International Journal of Engineering

Journal Homepage: www.ije.ir

RESEARCH NOTE

Sensitivity Analysis of a Wideband Backward-wave Directional Coupler Using Neural Network and Monte Carlo Method

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P A P E R I N F O

Paper history:
Received 27 May 2017
Received in revised form 20 February 2018
Accepted 08 March 2018

Keywords:
Backward-wave Directional Coupler
Neural Network
Monte Carlo Method
Probability Density Function
Cumulative Distribution Function

A B S T R A C T

In this paper sensitivity analysis of a wideband backward-wave directional coupler due to fabrication imperfections is done using Monte Carlo method. For using this method, a random stochastic process with Gaussian distribution by 0 average and 0.1 standard deviation is added to the different geometrical parameters of the coupler and the frequency response of the coupler is estimated. The applied process must be done several times for converging Monte Carlo method. Therefore, a large number of simulations is reqired for the coupler. This may take a long time if one uses High Frequency Structure Simulator (HFSS) as the simulation software. To decrease the required time of analysis, neural network model of the coupler incnjuction with Mone Carlo is used. Results showed that the bandwidth of the coupler, minimum return loss in passband and minimum isolation in passband won't be change considerably using the sepecified value of random process. The obtained results for a prototype of a backward wave coupler is presented, which confirm the results of the sensitivity analysis.

***doi**: 10.5829/ije.2018.31.05b.07*

1. INTRODUCTION

Microstrip coupled-line directional couplers are widely used in microwave and millimeter wave circuits [1]. These couplers operate based on two different mechanisms [2]. The first one is backward-wave coupler [3-7], in which the coupling is related to the even and odd mode characteristic impedances difference of the lines. In these components, the electrical lengths of the even and odd modes are assumed to be equal.

In the second type of couplers named forward-wave coupler [8-14], the coupling process depends on the difference electrical length of even and odd modes, while it is assumed that the even and odd mode characteristic impedances of these couplers are equal.

One of the most important features of the directional couplers is sensitivity to the geometrical parameters of it, due to fabrication imperfections, which can be studied using Monte Carlo method[2]. By this simulation technique, based on probability analysis, the risk and uncertainty of different geometrical parameters on the coupler performances such as the level of coupling and operating bandwidth is studied.

In a Monte Carlo process, a random value is selected for each of the tasks, based on a certain range of values. Then, a probabilistic model is derived based on the random values. The result of the model is recorded, and the process is repeated. A typical Monte Carlo simulation calculates the model hundreds or thousands of times, each time using different randomly-selected values. When the simulation is completed, a large number of results from the model, each based on random input values are available. These results are used to describe the likelihood or probability, of reaching various results in the model.

Calculating the model hundreds or thousands of times take a long time using simulation process using HFSS software; therefore, the structure must model by simple structure which can be simulated faster.

In this paper, sensitivity analysis of a backward-wave coupler which was designed in literature [4] is

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[2] https://en.wikipedia.org/wiki/Monte_Carlo_methods_in_finance

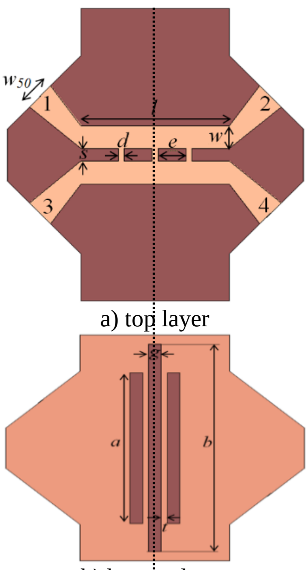
conducted. For this purpose, first this coupler is modeled by neural network, then, Monte Carlo method is used for its analysis. Results showed that this coupler can keep its performances under the normal fabrication imperfections

2. COUPLER DESCRIPTION

The proposed coupler in [4] is shown in Figure 1. It consists of a pair of microstrip coupled lines, which are spaced by distance *s* and their widths are *W*. The substrate thickness is designated by *h*. Also, *a*, *b*, *t* and *g* represents the patterned ground structure dimensions and the connections between lines have the space of *e* and the width of *d*. For the proposed coupler TLY031 substrate is used with electrical characteristics of *h*=0.787 mm, ε_r=2.2 and loss tangent of 0.001.

3. COUPLER MODELING

The coupler of Figure 1 can be modeled by neural network. The neural network which is employed for modeling the coupler is shown in Figure 2. This network is a back propagation neural network (BPNN), which is normally used to estimate a complicated function of several variables [15] over an enclosed interval. The network has 7 inputs, 3 outputs and 14 neurons in hidden layer. The inputs of the network are the dimensions *g*, *a*, *b*, *s*, *e*, *d* and *W* of the coupler and the outputs of it are the bandwidth of the coupler, maximum S_{11} in passband and maximum S_{41} in passband.



a) top layer

b) bottom layer

Figure 1. The structure of the proposed coupler

The network is trained by several input vectors and corresponding target vectors which are obtained by HFSS software. Input vectors are changed in the intervals shown in Table 1. The training function is trainbr in MATLAB software. After training, the network can predict the outputs for the inputs which is never seen.

This network is very fast and it can response in less than 0.01 seconds. So, it is a proper model for using in Monte Carlo method.

4. SENSITIVITY ANALYSIS

After modeling the coupler by neural network, Monte Carlo method is used for sensitivity analysis. For this purpose, first random error by Gaussian distribution with 0 average and 0.1 standard deviation are added to the inputs of the network independently, and the outputs of the network are obtained. This work is done *N* times and statistic characteristic of the outputs can be determined from these *N* responses. In this method *N* must be a large value. *N* is considered 5000 in this paper. Probability Density Function (PDF) of errors of each inputs are shown in Figure 3. It can be seen that all inputs have a Gaussian error distribution, whereas *N*=5000 is chosen.

Figure 4 shows the Cumulative Distribution Function (CDF) of the difference of bandwidth with error and without error $\Delta BW=BW-BW(N)$. This figure shows that for the probability of 25% the bandwidth of the fabricated coupler is more than the bandwidth of the designed one.

TABLE 1. The intervals of inputs changes. (units in: mm)

Parameters	Intervals	Parameters	Intervals
W	[1.6 2.4]	*a*	[14 18]
s	[0.5 1.5]	*b*	[18 22]
d	[0.25 1.25]	*g*	[0.5 1.5]
e	[1 2.5]		

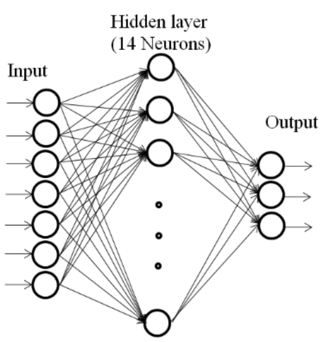


Figure 2. Back propagation neural network model

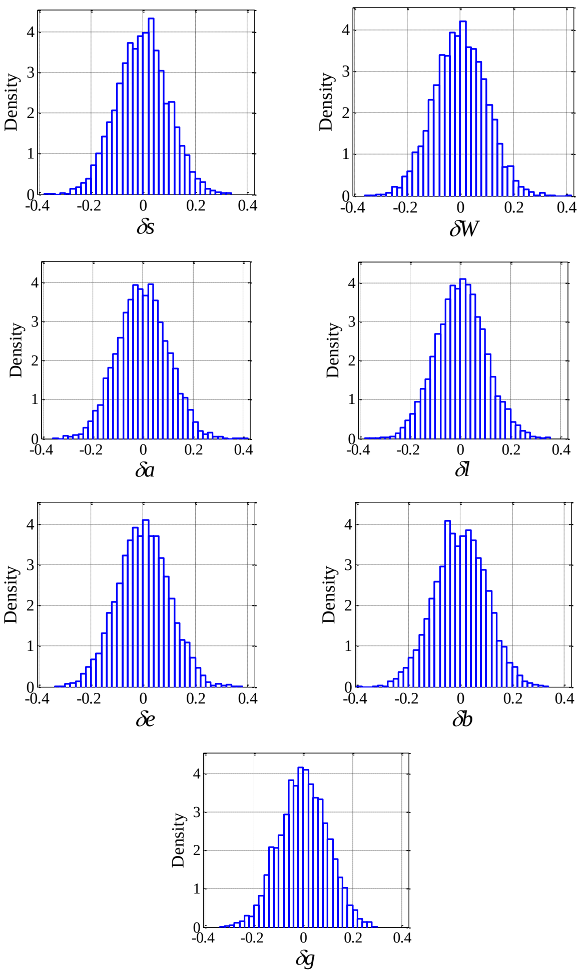


Figure 3. Probability Density Function (PDF) of fabrication imperfections of each inputs

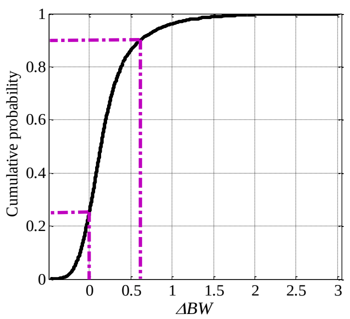


Figure 4. Cumulative Distribution Function (CDF) of the difference of bandwidth with and without fabrication imperfections

Moreover in 90% of occasions the bandwidth is decreased less than 0.62 GHz.

The CDF of the difference of maximum S_{11} in the passband with and without error (ΔS_{11}=|S_{11}|-|$S_{11}(N)$|) is shown in Figure 5.

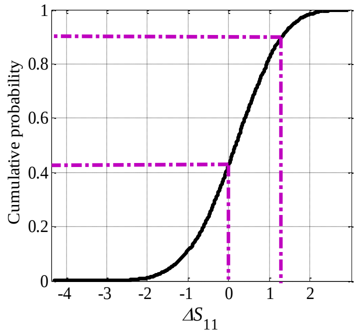


Figure 5. Cumulative Distribution Function (CDF) of the difference of maximum S_{11} in the passband with and without fabrication imperfections

This figure shows that for the probability of 90% return loss of the coupler is reduced less than 1.32 dB.

Figure 6 shows the CDF of the difference of maximum S_{41} in the passband with and without error (ΔS_{41}=|S_{41}|-|$S_{41}(N)$|). It can be seen that for the probability of 59% the isolation between ports of the fabricated coupler is more than the isolation of the designed one. Moreover, for 90% of occasions the isolation of the coupler is decreased in fabrication less than 0.57 dB.

The sensitivity analysis shows that the coupler can keep its performances under fabrication imperfections.

5. MEASURED RESULTS

The coupler is implemented on the TLY031 substrate with electrical characteristics of 2.2 dielectric permittivity and 0.001 loss tangent. The fabricated coupler is shown in Figure 7. The measured results are compared with simulation one in Figure 8. These figures show that the bandwidth of the coupler, maximum return loss in passband and maximum isolation in passband does not change in fabrication process. This reason verifies the sensitivity analysis of the coupler.

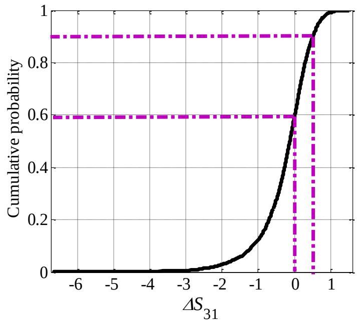
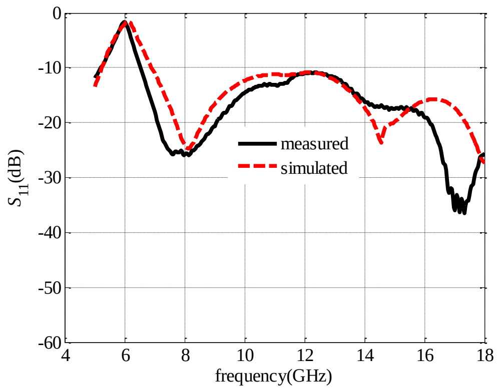
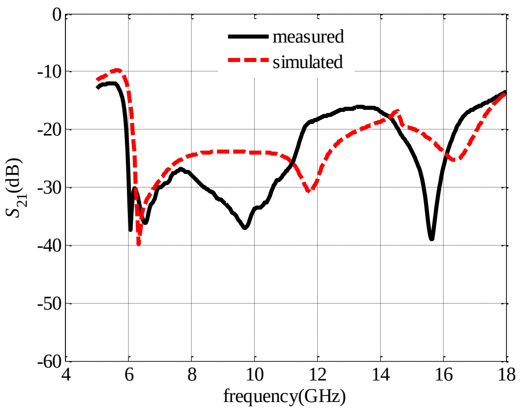
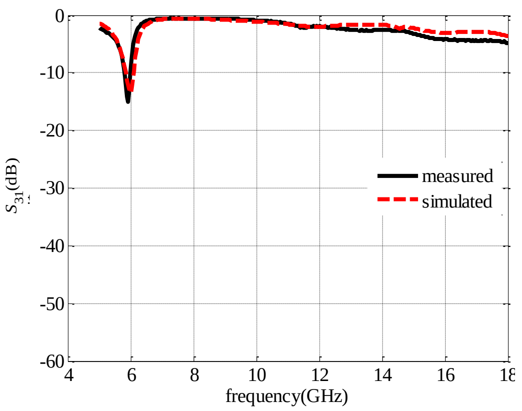


Figure 6. Cumulative Distribution Function (CDF) of the difference of maximum S_{41} in the passband with and without fabrication imperfections

Figure 7. The photo of the fabricated coupler







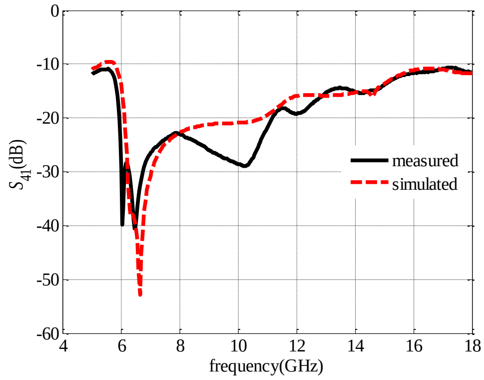


Figure 8. Comparison of the measured results and simulation

7. CONCLUSION

In this paper sensitivity analysis of a wideband backward-wave directional coupler due to fabrication imperfections using Monte Carlo method is presented. A typical Monte Carlo simulation calculates the coupler model thousands of times. In eash case, copler charateistics are stimated using randomly-selected values of the different geometrical parameters of the coupler. A random stochastic process with Gaussian distribution, 0 average and 0.1 standard deviation is added to the different geometrical parameters of the coupler and the frequency response of the coupler is estimated. Due to a very long time required for simulation using full wave simulator such as HFSS, neural network model in conjuction with Monte Carlo mehod is used. Results showed that the bandwidth of the coupler, minimum return loss in passband and minimum isolation between different porsts in passband does not change considerably due to fabrication imperfction. For a fabricated prototype of the backward wave coupler, meaured results are provided, which verify the method of the sensitivity analysis.

8. REFERENCES

1. Mongia, R.K., Hong, J., Bhartia, P. and Bahl, I.J., "Rf and microwave coupled-line circuits, Artech house, (2007).
2. Yeung, L.K. and Wu, K.-L., "A dual-band coupled-line balun filter", ***IEEE Transactions on Microwave Theory and Techniques***, Vol. 55, No. 11, (2007), 2406-2411.
3. Tabatabaeian, Z.S. and Neshati, M.H., "Design investigation of a wideband backward-wave directional coupler using neural network", in Electrical Engineering (ICEE), 2016 24th Iranian Conference on, IEEE., (2016) 1394-1398.
4. Tabatabaeian, Z.S. and Neshati, M.H., "Development of a low profile and wideband backward-wave directional coupler using neural network", ***Applied Computational Electromagnetics Society Journal***, Vol. 31, No. 12, (2016), 1404-1409.
5. Pourzadi, A., Attari, A.R. and Majedi, M.S., "A directivity-enhanced directional coupler using epsilon negative transmission

line", ***IEEE Transactions on Microwave Theory and Techniques***, Vol. 60, No. 11, (2012), 3395-3402.

6. Keshavarz, R., Movahhedi, M., Hakimi, A. and Abdipour, A., "A novel broad bandwidth and compact backward coupler with high couplinglevel", ***Journal of Electromagnetic Waves and Applications***, Vol. 25, No. 2-3, (2011), 283-293.
7. Caloz, C. and Itoh, T., "A novel mixed conventional microstrip and composite right/left-handed backward-wave directional coupler with broadband and tight coupling characteristics", ***IEEE Microwave and Wireless Components Letters***, Vol. 14, No. 1, (2004), 31-33.
8. Tabatabaeian, Z.S. and Neshati, M.H., "Development of a forward-wave directional coupler loaded with a periodic shunt structure", in Telecommunications (IST), 2016 8th International Symposium on, IEEE., (2016), 586-590.
9. Tabatabaeian, Z.S. and Neshati, M.H., "Development of forward-wave directional couplers loaded by periodic shunt shorted stubs", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 30, No. 3, (2017), 344-352.
10. Yen, J.-C., Hsu, S.-K., Lin, T.-H. and Wu, T.-L., "A broadband forward-wave directional coupler using periodic y-shaped ground via structures with arbitrary coupling levels", ***IEEE Transactions on Microwave Theory and Techniques***, Vol. 61, No. 1, (2013), 38-47.
11. Hsu, S.-K., Tsai, C.-H. and Wu, T.-L., "A novel miniaturized forward-wave directional coupler with periodical mushroom-shaped ground plane", ***IEEE Transactions on Microwave Theory and Techniques***, Vol. 58, No. 8, (2010), 2277-2283.
12. Ha, J. and Lee, Y., "Miniaturized quasi-asymmetric forward-wave coupled-line coupler with arbitrary coupling level", in Microwave Symposium Digest (IMS), 2013 IEEE MTT-S International, IEEE., (2013), 1-3.
13. Ha, J. and Lee, Y., "Generalised capacitive-loading method for miniaturisation of forward-wave directional coupled-line couplers with arbitrary strip impedances and coupling levels", ***IET Microwaves, Antennas & Propagation***, Vol. 10, No. 5, (2016), 494-501.
14. Tabatabaeian, Z.S. and Neshati, M.H., "Development of broadband forward-wave directional couplers loaded by periodic patterned ground structure", ***International Journal of RF and Microwave Computer-Aided Engineering***, Vol. 27, No. 8, (2017), 1-9.
15. Tabatabaeian, Z.S. and Neshati, M.H., "Design investigation of an x-band siw h-plane band pass filter with improved stop band using neural network optimization", ***Applied Computational Electromagnetics Society Journal***, Vol. 30, No. 10, (2015), 1083-1088.

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چکیده

در این مقاله، تحلیل حساسیت یک تزویج‌کننده‌ی پهن‌باند رو به‌عقب در اثر خطای ساخت با استفاده از روش مونت کارلو انجام شده است. برای استفاده از روش مونت کارلو، خطایی تصادفی با توزیع گوسی با میانگین صفر و انحراف معیار 0/1 به ابعاد هندسی تزویج‌کننده اضافه شده و برآوردی از پاسخ فرکانسی تزویج‌کننده به‌دست می‌آید. برای همگرا شدن روش مونت کارلو، این کار باید دفعات زیادی تکرار شود. برای این تعداد زیاد بررسی، استفاده از نرم‌افزار HFSS زمان زیادی نیاز دارد. برای کاهش زمان شبیه‌سازی، مدل شبکه عصبی تزویج‌کننده به همراه روش مونت کارلو استفاده می‌شود. نتایج نشان می‌دهد که مشخصات مهم تزویج کننده شامل پهنای باند، حداقل تلفات بازگشتی در باند عبور و حداقل جداسازی پورت‌های مختلف در اثر خطای ساخت تغییر قابل ملاحظه‌ای ندارند. هم‌چنین نتایج اندازه‌گیری مشخصات تزویج کننده برای یک نمونه ساخته شده تزویج کننده رو به‌عقب ارائه شده و مقایسه‌ی نتایج اندازه‌گیری با نتایج شبیه‌سازی، روش بررسی تحلیل حساسیت به‌کار رفته را تایید می‌کند.

***doi**: 10.5829/ije.2018.31.05b.07*