POWER AMPLIFIER LINEARIZATION METHODS

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ABSTRACT

The present paper outlines the characteristics of three different methods for linearizing microwave power amplifiers. A comparative study is presented so that the conclusion results can aid the designers in the choice of the most adequate linearization method.

INTRODUCTION

The evolution of digital or single sideband microwave radio systems, aiming at a more efficient use of the frequency spectrum, resulted in more stringent requirements for the linearity of the radio equipment, in particular for the microwave power amplifier[1]. In order to reduce the intermodulation distortion products generated by this component, three approaches have been proposed in the literature, namely: the feedforward, the feedback and the predistortion techniques. Application of these procedures have been extensively covered in the literature. However, the decision on which is the most adequate method for a specific application is not readily clear from these publications. The purpose of this paper is to briefly present the basic principles of each system and to establish a means of comparison between them.

DISTORTION ANALYSIS

It is well known that an amplifier is nearly linear at low input level. As the input level is Increased, the non-linearities become important, especially the third order products, in the case of narrow band amplifiers. Reduction of the third order intermodulation distortion, IMD, can be obtained operating the amplifier at 8 to 10 dB below saturation with consequent loss of efficiency and reduced power capability. The purpose of a linearizing system is to minimize the IMD with the power amplifier operating at a higher output power. The general principle is to cancel the generated intermodulation voltage A, at the power amplifier output, by another voltage B of equal amplitude and opposite phase provided by the system. However, the real systems are not perfectly balanced and there always remains a residue at the output. In order to evaluate the effect of these deviations from the balanced conditions, an improvement factor I, described by equation 1, can be defined by the normalized difference between the intermodulation amplitudes A and B at the output.

$$I = 20\log((A - B)/A) \qquad (1)$$

Defining the ratio B/A as a complex number a.exp(jb) there results equation 2, which can be used for evaluating the dependence of the distortion reduction on the system total phase and magnitude errors.

$$a = \cos b \pm \mathrm{sqrt}((\cos b)^2 - 1 + 10^{(R/10)}) \qquad (2)$$

This equation can be used to derive the chart of figure 1 which relates the system imperfections in dB's and degrees with the improvement factor as a paramete·.

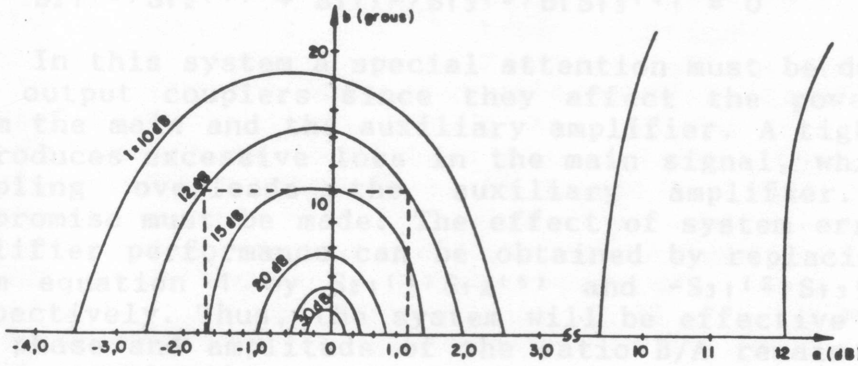

Fig 1 - Deviation from the balanced conditions

THE FEEDFORWARD TECHNIQUE

In the block diagram represented in figure 2, a main amplifier has its input and output signals sampled, resulting from their difference, the intermodulation products. An auxiliary amplifier is then used to bring these products to a level compatible with the level of the main amplifier. They are then subtracted, resulting, at the output, only the non-distorted signal. The delay lines $_{1,2}$ have been introduced to maintain the time frame compatibility. The design requires an analysis of the balance conditions for the perfect cancellation of the fundamental frequency components in the first loop, given by equation 3, and of the intermodulation products in the second loop, expressed by equation 4.

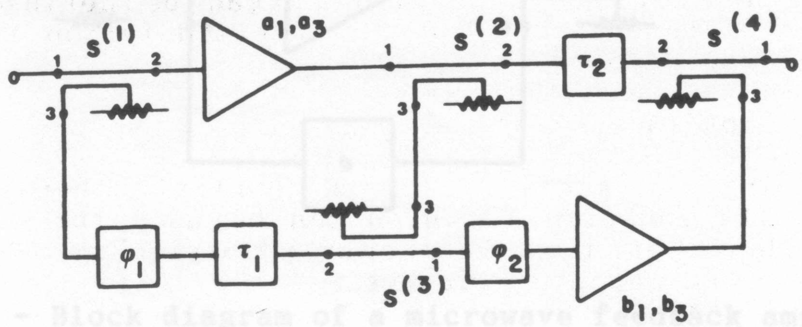

Fig 2 - Block diagram for the Feedforward amplifier

$$S_{21}^{(1)} a_1 S_{31}^{(2)} S_{13}^{(3)} + S_{31}^{(1)} S_{12}^{(3)} = 0 \qquad (3)$$

$$S_{21}^{(2)} S_{12}^{(4)} + S_{31}^{(2)} S_{13}^{(3)} b_1 S_{13}^{(4)} = 0 \qquad (4)$$

In this system a special attention must be dedicated to the output couplers since they affect the power required from the main and the auxiliary amplifier. A tight coupling introduces excessive loss in the main signal, while a loose coupling overloads the auxiliary amplifier. Thus, a compromise must be made. The effect of system errors on the amplifier performance can be obtained by replacing A and B from equation 1 by $S_{21}^{(2)} S_{12}^{(4)}$ and $-S_{31}^{(2)} S_{13}^{(3)} b_1 S_{13}^{(4)}$ respectively. Thus, the system will be effective as long as the phase and amplitude of the ratio B/A remain within the range mentioned in the previous section for a given bandwidth. Published results on this technique for a 1.5 W/ 2GHz amplifier, showed an improvement of 30 dB within a 200 MHz bandwidth[2].

THE FEEDBACK TECHNIQUE

The improvement of an amplifier performance by means of feedback at the expense of amplifier gain, is a common practice at low frequencies. The same improvements can be obtained at microwave frequencies if special design techniques are taken into consideration. It can be shown that the gain and intermodulation products are reduced by the same factor given by equation 5. The configuration of a typical microwave feedback amplifier is shown in figure 3.

$$K = \frac{1}{1 - a_1 b S_{23}^{(1)} S_{31}^{(2)}} \qquad (5)$$

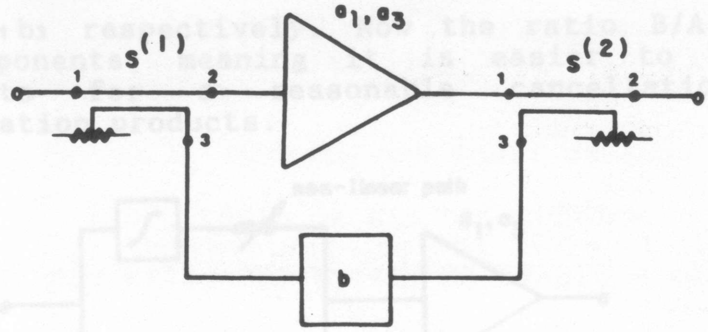

Fig 3 - Block diagram of a microwave feedback amplifier

An important step in the design is to guarantee that K < 1. This condition can be satisfied in a certain frequency band if the phase shift does not deviate excessively from the midband value, which is 180°. Out of this band the value of $a_1 b S_{23}^{(1)} S_{31}^{(2)}$ must be lower than 1 for stable operation. An estimative of the phase and amplitude deviations in the amplifier performance can be done by replacing A and B from equation 1, by 1 and $a_1 b S_{23}^{(1)} S_{13}^{(2)}$ respectively, resulting an offset of 180° added to the degrees indicated in figure 1. Assuming an IMD reduction of 12 to 14 dB, which results in a gain ripple of +/- 1 dB, it can be found from figure 1 that the loop gain must remain in the range 10 to 12 dB and the phase variation should not exceed +/- 25°. The main published results employing this technique are: a narrow band amplifier at 10.7 GHz operating in a wide temperature range (-30° to +70°) with an IMD improvement of 14 dB at + 30 dBm output power[3]; an amplifier for the 3.4 to 4.2 GHz band presenting an 8 dB improvement in the IMD at an output power of + 27 dBm[4].

THE PREDISTORTION TECHNIQUE

In this technique, a predistortion circuit precedes the power amplifier. The general concept of a predistorter consists in dividing the input signal in two paths, namely the linear and non-linear paths, as shown in figure 4. A perfect cancellation is possible when the amplifier and the predistorter have, at the output, the same IMD but an opposite phase, as in equation 6.

$$(1 + a_1 b_3 / a_3) = 0 \qquad (6)$$

The non-linear path contains a distortion generator, and the attenuator and phase shifter are adjusted for perfect cancellation of the intermodulation voltage at the output. The deviation from the balanced conditions can be estimated by replacing the terms A and B from equation 1, by

a_3 and $-a_1 b_3$ respectively. Now the ratio B/A depends on fewer components, meaning it is easier to fulfill the requirements for a reasonable cancellation of the intermodulation products.

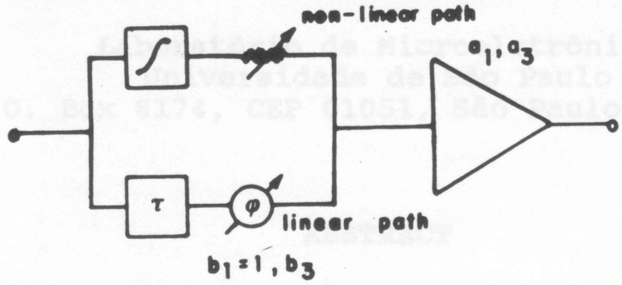

Fig 4 - Block diagram of a predistorter

Relevant published performance results are: an IMD reduction of 10 dB for an amplifier operating at + 40.8 dBm and a back-off of 5 dB at 3.7 to 4.1 GHz[5]; a reduction of 7 dB minimum in the 500 MHz bandwidth for a + 43 dBm/6GHz power amplifier operating at 8 dB back-off[6]

COMMENTS AND CONCLUSIONS

It was shown in this paper that the performance of a linearizer, concerning the intermodulation reduction and bandwidth, depends on the ratio B/A.

In the case of feedforward, B/A suffers from the influence of several couplers and of a considerable phase shift of the main amplifier from connector to connector. Thus, the linearization of a given amplifier is feasible only in a narrow bandwidth. However, when the system is balanced, it is able to achieve a low intermodulation distortion, is electrically stable, and relatively insensitive to temperature variation. This type of linearizer requires a more complex circuit, is heavier and consumes more power compared to other systems. This picture may change in the near future with the advent of thin-film miniaturized power amplifier modules and of monolithic amplifiers. These components at 6 GHz present flat amplitude response within a 20% bandwidth and delay in the order of 8.5 cycles. Adding this performance to its small dimensions, there is no doubt that an integrated design, comprising such amplifiers and the linearizing circuits, will overcome some of its present drawbacks.

The feedback technique is less effective for reducing the intermodulation products since it also affects the system gain. However, if characteristics like circuit simplicity, temperature stability and compacteness are considered, the feedback approach is far superior. Regarding bandwidth, this technique can operate successfuly because