Characterization of the power amplifier group delay by using predistortive cancellation technique

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Abstract— **This paper proposes a novel memory effect measurement technique in RF power amplifiers (PAs) using two-tone intermodulation distortion (IMD) signal with very simple and intuitive algorithm. Based on the proposed predistortive tone cancellation technique, the proposed measurement method is capable of measuring relative phase and magnitude of the third-order and fifth-order IMD as well as the fundamental signal. The measured relative phase between the higher and lower IMD signal for specific tone spacing can be interpreted as the group delay information of the IMD signal concerned. From the group delay analysis, we can conclude that adaptive control of group delay as well as the magnitude and phase is a key function in increasing the linearization bandwidth and the dynamic range in the predistortion (PD) technique.**

I. Introduction

To provide multimedia services such as video, music, photo, and other real-time location based applications in addition to the traditional voice and text message, digital modulation techniques employing complex coding schemes with broader channel bandwidth are utilized to maximize the spectral efficiency in the limited sources of frequency band. These digital modulation schemes increase the peak to average ratio of RF signal and as a result the signal envelope is seriously changed according to time [1].

For energy efficient operation, the PA is usually operated at a saturation region. Due to a nonlinear transfer function of the high power semiconductor devices and their intrinsic parasitic elements, the PA experiences an amplitude and phase distortions in terms of AM-AM and AM-PM, and the unwanted IMD signals are generated. Due to its extremely high output power and therefore the increasing possibility of interference with other mobile units or other communication channels, stringent linearity requirements are specified for the base-station PA [2].

The PD techniques have been recognized as a simple and promising solution along with the development of digital signal processing technology, and are still receiving considerable attentions in a form of digital PD. However, due to the memory effect of the PA, which is defined as the modulation bandwidth limitations that are amplitude or phase deviations of intermodulation (IM) responses, the PD technique exhibits some degree of performance degradation. It is important to emphasize that distortion itself is not a memory effect, but any non-constant distortion behavior at different tone spacings can be regarded as memory effect [3]-[5]. There is one important point of view missing in the previous study, and it is that the phase asymmetry which is induced by the memory effect eventually leads to the GD variation of the IMD signal. In other words, if we characterize the GD variation according to the tone spacing and output power, then we can minimize the performance degradation of the PD technique.

A number of techniques regarding the measurement of asymmetric IMD signal have been reported [6]-[10]. Some of them measured the relative phases using the frequency mixing operation or the mixing operation along with the direct comparison using the phase detector, and also the indirect tone cancellation technique was used.

In this paper, we propose a novel and simple phase asymmetry measurement technique based on the tone cancellation technique using two-tone IMD signal. Some advantages of the proposed structure are as follows: (1) no complicated RF circuit is required for measurement setup. Utilizing the commercial test instruments, the most complex circuit in the configuration is only the variable attenuator and phase shifter which can be easily designed and fabricated, (2) Measurement mode can be easily changed by the combination of four single-pole double-through (SPDT) switch operation, (3) The magnitude as well as phase asymmetry can be measured at the same time with a great precision, depending on the resolution of the vector network analyzer (VNA), (4) A calibration is very easily achieved by sending data to memory and data/memory operation in the VNA, and (5) since the main architecture and the operational mechanism are same with the PD structure, the measured result can be directly used for the PD linearizer.

II. Group Delay Characterization Based on the Predistortive Tone Cancellation Technique

Fig. 1 shows the IMD magnitude and phase measurement setup proposed in this paper. The test setup consists of three electronic signal generators (ESGs), spectrum analyzer, and the network analyzer with four SPDT switches and two variable attenuators and phase shifters. In the IMD_3 signal measurement mode, ESG_1 generates a fundamental two-tone

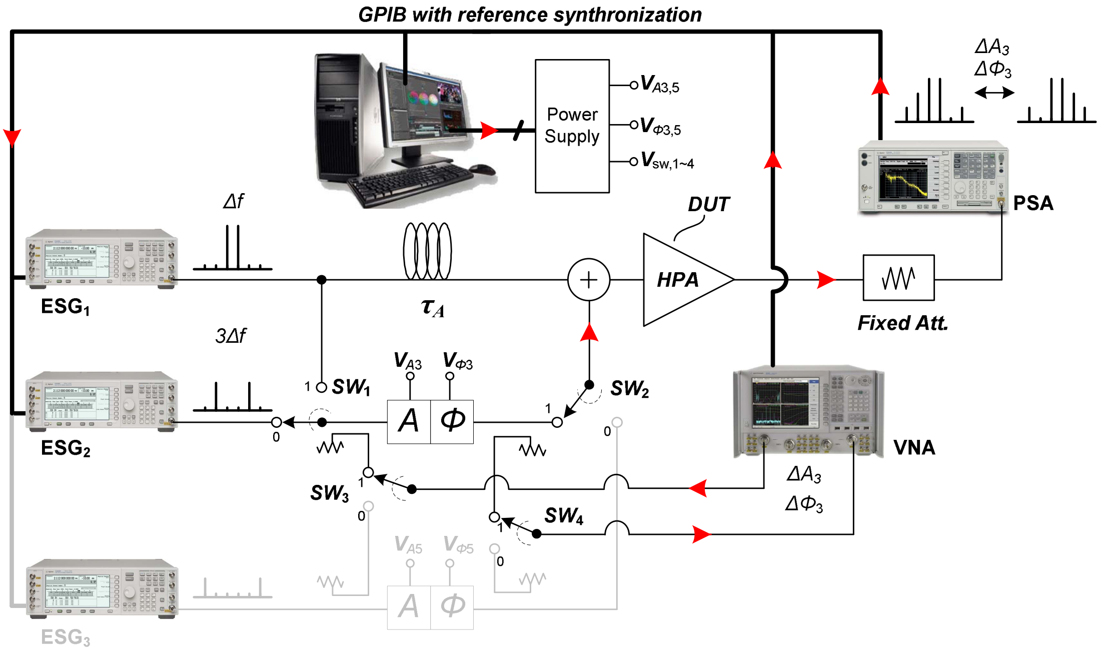

Fig. 1. Configuration of the proposed memory effect measurement setup which is adjusted for the IMD_3 signal measurement mode.

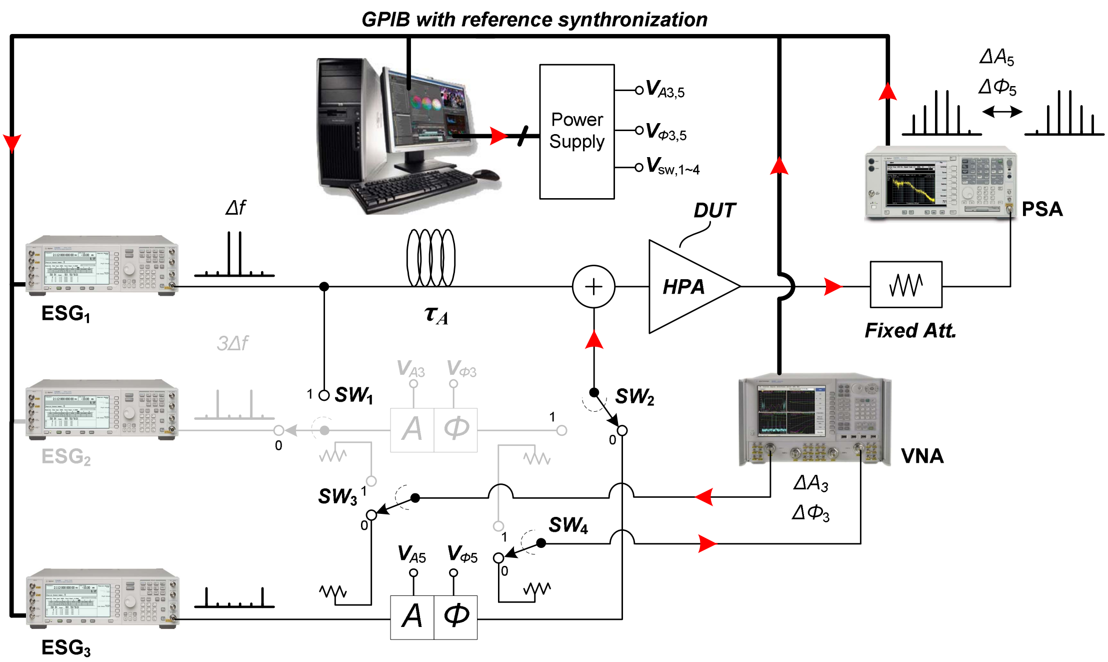

Fig. 2. Configuration of the proposed memory effect measurement setup which is adjusted for the IMD_5 signal measurement mode.

signal of which the tone spacing is Δf and ESG_2 generates the IMD_3 equivalent input signal, which is similar to the PD signal. The tone spacing of the IMD_3 equivalent signal is $3\Delta f$.

The fundamental signal experiences an arbitrary amount of group delay τ_A and is added with the third order PD signal before it is applied to the device under test (DUT), a high power amplifier (HPA). The value of τ_A has no effect on the result because the measurement is performed by single sideband (IMD) tone cancellation technique. The DUT consists of commercial broadband amplifier ZVE-8G+ of Mini-Circuits as a driver amplifier and Gallium Nitride high electron mobility (GaN HEMT) device of NPTB00025 of Nitronex as a high power device where the center frequency is 2.11 ~ 2.17 GHz for wideband code division multiple access (WCDMA) downlink base-station. A 20W peak envelope power (PEP) is achieved with the total gain of 50 dB including the driver amplifier.

The phase and the magnitude of the PD signal that is equivalent to IMD_3 signal generated at ESG_2 is adjusted by control voltages of V_{A3} and $V_{\Phi 3}$ so that one of the IMD_3 sidebands is perfectly cancelled at HPA output measured by a spectrum analyzer. Simultaneously, the magnitude and the phase response of the variable attenuator and phase shifter are measured by the VNA through the SW_3 and SW_4. The measured results are stored as memory traces. According to the same procedure, V_{A3} and $V_{\Phi 3}$ are adjusted so the opposite IMD_3 is cancelled out. By taking the memory trace previously stored in the VNA as the reference, the difference between the stored magnitude and phase response and the freshly measured response is indirectly interpreted as the relative magnitude and phase.

If we control SW_1 to be connected to 1 position (ESG_1), the relative phase and magnitude of the fundamental signal can be measured. The measurement setup capable of measuring the memory effects regarding IM_5 signal can also be set as illustrated in Fig. 2. In case of the IMD_5 measurement, SW_2, SW_3, SW_4 are connected to 0 positions. Since the measured result is directly represented in degree and dB scale, we may reduce the errors that could be generated during the measurement such as reading error between the voltage and the translated magnitude and phase, possible voltage drift over time, etc. Table I summarizes the three measurement modes of the proposed setup with respect to the combination of the SPDT switches.

TABLE I
THREE MEASUREMENT MODES ACCORDI NG TO THE SWITCH STATES

Switch State				Measurement Mode
SW_1	SW_2	SW_3	SW_4	
1	1	1	1	Fundamental
0	1	1	1	IM_3
0	0	0	0	IM_5

Suppose that the fundamental tone spacing is Δf and the group delay of the IM_3 and IM_5 signal are defined as τ_{IM3} and τ_{IM5}, then the GD response of the IMD_3 and IMD_5 signals can be calculated as follows:

$$\tau_{IM3} = -\frac{d\Phi_{IM3}}{d\omega} = -\frac{\Delta\Phi_{IM3}\times(\pi/180)}{2\pi f_{IM3H} - 2\pi f_{IM3L}}, \quad = -\frac{\Delta\Phi_{IM3}}{360\times(3\times\Delta f)} \tag{1}$$

$$\tau_{IM5} = -\frac{\Delta\Phi_{IM5}}{360\times(5\times\Delta f)}, \tag{2}$$

Where Φ_{IM3} and Φ_{IM5} are the measured relative phase in degrees and f_{IM3H} and f_{IM3L} are higher and lower IMD_3 frequencies, respectively.

III. EXPERIMENTAL RESULTS

Although the proposed setup is capable of measuring relative phase as well as magnitude asymmetry between the higher and lower IMD signals, our interest lies in the group delay variation according to the tone spacing Δf and output power dynamic range as a consequence of the memory effect regarding the phase asymmetry.

Fig. 3 shows the phase response for a 2.14 GHz WCDMA base station PA using GaN device as a power stage. At tone spacings smaller than 5 MHz along with high output power region, the relative phase between higher and lower IMD_3 seems close to small value. However, the phase differences at low output power become larger as the tone spacing is increased, which is a consequence of a significant memory effect.

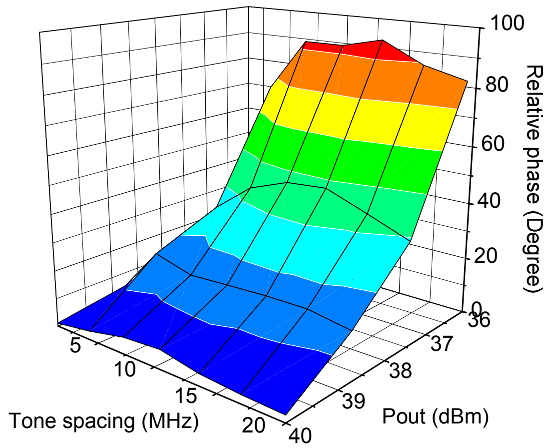

Fig. 3. IM_3 phase asymmetry according to tone spacing and average output power at V_{gs}=-1.2V and V_{ds}=27.5V.

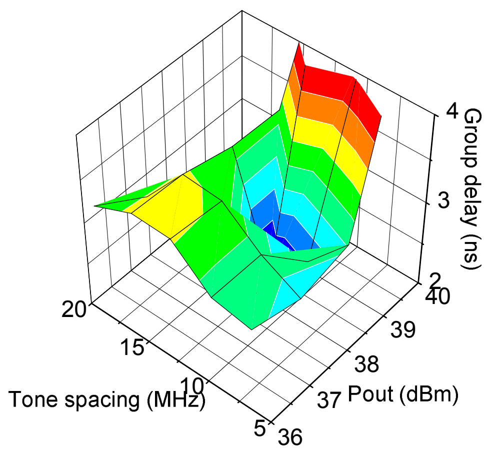

Fig. 4. Calculated group delay of IM_3 signal using the measured results according to tone spacing and average output power at V_{gs}=-1.2V and V_{ds}=27.5V.

Now, the GDs at different tone spacing and output power are calculated using (1), and the result is illustrated in Fig. 4. Some interesting properties of the PD technique can be found from Fig. 4. First, the GD of IMD_3 signal varies according to the output power, which implies that the cancellation bandwidth is limited over output dynamic range in case the GD matching between linear path (ESG_1 path in Fig. 1) and

IMD_3 path (ESG_2 path in Fig. 1) is fixed to one value. Therefore, the GD in IM_3 path should be properly adjusted with respect to the output power level to maintain wide cancellation bandwidth. Second, the GD of IMD_3 signal also changes with respect to the tone spacing, which implies that the GD matching should be optimized according to the signal bandwidth used in the linear transmitter system.

IV. CONCLUSION

This paper proposes the novel memory effect measurement technique in RF power amplifiers using two-tone intermodulation distortion signal with very simple and intuitive algorithm. Based on the predistortive tone cancellation technique, the proposed measurement method is capable of measuring relative phase and magnitude of the third-order and fifth-order IMD as well as the fundamental signal. The measured relative phase between the higher and lower IMD signal for the specific tone spacing can be interpreted as the group delay information of the IMD signal concerned. From the group delay analysis, we can conclude that the adaptive control of magnitude and phase as well as group delay is expected to be a key function in increasing the linearization bandwidth and the dynamic range of the predistortion technique.

Until now, the consequence of memory effect were only focused on the magnitude/phase asymmetry point of view, the importance of group delay matching in a predistortion technique being out of sight. Care should be taken in determining the optimum group delays in each linear and nonlinear path in a predistortion method. Since this result is just a portion of a great theme to research, much more detailed experimental study and its theoretical analysis is still remaining as a future work.

REFERENCES

[1] S. C. Cripps, *Advanced Techniques in RF Power Amplifier Design*, Norwood, MA, Artech House, 2002.

[2] P. B. Kennington, *High-Linearity RF Amplifier Design*, Artech House, 1999.

[3] J. Vuolevi, T. Rahkonen, *Distortion in RF Power Amplifiers*, Artech House, 2003.

[4] T. Nojima and T. Konno, “Cuber predistortion linearizer for relay equipment in 800 MHz band land mobile telephone system,” *IEEE Trans. Veh. Technol.*, vol. VT-34, no. 4, pp. 169-177, Nov. 1985.

[5] J. Cha, J. Yi, J. Kim, and B. Kim, “Optimum design of a predistortion RF power amplifier for multicarrier WCDMA applications,” *IEEE Trans. Microwave Theory Tech.,* vol. 52, no. 2, Feb. 2004.

[6] J. S. Kenney and P. Fedorennko, “Identification of RF power amplifier memory effect origins using third-order intermodulation distortion amplitude and phase asymmetry,” *in IEEE Int. Microwave Symp. Dig.*, pp. 1121-1124, Jun. 2006.

[7] P. Fedorenko and J. S. Kenney, “Analysis and suppression of memory effects in envelope elimination and restoration (EER) power amplifiers,” *in IEEE Int. Microwave Symp. Dig.*, pp. 1453-14656, Jun. 2007.

[8] N. B. Carvalho and J. C. Pedro, “A Comprehensive explanation of distortion sideband asymmetries,” *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 9, pp. 2090-2101, Sep. 2002.

[9] J. H. K. Vuolevi, T. Rahkonen, and J. P. A. 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.

[10] S. Y. Lee, Y. S. Lee and Y. H. Jeong, “A novel phase measurement technique for IM3 components in RF power amplifiers,” *IEEE Trans. Microwave Theory Tech.,* vol. 54, no. 1, pp. 451-457, Jan. 2006.