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A Review on Reconfigurable Antenna Analysis and Switch Technologies

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ABSTRACT

This paper presents concept and details the switching technology of reconfigurable antennas. Reconfigurable antennas provide solution where multiple types of wireless network are used for different application. The basic advantage of reconfigurable antennas is that they can alter the antenna parameter based on required field of operation. A common technique to design a reconfigurable antenna includes a microstrip patch antenna which is integrated with switching circuit. Here, a new design approach for frequency reconfigurable antenna is introduced for possible satellite applications. Reconfigurability can be achieved by using PIN diode switches.
Keywords: Frequency reconfigurable, Micro-Electro Mechanical Systems (MEMS), Microstrip patch antenna, Multiple Input Multiple Output (MIMO), PIN diode, Satellite communication.

I. INTRODUCTION

As the modern communication technologies are developed in recent years, the need of multifunctional antennas has attracted much attention. These multifunctional antennas called as reconfigurable antennas which can alter their antenna parameter as per service requirement or field of operation. According to antenna reconfiguring property it is categorized in four basic types, which are frequency reconfigurable antennas [1], polarization reconfigurable antennas [2], pattern reconfigurable antennas [3] and hybrid antennas [4].

Antenna reconfigurability for any of the above category can be achieved by changing the current distribution of the surface, by changing the feed position or feed point, by changing physical alteration or radiating edges. Frequency reconfigurable antennas can change their resonant frequency for different operating bands. In past couple of years advancement in frequency reconfigurable has been developed. Many switching techniques are used to get any operating state of frequency reconfigurable antenna for example; any desired single band resonant frequency and corresponding tuning band or multiband resonant frequencies. A patch antenna uses PIN diode for switching purpose which controls the surface current path length for different mode of switches [5]-[6].

PIN diodes or Varactors have appeared to be a faster and a more compact alternative to RF-MEMS. The switching speed of a PIN diode is in the range of 1–100 nsec [7]. Reconfigurable antennas using to p-i-n diodes [8] have more dynamic reconfiguration ability. Other reconfigurable antennas resort to varactors [9] where varying the biasing voltage can result in varying the capacitance of the corresponding varactor. Such antennas enjoy a vast tuning ability that is based on integrating a variable capacitance into the antenna structure. It is important to indicate that while electrical switching components may present efficient reconfiguration ability, they require an appropriate design of their biasing networks.

II. THE RECONFIGURABLE ANTENNA HISTORY

The concept of reconfigurable antenna used in 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 [7]. 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 [10].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” [11].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 [12].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 [13]. 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” [14]. 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 [15].

III. RECONFIGURABLE ANTENNA CLASSIFICATION METHODS

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

i. According to the reconfigurability function

The reconfigurable antenna can be grouped into 4 main categories based on their reconfigurability function as [16]:

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

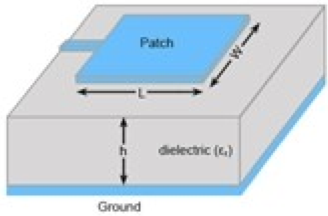

Figure 1: Microstrip Patch Antenna

Category 2: A radiating configuration that is able to adjust its radiation pattern, which is known as 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 or vertical etc.) is known as the polarization reconfigurable antenna.

Category 4: This category is a combination of the earlier three categories. For instance, one can accomplish 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.

ii. 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.

iii. According to the type of antenna used

The reconfigurable antenna can be classified into six important types which are: Antennas using semiconductor or varactor switches, using MEMS switches, using mechanically reconfigurable antenna, using reconfigurable feeding networks, reconfigurable array antennas, reconfigurable antenna with a tunable materials.

IV. ANTENNA SWITCH TECHNOLOGIES

This section gives a brief overview of the current state of RF switches available for use in antenna systems. In particular it explores PIN diodes and MEMS switches and makes recommendations of candidates for use in reconfigurable antenna designs.

The fundamental role of a switch or relay is a device to make or break an electric circuit. In static and quasi-static regimes, a switch operates simply as either a conduction path or a break in the conduction path. However, switch operation in an RF system will include additional electrical properties. Switch resistance, capacitance and inductance along the RF signal path must be included in the analysis of the system. In RF antenna systems, switch function typically entails controlling and directing the flow of RF energy along a desired RF path. Traditionally, this path may include any of the RF subsystems leading to the antenna feed distribution network as well as the antenna feed and, in the case of arrays, any power distribution network. The introduction of reconfigurable antennas has also added the antenna itself to the list of places where switches are utilized to control the direction and flow of RF current. Irrespective of the type of switch used, there are several important characteristics that must be evaluated for all RF switch applications and particularly reconfigurable antenna designs. The selection of switch type depends fundamentally on the switching speed required by the application and the switched signal power level. Other critical parameters to consider in the selection of RF switches include impedance characteristics, switch biasing and activations conditions, package and form factor, and switch cost.

i. PIN Diode Switches

The PIN diode switch is a popular in microwave circuit applications due to its fast switching times and relatively high current handling capabilities. Conventional electromechanical RF switches are inherently speed limited devices due to inertial and contact potential effects. The PIN diode can operate at speeds orders of magnitude faster than mechanical switches and can be placed in packaging measuring a fraction the size of mechanical RF switches. The PIN diode along with other solid state switches utilize a semiconductor junction as the RF control element which accounts for the increase in switch speed and reduction in package size. Switching speeds of less than 100 ns are typical. An important quality for RF applications is the fact that it can behave as an almost pure resistance at RF frequencies.

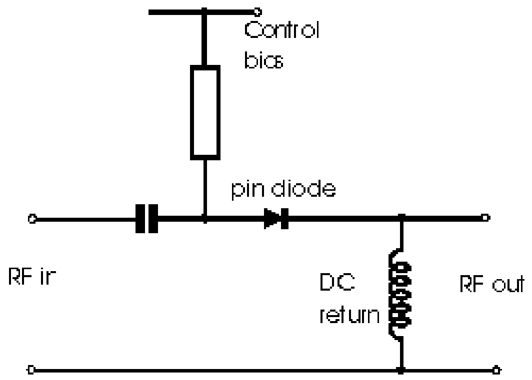

Figure 2: Pin Diode RF Switch

This resistance may be varied over a range of approximately 1ohm to 10 kohm biasing with a dc or low frequency current [17]. The bias current required for on state operation is normally on the order 10 mA. Construction of the P-I-N diode consists of two semiconductor regions a p-type and n-type separated by a resistive intrinsic region. The presence of this resistive intrinsic layer distinguishes it from a normal PN diode and is responsible for its unique properties [18]. Forward biasing the diode introduces electron-hole pairs into the intrinsic region. These charge pairs reduce the resistance of the region because they have a finite lifetime and do not recombine immediately. The charge density of the intrinsic region along with its geometry determines the diode conductance.

ii. MEMS Switches

As previously described, conventional PIN diode has seen limited use in RF and microwave antenna design. However, specific disadvantages make them unsuitable for reconfigurable antenna design where a large number of switches may be employed and individual device losses have a cumulative impact on overall antenna performance. Device deficiencies including narrow bandwidth, comparatively low isolation and high insertion loss, and finite power consumption make them unattractive for use in many reconfigurable applications. Additionally, the non-linear nature of solid-state semiconductor switches always has the potential to introduce undesirable inter-modulation products into the RF signal path. RF micro electromechanical systems (MEMS) have moved the forefront of reconfigurable antenna design because of their potential to overcome the limitations imposed by conventional RF switches. RF MEMS switches have been shown to exhibit excellent and consistent switching characteristics over an extremely wide range of operational frequencies. Additionally, their large isolation and low insertion loss characteristics result in a switch that is very close to an ideal switch for RF applications. This switch contrast ratio coupled with very low actuation power consumption, small feature size and extremely wide bandwidth makes MEMS switches ideally suited to reconfigurable antenna applications. MEMS are microscopic electronic devices fabricated using existing semiconductor process technologies that typically include a mechanical moving component. Surface micromachining has been the most important fabrication method for MEMS but other processes such as bulk micromachining, fusion bonding and LIGA (lithography, electroplating and molding) are frequently used [19].

Surface micromachining can be viewed as a three dimensional lithographic process and involves depositing various patterns of thin films on a substrate. Free-standing or suspended structures are created by applying patterns of sacrificial film layers below nonsacrificial or release layers. Selective etching of the sacrificial layers then leaves a suspended film which is capable of mechanical actuation. Active MEMS devices can function as variable capacitors, resistors and inductors; filters; resonators and switches. However, for reconfigurable antenna applications, the MEMS RF switch is the most important MEMS device.

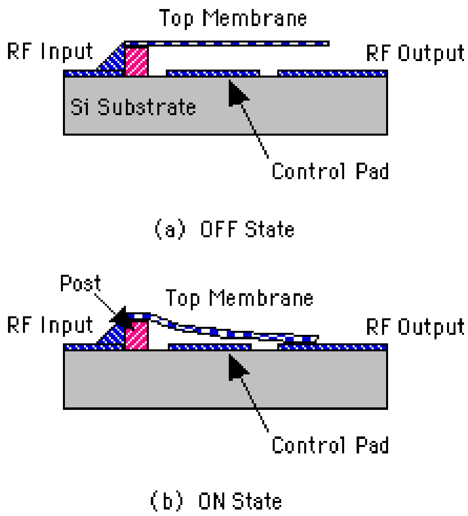

Figure 3: RF Mems Switch

As with other RF switch technologies, RF MEMS switches normally are designed in either series or shunt topologies. Shunt switches are commonly used with coplanar waveguide structures and function by shorting the RF signal path to the coplanar ground lines. A movable MEMS shunting bridge is placed between the ground lines and suspended above the signal trace. Activating the switch pulls the shorting bridge down and it into contact with the signal line which shorts the RF signal path [20]. Series MEMS switches are favorable for use in microstrip topologies and one configuration is illustrated in Figure 4. This is the socalled cantilever switch because the moving part is suspended above the microstrip transmission line like a cantilever beam. In the absence of a control voltage, the beam remains suspended above the microstrip transmission line and the switch is in the off state.

When a control voltage is applied to the pull-down electrode, the cantilever beam is brought into contact with the microstrip line and completes the transmission path. The switch is then in the on state and acts as a continuous microstrip transmission line. The off state isolation the simple dc-contact series MEMS switch is can be derived from its transmission coefficients.

V. FEEDING TECHNIQUES

The input impedance of the antenna should match with the source impedance which for all RF sources and microwave sources is 50 ohms. The antenna is looking into free space and hence acts as an impedance transducer between the 50ohms source and the 377 ohms free space. Hence a feed point should be chosen on the antenna such that, at that point the antenna has an input impedance of 50 ohms [21]. There are two types of feeding techniques. They are Contact and Non-Contacting feed Methods. The former supplies power to patch through direct path and the latter supplies power to patch through magnetic coupling. Inset feed and coaxial feed are contact feed methods. Aperture and proximity feed are non-contact methods.

i. Inset Feed

When the patch is fed by a source, the edge nearer to the source has infinite impedance because of zero current at the open circuit edge and at the middle of the patch the impedance is zero because of maximum current at the patch center. Hence, a 50 ohms input impedance feed point is selected by moving closer to the patch center [22].

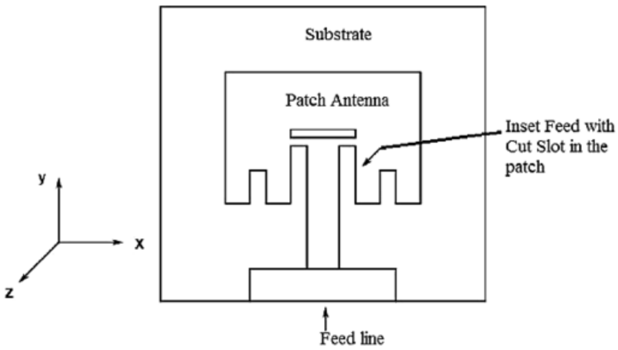

Figure 4: Inset Feed

This feed is easy to fabricate, simple to match by controlling the inset and unnecessary junctions can be avoided by printing the entire circuit in one go. The inset fed patch antenna offers good gain but its radiation efficiency is less efficient because of spurious radiation from the feed line and patch junction.

ii. Coaxial Feed

Co-axial feed is a non planar feeding technique in which a co-axial cable is used to feed the patch. The outer conductor of the cable is connected to the ground plane and the inner conductor penetrates through the dielectric making a metal contact with the patch [23].

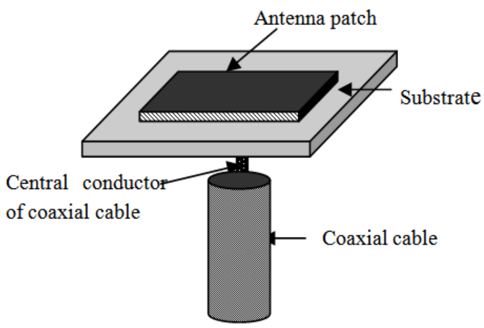

Figure 5: Coaxial Feed

The advantage with co-axial feed is that the co-axial probe can be placed at any desired location inside the patch metal in order to match with the input impedance, which is not easy with inset feed. Also, the ground plane isolates the spurious radiation from the feed and the radiation from the antenna leading to better radiation performance. The drawback with this feed is that, it is difficult to obtain impedance matching for thicker substrates due to probe inductance and significant probe radiation for thicker substrates. The probe used to couple power to the patch can generate somewhat high cross-polarized fields if electrically thick substrates are used. Co-axial feed has poor polarization purity. The location of probe is defined by the X co-ordinate and the Y co-ordinate. The probe is in direct contact with the antenna and it is located at the point where the antenna input impedance is 50 ohms.

iii. Proximity Feed

In proximity feed, the feed line is placed between two dielectric substrates. In edge fed technique it is not possible to choose a 50 ohms feed point since the impedance at the edges will be very high. To overcome this, the feed line is moved to a lower level below the patch. The edge of the feed line is located at a point where the antenna input impedance is 50 ohms. Here the power transfer from the feed to the patch takes place through electromagnetic field coupling. Since the feed line has been moved to a lower level, feed line radiation has been reduced to a great extent and also this technique allows planar feeding [24]. Also, it has an improved bandwidth efficiency compared to the other techniques. The disadvantage with this method is that multilayer fabrication has to be done and it offers poor polarization purity.

iv. Aperture Feed

Aperture feed technique consists of two dielectrics substrates namely antenna dielectric substrate and feed dielectric substrate [25]. These dielectric substrates are separated by a ground plane which has a slot at its centre. The metal patch placed on top of the antenna substrate. The ground plane is placed on the other side of the antenna dielectric.

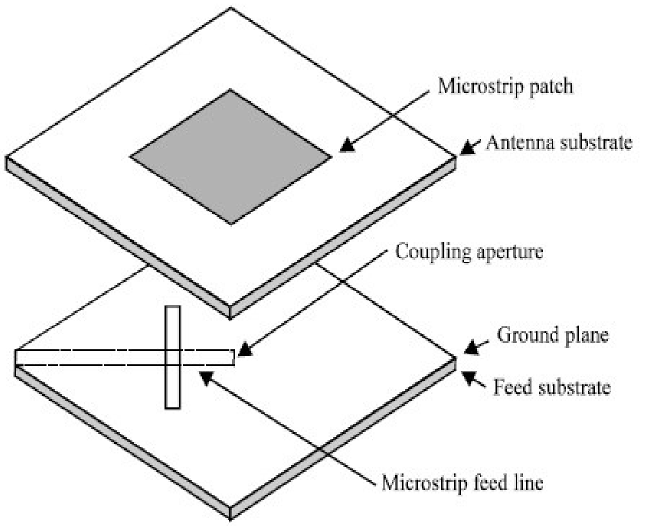

Figure 6: Aperture Feed

The feed dielectric and feed line is placed on the other side of the ground plane to provide isolation. The microstrip feed line is placed such that it is perpendicular to the ground plane slot. Power from feed line is coupled to the metal patch through electromagnetic field coupling. The microstrip feed line causes magnetic polarization in the ground plane slot which in turn excites the metal patch. The centre of the patch must coincide with the centre of the slot for maximum coupling. The major advantage of aperture feed technique is that it allows independent optimization of antenna substrate and feed line substrate. The antenna dielectric is chosen to have low dielectric constant and high dielectric thickness for maximum power radiation. The isolation of patch and feed line by the ground plane inhibits spurious radiation from corrupting the radiation pattern. Also, aperture feed provides excellent polarization purity which is something unattainable with other feed techniques [26]. Aperture fed antenna offers higher bandwidth. It is very useful in applications in which we don't want to use wires from one layer to the other. The disadvantage with this feed is that it requires multi-layer fabrication.

VI. CONCLUSION

The paper provided an expanded and detailed analysis of the reconfigurable antenna concept as well as different switching and feeding techniques. Descriptions of current and proposed reconfigurable antenna technologies including the various methodologies employed for achieving antenna reconfiguration were explored. The choice of switch is governed by electrical specifications, fabrication complexity, bias requirement, switching time, and price. For instance, RF MEMS switches are very low loss and their other advantages are that they do not require bias lines. However, they are costly. PIN diodes are low cost and have a simple fabrication process. They require a proper bias network isolating the dc bias current from the RF signal, which usually leads to a complicated biasing network. The complicated dc bias network can sometimes be avoided. Furthermore, the limited operating frequency of some commercial low cost PIN diodes can be overcome.

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