Multibroadband Slotted Bow-Tie Monopole Antenna

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***Abstract*—In this letter, a coplanar waveguide (CPW)-fed multiband bow-tie monopole antenna is proposed. This antenna can be easily designed to meet the requirement of multiple operating frequencies by using the proposed approach. Multiple bent monopoles, which correspond to different operating frequencies, are generated by etching slots of different lengths in a bow-tie patch. The length of each bent monopole is determined under the quarter wavelength resonance condition. Each frequency band can be easily satisfied for the broadband character because the bow-tie patch can be treated as a broadband impedance-matching structure. This study demonstrates a triple-band slotted bow-tie monopole antenna for WLAN/WiMAX/LTE applications with bands of 2.4–2.7 GHz, 3.4–3.7 GHz, and 5.2–5.8 GHz. The size of the proposed antenna fabricated on a 0.8 mm-thick FR4 substrate with a dielectric constant of 4.2 without considering the ground plane size is only $19.5 \times 9.0\ mm^2$. The good agreement between the simulation results and the measurement validates the proposed design approach.**

***Index Terms*—Multibroadband, slotted bow-tie monopole antenna, WLAN/WiMAX and LTE.**

I. Introduction

WITH the rapid development of mobile communication systems, multiband planar antennas have attracted considerable attention. They are commonly used in wireless communication systems, especially in wireless local area network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE) applications. In order to satisfy the WLAN/WiMAX/LTE standards, multiband antennas which operate at 2.4–2.484 GHz/5.15–5.825 GHz for WLAN, 2.5–2.69 GHz/3.4–3.69 GHz/5.25–5.85 GHz for WiMAX, and 2.5–2.69 GHz for LTE are required. Recently, printed dual- and triple-band antennas for WLAN, WiMAX and LTE applications have been proposed [1]–[13].

For dual- or triple-band antenna design, three design approaches are usually adopted. The first approach is to use multiple monopole or dipole antennas with different operating frequencies to create multiple operation bands [1]–[6]. Integrating multiple antennas requires additional matching or combining circuits. In addition, it is difficult to achieve a wide bandwidth with this approach because monopole and dipole antennas are resonance antennas, which have an inherently narrow bandwidth [3], [5]. Therefore, techniques such as those that use a coupling feed or an embedded slit are used to improve the bandwidth [1]. Other bandwidth improvement techniques include using a coplanar waveguide (CPW)-fed triangular monopole antenna [2]or an asymmetric CPW-fed antenna [4]. A multiband antenna using loading techniques is presented in [6], it is worked as a bow-tie monopole antenna with different lengths and its size is larger.

Dual- or triple-band antennas can be also made using an ultra-wideband (UWB) or wideband antenna with some slots to generate multiple operating bands [7]–[10]. In general, the location, length and width of these slots are sensitive to the operation frequencies and bandwidths. In addition, the responses of the desired bands influence each other strongly. Therefore, it is difficult to obtain the desired frequencies and bandwidths [7]–[9].

The final approach is to use a slot antenna with strips to create triple bands [11], [12]. These multiband antennas often have a bandwidth that is wider than the specifications and may thus receive unwanted noise, leading to the degradation of signal-to-noise ratio of the transceiver. In addition, for nonplanar multiband slot antenna, using co-located and folded slots on a slender columnar structure is also presented [14].

This letter presents a multiband slotted bow-tie antenna and its design procedures. The proposed structure and design procedure simplify multiband antenna design. Each operating frequency of the proposed antenna can be evaluated easily and almost independently. A triple-band antenna for WLAN/WiMAX/LTE applications that operates at 2.5 GHz, 3.5 GHz and 5.5 GHz bands is demonstrated.

II. Antenna Structure and Design Procedure

Resonance antennas, such as traditional half-wave dipoles or quarter-wave monopoles made using conducting wires, generally have small bandwidths. The planar versions of dipoles and monopoles have similar characteristics. To increase bandwidth, a wider or taper-shaped resonance element is often adopted. A bow-tie antenna is a commonly used taper-shaped antenna for broadband applications. The bandwidth of a bow-tie antenna can be controlled by tuning the included angle. In general, the included angle of a traditional bow-tie antenna is proportional to the bandwidth. The bandwidth widens as the included angle increases [14]. This study uses the wideband feature of the bow-tie patch to design a multiband antenna that comprises multiple monopoles with different operating frequencies.

Fig. 1 illustrates the proposed CPW-fed multiband monopole antenna which is a modified bow-tie antenna. Horizontal slots of different lengths are etched to create bent monopoles with different central frequencies. Each bent monopole consists of two patches, namely a horizontal part $(L_{n1} + W_{sn} \sec(\theta))$ and

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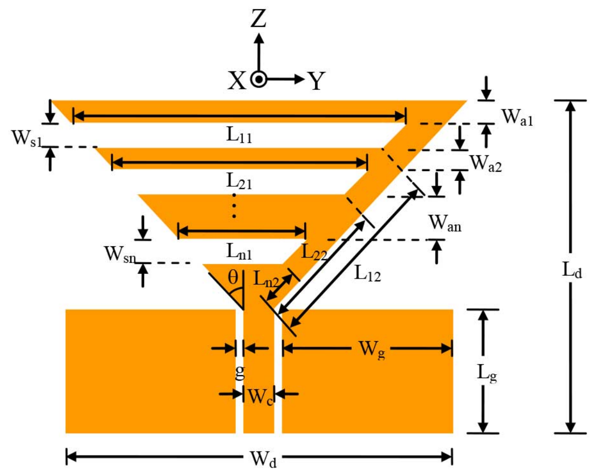

Fig. 1. CPW-fed multibroadband slotted bow-tie monopole antenna.

an approximately triangular edge (L_{n2}). The length of each bent monopole antenna can be estimated as

$$L_{n1} + L_{n2} + W_{sn}\sec(\theta) = \frac{1}{4}\lambda_n \tag{1}$$

where λ_n is the guided wavelength of the n-th operating frequency obtained using the suspended strip line model [15].

For example, the operating frequency of the top bent monopole, which has the longest length, is obtained using the length by $(L_{11} + L_{12} + W_{s1}\sec(\theta))$. The second operating frequency is controlled by the length of the second bent monopole, i.e., $(L_{21} + L_{22} + W_{s2}\sec(\theta))$. Similarly, the n-th operating frequency is determined using the length $(L_{n1} + L_{n2} + W_{sn}\sec(\theta))$. Therefore, each operating frequency of the multiband antenna can almost be designed independently. Similar to the traditional planar monopole antenna, the bandwidth can be increased by widening the width of the antenna [16]. Therefore, if the bandwidth of each band needs to be fine-tuned, it can be adjusted by the width (W_{an}) of the corresponding bent monopole. In addition, the bandwidth of the proposed bent monopole is larger than that of a single monopole for the same operating frequency because the bow-tie patch near the CPW feeding point acts as a broadband matching structure.

III. Numerical and Experimental Results

In this section, a triple-band slotted bow-tie monopole antenna is designed and measured to validate the proposed approach. The three designated operating frequencies are 2.5 GHz, 3.5 GHz, and 5.5 GHz, which are used for WLAN, WiMAX, and LTE. The antenna is fabricated on a 0.8 mm-thick FR4 substrate with a dielectric constant of 4.2. The simulation was conducted utilizing Ansoft HFSS 15.0.

The step-by-step design procedure is as follows. First, a CPW-fed bow-tie patch with parameters $L_d = 60.0$ mm, $W_d = 100.0$ mm, $g = 0.3$ mm, $W_c = 2.5$ mm $L_g = 45.0$ mm, $W_g = 48.45$ mm, and an included angle (2θ) of 90° is designed. For convenience, this CPW-fed bow-tie patch is denoted Antenna I.

TABLE I
Parameters of the Proposed CPW-Fed MultiBroadband Slotted Bow-Tie Monopole Antenna

Parameters (unit: mm)	L_{11}	L_{12}	$\sqrt{2}\,W_{s1}$ (W_{s1}=1.0)	$L_{11}+L_{12}+\sqrt{2}\,W_{s1}$	L_{21}	L_{22}	$\sqrt{2}\,W_{s2}$ (W_{s2}=1.0)	$L_{21}+L_{22}+\sqrt{2}\,W_{s2}$	L_{31}	L_{32}	$\sqrt{2}\,W_{s3}$ (W_{s3}=1.0)	$L_{31}+L_{32}+\sqrt{2}\,W_{s3}$
Antenna II (f_1=2.51 GHz)	16.50	9.54	1.41	27.45	-	-	-	-	-	-	-	-
Antenna III (f_1=2.54 GHz, f_2=3.55 GHz)	16.50	9.54	1.41	27.45	12.0	7.07	1.41	20.48	-	-	-	-
Antenna IV (f_1=2.47 GHz, f_2=3.55 GHz, f_3=5.17 GHz)	16.50	9.54	1.41	27.45	12.0	7.07	1.41	20.48	7.00	4.59	1.41	13.00

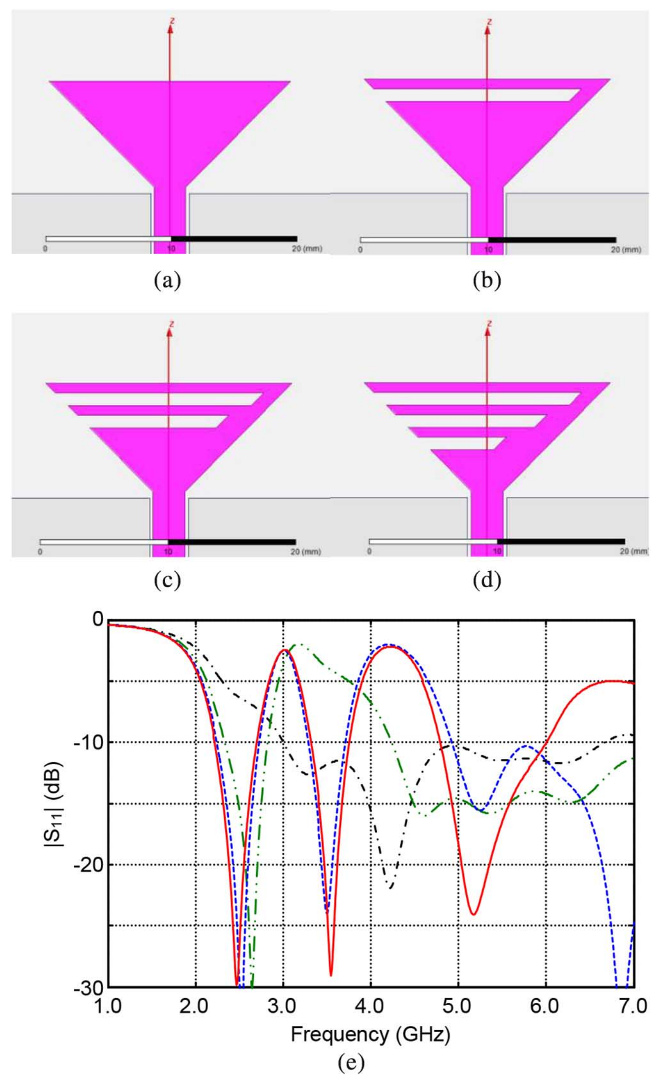

Fig. 2. Geometries of (a) antenna I without slots, (b) antenna II with single band, (c) antenna III with dual bands, and (d) antenna IV with triple bands and (e) the simulated reflection coefficient, - . - for antenna I, — . . — for antenna II, - - - for antenna III, and —— for antenna IV.

Secondly, a slot is etched to create bent monopole A whose resonance frequency is 2.5 GHz and its width W_{a1} is 0.75 mm.

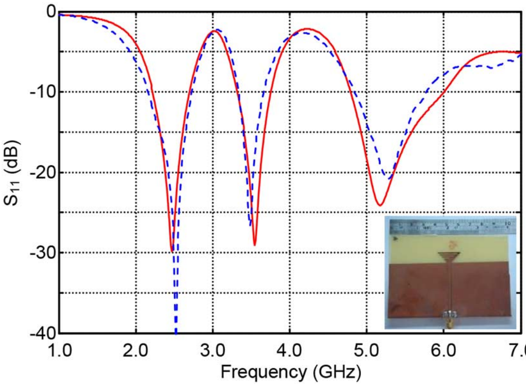

Fig. 3. Simulated (solid red line) and the measured (dash blue line) reflection coefficient of Antenna IV.

The length of the bent monopole A, $(L_{11} + L_{12} + W_{s1}\sec(\theta))$, equals the quarter wavelength at 2.5 GHz, which from the suspended stripline model is 26.39 mm. Because the triangular bent corner and the coupling between the bent monopole A and the remaining bow-tie patch affect the resonance frequency, the total length of bent monopole A is slightly modified to be 27.45 mm. For convenience, this bent monopole with a bow-tie patch below it is denoted Antenna II.

Thirdly, a slot is etched in the remaining bow-tie patch after the previous step to obtain bent monopole B, whose resonance frequency is 3.5 GHz and its width W_{a2} is 0.75 mm. The quarter wavelength at 3.5 GHz is approximately 19.03 mm. The total length of bent monopole B, $L_{21}+L_{22}+W_{s2}\sec(\theta)$, is modified to be 20.48 mm for the same reason as Antenna II. Monopole A remains unchanged during this step. For convenience, these two bent monopoles with a bow-tie patch below them are denoted Antenna III.

The next considered operating frequency is 5.5 GHz. The quarter wavelength at 5.5 GHz is approximately 12.19 mm. Bent monopole C whose width W_{a3} is 0.75 mm, which is obtained by etching a slot in the remaining bow-tie patch after the previous step, is modified to have a total length of 13.00 mm to compensate for the coupling between bent monopole B and the lowest bow-tie patch. In this step, the bent monopoles A and B remain unchanged. The final triple-band antenna is denoted Antenna IV. Detailed antenna geometrical parameters are listed in Table I.

Fig. 2 shows the migration of the simulated reflection coefficient from step 1 to step 4. Antenna II has a single band that covers 2.34 GHz to 2.82 GHz (18.60%) with S_{11} below the -10 dB criterion. The Antenna III has two bands that cover from 2.25 GHz to 2.73 GHz (19.28%) and 3.29 GHz to 3.71 GHz (12.00%). Antenna IV has three bands that cover from 2.22 GHz to 2.7 GHz (19.51%), 3.32 GHz to 3.75 GHz (12.16%) and 4.8 GHz to 6.0 GHz (22.22%). Antenna IV satisfies the requirements of WLAN, WiMAX, and LTE applications concurrently. Because the bow-tie patch near the CPW feeding point acts as a matching structure, each frequency band is wider than that of a single monopole antenna of the same frequency.

Fig. 3 summarizes the simulated results and the experimental results obtained using an R&S ZVB 8 network analyzer. The inset shows a photograph of the fabricated antenna. The measured operating frequencies of Antenna IV are 2.17 GHz to 2.72 GHz (22.49%), 3.34 GHz to 3.66 GHz (9.14%), and 4.85 GHz to 5.77 GHz (17.33%). The good agreement between the simulated and the measured reflection coefficients validates the proposed antenna design approach.

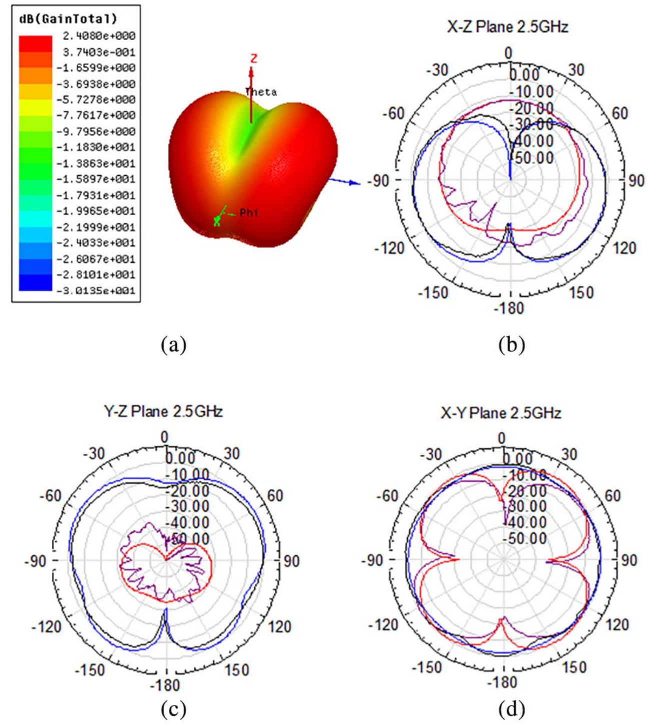

Fig. 4. Simulated 3-D radiation pattern and simulated (E_θ-blue line, E_ϕ-red line) and measured (E_θ-black line, E_ϕ-purple line) 2D radiation patterns at 2.5 GHz.

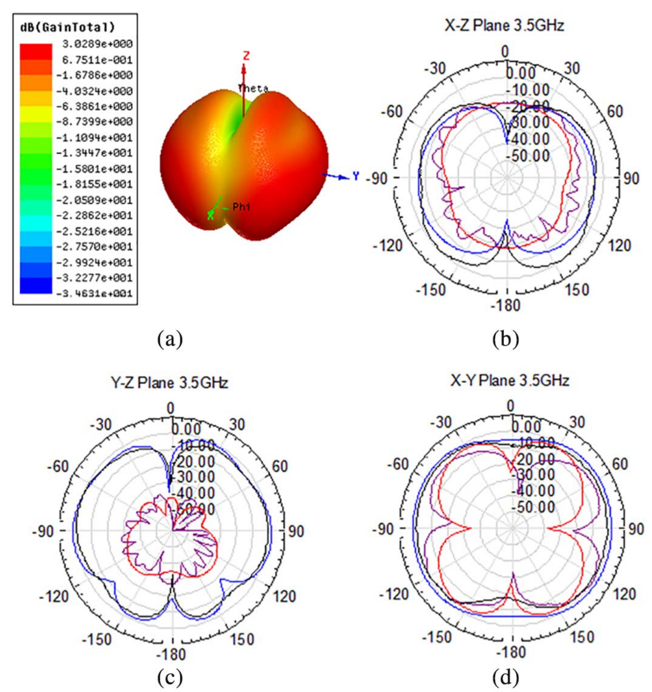

Fig. 5. Simulated 3-D radiation pattern and simulated (E_θ-blue line, E_ϕ-red line) and measured (E_θ-black line, E_ϕ-purple line) 2D radiation patterns at 3.5 GHz.

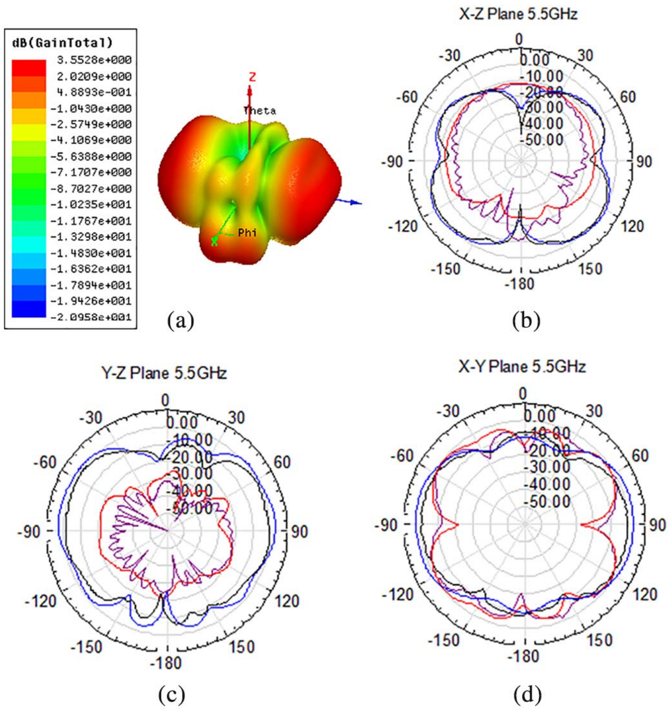

Fig. 6. Simulated 3-D radiation pattern and simulated (E_θ-blue line, E_ϕ-red line) and measured (E_θ-black line, E_ϕ-purple line) 2D radiation patterns at 5.5 GHz.

TABLE II
MEASURED PEAK GAIN OF THE PROPOSED ANTENNA IV

	2.5 Band				*3.5 Band*				*5.5 Band*						
Frequency (GHz)	2.4	2.5	2.6	2.7	3.4	3.5	3.6	3.7	5.2	5.3	5.4	5.5	5.6	5.7	5.8
Peak Gain (dBi)	3.02	3.75	3.52	3.62	3.62	3.56	3.28	3.39	4.91	4.06	4.02	3.93	3.96	3.79	3.89

Figs. 4 to 6 show the simulated and the measured radiation patterns at 2.5 GHz, 3.5 GHz and 5.5 GHz, respectively. The three-dimensional radiation patterns are similar to those of traditional monopole antennas, with omni-directional radiation on the horizontal $x-y$ plane. The two-dimensional simulated and measured radiation patterns are almost consistent.

Table II shows the measured peak gain (dBi). The measured peak gains at 2.5 GHz, 3.5 GHz and 5.5 GHz are 3.75 dBi, 3.56 dBi and 3.93 dBi, respectively. In addition, the simulated radiation efficiencies at these three frequencies are 87.51%, 81.08% and 80.33%, respectively. The radiation efficiencies at the three bands are all larger than 80%.

IV. CONCLUSION

This work presented a multibroadband slotted bow-tie antenna and its design procedure, which is based on simple monopole antenna design concepts. Each bent monopole in the slotted bow-tie antenna can be designed individually for a specified operating frequency. The proposed design approach does not require repeated parameter tuning and time-consuming EM simulation, which are generally required for traditional multiband antenna design. A triple-band antenna for WLAN/WiMAX/LTE applications was designed and manufactured. The simulation and measurement results were in good agreement, validating the feasibility of the proposed antenna design approach.

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