A survey on Application of Ferroelectric Materials for Fabrication of Microstrip Patch Antennas

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Abstract: Ferroelectric materials (FEM's) are very attractive because their dielectric constant can be modulated under the effect of an externally applied electric field perpendicular to the direction of propagation of a signal. In this paper, classification, properties and application of ferroelectric material for the fabrication of microstrip patch antennas is discussed.

Index Terms: Ferroelectric materials and Microstrip patch antenna.

I. INTRODUCTION

Ferroelectricity is a phenomenon which was discovered in 1921. The name refers to certain magnetic analogies, though it is somewhat misleading as it has no connection with iron (ferrum) at all. Ferroelectricity has also been called Seignette electricity, as Seignette or Rochelle Salt (RS) was the first material found to show ferroelectric properties such as a spontaneous polarization on cooling below the Curie point, ferroelectric domains and a ferroelectric hysteresis loop. A huge leap in the research on ferroelectric materials came in the 1950's, leading to the widespread use of barium titanate ($BaTiO_3$) based ceramics in capacitor applications and piezoelectric transducer devices. Since then, many other ferroelectric ceramics including lead titanate ($PbTiO_3$), lead zirconate titanate (PZT), lead lanthanum zirconate titanate (PLZT), and relaxor ferroelectrics like lead magnesium niobate (PMN) have been developed and utilized for a variety of applications. With the development of ceramic processing and thin film technology, many new applications have emerged. The biggest use of ferroelectric ceramics have been in the areas such as dielectric ceramics for capacitor applications, ferroelectric thin films for non volatile memories, piezoelectric materials for medical ultrasound imaging and actuators, and electro-optic materials for data storage and displays.

Since, Microstrip antennas are well known for their highly desirable physical characteristics such as low profile, light weight, low cost, ruggedness and they are well suited to integration with MICs. In comparison to traditional antenna elements, however, the electrical performance of the basic Microstrip antenna suffers from a number of serious drawbacks, e.g. narrow bandwidth; high feed network losses, poor cross polarization, and low power handling capacity. In many applications, the electrically shaping of the radiation pattern has received a great deal of attention. New possibilities are emerged by using new materials and structures. The uses of ferroelectric material with high dielectric constant as in antenna radiation element have received extensive research attention due to their favorable characteristics, which includes (1) high radiation efficiency; (2) low temperature coefficient, and (3) suitable scale in antenna design. Combined with the small amount of conductor losses that complements the designs, structures of this breed have allowed the achievement of high radiation efficiency. Ferroelectric material like Barium Strontium Titanate and Bismuth Titanate, also known as a solid solution perovskite with a field dependent permittivity, is one of the more popularly investigated in recent years. Ferroelectric materials with a perovskite structure are very significant electronic materials. They are most often used in the production of capacitors as it has a high temperature coefficient of resonant frequency, large dielectric constant and high dielectric losses.

II. CHRONOLOGICAL HISTORY OF FERROELECTRIC MATERIALS

Since the discovery of ferroelectricity in single-crystal materials (Rochelle salt) in 1921 and its subsequent extension into the realm of polycrystalline ceramics (barium titanate, $BaTiO_3$) during the early to mid-1940s, there has been a continuous succession of new materials and technology developments that have led to a significant number of industrial and commercial applications that can be directly credited to this most unusual phenomenon. Among these applications are high dielectric-constant capacitors, piezoelectric sonar and ultrasonic transducers, radio and communication filters, pyroelectric security surveillance devices, medical diagnostic transducers, stereo tweeters, buzzers, gas ignitors, positive temperature coefficient (PTC) sensors and switches, ultrasonic motors, electro-optic light valves, thin-film capacitors, ferroelectric thin-film memories and microstrip patch antennas.

The history of the discovery of ferroelectricity (electrically switchable spontaneous polarization) is a fascinating one that extends as far back as the mid-1600s when Rochelle salt (sodium potassium tartrate tetrahydrate) was first prepared by Elie Seignette in La Rochelle, France, for medicinal purposes. However, it was approximately 200 years later before this water-

soluble, crystalline material would be investigated for its pyroelectric (thermal–polar) properties, another half century before its piezoelectric (stress–polar) properties would be uncovered, and finally another 40 years would pass before ferroelectricity (a hypothetical but yet unproved property of solids at the turn of the 20th century) would be first discovered by Joseph Valasek in this same material [1]. Rochelle salt was a popular material in these initial studies, because it was readily available and easily grown as large single crystals of excellent optical quality, but its water solubility eventually led to its disuse in later years. Several excellent papers on the history of ferroelectricity have been written, and the reader is referred to these for many of the details [2]-[5].

A chronological listing of many of the more notable specific events in the history of ferroelectric materials is given in Table I. Because this article emphasizes a comprehensive review of ferroelectric (FE) polycrystalline ceramics from a materials point of view, timeline events involving compositions, processing, fabrication techniques, properties, patents, and applications are all included in Table I, whereas the specifics involving ferroelectric single crystals and the development of the phenomenological basis for the ferroelectric phenomenon are not treated in detail [5]. The time period is from the early 1800s to the present (2012), involving events from the early work on single-crystal Rochelle salt to (1) the birth of ferroelectric ceramics in the 1940s[5], (2) the development of lead zirconate titanate (PZT) piezoelectric ceramics in the mid-1950s[5], (3) the research and development of transparent electrooptic lead lanthanum zirconate titanate (PLZT) ceramics the late 1960s[5], (4) the engineered ferroelectric composites of the late 1970s[5], (5) the development of lead magnesium niobate (PMN) relaxor ceramics and the use of sol–gel techniques for the preparation of ferroelectric films in the 1980s[5], (6) the strain-amplified actuators of the early 1990s[5], (7) the current integrated ferroelectric films on silicon[5], (8) lead free ferroelectric material for high temperature application in 2005s[6], (9) fast switching ferroelectric material BST(M) developed in 2006[7], (10) A new family of ferroelectric materials: $Me_2Nb_4O_{11}$ (Me = Na and Ag) in 2010[8], (11) Organic Ferroelectric Material Based on Maleopimaric Acid Anhydride in 2011[9]-[10], (12) The first columnar ferroelectric liquid crystal is developed in 2012[11]. Many of the items listed in TableI are described in detail in separate sections throughout the paper.

TABLE I Notable Events in the History of Ferroelectric Materials [5]

1824	Pyroelectricty discovered in Rochelle salt
1880	Piezoelectricity discovered in Rochelle salt, quartz, and other minerals
1912	Ferroelectricity first proposed as property of solids
1921	Ferroelectricity discovered in Rochelle salt
1935	Ferroelectricity discovered in KH_2PO_4
1941	$BaTiO_3$ high-K (>1200) capacitors developed
1944	Ferroelectricity discovered in ABO_3-type perovskite $BaTiO_3$
1945	$BaTiO_3$ reported as useful piezo transducer, Pat. No. 2 486 560
1949	Phenomenological theory of $BaTiO_3$ introduced
1949	$LiNbO_3$ and $LiTaO_3$ reported as FE
1951	Concept of antiferroelectricity introduced
1952	PZT reported as FE solid-solution system, phase diagram established
1953	$PbNb_2O_6$ reported as FE
1954	PZT reported as useful piezo transducer, Pat. No. 2 708 244
1955	Alkali niobates reported as FE
1955	PTC effect in $BaTiO_3$ reported
1955	Chemical coprecipitation of FE materials introduced
1957	$BaTiO_3$ barrier layer capacitors developed
1959	PZT 5A and 5H MPB-type piezo compositions, Pat. No. 2 911 370
1961	Lattice dynamics theory for FE materials, soft modes introduced
1961	PMN relaxor materials reported
1964	Oxygen/atmosphere sintering for FEs developed
1964	FE semiconductor (PTC) devices developed
1967	Optical and E/O properties of hot-pressed FE ceramics reported
1969	Terms "ferroic" and "ferroelectricity" introduced
1969	Optical transparency achieved in hot-pressed PLZT ceramics
1970	PLZT compositional phase diagram established, Pat. No. 3 666 666
1971	Useful E/O properties reported for PLZT, Pat. No. 3 737 211
1973	Oxygen/atmosphere sintering of PLZT to full transparency
1977	FE thin films developed
1978	Engineered (connectivity designed) FE composites developed
1980	Electrostrictive relaxor PMN devices developed, Pat. No. 5 345 139
1981	Sol–gel techniques developed for the preparation of FE films
1983	Photostrictive effects reported in PZT and PLZT
1991	Moonie piezo flextensional devices developed, Pat. No. 4 999 819
1992	RAINBOW piezo bending actuators developed, pat. No. 5471 721
1993	Integration of FE films to silicon technology, Pat. No. 5 038 323
1997	Relaxor single-crystal materials developed for piezo Transducers
1998	Mineral fresnoite $Ba_2TiOSi_2O_7$ developed
1999	$K_2(Nbo)_2Si_4O_{12}$ new ferroelectric material
2005	Lead free ferroelectric material
2005	Pyroelectricty and spontaneous polarization in PZN-PT
2006	Development of BST(M) ferroelectric material
2010	A new family of ferroelectric materials: $Me_2Nb_4O_{11}$ (Me = Na and Ag)
2010	New method for measuring properties of ferroelectric material in microwave
2011	Organic Ferroelectric Material Based on Maleopimaric Acid Anhydride
2012	First-principles investigations of ferroelectricity and piezoelectricity in $BaTiO_3$/$PbTiO_3$ super lattices
2012	The first columnar ferroelectric liquid crystal

III. CLASSIFICATION OF FERROELECTRIC MATERIAL

Ferroelectric can be divided into two main groups, displacive (polarization along several axes that are equivalent in the unpolar state) and order-disorder (polarization along only one axis, "up" or "down") [12]-[13]. Table 1.2 describes the types of ferroelectric material.

A. Displacive Ferroelectric

This group of ferroelectric materials exhibits the polarization due to ionic displacements of certain atoms in the crystal lattice dynamics. The displacive class crystal contains oxygen octahedra, so it is also named as oxygen octahedral ferroelectrics. The most typical displacive ferroelectrics are perovskite type, for example $BaTiO_3$, $KNbO_3$, $PbTiO_3$, $KTaO_3$, $NaNbO_3$, $NaTaO_3$, $PbZrO_3$, $PbHfO_3$, $LiNbO_3$, $LiTiO_3$ [14]-[16].

TABLE II Classification of Ferroelectric Materials

Transition	Displacive	Order-disorder
Property	If in the paraelectric phase, the atomic displacements are oscillations about a non polar site, then after a displacive transition the oscillations are about a polar site.	If in the paraelectric phase, the atomic displacements are about double well or multi well configuration of sites, then in an order disorder transition the displacements are about an ordered subset of these wells.
Materials	Ionic crystal structure closely related to the perovskite and ilmenite structures. The simplest ferroelectric crystal is GeTe with the sodium chloride structure	Crystals with hydrogen bonds in which the motion of the proton is related to ferroelectric properties, as in potassium dihydrogen phosphate (KH_2PO_4,KDP) and isomorphous salts.

The typical ferroelectric perovskite BaTiO3 happens to be the first known ferroelectric perovskite. The perovskite structure has a general formula ABO3 shown in fig1, where A is a monovalent or bivalent metal (A+ or A2+), B is a tetra- or pentavalent one (B4+ or B5+), and O the oxygen atom.
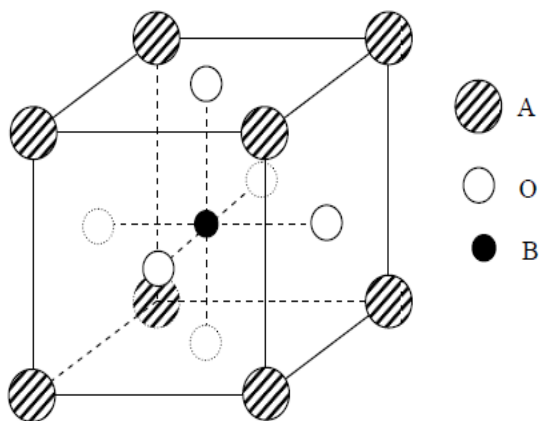

Fig. 1: The cubic structure of perovskite, ABO₃

B. Order- Disorder Ferroelectric

The order-disorder class of ferroelectrics includes crystals in which the spontaneous polarization is a result from the linear ordering of the proton ions in the structure [17]. There are two major groups of order disorder ferroelectrics.

The first one consists of elements, such as phosphates, sulphates, fluoroberyllates, cyanides, periodates and glycine compounds, where the spontaneous polarizations appears as a result of the ordering of protons in the hydrogen bonds. They are known as hydrogen bonded ferroelectrics. The second group consists of tartrates, potassium nitrate, sodium nitrate, dicalcium strontium propionate and

tetramethylammomium chloro- and bromomercurates. In this group, spontaneous polarization is caused by the arbitrary ordering of radicals, which takes place from hindered rotation. The typical examples of order-disorder ferroelectrics are sodium nitrite $NaNO_2$, potassium dihydrogen phosphate (KDP) KH_2PO_4 and triglycine sulphate (TGS) $(CH_2NH_2COOH)_3H_2SO_4$. KDP shown in fig 2 is tetragonal above 124K with a non-centrosymmetric space group 142d [15]-[18].
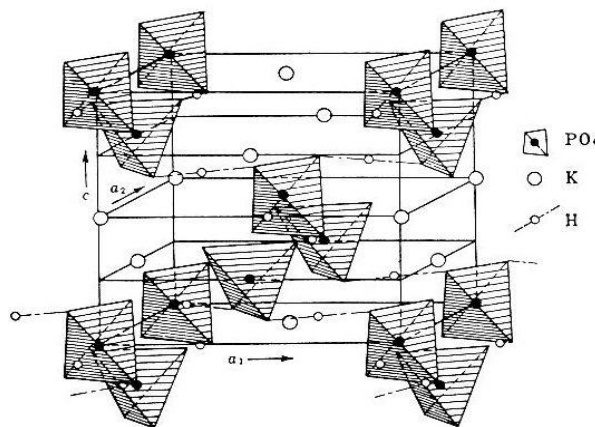

Fig. 2: The structure of KH₂PO₄ (KDP) crystal

IV. GENERAL PROPERTIES OF FERROELECTRIC MATERIALS

A. Crystal Symmetry

The lattice structure described by the Bravais unit cell of the crystal governs the crystal symmetry. Though there are thousands of crystals in nature, they all can be grouped together into 230 microscopic symmetry types or space groups based on the symmetry elements [19]. A combination of these symmetry elements gives us the macroscopic symmetry also called as point groups. It can be shown by the inspection of the 230 space groups that there are just 32 point groups. The thirty-two point groups can be further classified into (a) crystals having a center of symmetry and (b) crystals which do not possess a center of symmetry.
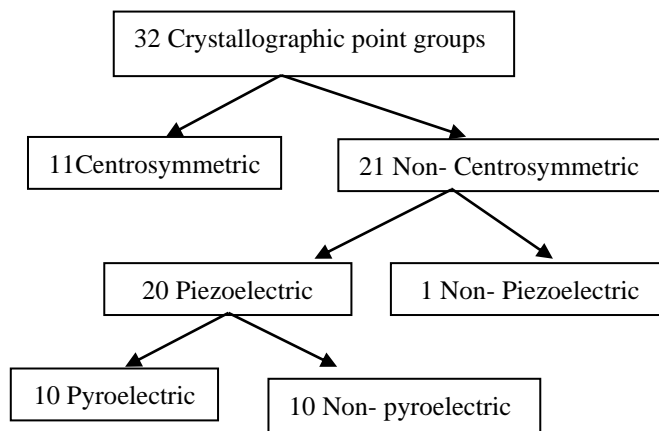

Fig.3: Crystal symmetry

Crystals with a center of symmetry include the 11 point group's labeled centrosymmetric in Figure3. These point groups do not show polarity. The remaining 21 point groups do not have a center of symmetry (i.e. non-centrosymmetric). A crystal having no center of symmetry possesses one or more crystallographically unique directional axes. All non-centrosymmetric point groups, except the 432 point group, show piezoelectric effect along unique directional axes. Out of the twenty point groups which show the piezoelectric effect, ten point groups (including 1, 2, m, mm2, 4, 4mm, 3, 3m, 6, and 6mm) have only one unique direction axis. Such crystals are called polar crystals as they show spontaneous polarization.

A. Spontaneous Polarization and Pyroelectric Effect

The spontaneous polarization is given by the value of the dipole moment per unit volume or by the value of the charge per unit area on the surface perpendicular to the axis of spontaneous polarization [20]. The axis of spontaneous polarization is usually along a given crystal axis. Although a crystal with polar axes (20 non-centrosymmetric point groups) shows the piezoelectric effect, it is not necessary for it to have a spontaneous polarization vector. It could be due to the canceling of the electric moments along the different polar axes to give a zero net polarization. Only crystals with a unique polar axis (10 out of 21 non-centrosymmetric point groups) show a spontaneous polarization vector P_s along this axis.

The value of the spontaneous polarization depends on the temperature. This is called the pyroelectric effect which was first discovered in tourmaline by Teophrast in 314 B.C. and so named by Brewster in 1824 [21]. The pyroelectric effect can be described in terms of the pyroelectric coefficient [22]-[26]. A small change in the temperature p T, in a crystal, in a gradual manner, leads to a change in the spontaneous polarization vector D P_s given by,

$$D P_s = p D T \qquad (1)$$

B. Ferroelectric Domains and Hysteresis Loop

Ferroelectric crystals possess regions with uniform polarization called ferroelectric domains [27]. Within a domain, all the electric dipoles are aligned in the same direction. There may be many domains in a crystal separated by interfaces called domain walls. A ferroelectric single crystal, when grown, has multiple ferroelectric domains. A single domain can be obtained by domain wall motion made possible by the application of an appropriate electric field [28]-[30]. A very strong field could lead to the reversal of the polarization in the domain, known as domain switching [19].

The main difference between pyroelectric and ferroelectric materials is that the direction of the spontaneous polarization in ferroelectrics can be switched by an applied electric field. The polarization reversal can be observed by measuring the ferroelectric hysteresis as shown in Figure 5. As the electric field strength is increased, the domains start to align in the positive direction giving rise to a rapid increase in the polarization (OB).

At very high field levels, the polarization reaches a saturation value (P_{sat}). The polarization does not fall to zero when the external field is removed. At zero external field, some of the domains remain aligned in the positive direction, hence the crystal will show a remnant polarization P_r. The crystal cannot be completely depolarized until a field of magnitude OF is applied in the negative direction. The external field needed to reduce the polarization to zero is called the coercive field strength E_c. If the field is increased to a more negative value, the direction of polarization flips and hence a hysteresis loop is obtained. The value of the spontaneous polarization P_s (OE) is obtained by extrapolating the curve onto the polarization axes (CE) [31].
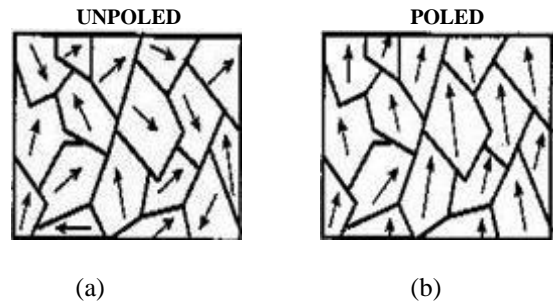

(a)   (b)

Fig. 4: Orientation of polarization in ferroelectric domain when (A) in the absence of electric field (B) in the electric field

A. Curie point and Phase Transitions

All ferroelectric materials have a transition temperature called the Curie point (T_c). At a temperature $T > T_c$ the crystal does not exhibit ferroelectricity, while for $T < T_c$ it is ferroelectric. On decreasing the temperature through the Curie point, a ferroelectric crystal undergoes a phase transition from a non-ferroelectric phase to a ferroelectric phase [32]. If there are more than one ferroelectric phases, the temperature at which the crystal transforms from one ferroelectric phase to another is called the transition temperature [33]-[39].
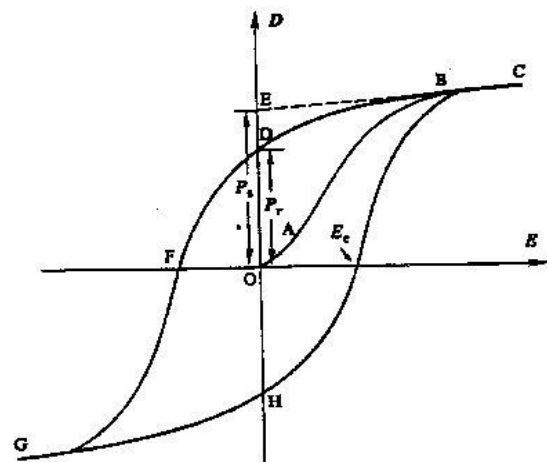

Fig. 5: A Polarization vs. Electric Field (P-E) hysteresis loop for a typical ferroelectric crystal

V. MICROSTRIP PATCH ANTENNAS BASED ON FERROELECTRIC MATERIALS

Since the ferroelectric materials are very attractive because their dielectric constant can be modulated under the effect of an externally applied electric field.

The ferroelectric materials may be particularly used for the development of different type of Microstrip patch antennas. In this paper, different type of configurations of Microstrip patch antennas are studied, which are fabricated by the used of the ferroelectric materials. The first design of ferroelectric materials used Microstrip patch antenna is the Microstrip antenna with ferroelectric layer. In this antenna a thin tape of ferroelectric material is used in the multilayered structure. This antenna was proposed in 2001. Ferroelectric materials of series BSTO, PSTO and similar titanates was used in this antenna. The next antenna is tunable ferroelectric antenna for fixed frequency scanning applications and proposed in 2006. This antenna consists of a grounded substrate – superstrate configuration covered with a two- dimensional periodic array in a conducting plane. The superstrate is a thin ferroelectric slab, under a bias voltage, changes its permittivity allowing for a fixed – frequency electronically controlled scanning process. The next antenna is frequency tunable Microstrip patch antenna using ferroelectric thin film varactor and proposed in 2009. This antenna is used BST thin film of ferroelectric material. This antenna shows a high tuning range with a lower variation of the DC biasing voltage applied on the ferroelectric varactor. The last antenna is Microstrip patch array antenna and proposed in 2012. There are two different ferroelectric had been used on the proposed antennas which include of Barium Strontium Titanate (BST) and Bismuth Titanate (BiT), suitable for Access Points operating in the WLAN IEEE 802.11 and WiMAX IEEE 802.16 within the range of 2.3 GHz to 2.5 GHz application. All above antennas are presented in the following section.

A. Microstrip Antenna with Ferroelectric Layer

Antenna Design

Figure 6 shows a basic configuration of the discussed microstrip antenna. The main feature of the ferroelectric antennas is the change of ferroelectric material permittivity with an applied dc (direct current) control voltage. The multilayer substrate consists of thin ferroelectric tape sandwiched between dielectric slabs (also for the heat transferring). Substrates are located on the conducting plate. Ferroelectric tape has thickness h_3 and is made up of ferroelectric material which permittivity (e_3) can be changed by applying and varying the dc electric field. DC voltage source V is used as shown in Figure4.

Dielectric slabs have thicknesses h_2 and h_4 and permittivities e_2 and e_4, respectively, and conducting plate is described by thickness h_1 and conductivity s. Microstrip line with current Jex is a source which excites the multilayer structure. Characteristics of this Microstrip antenna depend on parameters of dielectric substrate (i.e. thicknesses and permittivities). Radiating elements employing ferroelectric materials may give much better performance with compared to ferrite ones, because of their high power handling capability, low drive power, full military temperature range of operation and low cost [40]-[41].
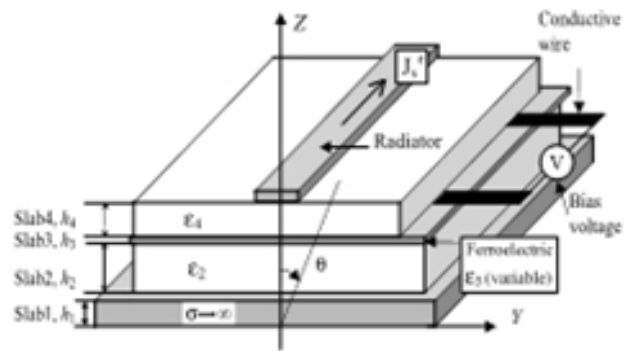

Fig. 6: Basic configuration of the ferroelectric microstrip antenna

Ferroelectric materials of series (Ba-Sr)TiO$_3$ (BSTO), (Pb-Sr)TiO$_3$ and (Pb-Ca)TiO$_3$ and similar titanates (for which the Curie temperature is in the vicinity of room temperature) are well suited for microstrip applications. Materials such as (Ba-Sr)TiO$_3$ series exhibit a significant variation of the dielectric constant with applied dc biasing fields at microwave frequencies (e.g. from 1000 to 6000) because the Curie temperature is close to the room temperature. Also, the loss tangent value of barium-strontium titanate materials can be reduced to 0.005 by adding a small percentage (1 to 4 percent) of iron, nickel or magnesium to the material mixture. The dielectric constant variation with dc biasing field is larger if the Curie temperature for a BSTO composition is closer to the ambient temperature (25^0C).

B. Tunable Ferroelectric Antenna for Fixed Frequency Scanning Applications

Antenna Design

Figure 7 shows the antenna (where the relevant geometrical and physical parameters are also shown) and consists of a grounded nonmagnetic substrate-superstrate configuration (already proposed in [42] as a highly directive frequency- scannable LWA) in which the superstrate is a thin FE slab. Under a bias voltage, the superstrate changes its permittivity allowing for a fixed-frequency electronically controlled scanning process [43].

The structure can be fed by a simple source (e.g., a printed dipole inside the substrate or a narrow slot on the ground plane): in any case, the radiated pattern and the tunable behavior mainly depend on the leaky-wave (LW) features and not on the adopted excitation. In order to uniformly apply the bias electric field, the FE superstrate is covered with a conducting plate supporting a 2-D periodic array of slots, which has been act as a partially reflecting surface (PRS) allowing for a highly directive radiation. Under this operation, if the superstrate is thin, its permittivity is essentially a scalar quantity; moreover, since in most of practical applications the amplitude of the RF signal is small (with respect to the dc bias), the response of the material at RF can be treated as linear. It should be noted that the proposed design differs from other FE LWAs such as those studied in, which are based on

the excitation of a 1-D LW along uniform or periodic 1-D waveguides; in fact, the present 2-D structure radiates a conical beam, whereas the antennas in radiate a fan beam.
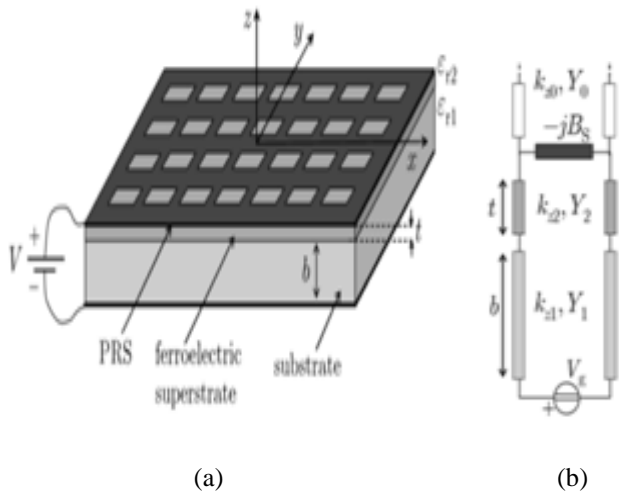

(a)   (b)

Fig. 7: (a) Three-dimensional view of the FE LW antenna, with the relevant physical and geometrical parameters. (b) Transverse equivalent network (TEN) model of the antenna in (a), excited by a magnetic dipole on the ground plane [43]

C. Frequency Tunable Microstrip Patch Antenna Using Ferroelectric Thin Film Varactor

Antenna Design

A shown in Figure 8, the structure of the frequency tunable antenna is composed of a microstrip patch antenna, impedance matching network, CPW feedline, and either a single [44] or multiple RF ferroelectric varactors [45].The microstrip antenna is a standard patch antenna with an inset feed to achieve an input impedance of 50. The MEMS capacitor was loaded at the radiating edge opposite to the inset feed. By varying the actuation voltage applied between the MEMS bridge and the center conductor, the loading capacitance of the patch antenna can be tuned and hence the resonant frequency. The similar concept of frequency tuning is employed in this design, but the RF ferroelectric varactor is used as part of the feedline. To connect the microstrip antenna to the varactor, a section of CPW feedline and a tapered microstrip line are used. The RF ferroelectric varactor is designed using a coplanar waveguide (CPW) transmission line with a multilayer substrate [46].
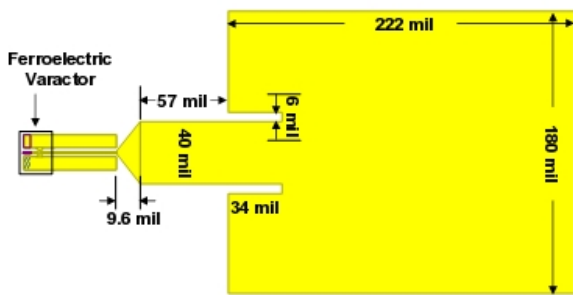

Fig. 8: Complete single varactor frequency tunable microstrip patch antenna.

Figure 9 shows the cross-section of the structure of the varactor. This cross-section consists of two layers of metal and the Barium-Strontium-Titanate (BST) thin film

sandwiched between the metal layers. The whole device is built on a silicon substrate. The top metal includes two ground lines and one signal line. The bottom metal layer employs exactly the same structure for the ground lines as the top metal, but without the signal line the two ground lines are shorted by a thin conductor, which is perpendicular to the signal line on the top metal. The overlap area between the narrower signal line (top metal) and the vertical thin conductor (bottom metal) forms the capacitor. By adjusting the DC biasing voltage applied to the signal line, the capacitance of the RF ferroelectric varactor can be varied; hence the resonant frequency of the antenna can be tuned. When the DC biasing voltage applied on the device is changed, the dielectric constant of the BST thin film will be tuned, hence the capacitance of the varactor. The relationship between the capacitance and the tunable dielectric constant is

$$C(V) = \frac{\epsilon(V)A}{d} \tag{2}$$

Where $\epsilon(V)$ is the voltage dependent dielectric permittivity, A is the overlap area between the two thin lines, and d is the thickness of the BST thin film.
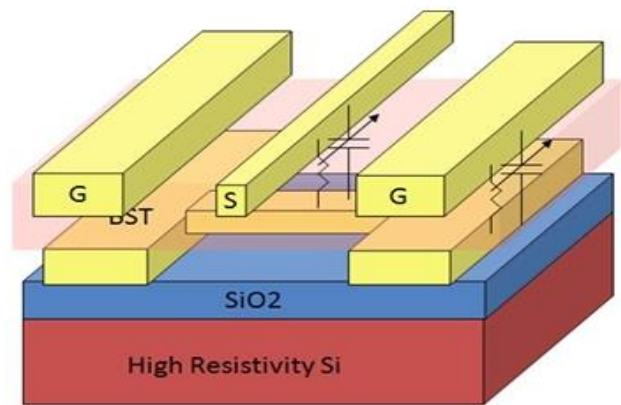

Fig. 9: A 3-D perspective of the RF ferroelectric varactor

When no biasing voltage applied, the capacitance of the ferroelectric varactor is at the largest value. As the bias voltage increases, the capacitance will monotonically decrease. This in turn changes the reactance of the antenna feedline and causes the resonant frequency of the antenna to change. The previous structure is also used for the multiple varactor design. The frequency agile antenna is fed with an additional six RF ferroelectric varactors connected in a cascade arrangement. This arrangement is known as a phase control circuit [44]. Figure 10 shows the additional feed added to the previous antenna structure.

Fig. 10: Multi-varactor design

D. Microstrip Patch Array Antenna

Antenna Design

A dielectric structure which is not entirely enclosed by a conductive boundary can radiate as an antenna. Figure 11 shows BST ferroelectric material microstrip patch array antenna (a) Simulated and its dimensions, (b) Fabricated [47]. In this design, rectangular ferroelectric material array antenna each of same height h, width w and thickness, t respectively are arranged in a planar configuration over a copper ground plane (GP) and are symmetrically packed together in the most compact fashion as shown in Figure11 and Figure12 respectively. The array is excited centrally by a metallic line feed having its length L above the GP. The central metallic plate is surrounded by dielectric ceramic in rectangular form so that its boundary just touches each DRA element and helps in exciting them [48].

The dielectric ceramic uses high dielectric constant bismuth titanate, which has a dielectric constant of 21 do have the ability to produce smaller antenna compare to barium strontium titanate that is of 15 in dielectric constant as shown in Figure9 Figure10 and Table 3. The metallic feeding line uses copper, which is a conducting material, in order to function as a feeding channel. The width, *W*, of feeding line was calculated to be 4.6 mm. This width of the transmission line will provide an input impedance of 50 ohm.

TABLE III. Dimensions of BST and BiT Array Antenna

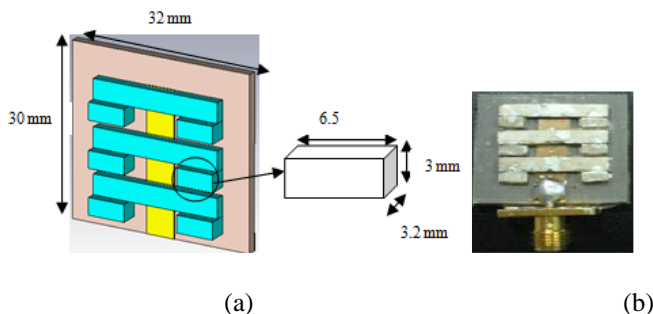| Configuration	Four element array antenna	
Dimension of substrate [mm]	BST	BiT
	H=30	H=27
	W=32	W=25
	T=1.575	T=1.575

(a)   (b)

Fig. 11: BST ferroelectric material microstrip patch array antenna (a) Simulated and its dimensions, (b) Fabricated
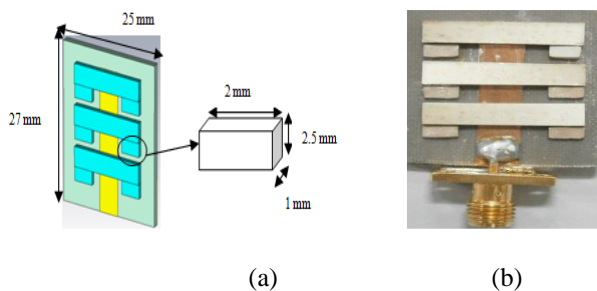

(a)   (b)

FIG. 12: BIT FERROELECTRIC MATERIAL MICROSTRIP PATCH ANTENNA (A) SIMULATED AND ITS DIMENSIONS, (B) FABRICATED

VI. CONCLUSION

Here, various types of microstrip patch antennas with ferroelectric layer have been presented. These antennas consists multilayer structure with thin film ferroelectric material or rectangular ferroelectric material array. By the use of the ferroelectric material in microstrip antennas shows that a higher frequency tuning range can be achieved for the microstrip patch antenna while keeping a very low variation of DC biasing voltages on the ferroelectric layer. Also, a good tuning accuracy is obtained by using the ferroelectric materials. Also through the ferroelectric material the antennas exhibited acceptable bandwidths, reflections and radiation characteristics (high gain antenna) for WLAN and WiMAX application

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