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Araştırma / Research

VARIOGRAM ANALYSIS OF A DUAL BAND PATCH ANTENNA

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ABSTRACT

In the present study, the variogram analysis of a patch antenna is performed in order to study its performance by examining the return loss that is closely depending on the design parameters. The studied patch antenna is a dual band textile antenna intended for body centric applications. The working frequencies are 900 MHz and 1800 GHz. For the sake of simplicity, only two design parameters are considered. Their effect on the return loss are examined by plotting the variogram and the results are compared with others given by alternative statistical methods such as Monte Carlo and Polynomial Chaos Expansion methods. It is shown that the variogram analysis may be a good technique for parametrical analysis of electromagnetic structures such as antennas.

Keywords: Dual band textile antenna, variogram analysis

ÇİFT BANTLI BİR YAMA ANTENİN VARİOGAM ANALİZİ

ÖZ

Bu çalışmada, bir yama antenin variogram analizi, tasarım parametrelerine bağlı olan geri dönüş kaybının hesaplanarak anten performansını incelemek için gerçekleştirilmiştir. Söz konusu yama anten, vücut merkezli uygulamalar için tasarlanmış çift bantlı tekstil antendir. Çalışma frekansı 900 MHz ve 1800 GHz'dir. Basitlik açısından, sadece iki tasarım parametresi düşünülmüştür. Dönüş kaybı üzerindeki etkileri variogram tekniği ile incelenmiş ve Monte Carlo ve Çok terimi Kaos Açılımı gibi alternatif istatistiksel yöntemlerin verdiği sonuçlar ile karşılaştırılmıştır. Çalışmada, antenler gibi elektromanyetik yapıların parametrik analizinde variogram yaklaşımının kullanılabileceği gösterilmiştir.

Anahtar kelimeler: Çift bantlı tekstil anten, variogram analizi

1. INTRODUCTION

Nowadays electromagnetic antennas are widely used for diverse applications such as biomedical applications, defense industry and wireless communication, etc. For instance, body centric applications where antennas are mounted on a person or animal body for monitoring and transmitting data to a remote-control device is at the center of many research activities [1]. The emerging concept of Internet of Things (IoT) relies on the deployment of many sensors, such as antennas that make the person or object to communicate with its surroundings to share information [2]. Antennas are of capital importance for implementing communication systems based on the IoT.

Thus, a good candidate for wireless body-centric applications is the microstrip patch antenna [3]. The main characteristic of these type of antennas is the radiation pattern which is perpendicular to the ground plane. Moreover, the metallic ground plane that is placed between the radiating patch and the body behave as a shield for protecting the body from unwanted back radiation.

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Different materials have been used successfully for fabricating the antenna for body centric applications. Due to their attractive features such as flexibility, light weight, low cost and maintenance free characteristics, fabric based (in other words textile) antennas plays an important role to fulfill requirements needed for such usages [4]. Most often, these wearable antennas are preferred to be planar for the easiness of their integration to RF circuits connected to the antenna.

The fabricated antenna must demonstrate good stability over the frequency bandwidth and for different antenna configuration. This feature is even more important for flexible textile antennas. Unfortunately, there is always discrepancies between measurements and theoretical calculations. This is mainly due to differences between the geometrical and/or physical characteristics of the fabricated antenna and the theoretical ones used for simulations and/or theoretical modeling. Therefore, a powerful technique has to be employed in order to assess the variation of the antenna performances obtained from the experiments when compared to the theoretical results given by the numerical modeling.

In the literature, various methods have been proposed for statistically quantifying those discrepancies. A widely used method for this purpose is the Monte Carlo technique [5] that has been successfully applied in a variety of areas such as engineering, physical sciences, finance, medicine, etc [6-9]. Recently, an alternative powerful technique, namely "Polynomial Chaos Expansion" or PCE has been proposed and spread out throughout the electromagnetic community [10-12]. Compared to the well-known Monte Carlo technique, it has the ability to attain the same accuracy with less data and thus to decrease the time spent for the analysis.

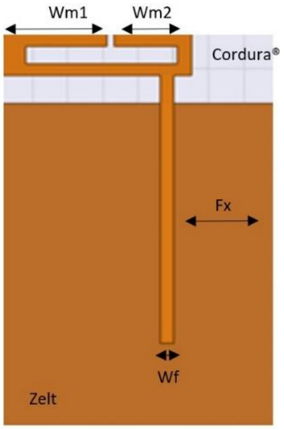
The method we propose in this manuscript is based on the use of the variogram describing the spatial correlation of data.

The present manuscript is organized as follows: First, the second section describe the dual band patch antenna used in this work and the variogram technique employed to statistically analyze the patch antenna performances. Second, the numerical results given by the variograms are given and discussed in the third section.

2. MATERIAL AND METHOD

2.1 Dual Band Patch Antenna

The microstrip antenna examined in this work is from the work of Loss et al. [13]. The antenna is intended for energy harvesting used for IoT applications. Due to their lightweight and flexible structure, textile materials have been used for constructing the antenna. The planar structure of the antenna makes it conformable to any surface. Furthermore, its low profile is suitable for discretion. It is composed of conductive parts (ground and radiating patch) and a dielectric substrate between the two. The materials used are Cordura® ($\varepsilon r \approx 1.9$ and $\tan\delta = 0.0098$) for the dielectric substrate and a fabric named Zelt® ($\sigma = 1.75105$ S/m) for the conductive parts. The antenna is design so that it resonates at two distinct frequencies, i.e. 900 MHz and 1800 MHz, widely used for mobile communication. The geometry of the antenna modelled using a high frequency electromagnetic software is given in Figure 1.



Variable	Value	Description
Wm1	31 mm	Conductive patch geometrical dimensions as indicated on the top view of the antenna
Wm2	21 mm	
Fx	30 mm	
Wf	1.5 mm	
hsub	0.5 mm	Substrate thickness
epsC	1.9	Substrate dielectric constant
condZ	1.75105e6 S/m	Patch conductivity

Figure 1. Dual band patch antenna, its nominal dimensions and physical properties

The effect on the antenna performance of all parameters shown in Figure 1 has already been studied in a previous work presented in [14]. Here, for the sake of simplicity and conciseness, only the position of the feeding strip (*Fx*) and its width (*Wf*) has been considered.

2.2 The Variogram Analysis

The variogram (or semi-variogram) analysis has been initially applied to the field of geostatics that is originated from the work in geology [15]. It is a method used to describe the spatial correlation of a phenomenon. The degree of relationship between the data values on a surface is given by the semi-variance which is half the variance calculated as [16]:

$$2\gamma(h) = \frac{1}{N(h)} \sum_{N(h)} [z(u) - z(u+h)]^2 \tag{1}$$

In expression (1), *z(u)* is the value of the data *z* taken at a position u, *z(u+h)* is another value of z calculated at a different position separated by a distance *h*, and *N(h)* is the number of separating distance (or pairs). *h* is called the lag distance. Thus, the variance is calculated as the average squared difference of the data values separated by the lag distance *h*.

The aim of a variogram analysis is to compute the variogram of a stochastic process and to demonstrate the auto-correlation between the data. A variogram plot is constructed for this purpose. It represents the variation of the semi-variance versus the lag distance *h*. A representative variogram plot showing different important parameters is shown in Figure 2.

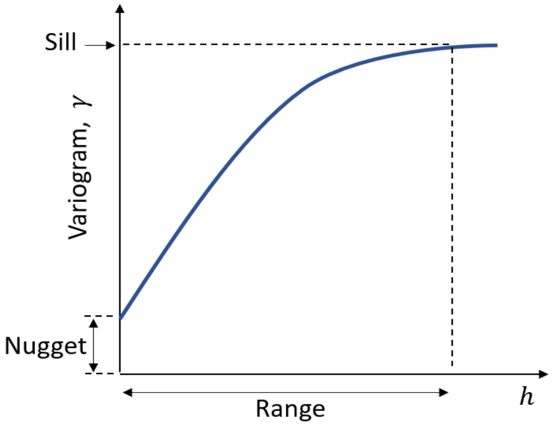


Figure 2. Generic representation of a variogram plot

The parameters shown in the Figure 1 are as follows:

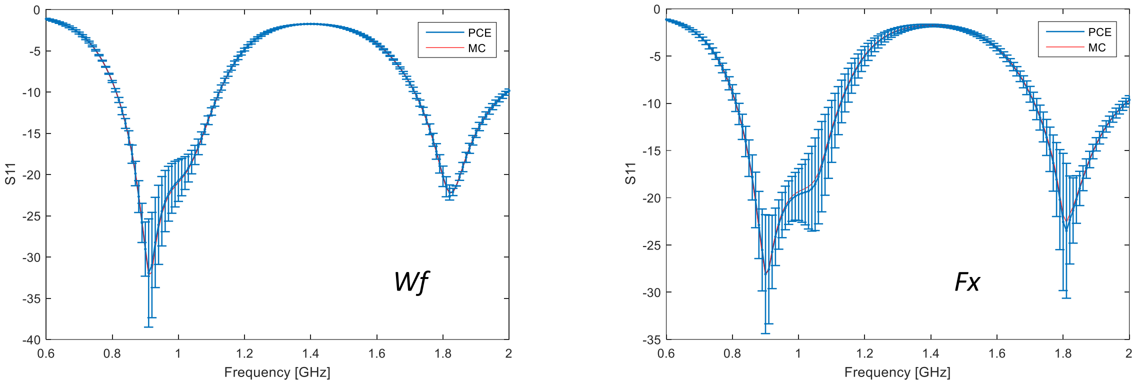
- Nugget: it is the variance value computed for a lag distance *h=0*. It represents the microscale variation of the data. It may be either due to the measurement errors or the sparsity (insufficient number of data) of the data.
- Sill: it represents the maximum variance that the stochastic process may reach. This maximum is obtained when the lag distance $h \to \infty$.
- Range: it gives the distance at which the sill is obtained. Beyond this distance data are considered as no longer autocorrelated.

The variogram analysis has the advantage to provide a clue on the parameter having largest influence on the return loss. However, as for many statistical analysis techniques, depending on the accuracy, and for more complex structure, this analysis may require a large number of data to be calculated using a simulation software. And this may become a time-consuming task.

3. RESULT AND DISCUSSION

In order to evaluate the effect on the antenna performances, i.e. the return loss and the resonance frequencies, two input parameters, that are the position *Fx* of the microstrip line of the patch and its width *Wf*, have been selected and studied.

First, in order to give an overview of what is the effect of the change of these parameters on the return loss, the average value and the standard deviation against the frequency are calculated using the well-known Monte Carlo simulations and the Polynomial Chaos Expansion (PCE) method and plotted in Figure 3. These plots are obtained when each parameter, *Wf* and *Fx* varies individually around their nominal values given in Figure 1. The percentage of variation is 10% for both parameters and only one input parameter is varying while the other is fixed and vice-versa. Comparing the plots in Figure 3, one can clearly distinguish which parameter influence more the S11. Obviously, around the higher resonance frequency, 1.8 GHz *Fx* has more effect on the return loss, whereas at 900 MHz *Wf* has considerable effect on the return loss but the level of its influence is still below of those of *Fx*. This is mainly due to the fact that *Wf* has very small dimension compared to *Fx*. Therefore, for comparable dimensions, the effect of their influence would not be distinguishable.



a) b)

Figure 3: Average and standard deviation of the return loss obtained by PCE and Monte Carlo methods when, a) *Wf* is varying only, b) *Fx* is varying only.

To circumvent this difficulty to distinguish between their respective effects, the semi-variance versus the lag distance is calculated at the two resonance frequencies i.e. 900 MHz and 1800 GHz and they are plotted in Figure 4. As can be seen from the plots, a very high sill is achievable even for very small variation (range) of *Wf* at 900 MHz. Also, for both frequencies, *Fx* has the largest semi-variance compared to *Wf*. In fact, the larger dimension of *Fx* plays an important role in this effect. However, the fact that the slope of the semi-variance is very high for *Wf* at 900 MHz proves that this dimension has considerable effect on the return los even for small lag distance *h*. Therefore, one can deduce that at the lower resonance frequency, *Wf* influence more the output i.e. the return loss compared to *Fx* at the same frequency 900 MHz.

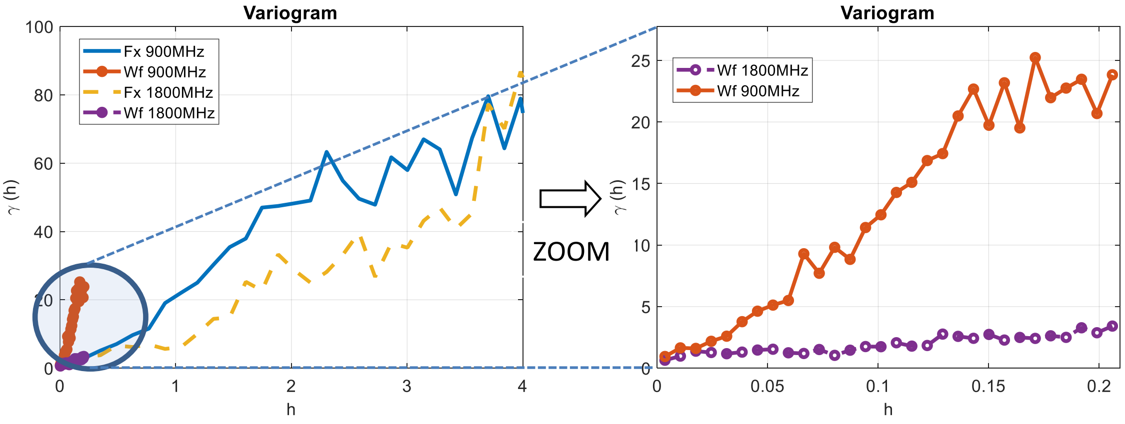
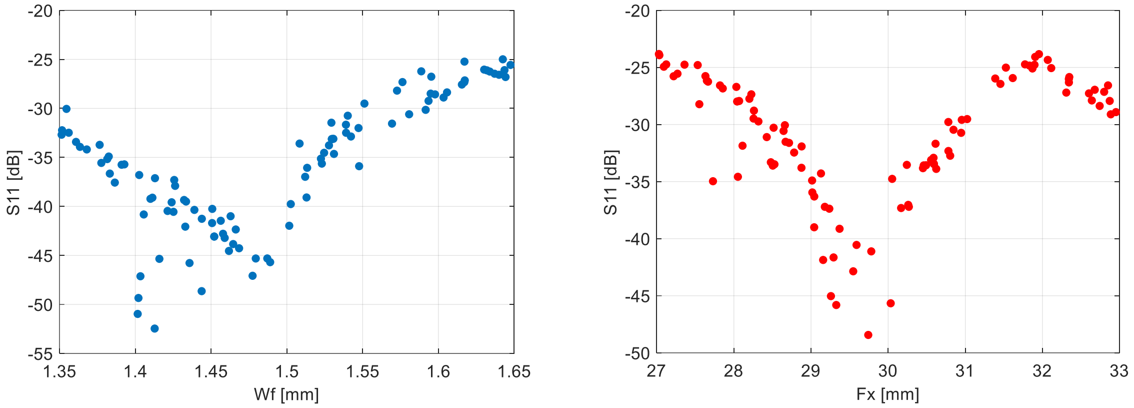


Figure 4: Variogram plot for both parameters *Wf* and *Fx* at the two resonance frequencies 900 MHz and 1800 MHz

3.1. Effect on the Return Loss and the Resonance Frequency at 900 MHz

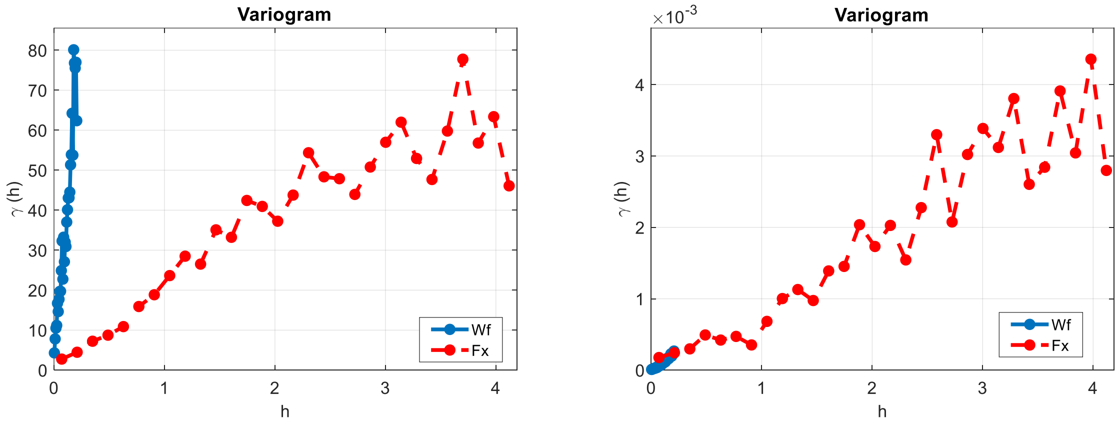
In this subsection, the effect of the same input parameters given above on both the resonance frequency and the return loss is studied separately. In Figure 5, variations of the return loss with respect to the variation of the input parameters *Wf* and *Fx*, computed at 900 MHz, are plotted. 100 data were used for this purpose. However, although the plots reveal the high variability of the return loss w.r.t. these parameters, they do not provide any information on how strong these parameters affect the return loss when compared with each other. The range of variation of the return loss remains similar.



a) b)

Figure 5: Variation of the return loss w.r.t. the variation of, a) Wf and b) Fx at 900 MHz

The sensitivity of the return loss to these parameters is better shown by computing the semi-variance. The variogram which is the plot of the semi-variance versus the lag distance gives an insight on how much the output varies depending on the uncertainty due to the input parameter.



a) b)

Figure 6: Variogram plot for, a) the return loss and b) the resonance frequency, at 900 MHz

It is shown in Figure 6a that, the return loss is highly dependent on both input parameters *Wf* and *Fx*. Moreover, S11 is more sensitive to *Wf* than to *Fx*. This behavior is easily noticeable by comparing the slope of the variogram given by *Wf* with the one obtained by varying *Fx* only. In fact, the semi-variance amplitude obtained for *Wf* reaches its highest value for $h < 1$. Whereas, the maximum value of the variance (sill) computed for *Fx* is obtained for $h > 3$. Only a small variation of *Wf* is needed to cause the output value, i.e. the return loss to vary considerably. Figure 6b is another plot of the variogram, this time computed for the variation of the resonance frequency. It is clearly seen that the amplitude of the semi-variance is very low and the slope of the two variograms are similar even though the amplitude of variance of the *Wf* is very small compared to the one with *Fx*.

3.2. Effect on Return Loss and the Resonance Frequency at 1800 MHz

The same study as in 3.1 is carried out this time at the second resonance frequency i.e. 1800 MHz. The Figure 7 shows the dependency of the return loss on the input parameters *Wf* and *Fx*. Obviously, the range of variation of the return loss (S11) w.r.t. *Fx* is higher than with the variation of *Wf*. As will be shown in Figure 8a, this behavior is mainly due to the smaller range of variation of *Wf*.

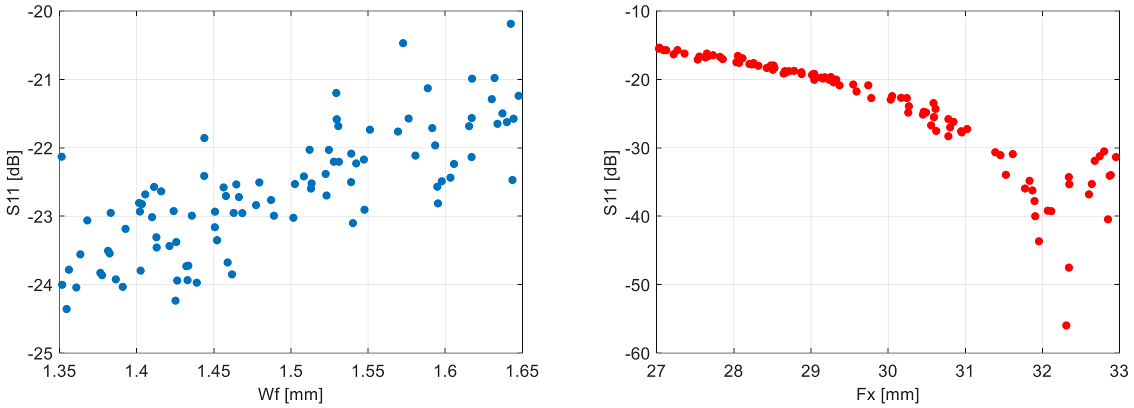


Figure 7: Variation of the return loss w.r.t. the variation of, a) Wf and b) Fx at 1800 MHz

The variogram plots shown in Figure 8a confirm the result obtained in Figure 7. In fact, the semi-variance is much lower for *Wf* compared to the one obtained with *Fx*. However, although the semi-variance for the resonance frequency is very low (there is no significant change in the resonance frequency), the width of the microstrip feed line has more effect on it. This effect is clearly marked by the slop of the semi-variance curve.

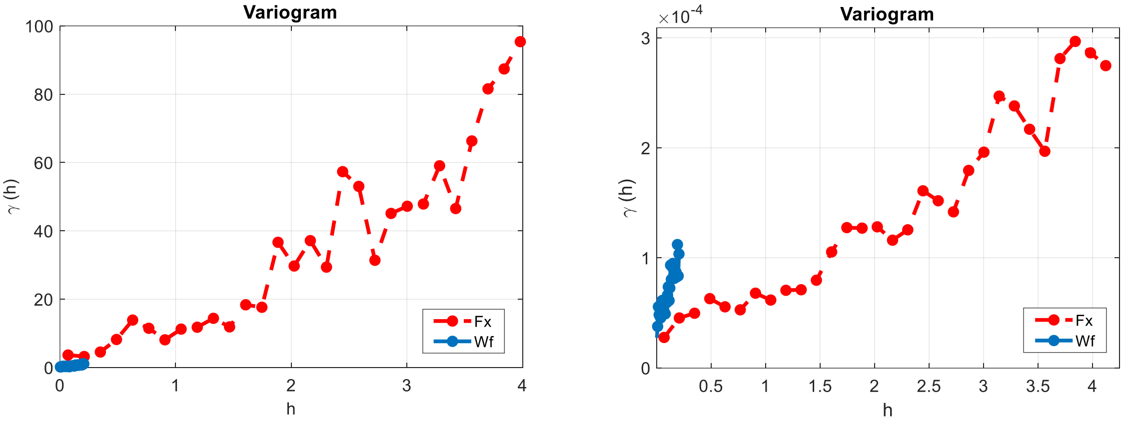


Figure 8: Variogram plot for, a) the return loss and b) the resonance frequency, at 1800 MHz

It is worth to note that, while one of the variables is changed, the other one is fixed to the nominal value given in Figure 1. It is believed that a similar behavior will happen if either Fx or Wf is fixed to a different value than the nominal value. This evidence is due to the fact that, in this case, the variogram depends only on the parameter being changed. However, it is obvious that S11 is a strongly dependent quantity on the antenna geometrical dimensions. Therefore, fixing this parameter to a different value will influence the semi-variance and therefore its magnitude will be different. However, this change will not alter the general evolution of the obtained variograms.

Furthermore, the variogram analysis as studied in this paper is not dependent on the structure being analyzed. It can be applied to any antenna types as long as an output data of interest (such S11, Gain, etc.) along with input data (such as geometrical ones) variation are provided. In this paper a patch antenna is considered but it is obvious that any other antenna type might be used for the same purpose.

4. CONCLUSIONS

In this paper, a new approach for studying the effect of the uncertainty that may be present on the input parameters of a microstrip patch antenna on its output performance S11 and the resonance frequency is presented. This approach is based on the use of variograms reproducing the variation of the semi-variance versus the lag distance representing the range of variation of the input parameters. It is shown that the slope of the variogram curve may be an important parameter to distinguish which of the inputs has more effect on the outputs. The results are supported with those given by the well-known Monte Carlo and Polynomial Chaos Expansion methods. It is shown that there is a good agreement between results given by the variogram analysis and the standard deviation plots given by those methods. Further studies are needed to include more input parameters in the model and to consider different type of statistical distribution of the inputs.

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