OPTIMUM NON-LINEAR DESIGN OF ACTIVE MICROWAVE MIXERS

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ABSTRACT

The optimum design of active microwave mixers is addressed by means of a full non-linear technique. Optimum matching conditions at the input/output ports and at all other ports are defined; a stable conversion gain is also defined ensuring high gain within safe stability margins in large-signal operating conditions.

INTRODUCTION

Active microwave mixers are a key component in many telecommunications applications. Given their strong non-linear behaviour and gain/instability potential, a complete and reliable non-linear design procedure is highly desirable. No such procedure is available so far, to the best of our knowledge, forcing the designer to rely on accurate but 'blind' non-linear simulations, and on practical experience and intuition [1]. In this paper a procedure based on fully non-linear concepts and algorithms is presented, that allows not only a numerically exact direct calculation of the optimum loading of all the relevant ports and frequencies, but also a clear and practical definition of stability margin and maximum stable conversion gain for a mixer under large-signal conditions. The non-linear algorithms and methods have already been applied by our group to other non-linear circuits as power amplifiers and frequency doublers [2, 3, 4], constituting a sound numerical foundation for the proposed method; the results are however based on a circuit-oriented approach.

THE NON-LINEAR METHOD

The design of mixers is often approached by the conversion-matrix technique, that linearises the behaviour of the non-linear device when pumped by a local oscillator, assuming that input and output signals are small with respect to the local oscillator waveform. When this assumption is not true, however, either a time-variant Volterra analysis [5] or a general-purpose Harmonic-Balance algorithm are employed. In order to gain a better insight in the behaviour of the circuit, in this work a modification of a Harmonic Balance algorithm has been used. In particular, the Jacobian of the Harmonic Balance system is used as a large-signal conversion matrix, as it relates all the harmonic components of the signals under large-signal drive [2]; the active device is thus treated as a multi-frequency linear network [2, 3, 4] very much as in the case of the conversion matrix, but including the non-linearities due to non-negligible amplitude of the RF and IF signals. This approach allows the definition and use of concepts similar to those applying to linear multiports, but rigurously valid under large-signal regime.

DESIGN - THE INPUT / OUTPUT PORTS

The design of an active gate mixer involves the choice of two types of terminations: the first type includes the gate termination at input frequency (for instance the RF in the case of a down-converting mixer), the drain termination at output frequency (the IF in the same case) and the gate termination at LO frequency. This type of termination directly affects the power transfer at the relevant ports, and in general turns out to be optimum when conjugately matched under large-signal conditions. The second type includes gate and drain terminations at all other frequencies, as for instance gate termination at output (IF) frequency, drain termination at RF and LO frequencies, image frequency, etc. This second types of terminations, that will be called 'idler terminations' in the following, is not directly involved in the power transfer, but obviously affect the conversion gain capabilities of the active device.
The optimum loading of the input and output ports and of the input LO port have first been investigated. Making use of the previously defined large-signal conversion matrix, the conjugate match is directly computed at these ports; then,

the terminations have been scanned within the whole Smith Chart, looking for the maximum conversion gain, with a load-pulling procedure. The maximum conversion gain is practically always obtained for the conjugate match; the small discrepancies observed in some cases are negligible (tens of dB) for practical purposes. In fact, even if the conversion mechanism is sometimes enhanced by terminations different from the conjugate ones, the decreased power transfer compensates for the advantage. The input/output ports have therefore been conjugately matched in the rest of the investigation.

DESIGN - THE IDLER PORTS

The 'idler ports', i.e. the ports at the frequencies not directly involved in the power conversion, are usually terminated in reactive loads, assuming that a reduction in the dissipated power will increase the conversion gain. No clear criterium is however available to determine which reactive termination is the most suitable. In fact, it is well known that some idler terminations will give very high gain, but will also bring dangerously close to instability [1]; a short circuit is often suggested as a safe and reasonable compromise.

In order to have a reliable and quantitative criterion the large-signal conversion matrix has been used. An idler termination, for example the gate termination at output frequency (IF, for a down-converting mixer), has been scanned within the whole Smith Chart, and the conversion gain has been correspondingy computed. Input/output ports have been conjugately matched for each value of the input IF termination, and all other idler terminations have been kept fixed (in this case they have been short circuited). The constant conversion gain contours have been plotted on the Smith Chart, as shown in fig.1.

In a region of the Smith Chart shown in white in the figure, the Harmonic Balance algorithm does not converge, indicating an instability. Outside this region the conversion gain has a minimum near the right corner of this region, and increases regularly turning clockwise on the Smith Chart. Therefore, arbitrarily high values of conversion gain are available, at the risk of instability. The need for a safe criterion for stable behaviour of the mixer is apparent from these results. If the large-signal reflection coefficients at all other ports are checked while the IF input termination scans the Smith Charts, it is found that some of them become greater than one in amplitude for some values of the IF input termination. As an example, the constant amplitude contours of the reflection coefficient at gate port at output frequency (IF) are shown in fig.2 as a function of the termination at the same port. The amplitude of the reflection coefficient becomes greater than one in a wide area of the Smith Chart outside the unstable region proper; this area clearly presents some risks, and should be avoided. In analogy with linear amplifiers, a stable conversion gain is therefore defined when none of the reflection coefficients at any other port becomes greater than one in amplitude.

CONCLUSIONS

In conclusion, an exact non-linear approach has been used to define a large-signal conversion matrix for the design of active mixers. By this approach the optimum terminations have been defined for a high conversion gain in safe conditions. An active mixer is currently under way of realisation for the demonstration of the principle.

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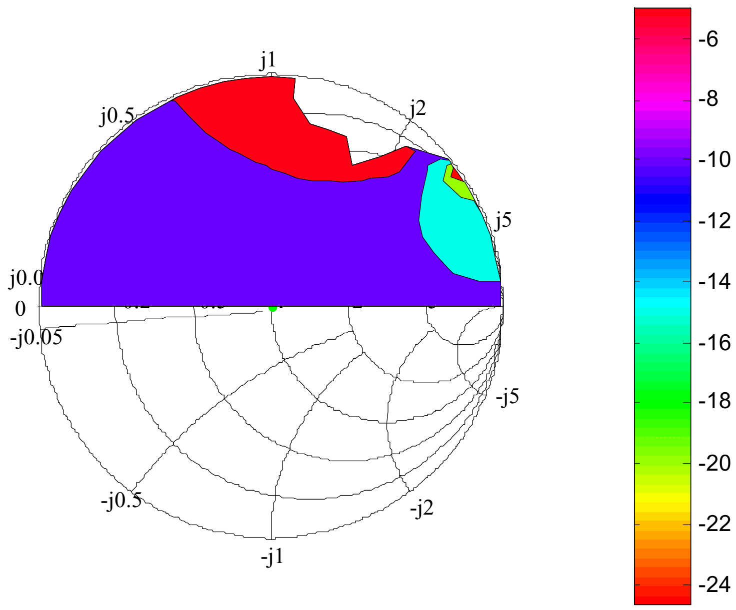

Fig.1 Constant conversion gain contours as a function of gate termination at output frequency (IF)

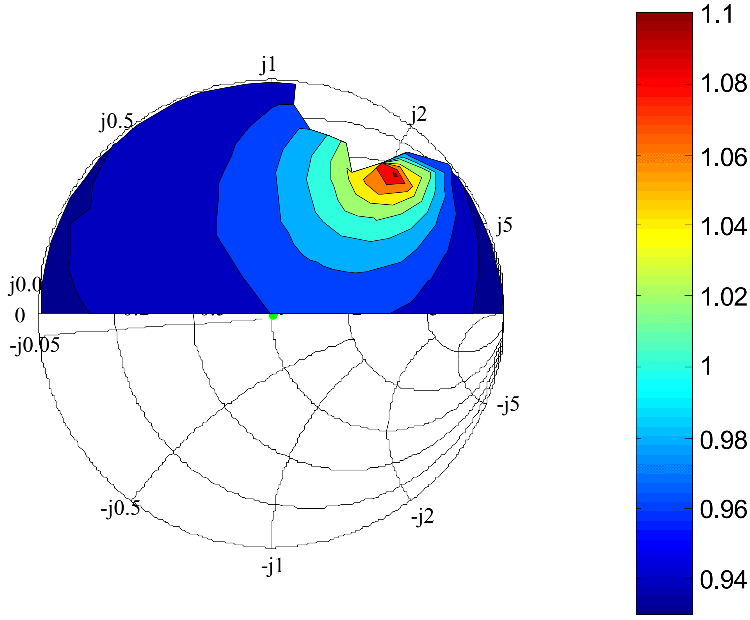

Fig.2 Constant amplitude contours of the reflection coefficient at the gate port at output frequency (IF) as a function of the termination at the same port