17-61

Spice-Oriented Harmonic Balance Method in Frequency Domain

T. Kinouchi[1] Y. Yamagami[1] Y. Nishio[1] J. Kawata[2] A. Ushida[2]
(Tokushima University[1] Tokushima Bunri University[2])

1. Introduction

For designing integrated circuits and communication systems, it is very important to analyze the frequency-domain characteristics of nonlinear circuits. There are two typical types of frequency-domain analysis of nonlinear circuits. One is Volterra series method which is widely used in European countries, because the algorithm is based on the bilinear theorem and the higher order solutions can be obtained in the analytical forms. However, it can be only applied to weakly nonlinear systems, and, furthermore, the nonlinear characteristics should be described by approximated polynomial functions at the DC operation points. The other is the harmonic balance (HB) method. In this study, we analyze a base modulation circuit using Spice-oriented HB method. The proposed HB method is the technique that Fourier coefficients can be obtained in symbolic forms by using MATLAB. The determining equation of HB circuit is given by the net-lists, which can be solved by the DC analysis of Spice. Thus, we can obtain a good solution for the strong nonlinear systems.

2. Proposed harmonic balance method

We consider a base modulation circuit driven by two inputs as shown in Fig. 1. We consider here 8 intermodulation frequencies given in Table 1. In our harmonic balance method, we have modeled the transistor by the Ebers-Moll model where

$$i_d = 10e^{\lambda v_d}, \quad \text{for} \quad I_s = 10^{-12}[A], \quad \lambda = 40, \quad \alpha = 0.99. \qquad (1)$$

Firstly, we approximate the nonlinear characteristics of the diode by Taylor expansion at v_{d0} as follows:

$$i_G = k_0(v_{d0}) + k_1(v_{d0})v_G + k_2(v_{d0})v_G^2 + k_3(v_{d0})v_G^3 \qquad (2)$$

The coefficients are functions of the unknown operating DC point $v_{d,0}$. We approximate the input voltage of the diode using Fourier expansion as follows:

$$v_d(t) = V_{d,0} + \sum_{k=1}^{8}(V_{d,2k-1}\cos\nu_k t + V_{d,2k}\sin\nu_k t) \qquad (3)$$

Substituting (3) into (2), the Fourier series are described as follows:

$$i_d(t) = I_{d,0} + \sum_{k=1}^{8}(I_{d,2k-1}\cos\nu_k t + I_{d,2k}\sin\nu_k t) \qquad (4)$$

These calculations are so troublesome by hand. Hence, we apply MATLAB and obtain the terms in the formula symbolic forms. Thus, we have the Sine-Cosine circuit that is equivalent to the HB determining equation. It can be constructed in the schematic forms using ABMs (Analog Behavior Models) of Spice. Thus, the circuit can be solved by the DC analysis of Spice, and the frequency response is obtained.

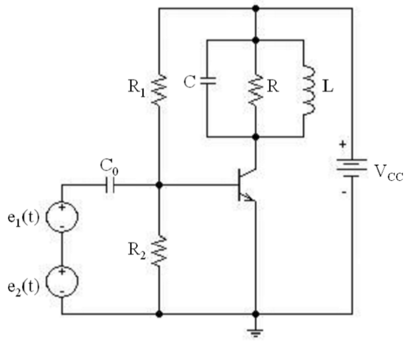

Fig. 1 Base modulation circuit.

$R_1 = 50\,[k\Omega]\,,\quad R_2 = 10\,[k\Omega]\,,\quad R = 1\,[k\Omega]\,,$
$C = 1\,[nF]\,,\quad C_0 = 1\,[nF]\,,\quad L = 10\,[\mu H]\,,\quad E = 10\,[V]\,,$
$e_1(t) = 0.01\sin\omega_1 t,\quad e_2(t) = 0.01\sin\omega_2 t.$

Table 1 Frequency components for input.

ν_1	ω_1	ν_5	$\omega_1-\omega_2$
ν_2	ω_2	ν_6	$\omega_1+\omega_2$
ν_3	$2\omega_1$	ν_7	$2\omega_1-\omega_2$
ν_4	$2\omega_2$	ν_8	$2\omega_1+\omega_2$

3. Simulation result

We show the analysis results in Fig. 2.

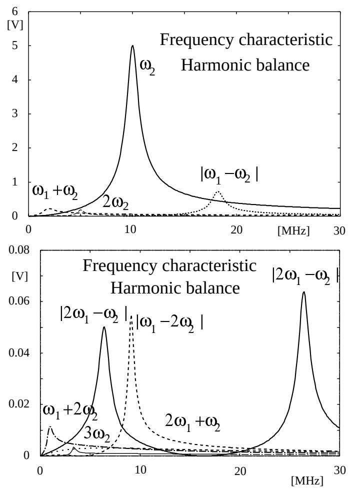

Fig. 2 Frequency characteristic

4. Conclusions and remarks

In this study, we proposed a Spice-oriented HB method which could efficiently trace the characteristic curves such as frequency responses. As the future work, in order to apply our method to large scale networks, we need to develop device HB modules for bipolar transistors and MOSFETs.

References

[1] A. Ushida, Y. Yamagami and Y. Nishio, "Frequency responses of nonlinear networks using curve tracing algorithm," Proc. of ISCAS'02, vol.I, pp.641-644, 2002.