Mapping Reconfigurable Antennas Using Graphs

J. Costantine
University of New Mexico, Albuquerque, NM 87131, USA
Jmc08@ece.unm.edu

C. G. Christodoulou
University of New Mexico, Albuquerque, NM 87131, USA
christos@ece.unm.edu

S. E. Barbin
Universidade de São Paulo, São Paulo, Brazil & Centro de Pesquisas Renato Archer, Campinas, Brazil
barbin@usp.br

Abstract

This paper introduces the modeling of reconfigurable antennas using graphs. Several examples are presented and analyzed. Graphs are shown herein to be useful for modeling reconfigurable antennas with different techniques and properties.

1. Introduction

Engineering reconfigurable systems is manipulating and coordinating a large number of objects so that all together they can perform a global task. Nevertheless, there are examples of sophisticated machines, such as the mechanical motor in the bacterial flagellum, that seem to be built in bulk spontaneously. One hypothesis for how this occurs is that simple small components self assemble into more complex aggregates which, in turn, self assemble into larger aggregates [1].

One can say that reconfigurable systems are a collection of subsystems assembled together in a way to perform a new function different than the function of each individual subsystem.

Our main focus in this work is on reconfigurable antennas. Here, we discuss the application of graphs to reconfigurable antennas which is not a trivial task since graphs so far have been used to control mechanical systems that assemble together to execute a new function like in control systems.

Reconfigurable antennas are a new generation of antennas that are not limited to a certain function, radiation pattern, or resonance but can change their functionality, depending on implementation requirements. Compared to broadband antennas, reconfigurable antennas offer many advantages, like frequency selectivity, which helps in reducing adverse effects like co-site interference and jamming [2].

Several examples are presented herein to show how graph theory can be used in the design of reconfigurable antennas.

2. Reconfigurable antenna operation

The radiation pattern and functionality of an antenna are related to the current distribution on its surface. Any slight change in the geometrical configuration of the structure will create new current paths and new radiation edges, which give the antenna new resonances and operational functionality [3].

A lot of reconfigurable antennas make use of switches [3], rotating parts and many other components to vary the current distribution over the physical surface of the antenna. This constitutes a transformation or a translation from a physical activity into an electrical behavior change. So far the goal of reconfigurable antennas has been to:

1. Radiate at pre-determined frequencies on demand
2. Change the polarization,
3. Change the radiation patterns, on demand

It is also expected that these antennas, can be reconfigured remotely without rebuilding the antenna or the platform on which it is placed on [4].

In the following, we introduce the use of graphs in the case of reconfigurable antennas.

3. Graph Outlines

A graph can be defined as the collection of vertices connected together with lines called edges. A simple labeled graph over an alphabet Σ is represented by G = (V, E) where V is a set of vertices and E is a set of pairs or edges from V. There are many types of graphs but here we are only interested in studying undirected graphs. Vertices may represent physical entities and edges between them in the graph represent the presence of a function resulting from connecting these entities. If one is proposing a set of guidelines for antenna design, then a possible rule may be to create an edge between two vertices whenever their physical connection results in a meaningful antenna function.

Edges may have weights associated with them to represent costs or benefits that are to be minimized or maximized. The weight of a path is defined as the sum of the weights of its constituent edges.

4. Example 1

4.1 Antenna structure and reconfigurability

Figure 1 depicts the proposed layout of a reconfigurable antenna with one sleeve on each side of the monopole designed by V. Zachou, et al., and detailed in [5]. A sleeve is attached to each side of the monopole. Switches are used to connect two additional patches to each sleeve. An extra patch is also connected to the monopole via a switch. All the switches are shown in Figure 1. Figures 2 and 3 give the result of the return loss for the different sleeve switch states when the monopole switch is ON and OFF, respectively [5].

7.2 Graph interpretation

When switches connecting different parts of the antenna are flipped ON, the antenna's surface currents will now flow through these switches to the connected parts and vice versa if the switches are flipped OFF, leading to different antenna resonances in each case. Several graph interpretations can be utilized to express this phenomenon, depending on how we define the vertices, edges, and the applications of these connections. As a first example of a graph interpretation we consider the antenna parts as vertices as shown in Figure 4. The antenna is divided into 6 parts (P0,P1,P2,P3,P4,P5), these 6 parts represent 6 different vertices. Whenever a swicth is on and a part (P1) is connected to another one (P2) an edge is created linking the corresponding vertices:

P1 ——— P2

The whole graph representation is shown in Figure 4.

Due to the abundant use of switches in the design of reconfigurable antennas, considering switches as vertices will constitute a general case. When the antenna's surface current is flowing through the different switches, then these activated switches are linked together. If S1 is a vertex representing swicth 1 and S2 is another vertex representing switch 2, then the activation of these switches at the same time will be represented by an edge connecting S1 to S2:

S1 ——— S2

The presence of an edge connecting two vertices represent a meaningful antenna application. The shape of the whole graph at one point is interpreted by the antenna function at that physical configuration. Another graph shape means a different antenna function.

A lot of other graph representations can be achieved. For example the resonance in the S11 parameter results can be considered as vertices , or the end points of a switch can be considered as vertices and the activation of the switch will be represented by an edge; however we restrict ourselves to the former two representations(Figure 4 & Figure 5).

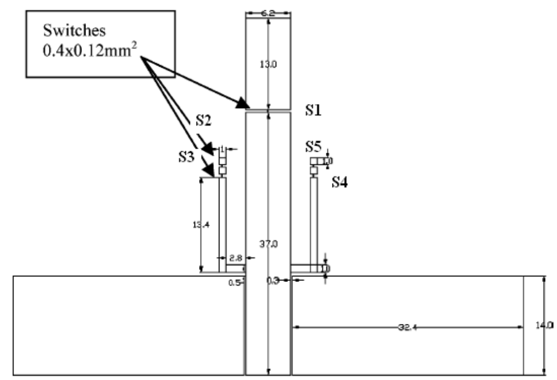


Figure 1. The Antenna Layout with Switches shown [5]

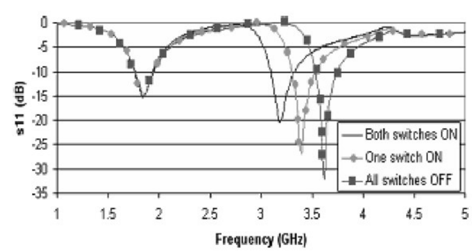


Figure 2.The Antenna S11 results when different switch configurations and the monopole switch (S1) is on [5]

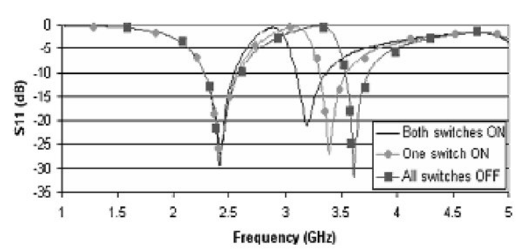


Figure 3. The Antenna S11 results when different switch configurations and the monopole switch (S1) is off [5]

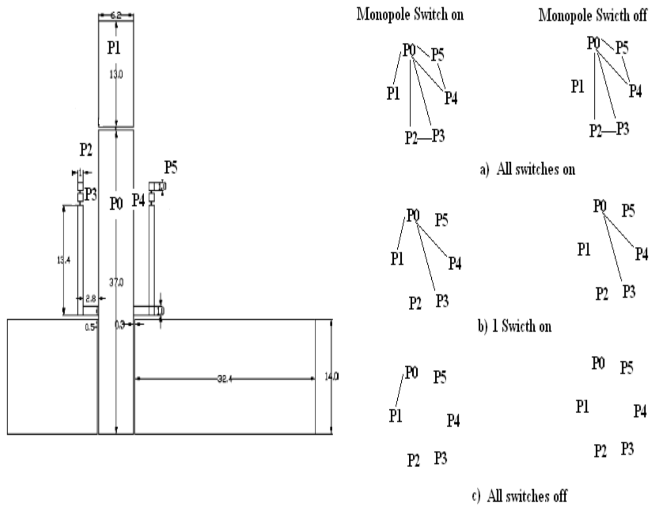


Figure 4. Graph Interpretation if different Parts of the antenna are considered as vertices.

5. Example 2

5.1 Antenna structure and reconfigurability

This antenna designed by J. costantine, et al., and detailed in [3] is a 6-armed star microstrip patch printed on a hexagonal-shaped substrate. The reconfigurability of the antenna is obtained by inserting small switches on rectangular slots cut in the patch. Different switch configurations were investigated and different functionalities of the antenna were obtained. The antenna changes its application according to which switches are activated. The structure of the antenna is shown in Figure 6.

The basic structure of the proposed antenna consists of 3 layers. The lower layer, which constitutes the ground plane, the middle layer, which is made of FR4, has a relative dielectric constant εr=4.4 and height 0.32cm. The upper layer, which is the patch, covers the hexagonal top surface. Six triangle slots are cut out of the original patch giving it the shape of a six armed star. Of the star six rectangular slots were cut on each branch. Six square switches were mounted at the center of the rectangular slots.

When the switches are activated, links between the center area of the star and the branches are established, which change the surface current distribution. In our experiment, the inserted switches were switched two at a time. Figures 7 and 8 show the different resonances that can be achieved for different switch configurations.

5.2 Graph interpretation

Switches are considered as vertices herein. These vertices are linked together as elaborated in example 1. Thus when both S1 and S4 (See Figure 6 and 7) are activated new resonances between 4 GHz and 5 GHz appear. The antenna regains its wireless LAN and broadband radio access network domain applications. The graph interpretation is shown in Figure 9.

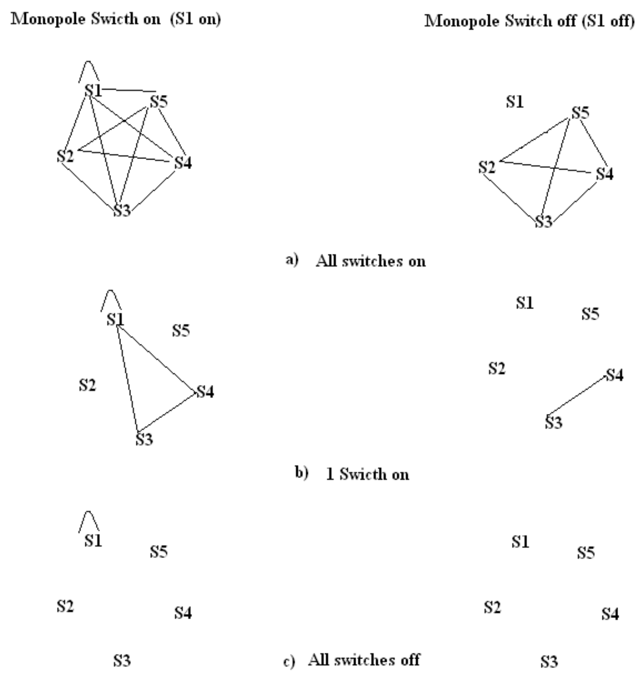


Figure 5. Graph Interpretation when the switches are considered as vertices.

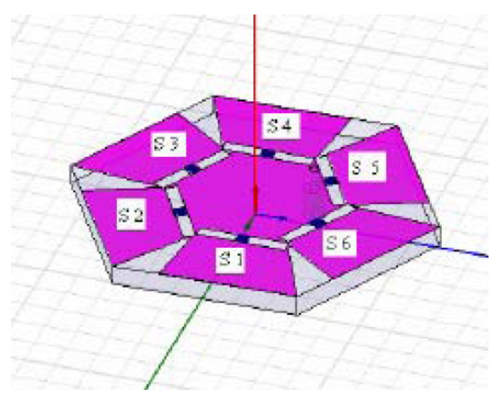


Figure 6.The structure of the antenna in [3]

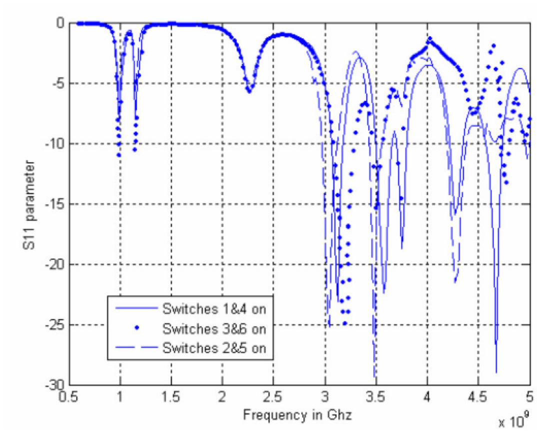


Figure 7. S11 parameter for different switch configuration [3]

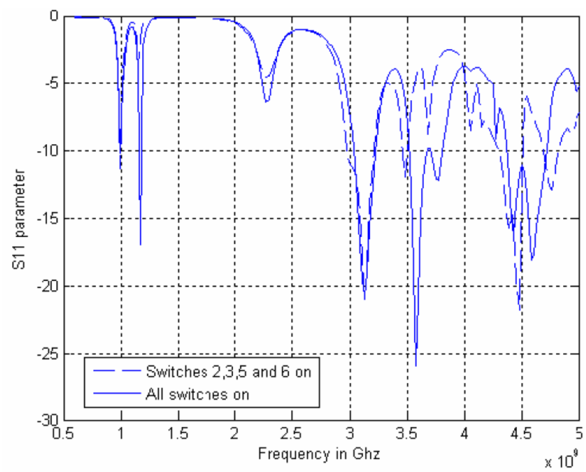


Figure 8.Comparison of the S11 parameter for different switch configurations [3]

6. Example 3

6.1 Antenna structure and reconfigurability

This example designed by L. M. Feldner ,et. al. and detailed in [6] the triangular patch antenna is designed to operate from 32 to 39 GHz and is fabricated on a quartz substrate diffusion bonded to a polished alumina microstrip feed substrate as illustrated in Figure 10. The common ground plane is about 6 µm thick gold. The antenna and feed-line are 2.5 µm thick evaporated gold patterned by lift-off. Five discrete tuning states are selectable by electrostatically actuating the ten monolithic RF MEMS capacitive switches fabricated on top of the radiating structure.

The RF MEMS switches bridge two symmetric slots on the triangular antenna surface. The slots are positioned perpendicular to the direction of RF current flow. The switches effectively control the length of this slot which dictates the direction of RF current flow.

When all of the switches are closed the antenna behaves essentially as if there were no slot present. With all of the switches open, the slot reaches its full length and the resonant RF current is forced to travel a substantially longer distance yielding a lower resonant frequency.

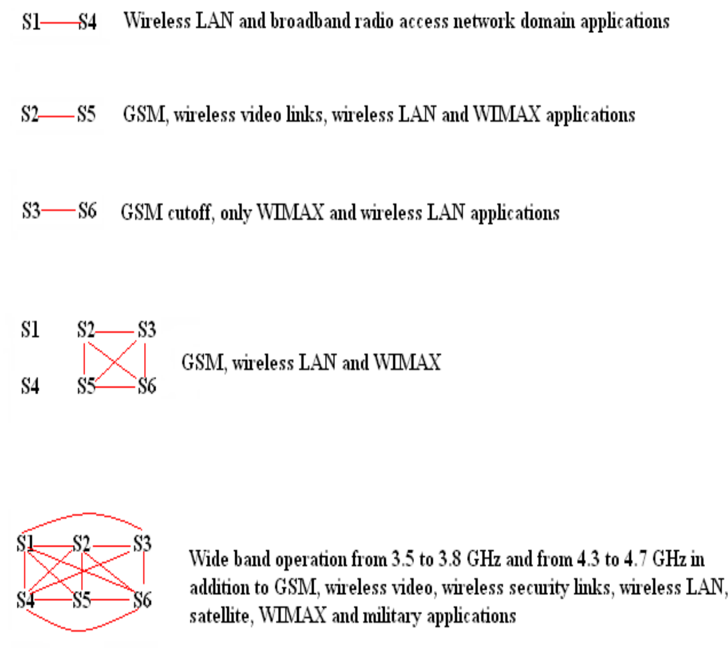


Figure 9. Graph interpretation

There is a total of 10 switches that are placed on the 2 slots we will numerate the switches from S1 to S10 from left to right. Figure 11 shows the S11 parameter results for each switch configuration. The first line represents the fact that all switches are closed and then the second line represents the fact that 2 switches from both sides are open, the third line represents the fact that 3 switches from both sides are open and so on.

6.2. Graph interpretation

Here the switches are considered as the vertices and the lines connecting these vertices (the edges) represent the fact that the corresponding switches are activated. Each vertex represents 2 switches that are at the same position in both slots since the structure is symmetric. For example - S1 represents the switches existing at position 1 in both slots. Also the connection between the same positions is shown by an edge starting and ending at the same point as shown in Figure 12.

The connecting edges lead to different antenna resonances due to different current paths and the results are represented in Figure 11. Fig.ure 12 shows the graph interpretation.

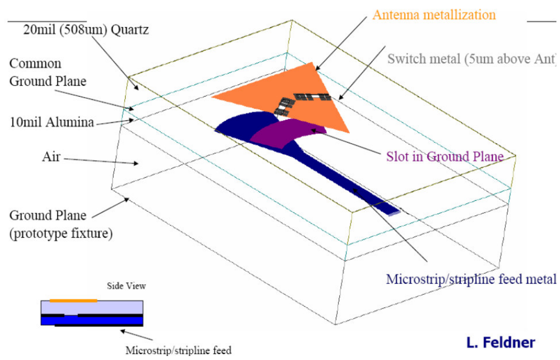


Figure 10.Structure of the antenna [6]

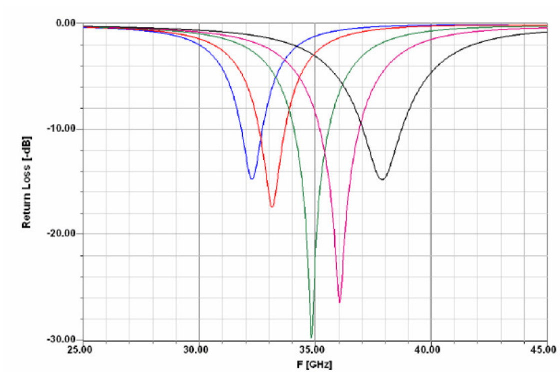
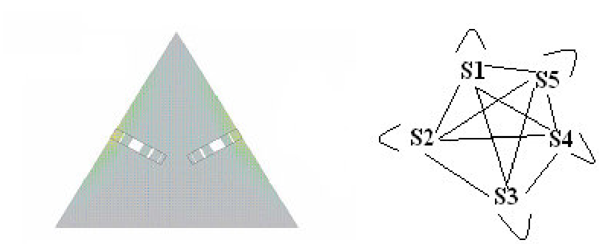
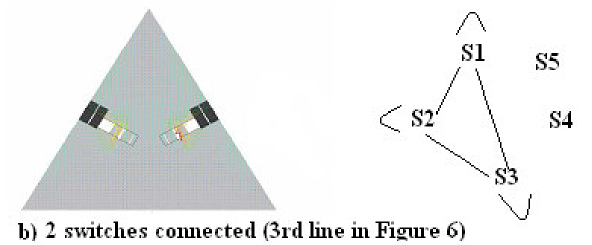


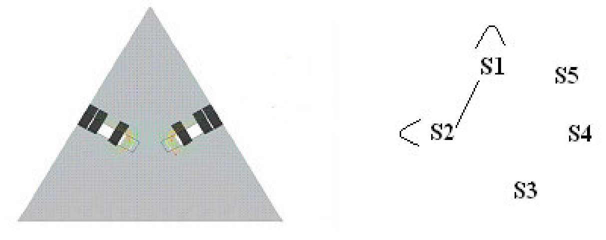
Figure 11.S11 parameter results for different switch configurations [6]



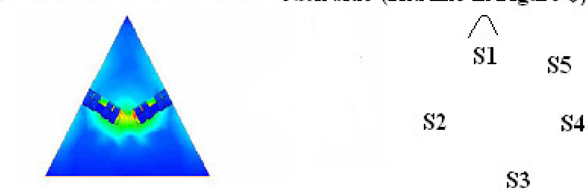
a) All swicthes connected (1st line in Figure 6)



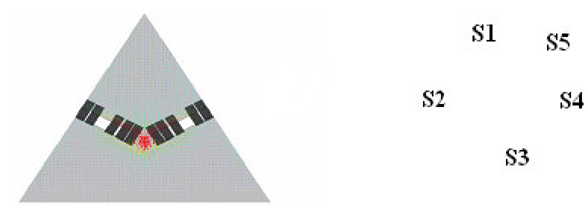
b) 2 switches connected (3rd line in Figure 6)



c) 3 switches connected from each side (2nd line in Figure 6)



d) 1 switch connected from each side (4th line in Figure 6)



e) All switches are open (5th line in Figure 6)

Figure 12.Graph interpretation.

7. Example 4

7.1 Antenna structure and reconfigurability

The proposed patch antenna discussed here was designed by Nanbo Jin, et. al., and detailed in [7]. In this design the switchable slot (PASS) concept is implemented with both frequency and polarization diversities. Using only one diode and a single patch, the antenna operates at 4.2 GHz with right-handed circular polarization and at 4.55 GHz with left-handed circular polarization [7]. The structure of the proposed antenna is shown in Figure 13.

As discussed in [7], the insertion of a diode between the two diagonal feeds makes the antenna having switchable LHCP/RHCP for each operation frequency. Different activation combinations and their associated operation status are summarized in Table I.

In summary, the proposed antenna utilizes a switchable slot to change the resonant features of TMz_{01} and TMz_{10} modes at its multiple operation status. The unique combination of reconfigurable components and diagonal feeds enables either reversed or switchable circular polarizations at different operation frequencies of the antenna.

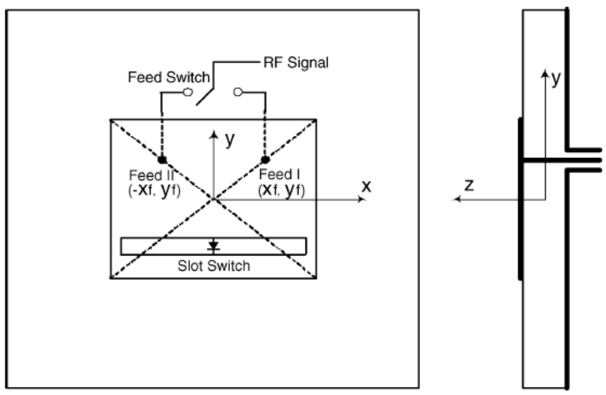


Figure 13.The structure of the antenna in example 3 [7]

7.2 Graph interpretation

The graph interpretation in this case is based on results shown in Table 1. The vertices represent the feed switches (1 and 2) and the state of the diode respectively. Let FS1 represents the feed switch 1 and DF represents the OFF state of the diode bridging over the slot. Then let us consider the case shown in the first row of Table 1. The representation of this case will be by connecting FS1 and DF with a line. That line is called the edge. The connecting edges are governed by the resulting frequencies and the corresponding polarization orientation for each link. Figure 14 shows the graph interpretation of this particular example. Let DF= diode in off state, DO=diode in ON state, F1=feed switch 1 is activated, F2=feed switch 2 is activated.

Feed Switch	Slot Switch	Frequency	Polarization
I	OFF	f_l	RHCP
I	ON	f_h	LHCP
II	OFF	f_l	LHCP
II	ON	f_h	RHCP

Table1. Different switch combinations and the associated operation status [7]

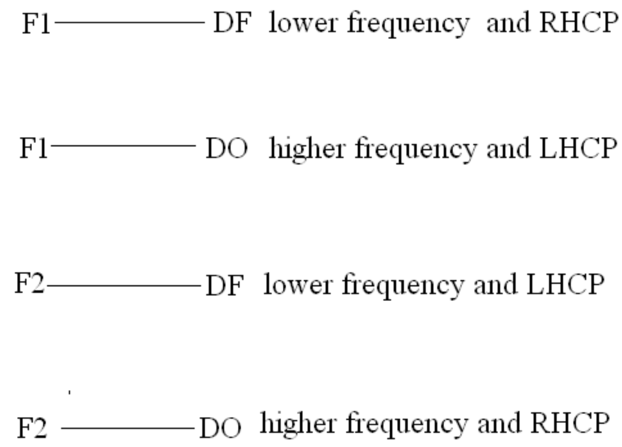


Figure 14. Graph interpretation

8. Examples 5 and 6

8.1 Antenna structure and reconfigurability

The antenna shown in Figure 15 was designed and published by J.C.Langer, et al., and detailed in [8]. The antenna was fabricated over a sacrificial layer residing on the substrate. A thin layer of magnetic material is then electroplated on the antenna surface. By etching away the sacrificial layer between the antenna and substrate, the antenna is released and connected only by its feed line [8]. When an external field is applied, the flexible region created at the junction between the released and unreleased microstrip line is plastically deformed and the structure is bent by an angle. After this plastic deformation, the antenna will remain at a certain rest angle above the substrate even after the field is removed [8]. This antenna exhibited tuning of the S11 parameter as shown in Figure 16.

Also in [9] an example of a reconfigurable frequency selective surface, designed and published by J.M. Zendejas, et al., provides a new variation by incorporating magnetically actuated dipole elements that are capable of being tilted away from the supporting surface. Each array of micro-actuators used in this work consists of a ferromagnetic plate. The high remnant magnetization of the ferromagnetic material allows for relatively small magnetic fields to induce significant angular deflections. This innovative reconfigurable FSS design has successfully demonstrated the tuning of its resonant frequency over a bandwidth of 2.7 GHz at a frequency of 85 GHz. The structure is shown in Figure 17 and the transmission coefficient results are shown in Figure 18.

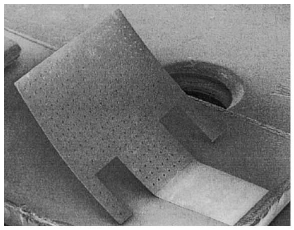


Figure 15. Structure of the antenna in [8]

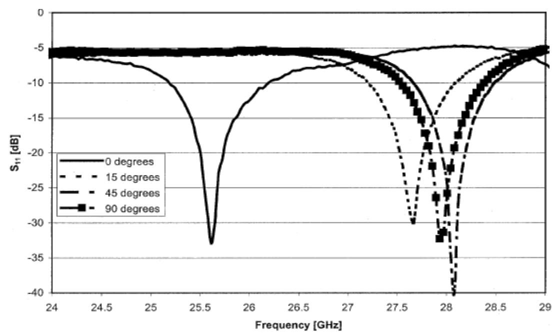


Figure 16. S11 parameter results for different angles [8]

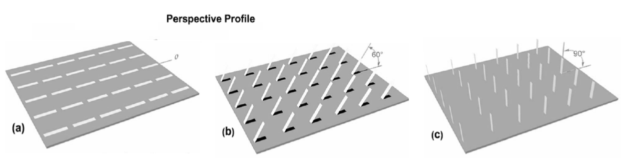


Figure 17. Structure description with perspective profile [9].

8.2 Graph interpretation

The vertices in the first graph interpretation for the antenna in [8] represent the angles that the patch can take over the substrate and the edges connecting these vertices represent the bending process. For example if A1 represents an angle of 0˚ and A2 represents an angle of 30˚ the translation from 0˚ to 30˚ or vice versa represents an edge connecting A1 and A2. If the bending of the patch, as shown in Figure 15, doesn't stop at 30˚ and goes for example to 60˚ then an edge will appear between A1 and A2 and between A2 and A3 representing 60˚. If we kept bending the patch antenna continuously then all the vertices will be connected. According to this example only 4 angles are represented in Figure 16. So we only have 4 vertices. Let A1 =0°, A2 =15°, A3 =45°, A4 =90°. This graph interpretation is shown in Figure 19.

The second example [9] represents an array of dipoles as a frequency selective surface.The reconfigurability technique used is similar, in principle, to the one used in [8] however, we are using a different graph interpretation in this case. Let the vertices represent the final structure at rest for each angular position as shown in Figure 17. Then we will have 8 vertices according to Figure 18. The edges connecting these vertices will represent the transfer from one structure to another however if you want to go from the structure at 0˚ to the structure at 28˚ you have to pass by the struture at 15˚ before hand since it is a tilting action and you can not jump from one angle to another directly. Each graph shape represents a different resonance. For example the connection between A (a vertex representing the structure at 0˚) and B (a vertex representing the structure at 30˚) represents the structure's final frequency resonance when the array of dipoles is at 30˚. The graph interpretation is shown in Figure 20. Let St1= 0˚, St2=15˚, St3=28˚, St4=47˚, St5=58˚, St6=66˚, St7=69˚ and St8=71˚.

9. Conclusion

Graph interpretations can be used to guide the designer of reconfigurable antennas. Even though the majority of reconfigurable antennas use switches to achieve reconfigurability we showed that graphs can be applied to model these antennas, regardless of whether the antennas are using switches or not.

The application of graphs in modeling reconfigurable antennas is the first step on the way to achieve a full theoretical model for their design. Future work will include a deeper theoretical approach into graph algorithms for dealing with any reconfigurable structure.

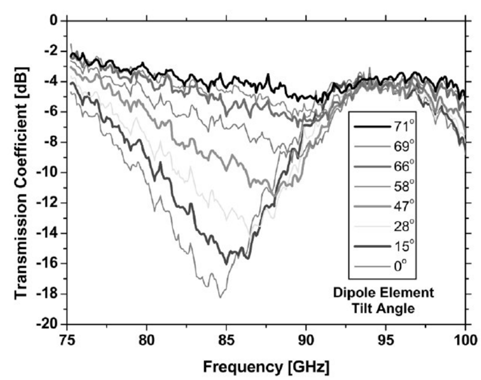


Figure 18. Measured Transmission Coefficient for the Suggested Structure [9]

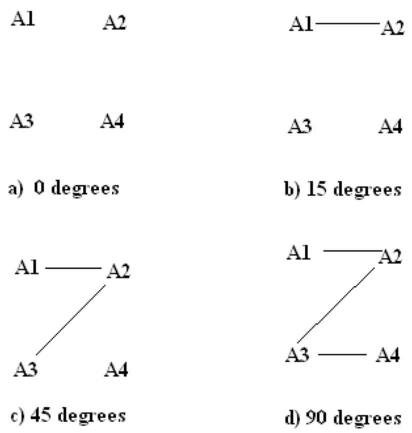


Figure 19. Graph Interpretation for the antenna in [7]

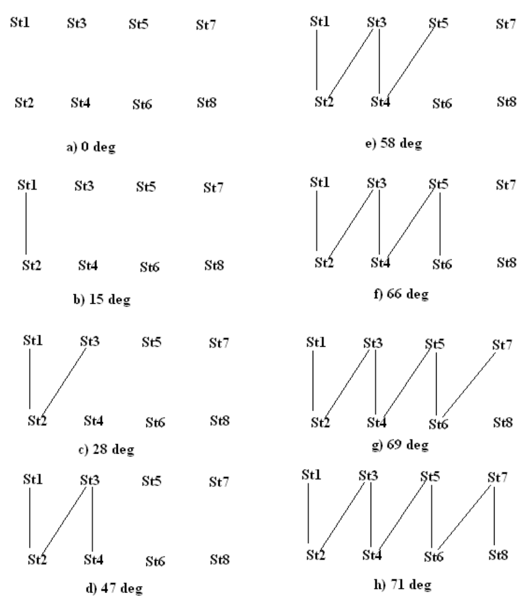


Figure 20.Graph Interpretation for the structure in [8]

10. References

[1] Eric Klavins, Robert Ghrist, and David Lipsky " A grammatical approach to self-organizing robotic systems". IEEE Transactions on Automatic Control, 51(6):949-962, June 2006.

[2] D. Peroulis, K. Sarabandi and L. P. B. Katehi "Design of reconfigurable slot antennas", IEEE Transactions on Antennas and Propagation, Volume 53, Issue 2, pp. 645-654, Feb 2005.

[3] J. Costantine, C. G. Christodoulou, S. E. Barbin, "A New Reconfigurable Multi Band Patch Antenna", IEEE IMOC Conference, Salvador, Brazil, pp.75-78, October 2007.

[4] C. G. Christodoulou, J. H. Kim, J. Costantine, and S. E. Barbin, "Reconfigurable RF and Antenna Systems", IEEE IMOC Conference, Salvador, Brazil, pp.17-20, October 2007.

[5] V. Zachou, C.G.Christodoulou, M.T.Chrisomallis, D. Anagnostou and S.E. Barbin, "Planar Monopole Antenna With Attached Sleeves", Antennas and Wireless Propagation Letters, Vol. 5 No 1, pp. 286-289, Dec. 2006.

[6] L. M. Feldner, C. D. Nordquist , and C. G. Christodoulou, "RFMEMS Reconfigurable Triangular Patch Antenna", IEEE AP/URSI International Symposium, Vol 2A, pp.388-391, July 2005.

[7] Nanbo Jin,Fan Yang, and Yahya Rahmat-Samii " A novel patch antenna with switchable slot (PASS): dual-frequency operation with reversed circular polarizations ". IEEE Transactions on Antennas and Propagation, 54(3):1031-1034, March 2006.

[8] J.C.Langer, J. Zou, C.Liu, and J.T. Bernhard "Micromachined Reconfigurable Out Of Plane Microstrip Patch Antenna Using Plastic Deformation Magnetic Actuation" IEEE Microwave and Wireless Components Letters, Vol. 13 No 3, pp. 120-122, March 2003.

[9] J.M. Zendejas, J.P.Gianvittorio,Y.Rahmat-Samii and J.W.Judy "Magnetic MEMS Reconfigurable Frequency Selective Surfaces", Journal of Micro-electromechanical Systems, Vol. 15, No. 3,pp. 613-623, June 2006.