

Review: Design Aspects of Reconfigurable Antenna

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ABSTRACT: The study of reconfigurable antennas has made great progress in recent research. Compared with conventional antennas, reconfigurable antennas have more advantages and better prospects. They are lighter in weight, smaller in dimension and lower in price. Moreover, the reconfigurable antennas can provide diversity feature of operating resonant frequency, polarization, and radiation pattern. Reconfigurable antenna are analyzed and summarized in this paper to present the characteristics, classifications and reconfigurable techniques. Reconfigurable antenna implementation can be differentiated into three main processes: Antenna design, simulation, and optimization. The aim of this paper is to present approach into the antenna designing that must be made to employ a reconfigurable antenna, serving as information for future reconfigurable antenna designers as to what requirements to be done before a model is constructed, such as choosing a suitable antenna structure and reconfiguration technology.

KEYWORDS: reconfigurable antenna, antenna designs, photoconductive switches, PIN diodes, varactor, polarization, radiation pattern, radiofrequency microelectro mechanical systems (RF-MEMS).

I. INTRODUCTION

Static single antenna structures can be tailored to fit specific requirements; such as operating frequency, radiation pattern, directivity, bandwidth etc, which keeping other factor (efficiency, return loss, input impedance, gain etc) at desired operating levels. However when a few of the specified requirements are altered, even by a slight margin, the designed antenna structure can be rendered useless. In current modern day applications, where adaptability and versatility have become key factors in antenna design, static single antenna structures are no longer an option. For this reason, low cost implementation with advanced simulation environments, reconfigurable antennas has been gaining enormous popularity over the years. The concept of reconfigurable antenna initially came into sight in D.Schaubert's patent "Frequency-Agile, Polarization Diverse Microstrip Antenna and Frequency Scanned Arrays" in 1983 [2]. In 1999, 12 well-known universities, research institutes and companies in the United States participate in the project of "Reconfigurable Aperture Program (RECAP)", commenced by the United States Defense Advanced Research Projects Agency (DARPA) [1].

The reconfigurable features of the antenna structure can be realized through changing its polarisation, frequency, or radiation characteristics. This change is achieved by various methods that redistribute the antenna currents and hence alter the electromagnetic fields of the antenna's effective aperture, implementing antenna arrays, changing feeding methods, etc. The choice of reconfiguration method is directly tied to the design requirements and desired performance level. Reconfigurable antennas can deal with complex system requirements by altering their geometry and electrical behavior, thereby adapting to changes in environmental conditions or system requirements (i.e., improved bandwidth, modifies in operating frequency, polarization, and radiation pattern).

Reconfigurability has become an important and desired feature of modern, agile, radio-frequency (RF) systems for wireless and satellite communications, sensing, and imaging. There is a shift toward integrating smart, cognitive, and agile RF devices that can both sense the surrounding RF environment and communicate at the same time in any contested/congested environment. The new desired capabilities include frequency agile, software defined, and cognitive radios to deal with expandable and reconfigurable multiservice, multistandard,

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and multiband operation, as well as with efficient spectrum and power utilization. These concepts can significantly reduce the number of components and thus hardware complexity, and cost compared to today's radio technology, which relies on incompatible communications systems with inflexible hardware. The major important aspects of reconfigurable antenna implementation are: design, simulation and optimization. The paper is intended to provide study of an overview of Design.

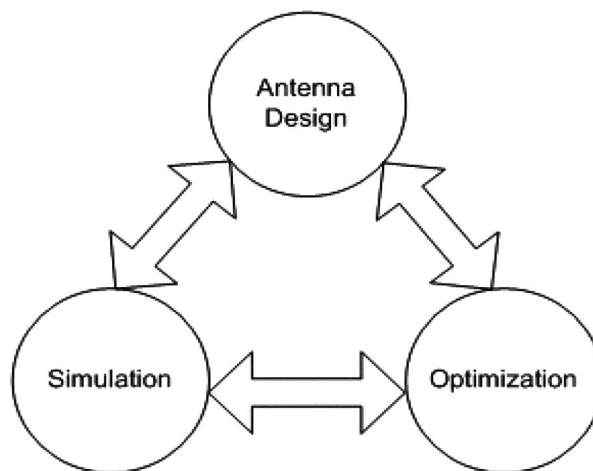


Fig 1. Major aspects of Reconfigurable antenna implementation.

II. ANTENNA DESIGN

An integral step in the implementation process is selection of an appropriate antenna design. Prior to selection of antenna design, a number of factors must be taken into consideration, for example the system performance requirements (substrate, minimum efficiency, operating frequency, power consumption, directivity, bandwidth, etc) and also other constraints like antenna size, cost, fabrication capabilities etc. For selection of the antenna structure of static single antenna design these factors need only be considered once. While for reconfigurable antenna, these factors must be judged at least twice; once for selection of the antenna structure, and another for the reconfigurable technology that is to be used. In reality, the system performance parameters should be considered each time the reconfigurable antenna switches from one reconfigurable state to the next, so the antenna design works optimally for all possible reconfiguration.

III. ANTENNA STRUCTURE

An antenna structure can take many shapes and sizes, according to the established design requirements. For this work, the important parameters to be consider will be low cost, small size, low profile, ease of fabrication and ability to reconfigure and additional benefits.

High power, high gain parabolic antennas can be automatically discarded because of size as it is ranges from medium size to very. They have high profile, are very expensive, and not easy to fabricate. For an antenna design where directivity was of the utmost importance, this antenna structure would be given serious consideration. However, given the design requirements, using this antenna structure would not be the best option .Other types of antennas that suffer from high profile and poor aerodynamics are wire antennas and horn antennas so these can be discarded as well.

An antenna structure who has received importance for its versatility in a vast number of applications is the microstrip antenna, also known as patch antenna. Microstrip antenna can make in very small size and having a low profile, making them attractive for mobile and portable application, are low cost and easy to manufacture and can be designed using different geometries (rectangular, circular, dipole etc) to confirm to several performance requirement.

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Due to their small sizes, they are also used in arrays when spacing is limited and can be designed to adapt to different radiation patterns, directivity, polarisation impedance, operating frequency etc. making them an optimal choice for reconfigurable antenna structure as mentioned [3]. Microstrip antennas have been known to suffer from some disadvantages such as low power, efficiency, and narrow bandwidth etc.

But with careful consideration during the design process, most of these undesired characteristics can be avoided. For instance, changing the height of the substrate can improve efficiency and expand the bandwidth. Bandwidth and directivity can also be improved when microstrip antennas are designed for arrays. Work presented in [4] shows how the gain and efficiency of an array antenna can be improved by changing the feeding technique. It is for all these reasons that the best possible choice for the reconfigurable antenna structure in this work is a microstrip array.

IV. THE FUNCTIONS OF RECONFIGURABLE ANTENNA

The reconfiguration techniques depend on performance parameter which should be either altered or remain fixed.

A. Frequency Reconfigurable Antenna

This feature of antenna reconfiguration is achieved by the reconfiguration of the resonant frequency by the change of the structure, while the radiation patterns and polarization remain unchanged. Hence, frequency reconfigurable antenna can be applied within a very wide arrangement of frequency band or within multiple frequency bands. This is attained by producing some tuning or notch in the antenna reflection coefficient.

B. Radiation Patterns Reconfigurable Antenna

This feature of antenna reconfiguration is achieved by the change of the structure, whereas the resonant frequency and polarization remain unchanged. For this category, the antenna radiation pattern changes in form of shape, direction, or gain.

C. Polarization Reconfigurable Antenna

A radiating structure that can change its polarization (horizontal/vertical, \pm slant 45° , right hand or left hand circular polarized, etc) is called polarization reconfigurable antenna while keeping operating frequency unchanged.

D. The Multiple Reconfigurable Parameters of the Antenna

The most significant feature of this antenna is that two or more parameters include resonant frequency, radiation patterns and polarization of the antenna can be reconfigurable. This trait is very useful to achieve diversity.

The corresponding reconfigurability for each of the four categories can be obtained by altering in the feeding network, redistribution of antenna surface current, a change in the antenna physical structure, or varying in the antenna radiating edges. It is essential to note that the change in one parameter in the antenna characteristics can affect the other parameters. Therefore, designer should be careful during the design process to analyze all the antenna characteristics to achieve the required reconfigurability.

V. RECONFIGURATION TECHNIQUES

Six main types of reconfiguration techniques are used to implement reconfigurable antennas, as indicated in Fig. 2. Antennas based on radio frequency microelectro mechanical systems (RF-MEMS) [5]–[10], PIN diodes [11]–[21], and varactors [22]–[27] to redirect their surface currents are called electrically reconfigurable antenna. Antennas that depend on photoconductive switching elements are called optically reconfigurable antennas [28]–[32]. By altering the structure of the antenna, physically reconfigurable antennas can be attained [34]–[37]. By using smart materials such as ferrites and liquid crystals [38]–[41], reconfigurable antennas can be implemented.

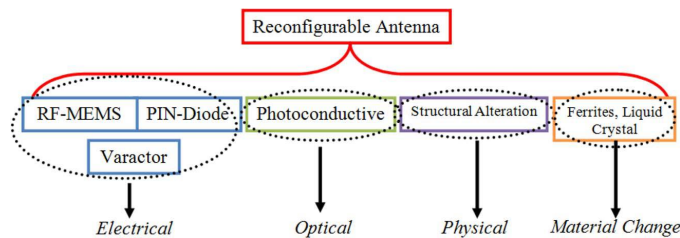


Fig. 2. Different types of techniques to achieve reconfigurable antennas.

VI. ELECTRICALLY RECONFIGURABLE ANTENNAS

An electrically reconfigurable antenna depends on electronic switching components (RF-MEMS, varactors, or PIN diodes) to change distribution of surface currents, and change the antenna radiating structure topology and/or radiating edges. The integration of switches into the antenna structure makes it easier for designers to reach the desired reconfigurable functionality in spite of numerous issues like the nonlinearity effects of switches, and the interference, losses, and negative effect of the biasing lines used to control the state of the switching components on the antenna radiation pattern.

Three different examples of electrically reconfigurable antennas are described.

A. Reconfigurable Antennas Based on RF-MEMS

Compared with PIN diodes and MESFET switches, MEMS switches are lower in on-resistance, parasitic capacitance, and insertion loss, higher in disconnect isolation and smaller in dimension. Because of these advantages, MEMS switches can be widely applied in reconfigurable antenna designs. In Fig.3, a reconfigurable single-arm scan-beam spiral antenna integrated with RF-MEMS switches and packaged onto the same substrate with a dielectric constant of 3.27 and feed through a coaxial cable at its center point is presented [5]. In order to control beam, this antenna employs a rectangular spiral single arm, which composed of five sections connected by four RF-MEMS switches. The spiral arm is increased by discrete steps in the following manner: $U, 2U, 2U, 3U, 3U, 4U, 4U \dots NU$, where U is the length of the first segment of the rectangular spiral and N is an integer. It is increased in the right-hand direction to give right-hand circular polarization for the radiated field. The position of switches is decided such that the axial ratio and gain of the antenna are most favorable at the frequency of interest. Based on the status of the integrated RF-MEMS, the antenna can change its radiation beam direction.

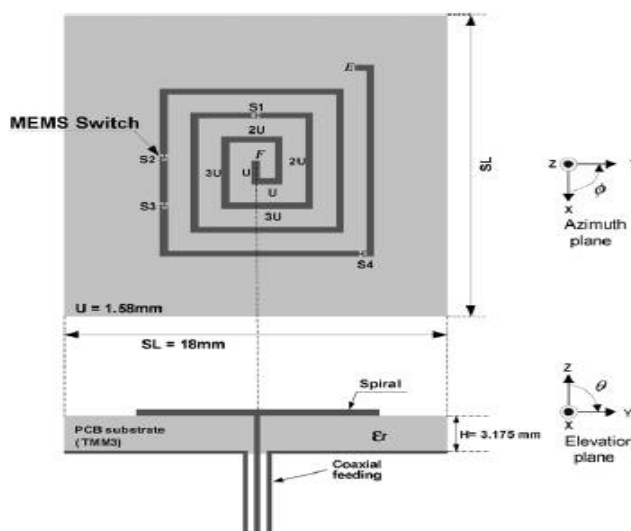


Fig. 3. Top and side view of spiral configuration and its feeding.

B. Reconfigurable Antennas Based on PIN Diodes

A single-feed square-ring reconfigurable patch antenna with pattern diversity is presented in Fig.4 [42]. The antenna structure has four shorting walls. They are placed at each edge of the square-ring patch respectively, in which two shorting walls are directly connected to the patch and the other two are connected to the patch using pin diodes. By controlling the position of the pin diodes it can be operated in two different modes: When the diodes are ON, the antenna is operated at the monopolar plate-patch mode which radiates conical patterns; when the diodes are OFF, the antenna is worked at the TM_{11} mode which radiates broadside patterns. The suggested antenna permits its radiation pattern to be switched electrically between conical and broadside radiations at a fixed frequency.

C. Reconfigurable Antennas Based on Varactors

In Fig.5, a dual frequency microstrip reconfigurable antenna is designed and presented [43]. A hexagonal slot with extended slot arms is embedded in a square patch, and varactor diodes D1, D2 and D3 are placed at the end of each slot arm. When the bias voltage is varied from 0 to -30V, the two operating frequencies can achieve tuning range of 20.75% and 14.36% respectively. This design provides greater area reduction compared to conventional microstrip patch antennas and high flexibility in frequency tuning. A highly simplified biasing circuitry is designed, in which transmission lines are avoided in between the radiating element and nonlinear components, hence, added noise and ohmic losses are suppressed and the resulting structure is more packed together. Another advantage of this design is that the antenna for the two operating frequencies in the entire tuning range shows almost similar radiation patterns without much affecting the gain.

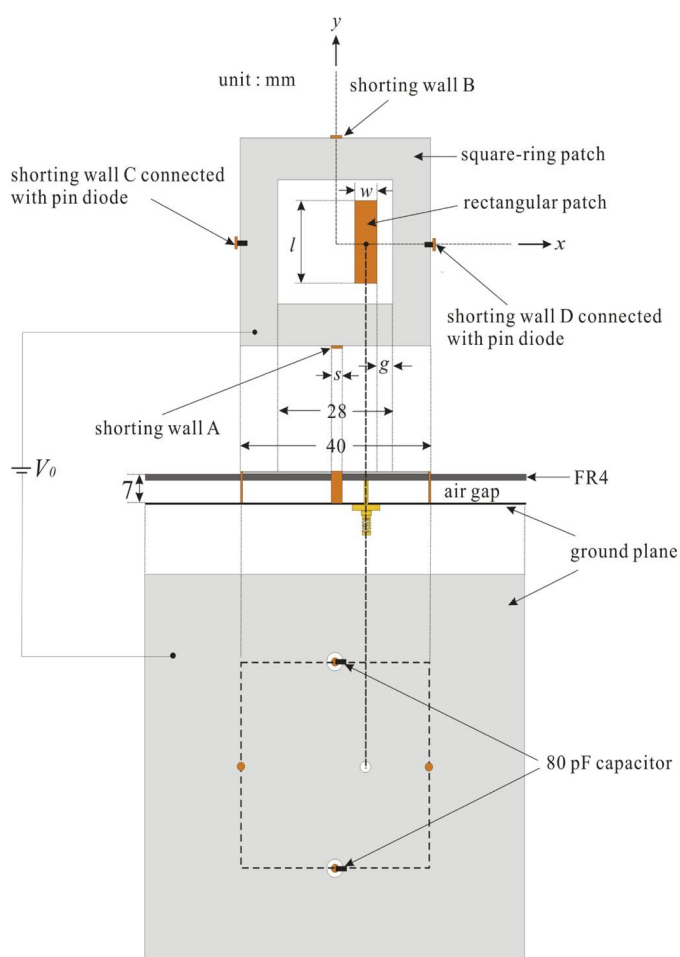


Fig. 4. Proposed reconfigurable pattern-diversity square-ring patch antenna.

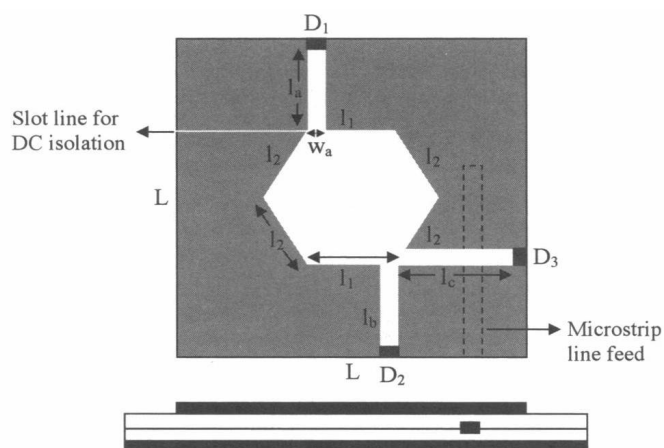


Fig.5. Reconfigurable microstrip antenna operated by varactor diodes.

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VII. OPTICALLY RECONFIGURABLE ANTENNAS

An optical switch is formed when laser light is incident on a semiconductor material (silicon, gallium arsenide). This results in exciting electrons from the valence to the conduction band and thus creating a conductive connection [33]. Integrating such a switch into an antenna structure and using it to reconfigure the antenna behavior is called an optically reconfigurable antenna. The linear behavior of optical switches, in addition to the absence of biasing lines, compensates for their lossy aspect and the need for laser light to activate them.

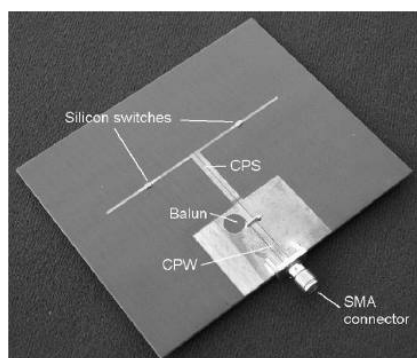


Fig. 6. Optically reconfigurable printed dipole antenna

An optically reconfigurable printed dipole antenna is presented [29] in fig. 6. To feed the balanced printed dipole, a wideband coplanar waveguide (CPW) to coplanar stripline (CPS) transition is used and this transition is realized by balun based on a CPW to slotline T-junction. In both dipole arms, two silicon photo switches are placed equidistantly from the centre feed on small gaps. Light from two infrared laser diodes channeled through fiber optic cables is applied to the switches. By the change of the states of the switches, the antenna can operate at various frequencies.

VIII. PHYSICALLY RECONFIGURABLE ANTENNAS

By physically altering the antennas radiating structure antennas can be reconfigured. The tuning of the antenna is attained by a structural modification of radiating parts of an antenna. This method does not rely on any switching mechanisms, biasing lines, or optical fiber/laser diode integration. But, this technique depends on the limitation of the device to be physically reconfigured.

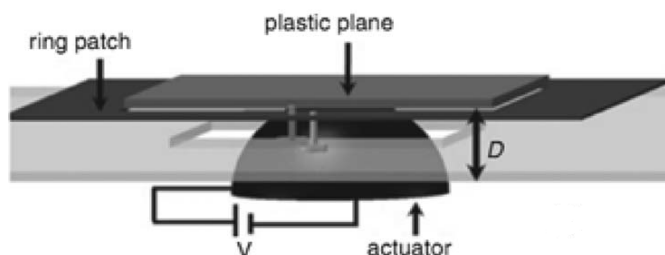


Fig. 7. Square ring Pattern reconfigurable patch antenna.

In Fig. [7] A square ring pattern reconfigurable patch antenna based on a movable parasitic plate within the ring patch is proposed [34]. The plate is triggered using a hemispherical dielectric elastomer actuator (HDEA). While maintaining reasonable impedance matching, small variations of the height of the parasitic plate can considerably change the antenna radiation pattern. The actuator is used in the antenna by placing it below the parasitic conductor

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plate. An electric field across the electrodes causes a radial expansion in the actuator, and as a result, the height of the parasitic plate is varied.

IX. RECONFIGURABLE ANTENNAS BASED ON SMART MATERIALS

A change in the antennas substrate characteristics by using materials such as liquid crystals [40], [41] or ferrites [42], [43] made a reconfigurable antenna. The change in the material is done by a change in the relative electric permittivity or magnetic permeability. A nonlinear material like liquid crystal whose dielectric constant can be changed under different voltage levels, by altering the orientation of the liquid crystal molecules. As for a ferrite material, a static applied electric or magnetic field can change the relative material permittivity or permeability. A liquid-crystal-based reflects array antenna with a switchable pattern is proposed in Fig. 8 [41]. The antenna structure can produce a beam that can be electronically switched from a sum to a difference radiation pattern based on the voltage supplied to the liquid crystal material.

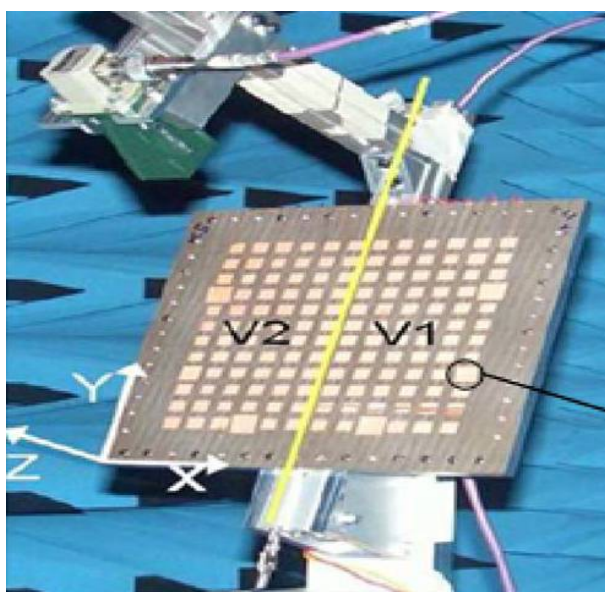


Fig. 8 Reconfigurable reflect array antenna with liquid crystal substrate.

There are a number of advantages in using reconfigurable antennas as summarized below [44]–[46].

- 1) Facility to support more than one wireless Standard:
 - a) minimizes cost;
 - b) minimizes volume requirement;
 - c) simplifies integration;
 - d) good isolation between different wireless standards.
- 2) Lesser front end processing:
 - a) no need for front end filtering;
 - b) good out-of-band rejection.
- 3) Finest applicant for software-defined radio:
 - a) ability to adapt and learn;

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- b) mechanized via a field
- c) programmable gate array (FPGA) or a microcontroller.

4) Multifunctional capabilities:

- a) change role as the operation changes;
- b) act as a single element or as an array;
- c) provide wideband or narrow band

IX. CONCLUSION

The characteristics, classifications and designing of reconfigurable antenna are studied in this paper. As a new concept of antenna, reconfigurable antenna enjoys great value and good prospects. A study of reconfigurable antennas based on different key parameters which includes electrical, optical, physical, and smart-material-based tunable structures is presented.

X. FUTURE WORK

Regarding to reconfigurable antenna designs; it is supposed for us to do an intensive research on new design methods. We look forward to future smart reconfigurable antennas which must be multifunctional and software controlled with machine learning capabilities that can sense changes in their RF environment and react accordingly. Further will be studied applications of reconfigurable antenna in cognitive radios and in MIMO system.

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