Miniaturized Uniplanar Triple-Band Slot Dipole Antenna with Folded Radiator

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Abstract

A miniaturized uniplanar slot dipole for triple-frequency operation is presented. The antenna consists of a folded slot radiator with an increased number of degrees of freedom that allow for efficient size reduction. Rigorous electromagnetic (EM)-driven design optimization is applied in order to achieve the smallest possible size while maintaining acceptable levels of antenna reflection at the required operating frequencies. The latter is ensured by using suitably defined design constraints. The size of the antenna is 51 mm × 33.4 mm (footprint area of around 1700 mm^2) which corresponds to $0.42\lambda_0 \times 0.27\lambda_0$ for the lowest operating frequency. Experimental validation confirms good electrical and field performance of the structure.

1. Introduction

Rapid development of mobile communication systems results in high demand for cheap, compact, low-profile and high-performance antennas for, e.g., wearable electronics [1], ambient energy harvesting [2], or biomedical implants [3]. Mobile terminals often exploits several frequency bands; for the sake of simplifying their RF frontends, multi-band operation of antennas is of key importance [3], [4].

Design of a multi-band antenna is a challenging task that requires handling of stringent requirements with respect to electrical (e.g., bandwidth [1], number of operating frequencies [3], etc.) and field performance (e.g., peak gain [4], circular polarization [1], etc.). Multi-band operation is often obtained by increasing the number of degrees of freedom through various topological modifications such as introduction of parasitic strips [5], resonators [6], multiple structure layers [7], or reconfigurable components [8].

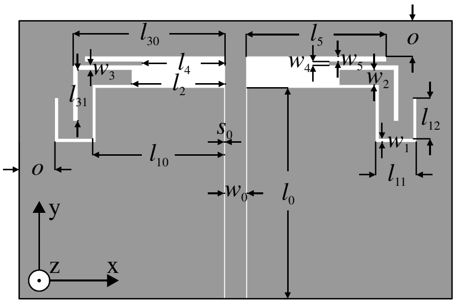
For compact structures, simultaneous fulfilment of the performance specifications as well as the size is required. However, the electrical size of the antenna is related to the length of the free space wave the device is coupled to, and thus, miniaturized design is a compromise between acceptable performance and small structure size [9]. Compact multi-band structures reported in the literature include various monopole designs [4], dipoles [6], as well as slots [10]. Miniaturized geometries are normally obtained through experience-based iterative modifications of the structure topology intertwined with visual inspection of the characteristics [11]. Unfortunately, due to complex mutual relations between design parameters of compact antennas, such approaches are inadequate for obtaining truly optimum designs [9]. To yield optimum designs, adjustment of antenna dimensions using automated numerical optimization algorithms is mandatory [9], [12].

In this letter, we propose a geometry of a compact tri-band uniplanar dipole. The antenna consists of a radiator in the form of a stack of folded slots fed through a coplanar waveguide (CPW). The structure is designed to operate at 2.45 GHz, 3.5 GHz, and 5.35 GHz frequencies. Compact dimensions of 51 mm × 33.4 mm (only $0.42\lambda_0 \times 0.27\lambda_0$ at the lowest resonant frequency) have been obtained by performing explicit size reduction of the antenna while controlling reflection characteristics by means of suitably defined constraints. Numerical results are supported by measurements of the fabricated antenna prototype.

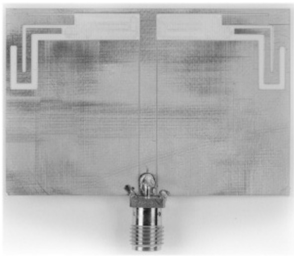
2. Antenna Structure and Design Procedure

The proposed structure is a triple-band uniplanar dipole antenna shown in Fig. 1 [6]. The antenna is implemented on a Rogers RO 4350B dielectric substrate ($\varepsilon_r = 3.48$, $\tan\delta = 0.0031$, $h = 0.762$ mm). It is composed of a three stacked narrow slots separated by two thicker ones. The radiator is fed through a 50 ohm CPW. Narrow slots are folded in order to allow for better utilization of the available space (cf. Fig. 1). The antenna geometry is described by twelve design parameters (see Table 1) to ensure sufficient control over its size and performance characteristics. The relative dimensions $l_{10} = \min\{\max\{0.5\cdot l_{1r}, l_2\}, l_5\}$, $d_3 = \max\{l_{10} + w_2 + w_3, l_2 + w_2 + w_3\}$, $d_1 = \min\{\max\{l_3 - d_3, 0.01\}, l_{1r} - l_{10}\}$, $l_{30} = \min\{d_3, l_3\}$, $l_{31} = \max\{l_3 - d_3, 0.01\}$, $l_0 = l_{0r} + \max\{o + d_1, l_{00}\}$, $l_{11} = \max\{\min\{l_{1r} - l_{10} - l_{31}, 2\cdot w_1 + w_3 + 2\cdot w_2\}, 0.01\}$, and $l_{12} = \max\{l_{1r} - l_{10} - l_{31} - l_{11}, 0.01\}$ ensure consistency of the antenna topology (cf. Fig. 1a). Parameters $w_0 = 3$, $s_0 = 0.15$ and $l_{00} = 10$ remain fixed. The unit for all dimensions is mm.

The electromagnetic (EM) model of the antenna has been prepared in CST Microwave Studio and evaluated using its time domain solver [13]. In order to achieve the smallest minimum size, all independent geometry parameters of the structure have been optimized with the antenna footprint, defined as $(2\,(o + \max\{l_{10} + (l_{11} - w_1), l_5\}) + w_0)\cdot\max\{o + l_0 + w_1 + w_2 + w_3 + w_4 + w_5,\ l_0 - d_1 + l_{12} + o\}$, being the primary (minimization) objective. Two types of constraints have been imposed on the reflection response: (i) equality constraint to allocate the antenna resonances at the 2.45 GHz, 3.5 GHz, and 5.35 GHz frequencies, and (ii) inequality constraint in order to ensure that $|S_{11}| \le S_{\max}$ at all resonances (here, $S_{\max} = -15$ dB was used). The optimization was performed using a feature-based optimization algorithm [12], which is an efficient routine for handling responses of multi-band antennas [12].The lower $\boldsymbol{l}$ and upper $\boldsymbol{u}$ design bounds for the optimization algorithm that ensure geometrical consistency of the EM antenna model are given in Table 1.



(a)



(b)

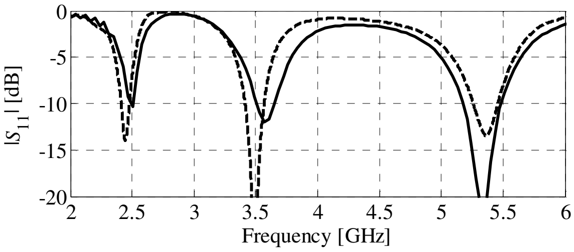
Fig. 1 Proposed miniaturized triple-band slot dipole antenna: (a) antenna geometry and design parameters and (b) photograph of the fabricated antenna prototype.

Table 1: Dimensions of the proposed antenna

	Design parameters [mm]											
	l_{0r}	l_{1r}	l_2	l_3	l_4	l_5	w_1	w_2	w_3	w_4	w_5	o
$\boldsymbol{l}$	0	30	5	22	5	15	0.2	1.2	0.2	1.2	0.2	1
$\boldsymbol{x}^*$	17.8	38.5	13.8	28.75	11.6	20.1	0.95	1.2	0.4	1.85	0.2	1
$\boldsymbol{u}$	30	50	15	29	15	21	2.2	4.2	2.2	4.2	2.2	10

3. Results and discussion

The final antenna design $\boldsymbol{x}^*$ is given in Table 1. Dimensions of the optimized structure are 51 mm × 33.4 mm, whereas its footprint is 1706 mm^2. The dipole was fabricated and measured. A photograph of the manufactured prototype is shown in Fig. 1b. Comparison of EM simulation and measurement results in terms of reflection and realized gain (in the direction z; cf. Fig. 1a) is provided in Fig. 2. The simulated responses are well centred at the prescribed operating frequencies. Slight violation of the desired –15 dB reflection for the first and the last resonance is due to handling of the design constraints using penalty functions [9], [12]. The simulation and measurement results are in acceptable agreement. For measurements, the first and the second resonance is shifted by 30 MHz and 70 MHz up in frequency. The measured –10 dB bandwidths are 5 MHz, 150 MHz, and 305 MHz for 2.45 GHz, 3.5 GHz, and 5.35 GHz frequencies, respectively. It should be noted that narrowband responses (particularly, at 2.45 GHz and 3.5 GHz) are due to objective function formulation that maintains antenna resonances at selected frequencies rather than frequency bands. For the gain characteristics, the measured response is slightly lower for the first two resonances with around 1dB and 0.5 dB difference at 2.45 GHz and 3.5 GHz, respectively. Visible small differences between simulations and measurements are mostly due to utilization of a simplified EM model of the structure that lacks SMA connector. To some extent, discrepancies are also due to fabrication tolerances, electrically large measurement setup (not accounted for in the EM model of the antenna), as well as manual adjustment of the dipole orientation during measurements of the gain characteristics.



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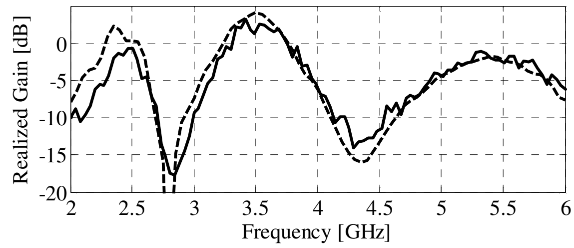

(b)

Fig. 2 Comparison of simulated and measured antenna responses: (a) reflection, (b) realized gain (in z-direction).

Figure 3 shows co- and cross-polarized E-field radiation patterns measured in x-z and y-z planes (cf. Fig 1a). The co-polarized responses obtained for the two lower resonances are nearly the same. For the x-z plane the pattern obtained for 5.35 GHz frequency is more omnidirectional compared to the remaining ones. The levels of the cross-polarized responses for 2.45 GHz, 3.5 GHz, and 5.35 GHz in x-z plane are below –8 dB, –13 dB, and –3 dB, whereas for y-z plane they are below –6 dB, –1.5 dB, and –14 dB, respectively. It should be noted that the cross-polarization is affected by topology of the structure, namely, varying orientation of the folded strips.

4. Conclusion

In this letter, a miniaturized triple-band uniplanar dipole antenna consisting of a slot radiator fed through a 50 ohm CPW has been presented. The reduced footprint of the proposed structure is partially a result of radiating elements folding that allows for better utilization of the available space. Final dimensions of the antenna of 51 mm × 33.4 mm =

1706 mm^2 ($0.42\lambda_0 \times 0.27\lambda_0$) have been obtained by explicit numerical minimization of its area while controlling performance characteristics using appropriately defined constraints. Measurement results confirm acceptable field and electrical performance of the antenna.

Acknowledgement

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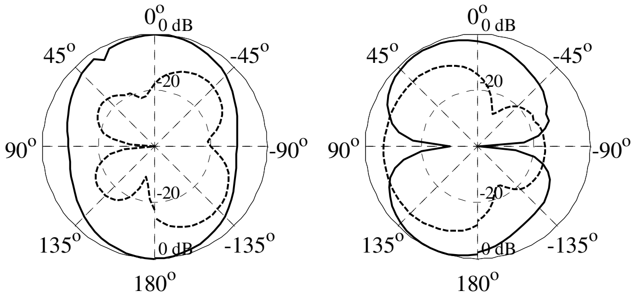

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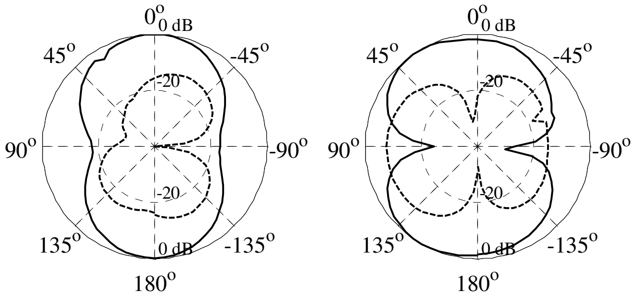

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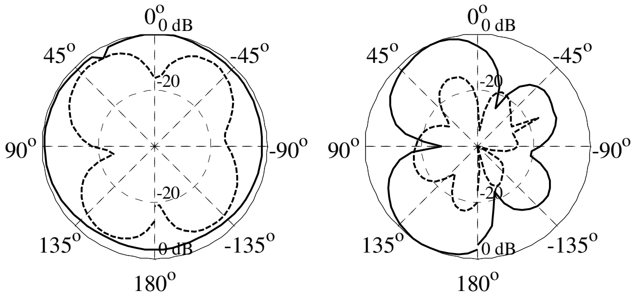

(c)

Fig. 3 Co- (—) and cross-polarized (– –) radiation patterns of the proposed antenna obtained in x-z (left) and y-z (right) planes. Plots have been obtained for frequencies: (a) 2.45 GHz, (b) 3.5 GHz, and (c) 5.35 GHz.

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