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Electrical Reconfiguration Techniques for Frequency Agility in Patch Antennas

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Abstract**:** ***Wireless Systems are subjected to overwhelming advancements with the exponential demands in the field of Communication. This has led to the evolution of Reconfigurable antennas which gained enough significance as they are capable of modifying them.selves to different operating frequencies, patterns or polarizations. Out of these, Frequency Reconfigurable Antennas which can be operated at multi-frequency environment have been found to have a wide range of applications. The reconfiguration can be achieved using various switching mechanisms like, electrical, optical, etc. These are found to support various communication standards, ensure effective utilization of spectrum, reduce system complexity and hence cost. The recent researches on frequency reconfigurable antennas using electrical switches are analyzed in this paper based on their performances and a comparison on various switching techniques is presented.***

Keywords: Biasing networks, cognitive radio, electrical reconfiguration, reconfiguration.

I. INTRODUCTION

As the number of wireless devices used worldwide increases in an aggressive manner, reconfigurable antennas become highly focused. These are able to reconfigure themselves in terms of the antenna characteristics like resonant frequency, radiation pattern, polarization or even combinations of the characteristics above mentioned [1]. Antennas that are reconfigured in terms of their resonant or operating frequency, called Frequency Reconfigurable Antennas are considered to be the most beneficial as they are able to function over a number of frequency bands with varying bandwidths. Such antennas are found to be extensively used in MIMO techniques, satellites, smart antennas, cognitive radio systems, etc. The construction of Reconfigurable antennas is based upon four different techniques. Electrical Reconfiguration Technique, is making use of the electronic switching components, MEMS [2]-[11], PIN diodes [12]-[23], varactors [24]-[32] and FET Switches [33]-[36].

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The switching states of the above-mentioned electronic switches decide, to which direction the surface currents must be directed and thus affect the radiating nature of the antenna.

Whereas, the Optical Reconfiguration Technique is using photoconductive switching components to attain reconfiguration of the antenna characteristics. [37]. The third one, Physical Reconfiguration Technique is solely based on the structural alterations done on the antenna radiators [38]-[39]. The last technique depends on the usage of smart materials like ferrites and liquid crystals [40]-[41]. Among the above four techniques, most of the researches are carried out with Electrical Reconfiguration Technique due to the easier integration of switches, less complexity of designing, availability of switches, better isolation, less losses, etc.As Frequency Reconfigurable structures handle an inevitable place in communication techniques, the recent researches on such antennas with the widely used Electrical Reconfiguration Technique is surveyed and analyzed in this paper. The reconfiguration using various electronic switching components and the comparison of switching components as reconfigurable elements are presented in the subsequent sections. Finally, the conclusion is discussed.

II. RECONFIGURATION USING VARIOUS ELECTRONIC SWITCHING COMPONENTS

The electronic switching components used to achieve frequency reconfiguration in antennas can be enlisted as MEMS switches, PIN, Varactor diodes and FET switches.

A. Reconfiguration with MEMS

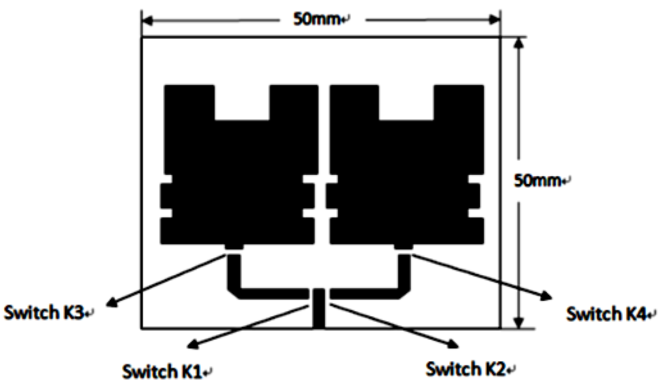

Fig. 1. Frequency reconfigurable antenna modified by Fractal Technology [2]

In [2], it reports a reconfigurable ultrawideband microstrip antenna with MEMS Switches and the fractal technique used to improve the bandwidth and the radiation properties of the design.

Four MEMS switches were used to vary the current distribution. The antenna realizes frequency reconfiguration in the frequency bands, 7.6 to 7.75GHz, 6.8 to 6.95GHz and 9.01to 9.8GHz. Comparing to the two MEMS switches design with the four switches design discussed in the same work, it could be found out that the operable bands increase as switches increase in number. And as the antenna was inefficient to work in low frequencies, fractal technology is implemented. Widening of bandwidth is achieved by modifying this antenna using fractal technology.

The effective length and hence the surface current path are improved using meander line structures in fractal technology [3]. Antenna with four switches modified using fractal technology is shown in the Fig. 1. This has caused an improvement in the bandwidth as well as in the gain. This modification enables the antenna to operate at L, C and X bands which was only limited to C and X bands when the fractal technology was not involved. The gain becomes more than 4.85 dB and the design exhibits fine radiation characteristics.

Another antenna reported in [4] is able to keep up right hand circular polarization satisfying the 3-dB axial ratio criterion while undergoing frequency reconfiguration at 4.8 GHz and 7.6 GHz. Here, six MEMS switches are employed between a diagonally fed center patch and outer patch that are responsible to control the surface current and hence the band of operation. The operating frequency increases with number of switches during their ON state. And for the switches in the OFF state, resonant frequency seems to be unaffected by the number of switches. Fig. 2 shows the frequency ratio at the ON and OFF states of the switch is decreasing with increase in the switches' number.

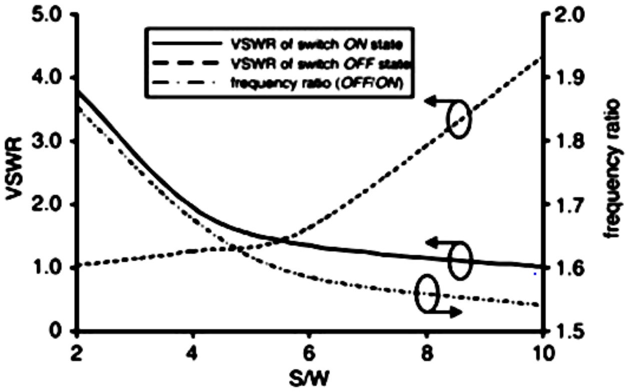

Fig. 2. VSWR and frequency ratio of switch [4]

B. Reconfiguration with PIN diodes

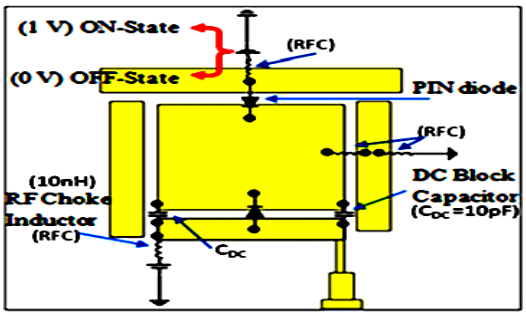

Fig. 3. Antenna Layout with Biasing circuit [12]

A multiband compact frequency reconfigurable antenna that uses PIN diodes is reported in [12]. The introduction of biasing circuits makes the design complicated as it requires vias and bias lines. The biasing circuit is integrated into the antenna plane in this work. No vias are involved in this design so as to avoid circuit complexity. The design layout is presented in Fig. 3. Two PIN diodes are used to obtain four switching configurations. Simulated and measured reflection coefficients of Configuration 1 (Both diodes OFF), Configuration 2 (First diode OFF, Second diode ON), Configuration 3 (First diode ON, Second diode OFF) and Configuration 4 (Both diodes ON) are seem to be matching. The antenna is tuned over the range 2.2 to 6 GHz which makes the antenna capable of WLAN and WiMAX applications.Another frequency reconfigurable circular patch antenna with ground surface consists of integrated biasing circuitry so as to simplify the biasing methodology is presented in [13]. 3 PIN diodes are employed to vary the slot dimensions and hence attains the frequency reconfiguration. In the fabrication, along with the PIN diodes, capacitors are used to block the DC to ensure the accuracy and certainty of the experiment.

C. Reconfiguration with Varactors

A planar double inverted F antenna is reported in [24]. The radiator and the ground surface are connected by a varactor diode is integrated in between the radiator and the floating ground plane to provide frequency reconfigurability for cognitive radio applications. A defective floating ground is employed at the back of the structure. When coupled with this plane, the effective permittivity of antenna sections varies, the electrical length of the radiator increases, and the antenna size reduces. When the supplied reverse bias varies, the frequencies could be found to alter from 700 MHz and 1975 MHz to 1450 MHz and 2800 MHz respectively. Fig. 4 presents the antenna prototype.

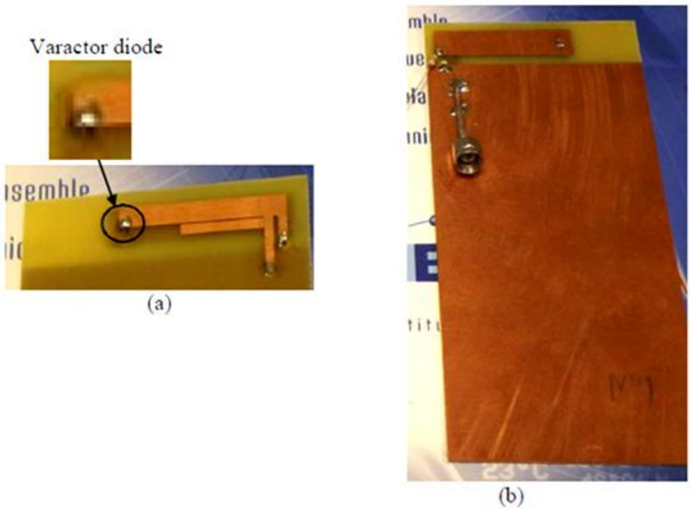

Fig. 4. The Antenna views (a) Front (b) Back [24]

A miniaturized reconfigurable slot antenna is presented in [25], that achieves reconfigurability using four varactor diodes and found its applications in cognitive radio. The frequency reconfiguration is achieved in such a way that the electrical length of the resonant slot is varied by incorporating varactor diodes within the slot.

This antenna offers a tuning range of 40.5 % within the operable band 1.83 GHz to 2.76 GHz. Along with, it provides a stable radiation pattern.

D. Reconfiguration with FET Switches

An antenna structure that uses a single Gallium Arsenide Field Effect Transistor (GaAs FET) Switch to achieve frequency reconfiguration is reported in [33]. No bias networks and blocking capacitors are used in this structure. The switch is activated by a digital signal. As the switching states changes, the design shifts in between narrow and dual band states with ease. Two strips are provided at the sides of the feed line in order to overcome the existence of some higher frequency bands. It could be seen that, in the absence of these strips, independent of the switching status, these unexpected bands appear. The top and bottom views of the design is presented in Fig. 5. The reflection coefficients, both simulated and measured can be seen in Fig. 6. Fig. 6 (a) is at the ON state, and Fig. 6 (b) is at the OFF state of the switch.

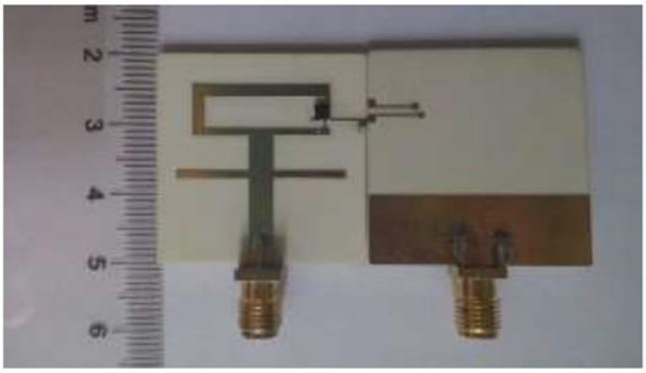

Fig. 5. The top and bottom surfaces of the antenna [33]

A Ultrawideband reconfigurable structure is discussed [34]. Three prototypes are discussed where the first two use PIN diodes for reconfiguration and the third uses FET switches replacing PIN diodes. Comparing to the first two, the third prototype is the simplest as the adverse effects of biasing are less on the antenna characteristics like gain, pattern, efficiency and return loss. As in the case of prototypes with PIN diodes, RF chokes are not needed in the biasing lines of prototype 3. This happens so, as the control mechanism of DC of FET switches and PIN diode switches are different.

A Q-band (Q-LINKPAN: 40.5 GHz - 50.2 GHz) antenna in which frequency reconfiguration is achieved by two on-chip N-Type FET Switches is reported in [35]. As the substrate used is Silicon with high resistivity, gain of the antenna is improved. The System-on-Chip (SoC) technology used here makes it a prominent candidate in millimeter wave communications. As the states of the on-chip switches changed, an operable band from 29.5 to 51 GHz could be realized that is covering the entire Q-band.

A reconfigurable matching network to attain frequency reconfiguration in an RFID patch antenna is presented in [36]. Other electronic switching mechanisms are not being used by UHF RFID antennas as the high power delivered by RF front end causes high voltage to pass through the feeding section as well as the antenna that leads to non-linearity and increased complexity in the design realization. The antenna size can be reduced with the introduction of four capacitors into the design to get an aperture loading effect. Fig. 7 shows the antenna design. Matching could be found in the band 865 to 868 MHz and in the band 902 to 928 MHz.

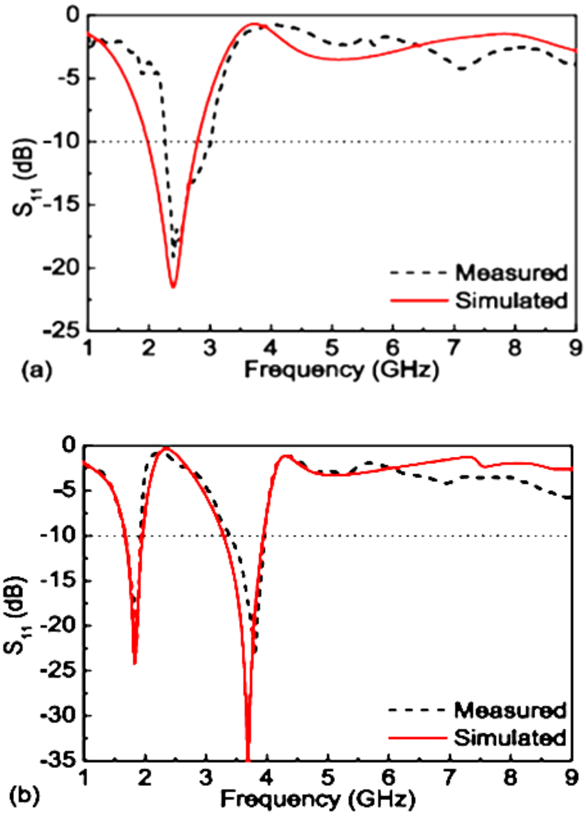

Fig. 6. The reflection coefficient plots (a) one band (b) two bands [33]

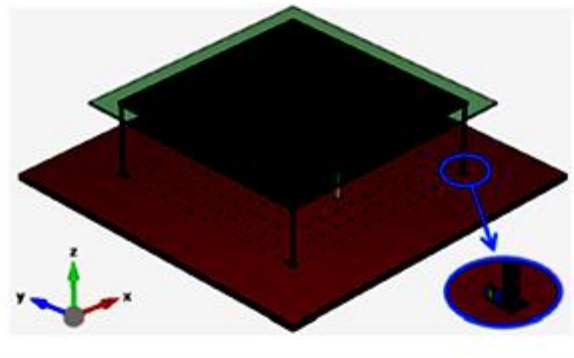

Fig. 7. The antenna structure [36]

III. COMPARISON OF VARIOUS ELECTRONIC SWITCHING COMPONENTS AS RECONFIGURABLE ELEMENTS

Among the reconfiguration techniques in antennas like electrical, physical, optical and the usage of smart materials, electrical reconfiguration has become the most prominent one particularly with the usage of RF MEMS switches. The lower consumption of power, less losses associated with the insertion and higher Q factor make antennas that use MEMS switches surpass those uses transistors and diodes as switches [4],[7],[8],[10]-[11],[27]. Insertion loss is found to be very small of order 0.16 dB [8]. MEMS switches are desirable when switching is demanded over an excessively wide frequency band [5].

Along with reconfigurable antennas, these switches are better opted at devices working in microwave and millimeter wave ranges of frequencies such as, tunable filter resonators, phase shifters, Radar, GPS etc. [5],[6],[8]. MEMS switches provide better RF isolation, linearity, good impedance matching and are comparatively cheaper in terms of expense [7],[8],[10],[33]. Being mechanical switches, MEMS exhibit excellent linearity [9],[10],[11]. The introduction of MEMS switches provides more bandwidth, nearly the double of original patch design [10].

MEMS switches are limited in terms of packaging of the switches, reliability and power handling abilities [5]. In MEMS switches, the responses are slow and the tunable range is low comparing to that of PIN diodes and varactors. Whereas, comparing to the discrete components' integration into the antenna design, monolithic fabrication of antenna and switches together minimizes the losses and parasitic effects [11]. MEMS switches require complex matching networks [29]. They need additional voltage up converter chips of 30 to 90 V if used in portable communication devices. The process of assembling these switches into the PCB is reportedly difficult. The high voltage requirement for activation is another disadvantage of MEMS Switches which makes those less reliable [10],[33].

The most common switching technique is the usage of PIN diodes due to the affordability, excellent power handling capability, scalability, prolonged lifetime, simple control, compactness, fabrication easiness for optimal results, higher switching speed of nanoseconds order and reliability [9],[10],[12],[27],[29],[33]. As the control current is varied in between the HIGH and LOW states, these diodes facilitate switching, pulse modulation, shifting of phases and attenuation of radio frequency signals [14]. PIN diodes are used for discrete tuning [16].

The disadvantage of PIN switches is its non-linearity, less isolation, high power loss and high insertion loss [9],[10],[33]. The insertion loss was found to be in between 0.4 to 0.7 dB [15]. PIN diodes when increased in number, the biasing circuitry becomes complicated and insertion loss considerably increases [20]. On the contrary, practically the losses and isolation are not of considerable difference between PIN diodes and MEMS [9].

Varactors are of fast switching speed with scalability and can be easily integrated into the antennas due to the small size [10]. Varactors are used for fine, fast and easier tuning and provides broader tuning range [16],[27],[29]. These are compact and easily available with less cost. As varactor diode switches are operated on reverse bias voltages, less current only needed compared to PIN diode and MEMS switches for activation and hence the power consumption is less for these [29]. A minimum number of varactor switches can provide multiple modes with more flexibility [29],[32].

The drawbacks of varactors are nonlinearity and high voltage requirement [10].

GaAs FET switches exhibit high switching speed, good isolation, less insertion loss, less size, less power consumption, easier integration of the antenna into the communication networks, less assembly cost and low ON resistance [33],[34]. FET switches, unlike PIN diodes, do not need RF chokes in the biasing networks [34]. As the biasing technique is simpler, the FET switches exhibit no adverse effects in pattern, gain, efficiency and pattern of the antenna. CMOS switches exhibit high power handling capabilities, easier integration into the antenna design, easier controlling. Even in high voltages, CMOS switches exhibit linearity. But, only a smaller number of tuning states are possible to obtain with these switches [36].

Generally, the installation of electrical switching components within antenna structures increases the circuit intricacy and associated losses are added up as these switches are using biasing lines for activation and the pattern is adversely affected [10]. At this point, some designs that are least affected with this issue are also to be considered. DC bias lines are not needed due to the novel geometry that uses MEMS switch in many recently reported works. It results in easier fabrication and improved radiations as there is no leakage loss or coupling loss with the bias lines. Biasing circuit is integrated into antenna plane for PIN diodes without any vias, which in turn reduce losses associated with bas lines [12]. Whereas, only three DC wires were used to control six PIN diode switches to reduce the losses in [18]. FET switches can be activated by digital signal with no need of DC bias and biasing networks [33].

IV. CONCLUSION

A detailed analysis about different types of Electrical Reconfiguration techniques is presented in this paper. Different switching schemes used up to attain frequency reconfiguration is considered. MEMS, PIN, Varactors and FET switches are enlisted as different electrical switches to design reconfigurable structures. A performance analysis of such switches in various frequency reconfigurable antenna structures is done in this paper. The scope of these radiating systems extends to MIMO systems, Cognitive Radio, Satellite communication, etc.

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