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A Spice-Oriented Designing Algorithm of Bipolar Transistor Amplifiers

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1. Introduction

RF power amplifiers are sometimes composed of bipolar transistor circuits [1]. For attaining the maximum gain, we need to set the suitable bias voltages, and choose appropriate load impedances which can be practiced by setting the resistance values. Usually, the optimization can be done by trial and error process using Spice simulator. It is really time-consuming when the design parameters are so many. In this paper, we propose a Spice-oriented optimization algorithm based on the steepest descent algorithm [2-3] whose circuit is realized by ABMs (analog behavior Models) of Spice, and the equilibrium point corresponds to the optimum solution. Firstly, we need to define the *objective function* as follow:

$$\Phi(\mathbf{x},\mathbf{p}),\quad \mathbf{x}\in R^n,\quad \mathbf{p}\in R^k \tag{1}$$

where

x: circuit variables such as voltages and currents.

p: optimization parameters such as bias voltages, resistor's values and so on. The gradient direction is decided by the solutions of sensitivity circuits [3], and the steepest descent algorithm can be realized by the equivalent RC circuits combining with nonlinear controlled current sources.

2. Transistor's sensitivity modules

2.1 Sensitivity analysis: The steepest descent method is the most basic optimization approach, where the gradient direction is decided by the solutions of sensitivity circuit. Using the *Tableau approach*, we have the following Tableau equation to calculate the sensitivities:

$$\begin{bmatrix} \mathbf{K}_i & \mathbf{K}_v & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & -\mathbf{A}^T \\ \mathbf{A} & \mathbf{0} & \mathbf{0} \end{bmatrix}\begin{bmatrix} \mathbf{S}_{i,p_i} \\ \mathbf{S}_{v,p_i} \\ \mathbf{S}_{v_n,p_i} \end{bmatrix} - \begin{bmatrix} \left.\frac{\partial \mathbf{g}(\mathbf{v},\mathbf{i})}{\partial \mathbf{v}}\right|_{\mathbf{v}_0,\mathbf{i}_0} \mathbf{S}_{v,p_i} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix}$$

$$-\begin{bmatrix} \left.\frac{\partial \mathbf{g}(\mathbf{v},\mathbf{i})}{\partial \mathbf{i}}\right|_{\mathbf{v}_0,\mathbf{i}_0} \mathbf{S}_{i,p_i} \\ \delta(i) \\ \mathbf{A}\delta(i) \end{bmatrix} = \begin{bmatrix} \left.\frac{\partial \mathbf{g}(\mathbf{v},\mathbf{i})}{\partial \mathbf{p}}\right|_{\mathbf{v}_0,\mathbf{i}_0} \delta(i) \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix} \tag{2}$$

where $\delta(i)$ means a delta function satisfying

$$\begin{array}{cccccccc} & 1 & 2 & \ldots & i & \ldots & k \\ \delta(i) = & [0, & 0, & \ldots, & 1 & \ldots, & 0]^T \end{array}$$

Thus, the sensitivity circuit configuration is equal to the original one except for the nonlinear elements being replaced by the linear incremental resistors at the operating points $\mathbf{V}_0, \mathbf{I}_0$. The elementary wise transformations are shown in Fig. 1.

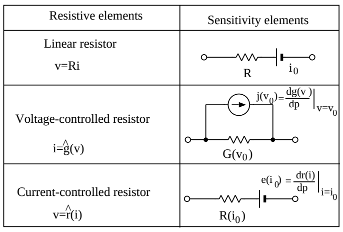

Fig. 1 Sensitivity elements for resistors.

Example : Now, consider a simple example for deriving the sensitivity circuit shown in Fig. 2(a). Then, the sensitivity circuits for E and resistor R_2 are given by Figs. 2(b) and (c), respectively.

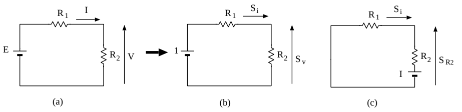

Fig. 2 (a) A resistive circuit, (b) Sensitivity circuit for E and (c) resistor R_2.

$$S_i = \frac{1}{R_1+R_2} \qquad S_{R_2} = -\frac{E}{(R_1+R_2)^2} \tag{3}$$

These results are equal to the direct calculation results of the sensitivity circuits.

2.2 Sensitivity modules of bipolar transistor: For simplicity, we consider NPN transistor modeled by Ebers-Moll model as shown in Fig. 3(a), where

$$i_d = I_s(\exp(v_d/v_T)-1),\quad \text{for } v_T = 0.026,\quad \alpha = 0.99 \tag{4}$$

The sensitivity module is shown by Fig. 3(c), where the incremental resistor is given by

$$\frac{1}{r_e} = \left.\frac{\partial i_d}{\partial v_d}\right|_{v_d=v_{d0}} \tag{5}$$

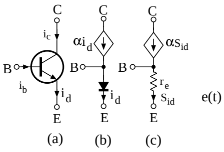

Fig. 3 (a) NPN Transistor, (b) Ebers-Moll Model, (c) The Sensitivity module.

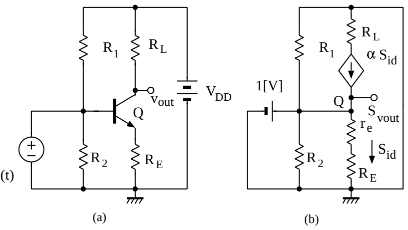

Fig. 4 (a) Common-emitter amp., (b) The sensitivity circuit for calculating the gain.

3. Steepest descent method attaining maximum gain

Now, we consider Spice-oriented optimization technique for attaining the maximum gain of Fig. 4, where resistors R_1, R_2, R_E should be optimized for setting the suitable bias voltage. We need to introduce the numerical differentiation technique as shown in Fig. 5 for the optimization of the gain, because the gain is obtained by the sensitivity circuit shown in Fig. 4(b). The output sensitivities Ss are obtained by Fig. 4(b), and the output p_i controls the resistive value using ABM. The simulation results are shown at our presentation of the conference.

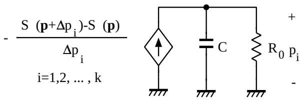

Fig. 5 Spice-oriented optimizing method.

4. Conclusions and remarks

In this paper, we proposed a Spice-oriented designing algorithm of bipolar amplifiers, the optimization technique is based on the steepest descent method, whose gradient is calculated by the sensitivity circuits. The equivalent steepest descent circuit consists of ABMs of Spice, and the optimum point can be found by the solution of the transient analysis.

References

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