Low intermodulation amplifiers for RF and microwave wireless systems.

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A novel linearisation technique for reduction in the third-order intermodulation distortion products, with the injection of the second harmonics through a feedback loop of a power amplifier was applied in this paper. The power amplifier including the feedback loop components (bandpass filter, phase shifter, attenuator) was designed as a hybrid microwave integrated circuit by using program Libra. The adjustable parameters are the phase and amplitude of the loop signals. Therefore, a voltage that controls a phase shift of the phase shifter and a control current of a PIN diode in the attenuator circuit were optimised to obtain a reduction in the third-order intermodulation distortion. The achievable improvement was found to be 21 dB for the case of two fundamental signals at the power amplifier input.

1 Introduction

In telecommunications systems, the intermodulation distortion (IMD) especially the third-order (IMD3) generated in-band, has always been of concern, particularly when many multilevel channels are simultaneously processed. Many different techniques for IMD reduction can be found in literature such as predistortion, feedforward, feedback and combination of them [1-2]. However, the application of these techniques requires the circuitry that may be complex, expensive and large in size, as well as limits the usage of active device full capability. In a novel technique for reducing the IMD product levels [3,4], the second harmonics of the input signals are fed together with the fundamental signal to the amplifier input. The injection of the difference frequency between the fundamental signals is another way to reduce IMD product levels [5]. Both approaches of a novel technique satisfy the reduction of IMD product levels without affecting the fundamental signal power levels. This work extends previous analyses of a multicarrier amplification. The effects of the injection of carrier second harmonics on the intermodulation in a microwave power amplifier were investigated. The published results preceding this paper is based on the approach in which feedback loop components were modeled by ideal elements from the library of commercial programs such as Libra or MDS. In our work, second harmonics are extracted from a non-linear power amplifier output, and returned to the amplifier input through the feedback loop, whose components are band pass filter, phase shifter, attenuator and isolator. Each of them, excepting the isolator, was designed for the application in a hybrid MIC of power amplifier.

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2 Power amplifier with feedback loop components

The power amplifier circuit with feedback loop is presented in Fig. 1. A design was applied on the substrate characterised by following parameters ε_r=4.3, H=0.635 mm, t=0.004 mm. In power amplifier simulation NEC MESFET from Libra library denoted as NE710 was used.

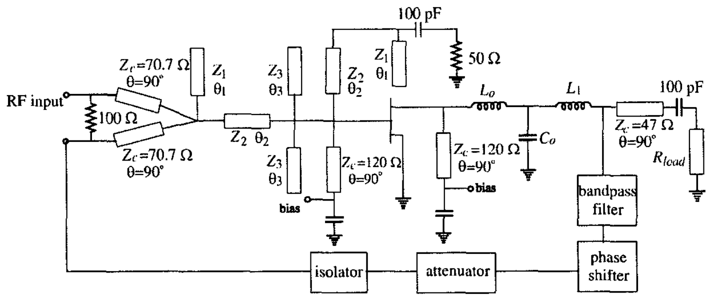


Fig.1. *Power amplifier with the second harmonics feedback loop*

The proposed technique uses the amplifier non-linear characteristic to generate a second third-order IMD signal which is used to cancel the original third-order IMD product at the output. Namely, by proper selection of phase and amplitude of the second harmonics, it is possible to make the third-order IMD product produced by the second harmonics out of phase and equal in the amplitude with the original third-order product. With the aim to select only the second harmonic components at the output of the power amplifier, the first device in the feedback loop must be a bandpass filter. The bandpass filter that can be conveniently fabricated in microstrip is the capacitiv-gap coupled resonator filter designed at 5.3 GHz centre frequency with 20% bandwidth and 0.5 dB equal-ripple response, with 3 sections. A 360° reflection-type analogue phase shifter with a single 90° branch line coupler [6] was designed. The phase shifter circuitry is shown in Fig. 2. The phase shift in this phase shifter is produced by reflecting the incident wave with a varactor diode, whose capacitance varies according to the bias voltage. As insertion loss strongly depends on impedance Z_1 (Fig. 2), its appropriate value to the reflection load (two varactors in series with a shorted stub and separated by quarterwave transmission line) is provided by the impedance transformer. GaAs hyperabrupt tuning varactor type MA-46553 was used for simulation. Varying the controlled voltage between 2 and 20 V, a full phase shift of 360° is achieved at the frequencies of the fundamental signal second harmonics. An appropriate attenuation of the second harmonics is accomplished by PIN diode attenuator shown in Fig. 3. For simulation purposes, HP hermetic PIN diode for microstrip attenuators was used. Changing a diode forward current from 0.01 to 100 mA, the resistance of the intrinsic region of the diode is varied, providing the control of attenuation with the bias point. The input and output of the attenuator are at the input and isolated ports of the 3 dB Lange-coupler selected in order to attain better performances over wider frequency range. Simulated results show that the attenuation controlled by the bias current varies from 0.5-33 dB.

Returned signals of the second harmonics are combined with fundamental input signals over Wilkinson's combiner, Fig. 1.

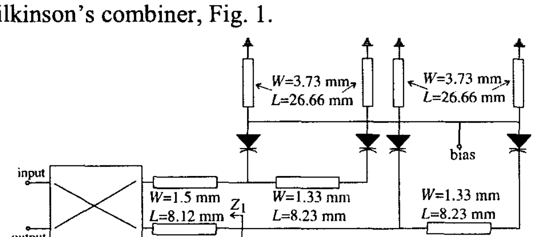


Fig.2. *Phase shifter*

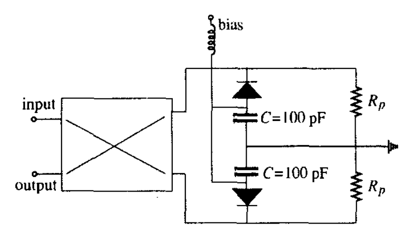


Fig.3. *Variable attenuator*

3 Numerical and Experimental Results

The realtiv phase shift characteristics of the phase shifter over the frequency range 5-5.2 GHz for the control voltage values of 4, 9, 14 and 20 V denoted as PH-control voltage are shown in Fig. 4. The attenuation characteristics of variable attenuator in the frequency range 5-5.4 GHz, that relate to PIN diode intrinsic resistance of 1, 50, 200 and 500 Ω are represented in Fig. 5, with an appropriate denotation ATEN-resistance value.

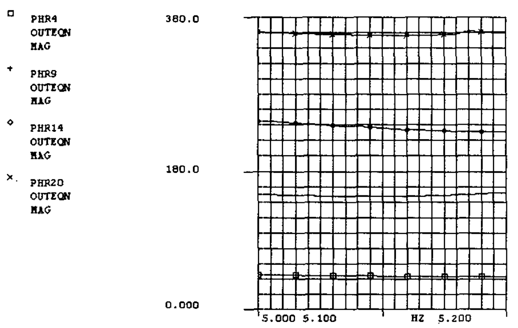


Fig. 4 *Relativ phase shift of reflection type phase shifter*

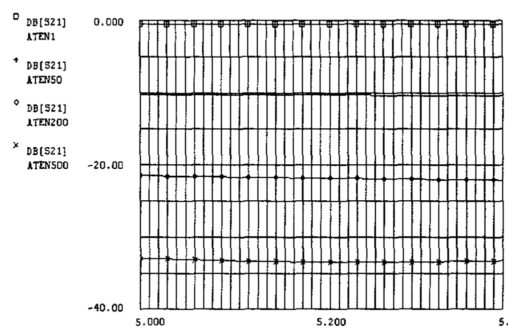
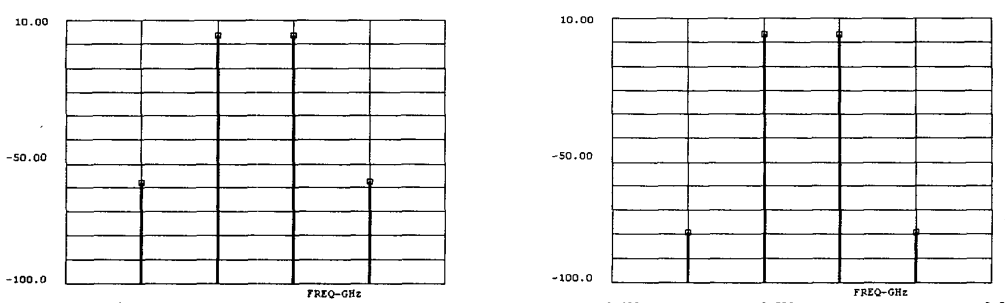


Fig. 5 *Attenuation of variable atteniator*

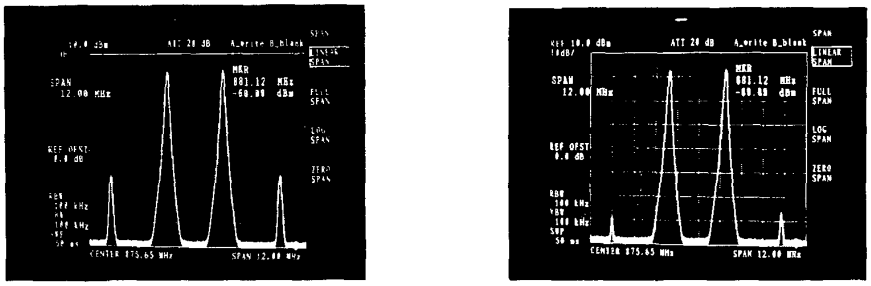
The chosen frequencies of two main input fundamental signals are 2.5 GHz and 2.51 GHz and their input power levels are −2 dBm. In the CAD simulation, non-linear Curtice's cubic model was used for MESFET modeling. Input reflection coefficient less than −10 dB in the frequency range 2-9 GHz as well as unconditionally stable operation of MESFET were achieved by the proposed input matching circuit (Fig. 1). The values of L_0, L_1, C_0 and transformer impedance, Fig. 1, were changed by using optimisation facility of program Libra in order to accomplish desired performance of fundamental signals' output power of approximately 3 dBm and the lowest third order IMD power of −57 dBm. The spectrum for the bias point V_{gs}=-0.4 V and V_{ds}=3 V, obtained at the output without applying our technique is shown in Fig. 6a). It includes fundamental signals and the third-order IMD products at 2.49 GHz and 2.52 GHz. When the second harmonics were returned from the output to the input of the power amplifier, CAD optimisation was used to find the right phase and amplitude of these signals in order to reduce the IMD3 products by keeping the fundamental signal power levels constant. The spectrum obtained after simulation are shown in Fig. 6b).



a) *b)*

Fig. 6. *The simulated fundamental powers and third order IMD powers*
a) Before employing the technique; b) After employing the technique

The results obtained during analyses show that a maximum reduction of approximately 40 dB of each IMD3 product can be obtained separately without reduction of the fundamental signals. The values of the phase shift and attenuation at which maximum reduction is obtained are different for the various IMD3 products. The second harmonic spectral components must have approximately the same power level so that all of them can be controlled to within a fraction of dB in amplitude and of a few degrees in phase in order to attain maximum reduction in IMD3 products. On the other hand, it is difficult to obtain a maximum reduction in all IMD3 products with the same amplitude and phase adjustment due to these products have slightly different amplitudes and phases. The results shown in Fig. 6 refer to the compromise between the maximum reductions in each IMD3 signal obtained separately, yielding 21 dB improvement in both. These results were achieved with phase shift of 14.5° and attenuation of 0.9 dB. The experimental results on a commercially available amplifier is plotted and shown in Figures 7a and 7b respectively.



a) *b)*

Figure 7 The measured fundamental power and third order IM power for Pin = - 20 dBm (a) before and (b) after employing the technique

Conclusion

In order to reduce the third-order intermodulation products of power amplifier, a novel linearisation technique was applied. The second harmonics of the fundamental signals were injected through the feedback loop of power amplifier. The proposed technique uses the amplifier non-linear characteristic to generate a second third-order IMD signal, which is used to cancel the original third-order IMD product at the output. The earlier published results referring to the same novel technique approach are based on the power amplifier simulation for the ideal feedback loop elements. In this paper the feedback loop components (band pass filter, phase shifter, attenuator) as well as a single stage amplifier circuit were designed as a hybrid microwave integrated circuit in a microstrip technique using program Libra. Adjusting the phase shift and amplitude of the loop signals; the reduction in third-order intermodulation distortion products obtained by simulation are 21 dB in both and obtained during experiment are approximately 17 dB.

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