Block-based Analysis of Microstrip Structures with Stubs by use of 1D Wave Digital Approach

Biljana P. Stošić, Miodrag V. Gmitrović

Abstract – **The purpose of this paper is to show that the one-dimensional (1D) wave digital approach can be used in analysis of stub-line structures. A stub-line structure, divided into uniform sections, can be efficiently modeled by wave digital network. Frequency response is obtained by direct analysis of formed block-based network. Two application examples, proving the response accuracy of the new technique, are given.**

Keywords – **Wave digital approach, wave digital networks, microstrip circuits, stub-line structures, uniform segments.**

I. Introduction

Modeling of the planar structures by wave digital elements is based on well known theory of wave digital filters (WDF). A detailed review of WDF theory is given in references [1-4]. A large variety of WDF-based techniques has been developed for a wide range of applications [2]. Recently, microwave planar structures are modeled by one-dimensional (1D) [5-8], [10-15], and by two-dimensional (2D) [5], [9] wave digital elements (WDE). Standard WDE, such as delay, adder, multiplier and adaptor, are used in design of wave digital networks (WDN) which represent one signal flow diagram. 1D and 2D wave digital approaches can be efficiently used for analysis of these structures in both the time and the frequency domains.

There does not essentially exist just one type of microstrip structures, but a whole variety of quite distinct subclasses, each of which can again be divided into varies families, etc. For example, there exist stepped-impedance filters, linearly tapered nonuniform transmission lines, stub-line structures and elliptic filters. This reflects the richness of WDN, and the most appropriate one have to be chosen for structure at hand.

Till now, stepped-impedance filters and nonuniform structures with linearly tapered lines are analyzed by use of suggested 1D approach [7], [10-15]. Section II is devoted to some of the basic ideas of the 1D wave digital approach.

In the previously published paper [9] microstrip structure with stub is analyzed by use of 2D wave digital approach. In this paper, the authors will mainly be dealing with 1D wave digital approach. In fact, in view of their geometry, structures with stubs are also natural candidates for 1D approach. A new way for connecting segments in the structure with stubs is developed and represented in the Section III of this paper.

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II. The Basic Ideas of the 1D Wave Digital Approach

A theoretical model for the modeling of the microstrip stepped-impedance structure as well as one type of regular discontinuity (step) is described in the papers [5-7], [10-15]. A nonuniform structure has to be divided into cascade-connected uniform transmission lines (UTL segments). A lossless uniform transmission line is modeled by a two-port digital element with a delay appears in forward path. This wave digital two-port is called the unit element (UE) [2]. The port resistances of the UE are equal and correspond to the characteristic impedance of UTL segment. The connection of two UE with different port resistances is achieved by two-port series adaptors (TA), [3]. A microstrip structure, divided into cascade connection of uniform sections, can be efficiently modelled by wave digital networks. The WDN is a model of the microstrip structure modeled by wave digital elements, and it is composed of two types of building blocks UE and TA.

In the complex microstrip structures, delays of the transmission lines vary from one another and because of this, each transmission line has to be represented as a cascade connection of a certain number of UE. A way of determination a minimal section numbers in WDN of complex microstrip structure is based on the given relative error [10], [14], [15]. Appropriate choice of a minimal section number in that model is very important because of the direct influence on the sampling frequency of that digital model, and on accuracy of the desired response. Also, it is very important to achieve a good compensation of the effects of identified step discontinuities.

Response in WDN of stepped-impedance structure can be found in two different ways. In the first way, efficient and very simple algorithms for calculating transmission and input reflection coefficients of WDN are described in the papers [7], [8]. The algorithms are very easily implemented in the MATLAB environment. The analysis of the wave digital network is efficiently automated, which is inevitable when structures with large numbers of building blocks are to be dealt with. Response can be counted in frequency or in time domain directly from known network function in z-domain.

In the second way, direct analysis of WDN is used. A very simple method of analysis of the WDN is a block-diagram method. WDN is formed directly in the Simulink toolbox of the MATLAB environment [16], [17]. Signal flow diagrams are the basis for block-oriented simulation programs such as Simulink. Response is obtained directly in the time domain, and Fourier transformation is used for frequency response calculation.

III. Modeling of the Structure with Stub

If 1D approach is used for analysis of structures with stubs, a new way for connecting UTL segments in that structures have to be developed. In order to better explain the approach, one microstrip structure with one stub, depicted in Figure 1*a*, is used. This structure can not be observed as simple cascade connection of UTL segments, these segments have to be connected as depicted in Figure 1*b*.

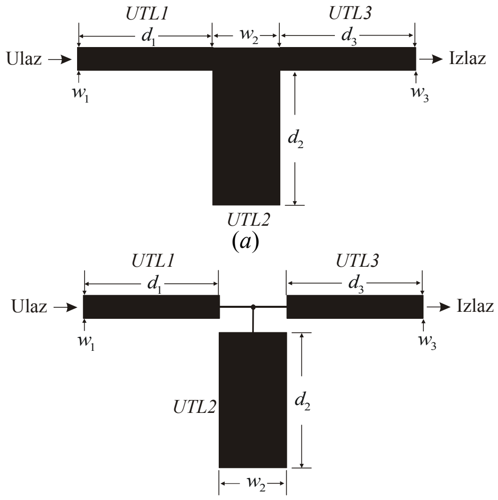

Fig.1. Stub-line microstrip structure:
(a) layout and (b) segment connections

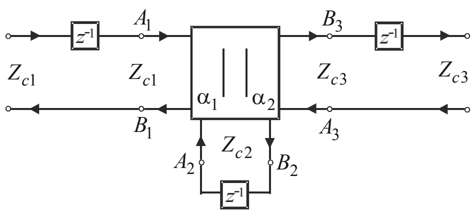

Fig.2. Network of the stub-line structure

A wave digital nertwork which corresponds to the segment connection shown in Figure 1*b* is depicted in Figure 2. In this network, the effects of discontinuity are not considered. Each uniform segment in the Figure 1*b* can be approximated with one transmission line of characteristic impedance Z_{ck} , $k = 1,2,3$. Models of UTL segments are connected by use of one three-port parallel adaptor with port 2 being dependent. Adaptors are memoryless devices whose task is to perform transformations between pairs of wave variables that are referred to different levels of port resistance. In the symbolic representation of the three-port parallel adaptor [4] given in Figure 3, they are shown explicitly the adaptor coefficients α_1 and α_2 next to the ports 1 and 3, respectively. These adaptor coefficients are

$$\alpha_j = \frac{2G_j}{G_1 + G_2 + G_3}, \qquad j = 1,2, \tag{1}$$

where port conductances are

$$G_k = 1/Z_{ck}, \qquad k = 1,2,3. \tag{2}$$

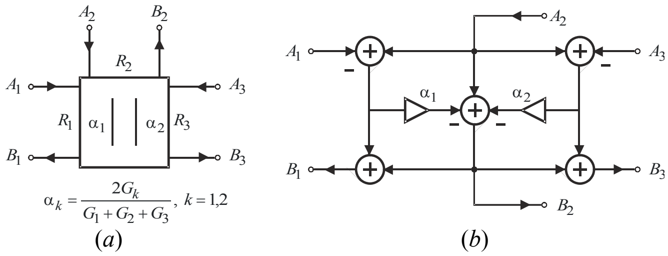

Fig.3. Three-port parallel adaptor with port 2 being dependent:
(a) symbol and (b) WDE

Segment UTL2 which represent open stub is connected to adaptor's dependent port 2. All UTL segments are modeled by several cascaded UE. In case of equal delays of UTL segments, each segment is modeled by one UE as shown in Figure 2.

The formed Simulink model of WDN is depicted in Figure 4. The blocks **TLine_1**, **Stub_2** and **TLine_3** represent UTL segments. The blocks **ADP-S** and **ADP-L** represent two-port series adaptors, and block **ADP_T1S2T3** three-port adaptor. The two-port adaptors at the ends are used for matching source and load resistances to the rest of the WDN. In the symbolic representation of a two-port series adaptor [1-4] given in Figure 5, it is shown explicitly the parameter α next to the port 1. The adaptor coefficients for the blocks **ADP-S** and **ADP-L** in the WDN are

$$\alpha_S = (R_S - Z_{c1})/(R_S + Z_{c1}), \tag{3}$$
$$\alpha_L = (Z_{c2} - R_L)/(Z_{c2} + R_L).$$

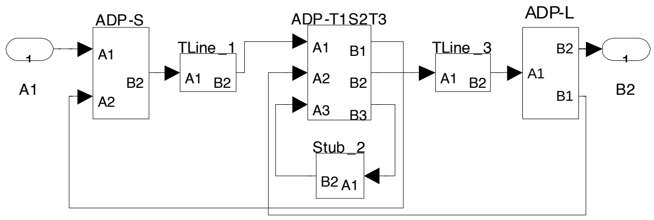

Fig.4. Simulink model of the structure

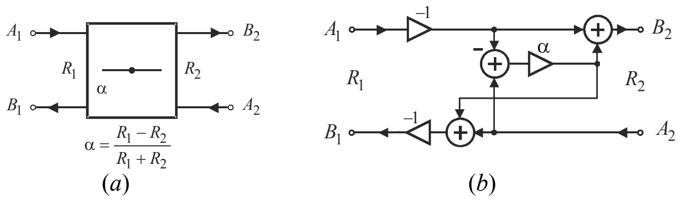

Fig.5. Two-port series adaptor: (a) symbol and (b) WDE

IV. Examples of Application

In this section, some simple examples of stub-line microstrip structures are analyzed by use of suggested 1D approach.

A. Microstrip Structure with a Single Stub

A microstrip structure with a single stub, depicted in Figure 1, is used for verification of the proposed method. The substrate dielectric constant is $\varepsilon_r = 2.32$ and the board thickness $h = 1.58\,mm$.

TABLE I
TRANSMISSION LINE PARAMETERS

nv	d [mm]	w [mm]	Zc [Ohm]	Tv [ps]
1	30.0000	4.7100	50.2540	139.8003
2	30.0000	15.7600	20.0016	145.0746
3	30.0000	4.7100	50.2540	139.8003

Microstrip structure given in Figure 1 is approximated by connection of 3 transmission lines with parameters given in Table I.

For given error of $n\_er = 0.01\,\%$, a total minimal number of sections in *WDN* is $n_t = \sum_{k=1}^{3} n_k = 161$, [10], [14]. For segments UTL1 and UTL3, a number of sections n_k is 53, and for segment UTL2 is 55. A total delay for the digital model of the structure is $T_t = n_t \cdot T_{\min} / q = 424.6763\ ps$ where $q = 53$ is a multiple factor and $T_{\min} = \min\{T_1, T_2, T_3\} = 139.8003\ ps$ is a minimum delay. A total real delay of the structure is $T_\Sigma = \sum_{k=1}^{3} T_k = 424.6752\ ps$. A sampling frequency of the digital model of the planar structure for the chosen minimal number of sections is $F_s = n_t / T_t = 379.1123\ GHz$. In this case, a relative error of delay is $er = \frac{T_\Sigma - T_t}{T_\Sigma} \cdot 100 = -0.00027\,\%$. According to the relations (1)-(3), adaptor coefficients are $\alpha_1 = \alpha_2 = 0.4432$ and $\alpha_S = -\alpha_L = -0.0025$.

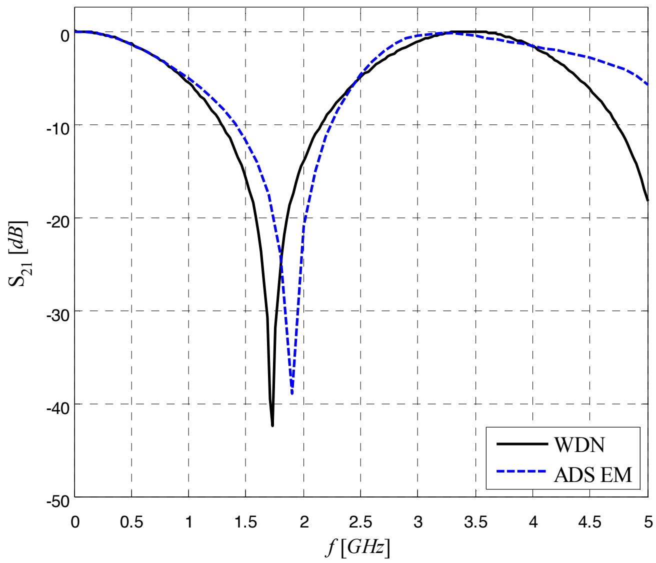

Fig.6. Frequency response

Response comparison for the proposed way of modeling structrure with stub by use of 1D approach is shown in Figure 6. It is clear that the curve corresponding to the WDN result is slightly shifted to the left comparing to the one of electromagnetic simulation done in ADS [18]. If the effects of the T-junction discontinuty are treated, the agreement between the results is going to be better. That will be considered in the future.

B. Microstrip Structure with Two Stubs

Consider a microstrip structure with two stubs depicted in Figure 7. The substrate dielectric constant is $\varepsilon_r = 9.9$ and the board thickness $h = 127\ \mu m$. Metalization is cooper and the strip thickness is $t = 36.068\ \mu m$. The observed structure is treated as a specific connection of 5 transmission lines with parameters given in Table II.

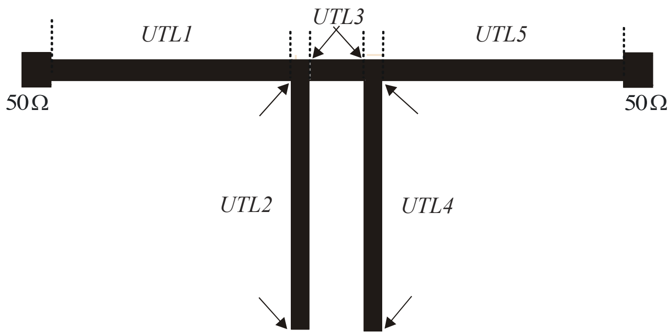

Fig.7. Layout

TABLE II
TRANSMISSION LINE PARAMETERS

nv	d [mm]	w [mm]	Zc [Ohm]	Tv [ps]
1	2.8778	0.1308	41.7076	25.1683
2	2.9210	0.1308	41.7076	25.5459
3	0.3810	0.1308	41.7076	3.3321
4	2.9210	0.1308	41.7076	25.5459
5	2.8778	0.1308	41.7076	25.1683

For given error of $n\_er = 0.01\,\%$, a total minimal number of sections in *WDN* is $n_t = 1006$, [10], [14]. For UTL segments, a number of sections n_k is 242, 245, 32, 245 and 242, respectively. A total delay for the digital model of the structure is $T_t = 104.7521\ ps$ where $T_{\min} = 3.3321\ ps$ and $q = 32$. A total real delay of the structure is $T_\Sigma = 104.7605\ ps$. A sampling frequency of the digital model of the planar structure for the chosen minimal number of sections is $F_s = 9603.6215\ GHz$. In this case, a relative error of delay is $er = 0.00795\,\%$. According to the relations (1)-(3), adaptor coefficients are $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0.6667$ and $\alpha_S = -\alpha_L = 0.0904$.

The result obtained by direct analysis of WDN and the ones obtained by linear simulations in the programs GENESYS [19] and ADS [18] are depicted in Figure 8. From the given responses, it can be inferred that the curve corresponding to WDN is slightly shifted to the left, and the curve corresponding to ADS result to the right, comparing to GENESYS curve.

In this example there are two types of discontinuities: T-junction and open-end. Here, the effects have not been taken under consideration. But, when the discontinuities are identified in the structure, they have to be treated. Only in that case, WDN curve is going to have better agreement with other results.

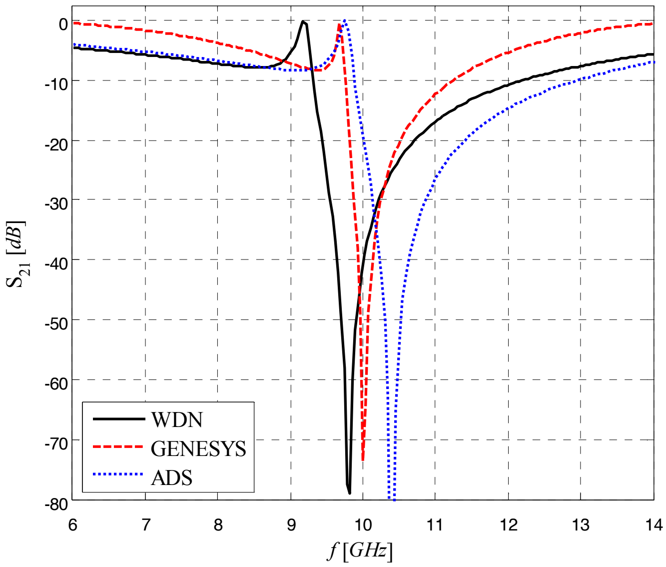

Fig.8. Frequency response

V. Conclusion

Approaches for frequency and time analyses of stepped-impedance microwave structure based on wave digital filter theory are described in references [5-8], [10-15]. The microwave structure is treated there as a cascade connection of uniform transmission lines with various lengths and widths.

Here, it is shown that the 1D wave digital approach used for analysis of microstrip stepped-impedance structures can be also used in analysis of stub-line structures. A new way for connection of identified UTL segments is described. That leads to a universal and effective procedure capable of solving a wide range of practical problems.

The efficiency and accuracy of the suggested procedure is shown in two examples realized in the microstrip line technique, such as structure with a single stub and with two stubs. The results of the analysis obtained by the WDN have shown good agreement with those obtained by other programs mentioned above. A much better agreement can be achieved by modeling discontinuities in the observed structure.

A very simple block-diagram method of analysis of the WDN is used here. WDN is formed directly in the Simulink toolbox of the MATLAB environment. Frequency response is obtained by direct analysis of formed block-based network.

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