

The ARFTG NVNA Users' Forum at IMS 2005

Two-Tone IMD Sweet-Spots for Highly Linear Power Amplifiers Subject to Telecommunications Signals

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Presentation Outline

- 1 – Introduction**
- 2 – Nonlinear Distortion Generation Process in a General Memoryless Nonlinearity**
- 3 – Experimental Validation**
- 4 – Conclusions**

1 – Introduction

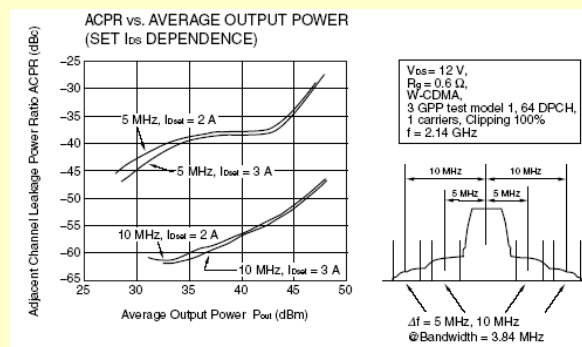
Motivations :

- 1 – Two-tone IMD measurements have always been used as the standard nonlinear distortion assessment tests, in the belief that they can serve as indicators of real distortion performance.
- 2 – However, the unavoidable nonlinear nature of this mathematical problem has impeded any attempt to derive general bounds between the distortion observed under a standard two-tone and a real excitation signal.

1 – Introduction

Motivations :

- 4 – However, many practical measurement results confirm that real signal distortion performance indeed resemble two-tone IMD.

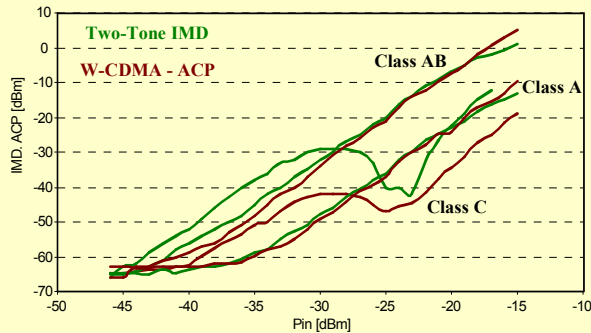


Adjacent Channel Power of a 180W Push-Pull Power GaAs FET,
subject to a **W-CDMA** excitation.

1 – Introduction

Motivations :

- 4 – However, many practical measurement results confirm that real signal distortion performance indeed resemble two-tone IMD.



Adjacent Channel Power of a microwave transistor biased for Class A, Class AB and Class C operation, subject to **Two-tone** and **W-CDMA** excitations.

1 – Introduction

Motivations:

Therefore:

Any measured, simulated or theoretical results that allow PA designers to extrapolate their two-tone lab tests for real operation are welcome .

Presentation Outline

1 – Introduction

2 – **Nonlinear Distortion Generation Process in a General Memoryless Nonlinearity**

3 – Experimental Validation

4 – Conclusions

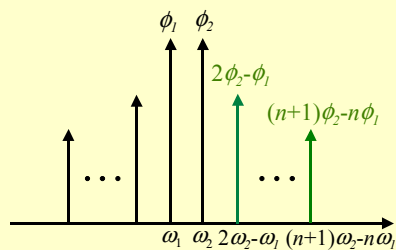
2 – Nonlinear Distortion Generation Process

Distortion Under Two-Tone Tests

3rd, 5th, ..., (n+2) order distortion components at the adjacent channels:

$$\omega_3 = 2\omega_2 - \omega_1, \omega_4 = 3\omega_2 - 2\omega_1, \dots, \omega_{n+2} = (n+1)\omega_2 - n\omega_1$$

$$\phi_3 = 2\phi_2 - \phi_1, \phi_4 = 3\phi_2 - 2\phi_1, \dots, \phi_{n+2} = (n+1)\phi_2 - n\phi_1$$



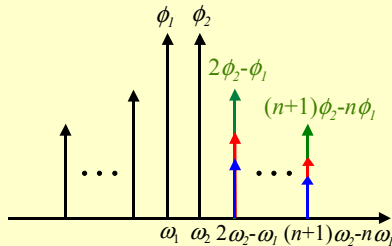
2 – Nonlinear Distortion Generation Process

Distortion Under Two-Tone Tests

Higher order distortion components at the adjacent channels:

$$\omega_3 = 2\omega_2 - \omega_1 + i(\omega_1 - \omega_1) + j(\omega_2 - \omega_2) \quad \omega_{n+2} = (n+1)\omega_2 - n\omega_1 + i(\omega_1 - \omega_1) + j(\omega_2 - \omega_2)$$

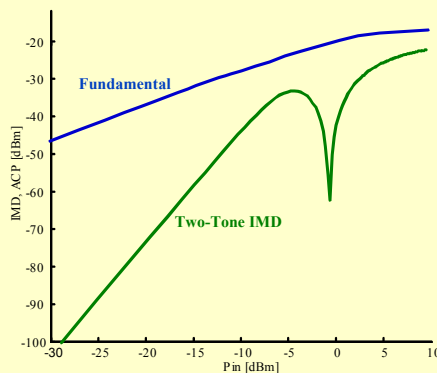
$$\phi_3' = 2\phi_2 - \phi_1 + i(\phi_1 - \phi_1) + j(\phi_2 - \phi_2) = \phi_3 \quad \phi_{n+2}' = (n+1)\phi_2 - n\phi_1 + i(\phi_1 - \phi_1) + j(\phi_2 - \phi_2)$$



2 – Nonlinear Distortion Generation Process

Distortion Under Two-Tone Tests

Mixing products at a single frequency component add in phase, producing sudden distortion degradation or IMD dips – Large-Signal IMD Sweet-Spots.



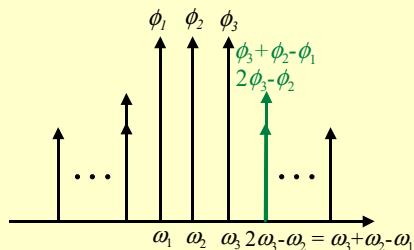
2 – Nonlinear Distortion Generation Process

Distortion Under Three-Tone Tests

3rd order distortion components at the adjacent channel:

$$\omega_4 = 2\omega_3 - \omega_2 = \omega_3 + \omega_2 - \omega_1$$

$$\phi_4 = 2\phi_3 - \phi_2 \neq \phi_3 + \phi_2 - \phi_1$$



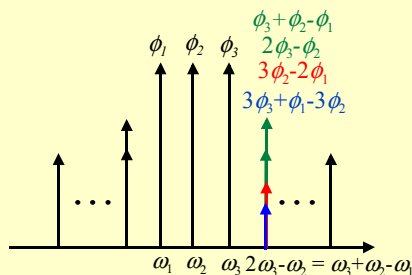
2 – Nonlinear Distortion Generation Process

Distortion Under Three-Tone Tests

Higher order distortion components at the adjacent channels add many other mixing products of uncorrelated phases:

$$\omega_4 = 2\omega_3 - \omega_2 = \omega_3 + \omega_2 - \omega_1 = 3\omega_3 - 2\omega_1 = 3\omega_3 + \omega_1 - 3\omega_2$$

$$\phi_4 = 2\phi_3 - \phi_2 \neq \phi_3 + \phi_2 - \phi_1 \neq 3\phi_3 - 2\phi_1 = 3\phi_3 + \phi_1 - 3\phi_2$$

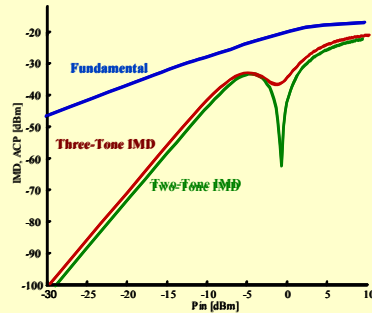


2 – Nonlinear Distortion Generation Process

Distortion Under Three-Tone Tests

Mixing products at a single frequency component have different phases and add in power. So, ideal IMD nulls are no longer possible.

However, since the products of the form $\omega_4 + m(\omega_1 - \omega_i)$ (in which $\omega_i = \omega_1, \omega_2$ or ω_3 and m is any positive integer) share the same phase, there will be many components that can cancel and a smooth IMD valley is still generated.



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2 – Nonlinear Distortion Generation Process

Distortion Under Stochastic Excitations

If now the number of tones K is increased without limit, while the tones' phases, ϕ_k , are randomized, the excitation tends to band-limited Gaussian white noise.

The output distortion auto-correlation function of our nonlinear memoryless system up to 5th order will be:

$$R_{yy}(\tau) = \left[6C_3^2 + 120C_3C_5R_{xx}(0) + 600C_5^2R_{xx}(0)^2 \right] R_{xx}(\tau)^3 + 120C_5^2R_{xx}(\tau)^5 + \dots$$

This can be decomposed into 3rd and 5th order distortion uncorrelated components:

$$R_{yy-U}(\tau) = 6C_3^2R_{xx}(\tau)^3 + 120C_5^2R_{xx}(\tau)^5$$

and 3rd and 5th order distortion correlated components:

$$R_{yy-C}(\tau) = \left[120C_3C_5R_{xx}(0) + 600C_5^2R_{xx}(0)^2 \right] R_{xx}(\tau)^3$$

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2 – Nonlinear Distortion Generation Process

Distortion Under Stochastic Excitations

Since the 3rd and 5th order distortion correlated components add in voltage, they can cancel each other (large-signal IMD sweet-spot under a stochastic stimulus) when:

$$6C_3^2 + 120C_3C_5R_{xx}(0) + 600C_5^2R_{xx}(0)^2 = 0$$

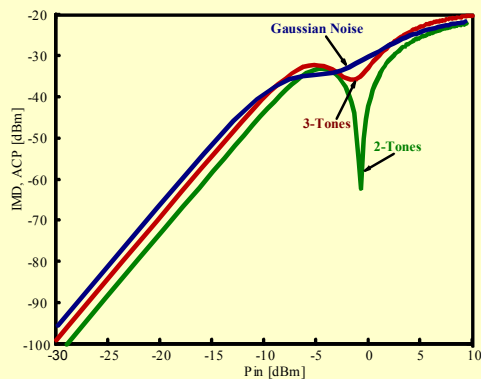
or:

$$R_{xx}(0) = -\frac{C_3}{10C_5}$$

2 – Nonlinear Distortion Generation Process

Distortion Under Stochastic Excitations

In a similar way to what was seen for the three-tone test, there is still an improvement of distortion, even if no complete cancellation of the nonlinear components is possible.



Presentation Outline

1 – Introduction

2 – Nonlinear Distortion Generation Process in a General Memoryless Nonlinearity

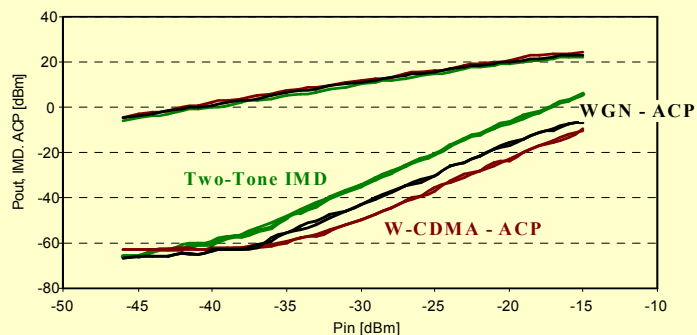
3 – Experimental Validation

4 – Conclusions

3 – Experimental Validation

To validate the proposed theory, a microwave power HEMT was biased for two distinct operation regimes: Class C and Class A.

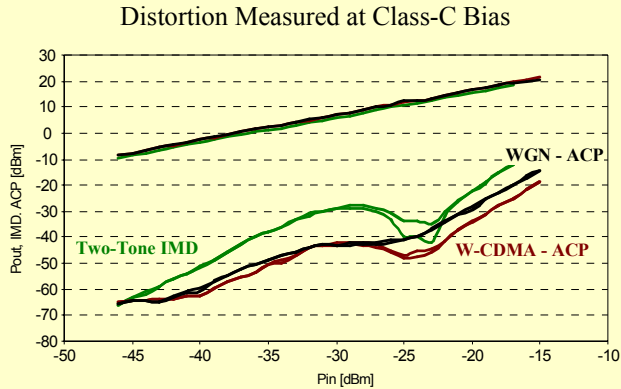
Distortion Measured at Class-A Bias



The Two-tone IMD, W-CDMA and White Gaussian Noise ACP behaviors are identical, all presenting a monotonic shape !

3 – Experimental Validation

To validate the proposed theory, a microwave power HEMT was biased for two distinct operation regimes: Class C and Class A.



The Two-tone IMD, W-CDMA and White Gaussian Noise ACP behaviors are similar in shape, all presenting a more or less pronounced large-signal IMD sweet spot !

Presentation Outline

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4 – Conclusions

Conclusions:

- 1 – This presentation briefly discussed the validity of standard Two-tone IMD tests as faithful indicators of PA distortion performance.
- 2 – Because complex signals produce nonlinear mixing products with correlated and uncorrelated components, only two-tone IMD can show sharp IMD nulls – ideal large-signal IMD sweet-spots.
- 3 – Nevertheless, correlated components still represent a major part of distortion power that can be canceled. So, useful distortion valleys are still observed under white Gaussian noise or W-CDMA signals.
- 4 – Since monotonic two-tone IMD and complex signal ACP plots are identical, and large-signal IMD sweet-spots are still associated to ACP valleys, the most important conclusion of this work is that two-tone IMD can indeed be used as a helpful indicator of the real nonlinear distortion of PAs (at least memoryless ones).