Yagi-Uda Monopoles with Elevated-Angle Suppression for Endfire Radiation

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***Abstract*—For monopole antenna mounted on a finite ground plane, the direction of its peak-radiation has an angle elevated off the horizontal plane. From the analysis based on spherical vector wavefunctions (SVWF), it is shown that the elevated angle arises from higher order transverse magnetic (TM) modes, which are mainly excited by the ground plane. By inserting resonance structures, i.e., slots, in the ground plane, a dipole-like (TM_{01} mode dominated) radiation pattern can be achieved with a maximum radiation along the ground plane. Accordingly, a new monopole-based Yagi-Uda antenna is proposed with the main beam along the ground plane. It has an improved gain compared with the traditional one without inserting resonant structures on the ground. A sector of a circular Yagi-Uda array operates at 3 GHz is then simulated and measured for the verification of the method.**

Keywords— Elevated angle, endfire antenna, finite ground plane, monopole, Yagi-Uda antenna

I. Introduction

Yagi-Uda antenna is a classic antenna that was developed for high gain endfire radiation [1][2]. For monopole-based Yagi-Uda antenna with a finite ground plane, the direction of the peak radiation has an angle elevated off the horizontal plane. The similar phenomenon can be observed in monopole antenna mounted on a finite ground plane as well. This is usually undesirable since the beam direction may vary across the operating band, and the energy will be delivered to another direction instead of the endfire direction.

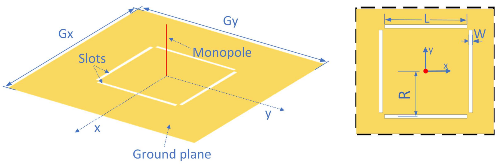
There are some solutions reported to direct the radiation back to the endfire direction. Firstly, electrically large ground plane can decrease the elevated angle of the beam pattern, but it is not an effective method as a very large ground plane may not be feasible for many applications [3]. Another solution is to use the sleeve structure [4]. Despite of the high profile, its feasibility on a medium-sized ground plane was not investigated. Alternatively, a reflector can be placed on top of the monopole antennas to direct the beam towards the endfire direction, but the profile of the whole antenna becomes higher [5].

In this paper, from the analysis of the radiation mechanism of the monopole antenna, it is known that the elevated angle is attributed to the higher order TM modes from the induced currents on the ground plane. To address this problem, resonant slots are inserted into the ground to suppress radiation from these unwanted modes. The developed method is also applied to a monopole-based Yagi-Uda antenna with a finite ground plane.

II. Monopole with Resonant Slots on the Ground

In this section, SVWF is used to analyze a λ/4 monopole located at the center of a square ground plane. For SVWF, the power radiated by outcoming modes is one half of the summation of squares of coefficient magnitudes [6]. Considering the orthogonality of SVWF, the percentage of radiated power of every mode can then be calculated individually. In this work, only TM_{0n} (n=odd) modes, which come from the monopole, and TM_{0n} (n=even) modes, which come from the ground plane, are considered. Note that TM_{mn} means there are m cycles in H-plane and n cycles in E-plane with respect to the field distribution.

The developed monopole with resonant slot structures are shown in Fig. 1. A reference (Ref.) one is with the same dimensions but without slots in the ground. The percentages of radiated power from two dominated modes, TM_{01} and TM_{02}, are compared in Fig. 2 for these two structures. It is obvious that by inserting slots into the ground plane, the radiated power from TM_{01} mode will dominate (increasing from around 45% to over 90%) and TM_{02} mode will be suppressed significantly (decreasing from around 40% to less than 10%). It is obvious that a dipole-like radiation pattern can be obtained, because the radiation from the ground plane is suppressed significantly.



(a) (b)

Fig. 1. Developed monopole. (a) Isometric view of monopole with the slots. (b) Top view of the slots in (a). The lengths of the ground plane along the x- and y-axes are denoted by Gx and Gy, respectively. Gx=Gy=λ. The slot length L = 0.420λ, slot width W = 0.015λ, and R = 0.225λ.

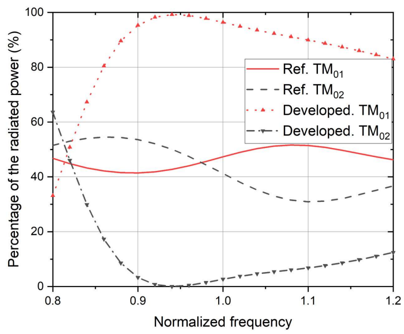


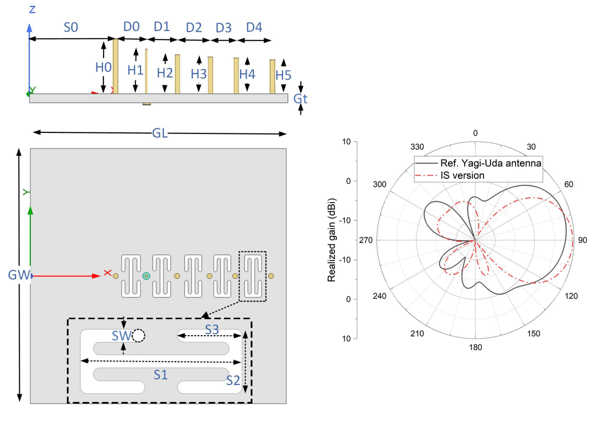
Fig. 2. Percentage of the radiated power from different TM modes.

III. Developed Yagi-Uda Antenna and Its Array

Based on the monopole antenna with slots shown in Section II, a Yagi-Uda monopole antenna with the maximum radiation along the horizontal plane is developed in this section. A prototype operating at 3.0 GHz is optimized and fabricated to verify the design.

As shown in Fig. 3 (a), I-shaped (IS) slots are inserted in the conducing ground plane, instead of the rectangular ones shown in Fig. 1, to realize a compact array design. For the reference Yagi-Uda antenna, there are no slots on the ground.

From Fig. 3(b), it is shown that the main beam of the developed Yagi-Uda antenna is pointed along the endfire direction with a gain improvement.



(a) (b)

Fig. 3. (a) Yagi–Uda antenna with IS slots in the ground plane. Optimized design parameters (dimensions in millimeter). The Ref. one is not shown here. Shared values: GL = 150, GW = 150, Gt = 5, S0 = 50, D0 = 18, D1 = 18, D2 = 19, D3 = 15, D4 = 21, and D5 = 21. Ref. Yagi–Uda antenna: H0 = 29, H1 = 26, H2 = 20, H3 = 19, H4 = 18, and H5 = 17. IS version: H0 = 32, H1 = 26, H2 = 23, H3 = 21.5, H4 = 21, H5 = 20, S1 = 26.5, S2 = 12, S3 = 10, and SW = 2. (b) Realized gain pattern at the operating band for the developed Yagi-Uda antenna and the Ref. Yagi-Uda antenna.

As shown in Fig. 4, a 60° sector of a circular Yagi-Uda array consisting of three Yagi-Uda antennas is fabricated. The IS slots are etched in a 5.0 mm thick, fan-shaped aluminum plate. For the sake of the impedance matching, a pair of parasitic rods which are 16.0 mm in height are placed 2.8 mm away from the monopole. A conducting plate is placed below the antenna, which facilitates the mounting of the antenna on the testing platform.

The middle Yagi-Uda antenna is excited and measured. From the comparison of the simulated and measured S-parameters shown in Fig. 5, the antenna is well matched with the 50 Ω loading and well isolated from the adjacent unit. The realized gain patterns in E- and H-plane at 3.05 GHz are illustrated in the Fig. 6. It can be seen that the main beam of the E-plane are toward the horizontal direction. By exciting other Yagi-Uda antennas, beam scanning in H-plane can be achieved [7].

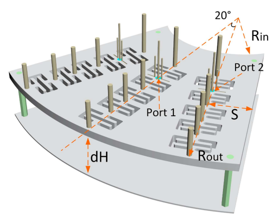


Fig. 4. (a) The Yagi-Uda monopoles prototype, S = 25.0 mm, R_{in} = 55.0 mm, dH = 30.0 mm, R_{out} = 187.0 mm.

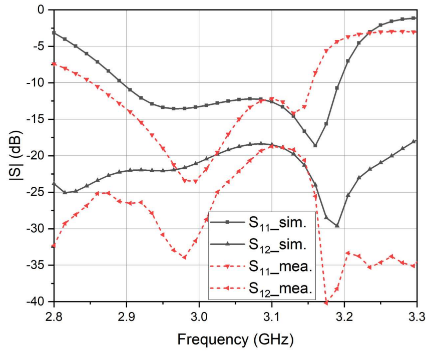


Fig. 5. Simulated and measured S-parameters.

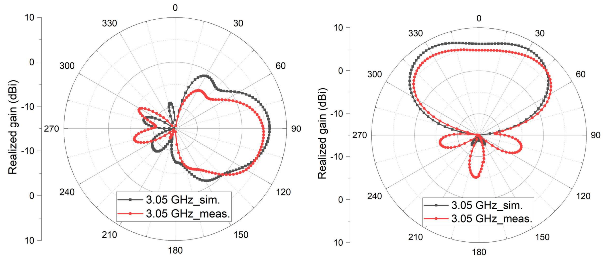


Fig. 6. Simulated and measured realized gain pattern for the antenna excited by port 1. (a) E-plane (b) H-plane.

IV. Conclusion

A monopole mounted on a finite ground plane radiates an elevated main beam, resulting from the induced currents on the ground. By inserting resonant slots in the ground, this elevated angle can be suppressed significantly. Yagi-Uda monopoles were then developed to redirect the beam back to endfire direction along the horizontal plane with a gain improvement. Simulation and measurements of a sector of a circular array verified the design concepts.

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