

# Analyzing Reconfigurable Antenna Structure Redundancy Using Graph Models

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**Abstract**—This paper investigates the redundancy and loss reduction in reconfigurable antenna structures. We use graph models as tools to understand and optimize reconfigurable antenna structures. Examples are given and formulas are suggested to be used by reconfigurable antenna designers to obtain non redundant structures.

## Introduction

Reconfigurable antennas come in a large variety of different shapes and forms. These antennas exhibit different forms of reconfigurability. They can have a reconfigurable return loss, reconfigurable radiation pattern, reconfigurable polarization or different combinations of the previous properties [1]. In this paper we investigate the redundancy in a reconfigurable antenna structure. This redundancy exists in designs where more configurations are possible than needed. We use graph models [2] to understand the structure of reconfigurable antennas and their mechanisms. In [3] the authors demonstrated that reconfigurable antennas can actually be graph modeled. Modeling a reconfigurable antenna with a graph allows the use of many algorithms developed for these models.

## Reconfigurable Antenna Structure Redundancy

An antenna exhibiting frequency tuning might show redundancy in its structure. This redundancy is due to the fact that the surface current change that tunes the frequency is achieved by connecting different nodes at different times. Redundant nodes in this case might be connected. Radiation pattern reconfiguration requires a drastic change in the whole antenna structure or in its feeding network. Redundancy in this case is not an issue since added or removed parts will alter the radiation pattern as long as the part is added or removed in a distinctive direction. In the case of a reconfigurable polarization antenna the surface structure of the antenna has to maintain a certain shape corresponding to the required polarization which means that added parts are always a necessity to achieve this polarization reconfiguration. In the case where the antenna is showing multiple reconfigurable properties, redundancy is investigated for each property at a time. As a conclusion, the designer needs to take into consideration the exact antenna requirements before setting up his design. The real problem exists in the reconfigurable return loss antenna, since a designer might add a redundant part to his antenna without realizing the losses he is adding to the whole system.

## Structure Redundancy Problem Solution

Identifying redundancy in an antenna structure leads to optimal designs and minimum losses. We suggest using graph models as tools to understand the reconfigurable antenna structure and its mechanism. The reconfigurable antenna designer has to choose the structure of his antenna and its reconfiguration

technique (Switches, part rotation...). Before simulating his structure we suggest that the designer graph model his antenna. Figure 1 shows a reconfigurable microstrip antenna. This antenna has parts attached to a main part using switches. Figure 1c shows the graph model of this antenna for all possible connections. The vertices in the graph represent the different parts added (P1, P2, P3, P4, P5, P6, P7, P8) to a main part represented by P0. The connection of each part is represented by an edge in the graph.

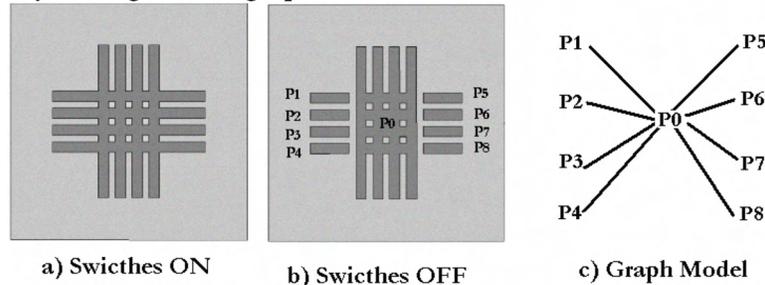


Fig.1. Antenna structure and graph model

Discovering redundancy requires from the designer to compare the number of possible unique paths in the graph model with the number of required antenna configurations. Every path in every graph model should correspond to a different antenna configuration. If the total number of unique paths existing in a graph model is more than the number of antenna configurations required then redundant paths may exist in that graph and the antenna has redundant parts. An example on counting the total number of unique paths in a given graph is shown in Figure 2. The antenna shown in Figure 1 exhibits a reconfigurable return loss and a reconfigurable radiation pattern as shown in Figure 3. This antenna has 5 resonances between 2.5 GHz and 6 GHz. In order to achieve 5 antenna configurations we need to have 5 unique paths in the graph model. These 5 different paths can be achieved by 4 vertices in the graph model. These vertices represent 3 parts added to a main part, however this antenna has to exhibit a reconfigurable radiation pattern at the same time which means that adding only 3 parts to a main part will disrupt the symmetry of the structure so 5 vertices are the least acceptable in this case. Two parts added from each side of the main section is sufficient for the antenna requirements. The new optimized antenna, graph model and a comparison between the return loss and radiation pattern of the optimized antenna and redundant antenna are shown in Figure 4.

### Structure Redundancy Problem Formulation

In this set of equations we investigate reconfigurable antennas using one reconfiguration technique.

Equation 1:

$$NAC = \frac{N(N-1)}{2} + 2 \tag{1a}$$

$$N^2 - N - 2 \times (NAC - 1) = 0 \Rightarrow N = \left\lceil \frac{1 + \sqrt{1 + 8 \times (NAC - 1)}}{2} \right\rceil \tag{1b}$$

Where NAC represents the number of all possible antenna configurations and N is

the number of vertices in the corresponding graph model. Equation 1 is valid for reconfigurable antennas composed of parts added to a main part where the vertices in the graph model represent the different parts added.

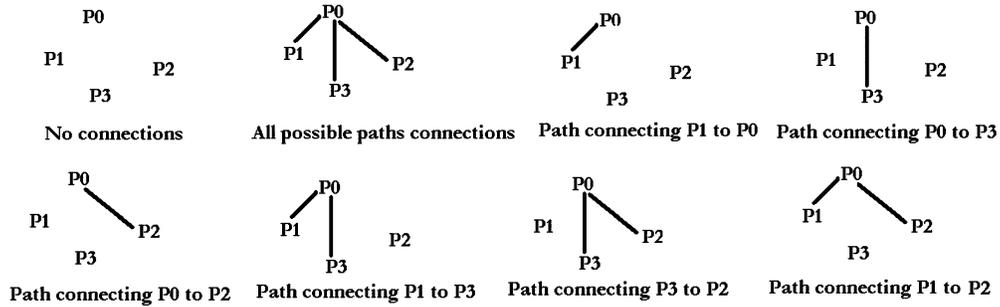


Fig.2. All possible unique paths in a graph

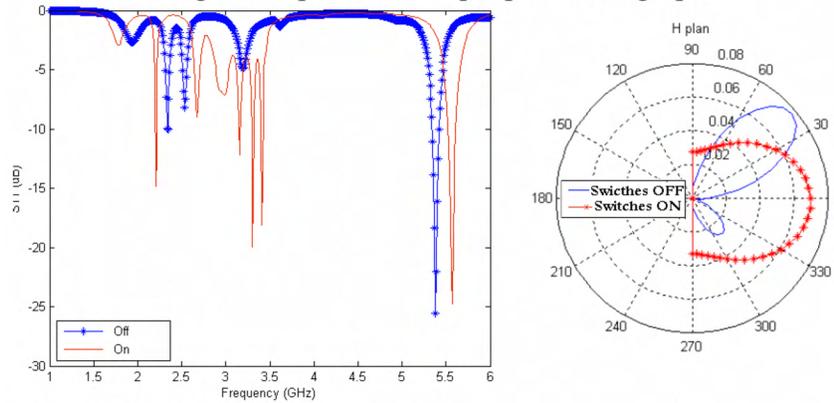


Fig.3. Return loss and Antenna Radiation Pattern in the H-Plane for F=2.33 GHz

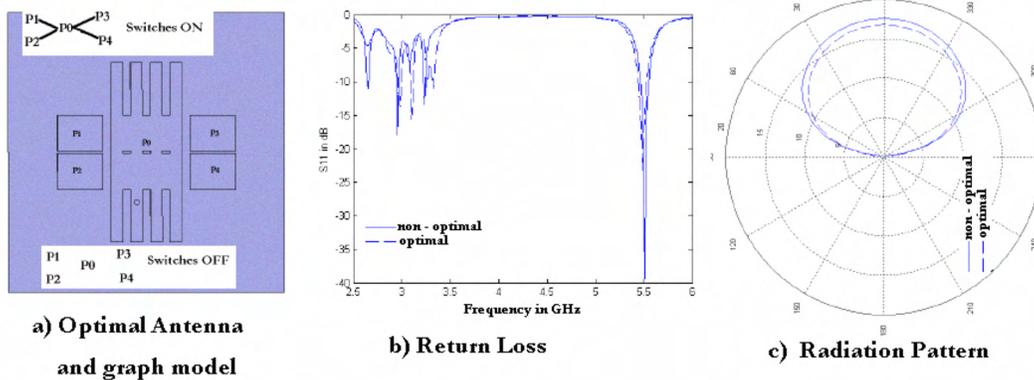


Fig.4. The optimized antenna and its graph model and a comparison between the optimal and non optimal antenna's return loss and E-plane radiation pattern at F=2.33 GHz

Equation 2:

$$NAG = \frac{N}{2} + 1 \quad (2)$$

Equation 2 is valid for reconfigurable antennas having slots in their structure where electronic components are bridging over these slots. In the graph model the vertices represent the different end points of the electronic component.

Equation 3:

$$NAC = N \quad (3)$$

Equation 3 is valid for reconfigurable antennas achieving their reconfiguration through an angular change in their structure. In the graph model the vertices represent the different angles of change.

Testing the formulas:

Applying equation 1b to the example shown in Figure 4 proves that 5 vertices are the least acceptable number due to the fact that the antenna requires 5 possible configurations with symmetric structure.

$$NAC \geq 5 \quad \text{for } NAC = 5,6,7 \quad N = \left\lceil \frac{1 + \sqrt{1 + 8 \times (NAC - 1)}}{2} \right\rceil = 4$$

N has to be  $> 4$  due to the necessity of symmetry conservation. Taking  $N=5$  leads to  $NAC = 5 \times 4 / 2 + 2 = 12$  according to equation 1a which proves that the optimization of the design shown previously was accurate. Applying Equation 2 to the antenna in [4] gives us  $NAC = (20/2) + 1 = 11$  possible antenna configurations while the number of configurations required in [4] is only 5 so by applying Equation 2 we end up in  $N = 2 \times (4) = 8$  vertices. These 8 vertices represent the 8 end points of 4 switches. The optimal design will include only one slot instead of 2 with four switches instead of ten bridging over it. Applying Equation 3 to the design in [1] confirms that this design is optimal since the number of possible antenna configurations or functions is equal to the number of angles of bending executed.

### Conclusion

This paper presented a new technique for investigating the redundancy in a reconfigurable antenna structure. This technique is based on graph modeling the reconfigurable antenna before simulating and fabricating it. By eliminating redundant parts and electronic components the designer saves losses and costs. This technique is formulated and tested by many examples provided from current and previous publications.

### References:

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