International Journal of New Technology and Research (IJNTR)
ISSN: 2454-4116, Volume-2, Issue-5, May 2016 Pages 125-134

A Study of Reconfigurable Multiband Antenna for Wireless Application

Haydar M. Al-Tamimi, Salah Mahdi

***Abstracts*- In This study an introduction to the reconfigurable antenna technology is presented. After that a discussion about the main advantages and disadvantages of the reconfigurable antennain addition to the most important applications that can be used with the reconfiguring techniques, studyingthe history of this technology with a brief literature survey is explained. A detailed description for this technique with examples and background information are specified, reviewing the different reconfigurable antenna components,which can be used in an antenna to adjust its construction and functionality. These reconfigurable antenna techniques are grouped with a different classification methods to explain whichever established on the physical modification of the reconfigurable antenna radiating component, or on the integration of micro-electro-mechanical structures (RF-MEMS), varactors, PIN diodes, photoconductive components, or on the function of smart materials like ferrites and liquid crystals, etc.**

***Index Terms*- Multiband Antenna, MEMS, Reconfigurable Antenna**

I. INTRODUCTION

Reconfigurable antenna used to modify radiation pattern, polarization, or even the operating frequency to deal with the varying in the system parameters. So there are more than one goal for using the reconfigurable antenna. The reconfigurable antennas that have an ability to radiate additional patterns on a different frequencies and polarizations, are required in the modern communication systems. This requirements used to increase the functionality (e.g., control, beam steering, direction finding, radar, and command) within a limited volume place a greater responsibility on today's transmitting and receiving techniques. Reconfigurable antennas act as a solution to these problems.

There are a number of advantages from using the reconfigurable antennas as reviewed in[1]. For Instance, the excellent ability to verify more than one wireless requirement, like the simpler combination and the suitable isolation between various wireless standards. Simpler band rejection processing. Suitable for controlling by a software programs. Multifunctional abilities, for instance the alteration functionality as the mission exchanges, agreement with a narrow band or wideband process.

At the same time as reconfigurable antennas represent a possible solution for the future wireless and space applications, there is absolutely a cost for inserting tunability to the antenna performance in the specific system.

Haydar M. Al-Tamimi, Department of Electrical Engineering, university of technology/ Baghdad, Iraq.
Salah Mahdi, M.Sc. student, Department of Electrical Engineering, University of technology/ Baghdad, Iraq.

This cost can be summarized to different parameters as. Design of the biasing network system for activation/deactivation of the switching components, which add difficulty to the antenna construction.Expand in the essential power consumption because of the incorporation of active elements which increases the system cost.Production of harmonics and inter modulation products to the system.Require to fast alteration in the antenna radiation features to guarantee an accurate functioning to the system.

Reconfigurable antennas are suitable for many applications especially when many operating modes are required from single antenna\element. These applications include (but are not limited to): Cognitive Radio Systems. Multiple Input Multiple Output (MIMO) Communication Systems. Cellular and Personal Communication Systems. Interference Rejection. Wireless Network Security. Reconfigurable antennas have also been applied in military applications.

The reconfigurable antenna history:

The reconfigurable antenna appeared since the thirties of the last century. In January 1934, the two-element array antenna nulls were directed by a calibrated variable phase changer, the purpose of this technique was evaluating the direction of the short wave signals arrive to the reception zone [2]. In April 1935, a rhombic antenna was altered in size by extending the wires with a motor, this technique used as a test with a "steerable antenna directivity" for the short wave signals at the receiver station [3].In 1937 the Multiple-Unit Steerable Antenna (MUSA) was an array of rhombic antennas with six-element array and a phase shifters at five of these elements and operated on a 5-20 MHz "short wave signal" [4].This idea was achieved and modified in 1936 for azimuth scanning in the radar field with a fourteen row by three column array of polyrod antennas. This array antenna had thirteen rotary phase changers for beam directing [5].The important fundamentals of this array were later used as the ship bornefire control antenna. During WW II the Wullenweber array was designed. It is a large direction-searching circular array antenna with a narrow beam used to scans 360° in azimuth by modifying a small group of active elements on the circular array antenna [6]. After the war, the Soviet Union built many Wullenwevers for HF direction receiving. The United States became concerned in this technology in the 1950s and 1960s. The Americans changed the name from Wullenwever to Wullenweber. In 1979, the term "reconfigurability" was described as "the ability to change beam shapes depends on a knowledge" [7]. The researchers designed a six-beam elements dynamically modified to the coverage area used for the satellite communications.In February 1995, A.D. Monk from the University of London discuss his paper reports on a reconfigurable parabolic reflector antenna which adaptively modifies the parabolic reflector surface in order to products a null toward the antenna source. Nulls in the sidelobe directions are determined after lower than 50 iterations, with a slight inaccuracy on the radiation pattern [8].

II. THE RECONFIGURABLE ANTENNA DESIGN REQUIREMENTS

Before planning to design a reconfigurable antennas, the RF engineers must address three difficult questions:

I. Which reconfigurable factor needs to be modified (e.g., polarization, radiation pattern, or frequency)?
II. How are the different radiating components of the antenna construction reconfigured to achieve the expected factor?
III. Which reconfiguration method minimizes the undesirable effects on the antenna radiation/impedance features?

III. LITERATURE SURVEY

As mentioned previously the concept of the reconfigurable antenna is moderately old. However, the reconfigurable antenna design during the current period have generally concerned with microstrip, which is a different semiconductor components connected to modifying the current on the reconfigurable microstrip antenna.

Configuring a microstrip antenna depend on the parameter of the substrate, type and position of the feeding point, the patch shaping, etc., in order to make the antenna radiate within the required polarization and frequency. If the required operating features of the antenna modify, the antenna need to reconfigured or reconstructed to reach the new conditions. Changing the current flow on an antenna, will make the reconfigurable antennas alter their performance, by using active materials, tunable materials, diodes, attenuators, phase shifters or mechanically movable parts. The reconfigurable antenna may be an array antenna or just a single antenna.

G. Wang. Define the function of MEMS switches in the microstrip antenna feeds to provide the capability to change from linear polarization to the orthogonal linear polarization, or even to the circular polarization [9].

In 2007, J.T Bernhard wrote an excellent overview of reconfigurable antennas, with many examples, for instance[1]:

I. A balanced dipole was designed with two photo-conducting switches. When both switches open, the antenna operated at 3.15 GHz. While the antenna operate on 2.16 GHz when both switches close.
II. A reconfigurable square microstrip developed by huff et al. that radiate with a broadside or 45° tilted beam. This antenna has two switches: the 1st one used to shorts the end of the spiral to the ground plane while the other one used to opens a small gap in the microstrip.

B.-Z. Wang proposed an E-shaped Reconfigurable patch-antenna with a tunable frequency by using an integrated switches, design for wideband wireless communication systems[10].

Ahmed Khidre in February 2013 proposed Circular Polarization Reconfigurable Wideband E-Shaped Patch Antenna for Wireless Applications. This antenna is capable of switching its polarization from right hand circular polarization (RHCP) to left hand circular polarization (LHCP) and vice versa. The design targets the WLAN IEEE 802.11 b/g frequency band (2.4–2.5 GHz) being used in various wireless communication systems[11].

An UWB Frequency Reconfigurable Antenna by Using a Switchable Slotted Ground Plane was designed by Chirag Gupta, in the 4th International Conference on Communication Systems and Network Technologies – 2014[12]. With six switchable states was performed.

A. C. Sodré Junior proposed an Optically Tuned Reconfigurable Antenna Array Constructed from E-Shaped Elements. In the International Journal of Antennas and Propagation, 27 April 2014[13]. To modify the frequency response over 2.4 and 5 GHz.

In 2014, H. Singh design a Steering Wheel Shaped Frequency Reconfigurable Antenna for Cognitive Radio which is act as a fast switching antenna capable of operating in seven different frequencies in the range of 6.25 to 8.25 GHz[14].

Mohammad M. proposed a Reconfigurable Antenna with Extended U-Slot used as a Switchable Polarization for Wireless Applications. In IEEE Antennas and Propagation Magazine, April 2015[15]. The antenna is capable to change among linear polarization (LP) and left hand (LH), right-hand (RH) circular polarizations (CPs) for 2.4-5.8-GHz.

In APRIL 2015, an Electronically Reconfigurable Patch Antenna Design for Polarization Diversity with Fixed Resonant Frequency for Wireless Local Area Network (WLAN) with a frequency band (2.4–2.48 GHz,) was proposed by Mohamed N.O[16].

IV. RECONFIGURABLE ANTENNAS CLASSIFICATION METHODS

The reconfigurable antennas come in a large variety of different shapes and forms, so there are different method to make a classification for these techniques.

A. According to the reconfigurability function:

The reconfigurable antenna can be grouped into 4 main categories based on their reconfigurability function as [17]:

Category 1: A radiating configuration that is able to modify its operating or notch frequency by shifting between various frequency bands, this type aka frequency reconfigurable antenna. This is accomplished by creating some tuning or notch in the antenna reflection coefficient.

Category 2: A radiating configuration that is able to adjust its radiation pattern, which is aka the radiation pattern reconfigurable antenna. For this type, the antenna radiation pattern modifies in terms of gain, direction, or shape.

Category 3: A radiating configuration that can modify its polarization (left-hand or right-hand circular polarized, horizontal/vertical, etc.) is also known as the polarization reconfigurable antenna.

Category 4: This category is a combination of the earlier three categories. For instance, one can accomplish a polarization diversity with frequency reconfigurable antenna at the same time.

The resultant reconfigurability for each of the four groups can be achieved by a modifying in the reconfigurable antenna surface current flow distribution, modifying in the antenna physical configuration, modifying in the feeding network, or modifying in the antenna radiation edges. It is important to note that the adjustment in one parameter in the antenna characteristics can alter the other parameters. So, an antenna engineer must be careful during the design procedure to analyze all the antenna features simultaneously so as to reach the essential reconfigurability.

B. *According to the design of the reconfigurable antenna:*

Also there are three different broad methodologies could be identified for achieving reconfigurable antenna designs and operation electrically namely:

Antenna geometry morphing. Feed geometry morphing. Smart geometry reconfiguration.

C. *According to the type of antenna used:*

The reconfigurable antenna can be classified into six important types which are:

Antennas using semiconductor or varactors switches. Antennas using MEMS switches. Mechanically reconfigurable antenna. Antennas using reconfigurable feeding networks. Reconfigurable Array Antennas. Reconfigurable Antenna with a Tunable Materials.

V. RECONFIGURABLE ANTENNA TYPES

A. *Antennas using semiconductor or varactor switches:*

The RF switch used to open or close the current path on the reconfigurable antenna. A common technique to construct a reconfigurable antenna is to assemble various components of the wanted antenna with RF switches. Opening and closing switches leads the current flow in a required path that modifies the antenna's radiation pattern, in addition to its impedance.

RF switches can be semiconductor (like PIN, Varactor switches) or mechanical (like MEMS switches). A switch is an open circuit when there is no applied voltage, and a low-impedance line for the RF signal when there is an applied voltage. The switch can be applied in a shunt or series arrangement. Some important features of a switch are [18]:

- Characteristic impedance: It's a transmission line factor that is verified by the physical construction of the line. It also used as a determination for how traveling signals are transmitted or reflected in the line.
- Bandwidth: The RF switch's bandwidth is one of the most important conditions. The bandwidth of the RF switch basically refer to the maximum frequency signal.
- Topology: The two most important category of the RF switch topologies are single-pole double-throw (SPDT) relays and multiplexers. A single SPDT relay can direct two inputs to one output or vice versa. A multiplexer is a switching system that successively guides several inputs to one output or vice versa. It's a very important to recognize the optimal usages for these different topologies to select the excellent choice for a specific application.
- Insertion loss: The "insertion loss" description of a switch component is a measure of the ratio between the input and output powers while the switch is on and off. Insertion loss of the RF switch at a specific frequency range can be used to determine the voltage attenuation or power loss produced by the switch on a signal at that frequency. The equation that used to calculating power loss:

$$\mathit{Insertion\ Loss}\ (dB) = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right) \qquad (1)$$

- Switching speed: Defines the time required for the transition from the on-off state or vice versa. The switching speeds of the semiconductor switches are in the range of nanoseconds, but the switching speeds of the mechanical switches are in the range of milliseconds.
- Expected life time: Estimation for the number of switch transitions before get failure.
- Power handling: The amount of power that required to operates this RF switches measured in watts.

In the range of lower than microwave frequencies, a low-pass switch behaves like a resistor (R_{on}) when the switch is on, and a capacitor (C_{off}) when the switch is off. But the bandpass switch performs like a capacitor in the on statues, and another capacitor value in the off statues. By increasing the frequency, the ground inductance, and transmission line characteristics turn out to be an important considerations, and make difficulties to the circuit configuration. Parasitic resistances in the RF switch reduce the upper frequency bound. The RF switch figure-of-merit (FOM) is the cutoff frequency [19]:

$$f_c = \frac{1}{2\pi\, C_{off} R_{on}} \qquad (2)$$

By dividing the RF switch Figure of Merit by 10, the maximum frequency that the system used to perform as a switch can be achieved. This equation known as a rule of thumb that used for the highest effective frequency for the RF switch $f_c/10$. As a result the system limitations may reduce the number of the switching types that can be used.

These RF Switches can be applied to the reconfigure microstrip antennas in a number of different methods. For example, Figure 1 shows a microstrip patch with slots that can be shorted, to control the required polarizations [20].

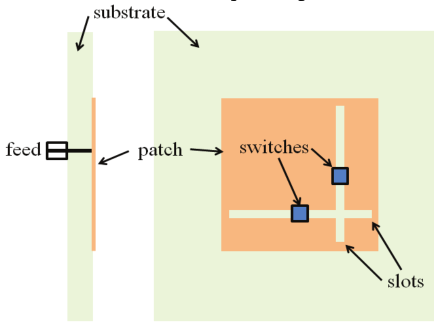

Figure 1: A reconfigurable slotted microstrip patch antenna.

While Figure 2is an example of a two-dimensional array antenna of metal patches over a substrate [21]. The sides of neighboring patches are connected with RF switches, to configure a required patch antenna.

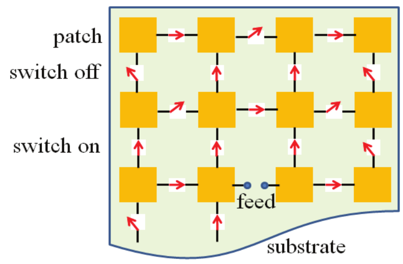

Figure 2: Reconfigurable array antenna patches.

Semiconductor switches:

In the semiconductor switches, amplifying the voltage at the gate expands the conducting channel's size under the gate, and make available current to flow between the source and drain.Figure 3 is a simple diagram for a field-effect transistor (FET) switch. This type of switches divided into a several varieties. Pseudomorphic High Electron Mobility Transistor (PHEMT) and Metal Semiconductor Field Effect Transistor (MESFET) switches are two types that are compared in Table 1.

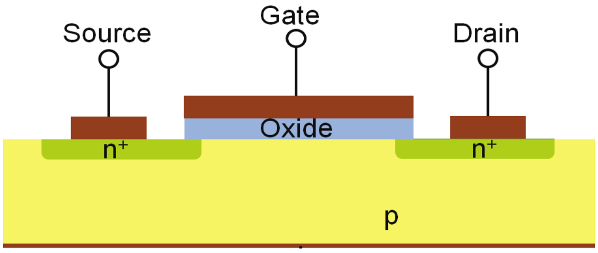

Figure 3: A diagram of a FET.

The author in [22] use FET switches in the reconfigurable antenna similar to Figure 2. The switch array was controlled by a light-emitting-diode backplane that separated the control circuitry from the RF directions in the antenna.

PIN diode is another commonly used microwave switch [23]. It has strongly doped p-type and n-type areas, which are disconnected by a wide, weakly-doped intrinsic area (Figure 4).

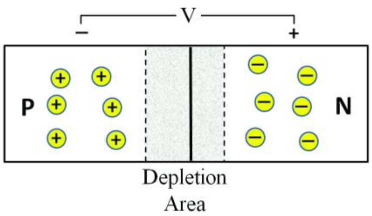

Figure 4: A diagram of a PIN diode.

Forward biasing a PIN diode generates a very low resistance on high frequencies, but reverse biasing of the diode causes an open circuit. The PIN diode is current managed. The author in [20] suggest using PIN-diode switches for the reconfigurable antenna in Figure 1. Table 1 compares between the features of FET and PIN diode switches.

Table 1: A comparison of FET and PIN-diode switches [19]

	1µm MESFET	*0.25µm PHEMT*	*Silicon PIN diode*
Number of terminals	3	3	2
Typical on resistance	1.5 Ω/mm	1.2 Ω/mm	1.7 Ω/mm
Typical off capacitance	0.4 pF/mm	0.32 pF/mm	0.05 pF/mm
RF switch F.O.M (Eq.2)	265 GHz	414 GHz	1872 GHz
Breakdown voltage	15 V	8 V	50 V
Lower frequency limit	dc	dc	10 MHz
Driver circuit complexity	low	low	high
Typical amount of power needed	Zero	Zero	Approximately 10mW
Controlled by	Voltage signal	Voltage signal	Current controlled
Driver requirements	0 V on & -5 V off	+0.5 V on & -5 V off	5 to 10 mA on & 0 to -30 V off

Varactor switches:

A junction diode is formed while P- and N-type semiconductors are created at some point in the construction procedures. As shown in Figure 5, a varactor diode has a thin layer called the depletion region [24], where there are definitely no free electrons, holes or carriers. This region work as an insulating dielectric area, in addition to the P and N regions that work as the conducting electroplates, dissimilar to the PIN diode, (Figure 4). If there is a forward bias operated to the varactor diode, it will conduct. The depletion layer simply disappears. If an external reverse voltage is employed to the varactor,the reverse bias expands the width of the depletion layer. The amount of increasing width are determined by the amount of the reverse bias. The schematic symbols used to represent varactors are shown in Figure 5 (b).

The capacitance is inversely relative with the square root of the operated voltage, while the thickness of the depletion area grows with the reverse bias. The varactor diode have a high-to-low capacitance relation that is usually six over a voltage change of (0 -12) V.

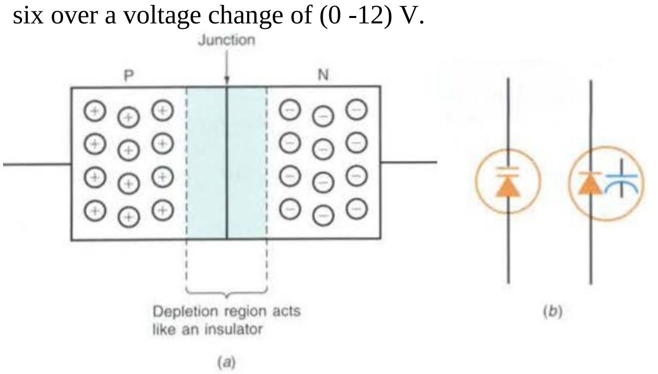

Figure 5: Depletion region in a junction diode, and the Schematic symbols of a varactor diode.

Varactor diodes are a suitable switching type for tuning the antenna's frequency range. For instance, varactor diode can be positioned on the radiating edges of a microstrip antenna so as to increase the narrow bandwidth to a bandwidth of around 30% [25]. A slotted monopole reconfigurable antenna, improved with a varactor, could be adjusted between 1.6 GHz and 2.3 GHz without any important change in the antenna's efficiency [26]. Reconfigurable radiation pattern antenna has also been verified by using varactor diodes [27].

B. Antennas using MEMS switches

MEMS switches are small mechanical switches positioned on a substrate (quartz, glass, silicon) [28]. Not the same as the FET switches and PIN-diode, a MEMS switch is mechanical.

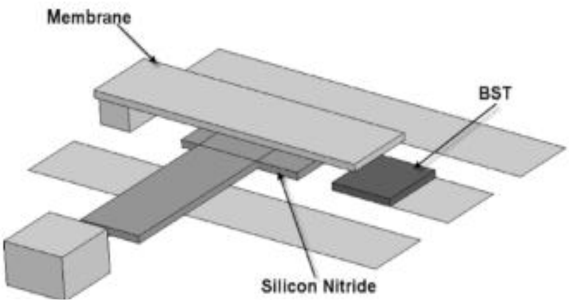

Figure 6: Close up view to a single barium strontium titanate (BST) MEMS switch.

Figure 7shows three categories of MEMS switches with their on and off positions. The cantilever beam in Figures 7 (a)and 7 (b) is placed to a post on the left side, at the same time as the other end of the beam is suspended directly above the drain. An electrostatic energy pulls the beam down as soon as the required voltage is applied, and makes an electrical path connecting the beam to the drain side. Figures 7 (c-f)show a MEMS membrane switch, which is contain a thin, flexible, metal membrane, located on the posts in both ends. A required voltage applied to the bias electrode moves the membrane down and connects the circuit. An ohmic connection is a metal-to-metal contact, but a capacitive connection has a dielectric between the two metal interactions. Ohmic switches have a greater bandwidth than capacitive switches.

The figure-of-merit for MEMS switches was stated at 9000 GHz [19]. Switching speeds for this type of RF switches are 10 µs. MEMS switches with piezoelectric films have been improved, and produce fast switching times (1-2 µs). The cantilever device movements 6 µm between the on and off situations [29].

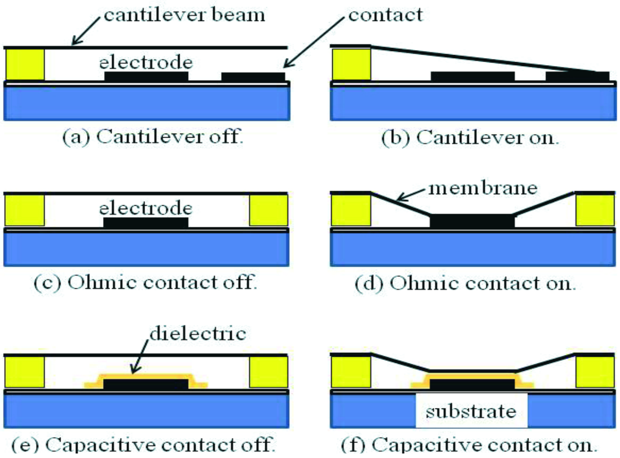

Figure 7: Various types of MEMS switches in the on and off positions.

MEMS switches have a high isolation, lower insertion loss and small power consumption similar to mechanical switches, but low cost, lightweight, and smaller the same as semiconductor switches [30]. However, MEMS switches have a limited power-handling ability (~100mW), high-level losses at microwave and mm-wave frequencies, and this switches may be required an expensive packaging to shield the movable MEMS bridges against the environment.

MEMS switches have been planned for use in reconfigurable antennas since the 1990s [28]. For instance, two antennas of ultra wide band monopoles that have a reconfigurable stop band in the frequency range (5.150 GHz to 5.825 GHz) as shown in Figure 8 [31].

The second antenna shown in Figure 8 had two inverted-L shaped open circuit stubs are symmetrically connected and disconnected near the elliptical microstrip patch by using MEMS switches. Connecting the inverted-L shaped stubs to the patch produced a stop band. When the stubs circuit were opened, the reconfigurable antenna radiated over the entire UWB range (3.1 GHz to 10.6 GHz) without any notch band.

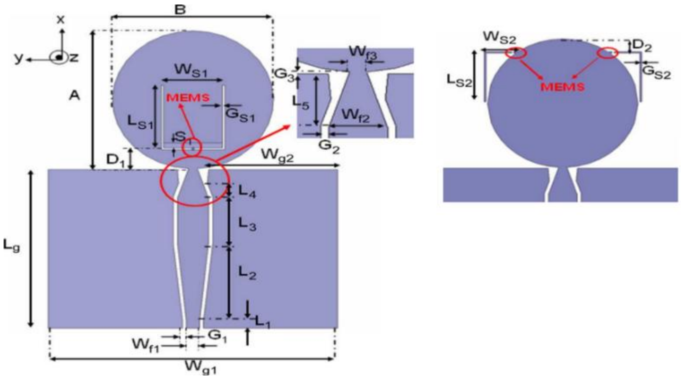

Figure 8: A reconfigurable antenna schematic U-slot and L-stub.

Reconfigurable antennas can be also used to modify the antenna's polarization. As reviewed previously in the literature survey [32].

Upcoming researches will require to address the cost and scalability for the MEMS procedure on the large array antennas. There are a number of significant substrate properties that need be organized, counting dielectric loss, permittivity, and surface roughness. In recent times, liquid polymer substrates with ε_r = 3 and tan δ = 0.002 have been used to be the practicable substrates for MEMS switches [33].

C. Mechanically reconfigurable antenna:

The reconfigurable antennas can be modifying by use a physically varying antenna radiating elements. The alteration of the required antennas characteristics is depend upon the mechanical adjustment of the antenna active elements. The main important concept in this technique type is that it does not depend on any optical fiber to laser diode connection,biasing lines, or even to a switching instruments. But this type of reconfigurable antenna is a subjectto the inadequacy of the device to be physically reconstructed[34].

The Arecibo sphericalreflector antenna is a very good example to describe this technique, shown in Figure 9.The Arecibo Observatory is a radio telescope, which is a large spherical reflector antennas with an exchanged antenna feed to alter the frequency bands, or a movable feeds to modify the main beam.

A Gregorian dome and with a number of linear antennas are on each side of a curved track, (aka the azimuth arm). The linear antennas, haveadjusted to a narrow band of frequencies. This acceptable to connecting a set of receiver stations, covering the complete 1–10 GHz range of frequencies. Making the Arecibo antenna more flexible[35].

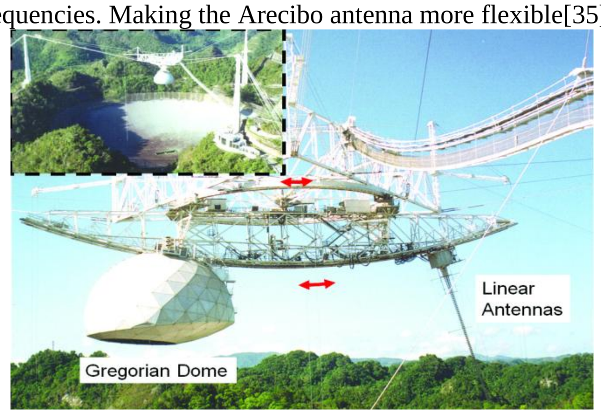

Figure 9:A blown-up picture of the feed for the Arecibo antenna (upper left)

There are a possibility to create nulls in the antenna radiation pattern by changing the reflector antenna's surface. One of these reconfiguringmethodismodifyingthe reflector's surface by moving a scattering plates closeto the surface in order to produce cancellation to the interfering waveswithin the sidelobes [36].

D. Reconfigurable array antennas:

The main idea from reconfiguring the array antenna is to control the array field pattern tochange the maximum beam shape, direct the beam, alter the sidelobe levels, or place a null. This type of reconfigurable antenna have been several applications that includevarying in the frequency or polarization of operation. A digital beam-former considerably improves the ability of the array to steer the radiation pattern, when all the reconfiguring process is finished in software.

Beam control can be done by altering the active elements on and off in the array, as was point out with a Wullenweber array antenna.

Figure 10shows this ideaexpanded to a spherical array antenna that was applied on a geodesic dome array. The geodesic dome array antenna is a multi-function, highly effective, low cost spherical phased array antenna which supplies hemispherical coverage area. The array antenna contains an amount of near-equilateral triangular, planar subarrays placed in the geodesic dome structure. Each triangle shape on this dome was a subarray [37]. The effective aperture was created by integrating the outputsfield pattern from adjacent subarrays. This reconfigurable antenna can be used for air/space surveillance on the sky, for simultaneousfull-duplex communication and control of several satellites.

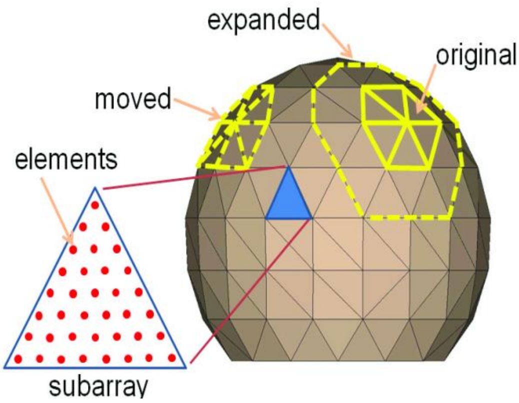

Figure 10:A phased array antennacreated on a geodesic dome. The yellow regions represent regions of activated subarrays.

Other reconfigurable array types that made by switching an active element on and off consist ofa dynamically contracted array elementsin order to modify nulls and the sidelobe levels to eliminate interference [38].

Another methodin thereconfigurable array antenna is to materially move elements. Some of thegreatest reflector-antenna arrays use this idea. As an example, the Atacama Large Millimeter/sub-millimeter Array (ALMA) system, whichwas a radio telescope combined from 66 (12 m and 7 m) parabolic reflector high-precision antennasin Chile's Andes Mountains (Figure 11 (a)) [39]. Each parabolic dish performs the same function as the mirror of an optical telescope: it assembles radiation coming from remote astronomical matters, and focuses it into a sensor that measures the radiation. The array antenna operated at frequency bands from (31.25 GHz to 950 GHz). Array structures from 250 m to 15 km can be probable. The ALMA antennas will be replaced between flat concrete blocks by a special vehicle.

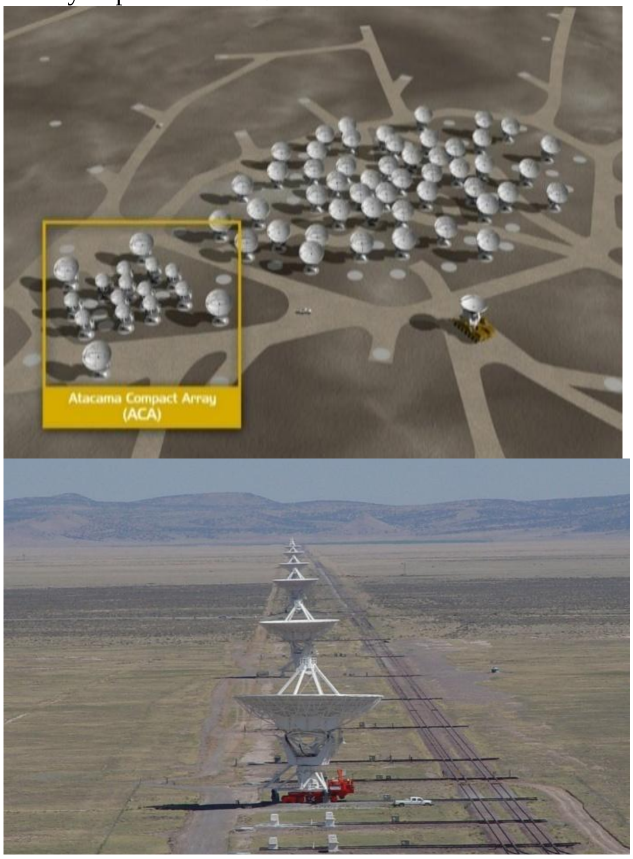

Figure 11:Reconfigurable ArrayAntenna (a)An artist's model of ALMA.(b) The VLA antennas on railroad tracks.

A second example on the same concept is the Very Large Array (VLA) radio telescope located in New Mexico, built from 27 dish antennas (25 m diameter)[40]. Antennas are arranged in a Y shape, and can be changed by moving the antennasby using railroad track (Figure 11 (b)). There are four possible formations, with array antenna sizes of (36 km, 10 km, 3.6 km, or 1 km), can be used. The array can operate in frequency bands between (73 MHz and 50 GHz).

The concept of rearranging elements to form a preferred array aperture furthermore extends to the outer space. For example, the TechSat 21 space-based radarsystem creates a great sparse array antenna by putting the antenna elements on a small spacecraft, and combining the aperture with anarrangement of the specific satellites [41]. Beam construction was a function of the satellite group and the increment of the radiation waves.

E. Reconfigurable antenna with a tunable materials:

The reconfigurable antenna can be based on the tunable materials that have tunable magnetic, electrical, and mechanical properties. For instance, the propagation frequency within the RF constructioncan be adjusted by permittivity (ε_r) or permeability (μ_r) variations, the ability to alter the configuration will be basicallyproportional to the magnitudes of (ε_r) and (μ_r) [42]. Tunable mechanical strain modifieswhichever the active length of the antenna, or improves the impedance due to the capacitive coupling. Many theories have been researched earlier for millimeter-wave and microwave phase shifters, such as tunable permeability[43]. A characteristic list of thepossible technologies for reconfigurable antennas is reviewed in Table 2.

Table 2:Potential technologies with tunable dielectric, magnetic, and strain for frequency-agile devices[43].

Method	*Tunability (%)*	*Q*	*Stimulus*	*Frequency*
Dielectric Thin Film [44]	**30**	**45**	**Electric Field E=70 kV/cm**	**1-20 GHz**
Dielectric Bulk Ceramic [45]	**16**	**>100**	**Electric Field E=15 kV/cm**	**1-10 GHz**
Magnetic Film	**15**	**5<Q<11**	**Magnetic Field 80 kA/m**	**0.3-5 GHz**
Magnetic Bulk Ceramic	**3.4* (12)**	**<1700**	**Magnetic Field**	**7 GHz**
Displacement Microstrip	**25* (625)**	**40 < Q < 100**	**Dielectric Translation (100 μm)**	**3-7 GHz**
MEMS variable capacitor	**80**	**100 < Q < 300**	**Mechanical Displacement 1 μm**	**0.5-4 GHz**
Varactor	**60**	**30 < Q < 60**	**Bias Voltage (20 V)**	**10 GHz**

* Tunable frequency is proportional to the square root of the tunable permittivityor permeability, and the squares of the value are shown for comparison with the other methods (shown in parenthesis).

Tunable conductivity:

The reconfigurable antenna can be adjusted the Conductivity in semiconductors bycreates a modifying in light, bias, or temperature. The conductivity of a semiconductor changes depending on the level of dopingand the bandgap energy, and depending on the imperfections in the material. For instance, shining light with a photon energy more than the bandgap on the semiconductor expands thehole-chargeand free-electron carriers, which in order to increases the semiconductor's conductivity. A good example for this type are the solar cells.

Using an electric field on the polymer electrolyte-silver-polyaniline composite modifies the material from a situation of low to high conductivity. Polymer combinations with manageable resistance at microwave frequencies have constant, reproducible switching on above 1000 test cycles [46].

Phase-change chalcogenides, like $Ge_2Sb_2Te_5$, are another tunable material that have a tunable conductivity. Calculations have establishedwhich is that amorphous chalcogenides keep a low conductivity standards into the GHz frequency range [47].

Silicon is a practicalmaterial for optically regulatory conductivity. In [48], the authors describedaproducing planar antennas over a high resistivity silicon while it was activated by the insertion a dc current. This process used to define the plasma-reconfigurable antennas which is enable to modifying the beam shaping, frequency hopping, and directing without the complexity of RF feed constructions. This idea displays a possibilities for providing a performance and capabilities for the phased array with a lowered cost. Modifying the conductivity of silicon via an IR LED was described for a reconfigurable antenna [49], also for a partly adaptive array antenna with a broadband monopoles [50].

Tunable permittivity:

A number of methods have been studied to accomplish economical results for a high ability to modify with low losses and quick response, for the reason of controlling microwave filters and phased array antennas. The relation "tunability" of the permittivity of a system is described as:

$$n_r = \frac{\varepsilon_r(0) - \varepsilon_r(E)}{\varepsilon_r(0)} \qquad (3)$$

Where $\varepsilon_r(0)$ and $\varepsilon_r(E)$ are the small-signal relative permittivities with no bias and with a bias of field strength E [V/cm], respectively. The value of Tunabilitiesreached to 75% have been registered for (Ba,Sr)TiO_3slim films at 1500 kV/cm [51]. A high E field is necessary to create a large tunability; on the other hand, the tuning voltage is low (25< V) for the reason that the films width are in the nanometerthickness. Tunable dielectric devices hasa figure-of-merit, which contains the device loss [52]:

$$K = \frac{Q\,(0)\,Q\,(V_{max})(n_r - 1)^2}{n_r} \qquad (4)$$

Where Q is the opposite of the device's loss;$Q\ (V_{max})$ and$Q(0)$are at the maximum voltage and at zero bias, respectively; and $n_r$is the tunability from Equation (2). For the paraelectric $SrTiO_3$ thin films on $SrRuO_3$ conductors, the K factors as high as 500 have been registered.

Dielectric materials with the maximum tunability have paraelectric/ferroelectric alteration temperatures that are under the operating temperature. The dielectric permittivity is directly proportional to the magnitude of the tunability, which approximates 1,000 for materials with the maximum tunability [53]. The fundamental dielectric loss rises with the increasing frequency that may be the operating frequency rises into the mm-wave range [54].

The dielectric permittivities of thin layers are changed through theouter applied E field. Large modifications in permittivity by a dc voltage bias have been confirmed in epitaxial paraelectric $Ba_{0.5}Sr_{0.5}TiO_3$ ("BST") thin layers that are placed on single-crystal $LaAlO_3$ and MgO substrates [44]. The dielectric film loss is characterized as an average Q value between the high electric field and zerofield bias. Bulk BST ceramics present a high tunability, and have greater Q values that BST films. New results have beendisplayed thatthe high electric fields can be operated to bulk ceramics with nanometer size, equivalent to the greater overall tunability [45].

Tunable permeability:

As same as the tunable response in the dielectric materials, the magnetic permeability reduces with the application of astable field. for example, a rectangular microstrip patch with a 1.4 cm by 1.8 cm was produced on a 1.27 mm thick substrate (Trans-Tech G-113YIG), then was fed with a coaxial probe close to the edge of a large dimension [55]. The designedcentralfrequency was 4.6 GHz that was tunable more than a 40% bandwidth while it was magnetically biased on the plane of the substrate, and vertical to the resonant dimension. The patch antennas polarization response on garnet single crystals has similarly been researched at 5 GHz for an applied magnetic fields approximately to 600 G. The active patch dimensions can be decreased, without degrading bandwidth quality, and this is one of the important advantages of higher permeability over high permittivity [56]. There are an important materials limitations for the tunable magnetic materials, for the reason thatthe highest operating frequency and the permeability μ_r arereverselyproportional[57]. On the other hand, the magnetic-film technology will be reduced to frequencies below 10 GHz, due to the imperfection in the ferromagnetic resonance frequency. So the magnetic response of ferrites is reduced to below the K band [58].

Tunable mechanical:

The reconfigurable antenna with a tunable mechanical materials are aka active materials, and this type of tunability changes the shapes when it's appliedwith a magnetic, electric, or thermal stimulus. Magnetostrictive materials modify shape due to the applied magnetic field. Electrostrictive materials strain bythe applied electric field. The magnetic field thatused to a ferromagnetic material aligns the magnetic domains, in addition togrowths the length of the material towards the magnetic field.

The Shape-memory materials alter shape because ofthe alteration temperature. The alloys and polymers have been displayed to demonstrate this change. The Shape-memory materials restore their original form or size when subjected and deformed to asuitablestimulus.

The earliest shape-memory alloy, (Nickel Titanium Naval Ordance Laboratory), was found in the 1960s [59]. Nowadays, iron-manganese-silicon, nickel-titanium, copper-zinc-aluminum, and copper-aluminum-nickel are other normally used samples of alloys that while plastically deformed at a low temperature, andrestore the original shape once there was subjected to a high temperature. Like Ni-Mn-Ga, Some shape-memory alloys response to the magnetic fields [60]. Shape-memory polymers (SMPs) arethe same of shape-memory alloys. Shape-memory polymers on the light-induced are available as will[61].

Electrostrictive, Piezoelectric, and Maxwell stress based actuations are mechanical responses to theoperated electric field. Piezoelectricity is usually limited to non-centro-symmetric crystal constructions, and $Pb(Zr,Ti)O_3$ ("PZT") ceramics are generally used for actuator applications. Unusually high piezoelectric coefficients have been used for $Pb(Mg,Nb)O_3$ –$PbTiO_3$ ("PMN-PT") single crystals, which have strain values more than 1%. Electrostriction is achievable in all materials, and the maximum strains are discovered in PMN-PT ceramics and ferroelectric poly. Maxwell stresses, produced by the electrostatic attraction between reversely charged conductor plates, produce a very high strains in compliant polymers, like silicone.

Only the strain considerations are shown in Table 2, also additional conditions must betake into account for the construction of active materials into a tunable device. For instance, the flexible modulus of high-strain polymers is low, and will limit the whole force that was available to transfer the tunable construction. Piezoelectric materials have hysteretic strain performance at higher electric fields thatcan bereduce reproducibility in the strain response. The reversibility of the phase transition and the time response in Nitinol will limit its procedure for fast adjusting systems.

CONCLUSION OF RECONFIGURABLE ANTENNAS

In this paper, a briefly study about the reconfigurable antennas that summarized as follows:

1. Reviewing the benefits of this technique, the main advantage for such techniques was that the effective use of frequencies and the utilization of radiation reconfigurability in addition to the polarization diversity to transmit the signals over "already used" frequencies. In addition to reviewing the main challenges that could be effected the performance of this technique.
2. Also discussing the main popular application that used the reconfigurable antennas such as MIMO systems, cognitive radio, and cellular communication system.
3. A various types of reconfigurable antennas was described.It's essential to use a single antenna to achieve multiple goals leads to a large number of research for studying this important technique to achieve a specific applications.
4. The research was based on a different reconfiguration procedures used to achieve the expected reconfigurability.
5. Reconfigurable antennas were generallyclassified according to three major methods into physically,optically, electrically, and smart-material-based tunable constructions.
6. A comparison between the various techniques used to construct such category of antennas was reviewed. In the beginning, the mechanical change of a feed or other antenna part was the main research. Antenna arrays make the reconfigurability techniques an important issue with the using of an electronic control to modify the antenna's pattern. Semiconductor and mechanical switches have been the most important subject in reconfigurable-antenna research since the ninetieth of the last century. Later, material change research introduce a new system to the reconfigurable antennas, by tuning the permittivity, conductivity or the shape of this material, which is used to steer antenna parameter.

REFERENCES

[1] J. T. Bernhard, Reconfigurable Antennas. Fort Collins, CO: Morgan and Claypool, 2007.

[2] H. T. Friis, C. B. Feldman, and W. M. Sharpless, "The Determination of the Direction of Arrival of Short Radio Waves," Proceedings of the Institute of Radio Engineers, 22, 1, January 1934, pp. 47-78.

[3] E. Bruce and A. C. Beck, "Experiments with Directivity Steering for Fading Reduction," Proceedings of the Institute of Radio Engineers, 23, 4, April 1935, pp. 357-371.

[4] H. T. Friis, and C. B. Feldman, "Multiple Unit Steerable Antenna for Short-Wave Reception," Proceedings of the Institute of Radio Engineers, 257, July 1937, pp. 841-917.

[5] H. T. Friis and W. D. Lewis, "Radar Antennas," The Bell System Technical Journal, XXVI, 2, April 1947, pp. 219-317.

[6] R. L Haupt, Antenna Arrays: A Computational Approach, New York, Wiley, 2010.

[7] E. W. Matthews, C. L. Cuccia, and M. D. Rubin, "Technology Considerations for the Use of Multiple Beam Antenna Systems in Communications Satellites," IEEE Transactions on Microwave Theory and Techniques, 27, Dec ember 1979, pp. 998-1004.

[8] A. D. Monk and P. J. B. Clarricoats, "Adaptive Null Formation with a Reconfigurable Reflector Antenna," Proceedings of the Institute of Electrical Engineers Microwave Antennas and Propagation, 142, 3, June 1995, pp. 220-224.

[9] G. Wang, T. Polley, A. Hunt, and J. Papapolymerou, “A High Performance Tunable RF MEMS Switch Using Barium Strontium Titanate (BST) Dielectrics for Reconfigurable Antennas and Phased Arrays,” IEEE Antennas and Wireless Propagation Letters, 4, 2005, pp. 217-220.

[10] B.-Z. Wang, S. Xiao and J. Wang, “Reconfigurable patch-antenna design for wideband wireless communication systems,” The Institution of Engineering and Technology 2007.

[11] Ahmed Khidre, Kai-Fong Lee, Fan Yang, and Atef Z. Elsherbeni,” Circular Polarization Reconfigurable Wideband E-Shaped Patch Antenna for Wireless Applications,” IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, FEBRUARY 2013.

[12] C. Gupta, D. Maheshwari, R. K. Saraswat, M. Kumar,” A UWB Frequency-Band Reconfigurable Antenna Using Switchable Slotted Ground Structure,” 2014 Fourth International Conference on Communication Systems and Network Technologies.

[13] C. S. Junior, L. T. Manera, I. F. da Costa, and J. A. Diniz,” Optically Controlled Reconfigurable Antenna Array Based on E-Shaped Elements,” In the International Journal of Antennas and Propagation, 27 April 2014.

[14] H. Singh, R. Kanwar, M. Singh,” Steering Wheel Shaped Frequency Reconfigurable Antenna for Cognitive Radio,” Journal of Engineering Research and Applications, May 2014.

[15] M. M. Fakharian, P. Rezaei, and A. A. Orouji, “Reconfigurable Multiband Extended U-Slot Antenna with Switchable Polarization for Wireless Applications,” IEEE Antennas and Propagation Magazine, Vol. 57, No. 2, April 2015.

[16] M. N. OSMAN, M. A. RAHIM, P. GARDNER, M. R. HAMID, M.M. YUSOFF, H. A. MAJID,” An Electronically Reconfigurable Patch Antenna Design for Polarization Diversity with Fixed Resonant Frequency,” RADIOENGINEERING, VOL. 24, APRIL 2015.

[17] J. Costantine, “Design, optimization and analysis of reconfigurable antennas,” Ph.D. dissertation, Electr. Comput. Eng. Dept., Univ. New Mexico (UNM), Albuquerque, NM, Dec. 2009.

[18] “Chapter 1: Understanding Key RF Switch Specifications,” in National Instruments, The Guide to Selecting an RF Switch, http://zone.ni.com/devzone/cda/tut/p/ id/5776.

[19] “Solid State Switches,” in the Microwave Encyclopedia, http://www.microwaves101.com/encyclopedia/switches _ solidstate.cfm, November 18, 2010.

[20] F. Yang and Y. Rahmat-Samii, “A Reconfigurable Patch Antenna Using Switchable Slots for Circular Polarization Diversity,” IEEE Microwave and Wireless Components Letters, 12, 3, March 2002, pp. 96-98.

[21] J. S. Herd, M. Davidovitz, and H. Steyskal, Reconfigurable Microstrip Antenna Array Geometry which Utilizes Micro-Electro-Mechanical System (MEMS) Switches, US Patent 6,198,438, March 6, 2001.

[22] L. N. Pringle, et al., “A Reconfigurable Aperture Antenna Based on Switched Links between Electrically Small Metallic Patches,” IEEE Transactions on Antennas and Propagation, AP-52, 6, June 2004, pp. 1434- 1445.

[23] “The PIN Diode Circuit Designers’ Handbook,” Microsemi Corp., Watertown, MA, 1998.

[24] Louis E. Frenzel Jr., Principles of electronic communication systems, Published by McGraw-Hill Education, 2016.

[25] P. Bhartia and BAHL, “Frequency Agile Microstrip Antennas,” Microwave Journal, 25, 10, October 1982, pp. 6770.

[26] H. Mirzaei and G. Eleftheriades, “A Compact Frequency Reconfigurable Metamaterial-Inspired Antenna,” IEEE Antennas and Wireless Propagation Letters, 2011, pp. 1154-1157.

[27] L. Zhang, F. Yang, and A. Elsherbeni, “Analysis and Design of a Reconfigurable Dual-Strip Scanning Antenna,” IEEE International Symposium on Antennas and Propagation, June 2009.

[28] E. R. Brown, “RF-MEMS Switches for Reconfigurable Integrated Circuits,” IEEE Transactions on Microwave Theory and Techniques, 46, 11, November 1998, pp. 1868-1880.

[29] S. J. Gross, S. Tadigadapa, T. N. Jackson, S. TrolierMcKinstry, and Q. Q. Zhang, “Lead-Zirconate-Titanate-Based Piezoelectric Micro machined Switch,” Applied Physics Letters, 83, 2009, pp. 174-176.

[30] P. D. Grant, M. W. Denhoff, and R. R. Mansour, “A Comparison between RF MEMS and Semiconductor Switches,” ICMENS, August 25-27, 2004, pp. 515- 521.

[31] S. Nikolaou, N. D. Kingsley, G. E. Ponchak, J. Papapolymerou, and M. M. Tentzeris, “UWB Elliptical Monopoles with a Reconfigurable Band Notch Using MEMS Switches Actuated Without Bias Lines,” IEEE Transactions on Antennas and Propagation, AP-57, 8, August 2009, pp. 22422251.

[32] G. Wang, T. Polley, A. Hunt, and J. Papapolymerou, “A High Performance Tunable RF MEMS Switch Using Barium Strontium Titanate (BST) Dielectrics for Reconfigurable Antennas and Phased Arrays,” IEEE Antennas and Wireless Propagation Letters, 4, 2005, pp. 217-220.

[33] G. Wang, D. Thompson, E. M. Tentzeris, and J. Papapolymerou, “Low Cost RF MEMS Switches Using LCP Substrate,” 34th European Microwave Conference, 2004, pp. 1441-1444.

[34] Christos G. Christodoulou, Youssef Tawk, Steven A. Lane, and Scott R. Erwin, Senior Member IEEE “Reconfigurable Antennas for Wireless and Space Applications” Proceedings of the IEEE Vol. 100, No. 7, July 2012.

[35] “Management and Operations of the National Astronomy and Ionosphere Center (NAIC),” NSF request for proposals issued in October 01, 2010.

[36] R. L. Haupt, “Adaptive Nulling with a Reflector Antenna Using Movable Scattering Elements,” IEEE Transactions on Antennas and Propagation, 53, 2, February 2005, pp. 887-890.

[37] B. Tomasic, J. Turtle, L. Shiang et al., “The Geodesic Dome Phased Array Antenna for Satellite Control and Communication – Subarray Design, Development and Demonstration,” IEEE International Symposium on Phased Array Systems and Technology, 2003, pp. 411-416.

[38] P. Rocca and R. L. Haupt, “Dynamic Array Thinning for Adaptive Interference Cancellation,” Fourth European Conference on Antennas and Propagation (EuCAP), 2010, pp. 1-3.

[39] “About ALMA Technology,” http:// www.almaobservatory.org/, May 27, 2009.

[40] National Radio Astrono my Observatory, “An Overview of the Very Large Array,” http://www.vla.nrao.edu/genpub/overview/, June 17, 2009.

[41] H. Steyskal, J. K. Schindler, P. Franchi et al., “Pattern Synthesis for TechSat21 – A Distributed Space-Based Radar System,” IEEE Antennas and Propagation Magazine, 45, 4, August 2003, pp. 19-25.

[42] A. K. Tagantsev, V. O. Sherman, K. F. Astafiev, J. Venkatesh, and N. Setter, “Ferroelectric Materials for Micro wav e Tunable Applications,” Journal of Electroceramics, 11, 2003, pp. 5-66.

[43] S. K. Koul and B. Bhat, Microwave and Millimeter Wave Phase Shifters, Volume I, Norwood, MA, Artech House, 1991.

[44] J. S. Horwitz, W. Chang, W. Kim, S. B. Qadri, J. M. Pond, S. W. Kirchoefer, and D. B. Chrisey, “The Effect of Stress on the Microwave Dielectric Properties of Ba SrTiO Thin Films,” Journal of Electroceramics, 4, 2-3, pp. 357-363.

[45] S. Kwon, W. Hackenberger, E. Alberta, E. Furman, and M. Lanagan, “Nonlinear Dielectric Ceramics and their Applications to Capacitors

and Tunable Dielectrics," IEEE Electrical Insulation Magazine, 2011 (accepted).

[46] R. V. Wright, B. Chambers, A. Barnes, K. Lees, and A. Despotakis, "Progress in Smart Microwave Materials and Structures," Smart Materials and Structures, 9, 2000, pp. 273270.

[47] M. Mirsaneh, E. Furman, J. V. Ryan, M. T. Lanagan, and C. G. Pantano, "Frequency Dependent Electrical Measurements of Amorphous GeSbSeChalcogenide Thin Films," Applied Physics Letters, 96, 2010, p. 112907.

[48] A. E. Fathy, "Silicon-Based Reconfigurable Antennas – Concepts, Analysis, Implementation, and Feasibility," IEEE Transactions on Microwave Theory and Techniques, 51, 6, June 2003, pp. 1650-1661.

[49] R. L. Haupt, "Reconfigurable Patch with Switchable Conductive Edges," Microwave and Optical Technology Letters, 51, July 2009, pp. 1757-1760.

[50] R. L. Haupt, J. R. Flemish, and D. W. Aten, "Adaptive Nulling Using Photoconductive Attenuators," IEEE Transactions on Antennas and Propagation, AP-59, 3, March 2011, pp. 869-876.

[51] C. Basceri, S. K. Streiffer, A. I. Kingon, and R. Waser, "The Dielectric Response as a Function of Temperature and Film Thickness of Fiber-Textured (Ba, Sr) TiO Thin Films Grown by Chemical Vapor Deposition," Journal of Applied Physics, 82, 1997, p. 2497.

[52] O. G. Vendik, E. K. Hollmann, A. B. Kozyrev, and A. M. Prudan, "Ferroelectric Tuning of Planar and Bulk Microwave Devices," Journal of Superconductivity, 12, 1999, pp. 325-338.

[53] A. K. Tagantsev, V. O. Sherman, K. F. Astafiev, J. Venkatesh, and N. Setter, "Ferroelectric Materials for Micro wave Tunable Applications," Journal of Electroceramics, 11, 2003, pp. 5-66.

[54] B. D. Silverman, "Microwave Absorption in Cubic Strontium Titanate," Physical Review, 125, 1962, pp. 1921-1930.

[55] D. M. Pozar and V. Sanchez, "Magnetic Tuning of a Microstrip Antenna on a Ferrite Substrate," Electronics Letters, 24, 12, June 9, 1988, pp. 729-731. 6 1. R. C. Hansen and M. Burke, "Antennas with MagnetoDielectrics," Microwave and Optical Technology Letters, 26, 2000, pp. 75-78.

[56] J. L. Snoek, "Dispersion and Absorption in Magnetic Ferrites at Frequencies above One Mc/s," Physica, 14, 1948, pp. 207-217.

[57] J. L. Snoek, "Dispersion and Absorption in Magnetic Ferrites at Frequencies above One Mc/s," Physica, 14, 1948, pp. 207-217.

[58] J. Smit and H. P. J. WIJN, Ferrites, Phillips Technical Library, Tokyo Electrical Engineering College Press, 1965, p. 269.

[59] P. K. Kumar and D. C. Lagoudas, "Introduction to Shape Memory Alloys," in D. C. Lagoudas (ed.), Shape Memory Alloys, New York, Springer Science, 2008, pp. 1-51.

[60] K. Ullakko, "Magnetically Controlled Shape Memory Alloys: A New Class of Actuator Materials," J. Materials Engineering and Performance, 5, June 1996, pp. 405-409.

[61] M. Behl, J. Zotzmann, and A. Lendlein, "Shape-Memory Polymers and Shape-Changing Polymers," in A. Lendlein (ed.), Shape-Memory Polymers, New York, Springer-Verlag, 2009, pp. 1-40.