# An Analog Compensation Method for Asymmetric IMD Characteristics of a Power Amplifier

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*Abstract* — **The modulation frequency affects the asymmetric intermodulation distortion (IMD) products of a RF power amplifier. This effect reduces IMD cancellation performance of power amplifiers in connection with predistortion linearization. A phase extraction method to determine phase difference between upper and lower 3rd order IMD products and a phase compensation circuit using an envelope injection technique is proposed. The experimental results demonstrate a significant improvement in the 3rd order IMD cancellation performance.**

## I. INTRODUCTION

RF predistortion techniques are often used to improve the linearity of high power amplifiers. The asymmetric intermodulation distortion (IMD) characteristic of a power amplifier is one of the important factors for increasing IMD cancellation performance of a predistorted power amplifier.

The asymmetry of the IMDs is caused by amplitude and/or phase variation of the IMD products in response to the modulation frequency of a two-tone signal [1]. This results in limiting the maximum IMD cancellation performance of a RF predistortion technique.

In this paper, we experimentally investigate an analog compensation method based on the modulation frequency dependent effects of asymmetric IMD characteristics of a power amplifier. Three aspects will be investigated: 1) Measurement of the asymmetrical characteristics of a power amplifier for memory effects 2) A phase extraction method using an analog predistortion technique is applied to determine the phase difference between upper and lower 3rd order IMD distortion products 3) A phase compensation circuit using envelope injection is applied to obtain the maximum 3rd order IMD cancellation performance in connection with predistortion.

## II. MODULATION FREQUENCY DEPENDENCE

Power amplifiers with modulation frequency dependent effects have IMD levels that vary as a function of the 2-tone frequency spacing of an input signal. Volterra analysis of these effects has been reported [2][3]. If we consider the 2-tone IMD products, the upper ($2\omega_2$-$\omega_1$) and lower ($2\omega_1$-$\omega_2$) 3rd order IMD products are $I_{ds}(2\omega_2-\omega_1) = \frac{3}{8}H_3(2\omega_2-\omega_1)$, $I_{ds}(2\omega_1-\omega_2) = \frac{3}{8}H_3(2\omega_1-\omega_2)$ [4].

$$H_3(2w_2-w_1)=\frac{1}{6+6G_{ds}Z_L(2w_2-w_1)}\cdot\left(6G_{m3}+2G_{md}Z_L(2w_2)\cdot H_2(w_2,w_2)+4G_{md}Z_L(w_2-w_1)H_2(w_2,-w_1)\right) \quad (1)$$

$$H_3(2w_1-w_2)=\frac{1}{6+6G_{ds}Z_L(2w_1-w_2)}\cdot\left(6G_{m3}+2G_{md}Z_L(2w_1)\cdot H_2(w_1,w_1)+4G_{md}Z_L(w_1-w_2)H_2(w_1,-w_2)\right) \quad (2)$$

where, $G_{ds}=\frac{\partial I_{ds}}{\partial V_{ds}}$, $G_{m3}=\frac{1}{3!}\frac{\partial^3 I_{ds}}{\partial^3 V_{gs}}$, $G_{md}=\frac{1}{2!}\frac{\partial^2 I_{ds}}{\partial V_{ds}\cdot\partial V_{gs}}$ and $H_n(\omega_1, \omega_2, \cdots, \omega_n)$ are the nonlinear transfer function.

Then, if $Z_L(\omega_2-\omega_1)$ and $Z_L(2\omega_2)$ in (1) and $Z_L(\omega_1-\omega_2)$ and $Z_L(2\omega_1)$ in (2) are different, it is possible to change the phase of $H_3(2\omega_2-\omega_1)$ and $H_3(2\omega_1-\omega_2)$. Consequently, the modulation frequency will give rise to asymmetry of $I_{ds}(2\omega_1-\omega_2)$ and $I_{ds}(2\omega_2-\omega_1)$.

Fig. 1 shows the predistorted IMD cancellation characteristics for two-tone spacing of 100 kHz and 10 MHz, respectively. This asymmetric phenomenon of 3rd order IMD products, in Fig 1(b), impairs the IMD cancellation performance of a predistorter.

## III. PHASE EXTRACTION AND COMPENSATION

### A. Phase extraction circuit using predistortion

When two-tone signals are injected into a power amplifier, the amplitude of the generated 3rd order IMD products can be easily measured using a spectrum



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analyzer. Extracting the 3rd order IMD phase information is slightly more complicated [5].

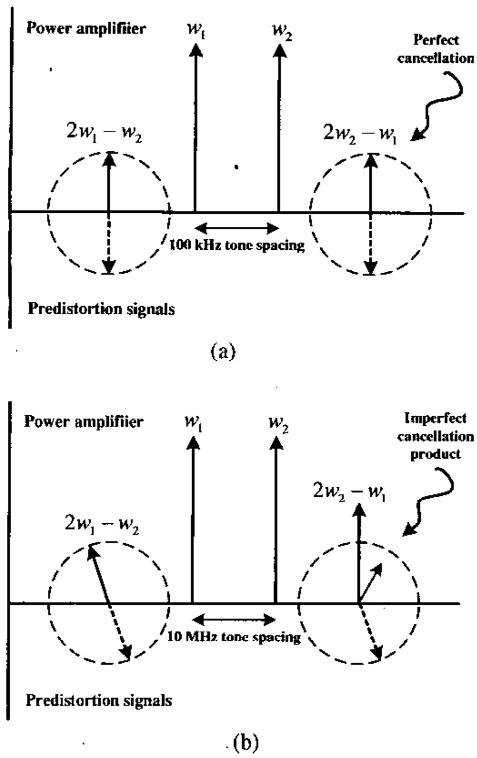


Fig. 1. IMD characteristics for 2-tone spacing (a) 100 kHz (b) 10 MHz.

This paper proposes a simple phase extraction method which uses a predistortion technique, as shown in Fig. 2. The objective is to measure the 3rd order IMD phase variation (DC voltage supplied into variable phase shifter) as a function of frequency at optimum cancellation (Path II). A one-tone signal, using variable attenuator in Path II, is generated to have equal amplitude to the upper or lower 3rd order IMD product from the power amplifier. A phase reference can be established using the 3 dB increment point of the 3rd order IMD amplitude (equal amplitude and in-phase). Re-adjusting the variable phase shift, a maximum 3rd order IMD cancellation can be determined (equal amplitude and out of phase). It is therefore possible to extract the phase of the upper and lower 3rd order IMD products.

*B. Phase compensation using envelope injection*

To compensate for the asymmetry of the 3rd order products, caused by the modulation frequency, we used an envelope injection technique. Fig. 3 shows a circuit diagram for the phase compensation circuit. The operation principle is based on the generation of the envelope frequency via a diode envelope detector and the adjustment of its amplitude and phase to minimize asymmetry of the output 3rd order IMD products from the power amplifier. From Equation (1), the envelope frequency dependence on the 3rd order IMD products can be observed. The attenuator and phase shifter frequency dependence will ultimately be replaced by a corresponding filter transfer function.

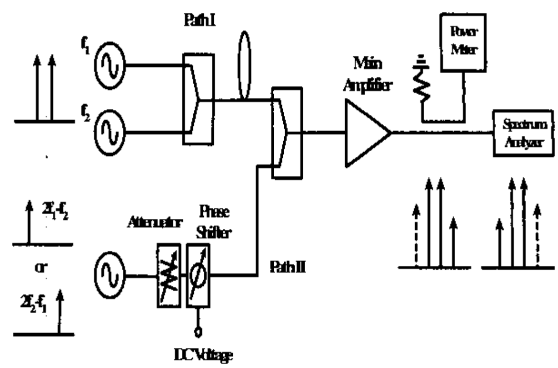

Fig 2. Circuit diagram for phase extraction.

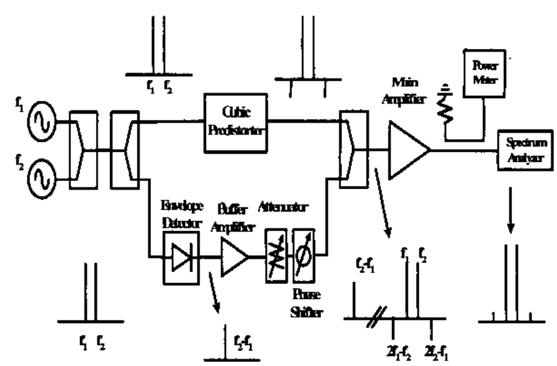

Fig. 3. Circuit diagram for phase compensation.

## IV. FABRICATION AND MEASUREMENT

All of experimental hybrid MIC (Microwave Integrated Circuit) test circuits were fabricated on a Teflon substrate with 2.52 dielectric constant and 0.54 mm thickness. The main amplifier is operated at 10 dB back-off from a 45W peak power capability. The two-tone signals centered at

1850 MHz, with tone spacing up to 10 MHz are generated within the power amplifier 20 MHz passband. A cubic predistortion linearizer, based on a conventional single loop type, was used for generating the 3rd order IMD compensation [6].

*A. Phase extraction results*

Fig. 4 shows the measured results for phase extraction of the upper and lower 3rd order IMD products for the power amplifier. A 20° phase difference, between the upper and lower 3rd order IMD products, was observed. Fig. 5 shows that asymmetry of 3rd order IMD products increased as tone spacing became wider, and the corresponding cancellation performance gradually degraded.

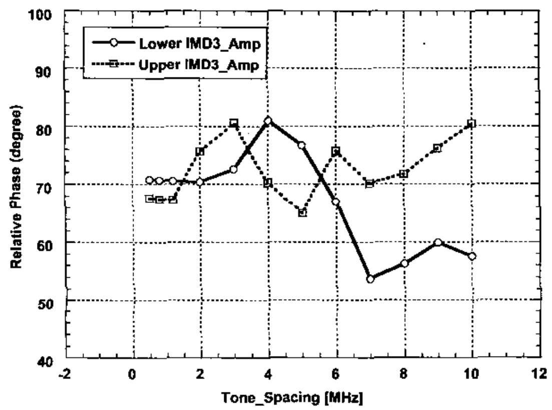


Fig. 4. Phase difference of upper and lower 3rd order IMD products.

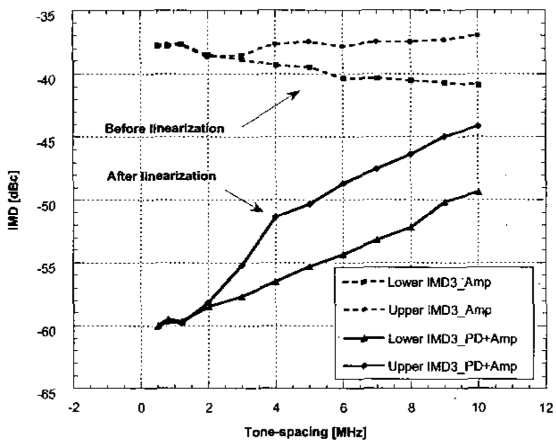


Fig. 5. 3rd order IMD cancellation performance

*B. Phase compensation results*

Fig. 6 shows IMD characteristics of upper and lower 3rd order products before and after applying the phase compensation method. The IMD difference between the 3rd order products decreased to within 3 dB after envelope frequency injection. Fig. 7 shows the phase difference of the 3rd order IMD products before and after applying phase compensation. The phase difference decreased to within 8 ° (tone spacing less than 8 MHz) after compensation was applied.

Fig. 8 shows the 3rd order IMD cancellation performance before and after applying predistortion, with and without the envelope frequency injection technique. From the results, the cubic predistorter alone could achieve a 22 to 5 dB IMD improvement over a tone spacing of 10 MHz. With the addition of the envelope injection technique, the 3rd order IMDs were improved by up to a further 5 dB.

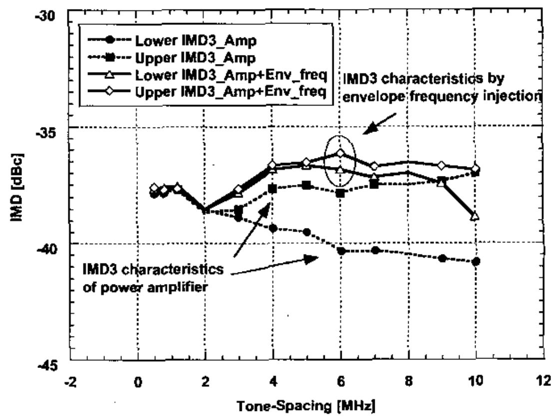


Fig. 6. IMD characteristic before and after phase compensation.

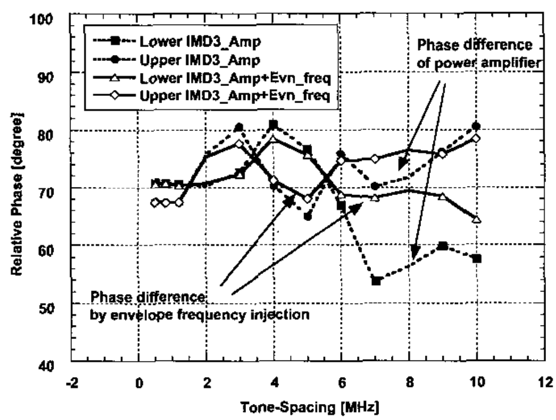


Fig. 7. Phase difference before and after phase compensation

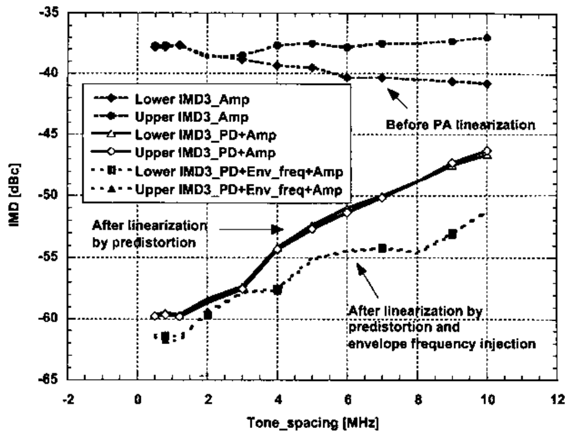


Fig. 8. Comparison of various 3rd order IMD cancellation

## V. CONCLUSION

In this paper, a phase extraction method which uses a predistortion technique and phase compensation method based on envelope frequency injection is proposed to reduce asymmetry between 3rd order IMD products.

From the experimental results, the asymmetric IMD characteristics of the power amplifier deteriorated the cancellation performance of the cubic predistorter. It was confirmed that such an asymmetric phenomenon could be reduced using the envelope injection method.


### ACKNOWLEDGEMENT

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### REFERENCES


[1] J. Voulevi, T. Rahkonen, J. Manninen, "Measurement technique for characterizing memory effects in RF power amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. 49, No. 8, pp. 1383~1389, Aug. 2001.

[2] S. A. Mass, *Nonlinear Microwave Circuits*, Artech House, 1997.

[3] J. Voulevi, J. Manninen, T. Rahkonen, "Memory effects compensation in RF power amplifiers by using envelope injection technique," *IEEE Radio and Wireless Conf.*, 2001, pp. 257~260.

[4] N. B. De Carvalho, J. C. Pedro, "Large-and small IMD behavior of microwave power amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. 47, No. 12, pp. 2509~2513, Dec. 1997.

[5] W. Bosch, G. Gatti, "Measurement and simulation of memory effects in predistortion linearizers," *IEEE Trans. Microwave Theory Tech.*, vol. 37, No. 12, pp. 1885~1890, Dec. 1989.

[6] P. Kenington, *High-Linearity RF Amplifier Design*, Artech House, 2000.

[7] Y. G. Yang, Y. Y. Woo, B. M. Kim, "New predistortion linearizer using low-frequency even-order intermodulation components," *IEEE Trans. Microwave Theory Tech.*, vol. 50, No. 2, pp. 446~452, Feb. 2002.

[8] K. J. Cho, J. S. Park, J. H. Kim, J. C. Lee, B. J. Lee, N. Y. Kim, and S. P. Stapleton, "RF predistortion of power amplifiers using 2nd harmonic based technique for optimization of intermodulation products," *IEEE Vechicular Technology Conf.*, 56 th, 2002, pp. 621-624.