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A Four Bandwidth-Resolution UWB Antipodal Vivaldi Antenna

Mounira Bitchikh* and Farid Ghanem

Abstract—In this paper, a frequency reconfigurable Antipodal Vivaldi Antenna (AVA), capable of covering a Band of Interest (BoI) spanning from 3 to 10.6 GHz with four different bandwidth resolutions, is presented. By incorporating four rectilinear resonators and two Split-Ring-Resonators (SRRs) into the AVA, the whole BoI can be covered by one (UWB mode), three (3-sub mode), seven (7-sub mode), or sixteen (16-sub mode) sub-bands. In the UWB-mode, all the six resonators are deactivated by disrupting their structures, so the antenna operates as a classical AVA. In the 3-sub mode, only one rectilinear resonator is activated; the low Q of these resonators allow narrowing the antenna operating band so that the BoI is covered by three sub-bands. In the 7-sub mode, two rectilinear resonators are activated at a time, which narrows the operating bandwidth furthermore, allowing to cover the BoI by seven sub-bands. In the 16-sub mode, one of the two SRRs is activated at a time to be used as a coupling-bridge to very narrow frequency bands that allows covering the BoI by sixteen different bands. To present the work, simulated and measured results are given and discussed.

1. INTRODUCTION

Wireless communication systems have seen, during the last years, very important developments. It is noticed that the frequencies used by these various systems spread over several octaves and concurrent access from the same terminal as small and compact at these frequencies is impossible with a conventional antenna.

Nowadays, a very important number of the radios are multiservice, and having frequency reconfigurable antennas can be of important help to filtering users from unused bands [1]. Cognitive radios that can opportunistically use whatever available band are even more demanding of the reconfiguration of the antennas since the frequency band to use depends on other users. In this perspective, proposing an antenna that can work in any part of a wide range of the spectrum with the largest number of bandwidth choices would be definitively interesting.

Reconfigurable antennas have been widely investigated, and different types of reconfiguration have been proposed. The frequency reconfiguration usually consists in translating the operating band [2], creating new bands [3–5], but an important proportion of them consists in switching between a wideband mode and one of its sub-bands [6–9]. This last category of reconfigurable antennas is of particular interest for the proposed context as they allow varying the operating bandwidth. The most relevant work is probably the one presented in [10] as it consists of an antenna that can cover 3 to 10.6 GHz band with three different bandwidth resolutions.

In this paper, a four-bandwidth resolution is presented. The antenna proposed here is the extension of the one presented in [10] and is capable of covering the 3 to 10.6 GHz Band of Interest (BoI) with four different bandwidths resolutions which correspond to one (UWB mode), three (3-sub mode), seven (7-sub mode), and sixteen (16-sub mode) sub-bands.

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2. PROPOSED APPROACH

The proposed antenna is based on the one presented in [10] which is in turn based on an Antipodal Vivaldi Antenna (AVA). Its schematic is given in Figure 1.

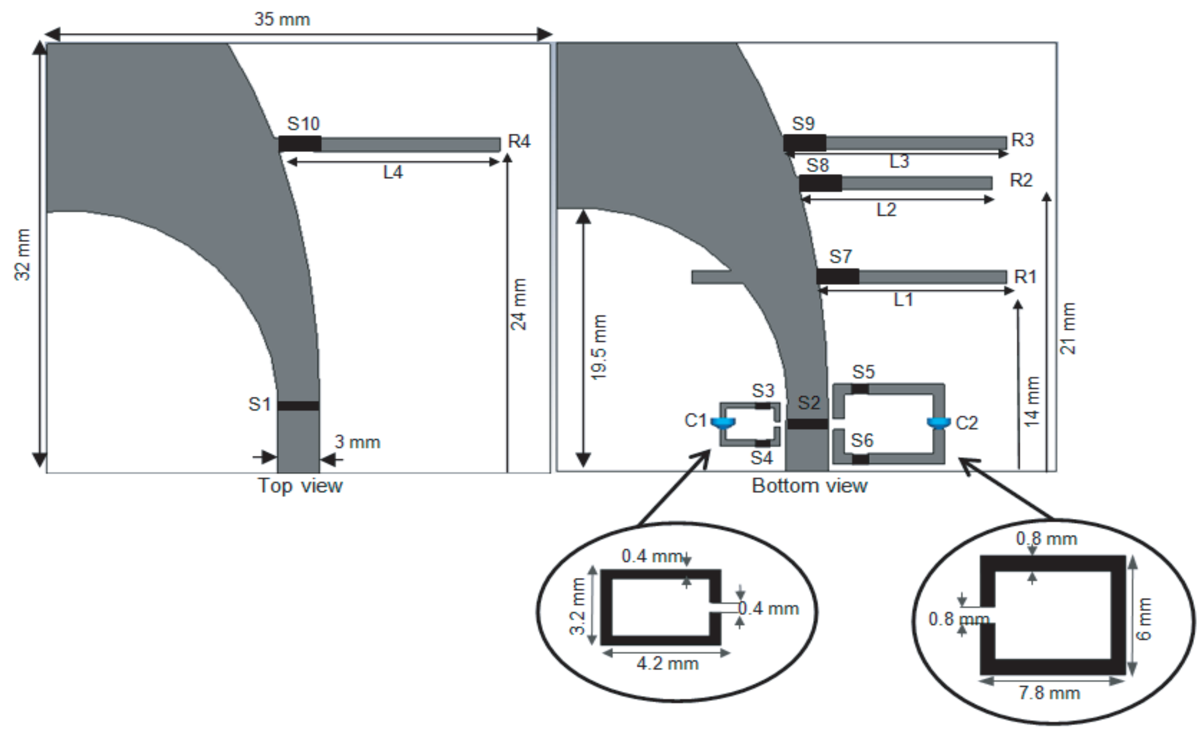


Figure 1. Schematic of the proposed antenna.

It consists of an AVA with four rectilinear resonators R1 to R4 and two rectangular Split-Ring Resonators (SRR's) to which ten switches S1 to S10 and two varactors C1 and C2 are integrated. The antenna is printed on a 32 mm $\times$ 35 mm FR-4 substrate with a dielectric constant of 4.3 and height of 1.6 mm.

Before going into details, it is important to mention that the activation and deactivation of a resonator or SRR, in this paper, refer to closing and opening, respectively, ideal switches disposed on these resonators. These switches are modeled by the presence and absence of a conductor. The varactors, in this work, are modeled by different value lumped capacitors.

Also, in what's coming, bandpass and bandstop modes are used in the same way as in [8, 10]. Bandpass mode designates a mode where the resonator acts as a bandpass filter, passing frequencies corresponding to roughly $\lambda/2$ and blocking the remaining frequencies. Bandstop mode corresponds to a mode where the resonator blocks frequencies corresponding to roughly $\lambda/4$ and lets other frequencies pass.

Now, by going into the details, when switches S1 and S2 are closed and all the remaining switches are open, then the proposed antenna acts as a classical AVA which is known to be UWB, and the operating band considered at -6 dB extents from 2.2 to 12 GHz.

To operate the antenna in the 3-sub mode, switches S1, S2 and either S7, S8 or S9 are closed; all the remaining switches are open. The closing of S7, S8 or S9 will connect the strip resonators R1, R2 or R3 to the AVA wing to act as filters having a very low Q. By closing S7, resonator R1 acts as a bandstop filter to block high frequencies, and the antenna will operate at low frequencies. By closing S9, R3 acts also as a bandstop filter but to block low frequencies causing the antenna to operate at the high frequencies. By closing S8, R2 acts as a bandpass filter to let a wide frequency band (low Q) centered around the frequency whose half wavelength is equal to the resonator length

To increase the frequency selectivity of the antenna and operate it in the 7-sub mode, two resonators are simultaneously activated. Switches S1, S2, S9 and S10 are closed; all the remaining switches are open. To translate the operating band, the electrical length of resonators R3 and R4 must be varied. This can be done by using either varactors to vary the electrical lengths or switches to vary the physical lengths. For simplicity, the band translation in this work is realized by considering different physical lengths regardless of the type of switching. The lowest band in this 7-sub mode is obtained by using R1 as a bandpass filter and R4 as a bandstop one. For the six remaining sub-bands, R3 and R4 are used as bandpass filters at the same frequency band.

In order to further increase the frequency selectivity of the antenna and operate it in the 16-sub mode, two rectangular split-ring resonators (SRR) are disposed close to the feedline of the AVA as shown in Figure 1. By opening switches S1 and S2 and closing either the pair S3-S4 or S5-S6, the electromagnetic waves arriving at the 0.4 mm gap, either from the wings in case of reception or from the port in case of transmission, will be coupled to one of the two SRRs before being coupled again to the other side of the gap causing the antenna to operate at frequencies whose quarter wavelength is equal to the active SRR. The other switches in this case are open. The property of this "bridge-coupling" operation is that it is very selective in frequency which gives very narrow operating bands.

3. NUMERICAL RESULTS

The design and parameter optimization of the proposed antenna have been done using CST software package. Table 1 gives information about the resonator configurations of the antenna in different resonator modes.

Table 1. Resonators configuration: A) UWB. b) 3-sub mode. C) 7-sub mode. d) 16-sub mode.

A): S1, S2 closed

UWB
All switches S3 to S10 open

B): S1, S2 closed — S3, S4, S5, S6, and S10 open

Band 1	Band 2	Band 3
L1 = 14 mm	L2 = 14.5 mm	L3 = 10.5 mm
S7 closed — S8, S9 open	S8 closed — S7, S9 open	S9 closed — S7, S8 open

C): S1, S2 closed — S3, S4, S5, S6, and S8 open

Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
L1 = 22 mm	L3 = 6 mm	L3 = 4.5 mm	L3 = L4	L3 = L4	L3 = L4	L3 = L4
L4 = 8.2 mm	L4 = 16 mm	L4 = 15 mm	15 mm	12.5 mm	10.5 mm	9.5 mm
S7, S10 closed	S9, S10 closed	S9, S10 closed	S9, S10 closed	S9, S10 closed	S9, S10 closed	S9, S10 closed

D): S1, S2, S7, S8, S9, and S10 open

Band 1 to band 9	Band 10 to band 16
C2 = 0.01 to 6 pF	C1= 0.035 to 4 pF
S5, S6 closed — S3, S4 open	S3, S4 closed — S5, S6 open

As can be seen from Figure 2, the antenna does have the possibility to cover the BoI by four different bandwidth-resolutions.

The in-band and out-of-band surface currents are given in Figure 3.

As can be noted from Figure 3(a), at the operating frequencies of the antenna in the NB mode, the current at the active SRR is dense which proves that all the radiated electromagnetic waves transit

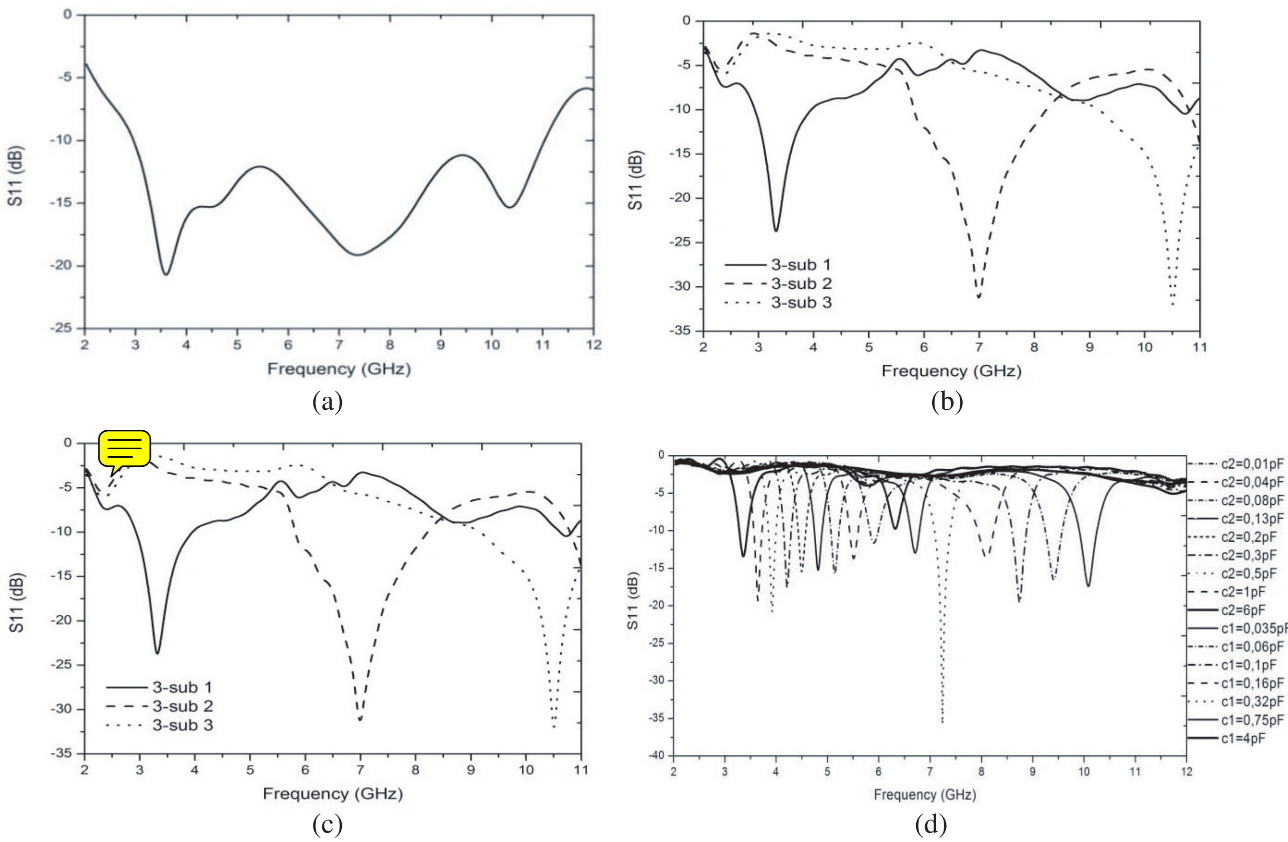


Figure 2. Simulated S11 of the antenna. (a) UWB. (b) 3-sub mode. (c) 7-sub mode. (d) 16-sub mode.

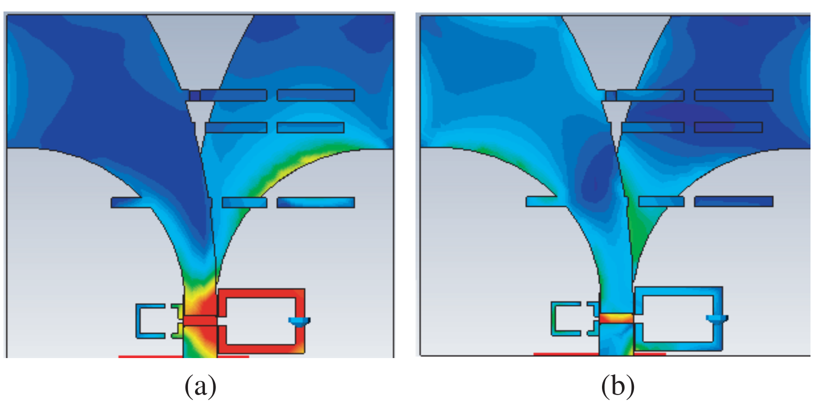


Figure 3. Surface current of antenna in 16-sub mode: (a) $f = 5.8\,\text{GHz}$. (b) $f = 9\,\text{GHz}$.

through this resonator. However, at frequencies falling outside the operating band, the current at the active SRR is very weak, and the antenna is not operating (Figure 3(b)).

To evaluate the filtering effect of the proposed frequency reconfiguration, 3D realized gain is computed in all the operating modes. Figure 4 gives a selection of gain curves in the sub modes and compared with the one achieved in the UWB mode.

As can be noted from Figure 4, the switching from the UWB mode to one of the sub-bands modes gives roughly the same gain in the operating band while providing out-of-band suppression to 8 dB in some frequencies.

The simulated radiation patterns in the UWB mode, 3-sub, 7-sub and 16-sub modes are provided at

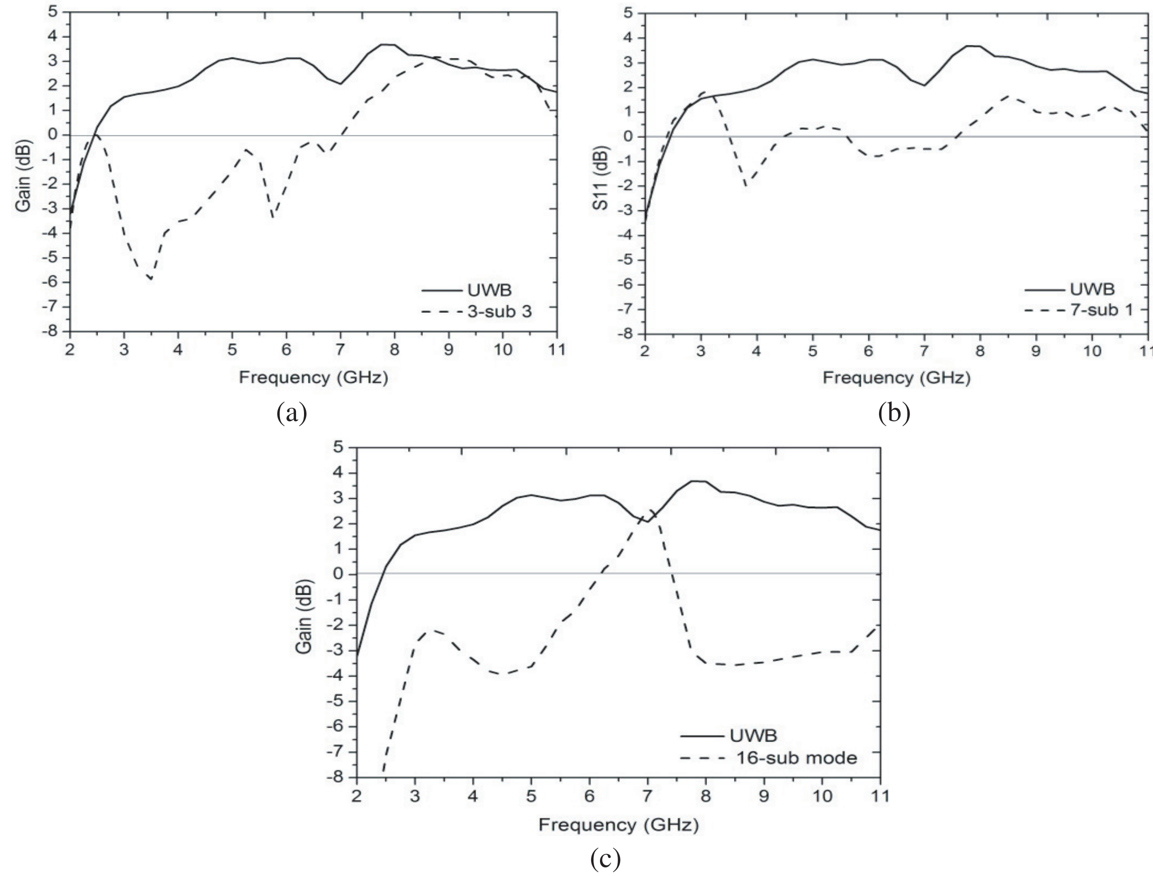


Figure 4. Superposition of the 3D realized gain of the antenna in the UWB mode with the different operating modes. (a) 3-sub mode. (b) 7-sub mode. (c) 16-sub mode for C1 = 32 pF.

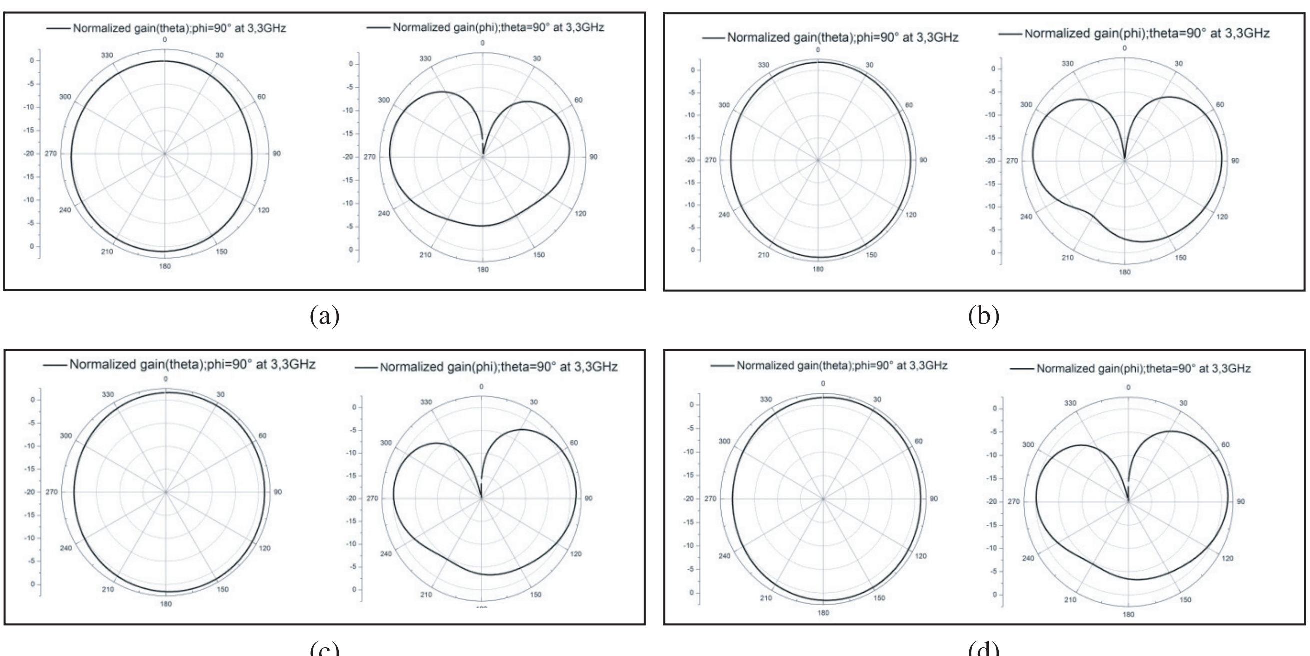
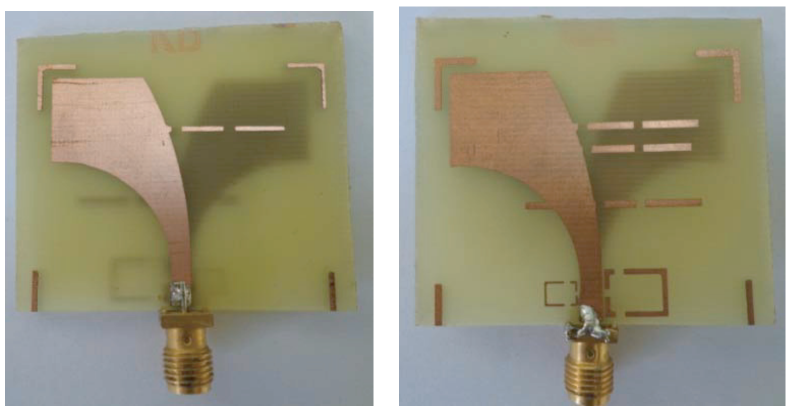


Figure 5. Radiation pattern excited at 3.3 GHz. (a) UWB mode. (c) 7-sub mode. (d) 16-sub mode.

an arbitrary frequency of 3.3 GHz. The obtained results are given in Figure 5. As can be seen from this figure, the reconfiguration does not considerably affect the radiation patterns in the three modes comparatively to the UWB mode. This result is predictable since the resonators incorporated in the antenna do not contribute to the radiation but are involved in blocking frequencies.

4. IMPLEMENTATION USING IDEAL SWITCHES AND LUMPED ELEMENTS

To validate the proposed approach to develop an antenna capable of covering the BoI by four different bandwidth-resolutions, four different prototypes, one for each mode, implemented with ideal switches and lumped capacitor elements are fabricated. Photographs of the antenna in the UWB mode are given in Figure 6.

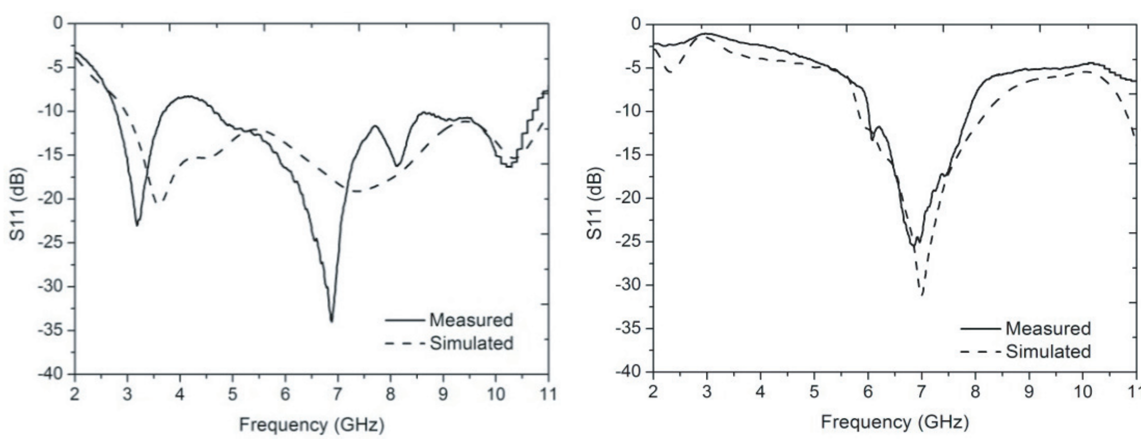


Top view Bottom view

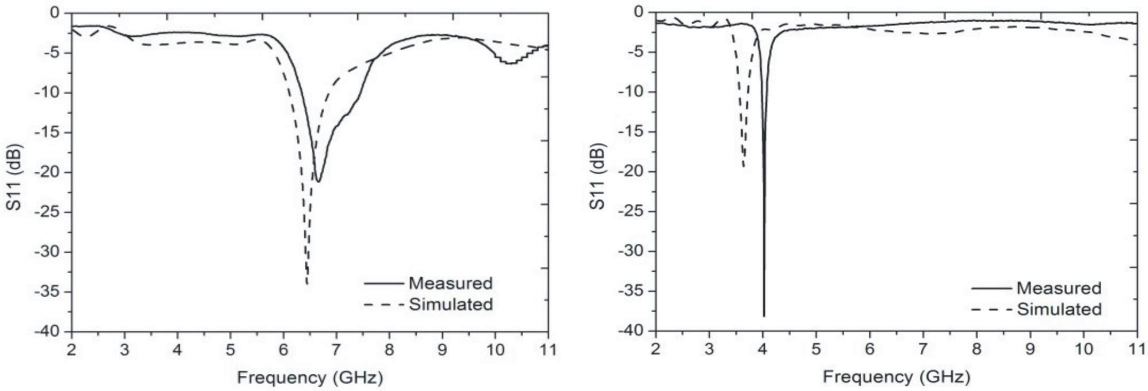
Figure 6. Photograph of a realized prototype antenna in UWB mode.

The measured results superimposed to the simulated ones are given in Figure 7.

As can be noticed from Figure 7, the multi-resolution behavior of the antenna is well demonstrated. The small discrepancies between simulations and measurements are believed to be very acceptable; the frequency shift in Figure 7(d) is because in simulations, the lumped capacitor element has been taken to be a pure capacitor.



(a) (b)



(c) (d)

Figure 7. Measured and simulated S11 in different modes. (a) UWB mode, (b) 3-sub 2, (c) 7-sub 4, (d) 16-sub mode for C2 = 1 pF.

5. IMPLEMENTATION USING REAL SWITCHES AND LUMPED ELEMENTS

To validate the use of real switches to achieve frequency reconfiguration, a prototype is fabricated to implement the switching from UWB mode to 3-sub mode. However, to simplify the implementation, the operating frequencies of the prototype are shifted to lower frequencies in order to handle the soldering more easily. To be able to operate the antenna in UWB mode or in one of three sub-bands, six BAR50-02V PIN diode switches are integrated to the resonators. To be able to bias the PIN diodes, 0.5 mm

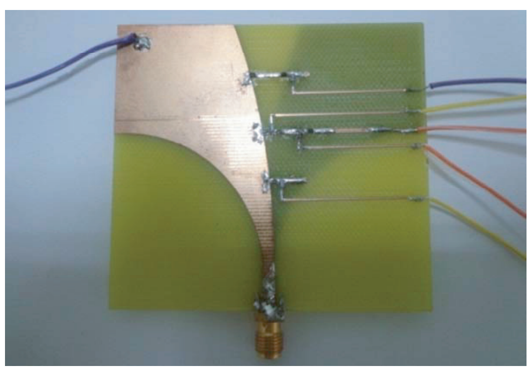
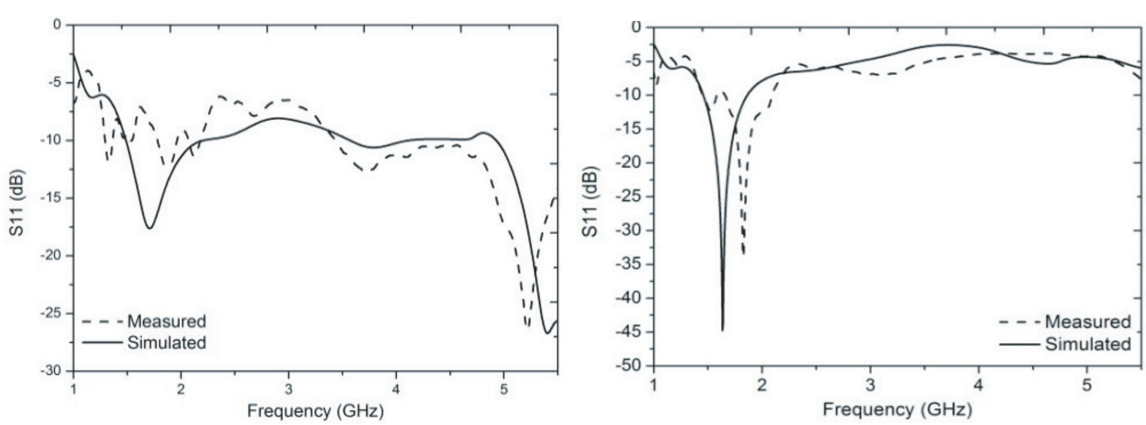
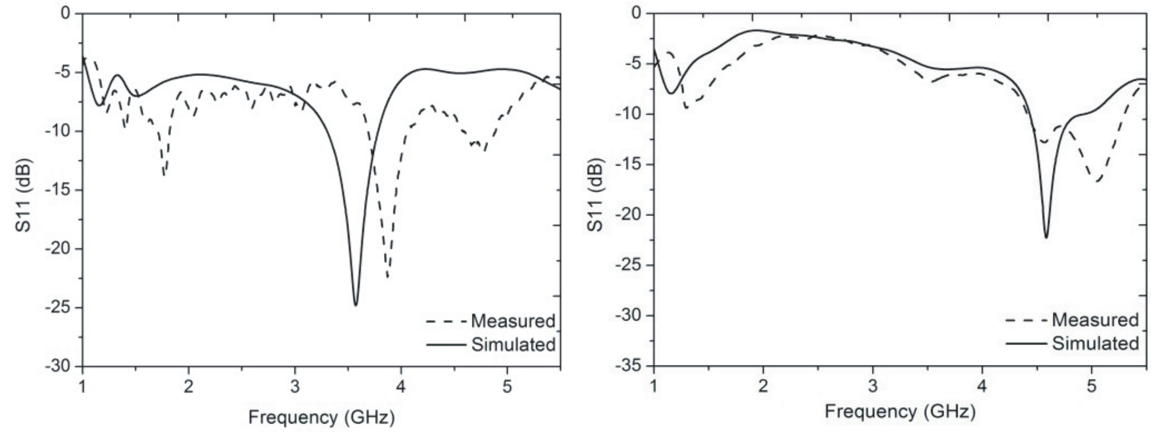


Figure 8. Photograph of realized antenna.



(a) (b)



(c) (d)

Figure 9. Simulated and measured S11 of antenna in UWB and 3-sub bands mode. (a) UWB mode, (b) 3-sub 1, (c) 3-sub 2, (d) 3-sub 3.

width lines are used to provide DC voltage; RF chokesare used to isolate the DC biasing part from the RF part. A photograph of the prototype with real switches is given in Figure 8.

The obtained measured results are superposed to the simulated ones and are provided in Figure 9.

As can be seen from Figure 9, by turning different switches ON and OFF, the antenna does have the capability to cover an ultra-wide band (UWB) and three sub-bands. The discrepancies between simulations and measurements are believed to be acceptable, which validates the use of PIN-diode switches to achieve frequency reconfiguration.

6. CONCLUSION

A four-resolution frequency reconfigurable antenna is presented. The antenna is capable of covering the frequency range 3–10.6 GHz in one, three, seven, or sixteen sub-bands, which allows its working in any part of the considered band with a choice of four different bandwidths. It is believed that this type of multi-resolution antennas can be a good candidate for cognitive radios.

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Errata to "A Four Bandwidth-Resolution UWB Antipodal Vivaldi Antenna" by Mounira Bitchikh and Farid Ghanem in Progress In Electromagnetics Research M, Vol. 53, 121–129, 2017

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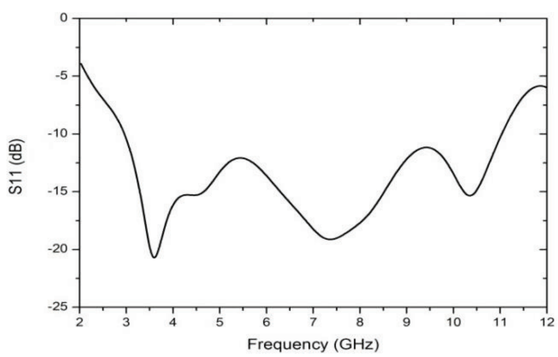
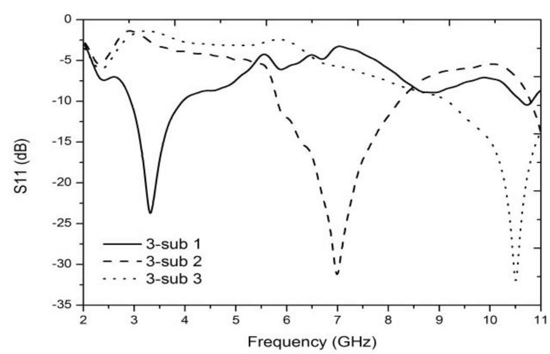
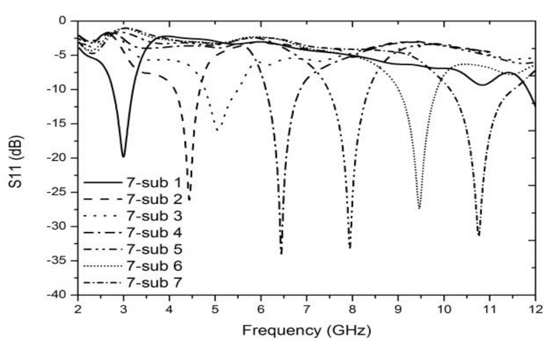
1- Erratum Figure 2:



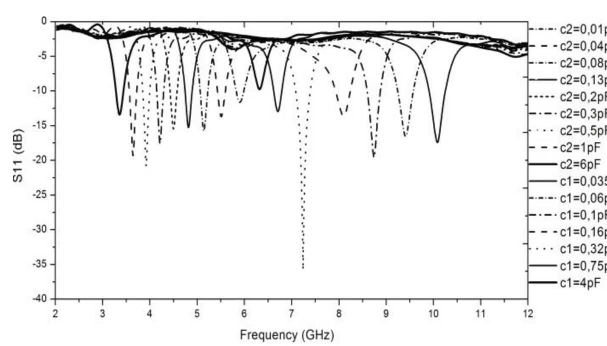
(a)



(b)



(c)



(d)

Figure 2. Simulated S_{11} of the antenna. a) UWB. b) 3-sub mode. c) 7-sub mode. d) 16-sub mode.

2- Erratum Figure 5:

Figure 5. Radiation pattern excited at 3.3 GHz. (a) UWB mode. (b) 3-sub mode. (c) 7-sub mode. (d) 16-sub mode.

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