Broad-Band and Wide Scan Phased Array Element Design Using Data Mining

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Abstract **─** Novel synthesis procedure, exploiting data mining technique for antenna design is presented. By utilizing data mining, investigating various combinations of a typical antenna configuration, all together, is feasible and this fact allows the selection of the specific design which possesses the desired properties. In this paper, a broad-band and wide scanning angle probe-fed microstrip patch array element with shorting posts is designed based on this procedure. For achieving acceptable bandwidth, scan angle and polarization, the coordination positions and the number of the incorporated shorting posts were considered as the design parameters. For a substrate with a thickness of $0.05\lambda_0$, the simulation results show a 15% frequency bandwidth with a scanning range of 70° in the main E, H and D-planes.

Index Terms **─** Broad-band antennas, data mining, phased array, shorting posts.

I. INTRODUCTION

Until now, much work has been done on designing vast scanning range or wide bandwidth phased array elements [1]. Also, wide bandwidth phased array elements have been thoroughly studied [2]. However, the phased array structures with simultaneous wideband and wide scan angle, have been less investigated in the literature such as [3] in which a tapered slot array has been investigated. Another example is the work done on aperture coupled microstrip array antenna [4]. Most of these structures have a bulky configuration. Having a low profile phased array elements with wideband and wide scanning range properties, is desirable. A microstrip patch antenna is a suitable low profile antenna as a phased array element, which has small size and light weight as well as relatively inexpensive production; however, its scanning range and bandwidth is limited [5]. A general and simple method for increasing the bandwidth of a microstrip patch antenna is increasing the substrate thickness. Although this approach promotes the chance of inducing surface waves. Surface wave propagation severely limits the scan angle in large microstrip arrays and moves the scan-blindness angle further to the broadsight (θ=0°) [6]. Limited scanning angle of patch phased array antennas is dominantly due to the presence of surface wave which has been alleviated to a great extent, by exploiting shorting posts [7]. However, the bandwidth of these types of antennas hasn't been addressed and the usual bandwidths presented are about 1-2 percent [8].

In this paper, we investigate the probe-fed microstrip patch antenna with different configurations of single, dual and triple-shorting post positions as the unit cell of phased array antenna for achieving vast scanning angles and large bandwidth. To this end, the positions of shorting posts are optimized by a data mining technique [9]. This technique is based on providing a data-base of different simulation results relating to single, dual and triple shorting post positions and then classifying the results. The advantage of this method is coming up with all possible cases without the need of simulating all of them. Thus the optimum cases would also be discovered. It should be mentioned that this method is not restricted to a typical group of antennas and could be extended to different antenna structures.

II. DATA MINING SYNTHESIS PROCEDURE

A. Data mining definition

Data mining is a branch of science emerged from the combination of different sciences such as statistics, artificial intelligence, machine learning, pattern recognition, and database technology. It is used for extracting the relationship existing between a large set of data. The main steps in applying data mining to a collection of data are:

1. Data preparation.
2. Relation discovery.
3. Evaluation and interpretation.

The aim of data preparation is creating a comprehensive look-up table of data, representing different aspects of the under-studying phenomenon. The look-up table is made up of columns of dataset related to different attributes and rows of different

Submitted On: October 18, 2015
Accepted On: February 26, 2016

samples regarded as records. In the second step by considering the data types and using various algorithms (such as classification or clustering), the correlation among the data is extracted. Afterwards, the achieved knowledge from the second stage is evaluated and its validity is determined in third step [10]. Two general methods for data mining are classification and clustering. In the former one, the data are divided into two sets called train dataset and test dataset. The train dataset is used for rendering a model and the test dataset is applied to the model for validating the accuracy of the model. One of the various attributes is always considered as a critique attribute for classification which is named label. In the clustering method, similarity critiques are chosen which upon them, records having the most similarity together are grouped into one cluster. This technique attempts to put most analogous records in common groups and separate the less similar ones.

B. Antenna design, utilizing data mining procedure

As mentioned in the introduction, by increasing the microstrip substrate and placing shorting posts at appropriate locations one can achieve high bandwidth and wide scan angle. In this section, conventional probe-fed patch antenna with single shorting post, dual shorting posts and triple shorting posts as the unit cells of an array antenna, are investigated by a data mining procedure to achieve broadband frequency and wide scanning range performance. To this end, a basic framework for exerting data mining techniques to antenna design is presented. Due to the fact that data mining is based on manipulating data, the first step in utilizing this technique for antenna design, is to convert design parameters and the result aspects into a dataset. Accomplishing this task, requires establishing a data base in which each column is dedicated to each specific design parameter or outcome aspect and for each variation of the design parameters a separate row is added to the data base accommodating the corresponding results. The procedure of applying data mining for antenna design is graphically shown in the diagram of Fig. 1.

The first step in applying data mining to antenna design is gathering a table of assets, indicating one or several of the antenna specifications for all different cases of the antenna design parameters. It should be emphasized that antenna specifications are chosen according to the antenna design goals and also the algorithm considered for data mining. It is feasible to use a minimum set of antenna specifications which results in less computational effort. As an example, for designing a wideband antenna, considering characteristics related to the bandwidth such as the reflection coefficient, is sufficient. Moreover, in the proposed procedure those assets which upon them data are clustered, should be chosen. Virtually, data which are irrelevant to the design goals, degrade the accuracy of the clustering process. For the antenna design case studied in this paper, the parameters consisting of return loss, polarization and shorting posts' positions are considered as the appropriate assets.

In the second step and before applying clustering based on analysis methods, outlying samples of records or simulation results which significantly differ from the rest of the records, are separated so that these outlying records couldn't degrade the accuracy of the clustering process. However, the mentioned records are all together considered as a single-member cluster because there might be a case where the optimum results would be found in these far apart records.

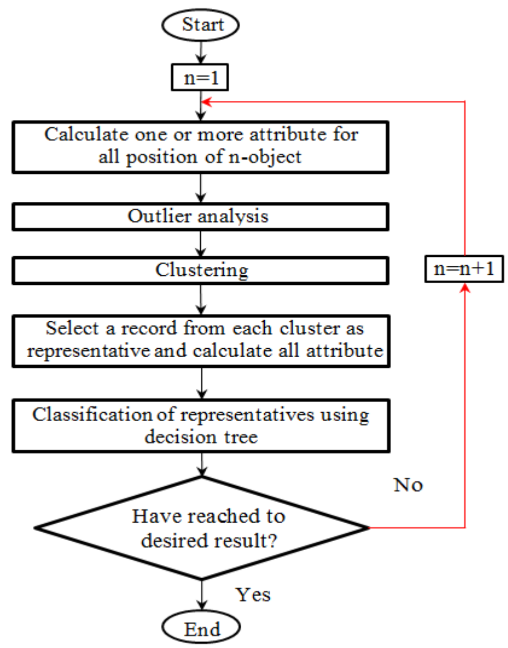

Fig. 1. Flowchart of antenna design using data mining.

In the third step, based on a clustering method such as K-medoids [11], different configurations of the antenna base structure are categorized. At the end of this stage, all design configurations with similar simulation results would be gathered into a unique group. The next step is choosing a member from each group as a representative of the cluster and then calculating all necessary aspects of the chosen members. Because every member in a specific group has similar antenna characteristics, the aspects calculated for the representing member of the group could be extended to assign to all the constitutive group members. Then by using a decision tree model and considering the design goal as the label, the data set is classified. This classification helps to arrive at a comprehensive overview of different aspects and attributes and facilitates decision making for choosing the most appropriate configuration. This is especially helpful when a large number of clusters are available and prevents from encountering probable errors. This process can be extended through adding more objects to the base structure for achieving the specific structure resulting to the desired properties. Although at each addition phase, the combination of the representatives of the former phase and the newly added object is considered rather than considering all permutations of former objects and the newly added one. In fact, this is the prominent advantage of the proposed procedure because it provides the prospective view into all various configurations of an antenna design with their corresponding results without the need of spending excessive time. In such a case, all cases or the optimum case could be achieved. Another advantage of the proposed procedure is that with only calculating a few numbers of aspects, the whole number of aspects can be calculated.

III. SHORTING POST PATCH ANTENNA, CASE STUDY

In this section, first, an array antenna with a conventional probe-fed microstrip patch unit cell as a basic configuration is designed. The unit cell has a length of $L = 0.29\lambda_0$, width of $W = 0.28\lambda_0$ and a height of $h = 0.06\lambda_0$ with a patch metal of $0.29\lambda_0 \times 0.28\lambda_0$ where λ_0 is the wavelength parameter at 5 GHz and the substrate has a dielectric constant of $\epsilon_r = 2.55$. The active reflection coefficient in the three principal planes for this array is depicted in Figs. 2-4. The simulations have been carried out by HFSS [12] and CST [13] softwares in which a floquet port has been applied to the unit cell structure for $\theta = 0$ and $\phi = 0$. These conditions create an infinite array based on the specified unit cell. As it can be inferred from Figs. 2-4, the array has a scanning range of 70 in the H- and D-planes, whereas in the E-plane, scanning angles up to 60 has been achieved. However, in the three planes the fractional bandwidth remains as low as 4 percent. Now, in order to improve bandwidth and scanning range, simultaneously, the proposed approach is utilizing shorting posts in different positions on the unit cell patch and using data mining method to find the best shorting post configuration. To this end, the patch surface is meshed with the size of shorting post diameter ($0.009\lambda_0$) where each grid indicates a position to reside a shorting post. Obviously, the shorting post position could be set at any point on the metallic patch. In this section, single-, dual- and triple-shorting post configurations are investigated. Figure 5 shows geometrical details of a typical triple-shorting post configuration. The coordinates of the shorting posts are designated as X_i and Y_i (i=1,2 and 3). X_f, Y_f and r_f indicate the position of the probe-feed and its radius, respectively. Also Dx and Dy are the overall dimensions of unit cell. Figure 6 indicates a typical illustration of the meshed surface patch plate, where the filled spots indicate cluster representatives in the single shorting post step.

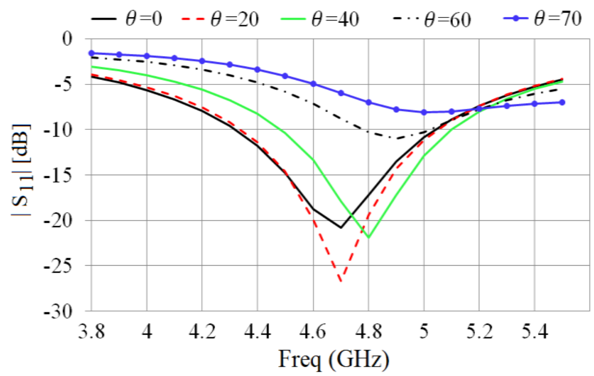

Fig. 2. Reflection coefficients of a conventional probe-fed microstrip patch array for E-plane scan ($\epsilon_r = 2.55$, $h = 0.06\lambda_0$, $W = 0.28\lambda_0$, $L = 0.29\lambda_0$, $X_f = 0.081\lambda_0$, $Y_f = 0$, $r_f = 0.009\lambda_0$, $D_x = D_y = 0.5\lambda_0$).

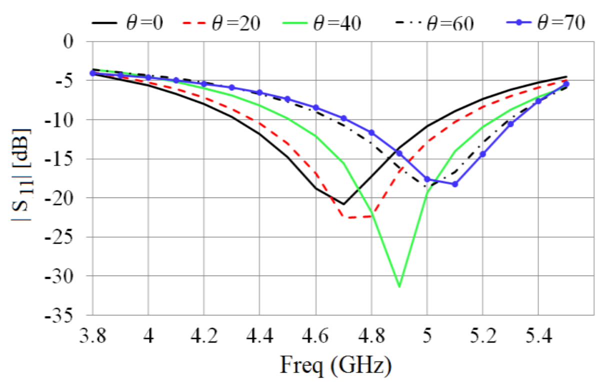

Fig. 3. Reflection coefficients of a conventional probe-fed microstrip patch array for H-plane scan (parameters, as in Fig. 2).

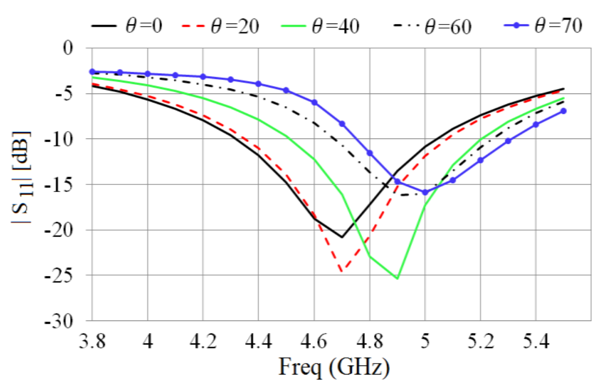

Fig. 4. Reflection coefficients of a conventional probe-fed microstrip patch array for D-plane scan (parameters, as in Fig. 2).

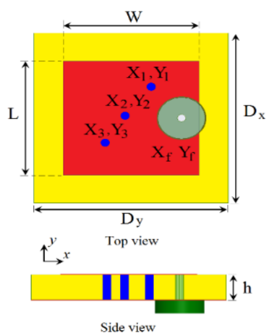

Fig. 5. Top view and side view of triple shorting post.

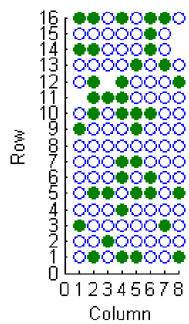

Fig. 6. Meshed surface of a patch element metal plate which the filled spots indicate cluster representative in the single shorting post step.

A. Applying data mining procedure to design patch antenna with shorting posts

Applying the data-mining procedure to a probe-fed microstrip patch antenna with shorting posts, starts with gathering a table of reflection coefficient values for all possible single shorting post configuration cases. Next, based on the X-means clustering method [14], single shorting post configurations which have a similar reflection coefficient curve are categorized in various groups which are named clusters. To achieve a more precise clustering, simulation results which are too different from others are left out from the clustering procedure by using outlier analysis introduced in [15]. Each of these out-left simulations are considered as a single member cluster because their combination with other clusters in proceeding steps may have good characteristics. The number of these clusters is determined by cluster evaluation algorithms which in this work the SSE method has been used and its result is shown in Fig. 7. All members of a single cluster would have similar antenna characteristics including bandwidth and scanning range in the E, H and D-planes (ϕ=45°). A specific member is chosen from each cluster which would represent its cluster. In the third step, the dual shorting post configuration should be determined, that is a composition of two single shorting post configurations. Therefore, instead of considering all two possible combinations of single shorting post configurations, the possible mixture of the cluster which represents the single post configuration, is considered. The reason for this proposition is that the results from the representative combinations will be similar to that of the corresponding cluster group members' combination. The outcome of the representative combination would be clustered again and for each one of them too, a representative would be chosen. In a similar manner, for achieving various cases of triple shorting post configuration, combinations of dual and single shorting post structures representatives are combined together. This procedure could be continued for any multiple shorting post configurations. After the stage of clustering an N-shorting posted configuration, the representative members of that configuration are simulated and their characteristics are extracted and exported into a data set table.

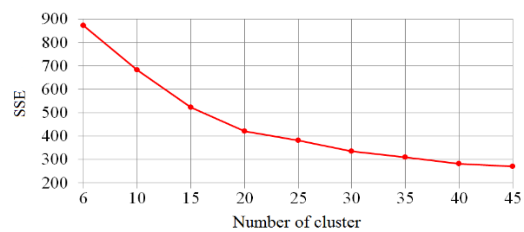

Fig. 7. Find number of cluster in two post using SSE.

As mentioned in the previous section, different single shorting post positions individually are simulated. In our simulations, we have considered that the probe feed is placed at the center line of the patch. Also, the shorting post is only placed on one half side of the patch surface which is determined by the patch center line. The obtained parameters from simulations are exported in a data set table. An inappropriate selection of parameters for exportation would result in a wrong clustering result. The parameters which are selected as the data set attributes must have a reasonable relation with the design goal. In this work, the parameters considered as attribute in the data set table are the coordinates of the shorting post and the reflection coefficient over the sufficient frequency band. The data set is clustered and the representatives of each cluster are shown as filled circles in Fig. 6. The representative cases are further simulated in E-, H- and D-plane with different scan angles. Once again the simulation results for the representative cases are exported as another table and by using the decision tree method and considering bandwidth as a label this table are classified. The classified results are shown in Fig. 8. For the problem addressed in this paper, 25 base structures were categorized in one post configuration and 37 base structures were categorized in two post configuration. It should be pointed out that it is possible that some post could be repeated in several branches of the decision tree.

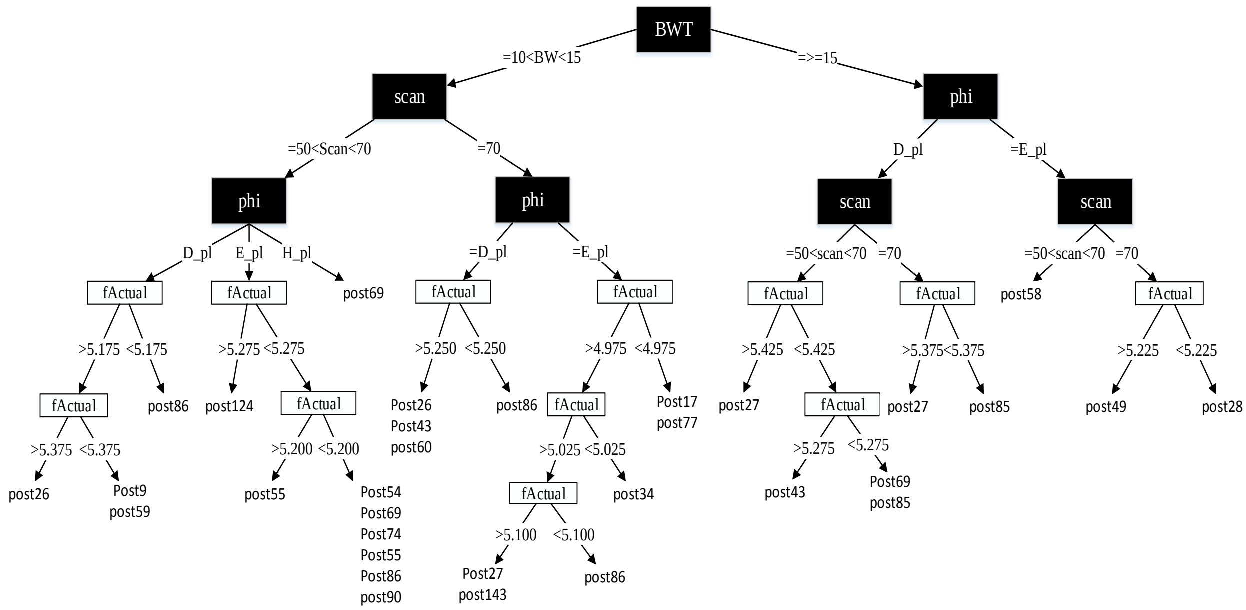

Fig. 8. Decision tree for one post.

B. Wide band and wide scanning element

As we can see in Figs. 9-11, by placing a shorting post on the specific and optimized point, the scanning angle is increased of about 60 degrees in the E and H-plane while the bandwidth is kept about 20 percent. Then with the increasing of posts to two posts, the scanning angle of 70 degrees and a bandwidth of 15% in the E and H-plane is achieved. It is observable in Figs. 12-14 as expected, a bit of bandwidth has been lost. However, the scanning angle has been increased about 10 degrees relative to the previous stage. At the final step, after a large number of simulations using data mining, the number of posts is increased to three posts and the results are depicted in Figs. 15-17. It can be seen that the bandwidth and scanning angle have improved slightly compared to the results of two posts. This process can be continued to N posts but three posts has been considered sufficient in this work, since the results of three posts were not significantly better than two posts.

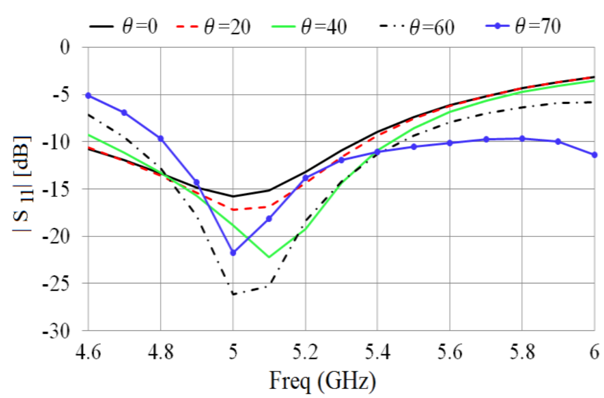

Fig. 9. Active reflection coefficient for single shorting post patch configuration in the E-plane ($\epsilon_r = 2.55$, $h = 0.06\lambda_0$, $W = 0.28\lambda_0$, $L=0.29\lambda_0$, $X_f = 0.081\lambda_0$, $Y_f = 0$, $X_1 = -0.06\lambda_0$, $Y_1 = 0.43\lambda_0$, $r_f=r_1=0.009\lambda_0$, $D_x=D_y=0.5\lambda_0$).

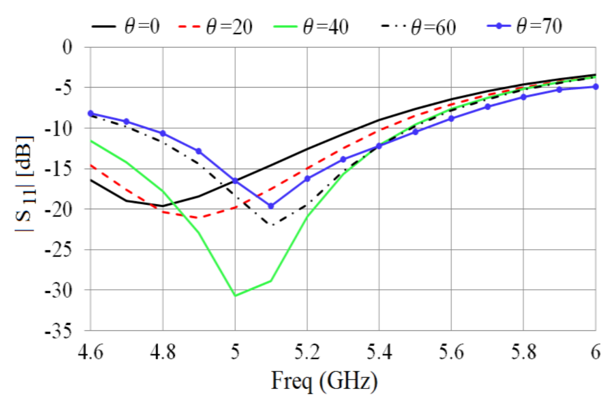

Fig. 10. Active reflection coefficient for single shorting post patch configuration in the H-plane ($X_1 = -0.095\lambda_0$, $Y_1 = 0.007\lambda_0$, the rest of the parameters are as in Fig. 9).

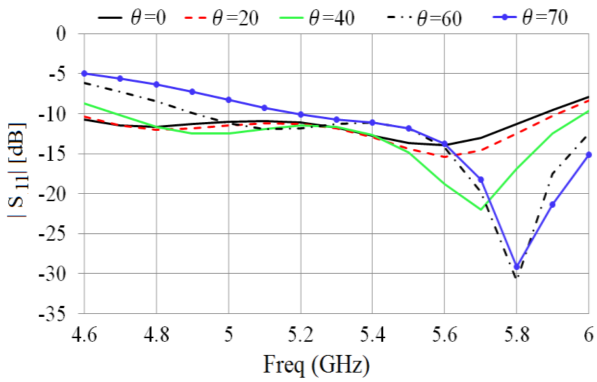

Fig. 11. Active reflection coefficient for single shorting post patch configuration in the D-plane ($X_1 = -0.113\lambda_0$, $Y_1 = 0.43\lambda_0$, the rest of the parameters are as in Fig. 9).

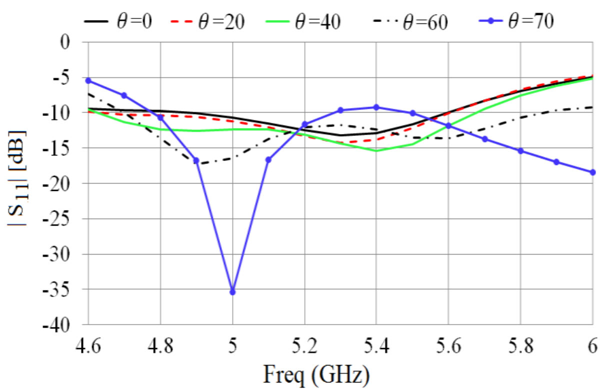

Fig. 12. Active reflection coefficient for double shorting post patch configuration in the E-plane ($\epsilon_r = 2.55$, $h = 0.06\lambda_0$, $W = 0.28\lambda_0$, $L = 0.29\lambda_0$, $X_f = 0.081\lambda_0$, $Y_f = 0$, $X_1 = -0.077\lambda_0$, $Y_1 = 0.06\lambda_0$, $X_2=-0.023\lambda_0$, $Y_2=0.08\lambda_0$, $r_f = r_1 = r_2 = 0.009\lambda_0$, $D_x = D_y = 0.5\lambda_0$).

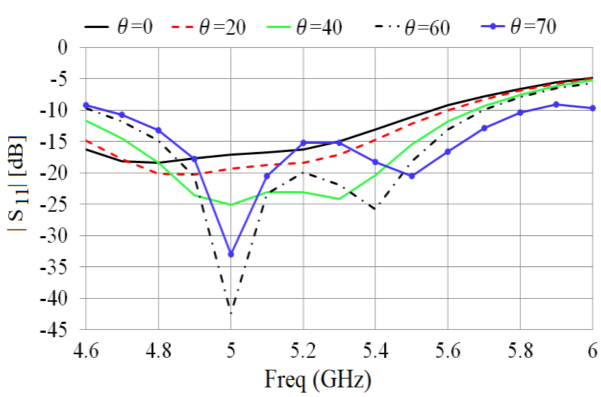

Fig. 13. Active reflection coefficient for double shorting post patch configuration in the H-plane ($X_1=-0.113\lambda_0$, $Y_1=0.025\lambda_0$, $X_2=-0.023\lambda_0$, $Y_2=0.08\lambda_0$, the rest of the parameters are as in Fig. 12).

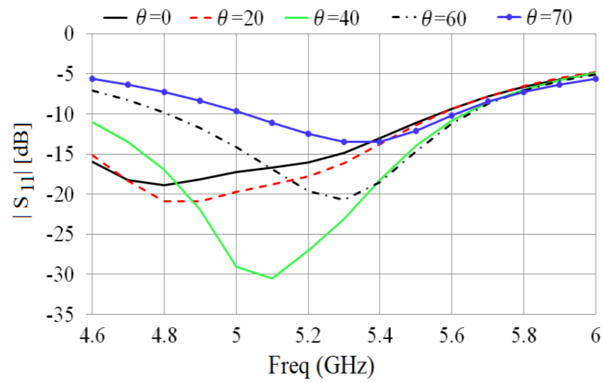

Fig. 14. Active reflection coefficient for double shorting posts patch configuration in the D-plane (parameters, as in Fig. 13).

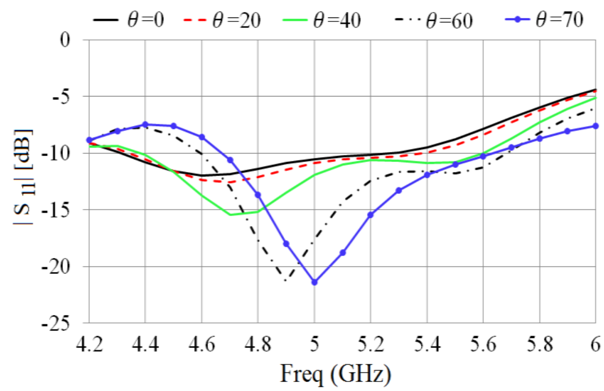

Fig. 15. Active reflection coefficient for triple shorting posts patch configuration in the E-plane ($\epsilon_r=2.55$, $h=0.06\lambda_0$, $W=0.28\lambda_0$, $L=0.29\lambda_0$, $X_f=0.081\lambda_0$, $Y_f=0$, $X_1 = -0.077\lambda_0$, $Y_1 = 0.043\lambda_0$, $X_2=0.041\lambda_0$, $Y_2=-0.046\lambda_0$, $X_3 = -0.005\lambda_0$, $Y_3= -0.01$, $r_f = r_1 = r_3 = 0.009\lambda_0$, $D_x = D_y = 0.5\lambda_0$).

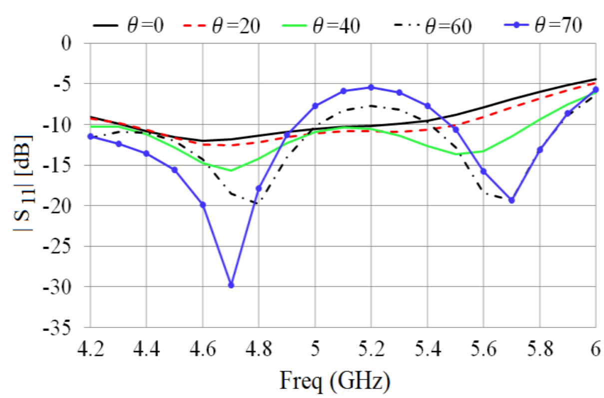

Fig. 16. Active reflection coefficient for triple shorting posts patch configuration in the H-plane (parameters, as in Fig. 15).

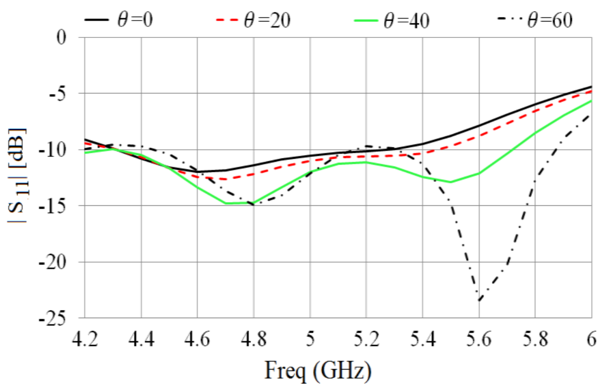

Fig. 17. Active reflection coefficient for triple shorting posts patch configuration in the D-plane (parameters, as in Fig. 15).

Figures 18 to 20 respectively show the reflection coefficients resulted from simulating single-post, dual-post and triple-post configurations in H-plane and E-plane conducted by HFSS and CST simulation softwares. The good agreement between these two simulation software results is an indication of the validity of the design procedure.

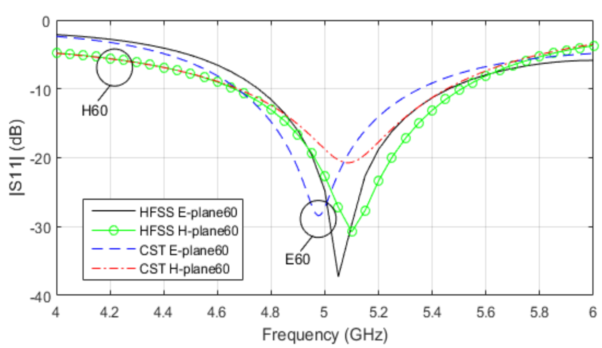

Fig. 18. Active reflection coefficient for single shorting post configuration in 60º E- and H-plane scan. CST Microwave Studio compared with HFSS.

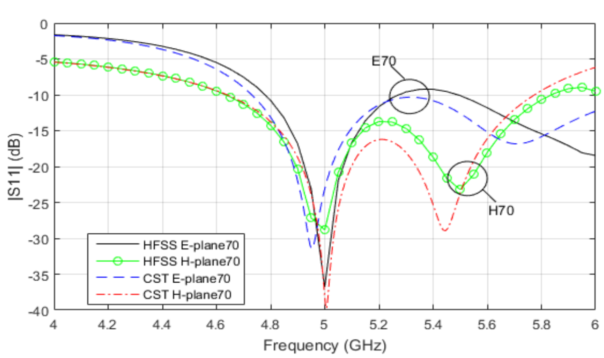

Fig. 19. Active reflection coefficient for double shorting post configuration in 70º E- and H-plane scan. CST Microwave Studio compared with HFSS.

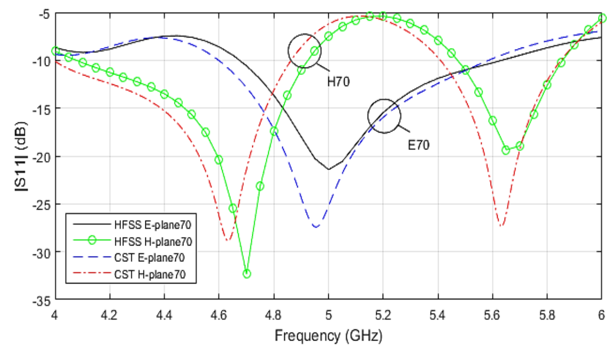

Fig. 20. Active reflection coefficient for triple shorting post configuration in 70º E- and H-plane scan. CST Microwave Studio compared with HFSS.

IV. CONCLUSION

Simulation of two posts and three posts, indicates that with increasing the number of posts positioned at specific points on the substrate, the scanning angle is improved while the bandwidth is slightly decreased. As the matter of fact that the scanning angle and bandwidth are inversely related together, increasing one of them leads to the decrement in the other one. Therefore with applying data-mining techniques on the locations of shorting posts, one can achieve the certain cases that the scanning angle increment has negligible effect on the bandwidth. The proposed method is very convenient and time saving for complex structures which are stemmed from a unique basic structure, and improves the optimization accuracy.

REFERENCES

[1] A. Ellgardt and H. Steyskal, “Antenna elements for wide-angle phased arrays,” *Division of Electromagnetic Theory, Royal Institute of Technology*, Tech. Rep., 2005.

[2] B. Thors, H. Steyskal, and H. Holter, “Broad-band fragmented aperture phased array element design using genetic algorithms,” *Antennas and Propagation, IEEE Transactions on*, vol. 53, no. 10, pp. 3280-3287, Oct. 2005.

[3] A. Ellgardt and A. Wikström, “A single polarized triangular grid tapered-slot array antenna,” *IEEE Transaction on Antennas and Propagation*, vol. 57, no. 9, Sept. 2009.

[4] L.-G. Huss, R. Gunnarsson, P. Andersson, and R. Erickson, “Wideband, wide angle scan, microstrip array antenna element,” *European Microwave Conf.*, Paris, Oct. 2005.

[5] C.-C. Liu, A. Hessel, and J. Shmoys, “Performance of probe-fed microstrip-patch element phased arrays,” *Antennas and Propagation, IEEE Transactions on*, vol. 36, no. 8, pp. 1501-1509, Aug. 1988.

[6] R. B. Waterhouse, “The use of shorting posts to

improve the scanning range of probe fed microstrip patch phased arrays," *IEEE Trans. Antennas Propagat.*, vol. 44, pp. 302-309, Mar. 1996.

[7] R. B. Waterhouse and N. V. Shuley, "Scan performance of infinite arrays of microstrip elements loaded with varactor diodes," *IEEE Trans. Antennas Propagat.*, vol. 41, pp. 1273-1280, Sept. 1993.

[8] S. Chattopadhyay, "Rectangular microstrip patch on a composite dielectric substrate for high-gain wide-beam radiation patterns, antennas and propagation," *IEEE Trans. Antennas Propagat.*, vol. 57, no. 10, pp. 3325-3328, Oct. 2009.

[9] J. Han and M. Kamber, *Data Mining: Concepts and Techniques*, Second Edition, Elsevier Inc., 2006.

[10] D. Zhang and L. Zhou, "Discovering golden nuggets: data mining in financial application," *IEEE Trans. on Systems, Man, and Cybernetics*, vol. 34, no. 4, Nov. 2004.

[11] D. Lian, X. Lida, G. Feng, L. Jun, and Y. Baopin, "A local-density based spatial clustering algorithm with noise," *Inf. Syst.*, vol. 32, pp. 978-986, Nov. 2007.

[12] Ansoft High Frequency Structure Simulation (HFSS), ver. 11.1, Ansoft Corporation, 2008.

[13] CST Microwave Studio, ver. 2015, Computer Simulation Technology, 2015.

[14] D. Pelleg and A. Moore, "X-means: extended K-means with efficient fstimation of the number of clusters," *Proc. of the 17th International Conference on Machine Leaning*, pp. 727-734, 2000.

[15] S. Ramaswamy, R. Rastogi, and S. Kyuseok, "Efficient algorithms for mining outliers from large data sets," *Proc. ACM SIGMOD Int., Conf. on Management of Data*, 2000.

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