Shorting Strap Tunable Single Feed Dual-Band PIFA

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***Abstract*—RF switches are integrated to the shorting straps of a single feed dual-band planar inverted-F antenna (PIFA) to make a tunable PIFA. The L-band switch yields 0.45-dB insertion loss (IL) and 10-dB isolation bandwidth (BW) of 40% at 1.5 GHz. The tunable PIFA yields 39% impedance BW at 900-MHz band and 7.8% BW at 2000-MHz band. The measured radiation patterns are nearly omni-directional and yield a gain of −7.8 dBi at 652 MHz and 4.3 dBi at 2104 MHz.**

***Index Terms*—Frequency tuning, mobile communications antennas, PIN diode, RF switches, tunable PIFA.**

I. INTRODUCTION

IN recent years, the rapid evolution in the wireless communication technologies has brought us many multi-functional telecommunications products. The most notable one is the mobile phone. In such a short time, it has evolved from a mere voice communication device on the move to a very sophisticated data transfer and processing tool with image/video, e-mail, and Internet facilities. To fulfill the need for this broad-range functionality, the transceiver must cater for a very large BW operation. Hence, the need for highly tunable antenna arises. The planar inverted-F antenna (PIFA) has gained much interest due to its compact and low profile configuration, ease of fabrication and favorable electrical performance such as wide beamwidths [1]. PIFAs can be modified to operate over multiple frequencies, commonly bifurcating the short-circuited patch radiator with slots [2]. However, using such slots is not a preferred option for broadband applications since this technique only generates very narrowband resonances at discrete two or three frequencies [3], depending on the number of perturbations or resonators. Recently, implementing diode switches does alleviate the bandwidth problem significantly and improves the frequency agility of the antenna in a greater degree [4].

The salient feature of a PIFA is that its resonance frequency depends on not only the length of the shorted patch, but also other dimensions, such as the width and height of the patch and the width of shorting straps. For the multifrequency resonance, the gap width and length also play a role. Therefore, designers have made various efforts to change the effective dimensions of the PIFA, without changing the physical dimensions for compactness. RF diode-switches [5] can electronically change any of these parameters. This communication implements an array of RF diode-switches to ground to change the effective width of the shorting strap of the PIFA. Thus a very broadband operation in the order of 36% BW around 1 GHz frequency band is achieved. To the best of the author's knowledge, such physical implementation is not reported before.

This paper presents the design and development of a shorting strap tunable dual-band PIFA. First, the designs of a single feed dual-band PIFA and an RF diode switch at L-band are presented. The switch is integrated with the dual-band PIFA to make it a frequency agile antenna. The return loss (RL) BW versus frequency for different shorting strap width and the radiation patterns and gain are presented.

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II. DESIGN

A. PIFA Element

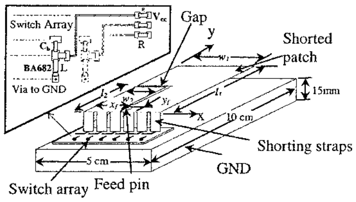
The design of a dual-band PIFA is accomplished bifurcating the low frequency shorted patch into an L-shape patch and a smaller rectangular patch separated by an L-shape slot [2]. While the L-shape patch resonates at a lower frequency, the inset small rectangular patch resonates at a higher frequency. Thus a dual-frequency operation is achieved. The shape distortion of L-patch does not affect the electrical performance [2] significantly. Although, the accurate model of such a dual-band PIFA is not straightforward (full-wave analysis is preferred), the approximate design formula is widely used [1] to obtain the resonant frequencies: $f_{0n} = c/4(w_n + l_n)$, where f_{on} = resonant frequency of n-th patch, c = velocity of light, w_n = width of n-th patch, and l_n = length of n-th patch. Here, $n = 1$ (for L-shape patch), and 2 (for inset rectangular patch).

The dual-band PIFA is designed for 900-MHz and 1800-MHz frequency bands [6]. The dimensions are L-shape patch-$l_1 = 55.26$ mm, $w_1 = 30$ mm, inset rectangular patch-$l_2 = 26.32$ mm, $w_2 = 23$ mm, L-shape gap width = 2 mm, PIFA height = 10 mm, shorting strap width = 3 mm with 2 mm gap, and SMA feed pin coordinates: $\mathrm{x_f} = 24$ mm, $\mathrm{y_f} = 3.4$ mm. The PIFA is made of a 1-mm thick brass sheet.

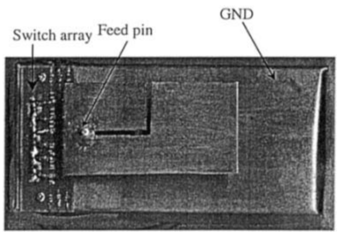
B. RF Switch

Inset of Fig. 1(a) shows the array of six L-band switches with inductors L, capacitors $\mathrm{C_b}$, and PIN diodes HP5802-3168. $\mathrm{C_b}$ blocks dc current to ground plane (GND), but directs any RF leakage to GND. The values are $\mathrm{L} = 120$ nH and $\mathrm{C_b} = 10$ pF. The GND acts as decoupling and provides a return path for dc signal. The $\lambda/4$-long thin bias line at 1.5 GHz is connected to the diode via a current limiting resistor $\mathrm{R} = 680\ \Omega$. The circuit is designed at 1.5-GHz frequency on FR4 substrate of thickness 1.6 mm and $\varepsilon_\mathrm{r} = 4.2$. The switch PCB is fixed on the GND of PIFA with screws such that the GND of the switch is short-circuited to the PIFA GND.

Fig. 1(b) shows the fabricated shorting strap-switching PIFA. Six shorting straps of width 3 mm are uniformly distributed along the shorting edge of the PIFA. As shown, the RF switches



(a)



(b)

Fig. 1. Shorting strip tunable single feed dual-band PIFA. (a) Schematic representation (inset: an RF switch array). (b) Top view of a fabricated PIFA on brass plate.

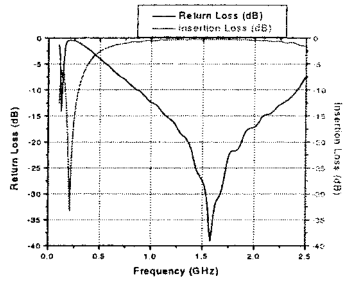
are placed at the GND-end of the shorting straps. The resistor is set to 680 Ω to limit the dc bias current that will flow into the switch. Surface mount capacitors of 10 pF are used to isolate the dc bias current so that it will only power-up a particular switch. To prevent the signal flow from the biasing source, surface mount inductors of 120 nH are also introduced. When a diode attached to a shorting strap is reversed biased (RB), it creates an open circuit to the PIFA's GND, and when the diode is forward biased (FB), it makes the strap shot-circuited to the PIFA's GND. Thus, the effective width of the shorting strap, as well as the resonant frequency of the PIFA, changes.

III. Results

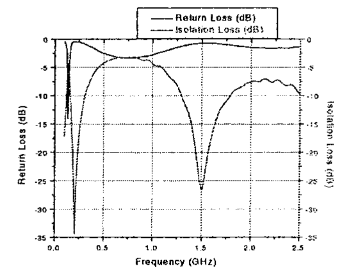
The successful implementation of such a shorting strap tuning PIFA depends on the performance of the diode switch. Therefore, it is imperative to check the diode switch's performance first. Once satisfactory results of isolation and insertion loss of the switch are obtained within the frequency band of interest, the switch is integrated with the PIFA and the performances of PIFA are measured. The followings are the measured results of the switch and the PIFA, respectively.

A. RF Switch

Fig. 2(a) shows the S-parameters of the PIN diode switch under the FB condition. A −10 dB RL BW of 97% is achieved. The RL at 1.51 GHz is −39.085 dB and the IL is −0.3 dB. Thus, under FB, the switch works well. The performance of the switch under RB condition is shown in Fig. 2(b). The RL is very low (−0.75 dB) and the isolation is as low as −26.705 dB at 1504 MHz. The 10-dB isolation BW is 31.9% Thus these results show that the RF switch acts as a high quality L-band ON-OFF switch. Since the developed diode switch cannot yield sufficiently large isolation bandwidth for dual band operation, a pair of diode switches designed individually at 0.9- and 1.8-GHz frequency bands connected in parallel to each shorting strap may improve the antenna performance. Certainly, this will increase the complexity and cost of design. Alternately, a single



(a)



(b)

Fig. 2. Measured S-parameters of RF switch. (a) Under FB (+5 V). (b) Under RB (−5 V). Diode: HP5802-3168, L = 120 nH, C_b = 10 pF, and R = 680 Ω.

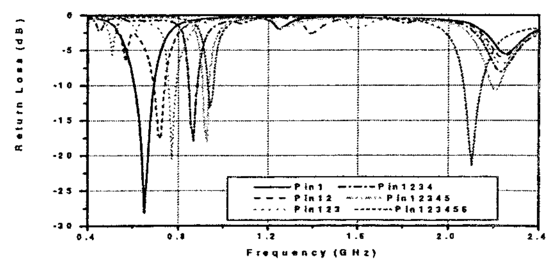
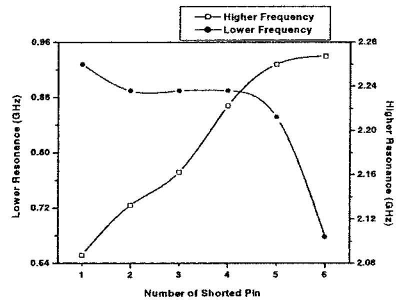


Fig. 3. Input RL versus frequency with the number of shorting straps as parameter. The dimensions are $l_1 = 55.26$ mm, $w_1 = 30$ mm, $l_2 = 26.32$ mm, $w_2 = 23$ mm, gap width = 1.5 mm, PIFA height = 10 mm, shorting strap width = 3 mm with 2 mm gap, $x_f = 24$ mm, and $y_f = 3.4$ mm.

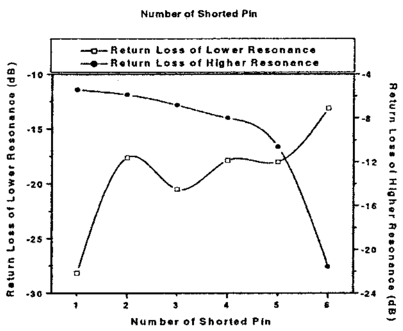
broadband switch, which covers both frequency bands, if available commercially, can also be used.

B. PIFA-Shorting Strap Switching

Fig. 3 shows the input RL vs frequency with the number of the shorting straps of the PIFA as a parameter. As can be seen, when only one shorting strap is connected to GND via a PIN diode switch, the first resonant frequency is at 652 MHz and the input RL is −27 dB. The second resonant frequency is at 2.24 GHz and the RL is −5 dB. With the number of shorting strap (starting from the first to the sixth shorting straps), the first resonant frequency shifts toward higher frequency region while the second resonant moves toward lower frequency. Increasing the number of shorting straps is identical to the increase in the shorting plate width. The results for the first resonant agree with the theory that an increase in shorting strap width increases the resonant frequency [1]. However shown by Fig. 3, the two resonances shift in opposite directions. Please note that individual tuning of both upper and lower frequency is not possible from the proposed configuration, but this is possible in a stacked patch configuration where shorting straps of individual shorted patches are turned on and off separately.



(a)



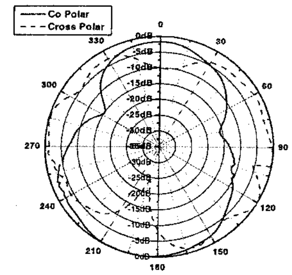
(b)

Fig. 4. (a) Resonant frequency and (b) input RL versus number of shorting straps for the shorting strap tunable single feed dual-band PIFA at L-band. The dimensions are as for Fig. 3.

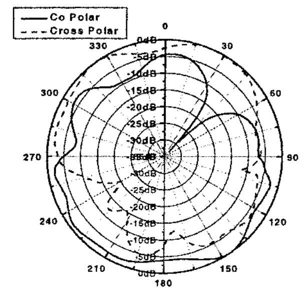
Fig. 4 analyzes the results in terms of the resonant frequencies and the RL at resonant frequencies vs the number of shorting straps. As can be seen in Fig. 4(a), the lower resonant frequency shifts upward almost linearly from 652 MHz to 940 MHz constituted to a total of 288 MHz BW. Whereas the higher resonance has only shifted 144 MHz downward, which is exactly half of the first one. The achieved bandwidth was quite high with the maximum lower resonance bandwidth reached up to 36% at the center frequency between 652–940 MHz, and for high frequency, the bandwidth would be 7.8%. As can be seen for the matching of low frequency resonance, the RL is always higher than 10 dB (neglecting some spurious resonance of the switch parasitics). For the high frequency resonance, the RL is quite poor until five straps are shorted to GND. Observing the trends of the two resonances, it can be concluded that a trade-off of matching between the two frequencies can be achieved playing with the proper adjustment of feed location, hence 10 dB RL BW for both frequencies can be optimized with a compromise of the input impedance match at the lower frequency resonance.

C. Radiation Pattern of PIFA

The radiation measurements were conducted at Nanyang Technological University's Anechoic Chamber. The RF switches are supplied by ±5 V dc bias voltage source. Fig. 5 shows the co-polar (solid line) and cross-polar (dotted line) E- and H-plane radiation patterns at 2104 MHz, respectively. Both co-polar and cross-polar (dotted line) E-plane and H-plane radiation patterns yield very wide beamwidth (nearly omni-directional), except single directional distortions in the patterns. This may be due to the finite ground plane of the PIFA and the parasitics of the RF switches. Similar omni-directional patterns are obtained at lower frequency band. The measured absolute antenna gain at 652 MHz and 2104 MHz is −7.78 dB and 4.3 dB, respectively. The overall antenna performances under both FB and RB states are satisfactory with uniform power levels and omni-directional radiation patterns.



(a)



(b)

Fig. 5. (a) E-plane and (b) H-plane radiation patterns of the shorting strap tunable single feed dual-band PIFA at 2.104 GHz. The dimensions are as for Fig. 3.

IV. Conclusion

The design and development of a shorting strap tunable single feed dual-band PIFA has been presented. RF switches are integrated to the shorting straps of the PIFA to make it a frequency agile antenna in a compact package. First, a dual-band PIFA has been designed. Next, the L-band switch was designed, which yielded 0.45-dB IL and 10-dB isolation BW of 40% at 1.5 GHz. The tunable PIFA yielded 39% impedance BW at 900 MHz band and 7.8% BW at 2-GHz band. The measured radiation patterns are omni-directional and gain was −7.8 dBi at 652 MHz and 4.3 dBi at 2104 MHz. The antenna performance is very promising for present and future wideband applications.

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