Broadband Printed-Dipole Antenna and Its Arrays for 5G Applications

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Abstract—In this paper, we propose a broadband printed-dipole antenna and its arrays for fifth-generation (5G) wireless cellular networks. To realize a wide frequency range of operation, the proposed antenna is fed by an integrated balun, which consists of a folded microstrip line and a rectangular slot. For compactness, the printed dipole is angled at 45°. The single element antenna yields a $|S_{11}| < -10$ dB bandwidth of 36.2% (26.5–38.2 GHz) and a gain of 5.8–5.5 dBi. We insert a stub between two printed-dipole antennas and obtain a low mutual coupling of < -20 dB for a 4.8-mm center-to-center spacing (0.42–0.61λ at 26–38 GHz). We demonstrate the usefulness of this antenna as a beamforming radiator by configuring 8-element linear arrays. Due to the presence of the stubs, the arrays resulted in a wider scanning angle, a higher gain, and a lower side-lobe level in the low-frequency region.

Index Terms—angled dipole, beamforming, integrated balun, mutual coupling, printed antenna, 5G communication.

I. INTRODUCTION

To overcome the global bandwidth shortage in today’s wireless cellular networks, the fifth-generation (5G) communication system is expected to utilize millimeter-wave bands [1], which have a large amount of available spectrum. Several measurements have demonstrated the promise of orders of magnitude greater bandwidths combined with further gain via beamforming and spatial multiplexing from multi-element antenna arrays [2]. As a result, designing an optimal antenna for millimeter-wave beamforming could be an important step for realizing 5G wireless cellular networks. Although there are different beamforming techniques [3], so far, the active-phased array [4], [5] is the most popular beamforming technology. Consequently, millimeter-wave phased-array antennas have recently drawn increased attention.

In the past two decades, planar antennas have attracted interest for millimeter-wave phased arrays because of their features of wide bandwidth, low cost, ease of fabrication, and high-efficiency. Several types of planar antennas have been developed for phased array systems. Examples include quasi-Yagi antennas [6], printed dipoles [7], and angled-dipole antennas [8]–[11]. As another kind of planar antenna, T-dipole antennas fed by integrated-balun have been widely developed for wireless communications at microwave frequencies [12]–[15]. These antennas can achieve wideband or multiband operations, but their disadvantage is that they have a large size.

In this paper, we propose a broadband printed-dipole antenna for use in 5G applications. We use an integrated balun as the feed structure to enable broadband operation. The printed dipole is angled at 45° to reduce the antenna size. We demonstrate both computationally and experimentally the advantages of the single element, including compact size, broad impedance-matching bandwidth, wide radiation pattern, small gain variation, and high radiation efficiency. To achieve a low mutual coupling in the linear-array environment, we insert a microstrip stub between the two printed-dipole antennas with close spacing. The usefulness of the proposed antenna is computationally and experimentally demonstrated in beamforming radiators by configuring 8-element linear arrays. Due to the presence of stubs, the arrays result in a wider scanning angle, higher gain, and a lower side-lobe level in the low-frequency region. We use an electromagnetic simulator by CST Microwave Studio (CST MWS; Computer Simulation Technology AG, Darmstadt, Germany) for the simulations in this work.

II. SINGLE ELEMENT

Fig. 1(a) shows the geometry of the printed dipole antenna, which was designed on both sides of a Rogers RT/Duroid™ 5880 substrate ($h_z = 0.254$ mm, $\varepsilon_r = 2.2$, and $\tan\theta = 0.0009$). The antenna was composed of a 50-Ω microstrip-line feed, a truncated ground plane, an integrated balun, and a printed dipole. The feed line was on the top layer of the substrate, whereas the dipole and the ground plane were on the bottom layer. The dipole was fed by a slot line with a characteristic impedance of 116 $\Omega$. To achieve the impedance matching over a broad frequency range, the balun acts as a microstrip-to-slot line transformer, which consists of a folded microstrip-line connected to the feedline and a rectangular slot etched on the ground plane. Impedance matching was realized by adjusting the folded line and rectangular slot. Also, the gap of the slotline $(g)$ and the stripline $(gap)$ are crucial design parameters of impedance matching. The printed dipole was angled to achieve a compact size, as well as to realize a wide pattern in the E-plane [16]. The antenna was characterized via CST...
Microwave Studio to ensure good impedance matching and a small gain variation at 26–38 GHz. The design parameters were: \( W_{\text{GND}} = 10 \), \( w_1 = 0.74 \), \( w_2 = 0.5 \), \( w_3 = 0.3 \), \( W_r = 0.4 \), \( L_r = 0.8 \), \( W_{\text{cp}} = 0.6 \), \( W_d = 0.6 \), \( L_d = 1.8 \), \( l_1 = 1.6 \), \( l_2 = 1.6 \), \( l_3 = 1.8 \), \( l_4 = 0.4 \), \( g = 0.1 \), \( gap = 0.2 \), \( S_d = 0.2 \), (all in millimeters) and \( \alpha = 45^\circ \).

We realized the printed-dipole antenna by using printed circuit board technology. We built the antenna on both sides of a Rogers RT/Duroid™ 5880 sheet with a copper thickness of 17 μm. Fig. 1(b) shows a fabricated sample of the antenna including an aluminum jig and a 2.92 mm SMA connector (not included in the simulations). To fit the jig and SMA connector, we extended the ground plane of the fabricated antenna.

Fig. 2 presents a comparison of the measured and simulated results for the printed-dipole antenna. As shown in Fig. 2(a), the measured impedance bandwidth for \( |S_{11}| < -10 \) dB was 36.2% (26.5–38.2 GHz), whereas the simulated value was 40% (25.8–38.8 GHz). In addition, the antenna yielded a small gain variation. Within the operational bandwidth, the measured gain was 4.5–5.8 dBi, while the simulated value was 5.0–6.12 dBi. The slight difference between the measurement and simulation could be attributed to the effects of the jig and the SMA connector. Fig. 2(b) shows the 32-GHz radiation patterns of the antenna. The measurement results agreed with the simulations, and the two resulted in a symmetric profile in both the \( E \) - and \( H \)-planes. At 32 GHz, the antenna yielded half-power beamwidths (HPBWs) of 66° and 152° in the \( E \)- and \( H \)-planes, respectively. The patterns were also measured for other frequencies at 26.5–38.0 GHz (not shown) and are very similar to the 32-GHz patterns. Within the operational bandwidth, the measurements yielded HPBWs of 60°–70° and 150°–160° in the \( E \)- and \( H \)-planes, respectively. The measured cross-polarization was not obtained, but the simulations resulted in a value of less than −15 dB in the \( E \)-plane. The higher cross-polarization level in the \( H \)-plane pattern is due to the imperfect balun. The measured radiation efficiency of the antenna was not obtained, but the simulations resulted in a high value of greater than 93% at 26.0–38.0 GHz.

III. ANTENNA ARRAYS

A. Mutual Coupling

For designing antenna arrays, the tradeoff between low mutual coupling and close spacing has attracted considerable attention from researchers. To obtain a low mutual coupling for close spacing, we inserted a microstrip stub between the two printed-dipole antennas with a 4.8-mm center-to-center spacing.
(0.42–0.61λ at 26–38 GHz), as shown in Fig. 3(a). The stub has a length of \( L_a \) and a width of \( W_a = 0.2 \) mm. The stub functioned in a manner similar to that of a radio frequency choke, which was designed according to the microstrip filter theory [17]. The mutual coupling characteristic is based on the LC resonance of the stub structure. The inductive and capacitive components can be controlled via adjustments to the stub length; consequently, the operating frequency can be determined by measuring \( L_a \). This is confirmed in Fig. 3(b), which illustrates the mutual coupling between the two antennas for various values of \( L_a \). We calculated mutual coupling as the transmission coefficient \(|S_{21}|\) from Port 1 to Port 2 of the layout. For the case without the stub \( (L_a = 0) \), the mutual coupling value was greater than −15 dB in the 26–30 GHz range. \(|S_{21}|\) significantly decreased in the high-frequency region (32–36 GHz) for \( L_a = 0.5 \) mm, whereas this coefficient was reduced in the low-frequency region (26–30 GHz) for \( L_a = 1 \) mm. Mutual coupling was affected in the frequency range centered at around 22 GHz for \( L_a = 1.5 \) mm (not shown). We chose \( L_a = 1 \) mm for the final design to obtain a low mutual coupling of < −20 dB across the operational bandwidth. The effects of \( L_a \) on the reflection coefficients \(|S_{11}|\) and \(|S_{22}|\) were small, so they are not shown.

B. Scanning Performance

We implemented an 8-element array with the printed dipole antennas and a 4.8-mm center-to-center spacing between adjacent elements, as shown in Fig. 4(a). We calculated the scanning performance with CST Microwave Studio for the array without and with stubs, which are given in Fig. 4(b) and (c), respectively. The arrays were fed by eight ports with the same magnitude, while the scanning was achieved by the phase control at each port. Due to the lower mutual coupling between adjacent elements, the array with stubs yielded a wider scanning angle, higher gain, and a lower side lobe level (SLL) as compared to the array without the stub. At 28 GHz, the array with stubs yielded a scan angle up to 75°, a SLL of <−10 dB, and a gain of 10.4–12.5 dB, whereas the array without stub yielded a scan angle up to 60°, a SLL of <−5 dB, and a gain of 6.2–12.5 dB. At 32 GHz, the array with stubs yielded a scan angle up to 50°, a side-lobe level of <−13 dB, and a gain of 12.5–13.7 dB, whereas the array without stub yielded a scan angle up to 50°, a SLL of <−9.5 dB, and a gain of 10.9–13.7 dB. At the higher frequencies, due to the mutual coupling of < −15 dB for both configurations [Fig. 3(b)], their scanning performance is similar, so the results are not shown.

C. Eight-Element Array Measurements

To verify the scanning performance, we fabricated and measured the eight-element arrays with stubs for different fixed scanning angles. Fig. 5(a) shows a fabricated sample of the array with the 0° scanning angle. Its feeding network was a standard corporate design with T-junction power dividers and tapering transformers. Fig. 5(b) shows the simulated and measured \(|S_{11}|\) and gain values; (c) normalized 32-GHz radiation pattern.
We presented a broadband printed-dipole antenna with advantages including compact size, broad impedance-matching bandwidth, wide radiation pattern, small gain variation, and high radiation efficiency. In addition, we demonstrated the proposed antenna with applications as single-element radiators and for phased-array systems. To achieve low mutual coupling for a close center-to-center spacing, we inserted a microstrip stub between the two printed angled-dipole antennas. Moreover, due to the presence of the stubs, the array resulted in a wider scanning angle, higher gain, and a lower side-lobe level in the low-frequency region. With these advantages, the proposed antennas are good candidates for mobile terminals and base stations in 5G wireless cellular networks, as well as other millimeter-wave wireless communication systems.

**REFERENCES**


