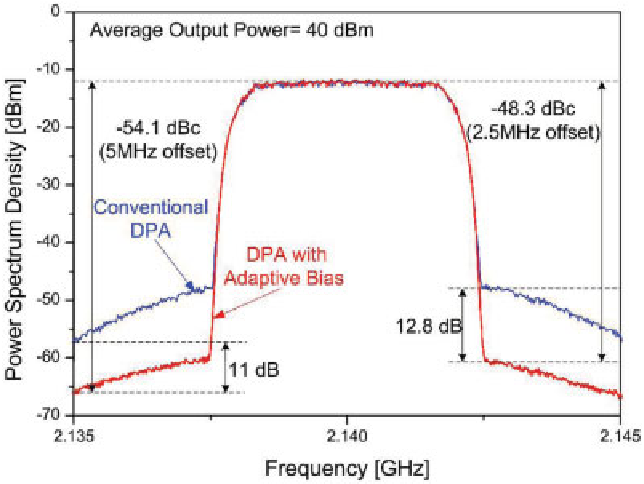

Figure 9 The measured power spectrum densities for a 1-carrier WCDMA signal at a Pout of 40 dBm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

which are improvements of 12.8 and 11 dB, respectively, over the conventional DPA.

Figure 10 shows the measured drain efficiency versus ACLR characteristics of various conditions for a 1-carrier WCDMA signal. The power tracking DPA at an ACLR of −45 dBc can produce a Pout of 43.4 dBm with the drain efficiency of 31%, which is the efficiency assuming that the efficiency of drain bias supply circuit is 100%.

4. CONCLUSIONS

We have proposed the three-way DPA with the adaptive bias supply using the power tracking method for improving linearity of the DPA while preserving high efficiency. To achieve good linearity of the DPA without extra linearization techniques, the drain bias voltage of the carrier amplifier and the gate and drain bias voltages of the peaking amplifiers are controlled adaptively according to input power levels. To verify this method, a three-way DPA was implemented using 30-W Si LDMOSFETs and tested using two-tone and 1-carrier WCDMA signals at 2.14 GHz. We have observed the significant IM3 cancellation for a two-tone test with 1-MHz tone spacing. We have also achieved superior ACLR performance for a 1-carrier WCDMA signal over a wide operating power range. At an ACLR of −45 dBc, the power tracking DPA can produce a Pout of 43.4 dBm with a drain efficiency of 31%. The measured results confirm that the linearity of the DPA is improved with the adaptive bias control of the gate and drain bias voltages of the DPA without extra linearization techniques, while obtaining high efficiency.

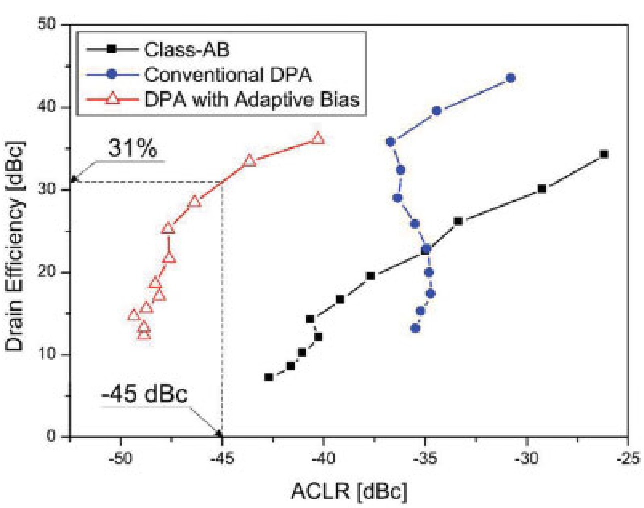

Figure 10 The measured drain efficiency versus ACLR characteristics for various conditions for a 1-carrier WCDMA signal. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

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A LOW-COST COMPACT UNIPLANAR QUASI–YAGI PRINTED ANTENNA

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ABSTRACT: *A low cost directive uniplanar broadband printed Quasi–Yagi antenna design is presented. As a particular realization, some prototypes have been designed to operate in the 2.45 GHz band. They have been then modeled, fabricated onto standard printed circuit dielectric substrate and tested successfully. For the design and the modeling processes, we have make use of FDTD based in-house developed algorithms. The obtained bandwidth is, for all the considered cases, better than 15%. The main radiation characteristics are 2–5.5 dBi gain, depending on the number of director elements, and better than 25 dB front-to-back ratio. Overall antenna size was, in any case lesser than 1 λ × 0.5 λ.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 731–735, 2008;

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Key words: *printed dipole; Quasi–Yagi; broadband; directivity; WLAN*

1. INTRODUCTION

Since 1928 [1], when Yagi described for the first time in English language the antenna with his name, Yagi-like antennas and their variations have been used almost in any wireless application. With novel applications of wire-less technologies (WiFi communications, Bluetooth links, MMDS distribution networks, sensors, and devices networks,[el]) printed versions of this antenna have jointly emerged. The widely accepted advantages of these antennas (compactness, robustness, ease of fabrication, low profile, light weight, and compatibility with printed circuitry) have decisively contributed to their rapid development.

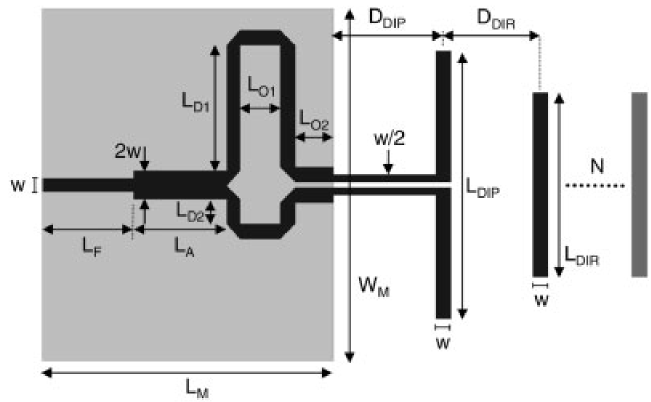
Most of the currently wireless networks assume the use of omnidirectional antennas in each of their nodes. Nevertheless, a particular topology case can suggest the use of a directional antenna. We are meaning, for example, an end access node or a far access node in a point-to-point or point-to-multi-point radio-link in a wireless sensors network. In such cases, the electrical characteristics of the directional antenna should match those of its omnidirectional counterpart, while enhancing the radiating properties. In this sense, one of the more common ways of improving the directivity of the antennas is to add some parasitic elements, usually called directors.

In this work, we report on a printed Quasi–Yagi antenna design, focusing on the addition of directing elements, in order to improve its directivity. The starting point is the coplanar antenna firstly introduced by Kaneda et al. at UCLA for the X-band. This original design has been extensively reported by the authors [2, 3] and widely applied throughout the literature. As illustrative examples, this antenna has been successfully used as a microstrip-to-waveguide transition [4], in arrays [5, 6], and designed at several frequency bands [7, 8]. In spite of its solid implantation, the specific design process has not been detailed throughout, so making difficult it to improve or to migrate the design to other bands or substrates. In fact, only brief comments are given by the authors in order to enhance its bandwidth or its gain. On the other hand, initial attempts have been carried out by other authors in this sense [8].

In the present study, we give a systematic design procedure in order to optimize the directivity properties of this sort of antenna, while keeping its broadband behavior. For the design process, we have specifically developed a FDTD based code. Even though the FDTD algorithm is commonly used as an analysis tool, it can be nowadays utilized for design purposes [9]. The software kernel was previously tested in complex profile antennas [10], and recently adapted for microstrip-planar structures [11]. Return losses, S_{11}, are calculated at the feed line, while the radiation pattern is calculated from the near field components. In addition, some protoypes were fabricated with the aim of testing simulated FDTD results against measurements. The measurements were carried out with the help of an E8363B network analyzer (Agilent Technologies), also used for the radiation pattern measurements within the anechoic chamber.

2. DESIGN

A simplified scheme of the proposed antenna is drawn in Figure 1. The antenna is uniplanar and can be fabricated onto a single piece of a low-cost standard printed circuit board dielectric ($\varepsilon_r = 3.9$) substrate. It uses the truncated ground plane of the microstrip feed line as a reflector. This way, only the upper metallized face of the substrate needs to be manufactured, so lowering the cost. In spite of its very compact design this antenna is demonstrated to display a very broad (>20%) bandwidth [2, 3]. The main body of the antenna consists of a driver dipole fed by an uniplanar microstrip-to-coplanar strip transition. This balun's phase shifter creates 180° phase difference between the coupled microstrip lines around the work frequency, so providing the correct fed to the antenna [3]. For its design, a simple scaling process was used. About the driver dipole, this is designed to work at λ/2 of the operating frequency (0.48[zmd]λ, after design optimization). The main specific dimensions for a work frequency of 2.45 GHz are collected in Figure 1, as a table. On the other hand, a number of equispaced and equal-in-length directors are added to the structure. The design of these elements has not been previously well stated.



L_F	30 mm	h	1.52 mm
L_A	20.68 mm	w	3.2 mm
L_{O1}	8.92 mm	L_{DIP}	58.72 mm
L_{O2}	8.53 mm	D_{DIP}	24.5 mm
L_{D1}	26.17 mm	L_M	74.53 mm
L_{D2}	5.33 mm	W_M	81.93 mm

Figure 1 Basic scheme of the antenna structure. Dimensions are also included

In the next paragraphs, a FDTD based systematic design procedure is applied in order to obtain the optimal configuration of such directors. The design approach will consist of systematic simulations sweeping over the main parameters of the directors, i.e., length, separation from the driver and number of items. As results, a set of design recommendations will be given.

2.1. Director Length

With the objective of finding the optimal length of the directors a series of simulations have been performed. A unique dipole has been arbitrarily placed at 0.2 λ (~25 mm at the design frequency) from the driver. For comparison, this dimension ranged from 0.1 λ to 0.25 λ [2, 3], depending either on bandwidth or gain enhancement. The length of this element has been swept from 15 to 45 mm. The results are presented in Figure 2. Figure 2(a) displays the S_{11} parameter and Figures 2(b) and 2(c) are the E-plane and H-plane radiation patterns, respectively. As observed, the radiation beamwidth, in both E- and H-planes, continuously decreases by increasing of the director's length. Nevertheless, the front-to-back radiation ratio gets its maximum at L_{DIR} = 35 mm. For bigger sizes, the director element displays a reflector character and the

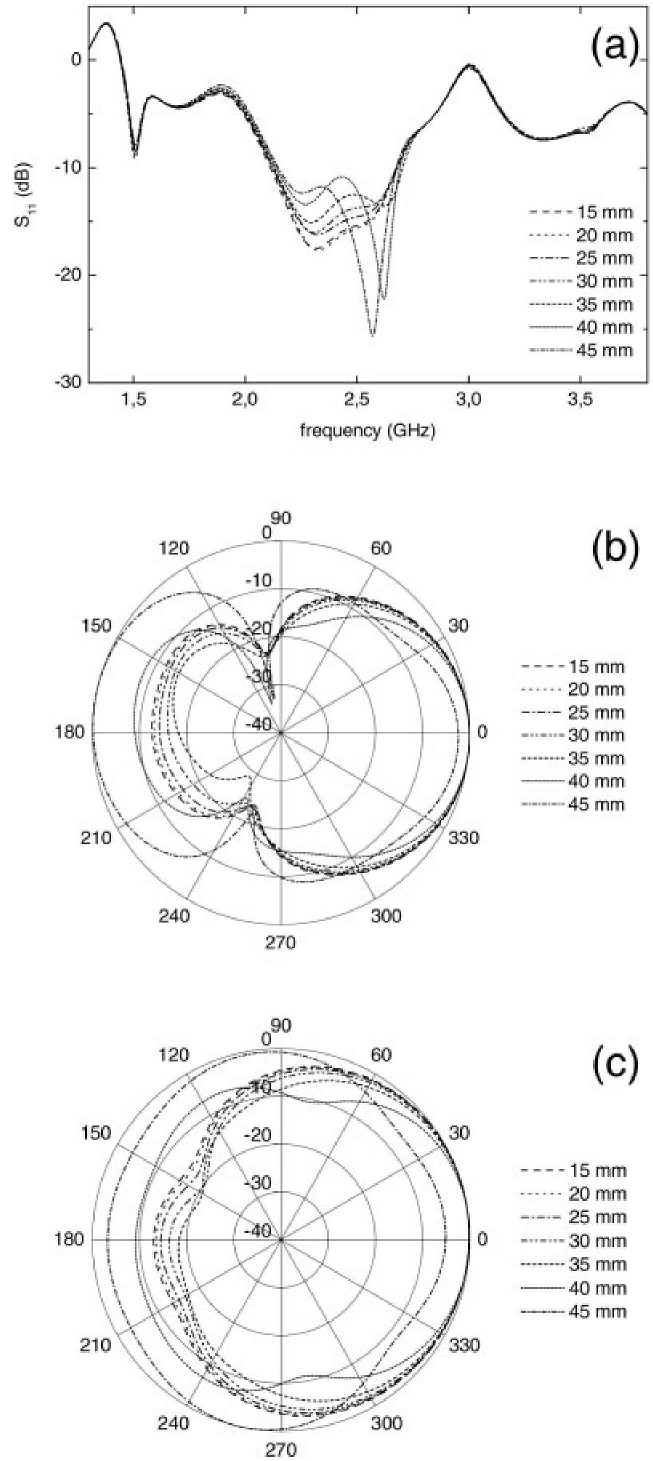


Figure 2 Variation of the antenna characteristics as a function of the directors' length (a) S_{11} parameter (b) E-plane radiation pattern (c) H-plane radiation pattern

back lobes get more important. On the other hand, even though bandwidth is formally independent with the director's length, the reflection coefficient response starts to get worse when L_{DIR} is about 35 mm. As a trade-off, $L_{\mathrm{DIR}} = 30$ mm was chosen.

2.2. Director Separation

Once the director's length has been selected, we focused our study on the separation among directors. A unique director element with $L_{\mathrm{DIR}} = 30$ mm has been considered. For the design, its position, D_{DIR}, has been shifted from 10 to 40 mm in steps of 5 mm. Simulated results are summarized in Figure 3. In this case, and for the reflection coefficient, better results are obtained with larger separations. This is obvious because the bigger is D_{DIR} the lesser coupling appears. About the radiation patterns, the E-plane beam width seems to be insensitive to D_{DIR}. About the H-plane, the best

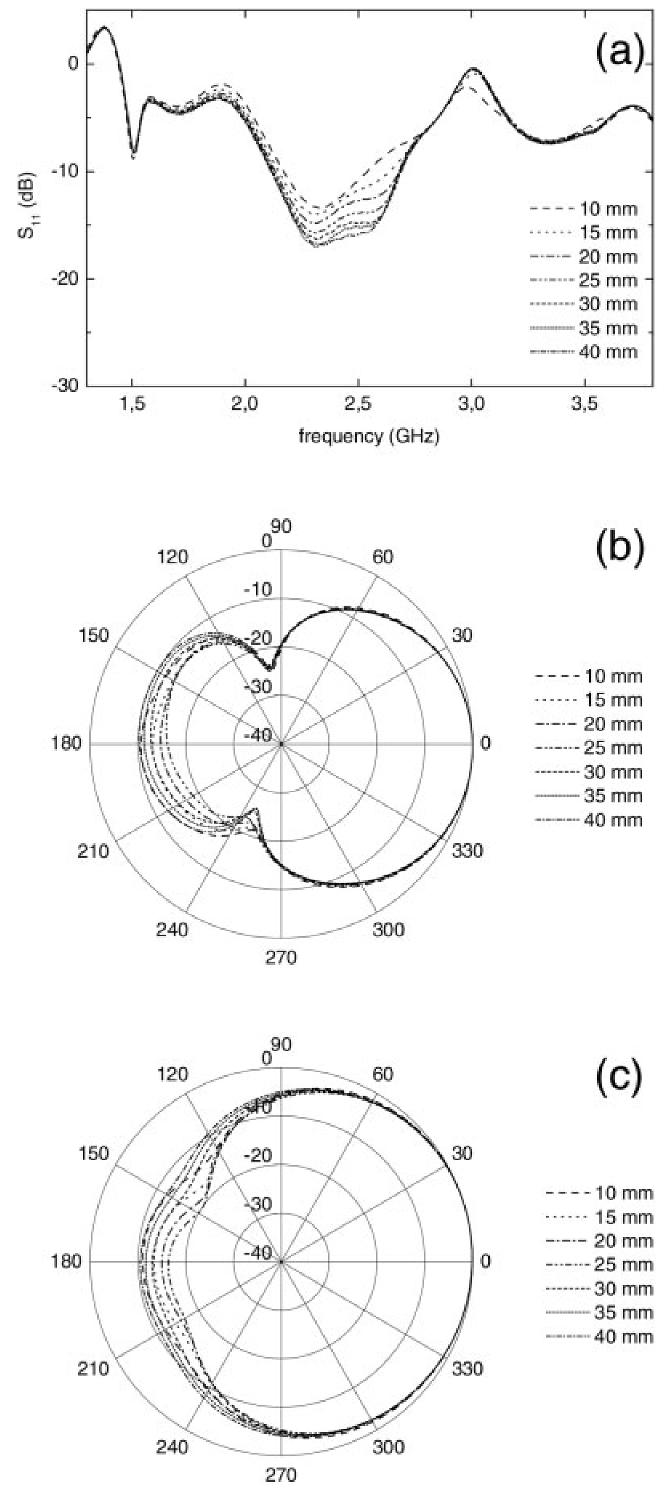


Figure 3 Variation of the antenna characteristics as a function of the directors' separation (a) S_{11} parameter (b) E-plane radiation pattern (c) H-plane radiation pattern

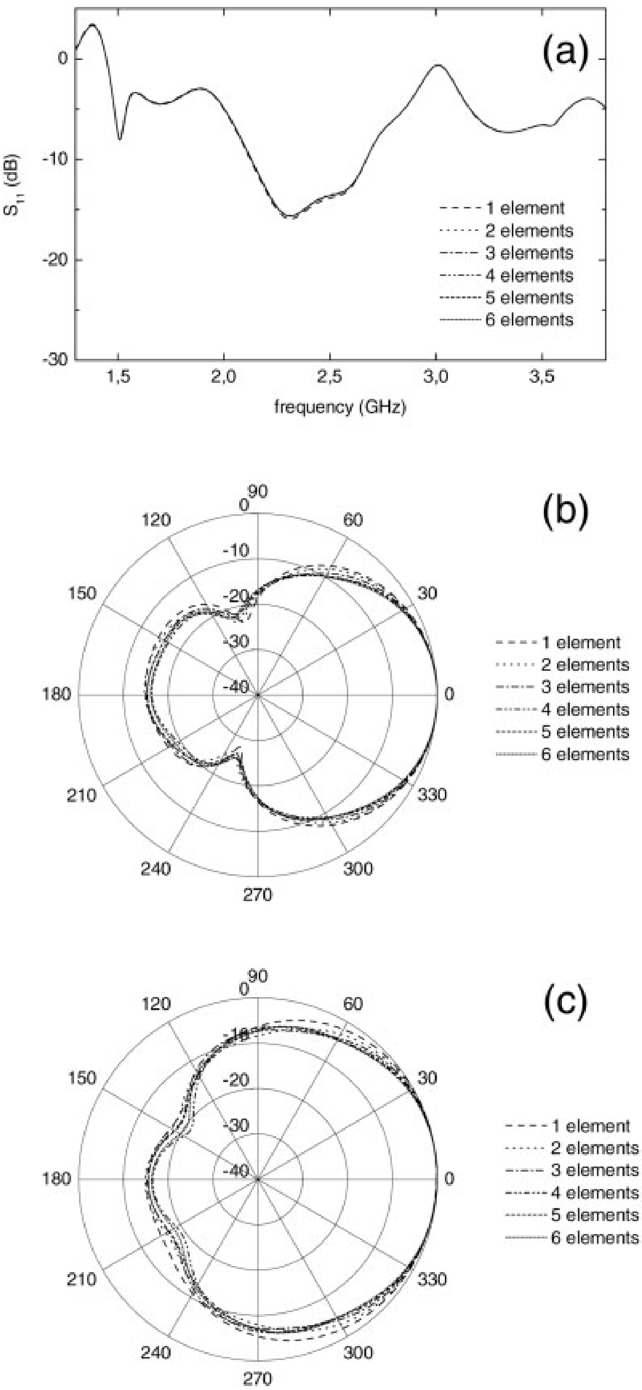


Figure 4 Variation of the antenna characteristics as a function of the number of directors (a) S_{11} parameter (b) E-plane radiation pattern (c) H-plane radiation pattern

directivity results are achieved with $D_{DIR} = 25$ mm (i.e., close to 0.2 λ), as can be observed. So D_{DIR} was selected to 25 mm.

2.3. Number of Directors

In Figure 4, we show the dependence of the reflection coefficient and radiation pattern on the number of directors. The dimensions of the directors are $L_{DIR} = 30$ mm and $D_{DIR} = 25$ mm. Some conclusions can be rapidly extracted. Firstly, the reflection is not a function of the number of directors. Second and subsequent parasitic elements have not a significant influence on the antenna impedance. Moreover, and as expected, the beamwidth of both E- and H-plane monotonically decrease with the increasing of the number of directors, so improving the directivity of the antenna.

3. RESULTS

To validate the entire process, we have fabricated some antennas. Protoypes with one, four, and six directors have been chosen. All of them have been designed with the optimal parameters previously obtained ($L_{DIR} = 30$ mm and $D_{DIR} = 25$ mm). The results are drawn in Figure 5, and summarized in Table 1.

As a preliminary comment, an excellent agreement is easily observed between both simulated and measured results.

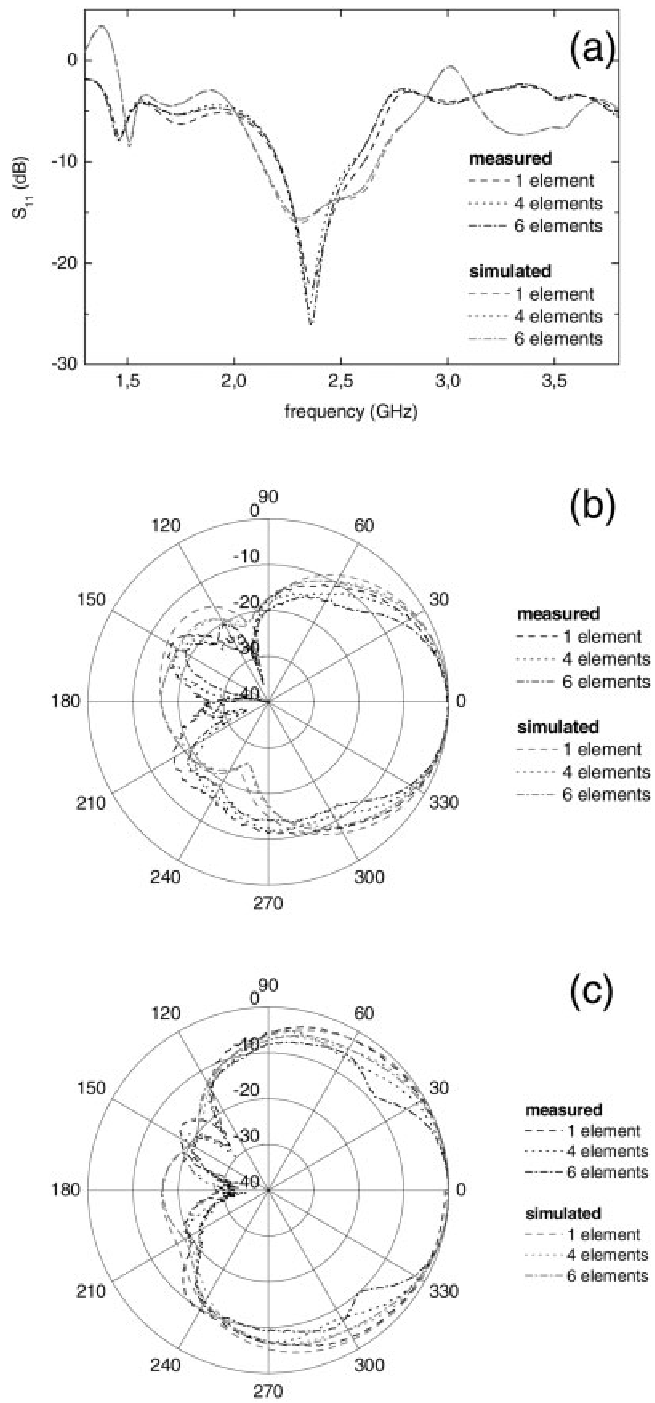


Figure 5 Experimental results for prototypes with 1, 4, and 6 elements (a) S_{11} parameter (b) E-plane radiation pattern (c) H-plane radiation pattern

TABLE 1 Experimental Results Summary

	1 Director		4 Directors		6 Directors	
	Simul.	Meas.	Simul.	Meas.	Simul.	Meas.
E-plane beamwidth	77°	63°	67°	58°	64°	49°
H-plane beamwidth	131°	133°	96°	75°	90°	57°
Front-to-back ratio (dB)	20.0	26	16.5	30	16.2	30
Frequency at midband (GHz)	2.40	2.41	2.40	2.39	2.40	2.39
Bandwidth (MHz)	570	430	570	370	570	380
Gain (dBi)	6	2	8	4	8.7	5.5

About the electrical characteristics, and as expected from simulations, the number of directors does not affect the return losses characteristics of the antenna. A bandwidth better than 15% and slightly lesser than predicted in the simulations is kept in any case. The coaxial connector, not considered in the simulations, is suggested to be in the origin of this small deviation. This bandwidth is comparable to that obtained by Y. Qian et al. [2] for 10.5 GHz, and wider to that obtained by P.R. Grajek et al. [12] for 24 GHz, and let us to be optimistic in scaling the antenna to other bands.

Regarding the radiation characteristics, measurements confirm the trend predicted in the simulations. The directivity is increased by increasing the number of directors, while the front-to-back ratio is about 20–30 dB. About the cross-polarization characteristics, the level was always better than 20 dB, unusually high for printed antennas.

At this point, a consideration should be taken into account. Even though the width of the ground plane is not a design parameter, it is obvious that it will affect the radiation characteristics of the antenna in general, and its directivity, in particular. To quantify this effect, a number of simulations were performed with the one-director prototype, with W_M ranging from 0.5 λ to 1 λ. The results let us state that the variation of the beamwidth of the E-plane (the directional plane) was <2° within this range. About the S_{11} parameter, no significant variation was appreciated.

In addition, the gain of the antennas was measured to be 2, 4, and 5.5 dBi for the 1, 4, and 6 directors antennas, respectively, while the calculated gain was 6, 8, and 8.7 dBi for the 1, 4, and 6 directors antennas, respectively. This relatively low measured gain is mainly due to the losses of the substrate, negatively affecting the antenna efficiency. To corroborate it, a one-director prototype was fabricated onto a Clad substrate ($\varepsilon_r = 3.2$, $h = 1.52$ mm). In this case the measured gain was 4 dBi. So, the estimated losses of the substrate are 2 dB, and the predicted gain for the 4 and 6 directors Clad prototypes should be 6 and 7.5 dBi, respectively, slightly lower than those predicted by simulations.

To state the limit of performance of the antennas, the range of simulations was extended up to 14 elements. This case, and due to the size (more than 35 cm long), the fabrication of prototypes was not possible. Only regarding the simulated gain, a value of 9.9 dBi (for lossless substrates) was obtained, similar to those displayed by wired Yagi–Uda antennas. This limit is very hard to be improved with single antennas. With the use of antenna arrays, the gain can be enlarged up to more than 13 dBi (eight antennas with one director at 9 GHz [5]). This way, the overall size of the array (antennas and feeding system) is of 4 $\lambda_0 \times 2.2\ \lambda_0$ (1.5 dBi/λ_0^2). In our case, and for the 6 elements case (1 λ × 0.5 λ, 5.5 dBi gain) this relationship is 11 dBi/λ_0^2 (15 dBi/λ_0^2) if specific high frequency substrates were used.

4. CONCLUSIONS

The directivity of printed Quasi–Yagi antennas can be notably improved by adding parasitic elements. A careful design of these elements has not a significant effect on the impedance properties of the antennas. The FDTD algorithm can be efficiently used for this purpose. Gains of >5 dBi can be achieved with 6 elements antennas placed on standard printed circuit board substrates. The gain can be improved up to >7 dBi by using specific high frequency substrates. Overall antenna size is, in any case <1 λ × 0.5 λ and, therefore, suitable for WLAN mobile applications.

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