The Study of Wave Digital and Circuit Models of Microstrip Single-Stub L-Tuners

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ABSTRACT: *We in this work proposed an elegant wave digital model for microstrip singlestub tuners. We have used Advanced Design System (ADS) software and MATLAB/Simulink environment for design and simulate the investigated microstrip circuits and their models. Also, we have presented a comparison for which the results are available and presented. We found that there is good agreement between circuits and models.*

1. Introduction

Recently, much work has been concentrated on the development of wave digital (WD) approach for modeling and analysis of different physical systems. Research on application of WD structures for electromagnetic (EM) field simulation is reported in many literatures, e.g. Bilbao [1] and Russer et al. [2]. Maggioni in [3] presented an application of Advanced Design System (ADS) to simulations of different microstrip structures based on their wave digital network (WDN) representations. In [4], Franken et al. gave a framework for the automated generation of the wave digital structures, and the reference circuit is assumed to comprise arbitrary connection types.

The concepts of WDNs have their origins in the field of filter design, where they are designated more specifically as wave digital filters [5]-[8].

Basically, it is important to analyze microstrip structure quickly, to get proper information in short time. In practice, many models have been in use: EM models, electric circuit models, etc. EM models are highly accurate, as they aim to model interactions in whole structure; however this makes them extremely complex and time consuming. Electric circuit models however are less complex and provide sufficient representation of a structure.

The modeling of microwave structures comes with challenges, one of which is to obtain the wave digital model of the different junctions with several arms (i.e. transmission lines). This study is carried out to develop WD models of microstrip single-stub L-tuners and to compare those models with the other ones. Various microwave devices require the use of tuners in experimental verification of their performances.

This paper describes modeling and analyzing procedures for microstrip circuits based on use of one-dimensional wave digital approach. Frequency responses are obtained by direct analysis of the block-based networks formed in Simulink toolbox of MATLAB environment. This wave-based method allows an accurate and efficient analysis of different microwave structures.

Amplitude-frequency responses of S_{21} parameter for different symmetrical microwave circuits are discussed in the previous paper [9]. In this paper, a comparative study of S_{21} and S_{11} parameters obtained from wave digital and circuit models is carried out. Asymmetric microwave circuits with very thin conductor lines are modeled and analyzed.

2. Wave Digital Network

Some general properties and basic aspects of the one dimensional wave digital approach that are of considerable importance, related to this work, will be discussed here briefly.

In order to generate a method for construction of algorithm that efficiently implements microstrip structures utilizing cross-junction opened stubs, their layouts have to be observed. Figure 1 illustrates the known configuration of considerable interest - a microstrip structure with cross-junction opened stubs; it is assumed that this structure consists only of uniform segments assigned from UTL1 to UTL4.

Figure 2 illustrates the equivalent WDN of the known microstrip circuit associated with Figure 1. In accordance with the general method outlined in Section 2 in [9], this WDN is created. The WDN is a general resultant network, i.e. structure model comprises $n_t = \Sigma_{k=1}^{4} n_t$ unit elements, one four-port parallel adaptor and two two-port series adaptors.
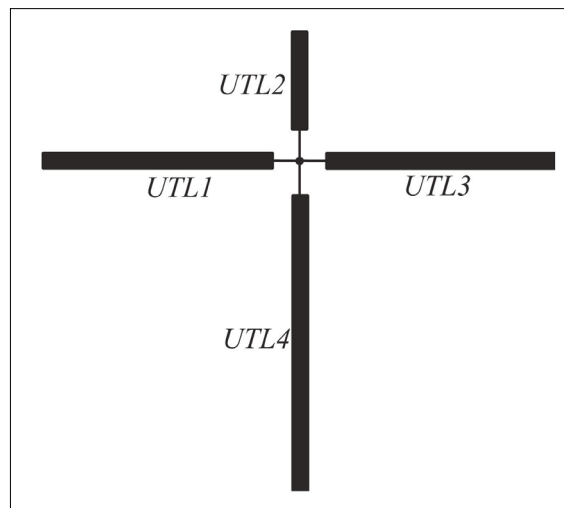

Figure 1. Microstrip circuit with cross-junction opened stubs: symbolical representation of uniform segment connection

The equation set for four-port parallel adaptor, symbolically presented in Figure 2, is:

$$B_k = (\alpha_1 A_1 + \alpha_2 A_2 + \alpha_3 A_3 + \alpha_4 A_4) - A_k \tag{1}$$

where the adaptor coefficients

$$\alpha_k = \frac{2G_k}{\Sigma_{k=1}^{4} G_j}, \quad k = 1, 2, 3, 4, \tag{2}$$

depend on port conductances $G_k = 1/R_k$, with R_k being port resistances, and

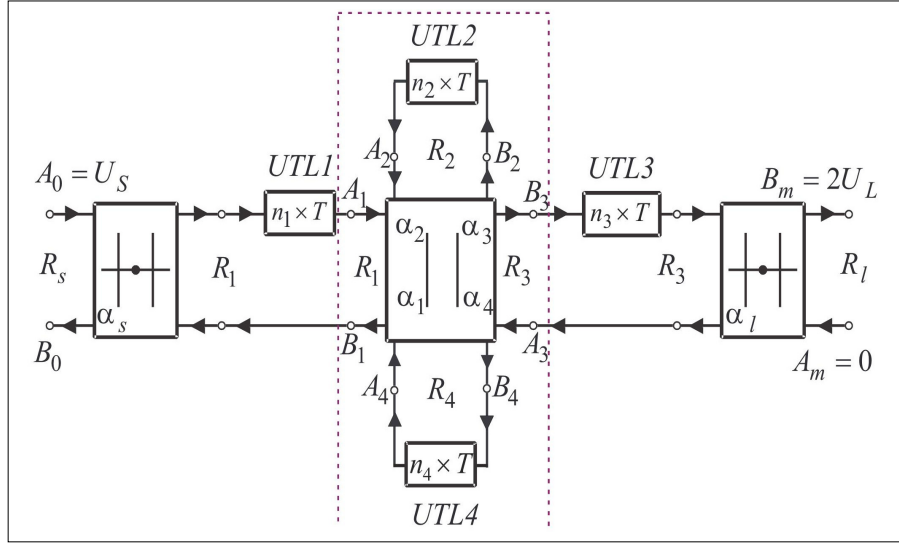$$\Sigma_{k=1}^{4} \alpha_k = 2 \tag{3}$$

Figure 2. Wave digital network of a planar microstrip structure with cross-junction opened stubs

According to the last equation, it is possible to eliminate one coefficient, i.e. α_4, in order to reduce number of adders in resultant wave digital network of this adaptor. In this case, the new equations are:

$$B_4 = A_4 - \sum_{k=1}^{3} \alpha_k (A_4 - A_k) \tag{4}$$

$$B_k = B_4 + (A_4 - A_k), k = 1, 2, 3 \tag{5}$$

3. Matlab/Simulink Model Implementation

MATLAB is an excellent tool for simulating structure, and for creating the valuable "proof of concept". Block diagram is a representation of physical structure using blocks. Individual blocks can be put together to represent the structure in block diagram form. Individual blocks can be the basic blocks or they can be subsystems. They are considered in the text given below.

Simulation of Simulink model represents a series of MATLAB and Simulink commands and functions which are used for its creation. Response is obtained directly in the time domain, and Fourier transformation is used for frequency response calculation. A major part here is formed Simulink model (slx-file), whereby the slx-file is run by m-file that is provided for initialization, response calculation and plotting.

A correct equivalent wave-based model depends on structure geometry. The models represented here are upgraded to the previous models given in [9] in order to calculate all Sparameters, not just S_{21}.

Figure 3 illustrates the general Simulink model formed in accordance with the present wave digital network shown in Figure 2. As stated hereinabove in association with Figure 2, Figure 3 comprises the blocks **Line_1**, **Stub_2**, **Line_3** and **Stub_4** representing models of uniform segments, the block **ADP_T1S2T3S4** representing four-port parallel adaptor, as well as the blocks **ADP-In** and **ADP-Out** representing twoport series adaptors. The two-port adaptors at the ends are used for matching source and load resistances to the rest of the WDN. The two-port adaptor coefficients are

$$\alpha_S = (R_S - Z_{c1})/(R_S + Z_{c1}) \tag{6}$$

$$\alpha_l = (Z_{c3} - R_l)/(Z_{c3} + R_l) \tag{7}$$

Simulink model of four-port parallel adaptor with port 4 being dependent, depicted in Figure 4, is formed in accordance with Eqs. (4)–(5).
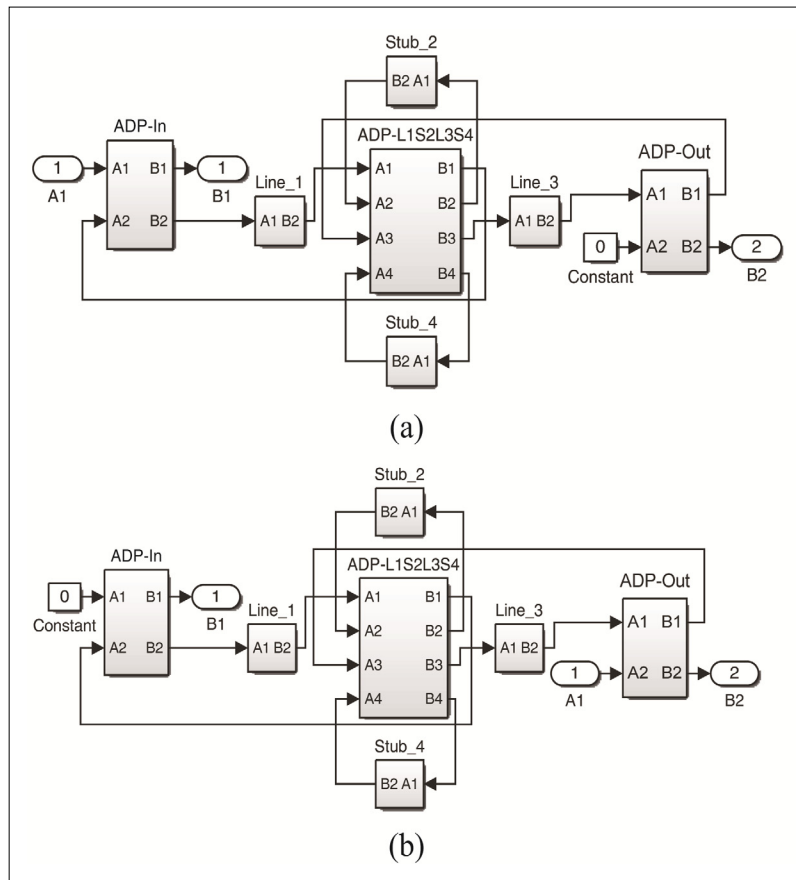

(a)

(b)

Figure 3. General Simulink models of WDN from Figure 2. (a) S_{11} and S_{12} parameters, and (b) S_{21} and S_{22} parameters
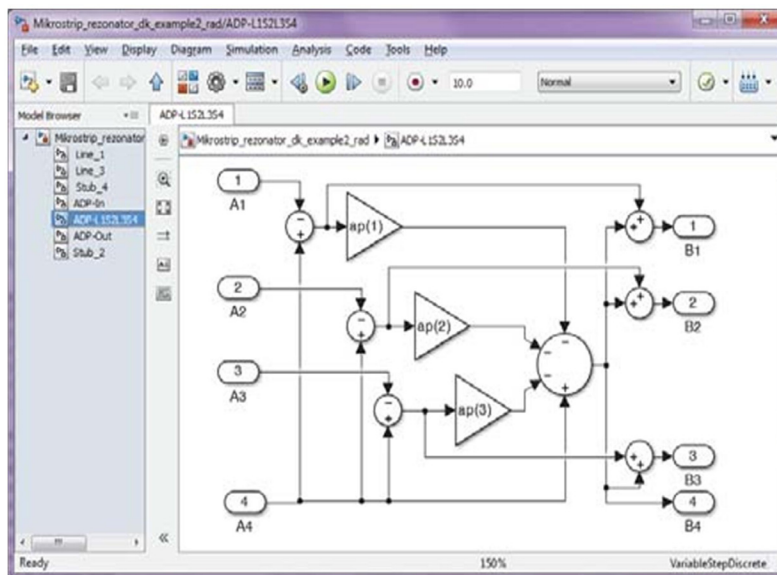

Figure 4. Simulink model of four-port parallel adaptor with port 4 being dependent

4. Results and Discussion

In radio frequency (RF) engineering, stub tuners are often very convenient because they are simple to implement and cheap to manufacture: they only require more of the same material used to make the transmission line. The stub can simply be fabricated as a part of transmision media onto the PCB (Printed Circuit Board) along with the rest of the circuit. The goal that stubs are designed to accomplish is to cancel out the reactive component of the load to be matched, thus they will only work at a specific frequency.

Validation of the proposed circuit modeling is demonstrated and discussed in this section as follows:

• Simulating the developed wave digital models,

• Extracting the model *S*-parameters,

• Plotting parameters.

In order to evaluate these results, a comparison is carried out. Different microwave structures based on microstrip technology are simulated using the same characteristics of the substrate. The structures chosen for the comparison are made on cheap FR-4 substrate of dielectric thickness $h = 0.8$mm, relative permittivity $\varepsilon_r = 4.5$, loss tangent $\tan\delta = 0.02$, and metallization thickness $t = 35\mu m$.

The circuits depicted in next figures have been manufactured by the other researchers and their S-parameters have been measured with an Agilent N5227A vector network analzyer and the results are shown in [10]. The measured results are then de-embedded in order to neutralize the influence of the SMA connectors. Circuits with very thin microstrip lines having high characteristic impedances are modeled, i.e. 0.3mm and 0.6mm in Figures. 5*a* and 6*a*, respectively. The effect of the manufacturing tolerances of narrow lines can influence the power division between the ports.

The models are build in both ADS and MATLAB/Simulink and illustrated in Figs. 5 and 6. The models are than simulated, and plots of the magnitudes of the reflection coefficient (S11) and transmission coefficient (S21) versus frequency are generated. The comparison between the results of simulation is given in Table 1. Table I summarizes the shift in resonant frequencies discussed for the electromagnetic simulator, circuit simulator, WD model and measured results.

The agreement between this simulated results and the measured ones is very good despite a frequency shift and an increase in the insertion losses. The degradation between results could be attributed to increased dielectric losses in the substrate fabrication error. The proposed approach is implemented on a processor Intel(R) Core(TM) i5-3470 CPU @ 3.20 GHz. A time for a response calculation from WD models is very low, i.e. 6.6*s* and 5.2*s*, respectively. ADS Momentum requires more than 20 *min* for response calculation. Generally, the WD method provides the fast simulations versus complex and time consuming 3D models.

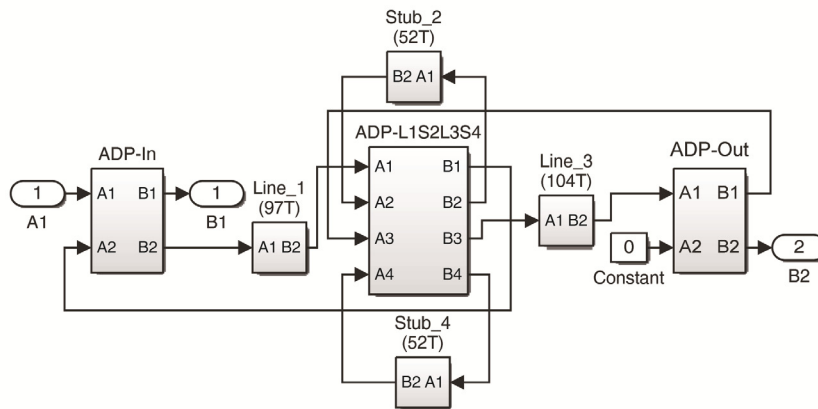| Simulation/Measured /WD results	Resonant frequency [GHz]	
	Example 1	Example 2
WD model	2.6	1.45
ADS circuit model	2.95	2.25
ADS Momentum	2.75	1.8
Measured [10]	2.8	1.85

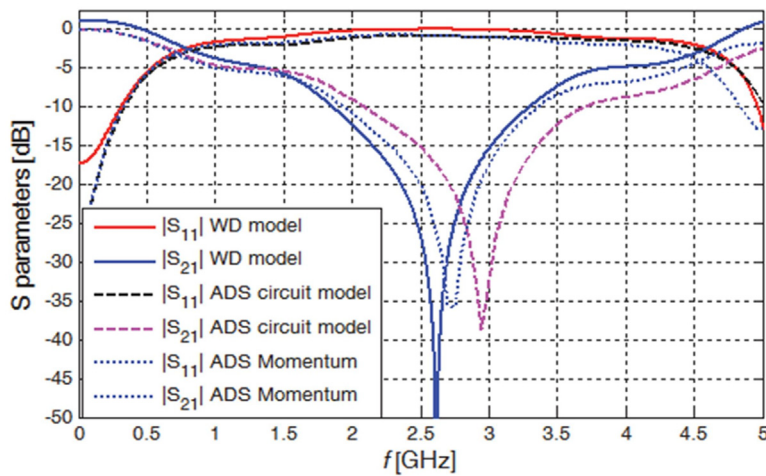Table 1. Shifting of resonant frequencies for simulated and measured results
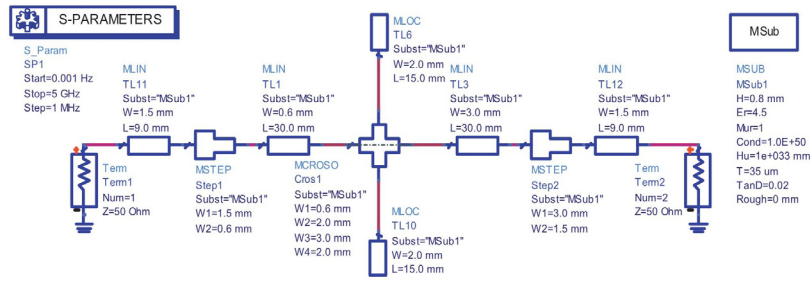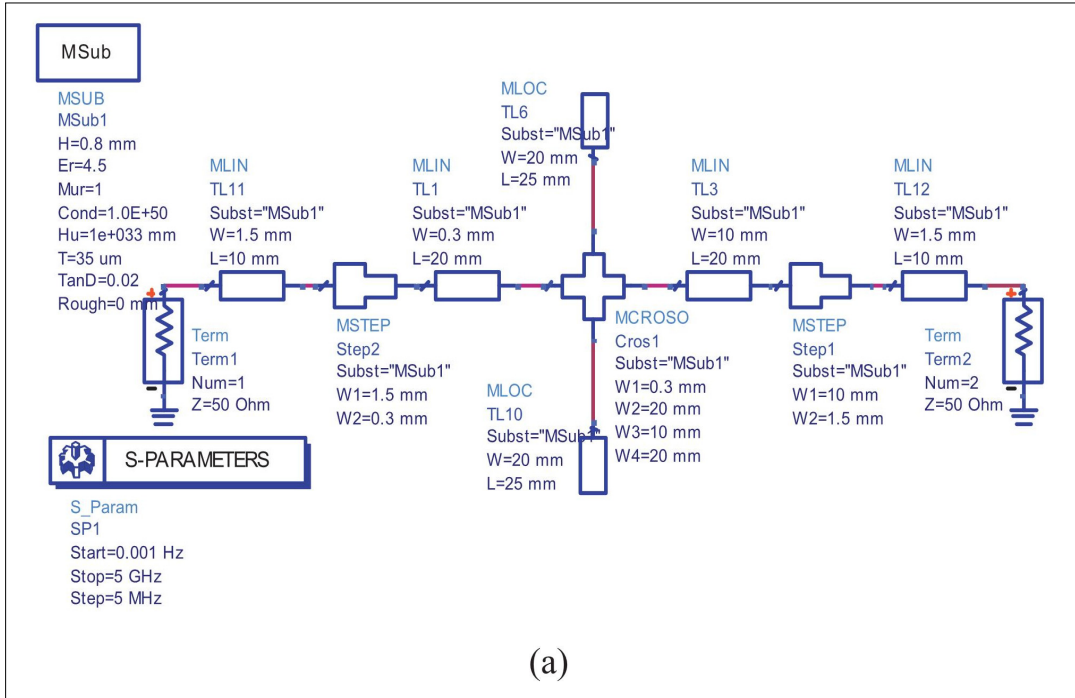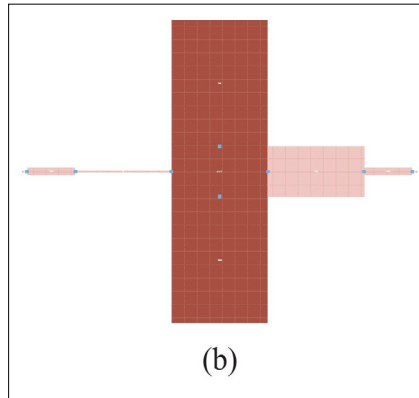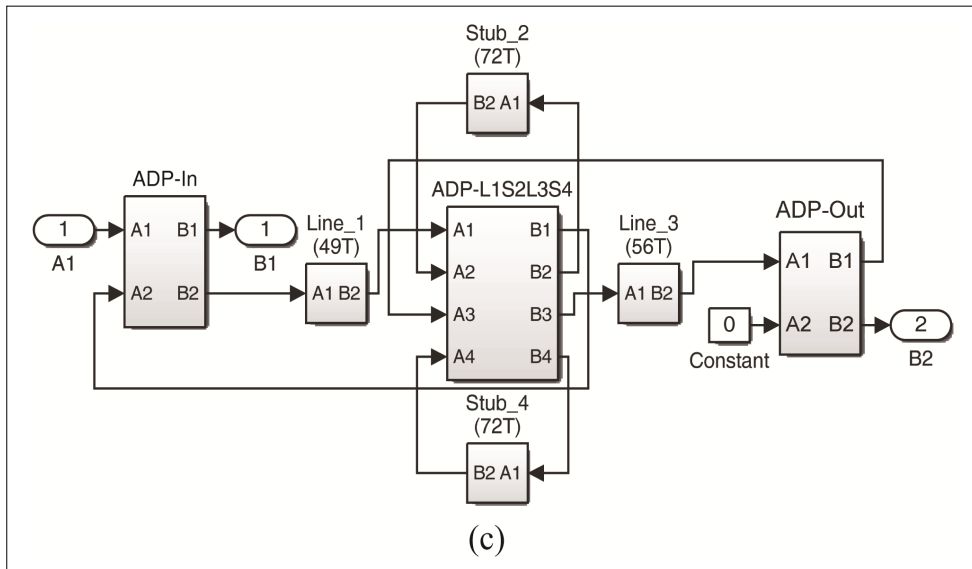
(a)
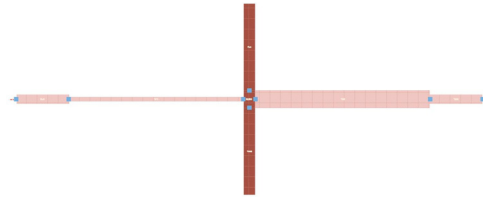
(b)

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(d)

Figure 5. Microstrip single-stub L-tuner (Example 1): (a) circuit model, (b) layout, (c) wave digital model, (d) result comparison
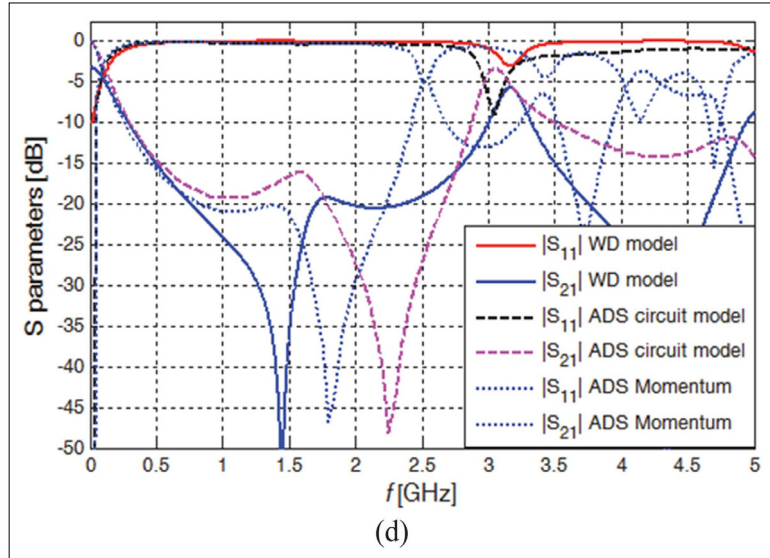
(a)

(b)

(c)

Figure 6. Microstrip single-stub L-tuner (Example 2): (a) circuit model, (b) layout, (c) wave digital model, (d) result comparison

5. Conclusion

Single stub tuners have the ability to match any load impedance that has a positive real component, but they require placement at a specific distance from the load to maintain matching. This paper presents an investigation of both wave digital model and circuit model for microstrip single-band tuners. The objective of the proposed models is to reduce time of simulations of different time-consuming electromagnetic structures.

Using ADS software the equivalent circuit models are simulated. Using MATLAB/Simulink enviroment wave digital models are generated and simulated. The development of the model would aid in reducing the time taken to design microstrip circuit in electromagnetic simulator, due to the fact that the developed WD elements can be built-in MATLAB simply by using library elements. Synthesis of wave digital model of structure with more or less elements is easy task with simple addition or substraction of existing blocks.

The results obtained from both wave digital and circuit models are in good agreement with one another, as well as the measured results. It can be observed also how dimensions of the microstrip lines of the circuit geometry contributes to the respective resonant frequencies.

Acknowledgement

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