Design of Broadband Quasi-Yagi Antenna Using a Folded Dipole Driver

Son Xuat Ta¹ · Byoungchul Kim¹ · Hosung Choo² · Ikmo Park¹

Abstract

This paper describes the development of a broadband quasi-Yagi antenna using a folded dipole driver. The antenna is designed on a low-permittivity substrate to reduce the surface wave effect, and hence the gain can be enhanced easily by adding directors. The folded dipole driver is connected to a 50- Ω microstripline via a simple broadband microstrip-to-coplanar stripline transition with a quarter radial stub. The key motivation for the use of a folded dipole is to increase the input impedance at the driver, allowing a smaller mismatch loss between the antenna driver and the coplanar stripline feed. The proposed antenna has a measured bandwidth of 4.67~6.26 GHz for the -10 dB reflection coefficient, and a flat gain of 4.86~5.15 dB within the bandwidth.

Key words: Broadband, Quasi-Yagi Antenna, Folded-Dipole.

I . Introduction

In recent years, quasi-Yagi antennas have been widely employed in microwave and millimeter-wave applications, due to their broad bandwidth, high efficiency, high directivity, low profile, uniplanar structure, ease of fabrication, and low cost. These antennas can be designed on a high-permittivity substrate [1]~[8] or a low-permittivity substrate [9]~[13] with a regular-dipole-driver feed and various types of feedlines, including microstriplines [1], [2], [9~13], coplanar waveguides [3]~[6], coplanar striplines [7], or slotlines [8]. If the antenna is designed on a high-permittivity substrate, the gain cannot be enhanced easily by adding directors, due to the surface wave effect. This effect can be reduced by using a low-permittivity substrate. However, when the antenna is designed on a low-permittivity substrate, a regular dipole driver is not quite compatible with a coplanar stripline feed, since the characteristic impedance of such a feedline is usually much higher than the input impedance of a regular dipole. Recently, folded dipole driven quasi-Yagi antennas [14], [15] have been reported with a microstrip-to-coplanar stripline transition feed which introduced a 180° phase delay between two microstripline branches by adjusting their length. However, this transition is guaranteed only at the center frequency of operation.

This paper introduces a broadband folded-dipole-driven quasi-Yagi antenna that is built on a low-permittivity substrate. The folded dipole, which is utilized to increa-

se the input impedance at the driver, is fed by a coplanar stripline that is matched with a 50- Ω microstripline by a quarter radial stub [14]. The antenna utilizes a parasitic strip as a director and a truncated ground plane as the reflector in order to minimize the gain variation.

II . Antenna Design and Characteristics

Fig. 1 shows the geometry of the folded-dipole-driven quasi-Yagi antenna. The antenna was designed on both sides of a 60×60 mm Rogers RO4003 substrate with a relative dielectric constant of 3.38 and a thickness of 0.508 mm. The antenna is comprised of a microstrip feedline, a folded dipole driver, a strip parasitic element used as a director, and the truncated ground plane used as a reflector. The ground plane was placed on the back side of the substrate, with a length of 30 mm and a width of 60 mm. The driver and the director were printed on the top side of the substrate, with a driver-to-director spacing of S . The initial length of the driver was approximately half the effective wavelength ($\lambda_{eff}/2$) at 5 GHz. The director was designed to achieve an optimal phasing for a small gain variation at 5~6 GHz with the length and width of L_{dir} =13 mm and W_c =3 mm, respectively. The feedline was designed to have a characteristic impedance of 50 Ω for a microstripline width of W_{ms} =1.14 mm. Since the structure of the antenna prevents the microstrip feedline from being directly connected to the driver, a broadband microstrip-to-coplanar stripline with a radial stub (of radius R and angle a) was

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Fig. 1. Folded dipole quasi-Yagi antenna geometry: $W_{ms}=1.14$ mm, $\alpha=90^\circ$, $g=0.5$ mm, $R=10$ mm, $T=8$ mm, $L_{driv}=21$ mm, $L_{dir}=13$ mm, $s_d=0.6$ mm, $S=5$ mm, and $w_c=3$ mm.

used to make the transition between the two. The coplanar stripline was designed with a characteristic impedance of 146Ω ; its length and gap size are T and g , respectively. R , a , and T were optimised for the wide-band impedance matching condition.

The variation of the antenna characteristics as functions of the main design parameters was investigated via the full-wave electromagnetic simulator MWS (by CST). Fig. 2 shows the simulated input impedances of folded and regular dipoles. Two identical dipoles (length of 21 mm, width of 1.14 mm, and feedgap of 0.5 mm) were placed on the top side of the substrate without the ground plane, transition, and coplanar stripline feed. In the simulations, the dipoles were excited by discrete port and Z-parameters were computed. As shown in Fig. 2, at 5 GHz, these were approximately 150Ω and 40Ω , respectively. Thus, the folded dipole was chosen for connection with the coplanar stripline, which has a characteristic impedance of approximately 146Ω . This allows a smaller mismatch loss between the antenna driver and the coplanar stripline feed.

The folded-dipole-driven quasi-Yagi antenna is fed by a simple microstrip-to-coplanar stripline transition with a radial stub, designed to obtain the most appropriate impedance matching conditions. These can be inferred from Fig. 3, which shows the simulated reflection coefficient with respect to radius (R) and angle (α) of the radial stub. Fig. 3(a) clearly shows that changing the radius of

Fig. 2. Simulated input impedances of the regular- and folded-dipoles with the same length of 21 mm on Smith chart from 4 to 7 GHz.

Fig. 3. Reflection coefficient as a function of the radial stub.

the stub significantly influences the reflection coefficient, and a 10-mm radius offers the best match.

According to Fig. 3(b), as the stub angle increases, the reflection coefficient improves. These two plots indicate that the reflection coefficient is optimized by using a quarter radial stub ($\alpha=90^\circ$) with a radius of 10 mm. Since the effect of the radial stub on the radiation pattern of the antenna is negligible, it is not shown here.

The coplanar stripline is used as the feed for the folded dipole driver. The length of the coplanar stripline is also equal to the space between the reflector (ground plane) and the driver. The reflection coefficient and the gain of the antenna were simulated for varying coplanar stripline length, and the results are shown in Fig. 4. The effects of the coplanar stripline length (T) on the antenna

Fig. 4. Antenna characteristics as functions of the coplanar stripline length (T).

characteristics are relatively significant. The reflection coefficient is optimized at a length of 8 mm, which is approximately one-quarter of the effective wavelength ($\lambda_{eff}/4$) at the center frequency of 5.5 GHz (see Fig. 4(a)). As the coplanar stripline length was increased from 6 mm to 10 mm (in increments of 2 mm), the gain also increased, as shown in Fig. 4(b). The best gain flatness was observed at a coplanar stripline length of 8 mm.

Fig. 5 shows the simulated reflection coefficient of the folded-dipole-driven quasi-Yagi antenna with respect to driver length. As the length was increased from 20 mm to 22 mm (in increments of 1 mm), the center frequency decreased, but the bandwidth for the -10 dB reflection coefficient did not change significantly. This indicates that the center frequency of the operating bandwidth is mainly determined by the length of the folded-dipole driver. However, the effect of the driver length on the radiation pattern of the antenna is negligible.

Fig. 6 shows the variations of the antenna characteristics as functions of space S between the driver and the director. As the space varied from 2 mm to 8 mm (in steps of 3 mm), the reflection coefficient changed slightly in the high-frequency region, but was unchanged in the low-frequency region (see Fig. 6(a)), while the antenna gain increased throughout the operating bandwidth (see Fig. 6(b)).

Because of the surface wave effect, the gain of a quasi-Yagi antenna is not as readily increased by adding directors, compared to the case of a conventional Yagi-Uda antenna. To avoid this problem, the proposed antenna was designed on a low-permittivity substrate. The increased gain effect is then evident in Fig. 7, which

Fig. 5. Reflection coefficient as a function of the driver length (L_{driver}).

Fig. 6. Antenna characteristics as functions of the space between the folded-dipole-driver and the director (S).

shows the gain as a function of the number of directors. As the figure indicates, the simulated antenna gains were $4.95 \sim 5.41$, $6.67 \sim 7.45$, and $7.8 \sim 8.9$ dB at $5 \sim 6$ GHz for 1-, 5- and 10-director designs, respectively, with a driver-to-director spacing of 5 mm. This indicates that the gain of the proposed antenna is linearly proportional to the number of directors. However, the final antenna design uses only one director with a moderate gain of $4.95 \sim 5.41$ dB, since the smallest gain variation is obtained with this configuration. The 5- and 10-director designs have a larger gain variation than the single director design owing to a non-optimal phasing condition of the director elements.

The antenna was fabricated on a Rogers RO4003 substrate with a copper thickness of $20 \mu\text{m}$ via a standard etching technique, and an SMA connector was used for

Fig. 7. Gain variation as a function of the number of directors.

the microstrip-to-coaxial line transition (not included in the simulation). An Agilent N5230A network analyzer and an Agilent 3.5 mm 85052B calibration kit were used for measurements. Fig. 8(b) shows good agreement between the simulated and measured reflection coefficients of the optimized antenna. The measured bandwidth for the -10 dB reflection coefficient was $4.67 \sim 6.26$ GHz, while the simulated bandwidth was $4.8 \sim 6.3$ GHz. There were some minor discrepancies between the simulation and the measurements, due to the effect of the coaxial-to-microstripline transition (SMA connector).

The radiation patterns and gain of the broadband folded-dipole-driven quasi-Yagi antenna were measured with an Agilent Vector Network Analyzer (E8362B). Two identical standard horn antennas (one for transmitting and one for receiving) were first connected to two ports of the network analyzer for calibration. The distance between the transmitting and receiving antennas was 10 m. The receiving antenna was then replaced with the proposed antenna. In the measurement process, the transmitting antenna was fixed, while the receiving antenna was rotated from -180° to 180° , with a scanning angle of 1° . The 5.0, 5.5, and 6.0 GHz radiation patterns of the antenna in the E - and H -planes are illustrated in Fig. 9. Again, the simulated and measured results agreed quite closely, with a front-to-back ratio better than 14, and a cross-polarization level better than -15 dB. The radiation patterns were not quite symmetrical, since the transition feed was asymmetric. At a frequency of 5 GHz, the half-power beamwidth (HPBW) obtained from the measurements was 76° along the E -plane and 191° along the H -plane. At the center frequency of 5.5 GHz, the HPBW obtained from the measurements was 84°

Fig. 8. (a) Fabricated folded-dipole-driven quasi-Yagi antenna, (b) measured and simulated reflection coefficient.

along the E -plane and 187° along the H -plane. At 6 GHz, the HPBW obtained from the measurements was 86° along the E -plane and 182° along the H -plane. As Fig. 10 shows, the measured gain of the antenna was $4.86 \sim 5.15$ dB over the $5 \sim 6$ GHz band, and this is in close agreement with the simulated gain of $4.95 \sim 5.41$ dB. The antenna also exhibited a very small gain variation across its bandwidth: the measured gain variation was 0.29 dB and the simulated gain variation was 0.46 dB. Therefore, this antenna can be stably operated in transmitting or receiving applications in a wireless communication system.

Fig. 9. Radiation patterns of the antenna. ----- mea. co-pol., ---- mea. x-pol., — sim. co-pol., ---- sim. x-pol.

Fig. 10. Gain of the proposed antenna.

III. Conclusion

A broadband quasi-Yagi antenna with a folded dipole driver was introduced. The measured bandwidth of the antenna was 4.67~6.26 GHz for a -10 dB reflection coefficient, and the measured gain was 4.86~5.15 dBi within the bandwidth. With its broadband characteristics, planar structure, simple feed, stable radiation pattern, and small gain variation, this antenna is widely applicable to wireless communication systems, power combining, and phased arrays.

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