A Compact Interdigital Capacitor-Inserted Multiband Antenna for Wireless Communication Applications

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***Abstract*—A compact coupled-fed antenna for multiband wireless communications is developed in this letter. It makes use of an interdigital capacitor for impedance matching at the frequency of 1.28 GHz. To improve its impedance-matching characteristics at 2.7- and 5.5-GHz bands, step-impedance transmission lines are implemented into its design. With overall optimization, such an antenna can operate at 1.26–1.3, 2.49–2.92, and 5.04–6.0 GHz, respectively, with the return loss of better than 10 dB. The two upper bands are wide enough for both applications of WiMAX (2.49–2.69 GHz) and WLAN (5–5.9 GHz). The size of the antenna prototype is only about 0.1 $\lambda_0 \times 0.0036\lambda_0 \times 0.0034\lambda_0$ at 1.28 GHz, with almost unchanged radiation patterns achieved at each operating band.**

***Index Terms*—Feed line, folded antenna, impedance matching, interdigital capacitor, multiband antenna, radiation pattern, wideband.**

I. Introduction

MULTIBAND antennas are becoming more and more favorable in modern wireless communications, and much effort has been devoted to integrating various frequencies into a single portable device. To satisfy this requirement, tri-, quad-, and even pentaband antennas have been proposed by some researchers [1]–[3].

On the other hand, compact printed loop antennas have also drawn special attention for multiband operation in the past several years [4]–[8]. Unlike the printed inverted-F antenna (PIFA) that generates quarter-wavelength mode, the conventional loop antenna excites half- and one-wavelength modes at lower and higher frequencies, respectively. Because of its closed shape, it has the advantage of better isolation with the system ground plane. However, it is difficult to get good impedance matching at its quarter-wavelength, resulting in serious limitations for its miniaturization.

More recently, a very small dual-band antenna has been reported in [6], which operates at the frequencies of 0.890–0.975 and 1.695–2.290 GHz, respectively. At its feed point, some lumped elements are introduced, and quarter-wavelength resonance is obtained with a 3:1 VSWR. Moreover, some distributed elements are implemented into the antenna, as proposed in [7] and [8]. However, the distributed circuit occupies a large area in the loop radiator.

Low-profile antennas are now facing another crucial problem of narrow bandwidth. Several methods were presented to achieve wideband operation, such as increasing the substrate thickness, meandering the radiator, using a coupled feed for wideband impedance matching, and cutting slots on the ground [9]–[13], etc.

In this letter, an interdigital capacitor-inserted printed antenna is proposed with a very compact structure. The capacitor, without occupying extra space, is etched on its feed line to provide good impedance matching at the quarter-wavelength mode. To achieve good wideband properties at both 2.7 and 5.5 GHz, one coupled feed line is used instead of a conventional direct feed. Furthermore, stepped impedance lines are introduced into the radiator and the feed line to increase the bandwidth. The proposed antenna is able to cover the Galileo E6 channel (1.260–1.30 GHz), WiMAX (2.49–2.69 GHz), and WLAN (5–5.9 GHz) bands for -10-dB specification, respectively.

II. Antenna Configuration

The proposed antenna, as shown in Fig. 1(a), is printed on an 0.8-mm-thick FR4 substrate, which has a relative permittivity of 4.4 and a loss tangent of 0.025. The ground plane is 60×50 mm^2. The antenna consists of a radiator, a coupled feed line, an interdigital capacitor, and an open stub. Its overall lateral size is 23.13×8.5 mm^2. The feed line is bent and coupled with the folded radiator to introduce additional mutual coupling at 2.7- and 5.5-GHz bands. This antenna is fed by a 50-Ω coaxial cable and can be integrated with other components easily due to its coplanar geometry.

The cross-sectional view of the antenna is presented in Fig. 1(b). The interdigital capacitor with 0.2 mm finger width is inserted into the vertical part of feed line (L_1). The finger length mainly affects the impedance matching at 1.28 GHz. The horizontal parts of the feed line (L_2, L_3, and L_4) are designed into a stepped pattern for broad bandwidth. Table I summarizes the geometrical parameters of the antenna, where W_1–W_9, corresponding to the line lengths of L_1–L_9, are the line widths, respectively.

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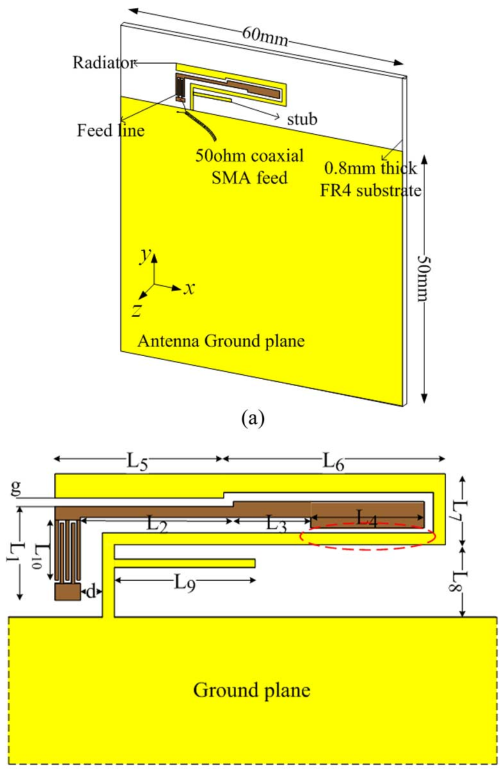

Fig. 1. (a) Geometry of the proposed antenna. (b) Geometrical parameters.

TABLE I
GEOMETRICAL PARAMETERS OF THE PROPOSED ANTENNA
(UNIT: MILLIMETERS)

L_1/W_1	L_2/W_2	L_3/W_3	L_4/W_4	L_5/W_5	L_6/W_6
5.55/1.5	9/0.63	4.58/0.9	6.74/1.55	10/1.42	13.13/1.12
L_7/W_7	L_8/W_8	L_9/W_9	L_{10}	g	d
4.19/0.69	4.3/0.69	8.36/0.50	3.56	0.52	1.33

The measured and simulated reflection coefficients of the proposed antenna are presented in Fig. 2, with the commercial software CST Microwave Studio implemented for the simulation. The quarter-wavelength mode is excited at 1.28 GHz with a bandwidth of 40 MHz. The higher frequency bands are broadened by connecting two or three resonances within a band. The bandwidths of 0.430 and 1.22 GHz are achieved for the two bands of 2.49–2.92 and 5.04–6.28 GHz, respectively. In Fig. 2, it is evident that the two curves agree well with each other at the operating bands. From 6.0 to 7.0 GHz, another resonance occurs in the measured reflection coefficient curve. In the simulation, this resonance is observed at about 8.7 GHz, which is caused by the resonance at the gap circled in Fig. 1(b).

III. Design Methodology and Parameter Analysis

Fig. 3(a)–(d) shows the main steps used for the antenna design, with the reflection coefficients plotted in Fig. 4 for comparison.

At first, a reference antenna with a simple loop shape is illustrated in Fig. 3(a). It resonates at 2.04- and 6.0–7.9-GHz bands, respectively. However, the reflection coefficients at both bands are worse than −10 dB [see Fig. 4(a)].

As shown in Fig. 3(b), a coupled feed line is introduced, which is capacitively coupled to the radiator. From Fig. 4(b),

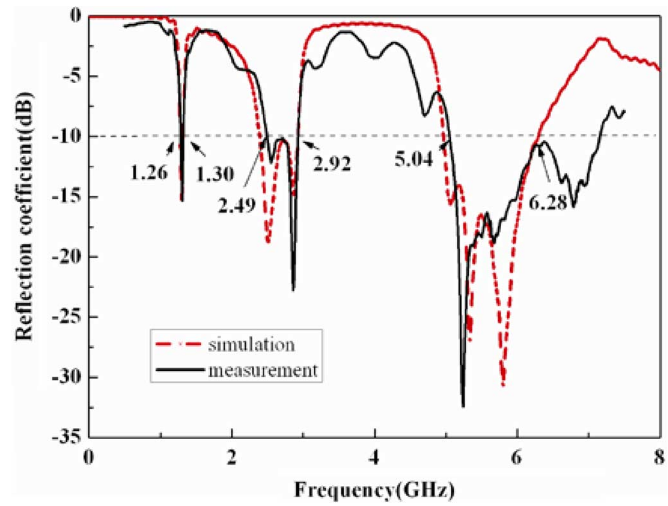

Fig. 2. Measured and simulated reflection coefficients of the proposed antenna.

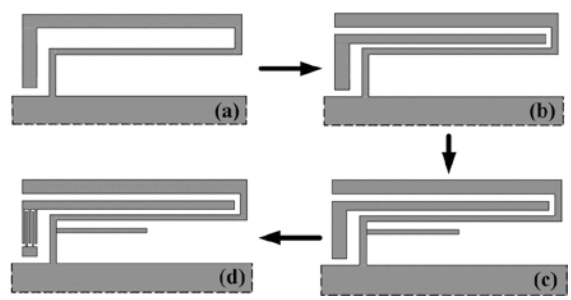

Fig. 3. Steps toward the final design target of the proposed antenna. (a) Reference antenna. (b) Antenna with a coupled feed. (c) Antenna with a stub added. (d) Antenna with a capacitor inserted.

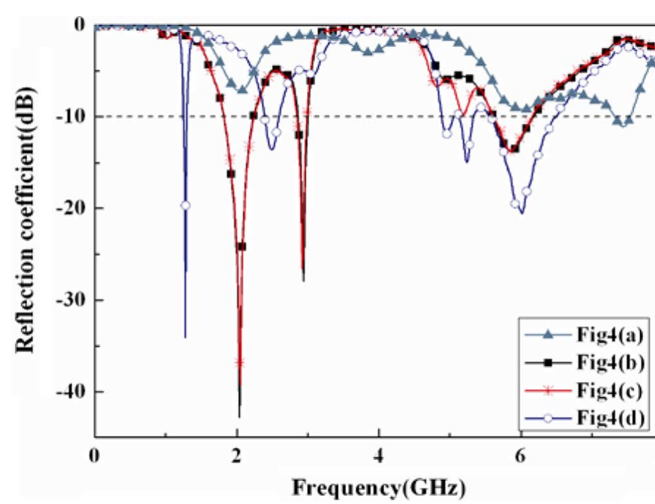

Fig. 4. Reflection coefficients as a function of frequency for the antennas in Fig. 3(a)–(d), respectively.

it can be understood that the coupled feed not only reduces the higher frequency to 4.9–5.87 GHz, but also creates another resonant frequency at the 2.7-GHz band, which corresponds to the quarter-wavelength resonance of the coupled feed line itself.

Since the two resonances are not wide enough to provide −10-dB bandwidth at the 5.5-GHz band, an open stub, as shown in Fig. 3(c), is added at the lower part of the radiator. It produces a third resonance at the 5.5-GHz band, as demonstrated

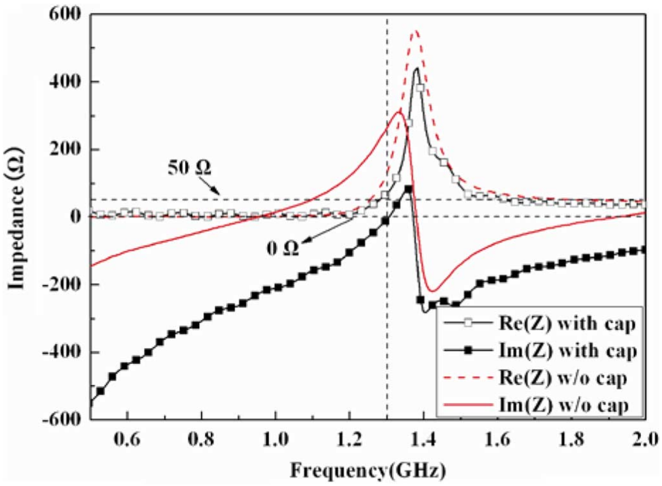

Fig. 5. Antenna impedances as a function of frequency with and without the capacitor implemented, respectively.

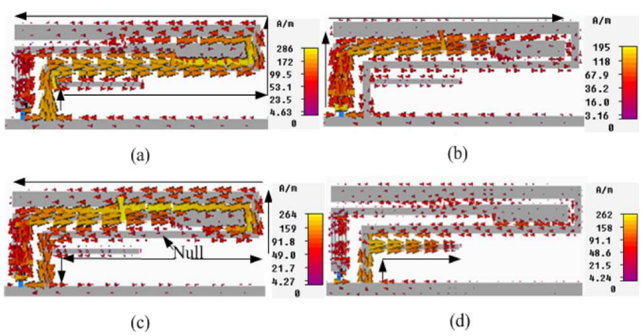

Fig. 6. Surface current distribution on the antenna at (a) 1.28, (b) 2.5, (c) 2.87, and (d) 5 GHz, respectively.

in Fig. 4(c). By tuning its length and position, a wider bandwidth of 5.0–6.0 GHz with three resonances can be achieved.

On the other hand, it is observed from Fig. 5 that the antenna has a resonance with large inductive reactance. To improve the impedance matching, an interdigital capacitor is inserted, as plotted in Fig. 3(d). Without the capacitor, the input impedance of antenna is as high as $114 + \mathrm{j}252\ \Omega$ at 1.28 GHz. The implemented capacitor can reduce the impedance to $64 - \mathrm{j}13\ \Omega$ effectively, thereby good impedance matching can be obtained. Meanwhile, the impedance at higher frequencies is slightly affected.

The capacitance of the interdigital capacitor is designed to be 0.36 pF, which is calculated by [14]

$$C = (\varepsilon_r + 1)l[(N - 3)A_1 + A_2)]\ (\mathrm{pF}) \tag{1}$$

where ε_r is the substrate permittivity, l is the length of each finger, N is the number of fingers, $A_1 = 4.409 \times 10^{-6}$ pF/μm, and $A_2 = 9.92 \times 10^{-6}$ pF/μm. The capacitance mainly affects the impedance at 1.28 GHz, while the operating frequency remains unchanged.

In Fig. 4(d), the expected reflection coefficients are achieved at both 1.28- and 5.5-GHz bands. However, the middle part of the 2.7-GHz band is still not satisfied. To merge the resonances at 2.5 and 2.9 GHz together, stepped microstrip lines, instead of conventional transmission ones, are used as both feed and radiator. By optimizing their lengths and widths, a 430-MHz bandwidth from 2.49 to 2.92 GHz is obtained.

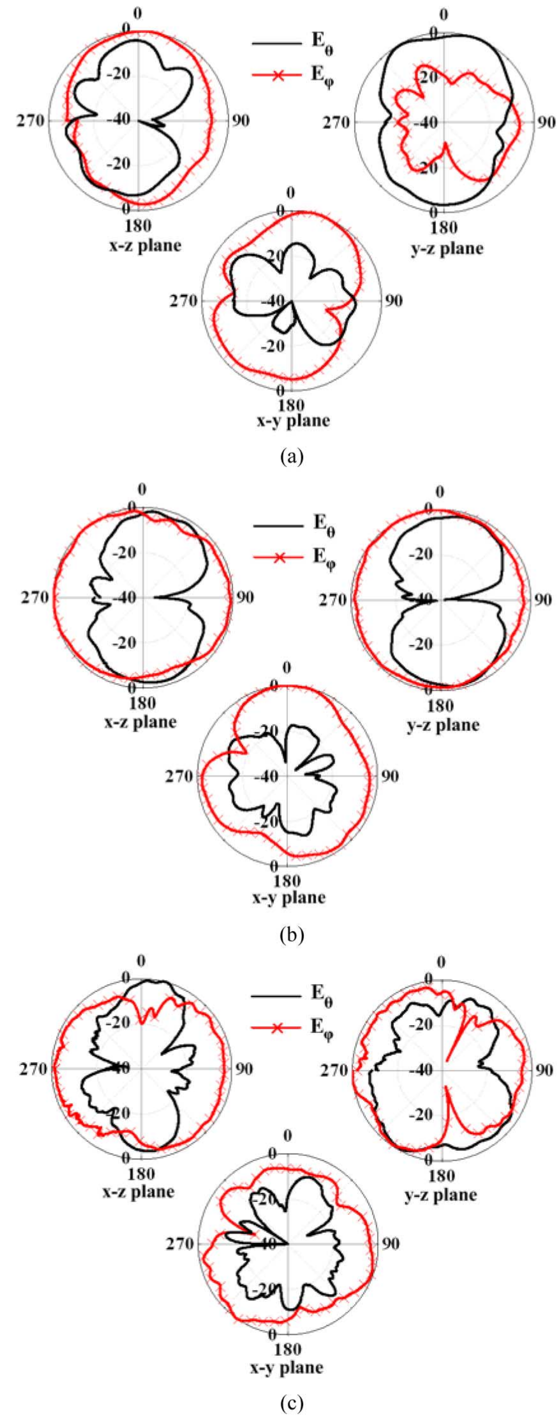

Fig. 7. Radiation patterns at xz, yz, and xy planes for 1.28, 2.5, and 5 GHz, respectively.

Fig. 6(a)–(d) shows the current distributions of the antenna at different frequencies. In Fig. 6(a), the main current resonates along the folded radiator. Its total length is 51.24 mm, which is about a quarter-wavelength of 1.28 GHz. In Fig. 6(b), the current flow at 2.5 GHz is also excited by a quarter-wavelength mode, and it mainly resonates along the feed line with the length of 27.45 mm $(L_1 + L_2 + L_3 + L_4)$. In Fig. 6(c), the current flow has a null and resonates at half-wavelength mode. It is obvious that the frequency of 2.87 GHz is the second resonant mode of the folded radiator. In Fig. 6(d), the frequency of 5 GHz is affected and tuned by the open stub, while the higher frequencies of 5.34 and 5.8 GHz correspond to the higher order modes of the proposed antenna, with their current flows suppressed here.

The measured radiation patterns of the proposed antenna are plotted in Fig. 7(a)–(c) for the relevant frequency bands, respectively. We would like to say that, although the simulated ones are not shown here, good agreement is still achieved with those of the measured ones. The radiation pattern at 1.28 GHz is similar to that of a dipole. In the xz plane, the radiation patterns at all bands are nearly omnidirectional. More variations and nulls are observed at the 5.5-GHz band. The radiation patterns across each band are also measured, and they demonstrate stable radiation characteristics. Also, the E_θ- and E_φ-components are comparable in most radiation patterns, which is favorable for their polarization diversity when used in complex propagation environments. Furthermore, compared to the conventional PIFAs [15], the measured radiation patterns show no special distinctions. The measured gain of the antenna is 0.5, 2.28, 1.126, 1.13, 1.5, and 3.9 dBi at 1.28, 2.5, 2.87, 5, 5.34, and 5.8 GHz, respectively. The simulated efficiency is 62%, 89%, 56%, 50%, 63%, and 89%, respectively.

IV. CONCLUSION

An interdigital capacitor etched multiband antenna has been developed for Galileo E6 channel (1.26–1.30 GHz), Wimax (2.49–2.69 GHz), and WLAN (5–5.9 GHz) applications. The antenna only occupies the area of 197 mm^2, and it is very compact in size compared to most antennas reported before. The bandwidth at 2.7- and 5.5-GHz bands are enhanced by the coupled feed structure, with the relative bandwidths of 15.9% and 21.5%, respectively. The proposed antenna is a good candidate for multiband wireless communication applications.

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