American Journal of Signal Processing 2015, 5(3): 56-58
DOI: 10.5923/j.ajsp.20150503.02

Design and Implementation of First Order Digital Differentiators at Microwave Frequencies

Srinivasa Rao Sankranti[1,*], Tirumala Krishna Battula[2], Malleswara Rao Veera[1]

[1]Dept. of ECE, GITAM University, Rushikonda, Visakhapatnam, India
[2]Dept. of ECE, UCEV, JNT University Kakinada, Vizianagaram, India

Abstract Conventional digital differentiators works efficiently up to Low frequency region only. The main purpose of the paper is to design and implement first order Al-Alaoui differentiator at microwave frequencies. Necessary derivations are carried out. The differentiator is implemented using transmission line configurations such as micro strip lines. The simulations are carried out using MATLAB and Advanced design software (ADS) environment.

Keywords Microwave Filter, Digital Differentiator, Stub, Micro strip, ADS (Advanced Design Software)

1. Introduction

Digital differentiators which are are used to find the time-derivative of the incoming signal play vital role in many of the electronic systems. A digital differentiator is defined as, $H(j\omega) = j\omega$. The FIR type differentiators find less use in real-time applications. Al-Alaoui have designed a IIR type digital differentiator [1-3] by the interpolation process which is given by, $H(z) = \frac{8\ (z-1)}{7T\ (z+1\ /\ 7\ )}$. The digital differentiators are mainly implemented in circuits for low frequency applications. So, the implementation of differentiators at high frequencies is a problem of practical interest.

The paper is organized as follows. Section 2 deals about design of digital filters at microwave frequencies. Implementation of Al-Alaoui digital differentiator at microwave frequencies is presented in section 3. Finally, Results and conclusions are drawn in Section 4.

2. Digital Filters at Microwave Frequencies

The Scattering Matrix which relates incident waves and emergent waves of a two port network is defined as,

$$\begin{pmatrix} b(1) \\ b(2) \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a(1) \\ a(2) \end{pmatrix} \quad (1)$$

* Corresponding author:
srinu16ssr@gmail.com (Srinivasa Rao Sankranti)
Published online at http://journal.sapub.org/ajsp

The Chain Scattering Matrix [4] of a two port network is defined as,

$$\begin{pmatrix} a(1) \\ b(1) \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \begin{pmatrix} b(2) \\ a(2) \end{pmatrix} \quad (2)$$

The relation between the parameters will be,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \begin{pmatrix} \frac{1}{S_{21}} & -\frac{S_{22}}{S_{21}} \\ \frac{S_{11}}{S_{21}} & S_{12} - \frac{S_{11}S_{22}}{S_{21}} \end{pmatrix} \quad (3)$$

The Chain Scattering Matrix for different Transmission Line configurations [5] will be calculated in this Section.

2.1. Open Circuited Transmission Line

Consider a Transmission Line with Open Circuited Stub. Let the length of the stub and transmission line be $l = \lambda_0/4$, where λ_0 is the wavelength at normalized frequency ω_0. If the Impedance of the Open Circuited Stub is Z_1, then the chain scattering matrix is given by,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}_{O.C} = \begin{pmatrix} 1 + j\frac{Z_0}{2Z_1} tan(\beta l) & j\frac{Z_0}{2Z_1} tan(\beta l) \\ -j\frac{Z_0}{2Z_1} tan(\beta l) & 1 - j\frac{Z_0}{2Z_1} tan(\beta l) \end{pmatrix} \quad (4)$$

where β is the propagation constant. Let ω be the angular frequency and τ be the propagation delay caused by the length l. If $jtan(\beta l) = jtan(\omega\tau)$, then,

$$j\tan(\omega\tau) = \frac{e^{j\omega\tau} - e^{-j\omega\tau}}{e^{j\omega\tau} + e^{-j\omega\tau}} = \frac{D - D^{-1}}{D + D^{-1}} \quad (5)$$

Then Equation (4) reduces to,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}_{O.C} = \frac{1}{1+D^{-2}} \begin{pmatrix} (1+c)+(1-c)D^{-2} & c-cD^{-2} \\ -c+cD^{-2} & (1-c)+(1+c)D^{-2} \end{pmatrix} \tag{6}$$

where $c = \frac{Z_0}{2Z_1}$ and $D^{-1} = e^{-j\omega\tau}$. If we set $z = D^2$, then,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}_{O.C} = \frac{1}{1+z^{-1}} \begin{pmatrix} (1+c)+(1-c)z^{-1} & c-cz^{-1} \\ -c+cz^{-1} & (1-c)+(1+c)z^{-1} \end{pmatrix} \tag{7}$$

The digital transfer function $H(z)$ or $S_{21}(z)$ is given by $\frac{1}{T_{11}(z)}$. So,

$$H(z) = S_{21}(z) = \frac{1+z^{-1}}{(1+c)+(1-c)z^{-1}} \tag{8}$$

2.2. Short Circuited Transmission Line

For the short circuited stub,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}_{S.C} = \begin{pmatrix} 1+j\frac{Z_0}{2Z_1}cot(\beta l) & j\frac{Z_0}{2Z_1}cot(\beta l) \\ -j\frac{Z_0}{2Z_1}cot(\beta l) & 1-j\frac{Z_0}{2Z_1}cot(\beta l) \end{pmatrix} \tag{9}$$

The above Equation can be expressed in terms of c and D as,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}_{S.C} = \frac{1}{1-D^{-2}} \begin{pmatrix} (1+c)-(1-c)D^{-2} & c+cD^{-2} \\ -c-cD^{-2} & (1-c)-(1+c)D^{-2} \end{pmatrix} \tag{10}$$

The chain scattering matrix in terms of delay z^{-1} will be,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}_{S.C} = \frac{1}{1-z^{-1}} \begin{pmatrix} (1+c)-(1-c)z^{-1} & c+cz^{-1} \\ -c-cz^{-1} & (1-c)-(1+c)z^{-1} \end{pmatrix} \tag{11}$$

The digital transfer function $H(z)$ or $S_{21}(z)$ of a short circuited stub is given by,

$$H(z) = S_{21}(z) = \frac{1-z^{-1}}{(1+c)-(1-c)z^{-1}} \tag{12}$$

3. Implementation of Digital Differentiators

3.1. Implementation of Al-Alaoui Differentiator

First order Al-Alaoui digital differentiator is given by

$$H_1(z) = \frac{8(z-1)}{7T(z+\frac{1}{7})} \tag{13}$$

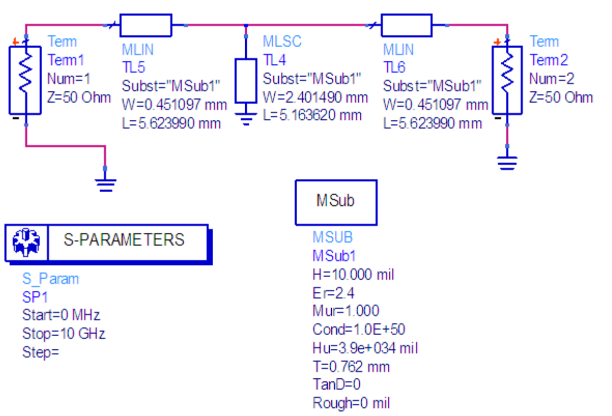

Figure 1. Implementation using ADS Software

Comparing Eqn. (13) with Eqn.(12), $c = \frac{Z_0}{2Z_1} = \frac{4}{3}$. If $Z_0 = 50\Omega$ then $Z_1 = 18.75\Omega$. The designed practical filter structure using micro strips is as shown in Figure 1. The experimental setup and the layout generated are as shown in Fig.5 and 4 respectively. The magnitude and phase responses are shown in Fig.2 and 3.

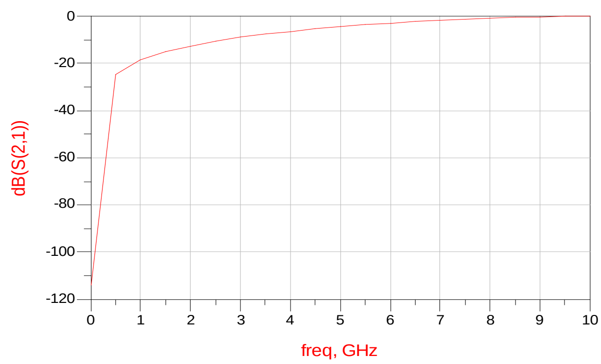

Figure 2. Variation of the gain of S_{21}

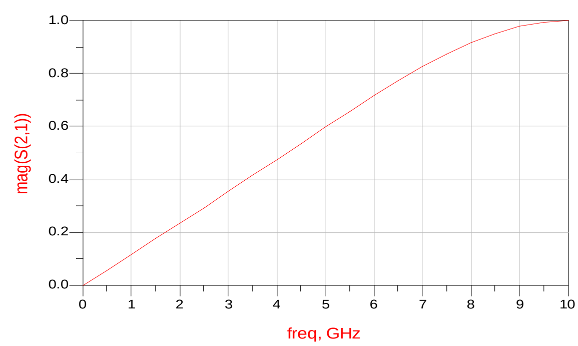

Figure 3. Variation of the Magnitude of S_{21}

Figure 4. Layout of First order differentiator

Figure 5. Experimental setup

4. Results and Conclusions

The first order microwave differentiator was constructed by using microstrip to emulate transmission lines. The shunted transmission line having a characteristic impedance of 18.75Ω and 50 Ω equivalent microstrips are placed both sides symmetrically. The simulation is performed by using Advanced Design System Software (ADS). The magnitude response of $S_{21}(f)$ of first order differentiator is shown in Fig.2. We generated the physical layout by using ADS The physical layout was built on FR-4 substrate. By using Network analyzer, the magnitude response of $S_{21}(f)$ was measured. The simulated and experimental results of a first order differentiator are in good agreement.

REFERENCES

[1] M.A. Al-Alaoui, *Novel Digital integrator and Differentiator* - IEEE Electronic Letters, Vol.29, no.4, pp.376-378, Feb.1993.

[2] M. A. Al-Alaoui, *Novel approach to designing Digital Differentiators*-IEEE Electronic Letters, Vol.28, no.15,pp. 1376-1378, Jul.1992.

[3] B.T. Krishna, S. Srinivasa Rao, *On design and applications of digital differentiators*, 978-1-4673-5584-1/12, IEEE-ICoAC 2012.

[4] D.-C. Chang and C.-W. Hsue, “Design and mplementation of filters using transfer functions in the Z domain,” *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 979–985, May 2001

[5] Ching-Wen Hsue, Lin-Chuan Tsai and Kuo-Lung Chen, *Implementation of First-Order and Second-Order Microwave Differentiators*, IEEE Microwave Theory and Techniques, vol.52, n0.5,pp.1443-1447, May 2004.

[6] Ching-Wen Hsue, Tun-Ruey Cheng and Hwan-Mei Chen, *A Second order Microwave Differentiator*, IEEE Microwave and Wireless Components Letters, vol.13, no.3, pp.137-139, March 2003.

[7] Lin Chuan Tsai, *A Novel Class of Digital Filters*, 2012 8th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM-2012), China, pp.1-4, September 21-23, 2012.

[8] Jia,-Sheng Hong, M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, John Wiley & Sons, 2001.

[9] Israel Arnedo, A. Lujambio, T. Lopetegi and M.A.G. Laso, *Design of Microwave Filters With Arbitrary Frequency Response Based on Digital Methods*, IEEE Microwave and Wireless Components Letters, vol.17, no.9,pp.634-636, September 2007.

[10] J.G. Proakis, D.G. Manolakis, *Digital signal processing, principles, algorithms, and applications*-3rd edition, PHI Publications, Newdelhi, 1999.