GAIN SENSITIVITIES OF A MICROWAVE AMPLIFIER WITH RESPECT TO THE MICROSTRIP PARAMETERS

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Abstract

This paper presents a method for the sensitivity analysis of the gain with respect to the width and length of a microstrip line used in any position of the input /or output matching circuit of a microwave amplifier. The method is applied to a low-noise amplifier and the resultant typical sensitivity variations are also given. This work shows which microstrip lines are sensitive with respect width/or length changes, therefore extra care should be taken for them during the practical realization stage.

1. Introduction

Sensitivities, or partial derivatives of certain network functions with respect to circuit parameters are very important in the design of microwave circuits [1]. Sensitivity analysis let us estimate the simulation errors; and by using the results of the sensitivity analysis, we can arrange network parameters according to the increasing values of the sensitivity measures. In consequence, the procedure can lead to the identification of circuit parameters with excessive values of the sensitivity or help us to simplify the model by eliminating the elements for which sensitivities are negligible.

In this paper, analytical formulations of gain sensitivities for a low-noise amplifier are obtained with respect to the width and length of any microstrip line used in the matching circuits and is compared to the numerical counterparts. Identification is made among these microstrip elements and the most sensitive microstrip elements are determined with their sensitivity variations with respect to the frequency. Thus, these elements must be realized within the tolerance limits subject to their sensitivities in the practice. Here, in order for a F network function not to be sensitive to circuit parameter "x", the limits of the normalized sensitivity $S_x(F)$ function should obey the following criteria:

$$0 \leq \left|S_x(F)\right| \leq 1,\;\; S_x(F) = \frac{\partial(\ln F)}{\partial(\ln x)} = \frac{x}{F} D_x(F) \tag{1}$$

In the next section, analytical derivation of the gain sensitivities with respect to any microstrip width W and length ℓ utilized in the matching circuits will be given, in the third section a worked example will be presented for the low- noise amplifier with the T-type matching circuits in the accompanied paper [2]. Finally, conclusions end the paper.

2. Gain Sensitivities with respect to the microstrip parameters for a microwave amplifier

Sensitivity of the Characteristic impedance with respect to the microstrip width

The characteristic impedance Z_c (W, T, ε_r, H) and effective dielectric coefficient ε_{eff} (W, T, ε_r, H) functions of microstrip lines for the quasi-static case are taken derivative with respect to the width W for a given set (ε_r, H, T) in Fig. 1:

$$Z_c = \frac{60}{\sqrt{\varepsilon_{eff}}} N_1,\;\; N_1 \triangleq ln\left(8\frac{h}{W} + 0.25\frac{W}{h}\right) \qquad W/h\;\leq 1 \tag{2.1}$$

$$\frac{\partial Z_c}{W} = \frac{60}{\sqrt{\varepsilon_{eff}}} \frac{\left(-\frac{8h}{W^2}+\frac{1}{4h}\right)}{\frac{8h}{W}+\frac{W}{4h}} - \frac{30\pi}{N_1\sqrt{\left(\varepsilon_{eff}\right)^3}} \frac{\partial \varepsilon_{eff}}{\partial W} \tag{2.2}$$

$$Z_c = \frac{120\pi/\sqrt{\varepsilon_{eff}}}{N_2} \qquad N_2 \triangleq \left(W/h + 1.393 + 0.667ln(W/h + 1.444)\right) \quad W/h\;\geq 1 \tag{2.3}$$

$$\frac{\partial Z_c}{\partial W} = \frac{120\pi/\sqrt{\varepsilon_{eff}}\left(\frac{1}{h}+0.667\frac{1}{W+1.444h}\right)}{{N_2}^2} - \frac{60\pi}{N_2\sqrt{\left(\varepsilon_{eff}\right)^3}}\frac{\partial \varepsilon_{eff}}{\partial W} \tag{2.4}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12H}{W}\right)^{-\frac{1}{2}} + F(\varepsilon_r, H, W) - 0.217(\varepsilon_r-1)\frac{T}{\sqrt{WH}} \tag{2.5}$$

$$F(\varepsilon_r, H, W) = 0.02(\varepsilon_r-1)\left(1-\frac{W}{H}\right)^2 \quad W/h \le 1 \tag{2.6}$$

$$F(\varepsilon_r, H, W) = 0 \qquad W/h > 1 \tag{2.7}$$

$$\frac{\partial \varepsilon_{eff}}{\partial W} = \frac{\varepsilon_r-1}{4}\left(1+\frac{12H}{W}\right)^{-\frac{3}{2}}\frac{12H}{W^2} - 0.04(\varepsilon_r-1)\left(1-\frac{W}{H}\right)\left(\frac{1}{H}\right) + 0.217(\varepsilon_r-1)\frac{T}{2\sqrt{H}}\frac{1}{\sqrt{W^3}} \quad W/h \le 1 \tag{2.8}$$

$$\frac{\partial \varepsilon_{eff}}{\partial W} = \frac{\varepsilon_r-1}{4}\left(1+\frac{12H}{W}\right)^{-\frac{3}{2}}\frac{12H}{W^2} + 0.217(\varepsilon_r-1)\frac{T}{2\sqrt{H}}\frac{1}{\sqrt{W^3}} \qquad W/h > 1 \tag{2.9}$$

Gain Sensitivities with respect to the microstrip width and length:

In this work, gain sensitivity matrix is obtained using the chain sensitivity matrix method [1-2] which can be applied to any network in cascaded configuration. This method calculates the overall chain matrix by dividing the network into the three groups: The two-port with the sensitivity parameters in question, the two-ports at the left-hand and right-hand sides (Fig.2). Thus the overall chain T matrix can be expressed as

$$\mathrm{T} = \mathrm{T_L}\ \mathrm{T_I}\ \mathrm{T_R} \tag{2.10}$$

where only $\mathrm{T_I}$ is needed to be taken derivatives with respect to the circuit parameters $\vec{x}$ which in our case $\vec{x} = [W_i\ \ell_i]^t$, $i = 1, \ldots \kappa$, κ is number of the microstrip line in the design. Thus, we have sensitivity of the overall T chain matrix as follows:

$$\frac{\partial \mathrm{T}}{\partial \mathrm{x_n}} = \mathrm{T_L}\ \frac{\partial \mathrm{T_I}}{\partial \mathrm{x_n}}\ \mathrm{T_R} \tag{2.11}$$

Gain of the overall network can be expressed in terms of the chain parameters as

$$G_T = \frac{4R_S R_L}{P}, P \stackrel{\Delta}{=} \left|AZ_L + B + Z_S(CZ_L + D)\right|^2 \tag{2.12}$$

Where the gain sensitivity with respect to the x_n can be shown to be equal to [3]

$$\frac{\partial G_T}{\partial x_n} = \sum_{i=1}^{4}\frac{\partial G_T}{\partial T_i}\frac{\partial T_i}{\partial x_n} + \sum_{i=1}^{4}\frac{\partial G_T}{\partial T_i^*}\frac{\partial T_i^*}{\partial x_n} \tag{2.13}$$

In the next section gain sensitivities are obtained with respect to the width and length of microstriplines in the T-configurations at both input and output ports (Fig.3).

3. Worked Examples

In the worked examples, NE3511S02 is chosen as a high technology low- noise transistor to be used in the front-end amplifier and the synthesized gain and noise figure performance variations with respect to the frequency at the bias condition V_{DS}=2V, I_{DS}= 5mA are given in the accompanied paper. Typical sensitivity variations with frequency are given in Figure 4 for the microstrip line at the input and output matching circuits. In these Figures, furthermore another method called “Gain Factorization” is also employed from [3] for the purpose of comparison. Besides, numerical derivatives are applied too.

5. Conclusion

In this work, a method is proposed that is directly applicable to sensitivities of gain with respect to the width and length of a microstrip line in any position in a low-noise amplifier. Results show us that gain performance is very sensitive to width / or length of some microstrip lines in the circuit. Thus, particularly, these microstrip lines should be cared during the practical realization stage.

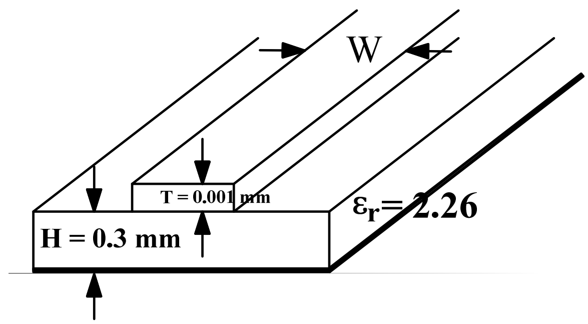

Figure.1 Microstripline used in the front-end low-noise amplifier

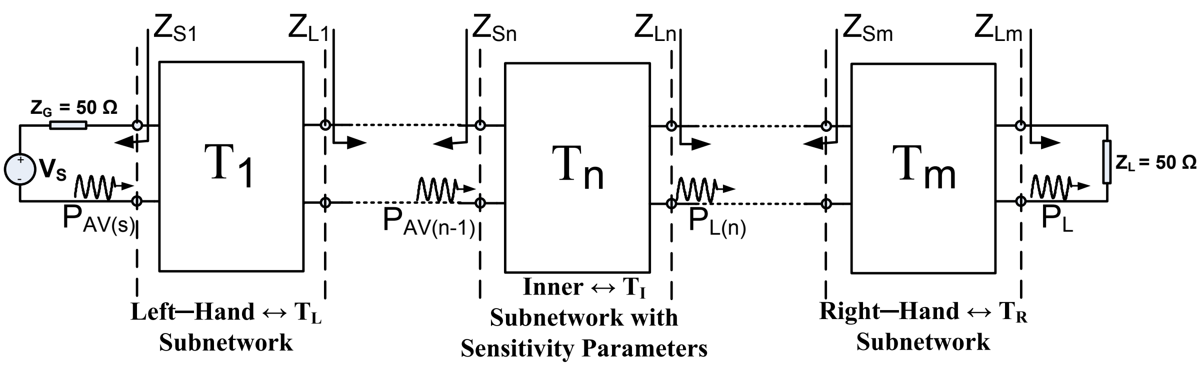

Figure.2 Block Diagram of the m Cascaded Two-Ports

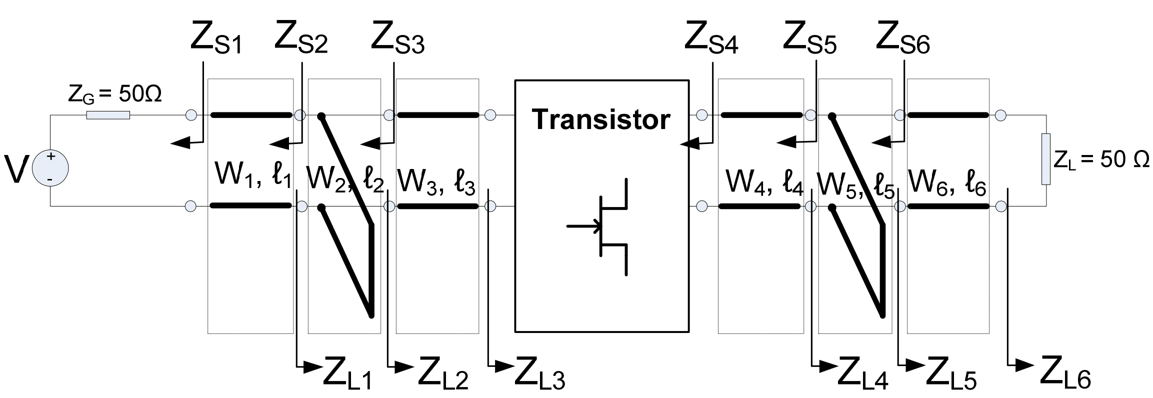

Figure.3 Low-Noise Amplifier with T- type Microstripline Matching Networks at both Input and Output Ports

TABLE – I Solution Space for the (T - T) IMC & OMC Elements

$W_1(mm)$	$W_2(mm)$	$W_3(mm)$	$W_4(mm)$	$W_5(mm)$	$W_6(mm)$	$\ell_1(mm)$	$\ell_2(mm)$	$\ell_3(mm)$	$\ell_4(mm)$	$\ell_5(mm)$	$\ell_6(mm)$
1.15	2.36	4.99	1.65	0.78	1.72	4.23	2.98	0.51	0.55	2.57	1.03

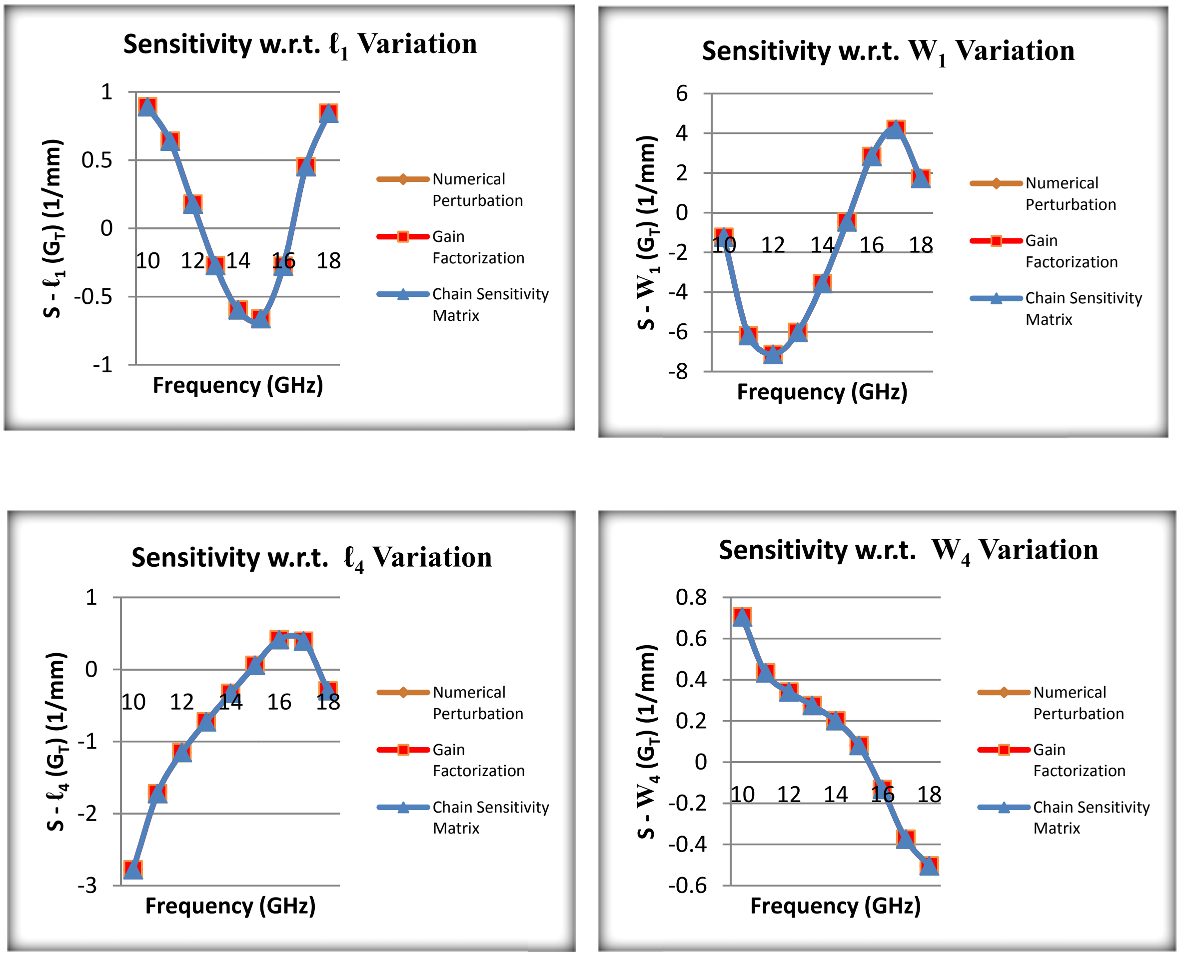

Figure.4 Typical Sensitivity variations with frequency w.r.t length and width for the microstrip lines numbered 1 and 4 at input and output ports, respectively.

6. References

1. A. Dobrowolski, “*Introduction to computer methods for microwave circuit analysis and design*”, Artech House, Norwood, MA, 1991.

2. Gunes F., Demirel S., “*A Microstrip Amplifier Design Subject to the Transistor Performance Limitations*”, *URSI,* 2011, Istanbul, submitted.

3. Gunes F., Altunc S., “*Gain-Sensitivity Analysis for Cascaded Two-Ports and Application to Distributed-Parameter Amplifiers*”, Int J RF and Microwave CAE 14, (2004), 462-474.