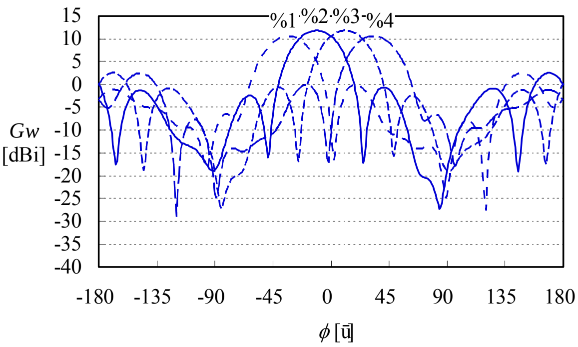


Figure 4: Working gain pattern for the stacking order %3, %4, %1, and %2.

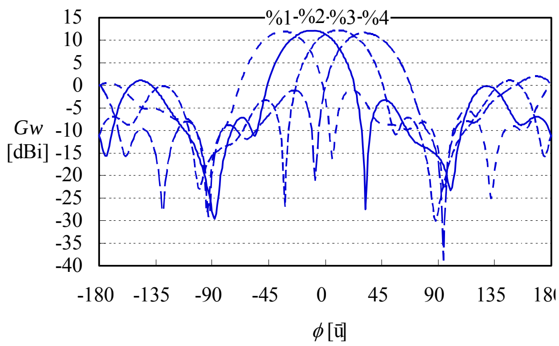


Figure 5: Working gain pattern when switches of #4 are reduced.

Table 4: Antenna characteristics for the stacking order %3, %4, %1, and %2.

%	1	2	3	4
Gd [dBi]	12.24	12.43	12.43	12.26
Rin [Ω]	147.3	53.51	52.61	152.1
Xin [Ω]	30.74	29.59	29.27	25.66
vswr	3.09	1.77	1.76	3.14

Table 5: Antenna characteristics when switches of #4 are reduced.

%	1	2	3	4
Gd [dBi]	12.33	12.37	12.37	12.02
Rin [Ω]	79.82	42.31	42.06	81.22
Xin [Ω]	2.861	1.142	1.187	1.126
vswr	1.60	1.18	1.19	1.63