Volterra Characterization and Predistortion Linearization of Multi-Carrier Power Amplifiers

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Background and Motivation

From recent studies:

- Memory effects (frequency dependence of non-linearities) in RF PAs (power amplifier) degrade the performance of a PA linearization [1]

- The linearization degradation for signals with bandwidth above 1MHz is linked to fast electrical memory effects rather than slow thermal memory effects [2]


Talk Outline

• Nonlinear PA Characterization: measurement of generalized 3\textsuperscript{rd} order Volterra coefficients: \(Y_{m3^+}\) and \(Y_{m3^-}\) for a Class AB amplifier

• Accuracy of the LSNA measurements of \(Y_{m3^+}\) and \(Y_{m3^-}\) (IMD3)

• New RF predistortion linearization algorithm accounting for differential memory effects between LSB & USB

• Results obtained with this linearization algorithm for two-carrier W-CDMA signals
Setup used for the PA Characterization

The vectorial source generator (ESG 4438C) is synchronized with the LSNA 10 MHz reference clock.

Large signal network analyzer is used for the non-linear measurements.
Amplifier Under Test

- Class AB LD-MOSFET PA operating at 895 MHz

Gain: 13 dB, P1dB: 27.5dBm, PAE = 34%,
Extraction of $Y_{m3^-}$ & $Y_{m3^+}$ using a 2-tone Signal

- The $a_1$ & $b_2$ waves are measured with the LSNA

- Generalized Volterra coefficients $Y_{m3^-}$ and $Y_{m3^+}$ for IMD3:

$$Y_{m3^-} = \frac{b_2(\omega - \omega_m)}{a_1^2(\omega)a_1^*(\omega + \omega_m)}$$

$$Y_{m3^+} = \frac{b_2(\omega + 2\omega_m)}{a_1^*(\omega)a_1^2(\omega + \omega_m)}$$
Comparison of Amplitude of $Y_{m3^-}$ and $Y_{m3^+}$

- Comparison of amplitude of $Y_{m3^-}$ and $Y_{m3^+}$ versus the modulation frequency $\omega_m$ for different power levels (-4 ~ 6 dBm).
- The amplitude difference at 3 MHz tone spacing is up to 40%
Comparison of the Phase of $Y_{m3-}$ and $Y_{m3+}$

- Comparison of phase of $Y_{m3-}$ and $Y_{m3+}$ versus the modulation frequency $\omega_m$ for different power levels (-4 ~ 6 dBm).
- 60° angle difference at 3MHz tone spacing: memory effects
The difference in amplitude and phase between $Y_{m3^-}$ and $Y_{m3^+}$ is mostly significant above 0.3 MHz. Referred to as a differential memory effect.
Results from Non-Linear Measurements

- Below 0.3 MHz the difference in phase and amplitude of $Y_{m3-}$ and $Y_{m3+}$ is small in the PA under test.
- Above 0.3 MHz the difference in phase and amplitude increases rapidly with tone spacing.
- This indicates the presence of a strong differential memory effect between the LSB & USB for wide bandwidth signals.
Accuracy & Repeatability of LSNA Measurements of $Y_{m3-}$ for $f_{RES} = 190$Hz

- $\Delta \omega_m$ is the error in modulation frequency $\omega_m$
- Reliable measurements are obtained when $\Delta \omega_m < f_{RES}/100 = 2$ Hz
FPGA Digital Testbed for RF Predistortion

- **RF output**
- **Linear amplifier**
- **Local Oscillator**
- **Spectrum analyzer**

**Predistortion**

- **RF source**
- **Vectorial RF source**
- **Internal DAC #1 & 2**
- **External DAC #3**
- **External ADC #3**
- **External DAC to IQ mixer adaptation stage**
- **External DAC #4**
- **Internal DAC to IQ mixer adaptation stage I & II**
- **Internal ADC #1 & 2**
- **External ADC #4**
- **IQ modulator**
- **Digital Testbed**

**DUT: Power Amplifier**
Linearization Without Frequency Selective Corrections For WCDMA signals

Before linearization

The spectral regrowth on the lower and upper side bands are reduced simultaneously (for an overall ACPR of 40dBc) but cannot be independently tuned

After linearization
FPGA Algorithm Used for 3rd & 5th Order Predistortion With Memory Effects

Hilbert Transform

Amplitude & Phase Adjustment of the USB & LSB
Linearization With Frequency Selective Corrections
For a 2-carrier WCDMA signal

- Each WCDMA band has a 5 MHz bandwidth. The centers of both band are separated by 15 MHz in our experiment.
- There are four regions of spectral regrowth to address.
- We can linearize just the USB as is shown in the right picture.
Linearization With Frequency Selective Corrections
(2 multi-carrier WCDMA signal)

• We can linearize just the **LSB** as is shown in the left picture
• We can linearize independently both the **LSB & USB** (right picture)

**LSB linearization**

**Both LSB & USB linearization**
Conclusion

• Measured generalized Volterra coefficients for a LDMOSFET PA
• Observed a strong differential memory effect between the lower and upper sidebands above 0.3 MHz
• Established the measurement condition for obtaining reliable and reproducible vectorial IMD3 measurements with the LSNA
• Demonstrated the independent cancellation of the lower and upper side-band spectral regrowths for a 2-carrier WCDMA signal
Future Work

- Extension of this linearization from 2-carrier to multi-carrier power amplifiers is needed
- The PA system identification with large-signal network analyzer (LSNA) measurements should facilitate the development of multi-carrier linearization by providing the needed multi-tone generalized Volterra coefficients
- An extension of the LSNA modulation bandwidth above 20MHz would be greatly desirable (180MHz tone spacing was recently demonstrated but a calibration algorithm is needed [3])