Optimization of a Yagi Antenna Director Array for Shaped Radiation Patterns in the Applications of Wireless Communications

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Introduction

An increasing trend to optimize the coverage in the cell planning of wireless communications utilizes shaped patterns of antenna radiations [1]. This paper investigates the potentials of implementing Yagi-type antennas[2], which has advantages of low cost and easy fabrication, by considering an array of directors. The orientations and dimensions of the directors are optimized via an electromagnetic (EM) optimization technique, such as genetic algorithm (GA)[3], which is integrated with a commercial EM simulation software of Ansoft HFSS[4], to produce a shaped radiation pattern. Numerical examples are presented to demonstrate the proposed concepts.

Yagi Antenna Design with an 3-D Array of Directors

Yagi-type antenna, in comparison with conventional dipoles, may increase radiation directivities via the uses of a reflector and parasitic directors. In a conventional design, the driven dipole, and its reflector and directors are linearly oriented and distributed in an 1-D fashion as illustrated in Figure 1 (a), and results in an end-fire radiation, whose directivity may be increased by properly increasing the number of parasitic directors.

The proposed work relaxes the linearity of parasitic directors’ distributing locations, and allows them distributed in a 3-D fashion as illustrated in Figure 1(b). This way allows the radiation patterns properly shaped with respect to the distribution of the parasitic directors.

As illustrated in Figure 1(b), the elements of a driven dipole, and its reflector and parasitic directors are printed on dielectric substrates for simplicity of prototyping, which also assist to reduce the sizes of antenna elements. The reflector is a ground plane and is placed at a distance of $\lambda/4$ below the driven dipole, where $\lambda$ is the wavelength of a free space, such that the fields reflected from the ground will propagate in-phase with that directly radiated from the dipoles in the boresite direction of the antenna.

Parameter Optimization of Parasitic Directors via Genetic Algorithm

A simulation tool integrating GA with HFSS as a computational engine is developed to optimize the radiation patterns of the Yagi-type antenna. In the design, the driven dipole is first adjusted to operate in the desired frequency band. A desired radiation pattern in terms of normalized gains is assumed, which is used as a goal to design the directors of this Yagi antenna. The parameters of the directors as illustrated in Figure 2 are consequently adjusted in the GA optimization procedure until the computed pattern has met the requirements within an allowable margin. In the current case, four sets of directors, with each has three directors, are considered, where their angular separations remain fixed at 30 degrees. These separations are found sufficient not to affect the return loss of the driven dipole.
Numerical Examples and Experimental Validation

Three examples are examined to exhibit the validity of the proposed works as described in the following:

A. Planar Distribution of parasitic directors:
In this case, 5 elements of identical parasitic directors are periodically printed on a FR4 substrate ($\varepsilon_r = 4.4$ and 0.4mm thickness) with dimensions shown in Figure 3(a). The substrate is placed in parallel to the driving dipole with a separation distance, $0.34\lambda$. The operational frequency is 5.0GHz. The spacing of the directors was adjusted to achieve a largest gain, where the pattern is shown in Figure 3(b). In this case, 11.4dBi gain has been measured in comparison to 12.96dBi of simulation.

B. 3-D Unequal Distribution of parasitic directors:
This case intends to produce a butterfly-like pattern with a low directivity at the antenna boresite direction. The antenna structure is illustrated in Figure 4(a). Thus each side uses two set of directors to produce higher directivities. The radiation pattern is shown in Figure 4(b), where measured and simulated patterns are shown. It is observed that the boresite has a gain 12dB below the peak. The peak gain is found to be 8.45dBi and 9.44dBi obtained by measurement and simulation, respectively.

C. Shaped Pattern Optimization
This case synthesizes a shaped pattern using the antenna structure in Figure 1(b). The parameters in Figure 2 are optimized using GA described in the previous section to achieve the contour constraint shown in Figure 5(b). The designed results are shown in Figure 5(a)-(c) for the return loss and radiation patterns. The return loss in Figure 5(a) shows that this antenna operates at 5GHz band. The radiation patterns, shown in Figure 5(b), exhibit the pre-set contour, simulated and measured patterns. They show good agreements, and indicate good achievement of design goal. Finally the pattern on the E-plane is also shown in Figure 5(c).

Conclusion

A Yagi-type antenna is presented for the shaped radiation pattern synthesis, which will become very useful in the applications of wireless communications. The shaped pattern is formed by properly allocating the directors to weight the directivities in a various directions since the uses of directors have been shown to increase the directivity of a Yagi antenna radiation. Both numerical and experimental examinations have validated the current approach to be very effective in both applications and cost.

References

**Figure 1:** A Yagi-type antenna structure

- (a) Conventional structure
- (b) Proposed Structure

**Figure 2:** Parameters of Yagi directors for the pattern optimization.

**Figure 3:** Antenna structure and radiation patterns of a planar distributed element.

- (a) Antenna Structure
- (b) Radiation Pattern

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(b) Radiation Pattern
Figure 4: Low boresite directivity design.

(c) E-plane pattern
Figure 5: Shaped beam synthesis.

(a) Return Loss

(b) H-plane Pattern