Reconfigurable Antenna's: A Survey

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Abstract - **In this paper, concept of reconfigurable antenna is presented. In order to satisfy the requirements for the advanced systems used in modern wireless and radar applications, different multiband and reconfigurable antennas have been proposed and investigated till now. Here, these design concepts, structures and results have been reviewed and discussed.**

Keywords - Reconfigurable Antenna, Artificial Neural Network, Mems Switch, Pin Diode, Varactor Diode

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I. INTRODUCTION

Rapid developments in the wireless communication industry continue to drive the requirements for small, compatible, and affordable reconfigurable antennas and antenna arrays. Reconfigurable multiband antennas are attractive for many military and commercial applications where it is desirable to have a single antenna that can be dynamically reconfigured to transmit and/or receive on multiple frequency bands. Such antennas find applications in space-based radar, unmanned aerial vehicles, communication satellites, electronic intelligence aircraft and many other communications and sensing applications.

Reconfigurable Radio Frequency Micro Electromechanical System (RF MEMS) antenna systems were first introduced in 1998 by E. R. Brown [1] and since then have been studied by several research groups. One of the crucial breakthroughs towards miniaturization in size and cost is the possibility of integrating all the radio modules including antenna, transmit/receive switch and RF circuits on a packaged module using a common monolithic batch fabrication process [2]. The RF MEMS switches are applied on various shapes and geometries like Planar Inverted F-shape Antenna (PIFA), E-shape, S-shape, spiral, fractal and many more to achieve different applications [3-5].

Due to the multi-scale nature of reconfigurable antennas, a single analytical method cannot characterize the whole structure. On the other hand, the use of different analytical methods for a single structure makes it a computationally intensive task, leading to the use of heavy computational resources. Neural Networks (NNs) have emerged in recent years as a powerful technique for modeling general input-output relationships. The distinguished characteristics of NNs such as learning from data, to generalize patterns in data and to model nonlinear relationships, makes them a good candidate to apply for many different branches of engineering [6]. NN's and genetic algorithms are being used extensively for new Reconfigurable multiband antenna designs.

II. ANTENNA

Antennas are metallic structures designed for radiating and receiving electromagnetic energy. An antenna acts as a transitional structure between the guiding device (e.g. waveguide, transmission line) and the free space. The official IEEE definition of an antenna as given by Stutzman and Thiele follows: "That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves". Microstrip antennas are well known for their features such as low profile, light weight, low cost, conformability to planar and non-planar surfaces, rigid, and easy installation [1]. They are most commonly incorporated into mobile, communications devices because of low cost and versatile designs. An emphasis has been given in microstrip antenna structures and reconfigurable aperture, in order to achieve multiple octave tunability [7-8]. Reconfigurable multiband slot antennas are receiving a lot of attention lately due to the emergence of RF-MEMS switches [9-12].

Often microstrip antennas are also referred to as patch antennas. The radiating elements and the feed lines are usually photo-etched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. Square, rectangular, dipole (strip), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation.

The feature of self-similarity of a fractal antenna can also provide a basis for the design of multiple-frequency antennas. These antennas have the advantage that they radiate similar patterns in a variety of frequency bands. The major predecessor is the widely studied Sierpinski gasket [13-14]. The various fractals shape that posse self-similarity have been applied to multi-band or miniaturized antenna design. There are many fractal geometries such as Sierpinski gasket, Sierpinski carpet, Koch Island, Hilbert curve and Minskowsi etc has been used in fractal antennas [15].

III. RECONFIGURABLE ANTENNAS

In recent time many interesting and novel concepts have been developed to achieve adaptable antenna properties [16]. Key aspects of some outstanding concepts will be addressed in the following sections. In our discussion we mainly focus on antenna design with frequency agility. Some examples of antenna structures with polarization, bandwidth and pattern reconfigurable property will be addressed as well.

There are basically three design approaches for achieving antenna frequency agility:

1. Antennas integrated with electronic switches, mechanical actuators, tunable materials for reconfigurability in terms of circuital characteristics and/or radiation properties;
2. Ultra Wide Band (UWB) or multiband antennas integrated with tunable filters;
3. Reconfigurable/multiband arrays where the same aperture is utilized for different operational modes.

IV. TUNABLE /SWITCHABLE ANTENNA TECHNOLOGY

Frequency reconfiguration has become important for many modern communication systems [16]. Therefore, there has been a notable advancement in adaptable antenna technology. Among them utilizing the same antenna aperture for different frequencies will provide the most compact solution.

Table 1 Comparison of tunable components [16]

Tunable Component	Advantages	Disadvantages
MEMS	Reduced insertion loss, good isolation, extremely high linearity, low power losses, consumes little or almost no dc power, wide bandwidth	Need high-control voltage (50- 100 V), poor reliability due to mechanical movement within the switch (0.2-100 μs), slow switching speed, discrete tuning, limited lifecycle
PIN Diode	Needs very low driving voltage, high tuning speed (1-100 ns), high power handling capability, very reliable since there are no moving part, extremely low cost	Needs high DC bias current in their 'ON' state which consumes a significant amount of DC power, nonlinear behavior, poor quality factor, discrete tuning
Varactor	The current flow through the varactor is small compared to PIN diode or MEMS, continuous tuning	Varactors are non-linear and have low dynamic range, complex bias circuitry are required

Relatively narrow-band antennas with tunable or switchable properties are the best solution when the size and efficiency are important issues. This approach reduces the requirements of the front-end filter compared to a UWB or multi-band antenna. Frequency reconfigurable antennas are often realized by employing RF-MEMS systems, varactors, or PIN diodes [16]. A comparison of these components is provided in Table I. Recent advancements in MEMS technology enable the realization of MEMS with high switching speed and compact size. However, integrating a large number of lumped components in the radiating element might increase the power loss, noise and complexity of the biasing circuitry. Furthermore, the power handling capability and the lifetime of these components are also important issues to take into account during the design stage.

V. RF MEMS SWITCHES

The technology of design and fabrication of MEMS for RF circuits had a major positive impact on reconfigurable antennas [17-18]. Electronic switching assumes a critical position in ensuring reconfigurability for frequency tuning, beam shaping and beam steering. Frequency tunability in an antenna enables its use for a range of frequencies [19]. Radio frequency switching normally has been done by using semiconductor devices such PIN diodes or FETs [20-21]. However, PIN diodes and FETs exhibit high insertion loss due to low Q (Q < 3 at 10 GHz) at high frequencies [22]. Recently, RF MEMS - a miniaturized version of the venerable toggle switch, have been used in switching of reconfigurable antennas. RF-MEMS switches have higher Q (Q > 10 at 10 GHz) and provide a reliable alternation to semiconductor devices [22-24]. Such switches have displayed excellent RF characteristics, including lower insertion loss, higher isolation, zero power consumption, small size and weight and very low inter-modulation distortion, and long battery life.

MEMS are the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro-fabrication technology. The micro-fabrication process normally involves a lithography-based micromachining, fabricated on batch basis, which offers great advantages of low cost when manufacturing in large volume. MEMS are also built on high-resistivity GaAs wafers, and quartz substrates using semiconductor micro fabrication technology. From a mechanical point of view, MEMS switches can be a thin metal cantilever, air bridge, or diaphragm, from RF circuit configuration point of view, it can be series connected or parallel connected with an RF transmission line. The contact condition can be capacitive or resistive, polar ceramics such as (Ba, Sr) TiO3 - BST and designed to open the line or shunt it to ground upon actuation of the MEMS switch. Each type of switch has certain advantages in performance or manufacturability. Tunable ferroelectrics have great potential applications in tunable microwave devices [25].

The first RF MEMS switch was introduced in 1991 under support of Defense Advanced Research Project Agency (DARPA), by Dr. Larry Larson at Hughes Research Lab. The switch was specifically designed for microwave applications [22]. The switch's ability to perform well up to 50 GHz was a significant leap forward over solid-state and mechanical switches.

VI. ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic

connections that exist between the neurons. This is true of ANNs as well. In recent years NN's and genetic algorithms are being used extensively for new antenna designs. NNs have emerged in recent years as a powerful technique

for modeling general input-output relationships. The distinguished characteristics of NNs such as learning from data, to generalize patterns in data and to model nonlinear relationships, makes them a good candidate to apply for many different branches of engineering. In this work, we have used two different neural architectures for analysis and design of a reconfigurable antenna. In the analysis phase, NNs are used to locate the operational frequency bands for different combination of switches. This is treated as a mapping formation problem and is accomplished by a Multi-Layer Perceptron (MLP) trained in the back propagation mode. In the design phase, the job of the NN is to determine the switches that are to be made ON for the structure to resonate at specific bands. This task is handled as a classification type of problem and is accomplished by a Self Organizing Map (SOM) NN [26].
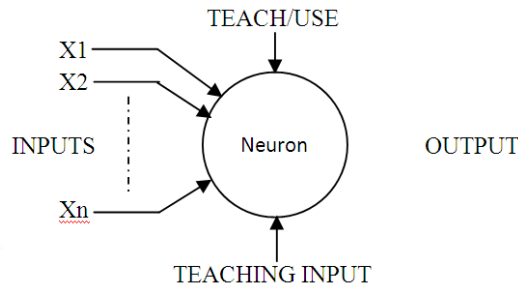

Fig 1 A Simple Neuron

An artificial neuron is a device with many inputs and one output. The neuron has two modes of operation; the training mode and the using mode. In the training mode, the neuron can be trained to fire (or not), for particular input patterns. In the using mode, when a taught input pattern is detected at the input, its associated output becomes the current output. If the input pattern does not belong in the taught list of input patterns, the firing rule is used to determine whether to fire or not.

6.1 Architecture of Neural Networks
1. **Feed-Forward Networks:** Feed-forward ANNs allow signals to travel one way only; from input to output. There is no feedback (loops) i.e. the output of any layer does not affect that same layer. Feed-forward ANNs tend to be straight forward networks that associate inputs with outputs. They are extensively used in pattern recognition. This type of organization is also referred to as bottom-up or top-down.
2. **Feedback Networks:** Feedback networks can have signals travelling in both directions by introducing loops in the network. Feedback networks are very powerful and can get extremely complicated. Feedback networks are dynamic; their 'state' is changing continuously until they reach an equilibrium point. They remain at the equilibrium point until the input changes and a new equilibrium needs to be found. Feedback architectures are also referred to as interactive or recurrent, although the latter term is often used to denote feedback connections in single-layer organizations.
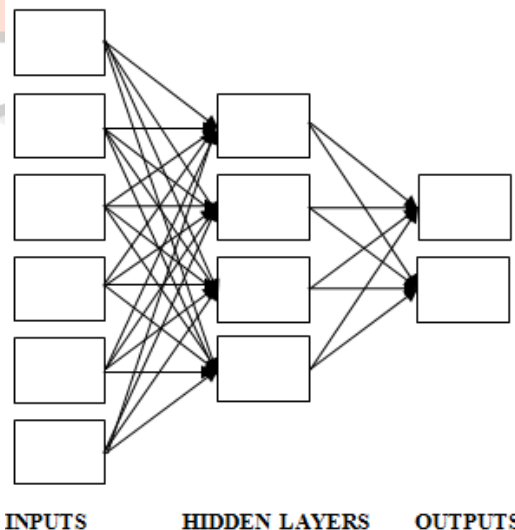

INPUTS   HIDDEN LAYERS   OUTPUTS

Fig 2 An example of a simple feed-forward network

VII. LITERATURE SURVEY

The multiband behavior of the fractal Sierpinski antenna is described in [2]. Due to its triangular shape, the antenna is compared to the well-known single-band bow-tie antenna. Both experimental and numerical results showed that the self-similarity properties of the fractal shape are translated into its electromagnetic behavior. All of them describe a multiband behavior of the fractal antenna. Broadly speaking, RF MEMS is a new class of passive devices (e.g., switches) and circuit components (e.g., tunable transmission lines) composed of or controlled by MEMS.

In [3] the only device addressed is the paradigm RF-MEMS device. Two possibilities addressed here are quasi-optical beam steering and electrically reconfigurable antennas. Much of this activity has been driven by the ability of MEMS to miniaturize and reduce the cost.

In [4], the NN method evaluates the integrals appearing in the spectral domain analysis of microstrip antennas. This technique eliminates the difficulties of handling the singularity points encountered in the numerical evaluation of integrals. Results are compared with those of the standard spectral domain method.

The integration and use of RF MEMS switches in microstrip patch antennas and feed structures were investigated in [27] for developing reconfigurable multiband antennas. The current application focuses on the development of a dual L/X-band antenna that would support several satellite or unmanned aerial vehicles based communications & radar applications such as specific absorption ratio terrain mapping etc.

The author J. Kiriazi et. al. [8] presents a reconfigurable dual-band 4.86 and 8.98 GHz dipole antenna on silicon using series MEMS switches. The effects of series MEMS switches on the antenna performance are studied. Using the designed series MEMS switches, the obtained antenna return loss is -l0.2 dB and -21.6 dB, at the lower and upper frequencies, respectively. However, comparable to the case of ideal switches, a frequency shift of 0.4% and of 2.8% at the lower and upper frequencies, respectively, is observed. The antenna, including the MEMS switches, has bandwidth of 1.9% and 13.6% at the lower and upper frequencies, respectively.

In [20] a novel pattern and frequency reconfigurable microstrip antenna that uses switched connections is presented. The basic antenna operates with linear polarization around 3.7 GHz.

In [12] a new method for developing computer-aided design models, using spectral domain formulation is proposed. Using the ANN technique, a combination of continuous function and delta functions constitutes the spectral domain Green's functions. We obtain closed-form formulas for integration involving these equations.

The development of a NN modeller for the optimization of a dual-band multilayer microstrip patch antenna is presented in [25], the use of a NN model to optimize a multilayer patch antenna offers considerable time savings in the design optimization. The NN model was used to estimate the first and second resonant frequencies with accuracy .The optimized design of the multilayer patch antenna obtained by using the NN model not only has smaller patch sizes, but also offers slight wider resonance bandwidths.

In [6], procedures using NN's are developed for characterizing multiband reconfigurable antennas. A MLP is used to locate the operational frequency bands of the antenna at different reconfigured conditions. Another SOM NN accomplishes the task of locating the switches to be turned ON for a desired frequency response. In analysis, an MLP trained in the back propagation mode is developed to identify the operational frequency bands of the reconfigurable structure. It drastically reduces the mathematical complexity involved in the different numerical methods used to model the entire reconfigurable antenna due to its multiscale structure. The design phase is approached as a clustering problem and a SOM network is used to categorize the frequency responses of the reconfigurable structure. Corresponding to a new frequency response, the position of the switches to be made ON can be identified from a group of typical structures approximately.

ANN based modeling approach for the design of RF-MEMS switches is presented in [28], a finite element method analysis is performed for the switch characterization and for the creation of training and testing sets for the ANN. Developed full-wave/ANN models allow for circuit level design, simulation, and optimization in a schematic of a circuit simulator.

The performance of the RF MEMS reconfigurable antenna depends on MEMS material. Alumina as a MEMS switch material has performed better frequency response i.e. low insertion loss compared to other materials as a MEMS switch is presented in [29].

In [18], reconfigurable reflect arrays with steerable beams have been designed with patch elements which can vary the reflected phase by varying the height of the patches. These patches have been designed using a periodic method of moment's simulation.

According to the open/closed experiment results, when switch is on and off, the antenna operating frequency is 12.3 GHz and 13.1 GHz with low return loss, respectively is presented in [21]. Furthermore, the antenna structure should be compatible with the switch structure and made with specific materials for the tape-out.

A fully integrated solution providing scan-beam capability with a single antenna is presented in paper [3]. The proposed system includes a reconfigurable rectangular spiral antenna with a set of MEMS switches

An effective design of a reconfigurable patch antenna, with a wide operational bandwidth for wireless communication and radar systems, is presented in [4]. The reconfigurable patch possesses an E-shaped structure and its operation frequency can be changed by integrated switches. The operational frequency of the antenna can cover an octave frequency range by utilizing only two switch states.

A dual S shaped microstrip antenna with a realistic feed is proposed in [5] for generation of tilted beam radiation pattern pertaining for beam steering applications. To achieve this, four feeding points are located at a distance of 5.6 mm from the antenna centre. Additionally, using capacitive coupling between the feed and the antenna strip, the antenna is matched and its input impedance bandwidth is enhanced to 950 MHz the gain of the antenna is 7.7 dBi with the antenna axial ratio being 12.2dB

In [30], the NN is employed as a tool in design of the microstrip antennas. In this design procedure, synthesis is defined as the forward side and then analysis as the reverse side of the problem. Finally, in this work, a general design procedure for the microstrip antennas is suggested using ANN and this is demonstrated using the rectangular patch geometry.

In [31], three sets of RF MEMS switches with different actuation voltages are used to sequentially activate and deactivate parts of a multiband Sierpinski fractal antenna. The implementation of such a concept allows for direct actuation of the electrostatic MEMS switches through the RF signal feed, therefore eliminating the need for individual switch dc bias lines.

A novel MEMS technology based reconfigurable dual band monopole antenna implementing RF-MEMS switch is proposed in [32] for satellite communications applications.

In [33], a low-actuation voltage DC contact RF MEMS switch is developed for a reconfigurable microstrip rectangular loop antenna implementation providing frequency tunability. Electromechanical design optimization, microfabrication through the PolyMUMPS commercial process, and RF simulation is presented. The application of such RF MEMS switches to frequency-tunable reconfigurable microstrip loop antennas is subsequently investigated by electromagnetic full wave analysis simulation tool.

In [34], the objective is to demonstrate how clustering techniques such as Kohonen SOM can dramatically reduce the amount of time necessary for optimizing the reconfigurable aperture. Herein, a microstrip line-fed rectangular patch antenna is targeted as the reconfigurable aperture of interest. The patch element is divided into smaller elements, which by themselves are too small to radiate efficiently, yet in combination become a viable radiating structure. A 3-D finite-difference time-domain full-wave analysis utilizing perfectly matched layers is performed to determine the broadband return loss of a reconfigured aperture representing the optimization goal of our SOM. Simulations were performed for a large subset of possible state combinations of the reconfigurable aperture in order to cluster in an unsupervised way the states of the reconfigured apertures using SOM subject to broadband return loss. The SOM is shown to be an efficient method for reconfiguring the aperture from one state to the next within its respective cluster for large populations of feasible reconfigurable states.

In [35], an investigation of the properties of square slot microstrip patch antennas is done. These antenna geometries are obtained by printing square slots in the conducting patches of rectangular microstrip antennas. Measured results of the return loss versus frequency are used in the ANN training. A particular set of measured results is used in the validation of the ANN. The effect of the feed position and square slot size on resonant frequencies is investigated using the developed ANN.

K. Kumar et al. [36] proposed a novel design of microstrip patch antenna operating at a frequency of 2.5 GHz. The designed antenna operates in a dual band operation. Using IE3D, the return loss values and the bandwidth are calculated. Further, using NN technique the bandwidth is calculated. Both the results are compared. The NN based results shows improved bandwidth compared with the IE3D results.

In [37] two different ways to analyze microstrip antenna namely analytical method and numerical method. Analytical method as compared to Numerical methods are easy but only restricted to some definite shapes. On the other hand, though the numerical methods are complicated and require more time to solve, but are applicable to any shape. Therefore in order to eradicate these problems, researchers use neural models which are applicable to any shape, any complicated circuits and it also takes less time with more accuracy.

A novel multi-state RF MEMS switch for microstrip antenna applications is presented in [38]. The proposed switch exhibits seven different states of operation, has a very simple DC biasing mechanism, and can be integrated with antenna structure. Based on these properties, this switch may find its usage in multifunction reconfigurable antennas. To exhibit this application, it is employed in the reconfiguration mechanism of a U-slotted antenna. The schematic structure of this antenna and fabricated prototype, without RF MEMS switches, are shown in Fig. 3. TM01 and TM10 are the fundamental modes of a rectangular microstrip antenna, where the former has longitudinal current path. Here, for achieving reconfigurable characteristics, three RF MEMS switches are used on the U-slotted, as shown in Fig. 3. The parameter values of this antenna are given in Table 2. Moreover, the proposed antenna structure is a cost-effective solution since it comprises a commonly used FR4 substrate. The switch is integrated with antenna structure on the same substrate. A prototype of the designed antenna was fabricated and tested for performance verification of the proposed switch and antenna.
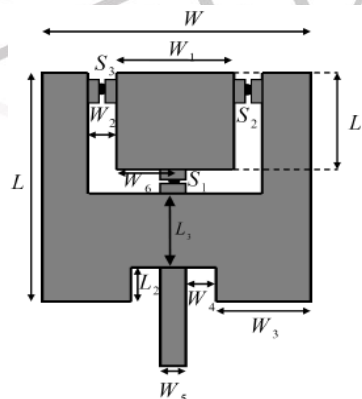

Fig 3 Top view of the U-slotted antenna [38]

Table 2 Parameter values of the antenna [38]

Parameter	L	W	L_1	L_2	L_9	W_1	W_2
Value (mm)	40	36	16	8	60	19	3.5
Parameter	W_3	W_4	W_5	W_6	W_9	h	ε_r
Value (mm)	11	4	6	9.5	50	3.2	4.4

In [39] a shaped-beam series-fed aperture-coupled stacked patch array antenna at X-band is presented. To improve the array bandwidth, two-port aperture-coupled stacked patch antennas, which are suitable for the series-fed array configuration, are presented as the radiating elements. To order the pattern design and optimization progresses more flexibility, a uniformly spaced

array configuration is applied in the shaped-beam pattern design, instead of the conventional non-uniformly spaced array configuration. The experimental results show that, in a 7.6% bandwidth, the main beam shape of the array maintains in good agreement with the design goal, and the side lobe level maintains lower than -18 dB.

In [40] a novel compact reconfigurable antenna based on Substrate Integrated Waveguide (SIW) technology is introduced. The geometry of the proposed antennas is symmetric with respect to the horizontal center line as shown in Fig. 4. The electrical shape of the antenna is composed of double H-plane SIW based horn antennas and RF-MEMS actuators. The RF-MEMS actuators are integrated in the planar structure of the antenna for reconfiguring the radiation pattern by adding nulls to the pattern. The proper activation/deactivation of the switches alters the modes distributed in the structure and changes the radiation pattern. When different combinations of switches are on or off, the radiation patterns have 2, 4, 6, 8, : : : nulls with nearly similar operating frequencies. The attained peak gain of the proposed antenna is higher than 5 dB at any point on the far field radiation pattern except at the null positions.
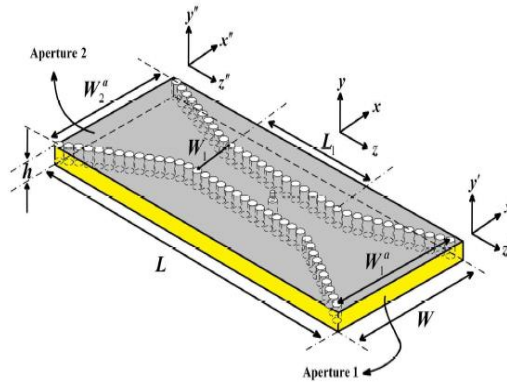

Fig 4 3-D configuration of the proposed antenna [40]

The design procedure and closed form formulation are provided for analytical determination of the antenna parameters [40]. Moreover, the designed antenna with an overall dimension of only 63.6 * 50 mm2 is fabricated and excited through standard SMA connector and compared with the simulated results. The measured results show that the antenna can clearly alters its beams using the switching components. The proposed antenna retains advantages of low cost, low cross-polarized radiation, and easy integration of configuration.

A. Kumar et al. [41] proposed a new designed patch antenna in multi band and then some parametric variations are applied so that the required resonant length can be changed by which the resonating frequencies can be changed. 1st Proposed antenna is analyzed and then a new type of Patch antenna is introduced. The proposed Antenna is designed by using substrate of Rogers RT/duroid 5880(tm) having thickness of 0.8mm initial design, and then substrate is changed to Z paper with different substrate thickness so that multiple resonating band can be achieved with enhanced Band width of application. The antenna proposed is designed and simulated using HFSS and results like VSWR and S11 Parameter for analysis is plotted. Finally a comparative study is done to show that how number of band and operating Band Width can be enhanced for planer Antenna system.

In [42] a new antenna structure that can be adjusted for narrow band as well as UWB applications is proposed. The proposed antenna is of very simple geometry and easy to manufacture. It is monopole type antenna and made of copper. We present antennas with the same geometrical concept and different dimensions. Antenna designed for narrow band operation exhibits 3.7% bandwidth at 800MHz frequency (S11 < -10 dB). Two UWB antenna designs exhibit 77% bandwidth (from 2 to 4.5 GHz) and 54% bandwidth (from 2.6 to 4.5 GHz) and are of smaller size compared to the dielectric resonator antennas. Furthermore, it can be easily shown that using the proposed geometry broad family of antennas (for operation in various frequency bands) can be designed.

In [43] the parameter optimization by means of the NN is the major attraction, which highlights the ease, precision and reduction in computational time for the designers of interest. The paper deals with the design of a probe fed rectangular Microstrip patch antenna for 2.4 GHz frequency. The analytical results for various conceivable dimensions and different dielectric values were intended without any structural complexities. To achieve an optimum value for the design parameters of the Microstrip antenna, Multi-

Layer Perceptron NN (MLP) and Back Propagation algorithm were implemented to train the network. The analytical results were tested by simulating with basic design software HFSS. The bid of artificial NNensures an optimal design methodology which is revealed when relating the results with analytical methods, results of the simulation software.

In [44] two pattern reconfigurable slot antennas on the circumference of metallic cylindrical cavity are studied. The first one is designed to work in 5.8GHz Industrial, Scientific and Medical (ISM) band with four slots curved around the metallic cylindrical cavity. There is one switch in each slot to achieve the reconfiguration of four different radiation patterns. The second antenna is designed for applications of Dedicated Short Range Communications (DSRC). Its central frequency is 5.88GHz with a bandwidth of 75MHz which is used in intelligent transportation system applications. Reconfiguration of two different radiation patterns is realized.

In complex EM environment, EM field distribution inside a metallic enclosure is determined by the external EM radiation and emissions from internal contents [45]. In the design of an electronic system, we usually need to estimate the EM field level in a concerned region inside the enclosure under various EM environments. Here ANN is used rather than full wave analysis, combined with the numbered measurements to predict the EM field in the concerned region inside a metallic enclosure. To verify this, a rectangular metallic enclosure with a printed circuit board is illuminated by external incident wave. The measured electric

fields inside the enclosure combined with ANN model based on back propagation training algorithm are used to estimate the values of electric field.

In [46] design of a single varactor-based reconfigurable reflect array is presented which adopts an aperture-coupled single-element configuration. A planar array prototype of 3x15 radiators is considered as validation example of the proposed structure. A DAC-board is integrated to the reflect array antenna for driving the varactor bias voltages. The configuration proposed for the single element consists of a patch printed on a grounded dielectric substrate and slot coupled to a microstrip line (Fig. 5). The line is composed of two parts: a segment Lv terminating on a varactor load and an open ended stub Ls. The following dimensions are derived for a radiator working at a frequency f = 11.5 GHz: W= 9.3 mm, L= 8.2 mm, Wa= 0.6 mm, La= 5.8 mm, Ws= 3.07 mm. The patch is printed on a substrate composed by a 0.762-mm thick layer of Diclad870 with a relative dielectric constant $\varepsilon r1$=2.33 and a layer of air with a thickness of 0.762 mm. The microstrip line is located on a dielectric substrate with permittivity $\varepsilon r2$=2.33 and thickness equal to 0.762 mm. The two line sections Lv and Ls are optimized in order to maximize the phase agility of the element for a varactor with a tunable capacitance ranging from 0.2 pF to 2 pF.
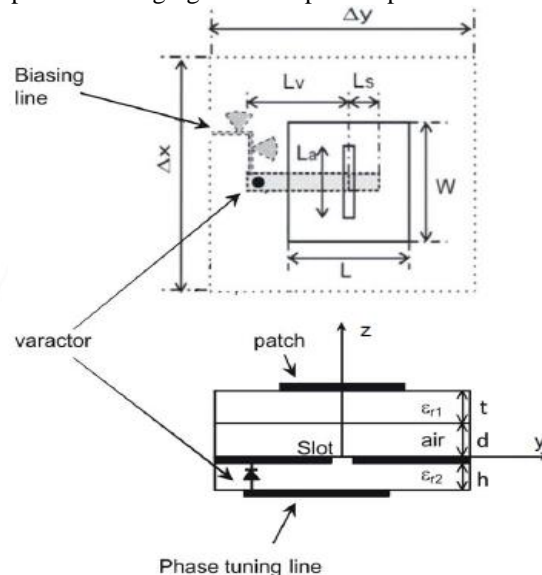

Fig 5 Reflect array element configuration: (a) top view; (b) side view [46]

Measured radiation patterns are reported to demonstrate the beam-scanning capabilities of the designed reflect array prototype [46].

A technique which uses Feed-Forward Back-Propagation ANN with one hidden layer & trained by Levenberg-Marquardt back propagation learning algorithm as an approximate model for design of circular micro strip patch antennas with reasonable accuracy is proposed in [47]. IE3D has been used to generate data dictionary for training and validation set of ANN. Results of proposed ANN models are compared with simulated and theoretical values, these results are found in agreement with same.

A new frequency-reconfigurable antenna structure, denoted as a pixel slot antenna is proposed in [48]. The antenna makes use of a canonical switched slot element that is concatenated together to form various radiating structures. The resonant path of the pixel slot antenna can be a conventional slot or a slot plus a loop, so higher degrees of freedom in generating various resonant frequencies is achieved. The maximum-to-minimum achievable resonance values of a demonstrated 4-switch single-pixel slot antenna are 3.30 GHz to 1.56 GHz in which the feed mechanism remains unchanged. Other frequency tuning ranges are also achievable by changing the switch allocation along the slot structure.

In [49] a single layer, single feed compact slotted patch antenna is simulated. Resonant frequency has been reduced drastically by cutting two equal slots which are the combinations of one triangular and another rectangular slot at the upper right and lower left corner from the conventional microstrip patch antenna. Simulated antenna size has been reduced by 48.89% with an increased frequency ratio when compared to a Conventional microstrip patch antenna.

In [50] design of Sierpinski Carpet Fractal Antenna (SCFA) up to third iteration is presented. To increase the gain further some modifications in the fractal geometry have been proposed. Further the modified geometry SCFA and a corporate feed SCFA array is proposed. These antennas are designed using HFSS on FR4 substrate with dielectric constant of 4.4 and fed with 50 ohms microstrip line. Out of these a simple 3rd iteration SCFA antenna has been fabricated and tested using a VNA and the fabrication results were in good comparison to the simulation ones, thereby suggesting the credibility of all the designed antennas.

In [51] a novel method is presented for electrically tuning the frequency of compact RF identification (RFID) tag antenna. A tuning circuit, comprising a RF switch and discrete passive components, was completely integrated into the antenna element, which is thus free of DC wires. This study was simulated on an FR4 substrate with relative permittivity of 4.6, width of 1.6 mm, and dimensions of 103×33 mm2. The fractal dipole antenna has a rectangular compact shape and a pair of meander patches with a metal length of 23 mm and a width of 1 mm; there is an end gap distance of 2 mm between the meander patch end and the feed microstrip line. The optimal dimensions of the proposed antenna are W1 = 33 mm, L1 = 41.5 mm, W2 = 3 mm, W3 = 2 mm, L2 = 9.3 mm, L3 = 23 mm, and L4 = 15.2 mm. To observe the tag's response for the proposed tag antenna shown in Fig. 6. Prototype designs showed that the in-band frequency (return loss < 10 dB) was tunable from 2.4 GHz to 2.8 GHz when the bias voltage

varied from 4 V to 7 V. The impact of the tuning circuit on the antenna's return loss and radiation pattern were experimentally studied through comparison with the performance of a reference antenna not incorporating the tuning circuit.
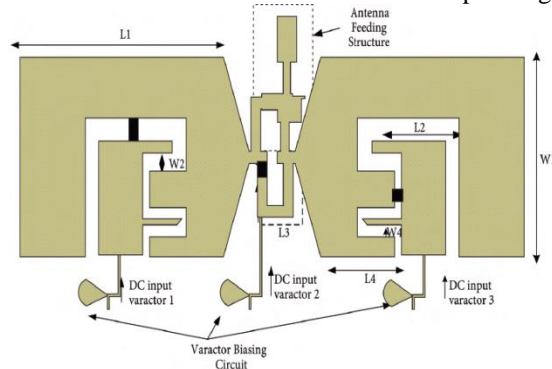

Fig 6 Schematic of the proposed varactor-loaded antenna for RFID tag [51]

The dimensions of the antenna were first studied with AWR Microwave Office simulation electromagnetic software and then verified by the experiment. Details of the proposed antenna and results of the prototypes are discussed below.

VIII. CONCLUSION

Reconfigurable antennas are used in numerous application areas such as communications, surveillance, etc. They are used to modify the relevant circuital characteristics and/or radiation properties in real time.

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