A LOW THIRD ORDER INTERMODULATION AMPLIFIER WITH HARMONIC FEEDBACK CIRCUITRY

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ABSTRACT

This paper describes a novel technique for reducing the third-order intermodulation product levels in a non-linear amplifier. This technique is based on feeding the second harmonic signal produced at the output of the amplifier back to its input. Mathematical analysis and computer simulation are presented. The results of the related experiment which gave a measurement of 16 dB reduction in the level of the third order intermodulation is reported.

INTRODUCTION

A common performance parameter of amplifiers used in communication systems, is the effect of nonlinearity on the amplifier performance. The intermodulation (IM) products, especially the 3rd order IM, are regarded as the most troublesome in communication system amplifiers. The conventional techniques for reducing IM distortion which are reported in the literature [1-3] require rather complex and expensive circuitry and/or they may prevent the designer from using the full capability of the active device. For example, the negative feedback technique causes a reduction in the amplifier gain, and its alternative, the feedforward technique requires a second high performance amplifier closely matched to the main amplifier [4].

A novel technique for reducing the third order IM product levels in non-linear MESFET amplifiers is proposed in this paper [5]. In this novel technique, not only is there no trade off between the gain and the levels of the 3rd order IM but also the required circuitry is simple, inexpensive and small in size.

DESCRIPTION

This novel technique is based on using non-linearity of the amplifier to cancel out the 3rd order IM product. In this technique the second harmonics of the source signals which are produced at the amplifier output are feedback to the input of the amplifier. Non-linearity of the amplifier causes interaction between the source signals and their fedback second harmonics. This interaction results in additional signals at the output of the amplifier at the 3rd order intermodulation frequencies. By proper selection of phase and amplitude of the fedback second harmonics, it is possible to make the 3rd order intermodulation product produced by the second harmonics and the original 3rd order product out of phase and equal in amplitude. As a consequence the 3rd order intermodulation distortion is totally eliminated, in principle.

In order to analyse the technique mathematically, a simplified non-linear model is used for the MESFET transistor. In this model the transconductance is regarded as non-linear as it is dominant nonlinearity in amplifiers. This nonlinearity can be approximated by a three-term power series expansion for the drain current, i_d , as

$$i_d = g_{m1} v_{in} + g_{m2} v_{in}^2 + g_{m3} v_{in}^3 \qquad (1)$$

in which v_{in} is the gate to source voltage.

Writing the signal from fundamental signal sources as $A_1 \cos(\omega_1 t)$ and $A_2 \cos(\omega_2 t)$ and the fedback second harmonics as $A_{11} \cos(2\omega_1 t + \phi_1)$ and $A_{22} \cos(2\omega_2 t + \phi_2)$, ($\phi_1$ and ϕ_2, are the phases

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introduced at the second harmonics), the input signal to the amplifier is

$$v_{in} = A_1\cos(\omega_1 t) + A_2\cos(\omega_2 t) +$$
$$A_{11}\cos(2\omega_1 t + \phi_1) + A_{22}\cos(2\omega_2 t + \phi_2) \qquad (2)$$

Substitution of Equation 2 into Equation 1 gives all the relevant components in the output spectrum. For brevity here, we only show the third order IM components. For the third order intermodulation product type $(2\omega_2 t - \omega_1 t)$ we have

$$A_1 A_{22} g_{m2}\cos(2\omega_2 t - \omega_1 t - \phi_2) +$$
$$\frac{3A_1 A_2^2 g_{m3}\cos(2\omega_2 t - \omega_1 t)}{4} +$$
$$\frac{3A_{11}A_{22}g_{m3}\cos(2\omega_2 t - \omega_1 t + \phi_2 - \phi_1)}{2} \qquad (3)$$

The second term in Equation 3 is the result of interaction between fundamental signals (original 3rd order IM). The first and the third terms are the consequence of the fedback of the second harmonic into the amplifier. The third term in the above equation is small in comparison to the two other terms and can be ignored.

In order that the first term of Equation 3 cancels the second term, given total suppression of $(2\omega_2 t - \omega_1 t)$, the following condition must be satisfied:

$$A_{22} = \frac{3A_2^2 g_{m3}}{4g_{m2}} \qquad \text{and} \qquad |\phi_2| = 180^o$$

Similarly for suppression of the $(2\omega_1 t - \omega_2 t)$ term we must have

$$A_{11} = \frac{3A_1^2 g_{m3}}{4g_{m2}} \qquad \text{and} \qquad |\phi_1| = 180^o$$

Thus, these conditions would totally cancel out both terms of the third order intermodulation product.

The above analysis also was confirmed by the CAD simulation. For this investigation the circuit structure of Figure 1 was used. This circuit has a wideband input configuration which consists of a T-section with its corresponding m-derived half T-sections to ensure a wideband match at the input. This configuration is used so that the input circuit bandwidth does not affect the predicted performance. A parallel resonant circuit is used at the output together with a transformer to provide the optimum load for the amplifier. The figure also shows the circuitry which feeds back the generated second harmonics to the input. The fundamental input signals are arbitrarily chosen at frequencies 2.5 GHz and 2.51 GHz. The results of this investigation is shown in Figure 2 and 3. A typical fundamental and third order IM product power versus frequency plot is drawn in Figure 2 when no second harmonic is fedback to the input. The simulated effect of the feeding back the second harmonic on the third order IM at lower power levels is shown in Figure 3. As it can be seen from this figure, there is no change in the fundamental power at the output while there is a reduction in the 3rd order IM by about 30 dB. This is clearly a substantial improvement and is maintained over a large range of input power level.

It was observed that there are some modest discrepancies between required simulated and calculated phase and amplitude of the fedback second harmonic, which occurs because of the effects of the elements (especially feedback elements) of the transistor which are ignored in mathematical analysis. CAD simulation also revealed that this technique can be employed at higher power levels than those considered above and even at 1dB gain compression point (Figure 4). However, the required phase and amplitude of the fedback harmonic are considerably different from the lower power region. This is predictable as at higher power region distortion is produced by many other nonlinearities such as clipping as well as device function nonlinearity. Figures 3 and 4 also suggest that if the technique is going to be used for the entire dynamic range, some sort of active control loop on the phase and amplitude would be viable.

Figure 5 shows the situation where the amplitude and phase of the fedback signal are kept fixed but the frequency difference between the two fundamental signals is changed. This figure suggests that the reduction of intermodulation benefit is not confined to a narrow band. The mathematical analysis and CAD simulation showed that the fifth order intermodulation product remain almost unchanged using this technique.

The concept has also been examined experimentally. For experimental simplicity instead of feeding back the second harmonic signals, they were generated and were injected into the amplifier input together with two fundamental signals. Figure 5 shows the spectrum at the output of an amplifier with an input at 500 and 501

MHz without injecting the second harmonics, at a power point below the 1 dB gain compression point. Figure 7 shows the corresponding spectrum with the second harmonic signals are injected at the optimum amplitude and phase. This shows that the third order intermodulation levels have been reduced by 16 dB and the fundamental levels are unchanged.

CONCLUSIONS

The mathematical analysis and CAD simulation of the performance of a MESFET non-linear amplifier reveal that the level of the 3rd order intermodulation product can be reduced by feeding back the generated second harmonics to the input of the amplifier. The third order IM levels at lower or higher power level or indeed at the 1dB compression point can be reduced substantially by this technique. The absence of trade-off between the gain and the third order IM level (and higher efficiency as a result), simple circuitry are among other advantages of this technique. The related technique has been investigated in practice at 500 MHz and has given a 16 dB reduction in the third order intermodulation levels without reduction in the fundamental outputs.

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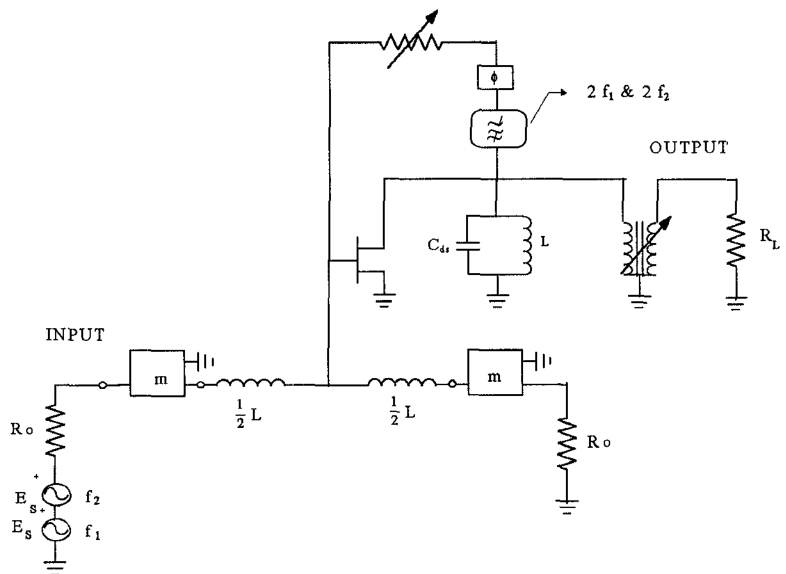

Fig. 1 Schematic of the circuit used to predict the 3rd order intermodulation reduction by feedback of the 2nd harmonic of the input signal

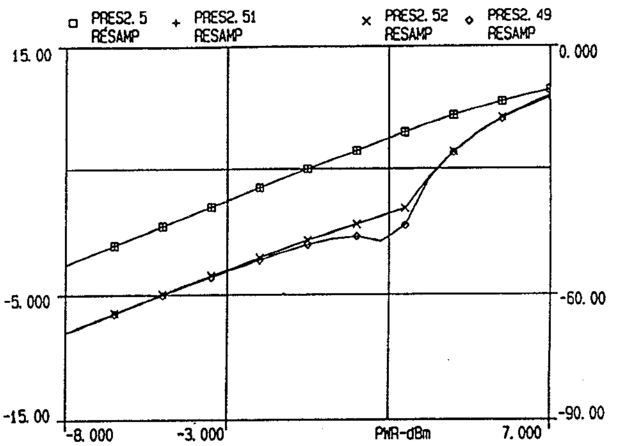

Fig. 2 The fundamental powers (left hand axis) and the 3rd order IM powers (right hand axis) vs. input power without feedback of the second harmonic.

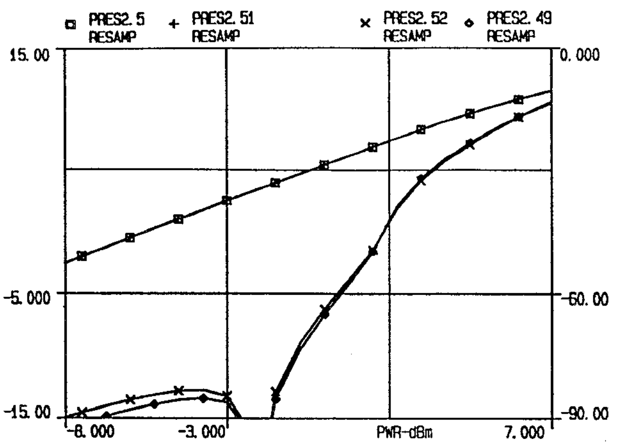

Fig. 3 The fundamental and the 3rd order IM powers vs. input power with feedback of second harmonic at lower power levels (Δf = 10 MHz).

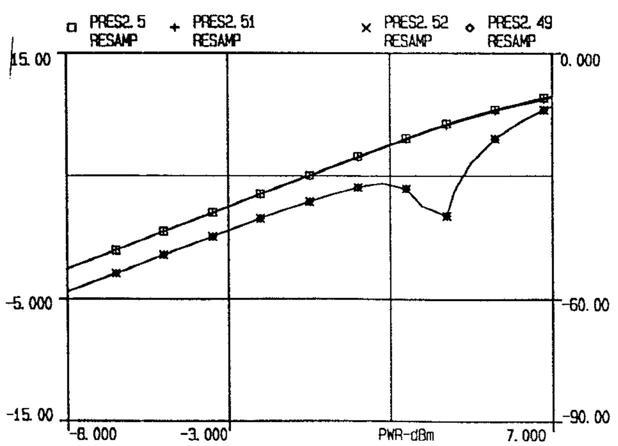

Fig. 4 The fundamental and the 3rd order IM powers vs. input power after employing the feedback technique at a point close to the 1 dB gain compression point.

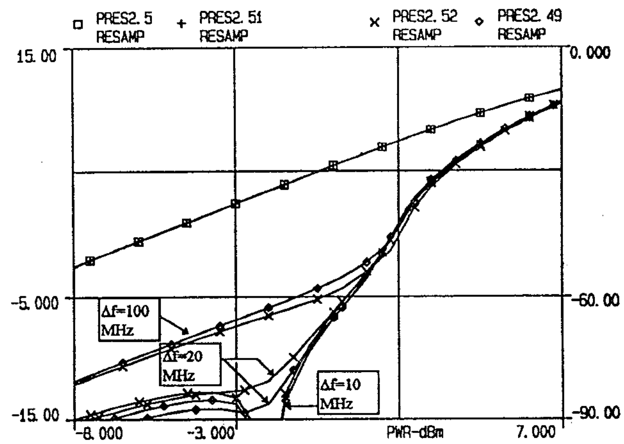

Fig. 5 The fundamental and the 3rd order IM powers vs. input power after employing the feedback technique at lower power levels and using the frequency difference between the two input signals as parameter.

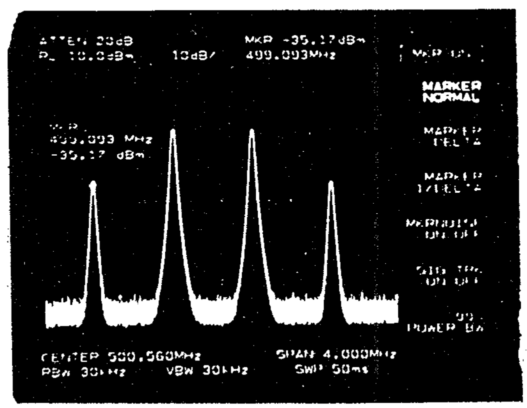

Fig. 6 The measured fundamental and the 3rd order IM powers before injecting the second harmonic signals to the amplifier.

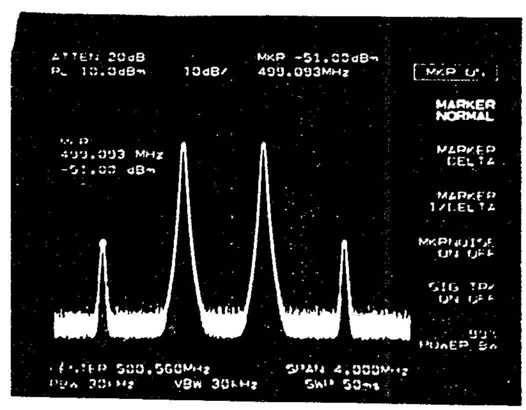

Fig. 7 The measured fundamental and the 3rd order IM powers after injecting the second harmonic signals to the amplifier.