High Linearity Power Amplifier Design

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Course Outline

Morning 1   Fundamentals

Afternoon 1 Measurements and Experiments

Morning 2   Clever Things That Almost Work

Afternoon 2 Practical Linearity Improvements
Fundamentals

Definitions

Analysis: Time and Frequency Domains

Distortion Mechanisms and dB

Envelope Distortion
Viewpoints: Mathematics

\[ s(t) = \cos \left( 2\pi (f_0)t + \phi(t) \right) \]
\[ + 0.5 a_m(t) \cos \left( 2\pi (f_m + f_0)t + \phi(t) \right) \]
\[ - 0.5 a_{pm}(t) \sin \left( 2\pi (f_0 + f_m)t + \phi_p(t) \right) \]
\[ + 0.5 a_m(t) \cos \left( 2\pi (f_m - f_0)t + \phi(t) \right) \]
\[ + 0.5 a_{pm}(t) \sin \left( 2\pi (f_0 - f_m)t - \phi_p(t) \right) \]
Viewpoints: RF Waveforms

\[ \cos(2\pi f_0 t) \] -- Black

\[ \cos(2\pi f_0 t) - 0.3\cos(6\pi f_0 t + \pi/6) \] -- red

\[ \cos(2\pi f_0 t) - 0.3\cos(6\pi f_0 t + \pi/3) \] -- blue
Viewpoints: Envelope Waveforms

Small Signal

Large Signal
Viewpoints: Distortion Mechanisms

Power Supply

Device

Circuit

Thermal

Drive

Load
More Necessary and Insufficient topics

Two-Tone Analysis and Measurements

AM to PM Conversion

Quantitative Practical Limitations

Memory Effects

Fundamental Limitations of Simulation

Fundamental Limitations of Measurements
Definitions: Some Basic Math

Any Band-Limited Signal

\[ s(t) = a(t)\cos[2\pi ft + \phi(t)] \text{ volts} \]

Time-varying amplitude

Frequency

Time-varying phase

this little bit of textbook math has caused more trouble for more bright and talented people for more decades...
Definitions

Simply Perfect Linear Amplifier:

Input: $s_i(t) = a(t)\cos[2\pi f_0 t + \phi(t)]$ volts

Output: $s_o(t) = ga(t)\cos[2\pi f_0 t + \phi(t)]$ volts

where $g$ is a constant
This is an Over-Simplification

Linear **Power** Amplifier:

Power = Voltage x Current

Voltage = Current x Impedance

Power Gain \( \neq g^2 \)

Since PA is often voltage limited,

Power Gain involves Impedance Transform
Over-Simplified Math Part 1

Linear Power Amplifier: \[ \text{Power} = \text{Voltage} \times \text{Current} \]

Voltage = Current \times \text{Impedance}

Current = \text{non-linear function of voltage}

For Every Known Active Device

![Diagram showing load lines for different values of Vgs and Vds with corresponding Ids values.]
Over-Simplified Math Part 2

Input: $s_i(t) = a(t)\cos[2\pi f_o t + \phi(t)]$ volts

Output: $s_o(t) = ga(t)\cos[2\pi f_o t + \phi(t)]$ volts

$a(t) = \text{non-linear } f [\phi(t)]$

For Every Modulation Scheme *

*at input to Linear Power Amplifier
What Really Happens:
Limitation of Analytical Approach

\[ s(t) = a(t)\cos[2\pi f_0 t + \phi(t)] \text{ volts} \]

Even with simplified models, math quickly becomes too complicated.

When math is too complicated, understanding and intuition are lost.

Complex math appeals to a certain type of Engineer--it becomes a secret language...

...that serves as a barrier between the design engineer and the people at the bench making measurements
Limitation of Analytical Approach

Simplified analysis untested by experiment is always wrong. It is usually a little wrong even when mature and well tested.

In the PA Manufacturing World we trust the guy at the bench and focus on making things smaller and cheaper...

...and fail to learn the lessons that simplified analysis well correlated with experiments can teach.
Speaking of Tests:

1 dB Compression

AM Waveform

AM Spectrum

Two-tone

Multi-tone

Noise
Field Trials