Reconfigurable Loaded Planar Inverted-F Antenna Using Varactor Diodes

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***Abstract*—This letter presents a compact reconfigurable multiband microstrip antenna. The multiplicity of bands is achieved by the use of concentric external metallic semirings around a central internal semicircular microstrip patch. These are all shorted to the ground plane via a vertical metallic wall through the common diametric plane, thereby adopting the concept of the planar inverted-F antenna (PIFA) for size reduction and thus compactness. The operation frequencies are tuned by varactor diodes placed between the inner semicircular patch and the outer half-rings. In addition to tunability, the overall bandwidth may also be widened by combining the tunable range. Theoretical simulations and measurements of manufactured prototypes agree well with each other.**

***Index Terms*—Dual band, microstrip patch antenna, planar inverted-F antenna (PIFA), reconfigurable, varactor diodes.**

I. Introduction

Modern wireless devices are required to provide a myriad of services, leading to increased demands for mobile terminals that support multiple applications. In addition to this multifunctionality, users expect compactness of their gadgets, in which the antennas and batteries are the most restrictive components that hinder the accomplishment of size requirements [1].

Many authors and antenna designers have worked on obtaining compact radiating elements with relatively good efficiencies. Several of these studies have been focused on planar inverted-F antennas (PIFAs) with excellent results [2], [3]. However, as these PIFAs have high Q-factors, they are efficient and well matched only within small frequency bands.

In order to extricate this drawback, some investigators have proposed making the devices reconfigurable, i.e., to develop antennas whose bands are modified by using an external parameter, typically a dc voltage [1], [4]. Since some of these compact antennas are based on resonances created by a capacitance and an inductance, one of the most common techniques described in the literature is based on using varactor diodes that provide a changeable capacitance as a function of the inverse voltage introduced across their terminals [5], [6], thus allowing the operation bands to be tuned. In this way, even if the instantaneous bandwidth of a nontunable antenna is statically narrow, the combined operational range produced by superposing the dynamic bands of a reconfigurable version will be much larger. This frequency band is defined herein as the *equivalent* bandwidth.

In this letter, a reconfigurable microstrip patch antenna based on varactor diodes is proposed, initially mooted in [7], but extended here. The basic version of the antenna was previously described in [8], and it has a multifrequency response, although here the reconfigurability will be explored only in one of its bands, particularly the one with the lowest frequency of operation.

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II. Loaded PIFA (Nonreconfigurable)

The loaded PIFA, which will be later modified in order to exhibit reconfigurability, is illustrated in Fig. 1(a). This antenna was studied in depth in [8], and it has a multifrequency operation. For the present purpose, the load will be a single external short-circuited semiring, although the concept could be extended to effectuate more bands. This semiring produces a radiation band below that of the ordinary fundamental mode (TM_{11}), thereby achieving two operation bands. Both modes are represented in Fig. 1(b) for an antenna with the following dimensions: $R1 = 2.5$ mm, $R2 = 3.5$ mm, $R3 = 18$ mm, in a polypropylene substrate ($\epsilon_r = 2.2$) with 10 mm thickness. The lowest mode has a bandwidth of less than 1%. For this reason, Section III discusses a method for tuning the frequency of operation.

More bands can be created by adding external semirings, as demonstrated in [8]. Each new semiring brings about new capacitances and inductances, thus producing a replica of every ordinary mode, the latter being attributed to the inner semicircular disc and having radiation patterns that are similar to those of its ordinary mode.

III. Reconfigurable Antenna

The proposed reconfigurable version of the dual-band antenna is illustrated in Fig. 2(a). In order to modify the operational frequency of the lower radiating mode, one of the possible options is to modify the series capacitance created by the patch [internal semicircle in Fig. 1(a)] and the load [external semiring

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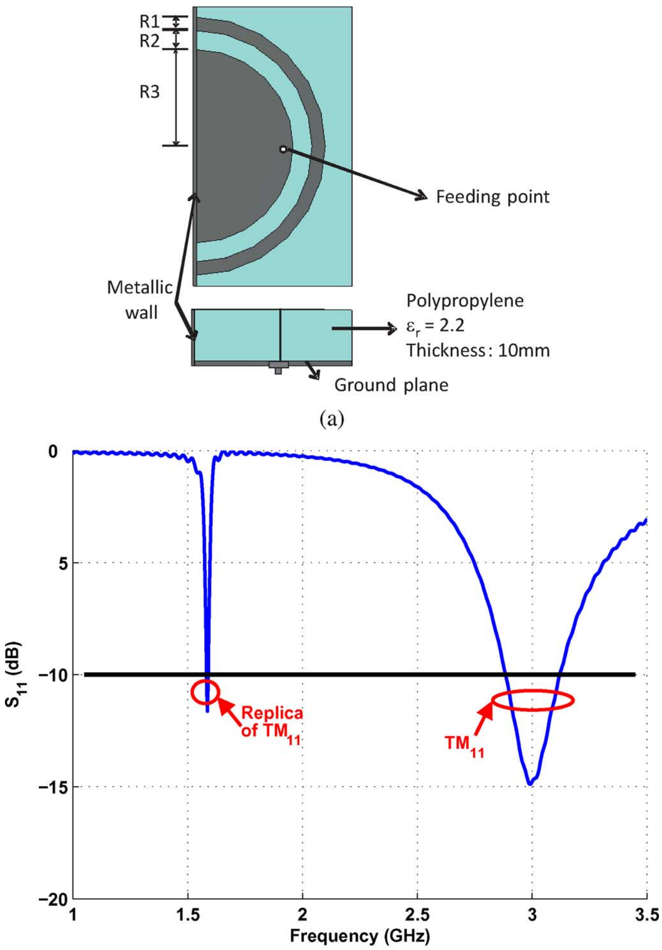
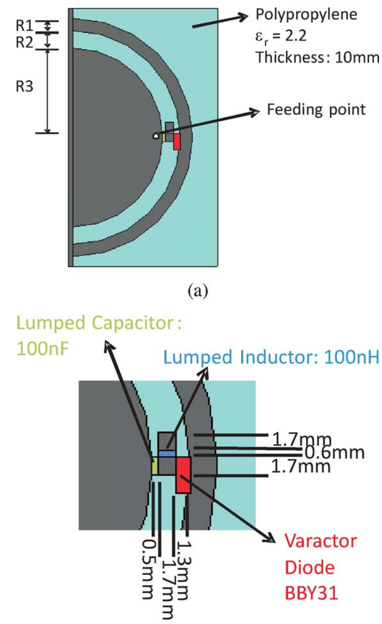


(b)

Fig. 1. Description and $|S_{11}|$ of the proposed (nonreconfigurable) loaded PIFA. (a) Top and side views of the proposed (nonreconfigurable) loaded PIFA. (b) Simulated $|S_{11}|$ for the dual-band PIFA (nonreconfigurable): $R1 = 2.5$ mm, $R2 = 3.5$ mm, $R3 = 18$ mm, in a polypropylene substrate ($\epsilon_{\rm r} = 2.2$) with 10 mm thickness.



(b)

Fig. 2. Reconfigurable loaded PIFA. (a) General description of reconfigurable loaded PIFA. (b) Zoom of lumped elements and varactor diode.

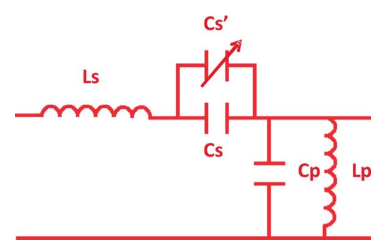


Fig. 3. Equivalent circuit of the reconfigurable loaded PIFA.

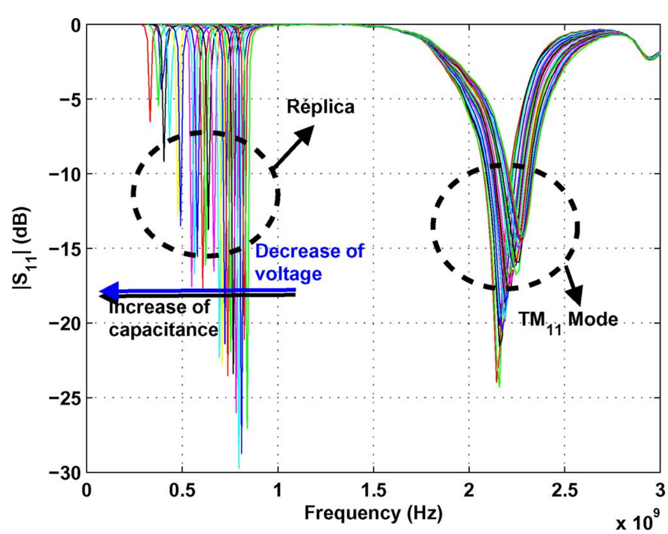


Fig. 4. Variation of operation frequencies with increasing capacitance. Measurement results, for which the voltage varies from 0 to 23 V and the capacitance correspondingly changes from 19 to 1.5 pF.

in Fig. 1(a)]. To this aim, a lumped capacitor ($C_{s'}$) can be employed, obtaining an equivalent circuit as illustrated in Fig. 3. In order to have a variable capacitance (and therefore a variable band of operation), a varactor diode can be introduced between the external semiring and the internal semicircle instead of a lumped element. Particularly, for the purpose of this letter, a Philips BBY31 has been employed. Moreover, since the antenna is connected to the ground plane, it is necessary to add a lumped capacitor to avoid a short-circuit in dc and a lumped inductor in order to eliminate the influence of the dc network on the RF elements. The locations of these two lumped elements are illustrated in detail in Fig. 2(b), zooming in the circuitry of Fig. 2(a).

Fig. 4 demonstrates the measured variation of the two bands with the tunable capacitance for a prototype (which is illustrated in Fig. 5) having the same dimensions as the simulated model without the varactor diode [with frequency response shown in Fig. 1(b), and with dimensions of the polarization networks as detailed in Fig. 3(b)]. Evidently, the resonant frequency of the replica mode decreases with increasing capacitance values. For this latter experimental case, the voltage changes from 0 to 23 V with correspondent variation of the capacitance from 19 to 1.5 pF.

The simulated and measured *equivalent* bandwidth of the reconfigurable antenna for the capacitance values of the men-

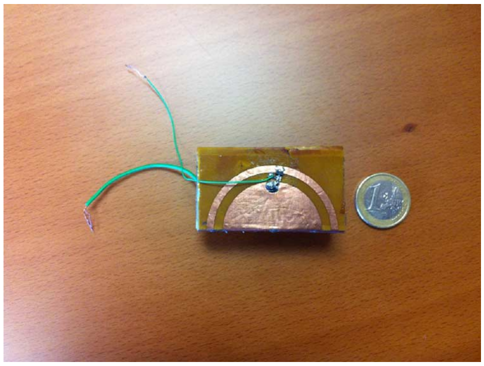


Fig. 5. Photograph of the manufactured prototype.

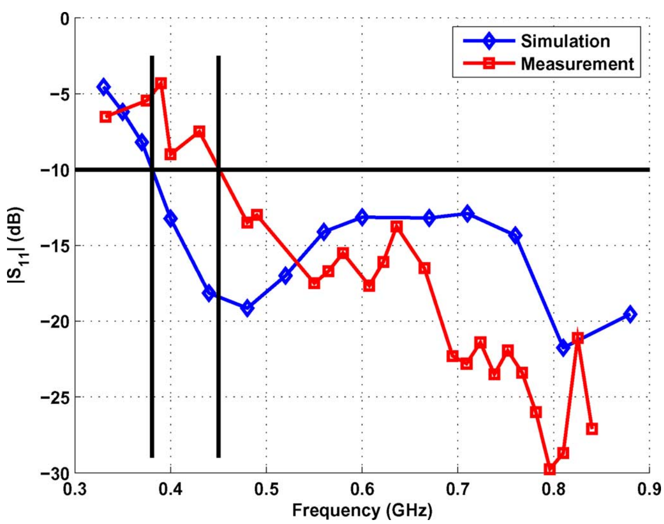


Fig. 6. Measured and simulated *equivalent* $|S_{11}|$ for the reconfigurable antenna.

tioned varactor diode (1.5–19 pF) are presented in Fig. 6. The overall bandwidth achieved by superposing the bands over the tunable range is approximately 75%, a whopping improvement from the 1% of the nonreconfigurable version. Although the usable range of the center frequency has significantly increased, any applications that utilize this antenna will still be limited to 1% bandwidth at the tuned center frequency, i.e., the entire 75% bandwidth would not be available all at once, limiting the applications. The corresponding measurement results are also given in Fig. 5, demonstrating a 56% effective bandwidth.

IV. Conclusion

In this letter, a reconfigurable microstrip patch antenna has been proposed and studied. The bandwidth of the original nonreconfigurable version was extremely narrow at about 1%. However, simulations have demonstrated that the operation frequencies can be increased up to 75% through reconfigurability. This was achieved by modifying (using a varactor diode) the shunt capacitance, which produces the lowest radiating mode of the antenna. A polarization network based on lumped elements has been required to isolate the RF to the dc, being critical in this particular design, since the antenna is short-circuited to the ground plane. Measurements of prototypes of these reconfigurable antennas exhibit achievable effective bandwidths of as high as 56%, corroborating theoretical expectations.

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