



Agilent EEsof EDA

Presentation on RF Predistortion of Power Amplifiers - Part 1

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Seminar: Gain Without Pain
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RF Predistortion of Power Amplifiers

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Abstract

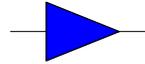
With the advent of linear modulation methods, linearization of power amplifiers has become an important technology. The adaptive work function predistorter is an approach to optimizing out-of-band intermodulation performance. This technique can adapt to changes in the power amplifier's characteristics, including effects such as temperature changes, channel switching, power supply variation, and transistor degradation. The technique can also handle larger bandwidths than current DSP-based digital predistorters.

Biography

Dr. Shawn P. Stapleton has 17 years of experience in the design of RF and microwave circuits and systems. He is presently professor of electrical engineering at Simon Fraser University as well as a consultant for Agilent EEsof. He has developed GaAs MMIC components, including mixers, amplifiers, frequency dividers and oscillators. His most recent work includes digital signal processing, mobile communications and RF/microwave systems.



Agenda & Topics



RF Predistortion of Power Amplifiers

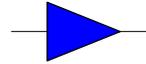
- Introduction to Adaptive RF Predistortion
- Key Features: RF Predistortion Techniques & Concepts
- RF Predistortion Design Example
- Conclusion



This section of the workshop provides an introduction to predistortion. We will cover key features, technologies, and performance issues. Approaches to solving some of the design challenges will also be presented. An adaptive work function based predistorter is demonstrated using the Agilent Advanced Design System. Additional reference information is also available.



Technology Overview



Linearization approaches:

- FeedForward Linearization
 - Based on inherently wideband technology
- Digital Predistortion
 - Limited Bandwidth (DSP implementation)
- Cartesian Feedback
 - Stability considerations limit bandwidth and accuracy
- LINC
 - Sensitive to component drift and has a high level of complexity
- Dynamic Biasing
 - Limited ACI suppression
- **RF-Based Predistortion**
 - Limited accuracy of function model
 - Implemented at RF with low complexity
 - Adaptation is required



Of the various linearization techniques that have been developed, predistortion is the most commonly used. The concept behind predistortion calls for the insertion of a nonlinear module between the input signal and the power amplifier. The nonlinear module generates IM distortion that is in anti-phase with the IM distortion produced by the power amplifier, thereby reducing out-of-band emissions.

The RF-based predistorter has two distinct advantages over other approaches. First, the correction is applied before the power amplifier where insertion loss is less critical. Second, the correction architecture has a moderate bandwidth.

Digital predistortion techniques are more complex, but provide better IM distortion suppression. However, bandwidths are low due to limited DSP computational rates.

Cartesian feedback is relatively less complex and offers reasonable IM distortion suppression, but stability considerations limit the bandwidth to a few hundred KHz.

The LINC technique converts the input signal into two constant envelope signals that are amplified by Class C amplifiers, and then combined, before transmission. Consequently, they are very sensitive to component drift.

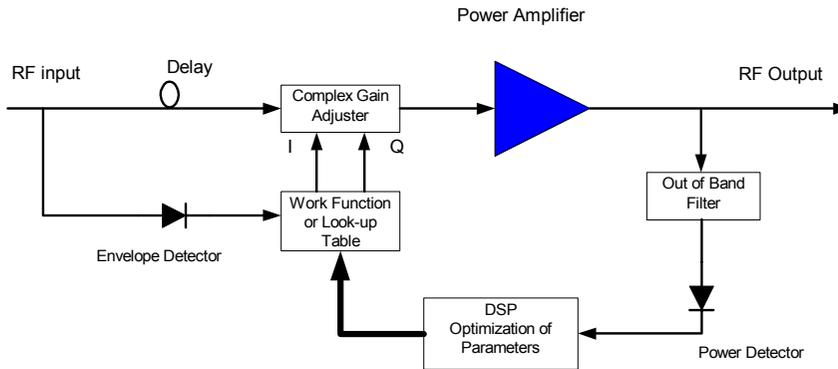
Dynamic biasing is similar to predistortion, however the work function operates on the power amplifier's operating bias.

Feedforward linearization is the only strategy that simultaneously offers wide bandwidth and good IM distortion suppression. The price for this performance is higher complexity.

Automatic adaptation is essential to maintain performance.



RF-Based Predistortion

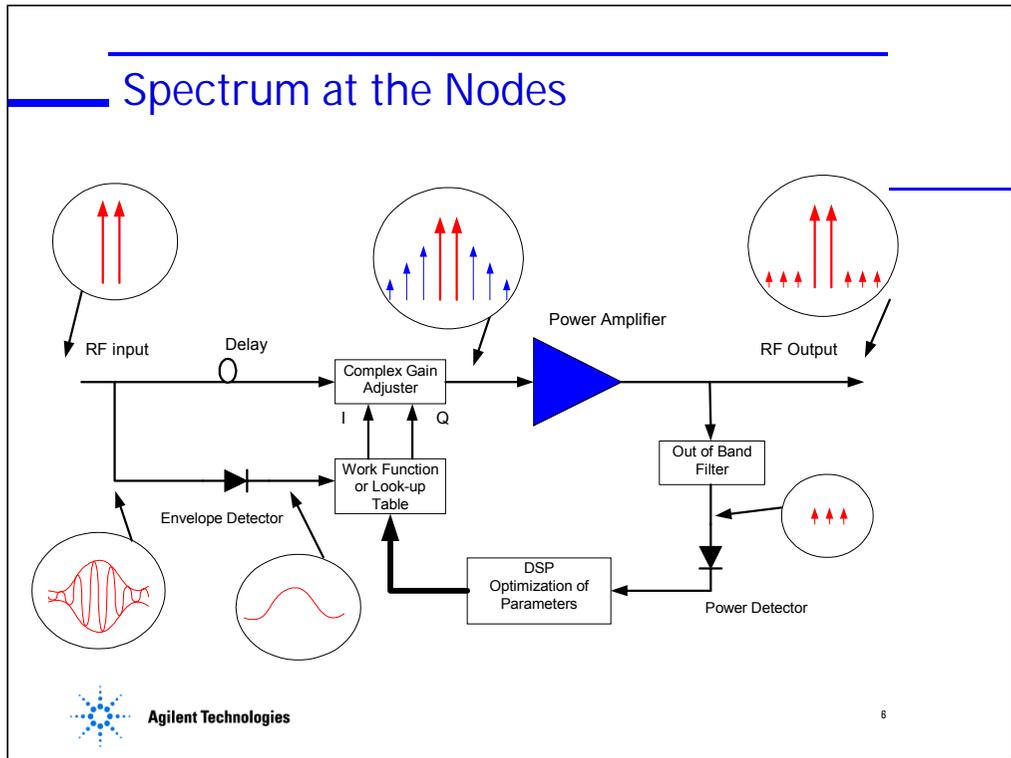


The linearizer creates a predistorted version of the desired modulation. The predistorter consists of a complex gain adjuster that controls the amplitude and phase of the input signal. The amount of predistortion is controlled by two nonlinear work functions that interpolate the AM/AM and AM/PM nonlinearities of the power amplifier.

Note that the envelope of the input signal is an input to the work functions. The feedback path samples a portion of the undesired spectrum. The work function parameters are then adjusted by the DSP to minimize the undesired signal. The undesired signal is typically the adjacent channel power.



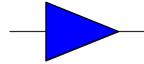
Spectrum at the Nodes



Given a two-tone input signal, we can observe the spectral response at various nodes in the RF predistorter. The function of the envelope detector is to extract the amplitude modulation of the input RF signal. The delay line in the upper branch compensates for the time delay added as the envelope passes through the work function. The complex gain adjuster, once optimized, provides the inverse nonlinear characteristics to those of the power amplifier. Thus, we can observe the spectral growth from the predistorter at the input node of the power amplifier. Ideally the IM products will be equal in amplitude, but anti-phase the IM products created as the two tones pass through the power amplifier. The out-of-band filter samples the adjacent power interference (ACPI). The function of the DSP is to slowly adapt the work function parameters so that the ACPI is minimized.



Design Techniques



RF-Based Predistortion

- Generic RF predistortion techniques
 - Work function (I.e. polynomial, exponential)
 - Look-up table
 - Analog nonlinearity (I.e. Diodes)
- Generic adaptation techniques...
 - ACI power minimization
 - Gradient evaluation



In the mid-'80s and early '90s, many patents were filed covering adaptive predistortion. These patents encompass two general adaptation methods—adaptation based on power minimization and adaptation based on gradient signals.

The control scheme for power-minimization adaptation is based on trying to adjust the complex gain adjuster to minimize the measured power of the error signal in the out-of-band frequency. Once the optimum parameters have been achieved, deliberate perturbations are required to continuously update the coefficients, which reduces the effects of IM distortion suppression.

Adaptation based on the use of gradient signals requires a continuous computation to estimate the gradient of a three-dimensional power surface. The surface for the RF predistorter circuit is the difference between the input signal and the scaled output signal. This power is minimized when the error signal is completely suppressed. Since the gradient is continually updated, no deliberate misadjustment is required.

There are three distinct RF predistortion techniques.

The work function-based approach utilizes a low-order polynomial to fit the AM/AM and AM/PM characteristics of the power amplifier.

The look-up table technique fits the power amplifier's characteristics more accurately. However, it requires a more sophisticated adaptation technique.

The analog nonlinearity technique uses diodes to generate IM distortion. This IM distortion is then phased and attenuated to make it anti-phase with the distortion created by the power amplifier.

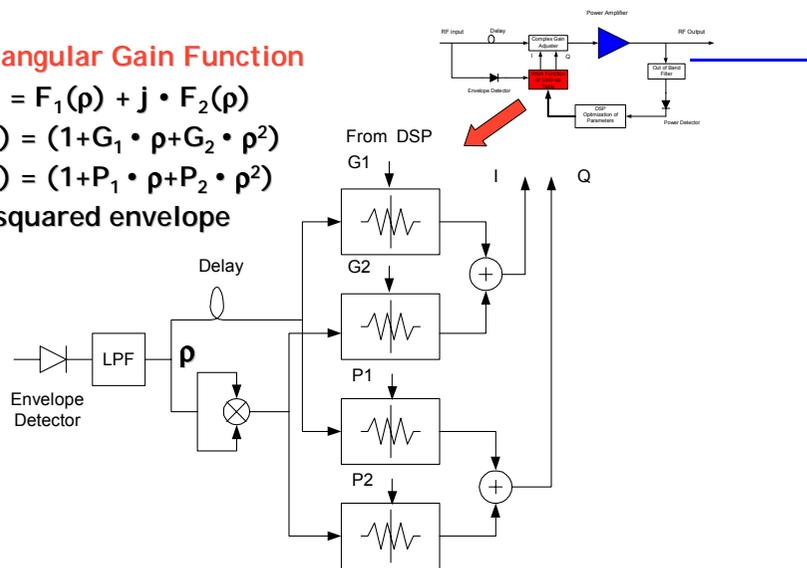


Rectangular Work Function Predisorter

Rectangular Gain Function

$$F(\rho) = F_1(\rho) + j \cdot F_2(\rho)$$
$$F_1(\rho) = (1 + G_1 \cdot \rho + G_2 \cdot \rho^2)$$
$$F_2(\rho) = (1 + P_1 \cdot \rho + P_2 \cdot \rho^2)$$

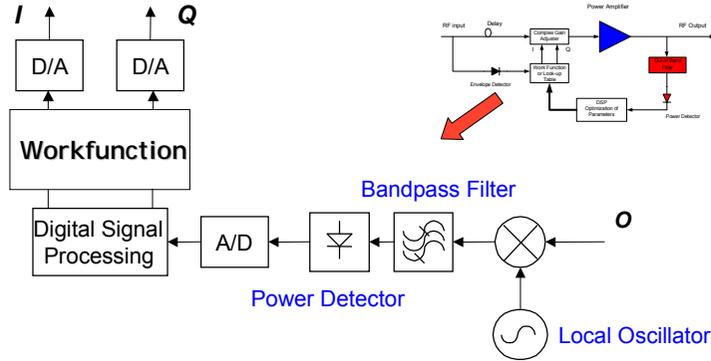
ρ is squared envelope



The rectangular work function implementation requires the use of a complex gain adjuster, which has in-phase and quadrature controls. The work function consists of a simple second-order polynomial expressed in terms of the squared envelope. When this function is multiplied by the input signal in the complex gain adjuster, a fifth-order polynomial is produced which is expressed in terms of the signal envelope. There are four parameters that are slowly adapted by the DSP or microprocessor, with the ultimate goal of minimizing the adjacent channel power interference.



ACI Power Minimization



This adaptation controller is representative of the “minimum power” principle applied to RF predistortion. The I and Q control voltages are adjusted to minimize the power in port O , which is a sample of the interference created in the adjacent channel.

Drawbacks to this method are slow convergence to minimum and sensitivity to measurement noise, especially near minimum. Power measurements are inherently noisy, therefore long dwell times are required at each step to reduce the variance of the measurement.

Two methods have been devised to mitigate this problem. In the first, a tunable receiver is used to select a frequency band that includes only distortion, and then the controller works to minimize this quantity. Another approach subtracts a phase- and gain-adjusted replica of the input from the output. Ideally, this leaves only the distortion, which is then fed into port O and used in the minimization algorithm.



ADS RF Predistortion Simulation

Simulation Parameters:

- 1) Two-tone modulation ($F_c=850$ MHz, $\Delta=1$ MHz)
- 2) Fifth-order polynomial work function
- 3) Adjacent channel power minimization
- 4) Dwell time of 450 μ sec per iteration
- 5) Iterative LMS adaptation between α_3 and α_5
- 6) Motorola power amplifier
- 7) Ideal passive components assumed

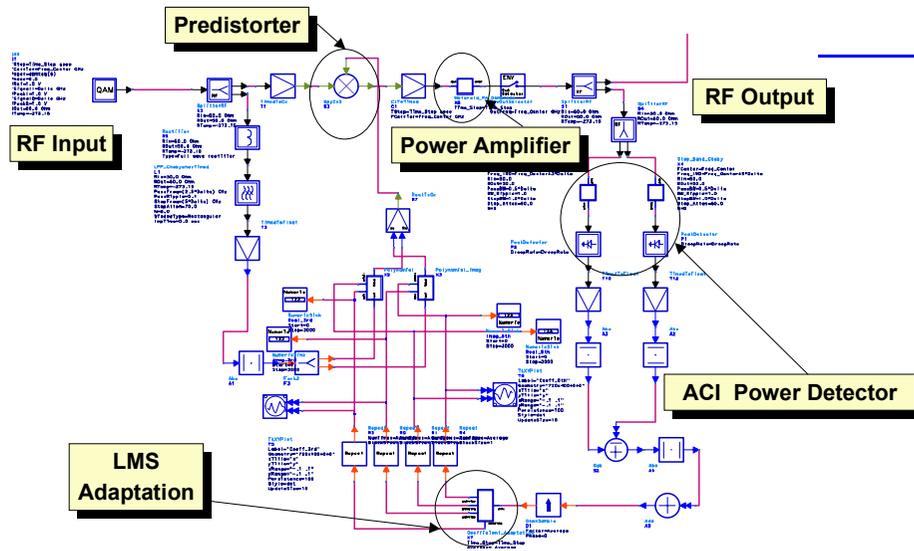


The Advanced Design System RF predistorter simulation example is based on the rectangular work function technique. In this approach we utilize the secant method to adapt the work function coefficients to minimize ACPI. The four coefficients are iteratively adjusted with 450 microseconds of power averaging. A Motorola power amplifier is used in the cosimulation, and the passive components, such as power splitters and combiners, are assumed to be ideal.

For demonstration purposes, a two-tone input centered on 850 MHz is used.



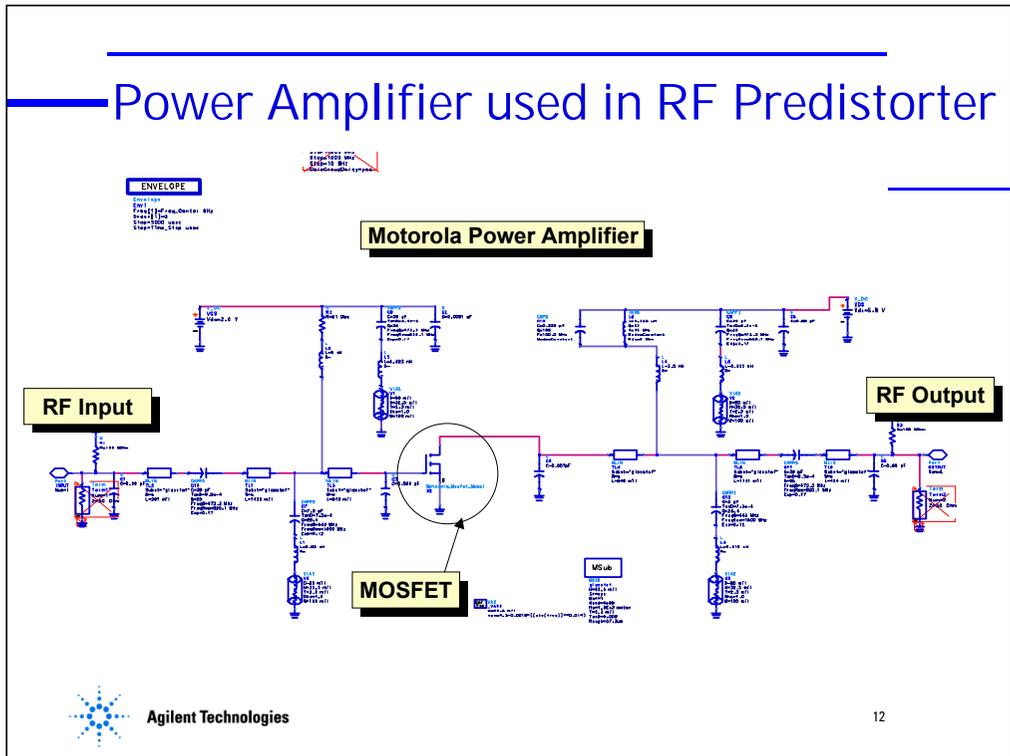
ADS RF Predistortion Circuit



Here is the Advanced Design System circuit schematic for the RF predistorter. The adaptation technique is based on the power-minimization method. The rectangular implementation is used for the complex gain adjuster, and the input consists of a two-tone modulation. The least-mean-squared adaptation technique is used.



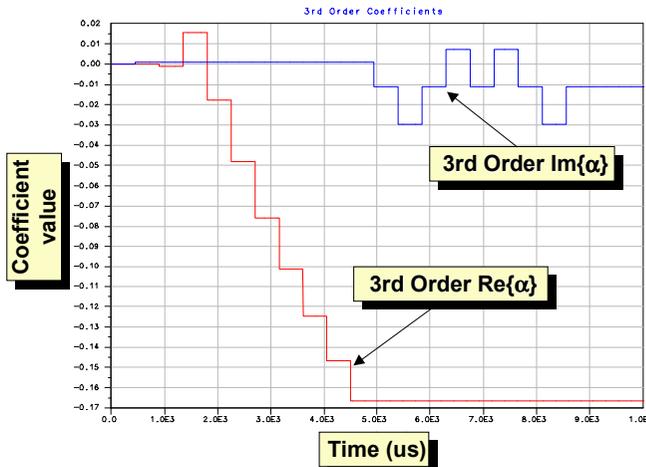
Power Amplifier used in RF Predistorter



A Motorola power amplifier is used in this example.



Coefficient values for RF Predistorter



Adaptive RF Predistorter Using Rectangular Coordinate Work Function



Notice in this adaptation example that the real third-order coefficient is adapted first, followed by the imaginary third-order coefficient. The coefficients adapt slowly—a dwell time of 450 microseconds is used to obtain a stable output power measurement. Instability can occur if proper attention is not paid to the adaptation procedure. The fifth-order coefficients are adapted using the same approach.



Third-Order IM Distortion Performance



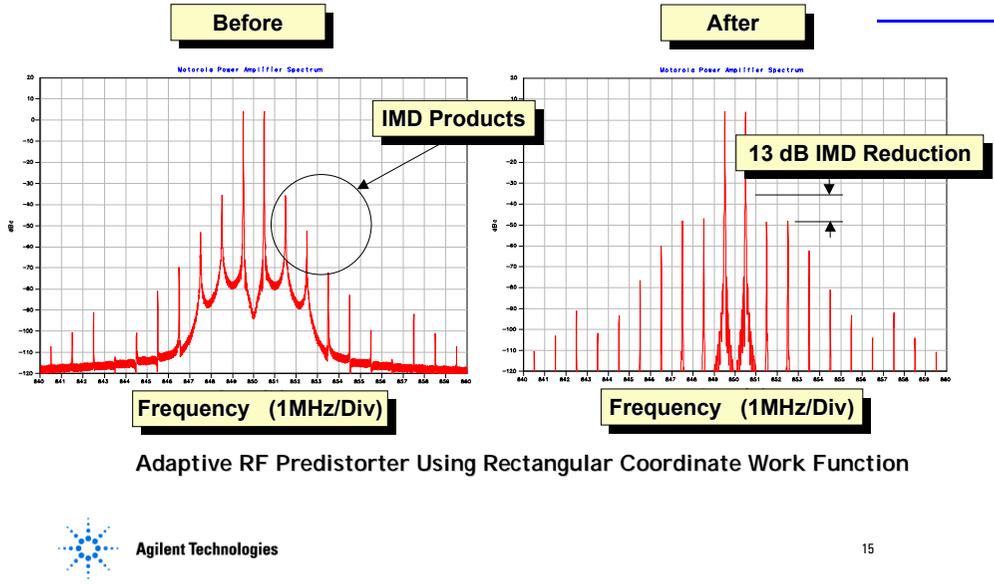
Adaptive RF Predistorter Using Rectangular Coordinate Work Function



This plot demonstrates the improvement in third-order intermodulation levels at the output of the RF predistorter.



Two-Tone Simulation of RF Predistorter



The plot on the left reveals the effects of driving the power amplifier at 5dB back-off. High levels of intermodulation power and harmonics are generated. The plot at right shows the improvement in the output from the RF predistorter once the coefficients have adapted. We can observe the spectral growth that occurs using a predistorter. The adjacent channel power is spread over a wider bandwidth, but mask requirements can be met.



Summary

RF Based Predistortion

- Adaptive RF predistorters are moving from the research to the development phase.

Design Solutions

- The ADS RF predistorter design example demonstrates the performance achievable with linearization.
- System level simulation provides a solid starting point for building an implementation quickly.
- Designed components can be integrated into a system to witness the impact on overall performance.



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