A New Approach to Amplifier Linearization by the Generalized Baseband Signal Injection Method

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***Abstract*—This letter presents a new technique for the reduction of third-order intermodulation distortion (IMD) in microwave amplifiers. Baseband predistortion signal is injected into a diode circuitry and the main amplifier to mix with the fundamental to generate a canceling signal for the suppression of the inherent IMD component. The proposed method can achieve higher linearity performance, in comparison to the conventional difference-frequency approach, and unlike many other techniques, no RF circuitry, such as variable gain amplifiers and phase-shifters, is needed other than baseband amplifiers. Both two-tone and vector signal measurement results are included.**

***Index Terms*—Amplifiers, baseband, linearization.**

I. Introduction

Wireless communication systems have experienced phenomenal growth in recent years. In order to accommodate high data rate applications, spectral efficient modulation schemes have to be adopted which poses a stringent requirement on the linearity of RF amplifiers. In past years, various linearization methods [1]–[4] have been studied that offer different degree of performance at the expense of circuit complexity. Unfortunately, most of these methods require costly and complex RF circuitry that are unacceptable for mobile terminals. In this paper, a novel linearization scheme utilizing the concept of generalized baseband signal injection is introduced. Unlike the feedback and the feed-forward approaches, this technique is highly stable, power efficient, easy to implement, and has little effect on amplifier gain.

II. Generalized Baseband Injection

Fig. 1 shows the basic configuration of the conventional baseband injection technique [6] by using a MESFET as the active device. For the sake of analysis, only the gate and drain nonlinearities of the MESFET are considered here. Note that the linear part of g_m and C_{gs} is explicitly specified in the diagram, whereas the drain-to-source conductance and capacitance are embedded inside the load network. Furthermore, it is assumed that the nonlinear drain and gate currents can be represented by Taylor series expansion as

$$i_{\mathrm{dsn}} = g_{m2} v_{\mathrm{gs}}^2(t) + g_{m3} v_{\mathrm{gs}}^3(t) \qquad (1)$$

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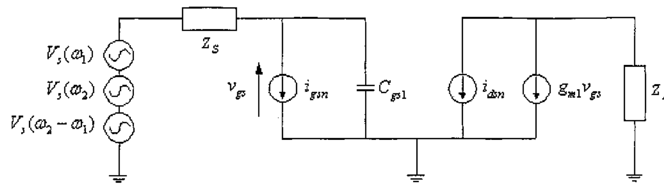

Fig. 1. Equivalent circuit for nonlinear analysis.

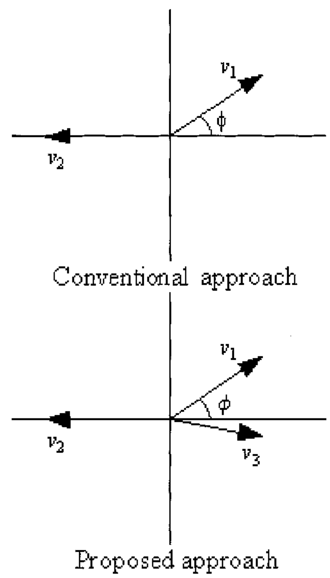

Fig. 2. Phasor diagram representation.

$$i_{\mathrm{gsn}} = \frac{d}{dt}\left[C_{\mathrm{gs2}} v_{\mathrm{gs}}^2(t) + C_{\mathrm{gs3}} v_{\mathrm{gs}}^3(t)\right] \qquad (2)$$

where $g_{m2}, g_{m3}, C_{\mathrm{gs2}}$, and C_{gs3} are bias-dependent coefficients.

By applying the concept of Volterra theory and the method of nonlinear current [5], the third-order IMD component of the output voltage at $\omega = 2\omega_2 - \omega_1$ can simply be derived as seen in (3)–(5), at the bottom of the next page, where α and β are transfer functions between the corresponding nonlinear current source and load voltage; v_{gs1} and v_{gs2} are the first- and second-order voltages; κ and ξ are complex coefficients.

Fig. 2(a) illustrates the phasor representation of (3). Note that the amplitude of v_1 can be made variable under the control of the injected baseband signal, $v_{\mathrm{gs1}}(\omega_2 - \omega_1)$. These results suggest that only partial cancellation of the inherent third-order IMD signal (v_2) is possible, unless $\phi = 0$. The value of ϕ is normally nonzero due to the presence of the nonlinear gate capacitance. Because of this, the conventional baseband approach can only offer limited improvement in IMD performance [6]. A possible

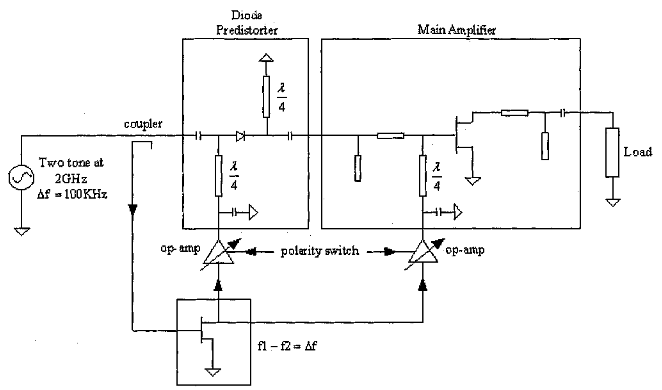

Fig. 3. Experimental setup.

solution to this problem is to introduce an additional canceling signal (v_3) to the circuit as shown in Fig. 2(b). Note that this signal can be generated externally by using a nonlinear diode (to be explained in the next section). As a result, v_2 now represents the combined distortion signal generated by the main amplifier, as well as the diode circuit. In theory, both the phase and amplitude of the combined canceling signal $(v_1 + v_3)$ may be varied independently by the control of the two baseband components. Consequently, by neglecting any higher order mixing products, the third-order IMD component may be eliminated entirely (i.e., $v_1 + v_2 + v_3 = 0$) by adjusting the strength and polarity (either 0° or 180°) of the baseband signals injected into the main amplifier and the diode circuitry.

III. Diode Predistortion Circuit

As mentioned before, an additional canceling signal (v_3) is required for the ultimate suppression of the IMD component and this signal can be produced by Schottky diode. Under the forward-biased condition, the IMD products generated by the nonlinear resistance are dominating and the effect of the junction capacitance may therefore be neglected in the analysis. Hence, the I–V characteristics of the diode can be modeled as

$$i_D = g_1 v_D + g_2 v_D^2 + g_3 v_D^3 \tag{6}$$

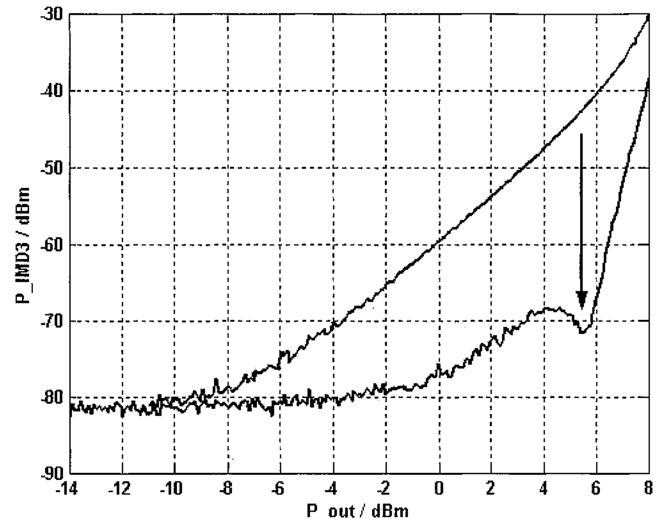

Fig. 4. Two-tone test results (with and without linearization).

where g_1, g_2, and g_3 are bias dependent coefficients. Subsequently, the third-order IMD component of the output voltage at $\omega = 2\omega_2 - \omega_1$ is simply given by

$$\begin{aligned} v_3 &= \gamma \cdot i_3 \\ i_3 &= g_2 v_{D1}(\omega_2) v_{D1}(\omega_2 - \omega_1) + g_2 v_{D1}(\omega_2) v_{D2}(\omega_2, -\omega_1) \\ &\quad + \frac{1}{2} g_2 v_{D1}(-\omega_1) v_{D2}(\omega_2, \omega_2) \\ &\quad + \frac{3}{4} g_3 v_{D1}(\omega_2) v_{D1}(\omega_2) v_{D1}(-\omega_1) \end{aligned} \tag{7}$$

where γ is the transfer function between the diode current and the load voltage. Note that the magnitude of v_3 may be adjusted by controlling the strength of $v_{D1}(\omega_2 - \omega_1)$.

IV. Experiment and Results

Fig. 3 shows the configuration used for the experimental demonstration of the proposed scheme. MESFET CFY30 from Infineon Technologies was chosen for constructing the main amplifier. Schottky diode SMS7621 from Alpha Industries was chosen for the pre-distortion circuit. The insertion loss introduced by the diode circuitry is found to be less than 2 dB. The amplifying system is designed to operate at approximately 2 GHz. A simple MESFET circuit, operating near pinch-off, is employed for generation of the injection baseband signal. The

$$\begin{aligned} v_L(2\omega_2 - \omega_1) &= \alpha \cdot i_{\mathrm{gs3}}(\omega_2, \omega_2, -\omega_1) + \beta \cdot i_{ds3}(\omega_2, \omega_2, -\omega_1) \\ &= \kappa \cdot v_{\mathrm{gs1}}(\omega_2 - \omega_1) + \xi \\ &= v_1 + v_2 \end{aligned} \tag{3}$$

$$i_{\mathrm{gs3}}(\omega_2, \omega_2, -\omega_1) = j(2\omega_2 - \omega_1) \times \left\{ \begin{array}{l} C_{\mathrm{gs2}} v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs1}}(\omega_2 - \omega_1) + C_{\mathrm{gs2}} v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs2}}(\omega_2, -\omega_1) \\ + \frac{1}{2} C_{\mathrm{gs2}} v_{\mathrm{gs1}}(-\omega_1) v_{\mathrm{gs2}}(\omega_2, \omega_2) \\ + \frac{3}{4} C_{\mathrm{gs3}} v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs1}}(-\omega_1) \end{array} \right\} \tag{4}$$

$$\begin{aligned} i_{\mathrm{ds3}}(\omega_2, \omega_2, -\omega_1) &= g_{m2} v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs1}}(\omega_2 - \omega_1) + g_{m2} v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs2}}(\omega_2, -\omega_1) + \frac{1}{2} g_{m2} v_{\mathrm{gs1}}(-\omega_1) v_{\mathrm{gs2}}(\omega_2, \omega_2) \\ &\quad + \frac{3}{4} g_{m3} v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs1}}(\omega_2) v_{\mathrm{gs1}}(-\omega_1) \end{aligned} \tag{5}$$

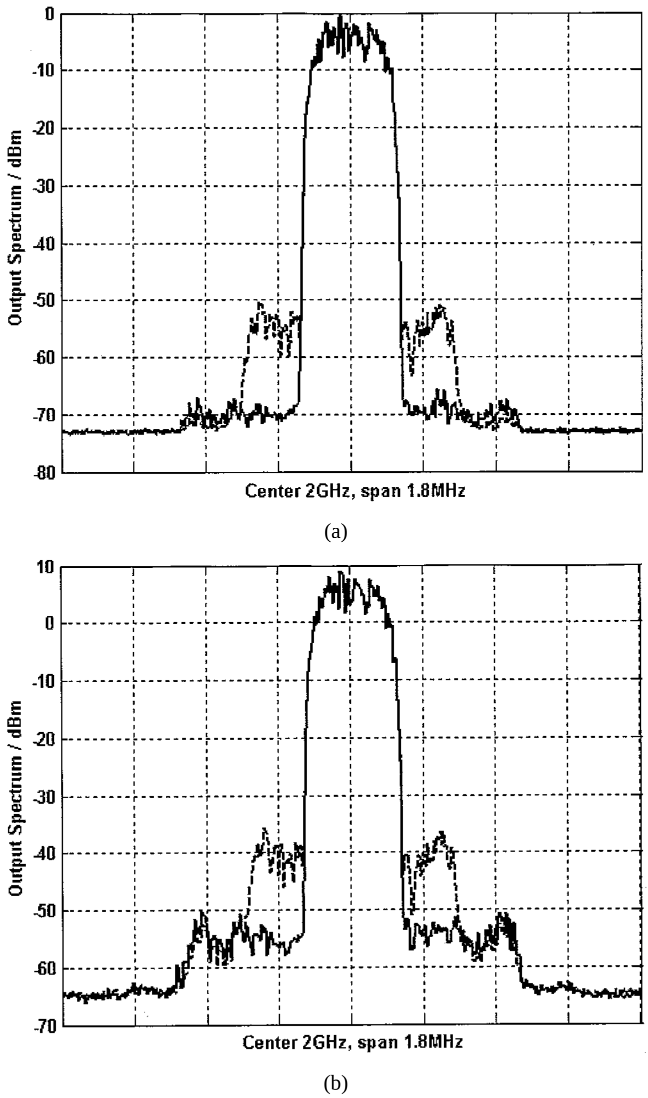

Fig. 5. PHS signal test results (with and without linearization): (a) CFY30: P_out = 14dBm, P_1dBm = 16dBm; (b) CLY2: P_out = 23dBm, P_1dBm = 23.5dBm

baseband signal is subsequently amplified by simple op-amps. Both two-tone and vector signal test have been carried out.

For the first experiment, a two-tone signal centered at 2 GHz with 100 KHz spacing is applied. Fig. 4 shows the measured third order IMD level as the output power is varied. The system is optimized for minimum IMD3 at an output power of 6 dBm per tone. The diagram indicates that the proposed scheme can offer substantial IMD improvement over a wide range of operating power level. For the vector signal test, standard PHS signal is employed. Fig. 5 shows the IMD performance of an amplifier using both low power and medium power devices, operating at different saturation levels. In both cases, a reduction in adjacent channel power ratio (ACPR) of almost 15 dB is observed. For the medium power amplifier, higher adjacent channel power is found due to the increasing level of fifth-order mixing products at deep saturation. For wideband operation, this scheme is mainly limited by the group delay associated with the matching network and the phase delay introduced by the baseband circuitry. Effect of group delay can be minimized by the careful design of the matching circuits, whereas phase delay may be compensated using wideband operational amplifiers.

V. Conclusion

A novel linearization technique for microwave amplifiers based on generalized baseband signal injection is presented. A substantial amount of reduction in third-order IMD has been demonstrated experimentally. The new scheme is easily amendable to integrated circuit implementation.

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