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A Low-Cost Dual-Band CPW-fed Printed LPDA for Wireless Communications

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***Abstract*—A dual-band printed Log-periodic dipole array (LPDA) antenna for wireless communications, designed on a low-cost PET substrate and implemented by inkjet-printing conductive ink, is presented. The proposed antenna can be used for wireless communications both within the UHF (2.4–2.484 GHz) and SHF (5.2-5.8 GHz) wireless frequency bands, and presents a good out-of-band rejection, without the need of stop-band filters. The antenna has been designed using a general purpose 3D CAD, CST Microwave Studio, and then realized. Measured results are in very good agreement with simulations.**

***Index Terms*—Log-periodic arrays, Multiband Antennas, PET Inkjet-Printed Antenna, Wireless communications**

I. Introduction

THE recent developments in wireless communications require the use of multiband antennas able to cover all the wireless service frequency bands. The typical frequency bands required to a single antenna are therefore: 2.4 - 2.484 GHz for Bluetooth applications, and 2.4 GHz, 5.2 GHz, 5.4 and 5.8 GHz for WLAN applications (following WLAN IEEE 802.11 standards). The use of printed technology is the best choice, since it allows to design low-cost planar antennas with high performances and compact size. Moreover, a printed antenna can be easily integrated into front-end circuits [1, 2], providing low profile and a relatively simple fabrication.

In the literature, a number of printed multiband antennas have been proposed, and implemented using robust and cheap materials as dielectric substrates [1-5]. Following the recent developments on planar structures, the current leading technology for the design of low-cost antennas is based on plastic or paper substrates, wherein metallic tracks are realized using conductive inks. Such technologies allow additional manufacturing methods (for example inkjet printing, flexography, gravure printing), thus reducing the overall production cost, and with a more efficient use of the materials. Cost-effective inkjet-printable microwave components require suitable substrates, such as Polyethylene Terephthalate (PET), paper, or adhesive layer substrates, whose development is in progress [6-9].

In order to fully exploit the advantages of these technologies, we present in this work a multiband printed log-periodic dipole array (LPDA) for WLAN applications, fed by a grounded coplanar waveguide (GCPW), able to work both in the 2.4 GHz to 2.5 GHz band (WLAN-UHF band) and in the 5.2 GHz to 5.8 GHz band (WLAN-SHF band), implemented by inkjet-printing conductive ink on a PET substrate. Though LPDA are usually employed as broadband antennas [10, 11, 12], we select here the LPDA configuration for dual band operation, exploiting the same idea as in [5], but using a cost-effective PET substrate and a different layout, based on a GCPW, which allows a fully planar realization [13].

In LPDAs, the active region shifts with the operating frequency, and, therefore, at a certain frequency, only a few dipoles are actually working. Then, we use the LPDA configuration to accommodate only the (relatively small) required frequency bands by a proper selection of the dipoles of a complete LPDA, achieving a good out-of-band rejection, with a good control on the antenna gain in each sub-band. As a consequence, the proposed antenna is composed by two separate groups of dipoles (one working within the WLAN-UHF band, and the other one in the WLAN-SHF band). In other words, this antenna is not a "complete" LPDA. The "missing" dipoles significantly affect the propagation of the odd mode of the GCPW, and, therefore, particular care has been taken in the design of the feeding GCPW in order to avoid the use of air-bridges [14]. The "balun" of the LPDA proposed here is obtained by using a via-hole between the GCPW and the strip on the other side of the slab, as in [13]. Finally, the electrical connections between the SMA connector and the GCPW have been realized using conductive glue and silver paste. As a consequence, the similarity of the proposed antenna with [5] (or [13]) is merely superficial. In fact, different solutions have been worked out to implement a cost-effective, inkjet-printed PET antenna with the required EM behavior.

The proposed antenna has been designed using a general purpose 3D CAD, CST Microwave Studio, and then manufactured. The measured results are in very good agreement with the simulations.

II. Antenna Design

The proposed printed LPDA is shown in Fig. 1. It is fed by a

Manuscript received July 3, 2015.

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This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/LAWP.2015.2507938, IEEE Antennas and Wireless Propagation Letters

GCPW realized on the two sides of a PET dielectric slab, and the array dipoles are connected alternately on the two layers of the GCPW. The central conductor of the coplanar waveguide is connected through a via-hole to the ground of the GCPW (as explicitly indicated in Fig. 1b), in order to obtain the typical alternate feeding of the elements of the LPDA, required to radiate an end-fire pattern. The structure is similar to a standard LPDA, and therefore the design technique of a CPW-fed LPDA [13] has been applied, separately, to two different groups of dipoles, one designed to operate in the WLAN-UHF band and, the other, in the WLAN-SHF band. Then, the two groups of dipoles have been connected together, obtaining the configuration shown in Fig. 1.

The antenna substrate is a PET film, with a dielectric constant ε_r= 3.0, a thickness of 1 mm and a loss tangent of 0.002. The metallization is made by inkjet-printed silver-based ink (Cabot Conductive Ink CCI-300), which has a conductivity of 90 MS/m. The thickness of the conductive traces is around 1.5 µm, and the inkjet drop spacing is 15 nm. After the printing process, the prototype has been thermally cured in oven, at 60°C for 3 days, in order to allow a proper drying of the ink.

The design specifications of the proposed LPDA antenna are the operating bandwidth and the directivity. The design parameters are the spacing factor, $\sigma = S_n/4L_n$, and the log-period, $\tau = L_{n+1}/L_n$ (see Fig. 1a), which are selected by using Carrell design curves for the specified bandwidth and directivity [15]. We require an average directivity of 9 dB for both groups of dipoles of the printed LPDA, obtaining $\tau = 0.88$ and $\sigma = 0.16$ [15]. Following [13, 15], we get N = 4 dipoles for the WLAN-UHF band (from 2.4 to 2.5 GHz), and N = 8 dipoles for the WLAN-SHF band (from 5.2 to 5.8 GHz), with an aperture angle 2α (see Fig. 1) equal to 10.62°.

The distance d between the two groups of dipoles has subsequently been optimized using CST, aiming at the best input match of the whole antenna. The optimal distance is d = 12.39 mm, and it came out comparable to the spacing between two adjacent dipoles of the UHF part of the LPDA. This relatively small value is a consequence of the low interaction between the two groups of dipoles, which work in different frequency bands (2.4 - 2.5 GHz and 5.2 - 5.8 GHz). Therefore, this solution allows to obtain a log periodic antenna with a reduced size with respect to a standard (i.e., complete) printed LPDA array working between 2.4 and 5.8 GHz, which would be about three times longer than ours.

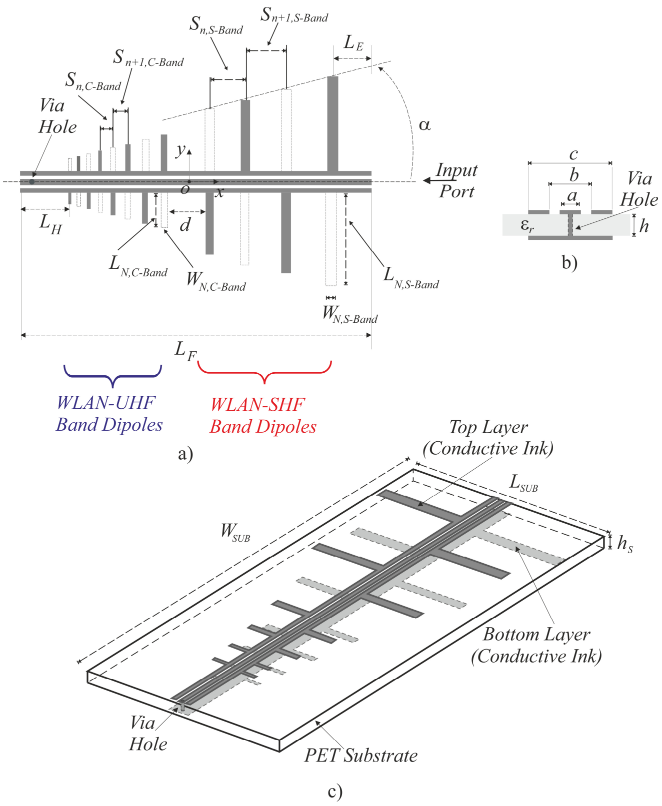

Fig. 1. (a) Antenna Layout (Top Layer). L_F = 111.60 mm, L_H = 15.60 mm, L_E = 12.55 mm. (b) Grounded Coplanar Waveguide transverse section, with the via hole connecting the central conductor of the GCPW with the bottom feeding line: a = 1.125 mm; b = 1.575 mm; c = 4.027 mm. (c) 3D view of the designed LPDA: L_{SUB} = 111.98 mm, W_{SUB} = 55 mm, h_S = 1 mm.

Since the printed LPDA lies on a dielectric substrate, the geometric parameters of this antenna cannot be computed as in the case of a standard wire LPDA [15], which radiates in free space, and their values strongly depend on the LPDA substrate. This affects both the GCPW and the radiating dipoles.

In Table I the geometry of the dipoles (see Fig. 1) is reported. The spacings S_n are computed using the aperture angle α, according to [15].

TABLE I.
GEOMETRY OF THE PRINTED LPDA WORKING IN THE S-AND C-BAND. ALL UNITS ARE IN [MM].

Dipole	$L_{n,SBand}$	$W_{n,SBand}$	$S_{n,SBand}$	$L_{n,CBand}$	$W_{n,CBand}$	$S_{n,CBand}$
8	-	-	-	9.50	1.92	6.08
7	-	-	-	8.36	1.69	5.35
6	-	-	-	7.36	1.48	4.71
5	-	-	-	6.48	1.31	4.14
4	23.00	3.10	14.72	5.70	1.15	3.65
3	20.24	2.73	12.95	5.02	1.01	3.21
2	17.81	2.40	11.40	4.41	0.89	2.82
1	15.67	2.11		3.88	0.78	

The characteristic impedance of the GCPW feeding line has been chosen equal to 50 Ω, so as to obtain an easy matching with a standard SMA connector. The GCPW parameters a and b, shown in Fig. 1b, are computed using the well-known GCPW design equations [16]. However, different GCPW geometries lead to the required 50 Ω characteristic impedance, but with a completely different antenna behavior.

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The total width *c* of the GCPW feeding line has been chosen equal to the width of the "boom" microstrip line corresponding to an equivalent impedance of 50 Ω, i.e. *c* = 4.027 mm [13]. This allows the backward waves, which actually feed the dipoles, to see a symmetric transmission line. Then, an optimization procedure has been carried out for the parameters *a* and *b*, aiming at minimizing the deviation of the antenna pointing direction (the maximum of the pattern) from end-fire, with the constraint that the characteristic impedance of the GCPW is Z_0 = 50 Ω. The size of this deviation from end-fire, as a function of *a* and *b*, is shown in Fig. 2, using a shaded band representation with the lowest, i.e. the best, values indicated in light gray. From it we get the optimal values of *a* = 1.125 mm, and *b* = 1.575 mm, for both the operating frequency bands. These values correspond to the case where the radiation pattern has its maximum in the end-fire direction (antenna pointing angle = 0 degrees). Only the E-Plane values are shown in Fig. 2, since a similar behaviour, with the same optimal values of *a* and *b*, has been observed for the H-Plane.

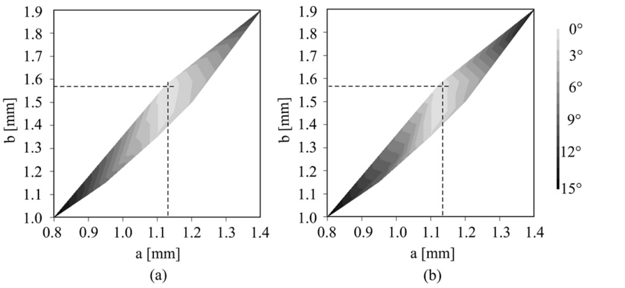

Fig. 2. Modulus of the antenna pointing angle deviation (degrees) from end-fire as a function of *a* and *b* (only the values of a and b which give Z0= 50 Ω are allowed). The dashed lines represent the optimal values of *a* and *b*. (a) 2.45 GHz; (b) 5.4 GHz.

We have also found that the selected geometry is able to maintain the odd mode of the GCPW within the whole feeding structure without using air-bridges. This is actually a consequence of the optimization procedure carried out for the radiation pattern, since the field distortion is minimum when the dipoles are fed symmetrically. This is an important requirement, since it would be very critical connecting air-bridges on conductive ink on a PET substrate.

The length of the open-end termination L_H (see Fig. 1) of the GCPW, and the corresponding position of the via-hole, which is adjacent to the open-end termination, influences both the input matching and the radiated field of the antenna. Therefore, it has been optimized, and the best results have been obtained for L_H = 15.60 mm.

III. Results

The LPDA antenna designed in Section II has been realized and a photo of the optimized antenna is shown in Fig. 3

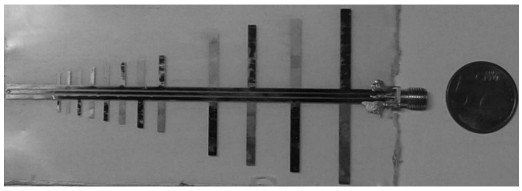

Fig. 3. Photo of the LPDA antenna.

The electrical contact between SMA and conductive ink has been realized through conductive glue. Particular care must be taken during this operation, in order to avoid to short-circuit the central strip of the CPW with the external strips, since the working space is very limited. The end balun has been realized using a via-hole, which has been realized by perforating the PET substrate with a precision drill. The electrical contact between the ground and the central strip of the coplanar waveguide has been obtained first by carefully pouring the silver ink into the hole, and then by filling the hole with conductive paste, in order to obtain an effective electrical connection. The via-hole position is quite critical, since the correct feeding of the antenna depends in an essential way on the balun [13]. This is even more important in our thin PET substrate. Fig. 1 shows the details of the designed via-hole.

A thorough characterization of the realized antenna has then been performed. The results of the simulations and measurements are shown in Figs. 4 and 5 in the frequency range 2 - 6.5 GHz, though the operating frequency bands requested to our antenna are: 2.4 - 2.484 GHz (3.4% bandwidth) and 5.2-5.8 GHz (11% bandwidth).

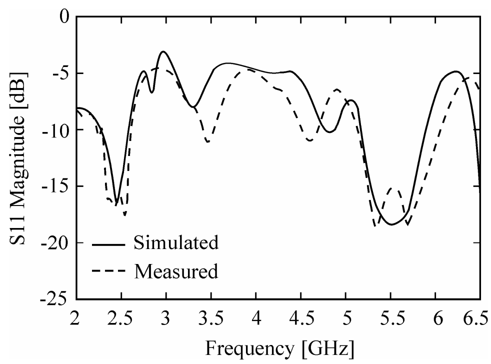

Fig. 4. Reflection coefficient of the designed LPDA antenna.

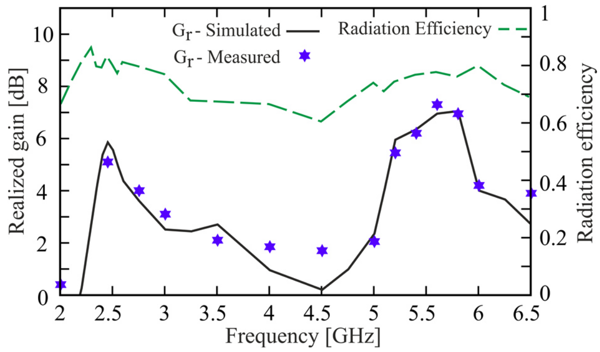

Fig. 5. Realized Gain (G_r) and simulated radiation efficiency of the designed LPDA antenna.

The numerical and experimental data are in good agreement, the reflection coefficient is below -10 dB in both the operating bands, and the out-of-band rejection is satisfactory, in particular if we consider that no stop-band filters have been used in the antenna design.

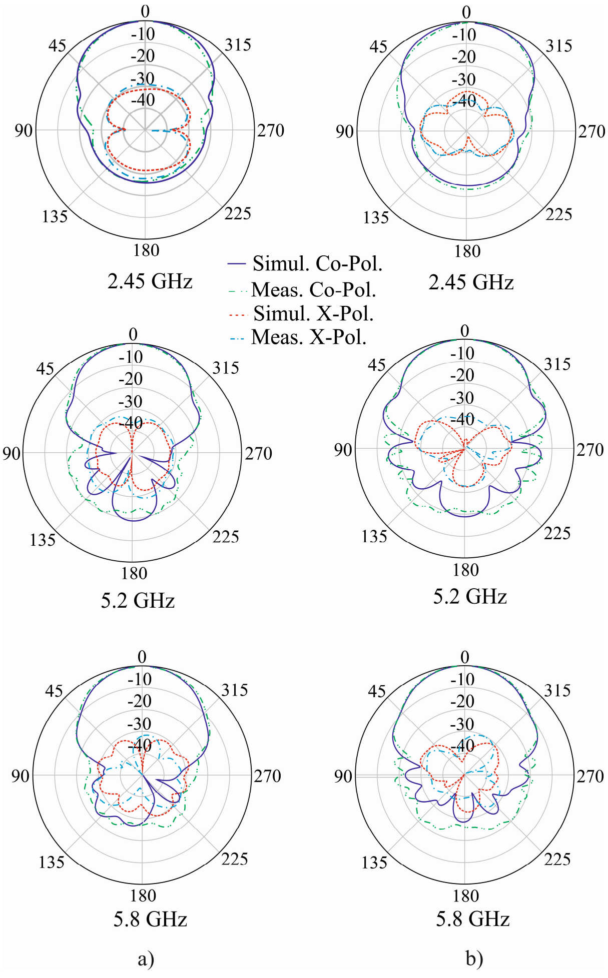

Fig. 6. Simulated and Measured Co-Polar and Cross-Polar normalized radiation pattern of the designed LPDA antenna. a) E-Plane; b) H-Plane

The antenna realized gain is about 5.5 dB in the WLAN-UHF band, and varies from 6 dB to 7 dB in the WLAN-SHF band. On the other hand, it quickly decreases out of the operating frequency bands, thus confirming the good out-of-band rejection of the proposed antenna. The antenna radiation efficiency is also reported in Fig. 5. It is between 80% and 85% in the working frequency bands, and decreases out-of-band. The simulated and measured E-Plane and H-Plane far field patterns of the designed antenna are reported in Fig. 6. The agreement between simulated and experimental results is very good, with a cross-polar component always below -25 dB in the operating bands. The antenna has an end-fire radiation pattern in both the design frequency bands, while it quickly deteriorates out-of-band (showing also unsatisfactory values for both SLL and Front-to-Back ratio).

IV. Conclusion

A multiband printed Log-periodic dipole array (LPDA) antenna for wireless communications, covering both the WLAN-UHF band from 2.4 GHz to 2.5 GHz and the WLAN-SHF band from 5.2 GHz to 5.8 GHz has been presented. The antenna is fed by a GCPW and implemented by inkjet-printing conductive ink on a PET substrate. In the proposed configuration, no air-bridges are required on the GCPW, and the realization is fully planar. Therefore, the presented structure offers all the advantages of the printed technology, resulting in an antenna very easy to realize, and with a very low production cost. The simulated and measured results are in a good agreement, showing a very good input matching, an end-fire radiation pattern, and a good rejection out of its operating frequency bands, without the use of stop-band filters, avoiding undesired interferences.

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