INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

Reconfigurable Antenna Methodologies and Switch Technologies: A Review

Saneh Surya Phadte
Assistant Professor, Department of ETC, SRIEIT College, Goa, India

Abstract:
Reconfigurable antennas can utilize more efficiently radio frequency spectrum, facilitating a better access to wireless services in modern radio transceivers. This paper presents the concept of reconfigurable antennas and details the emerging technologies that make reconfigurable antennas possible. First, a description of the methodologies available for designing reconfigurable antennas is presented. Then a description of the physical switch technologies and how they can be utilized for antenna design. Their electrical characteristics are described and comparison done between the two technologies.

Keywords: *Reconfigurable antennas, switch technologies*

1. Introduction

Recent years have observed the demand for reconfigurable antennas. This trend has been driven by many newly emerging wireless services. With multiband capability, reconfigurable antennas can utilize more efficiently radio frequency spectrum, facilitating a better access to wireless services in modern radio transceivers. From a systems standpoint, antennas have historically been viewed as static devices with time-constant characteristics. Once an antenna design is finalized, its operational characteristics remain unchanged during system use. However, the recent advent of microelectromechanical system (MEMS) components into microwave and millimeter wave applications has opened new and novel avenues of antenna technology development. High quality, miniature RF switches provide the antenna designer with a new tool for creating dynamic radiating structures that can be reconfigured during operation. MEMS switches are of particular interest because they offer broadband operation, low insertion loss and high contrast between active states. In the near future the antenna will evolve as a component that will offer intelligence that alters itself in-situ to meet operational goals.

While the method of antenna operation is evolving, its role in communication systems still remains the same. The task that an antenna must perform is fundamentally that of a radiator and thus the metrics by which antennas operate and are measured are still intact. Gain, bandwidth, polarization, antenna feature size, etc. are still the realizable quantities of interest. Only now the introduction of dynamic radiating structures has given the antenna designer an additional degree of freedom to meet these design goals.

2. Reconfigurable Antenna Methodologies

This section details the methodologies identified for designing reconfigurable antennas. It describes each method and illustrates the strengths and weaknesses associated with each. Example designs are presented for each method. The short existence of reconfigurable has produced two primary design methods: total geometry morphing and matching network morphing. A third method is also identified and expanded in this paper smart geometry reconfiguration. Thus, three broad methodologies have been identified for achieving reconfigurable antenna designs and operation.

Total geometry morphing represents the most structurally complicated of the methods. It is implemented though a large array of switchable sub-elements which are combined to form the desired radiating structure. Matching network morphing is the simplest of the methods and modifies only the feed structure or impedance matching network of the antenna while the radiating structure remains constant. The smart geometry reconfiguration method lies between the other two in its structural implementation complexity. It modifies only critical parameters of the antenna radiating structure to achieve the desired range of reconfigurable control.

2.1. Total Geometry Morphing Method

The total geometry morphing method achieves reconfigurable operation by switching a large array of interconnected sub-elements. The sub-elements are connected together via RF switches and are typically less than λ/20 in size. Because the sub-elements are much less than a wavelength in size they do not form efficient radiating elements individually. However, switching together multiple adjacent sub-elements results in an aggregate structure that forms the desired radiator. This sub-element arraying allows considerable exibility in forming the radiator. The geometry of the aggregate radiating structure can take a wide variety of forms depending on the desired application. The reconfigurable antennas designed via this method are often referred to in the literature as distributed radiators because the total radiating structure is distributed over many smaller structures.

Figure 1 illustrates the concept of the total geometry morphing method. The example is a reconfigurable microstrip patch antenna consisting of a large grid of switched microstrip sub-patches that are available on the dielectric substrate.

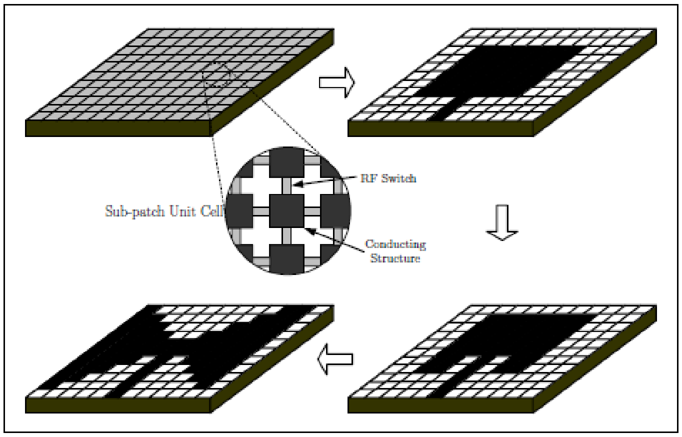

Figure 1: The total geometry morphing method of reconfigurable antenna design.

These sub-patches do not represent individual microstrip patch antennas themselves but act as actively reconfigurable conducting structures. The detailed blow-up in Figure 1 shows a single functional unit cell for the composite antenna. These unit cells illustrate the concept of the sub-patch conducting structure. Each unit cell consists of a small conducting patch of metal and four RF micro switches. The switches provide the RF conduction path to the nearest neighboring unit cell. The composite antenna is then constructed by activating the necessary switches to form then antenna. In this example the structure is first configured to form a conventional rectangular microstrip patch antenna. Next, several of the sub-patches along the length of the microstrip feed are switched to the off state. This moves the effective feed point for the patch antenna closer to the center of the patch and alters the input impedance of the patch. Finally, the unit cells are configured to form a bow-tie patch antenna which has different radiation characteristics than the rectangular patch.

The total geometry morphing method has the obvious advantage of providing a large amount of antenna reconfigurability. The array of sub-elements provides a large level of exibility in composing the aggregate antenna. Because of the exibility in configuring the antenna, a wide range of control over many antenna characteristics is offered by employing this method. Thus, a single reconfigurable platform could be used for a large number of applications. System operation over multiple frequency bands, with variable radiation pattern characteristics and selective polarization is possible with a single reconfigurable platform. Likewise, the layout of the sub-element array pattern is not limited to two dimensional planar microstrip geometries. Surface conformal and three dimensional geometries also represent viable configurations. The highly exible nature of total geometry morphing dictates the primary difficulty with implementing this method. The extreme complexity involving numerous individual components to necessary to realize the geometries is inherent in this method.

A large number of sub-elements, switches and control lines are required to implement the reconfigurable geometry. This leads directly to geometry and component management issues. A large number of active components also means there are a large number of points of failure. Recent advancements in RF MEMS switches have been the driving force behind much the reconfigurable antenna designs. As with any mechanical switch, MEMS devices are susceptible to reliability issues due to mechanical fatigue. Thus, any structure which depends explicitly on the reliable operation of these switches will be subject to performance degradation in the case of switch failure.

2.2. Matching Network Morphing Method

The matching network morphing method represents the simplest of the three techniques for achieving reconfigurable antenna operation. In this method, the actual radiating structure remains constant and only the feed or impedance matching section of the antenna is reconfigured. Like the total geometry method, this method is often employed with microstrip geometries because of the relative ease in placing RF switches on planar structures. In the case of microstrip feed lines, there are typically 10 or more subelements in the transverse direction across the width of the microstrip line for adequate parameter control. They are on the order of $\lambda/20$ in length along the longitudinal direction.

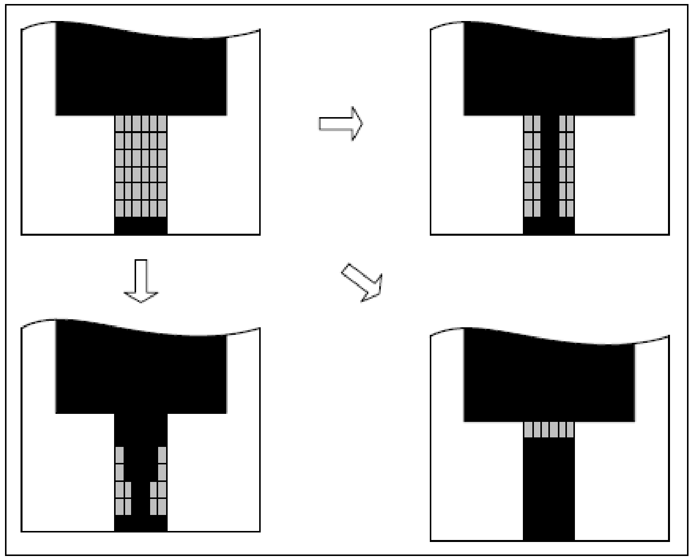

Figure 2: Microstrip feed configurations for impedance matching of reconfigurable antenna design.

Figure 2 illustrates one implementation of the matching network morphing method. In this example a microstrip patch antenna is edge fed by a reconfigurable microstrip line. The reconfigurable microstrip line consists of a small array of switchable microstrip sub-elements. Each of these sub-elements may be switched on or off by activating one of the miniature RF switches that form the interconnections between the sub-elements and compose the overall microstrip structure. The width and length of the feed line is altered to change the impedance of the microstrip. The grey boxes represent inactive sub-elements and the block boxes represent active sub-elements.

The top left configuration in Figure 2 shows the microstrip patch antenna and the available microstrip feed lattice. The top right sub-element arrangement shows the feed configured as a narrow microstrip line having a characteristic impedance. The patch antenna operates in a radiation mode that is specified by this feed configuration. The bottom two arrangements in Figure 4 show the microstrip feed line configured in two other possible formations. These variations in feed impedance then excite different radiation modes in the microstrip patch antenna. The matching network morphing technique carries the distinct advantage of being extremely simple to implement in practice. The only component of the antenna that is changed is the feed network and thus the complexity of the design is minimized.

As a result, the number of physical switching components is kept to a minimum and switch reliability becomes less of an issue. Conversely, this method exhibits the disadvantage of limited antenna reconfigurability. The antenna operation is varied only through changes in matching. Consideration is not given to other critical radiation characteristics. Because the principal radiation mode is altered by the impedance, the electrical performance characteristics are likely to change as well.

2.3. Smart Geometry Configuration

The final identified method of reconfigurable antenna design is smart geometry reconfiguration. Falling between total geometry morphing and the matching network morphing method in both the amount of achievable parameter control and system complexity, this method modifies only critical parameters of the antenna radiating structure to achieve the desired reconfigurable performance. It can be implemented with considerably fewer control elements than the total geometry method and thus has the advantage of reduced design complexity. However, with a thorough understanding of the underlying antenna design and careful design consideration it can yield a high level of reconfigurability and antenna parameter control. The primary disadvantage of this method is that the underlying physics of the particular antenna must be known in order to take advantage of minor geometry modifications to achieve the reconfigurable goal. Additionally, the amount of reconfigurability is ultimately limited by the electrical characteristics of the antenna geometry.

3. 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.

3.1. 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. This resistance may be varied over a range of approximately 1ohm to 10 kohm biasing with a dc or low frequency current [4]. 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 a 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 [5]. 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.

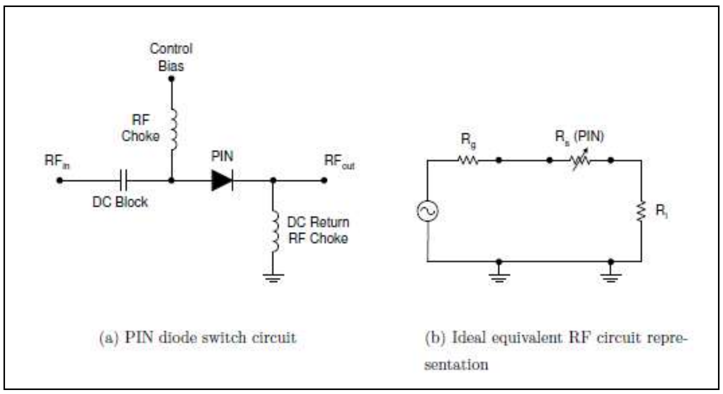

Figure 3: Series PIN diode RF switch model.

3.2. 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 [6]. 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 non-sacrificial or `release' layers [6]. 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.

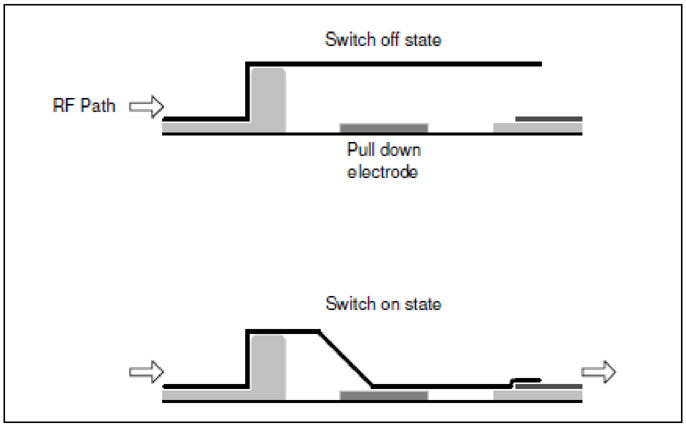

Figure 4: Cantilever style RF MEMS series switch layout in both on and off states.

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 [7].

Series MEMS switches are favorable for use in microstrip topologies and one configuration is illustrated in Figure 4. This is the so-called 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.

The advantages that MEMS switches offer over current PIN diode switches are as follow:

3.2.1. Wide Bandwidth

Similar to conventional mechanical switches, the bandwidth of RF MEMS switches is quite large. Unlike solid state which relies on a semiconductor junction, the conduction path is based on metal to metal contact. The upper limit on frequency of operation is normally restricted by reduced device isolation in the off state. RF MEMS switches have been reported to operate with high reliability from dc to 110 GHz.

3.2.2. High Isolation

The attenuation between input and output ports of the switch when in the off state is isolation. The small switch contact area and air gap filling of metal contact switches produces very little electromagnetic coupling between switch points while in the off state. Consequently, the off state capacitance of MEMS switches are in the femto-farad range. DC-contact switches operating at less than 60 GHz can achieve isolations of 50-60 dB while higher frequency capacitive switches produce acceptable isolation up to 100 GHz.

3.2.3. Low Insertion Loss

The attenuation between input and output ports of the switch when in the on state is insertion loss. Small on state capacitances and very low contact resistance facilitate very low insertion loss characteristics for MEMS switches. Insertion losses of less than 0.1 dB can be achieved for switches up to 40 GHz.

3.2.4. Low Power Consumption

Many RF MEMS switches are actuated using electrostatic mechanisms which consume almost no power and offers several critical advantages.

The first and most obvious result is that total system power is minimized which is critical for portable applications. The second result of very low power consumption is one of potentially greater significance. One of the primary concerns in designing highly integrated reconfigurable antennas is to what degree do the dc bias and control lines effect the performance of the RF structure by coupling from the RF portions of the antenna to the bias sections. Because almost no power is required to bias the switch, control lines may be created with high impedance materials and thus provide poor conduction paths for RF energy. This fact can be used to minimize and or eliminate any antenna performance degradation from the bias section.

3.2.5. Linearity

The quality of the signal passed through the switch is measured by its linearity. Switches which pass signals without distortion or the introduction of harmonics are said to be highly linear. The linearity of MEMS switches can be as much as 50 dB better than that of solid-state switches. This results in very low inter modulation products in switching operations.

There are also critical disadvantages of RF MEMS switches compared to PIN diode switches. Though none are considered insurmountable, it is necessary to identify the characteristics of MEMS switches that could potentially cause problems for reconfigurable antenna applications.

3.2.6. Slow Switching Speed

Switching speed is one aspect where MEMS switches lag behind PIN diode in performance significantly. Because MEMS are inherently mechanical in nature they are subject to inertial forces and bound by structural resonant frequencies. The fastest electrostatic topologies switch in 2-40 ms whereas PIN diode switches can operate in the nanosecond range.

3.2.7. Low Power Handling

One of the biggest limitations that MEMS switches currently face is power handling capability {most cannot reliably handle more than 200- 500 mW of power. This number however, has increased by a factor of ten in just two years and current research is targeted at improving the power capabilities.

3.2.8. High Actuation Voltage

Typical dc-contact MEMS switches require 20-80 V for electrostatic actuation. This can present a problem for portable devices where high voltage signals may not be readily available and up-converters would be needed to provide adequate switching potential. Low voltage switches are being developed to help mitigate this problem and devices have been produced which require as little as 6 V.

3.2.9. Low Reliability

Reliability considerations have been another major stumbling block for widespread use of MEMS switches. Current designs have demonstrated only 40 billion switching cycles. While this may appear to be a very large number of switch toggles, many systems require switches capable of withstanding over 200 billion cycles.

Packaging Considerations MEMS switches are inherently moving devices and thus are susceptible to environmental contamination and physical contact. Special attention must be given to the protective packaging used to shield the components and hermetic sealing is an essential part of the package assembly. Packaging also has an impact on device size, performance and cost.

4. Conclusion

The paper provided an expanded and detailed analysis of the reconfigurable antenna concept. Descriptions of current and proposed reconfigurable antenna technologies including the various methodologies employed for achieving antenna reconfiguration were explored. The three broad methods for achieving reconfigurable antenna operation were identified as total geometry morphing, matching network morphing and smart geometry reconfiguration. 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.

5. References

i. Peroulis, D., K. Sarabandi, and L. P. B. Katehi, “Design of reconfigurable slot antennas," IEEE Trans. Antennas and Propagation, Vol. 53, No. 2, 645{654, 2005.
ii. C. A. Balanis, Antenna theory: analysis and design, chapter 14, John Wiley & Sons, 1997.
iii. Broadband Microstrip Antennas by Girish Kumar and K. P. Ray.
iv. Applications of PIN Diodes, Hewlett-Packard, 1997.
v. PIN Diode Designers' Handbook, Microsemi Corp., Watertown, MA, 1998.
vi. E. R. Brown, “RF-MEMs switches for reconfigurable integrated circuits," IEEE Transactions on Microwave Theory and Techniques, vol. 46, no. 11, pp. 1868{1880,
vii. November 1998.
viii. G. M. Rebeiz, RF MEMS: Theory, Design, and Technology. Hoboken, NJ: Wiley-Interscience, 2003.