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Non-Linear Optimum Design of Microwave Active Mixers

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Abstract

The optimum design of microwave active mixers has been accomplished using powerful and advanced design-oriented non-linear techniques. Optimum loads at all relevant frequencies (RF, IF, LO, Image) are determined, using a combination of a frequency-domain (Spectral Balance) non-linear algorithm and a numerical scheme for optimum load determination. Moreover, a simplified and fairly accurate quasi-linear method has been developed for a fast and inexpensive preliminary evaluation of mixer's performances.

Introduction

The optimum design of strongly non-linear circuits requires the use of powerful non-linear algorithms. The frequency-domain Spectral Balance technique [1] is very suitable for multi-frequency analysis, and has recently been improved for practical application as a general-purpose analysis method [2]. The design of a circuit, however, requires either long and uncertain optimisation procedures, or the use of design-oriented numerical schemes for the direct synthesis of suitable optimum conditions. Such a scheme has been developed by our group for applications with mixed time-frequency non-linear algorithms (Harmonic Balance) [3], and applied to the design of power amplifiers [4] and active frequency multipliers [5]; with this work it has been extended to frequency-domain methods, and applied to the optimisation of active mixers. By using this powerful tool the optimum load impedances at all relevant frequencies (RF, IF, LO, Image) and the optimum power levels of RF and LO signals are easily and automatically determined. The result can also be presented as tables or charts for design trade-offs.

In addition to the full-non-linear procedure, a simplified method has been developed, for a fast and inexpensive preliminary evaluation of the mixer's performances. The method is based on a quasi-linear model of the active device, already successfully applied to the study of power amplifiers [6] and active frequency multipliers [7]. A piecewise-linear analysis provides fast and fairly accurate results, that correctly evaluate the important quantities of the circuit (conversion gain maxima, instability regions, etc.).

The Full-Non-Linear Method

The adopted frequency-domain non-linear analysis technique (Spectral Balance) is based on a special phasor-manipulation technique for the analysis of the non-linear elements. Since no Fourier transform is required, this technique is potentially better suited than Harmonic Balance algorithms to handle multi-tone excitations, as in the case of a mixer. A rational-function representation of the non-linearities of the active device has been developed, that keeps the phasor-manipulation computational burden to a minimum [2].

In order to efficiently use the non-linear analysis algorithm for design purposes, a special numerical arrangement has been developed. The non-linear Kirkhhoff's equation is augmented by equations imposing special design conditions, as for instance conjugate match or zero reactive energy transfer at some ports and frequencies. The design conditions are therefore satisfied simultaneously and consistently with the non-linear analysis, and are fulfilled with large-signal quantities [3]. In this way a direct synthesis is performed, and no optimisation is required. Tables or charts are then easily computed as a function of the remaining free design parameters (e.g. bias point, input power, etc.), for design trade-off determination.

The Simplified Method

An accurate full non-linear design is needed for the final design of an actual circuit. However a simplified quasi-linear analysis, not requiring a full non-linear characterisation of the active device and running on any PC, can be useful for device performance evaluation, or for a preliminary study of the potential performances of the mixer. A simplified model of the active device, with a single non-linearity (the controlled current source) with a quasi-linear behaviour, has been used for a piecewise-linear analysis of waveforms. Characterisation of the active device requires in fact only the DC (or pulsed, if available) output characteristics and the equivalent circuit (deduced from S-parameters) at the selected bias point.

For the large-signal analysis, current and voltage waveforms are analytically Fourier-transformed to get the cross-frequency terms of the conversion matrix. The electrical variables are arranged in such a way that the output quantities are analytically computed from voltage and current waveforms, with a reasonable degree of accuracy and a negligible computing time. Design conditions are easily imposed in a similar way as in the full non-linear method, and plots are accordingly drawn for design use. Such a scheme is the extension to multi-tone excitation of a principle already applied to the study of power amplifiers [6] and active frequency multipliers [5], with remarkably good results.

Simulated Results and Discussion

Input and output of the transistor at RF, IF and Image frequencies have been taken into consideration as the important terminations for the mixer. Maximum conversion gain is obtained for (large-signal) conjugate match at the input port at RF and output port at IF frequency (signal input and output ports), with maximum power transfer ensured for the signal. This is shown e.g. in fig.1 and fig.2 (conversion gain *vs* output termination reflection coefficient at IF) with the full non-linear and the simplified method respectively. As it can be noted, the agreement between the two is remarkable. This design condition has therefore been automatically ensured by our design-oriented algorithm for further study.

Terminations at the other ports have been set to be reactive for minimum energy dissipation. The dependence of conversion gain on the phase of output termination at RF frequency (fig. 3 left and right, full non-linear and simplified method respectively) and of input termination at Image frequency has been computed. Again, the agreement between the two methods is quite good. The presence of an instability region is clearly shown for both cases. Optimisation of the conversion gain can therefore be accomplished, and the safety margins must be accurately evaluated to avoid self-oscillation of the mixer (unless intentionally pursued).

The dependence of conversion gain on the phase of input termination at IF frequency (fig. 4 left and right) and of output termination at Image frequency are best set to a safe short circuit in order to avoid instabilities, and without any great deterioration of performances. All those results are in agreement with previous knowledge [7], and have been reliably and efficiently obtained by the proposed methods.

Conclusions

All the relevant tables for the optimum design of an active mixer have been obtained by means of an accurate and powerful non-linear algorithm. However, results in remarkably good agreement have also been obtained with a simplified quasi-linear method, that allows fast and inexpensive preliminary evaluation of the performances of the mixer. Both methods are best suited for designer's applications.

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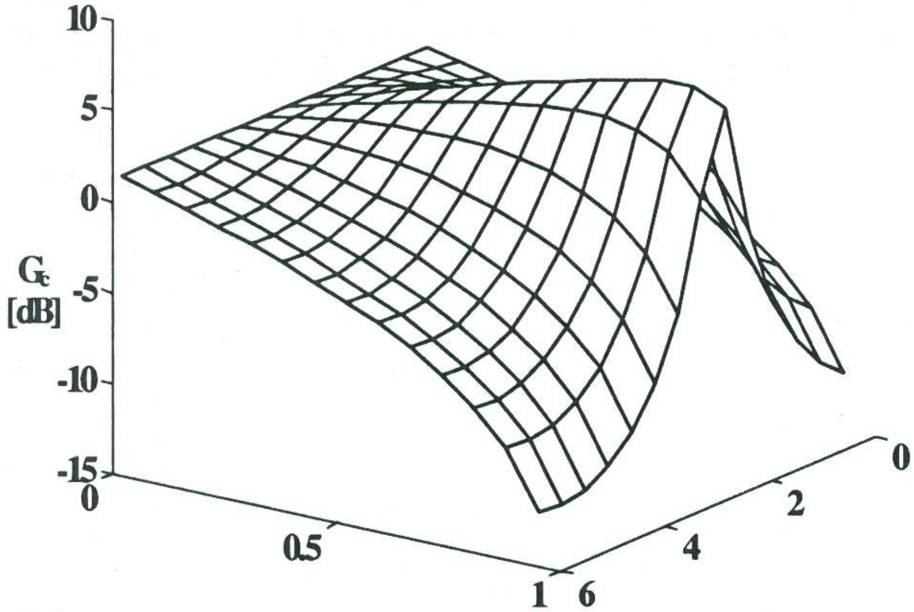

Fig.1 - Conversion gain *vs* input termination (magnitude and phase) reflection coefficient at RF frequency (full non-linear method)

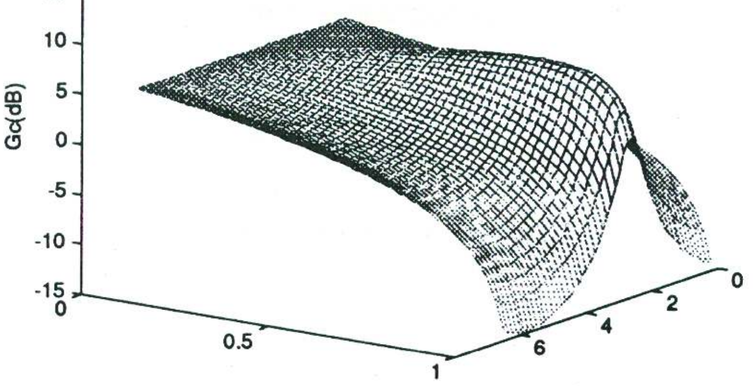

Fig.2 - Conversion gain *vs* input termination reflection coefficient (magnitude and phase) at RF frequency (simplified method)

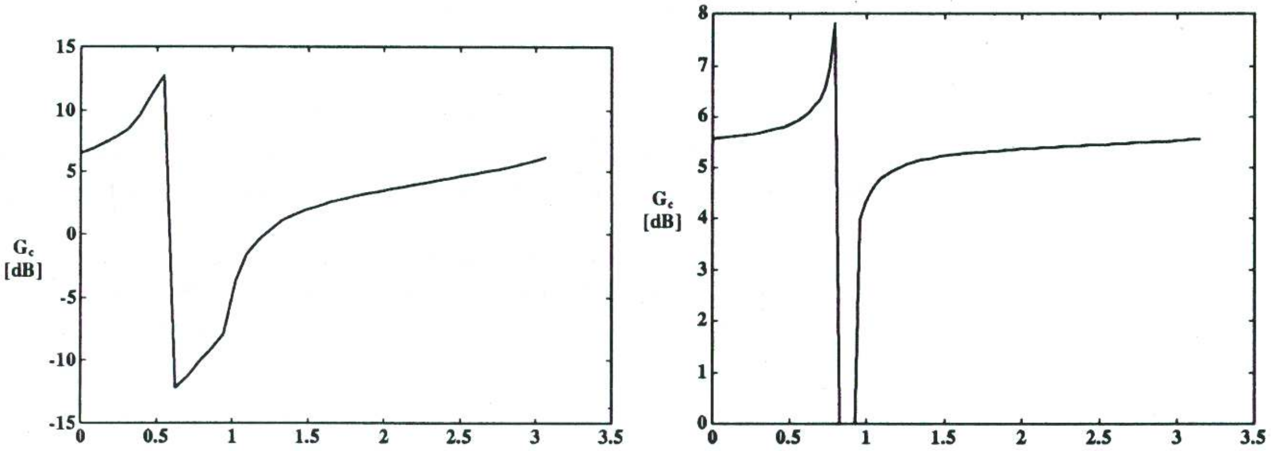

Fig.3 - Conversion gain *vs* the phase of the output termination reflection coefficient at RF frequency (full non-linear method, left and simplified method, right)

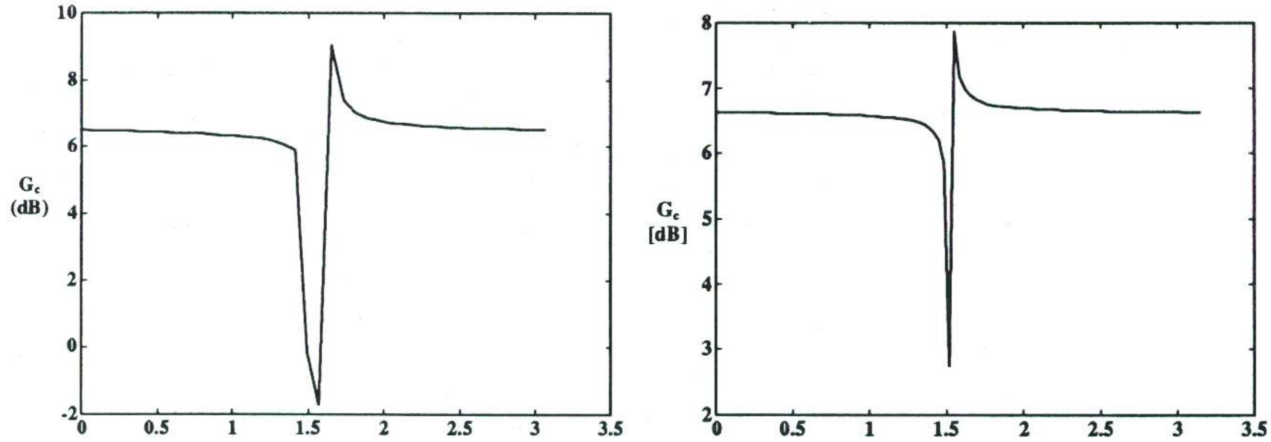

Fig.4 - Conversion gain *vs* the phase of the input termination reflection coefficient at IF frequency (full non-linear method, left, and simplified method, right)