Design of Microstrip bi-Yagi and Microstrip quad-Yagi Antenna Arrays for WLAN and Millimeter-Wave Applications

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I. Introduction

Throughout the last several years, many contributions have taken place in the design and optimization of printed microstrip Yagi antenna arrays [1-4]. John Huang introduced the first standard design in 1989 for mobile satellite (MSAT) applications, which required a low-cost, low-profile antenna that covers a 40º beamwidth [1]. This design consisted of four elements of different sizes that are capacitively-coupled to each other to produce a fixed beam between 20-60º. One of the major limitations to this design was the low front-to-back (F/B) ratio (as low as 5 dB) where the back radiation considered in this design was the radiation in the elevation angles between $-90° \leq \theta \leq 0°$. Another limitation in design of microstrip Yagi array antennas is the necessity of low dielectric materials ($\varepsilon_r<5$), because the center-to-center spacing between elements is a function of the free space wavelength, λ_0, not the guided wavelength, λ_g, which includes the dielectric constant. This means that high dielectric constant materials will result in a large center-to-center spacing between elements, hence, the patch elements will not be coupled to each other. Since Huang's initial design, there have been some modifications to this antenna design process and configuration to address these limitations. Padhi and Bialkowski developed a periodic bandgap (PBG) structure that can be applied to microstrip Yagi antenna arrays for reducing the cross-polarized radiation and increasing the gain [2]. DeJean and Tentzeris developed a printed microstrip Yagi antenna array that can achieve a gain above 10 dB and a high F/B ratio (as much as 15 dB) that can be used for ISM, HIPERLAN, and millimeter-wave applications above 30 GHz [3].

In order to meet the challenges of the design of printed microstrip Yagi antenna arrays with quasi-endfire radiation (radiation between broadside ($\theta=0º$) and endfire ($\theta=90º$)) that can achieve a high gain (> 12 dBi) while maintaining a low cross-polarization and a high F/B ratio, two new designs are introduced which are derived from the microstrip Yagi array presented in [3]. The first structure is called the microstrip bi-Yagi array and the second is called the microstrip quad-Yagi array. The microstrip bi-Yagi and quad-Yagi arrays can achieve directivities of 13.4 and 16.1, respectively, while a high F/B ratio can be maintained. These qualities are essential to the design of a planar antenna geometry that can be easily integrated with multilayer or planar wireless communicational devices.

II. Antenna Structure

The microstrip Yagi antenna array architecture is shown in Fig. 1a. It consists of six patch elements along with the feeding structure. The seven elements are denoted as follows: the driven element (D), the gap-loaded reflector element (R), the top director1 element ($D1_T$), the bottom director1 patch ($D1_B$), the top director2 element ($D2_T$), and the bottom director2 patch ($D2_B$). The dimensions of the antenna in Fig. 1a are as follows: the length and width of the reflectors (L_R and W_R) are 245 x 1002 mils, the length and width of the driven element (L_D and W_D) is 724 x 724 mils, and the length and width of the director1 and director2 elements (L_{D1} and W_{D1}) are 688 x 492 mils. The distance between the elements along the x-axis (g) is 35 mils. Furthermore, the distances between the director1 and director2 elements are represented by S_1 and S_2, respectively. S_1 is 72 mils and S_2 is 902 mils. This antenna structure is designed on a double copper (Cu) clad board of RT/duroid 5880 material (ε_r=2.2, tan δ =0.0009 @ 10 GHz). The thickness of the substrate (h) is 62 mils. The operational frequency of this design is around 5.2 GHz. In order to maintain the simplicity of the fabrication on a double clad copper (Cu) board, a gap was inserted between the reflector patch, and the feedline was connected to the driven patch through the gap of the reflector. The feeding structure consists of a 50Ω feedline that is transformed to a high impedance line through the use of a quarter-wave transformer. It is necessary to use a high impedance line (width less than 0.15 times a patch length) due to its small width in order to ensure that the feedline radiation close to the driven element will not disrupt the radiation of the antenna and lead to an increased F/B ratio. The high gain of this design is obtained through the constructive interference of two individual microstrip Yagi structures (R-D-$D1_T$-$D2_T$ and R-D-$D1_B$-$D2_B$) that maximally radiate at $10° \leq \varphi \leq 16°$ and $-16° \leq \varphi \leq -10°$, respectively. Using a common director2 element and modifying the feeding structure, designs of two and four microstrip Yagi antenna arrays can be excited in phase to allow an increased gain. This follows the principles of antenna array design where additional elements excited in phase produce increased directivity. The two microstrip Yagi array is called a “microstrip bi-Yagi antenna array” while the four microstrip Yagi array is called a “microstrip quad-Yagi antenna array”. These structures are shown in Figs. 1b and 1c, respectively. The bi-Yagi array consists of 11 patch elements: two driven patches, two gap-loaded reflectors, and seven director elements. The middle director2 element is common to both Yagi arrays. A figure of merit that is considered in this design is the sidelobe level in the H-plane due to the excitation of two driven elements. The distance between the two microstrip Yagi arrays in the bi-Yagi antenna array must be considered to maintain a low sidelobe level. The quad-Yagi array consists of 21 elements: four driven patches, four gap-loaded reflectors, and 13 director elements. In this structure, there are three common director2 elements: one in common with the first and second Yagi arrays, one in common with the second and third Yagi arrays, and the last in common with the third and fourth Yagi arrays.

III. Results

The designs in Figs. 1 and 2 were simulated using the 3D TLM-based MicroStripes 6.5. The return loss plots versus frequency for the three designs are shown in Fig. 3. There are two resonances present in each of the plots. The lower resonance occurs from the TM_{10} mode, while the higher resonance comes from a parasitic mode that resonates due to the capacitive coupling of energy between the individual arrays. The relative bandwidth decreases as the size of the total array increases. The relative impedance bandwidths for the A, B, and C are 7.8, 7, and 5.5%, respectively. The radiation patterns at 5.2 GHz are shown in Fig. 4. The co-polarized components of the E-plane elevation pattern exhibit maximum radiation at θ angles between 35^o and 45^o with beamwidths of 40^o for all three designs. The maximum directivities for A, B, and C are 11.6, 13.4 and 16.1 dBi, respectively. The F/B ratios decrease as the size of the total array increases probably due to feedline radiation as the complexity of the feeding increases. At some frequencies close to 5.2 GHz, the F/B ratio can be increased as the cost of lower directivity; hence, there is a tradeoff. One possible way of improving the F/B ratio is to connect the reflector elements to each other to produce one large reflector patch. Measurements will be presented at the conference.

IV. Conclusion

Two new antenna designs are presented that are extensions of the microstrip Yagi antenna array proposed in Fig. 1. Simple fabrication techniques that are inexpensive can be employed to realize these structures due to the placement of the feeding structure on the same layer as the antenna. These designs effectively increase the gain of quasi-endfire antennas while maintaining an acceptable F/B ratio. This design approach can be integrated with 3D modules that consist of embedded passives, filters, and MMICs to realize a wireless system-on-package (SOP) RF front end devices for ultrafast applications in WLAN (WiFi, WiMax) and millimeter-wave frequencies.

References

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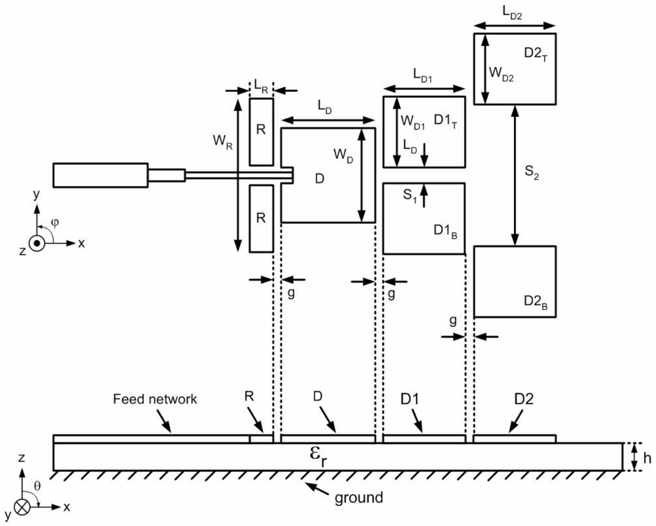

Fig. 1. Microstrip Yagi antenna array

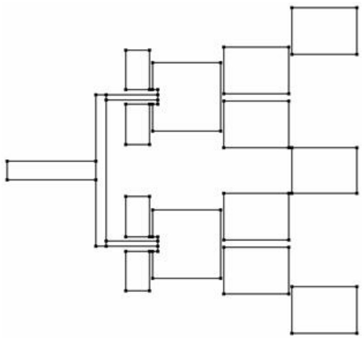

Fig. 2a. Microstrip bi-Yagi antenna array

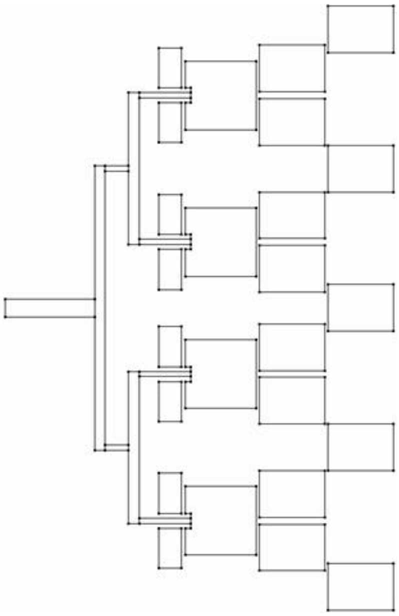

Fig. 2b. Microstrip quad-Yagi antenna array

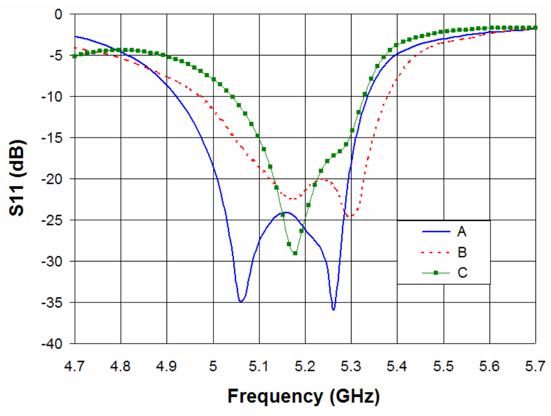

Fig. 3. Return loss versus frequency for A. Fig. 1 Yagi, B. bi-Yagi, and C. quad-Yagi

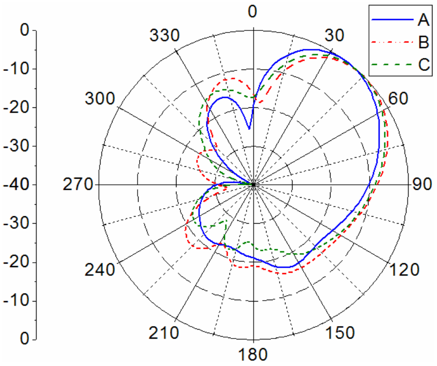

Fig. 4. E-plane radiation pattern for A. Fig. 1 Yagi, B. bi-Yagi, and C. quad-Yagi