Nonlinear Model and Measurement Method for Microwave Mixers

G. Vandersteen and A. Vander Vorst, *Fellow IEEE*

***Abstract*—A novel approach to characterize and measure the static and dynamic nonlinear properties of a microwave mixer is described. It is based on the use of Generalized Volterra Series. The modeling capabilities of this novel approach are illustrated by simulation results of nonlinear microwave devices, as well as by measurements. Furthermore, a new measurement setup has been developed. It uses a sampling oscilloscope. It yields both the amplitude and phase of the different spectral components of the measured signal.**

I. Introduction

THE NONLINEAR PROPERTIES of a microwave mixer can be characterized using a power series model [1]. This method, however, is unable to yield any phase relationships between the various input and output signals. Volterra series, on the other hand, yield phase relationships but can only be used on weakly nonlinear systems [2]. The Generalized Volterra Series (GVS), used in the literature to develop new nonlinear simulators, are able to predict both amplitude and phase of the response of a strongly nonlinear system [3]. Simulations on a microwave diode have proved the usability of GVS for nonlinear microwave simulations.

In this letter, GVS is used for a different purpose, namely the characterization of the nonlinear phenomena involved with a microwave mixer. GVS is developed in the frequency domain because only sine waves at different frequencies enter the mixer. The LO wave of the mixer is chosen as a reference for the series development, because its amplitude is much larger than the amplitude of the RF signal.

To prove the usability of GVS to characterize a mixer, computer simulations obtained by Microwave Design System of Hewlett-Packard (MDS) have been used. A series of simulations have been performed on several nonlinear microwave structures, such as diodes and a mixer. For every configuration, simulations with various amplitudes of the excitation signals have been obtained to calculate the kernels of the GVS. The phase and amplitude differences between the simulated data and calculations from the model are small, which proves the usability of the GVS.

To make actual measurements, a new measurement setup, capable of measuring a signal containing different spectral components, has been developed. The necessity of a time reference obliges the measurement in time domain. This measurement setup, built around a sampling oscilloscope and fully synchronized by a reference generator, measures the nonlinear response of a simple diode. Comparison of the derived GVS model with the measurements proves the validity of the method for mixer characterization.

Manuscript received November 25, 1992.

G. Vandersteen is with the Department of ELEC, Vrye Universiteit Brussel, Pleinlaan, B-1050 Brussels, Belgium.

A. Vander Vorst is with Microwaves UCL, Batiment Maxwell, B-1348 Louvain-la-Neuve, Belgium. IEEE Log Number 9208614.

II. Generalized Volterra Series

GVS is an extension of the Volterra series. Classical Volterra series can be interpreted as a development in series of the system around a fixed reference point. The generalization consists in developing the series around a time-varying reference point [3]. Generalization to multiple input-multiple output systems is straightforward when using Kronecker multiplications [4]. In the case of a mixer, the series are developed around the strongest signal, namely the local oscillator signal. To characterize a microwave mixer, series of the fourth-order are used. Because of the length of the equations relating the various spectral components, the reader is referred to reference [5].

A fourth-order series development does predict both phase and amplitude of the output signal of the mixer for various excitation signals. Therefore, the model can be used in a CAD program. Using a fourth-order series, the harmonic distortion of the converted signal, defined as the ratio between a second- and a fourth-order kernel, is calculated. The optimal dc bias point and the optimal power of the LO signal to minimize the conversion loss can also be calculated when using a fourth-order series.

III. Modeling Results Using Simulation

The ability to characterize nonlinearities is shown by simulations obtained with the MDS program. The nonlinear response of diodes, with or without matching networks, and a singly balanced diode mixer were computed and used to derive the GVS kernels. Afterwards, this GVS model was used to predict the nonlinear response when the same input signals were applied. The simulation results and the results obtained using the GVS model were compared afterwards.

When the RF power of the singly balanced diode mixer was varied from -20 to 0 dBm, and the LO power from 6 to 10 dBm, the IF signal using GVS is predicted with an amplitude error of better than 0.25 dB and a phase error less then 0.8 degree, compared to the MDS simulations. Modeling the IF wave produced by a single diode is done with a higher precision. Modeling errors of the intermodulation product of less then 0.2 dB and 2.5 degree, for amplitude and phase respectively, are obtained when varying both the LO power

1051-8207/93$03.00

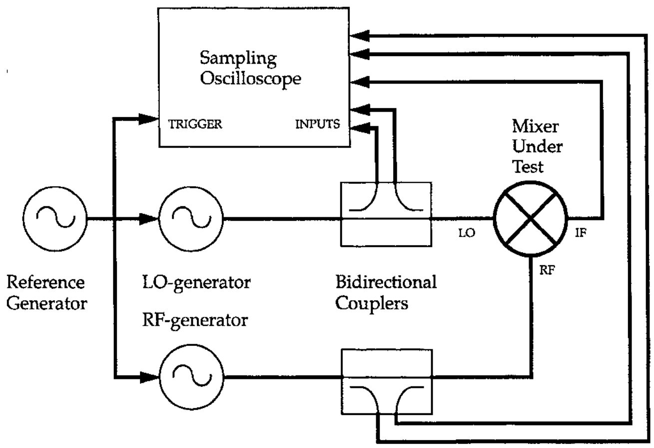

Fig. 1. Sampling oscilloscope arrangement.

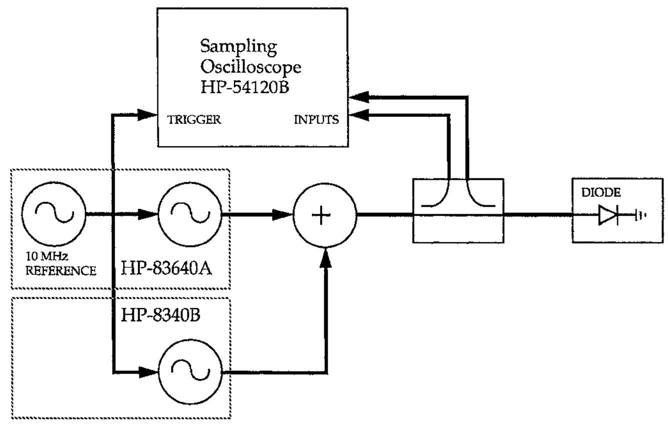

Fig. 2. Measurement setup.

(from 9 to 30 dBm), the RF power (from −25 to 5 dBm) and the dc bias (from −0.5 to 0.5 V).

These results prove the ability of GVS to characterize a microwave mixer. To verify this statement on actual measurements, a new measurement setup has been designed.

IV. Measurement Method

To measure the nonlinearities of a mixer, it is necessary to have a time reference so that the phase of different spectral components can be measured. The measurement setup is shown on Fig. 1. It is built around a Hewlett-Packard HP-54120B sampling oscilloscope, which has a 20-GHz bandwidth. The measurement principle of a sampling oscilloscope requires a triggering signal, which plays an important role in the synchronization of the measurement setup. The triggering signal is generated by a reference generator. This limits the measurable signals to harmonics of the reference generator frequency. The time window is chosen as small as possible to reduce jitter, which reduces the bandwidth [6]. The total sampling period and number of samples have to be chosen correctly, to eliminate aliasing and leakage when using a Fast Fourier Transform (FFT) to calculate the frequency spectrum. Otherwise an Interpolated FFT is required.

The ability of measuring a microwave mixer is verified using the setup of Fig. 2 with a single diode as the nonlinear element. Measuring nonlinear devices requires an absolute calibration. Because such a method is not available yet, a linear one-port calibration and a power measurement are used. A typical measurement of the entering and reflected wave in both the time and the frequency domain is shown on Figures 3. The frequency domain plots prove that the new measurement setup is able to measure the different harmonics and intermodulations produced by the diode. The setup operates with a dynamic range of 60 dB and a noise level of about −90 dBm.

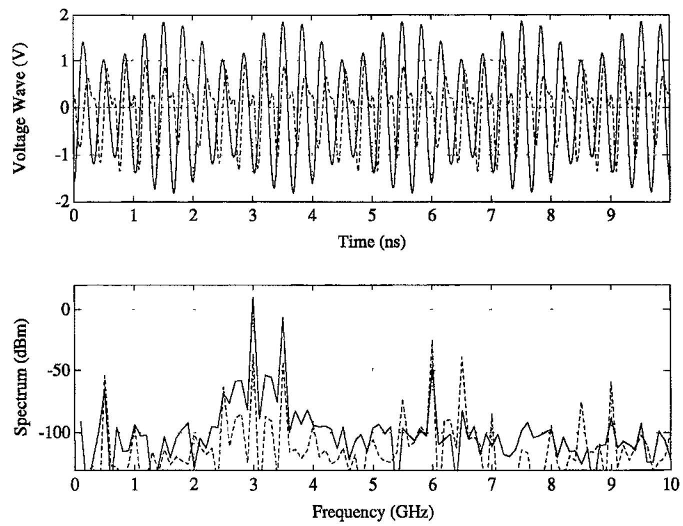

Fig. 3. Entering and reflected voltage wave, respectively full and dashed line. Above: Time domain representation. Below: Frequency domain representation.

V. Results

Through the use of the measurement setup described above, the nonlinear response of a single diode at five different dc bias points has been measured. At every bias point a set of 108 computer-controlled measurements were performed; the LO power was varied from 0 to 10 dBm and the RF signal from −20 to 0 dBm. A dc bias of 0.2 volt results in a difference of 0.6 dB in amplitude and 10 degrees in phase between the measurements and the GVS model. Simulation errors at other bias points are comparable.

In spite of the higher modeling errors when compared with simulations, the results demonstrate the capability of GVS to characterize strongly nonlinear microwave devices.

VI. Conclusion

In this letter, the usability of the generalized Volterra series to characterize the nonlinear properties of a microwave mixer has been demonstrated. Several nonlinear microwave configurations have been simulated. The simulation results prove the usability of GVS.

To test the new method on actual measurements, a new measurement setup built around a sampling oscilloscope has been designed. This measurement setup yield not only the amplitudes, but also the phase relationships between the various spectral components.

ACKNOWLEDGMENT

The authors thank M. Vanden Bossche for his comments and discussions. They also gratefully acknowledge L. Van den Torren for the measurement support.

REFERENCES

[1] S. A. Maas, *Nonlinear Microwave Circuits.* Artech House, 1988.
[2] M. Schetzen, *The Volterra and Wiener Theories for Nonlinear Systems.* Melbourne, FL: Robert E. Krieger, 1989.
[3] E. Van den Eijnde, "Steady-state analysis of strongly nonlinear circuits," Ph.D. dissertation, Dept. ELEC, Vrije Universiteit Brussel, 1989.
[4] A. A. Saleh, "Matrix analysis of mildly nonlinear multiple-input, multiple-output systems with memory," *Bell. Syst. Tech. J.*, vol. 61, pp. 2221–2243, 1982.
[5] G. Vandersteen, "Nonlinear characterization of a mixer," dissertation, Univ. Catholique de Louvain, Dept. Telecom. et Hyperfreq., 1992.
[6] T. M. Souders, "The effects of timing jitter in sampling systems," *IEEE Trans. Instrum. Meas.*, vol. 39, no. 1, pp. 80–84, Feb. 1990.