Bias induced memory effects in RF power amplifiers

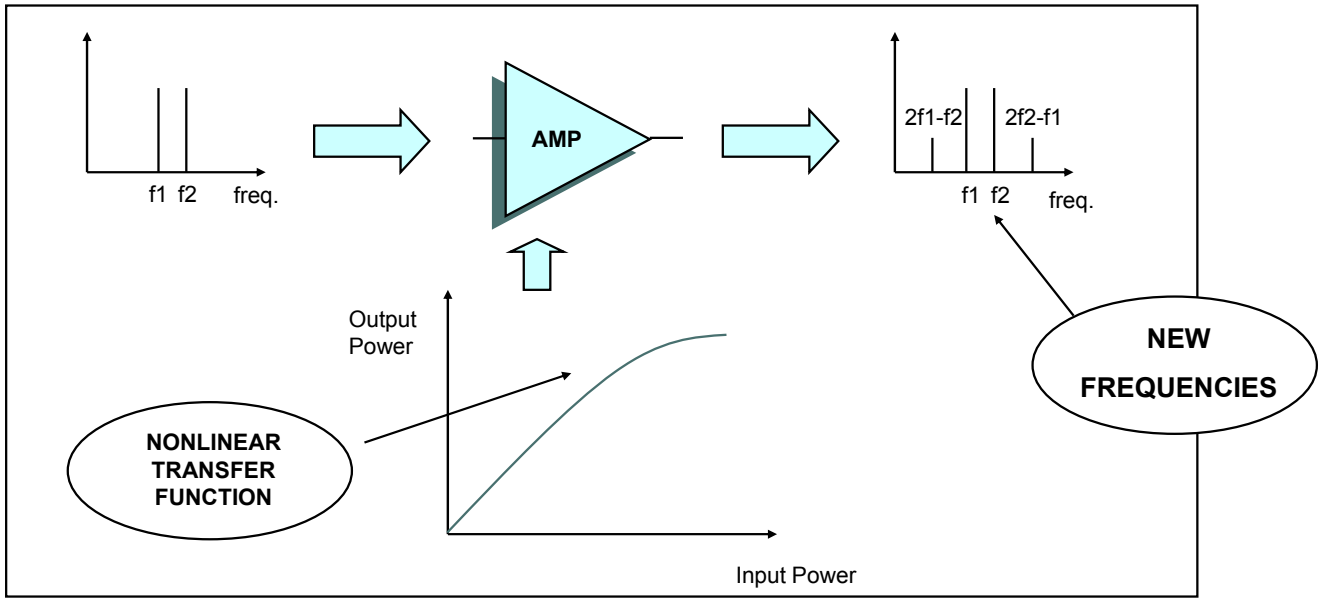
DR. MARC J. FRANCO

LINEARIZER TECHNOLOGY INC.
Hamilton, New Jersey, USA

www.lintech.com

Introduction

- **In practice, the gain of an RF power amplifier is a nonlinear function**



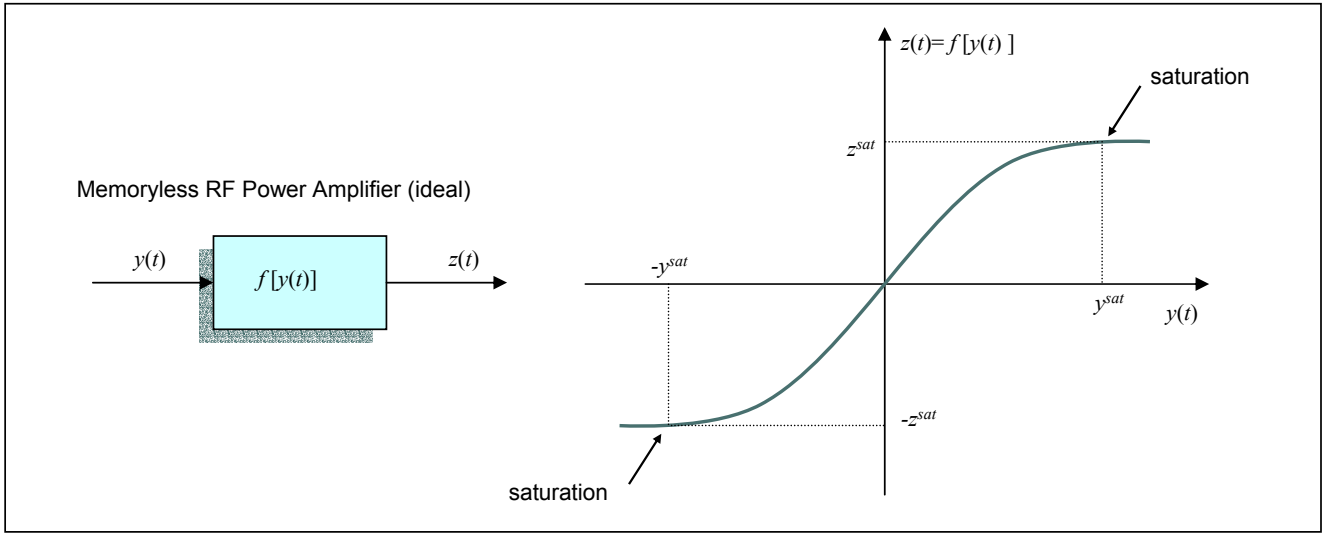
Introduction

- In practice, the gain of an RF power amplifier is a nonlinear function
- If the gain is *ideally* nonlinear, it should be only a function of the input signal level
- Real RF power amplifiers have *memory* – their gain is a function of various parameters (frequency, temperature, etc.)

Outline

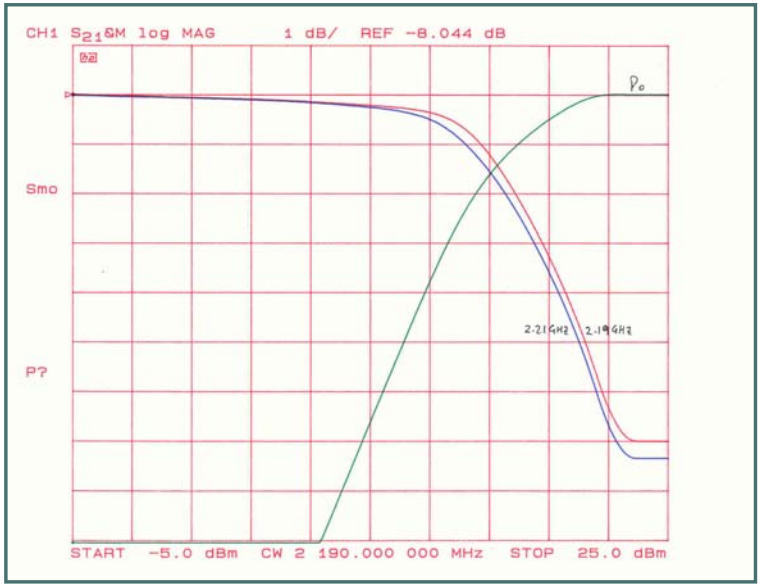
- RF power amplifier models
- Generation of memory effects in RF power amplifiers
- Typical memory effects
- Why memory effects are a problem?
- Minimization of memory effects

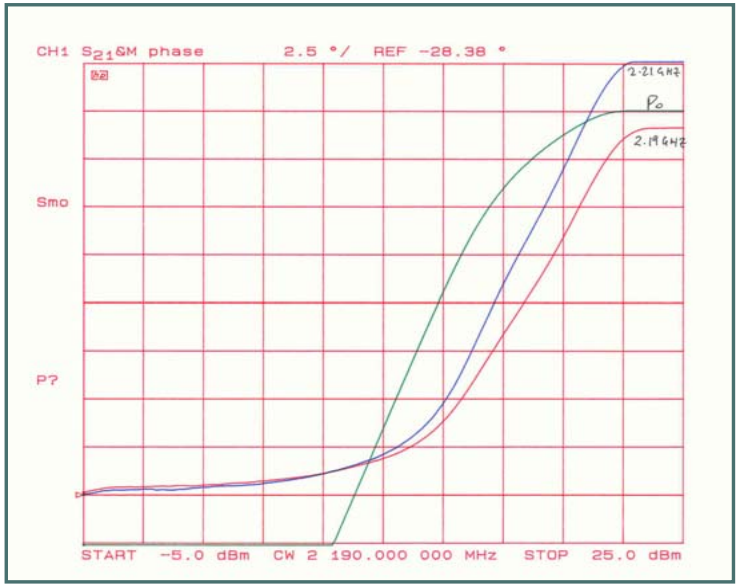
RF power amplifier model



Memoryless RF power amplifier model and transfer function (ideal)

RF power amplifier model

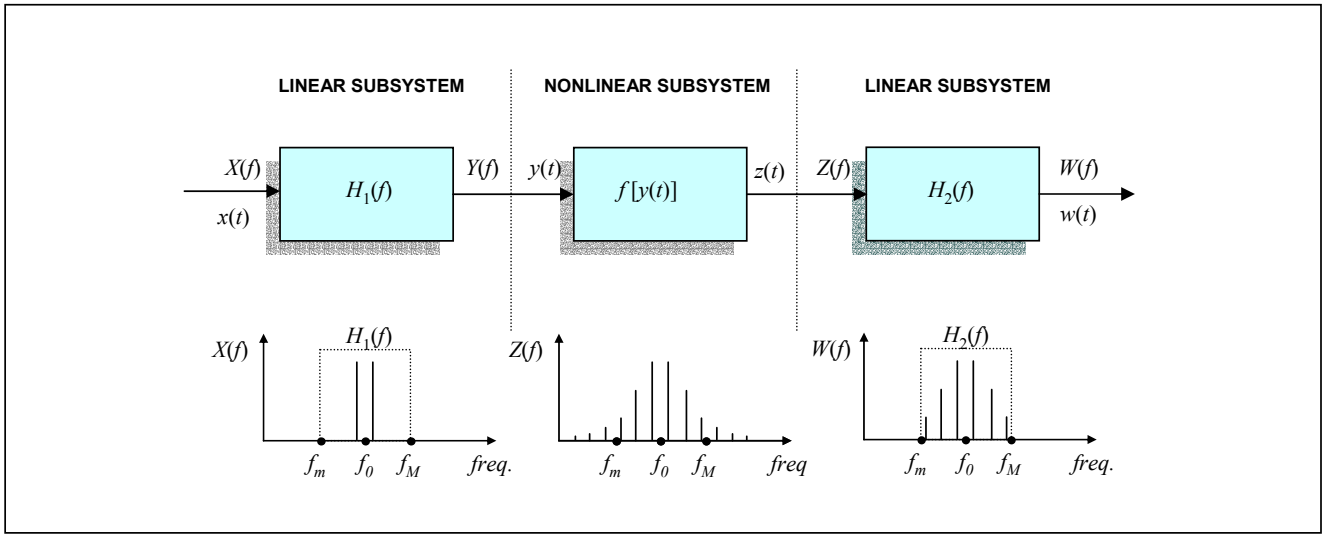




Magnitude and phase of the gain of an RF power amplifier at two different frequencies

Linearizer Technology, Inc.

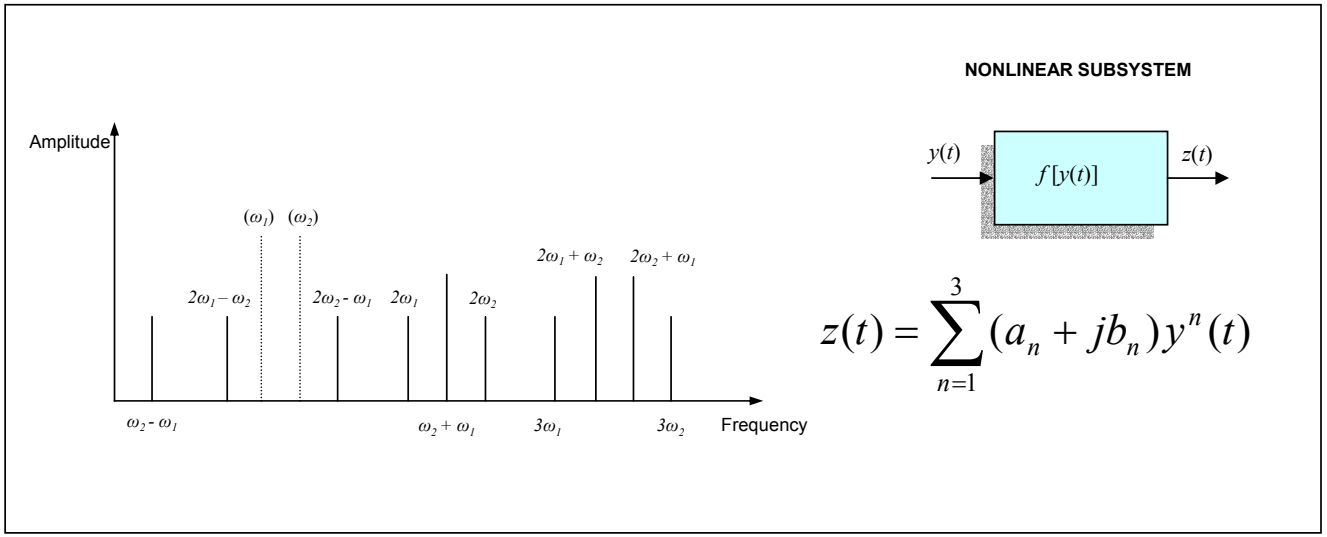
RF power amplifier model



RF power amplifier model (with memory)

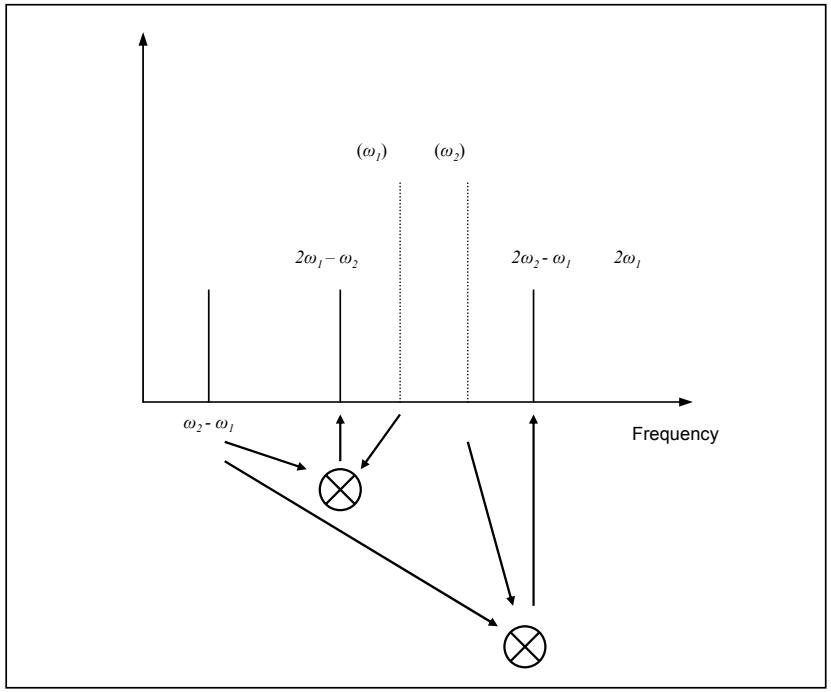
- the nonlinear gain depends on the frequency of the signal -

RF power amplifier model



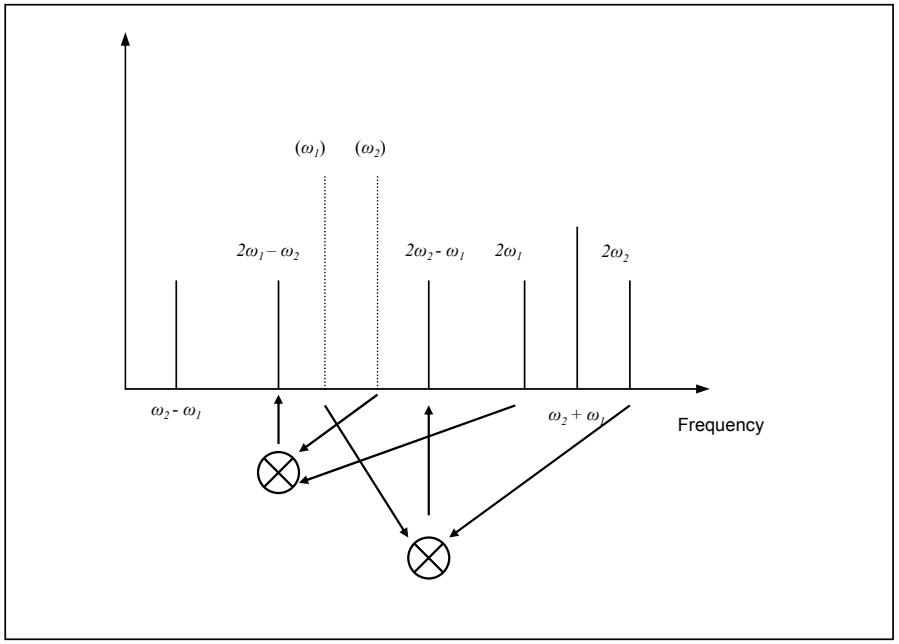
Transfer function *f* [*y*(*t*)] of the nonlinear subsystem and generation of intermodulation distortion (IMD) and harmonics

Envelope memory effects



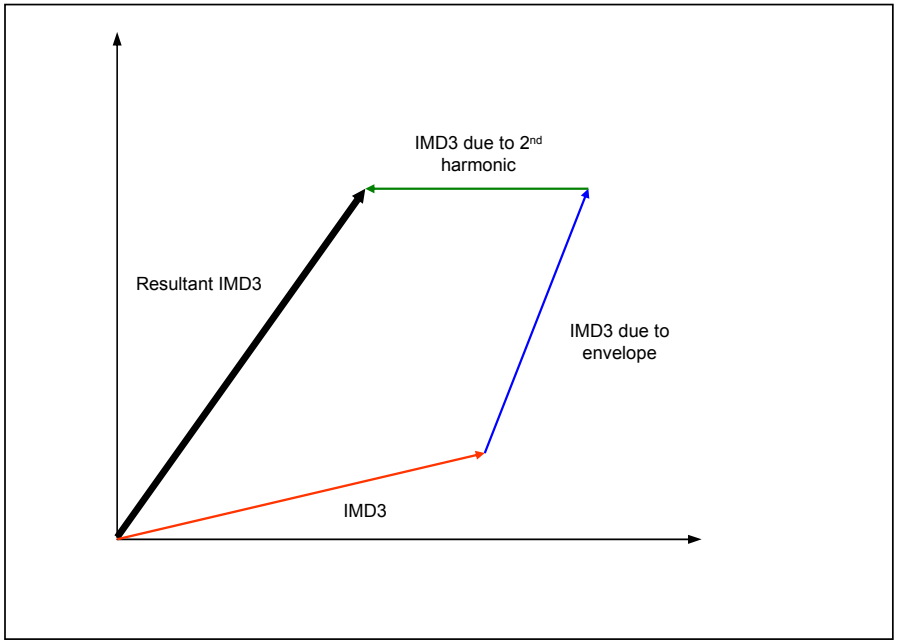
Effect of the envelope frequency on the generation of third order intermodulation distortion products

Memory effects due to harmonics



Effect of the second harmonic on the generation of third order intermodulation distortion products

3rd order intermodulation distortion composition



The 3rd order intermodulation distortion (IMD) is caused by

- **IMD3 of the nonlinear active device**
- **IMD3 due to the envelope of the signal**
- **IMD3 due to the second harmonic**

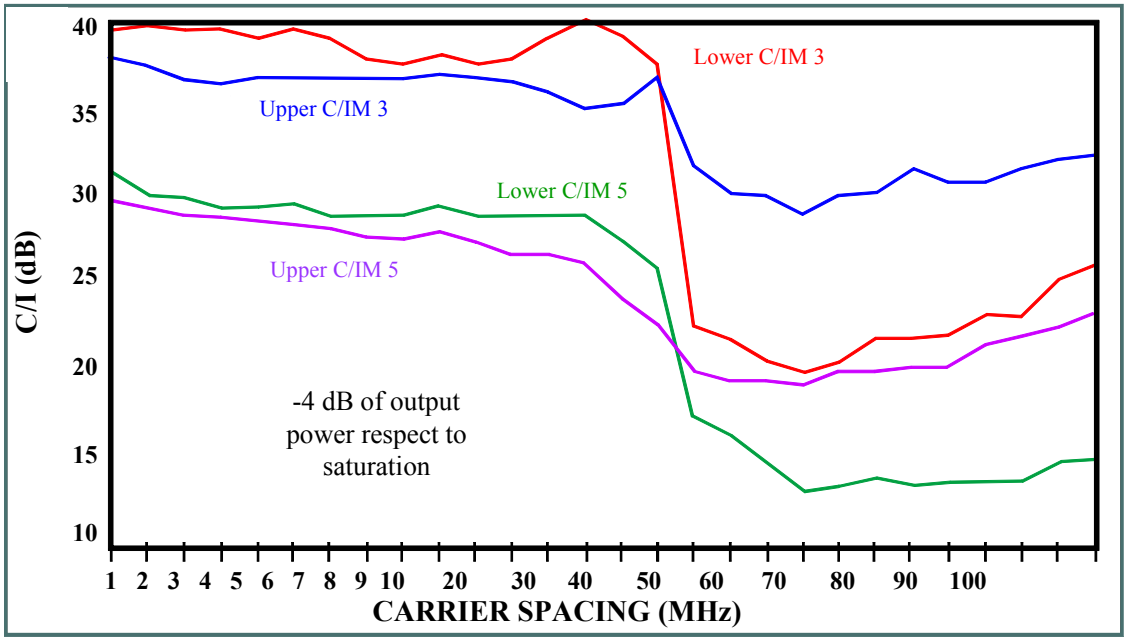
Thermal memory effects

- Variations in the envelope of the signal produce rapid changes in temperature in the active device of the amplifier
- If the envelope frequency is high (>100 KHz), the thermal inertia is such that the device temperature will be constant
- If the envelope frequency is low (<100 KHz), the temperature of the active device will vary as a function of the envelope
- Changes in the temperature of the active device affect its nonlinear gain

Problems due to memory effects

- The intermodulation distortion can increase due to the contribution of the envelope and second harmonic

Effects of the envelope frequency on the intermodulation distortion

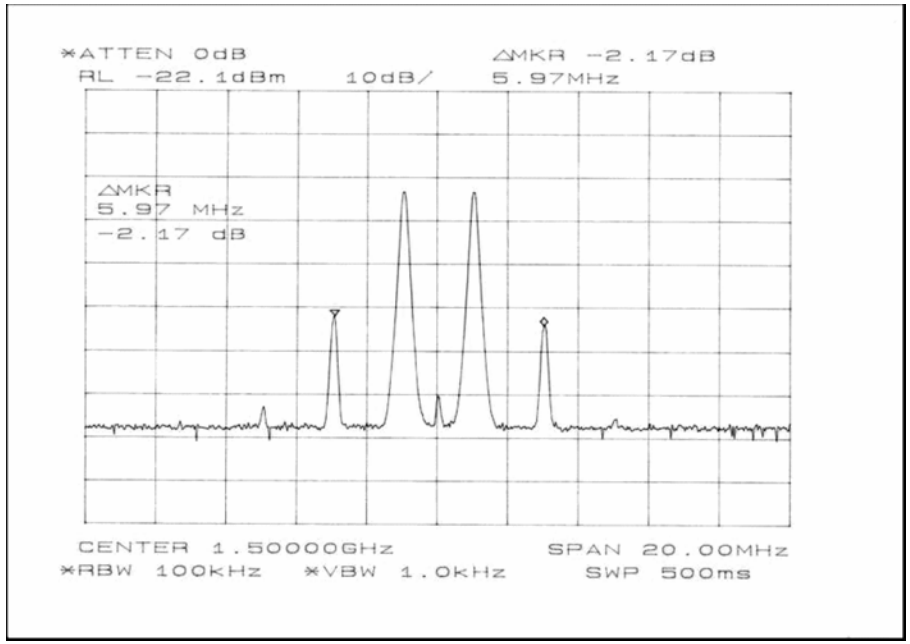


The carrier to intermodulation ratio (C/IM) usually decreases for a very widely separated two-tone signal

Problems due to memory effects

- The intermodulation distortion can increase due to the contribution of the envelope and second harmonic
- The intermodulation distortion can be asymmetrical

Asymmetric intermodulation distortion

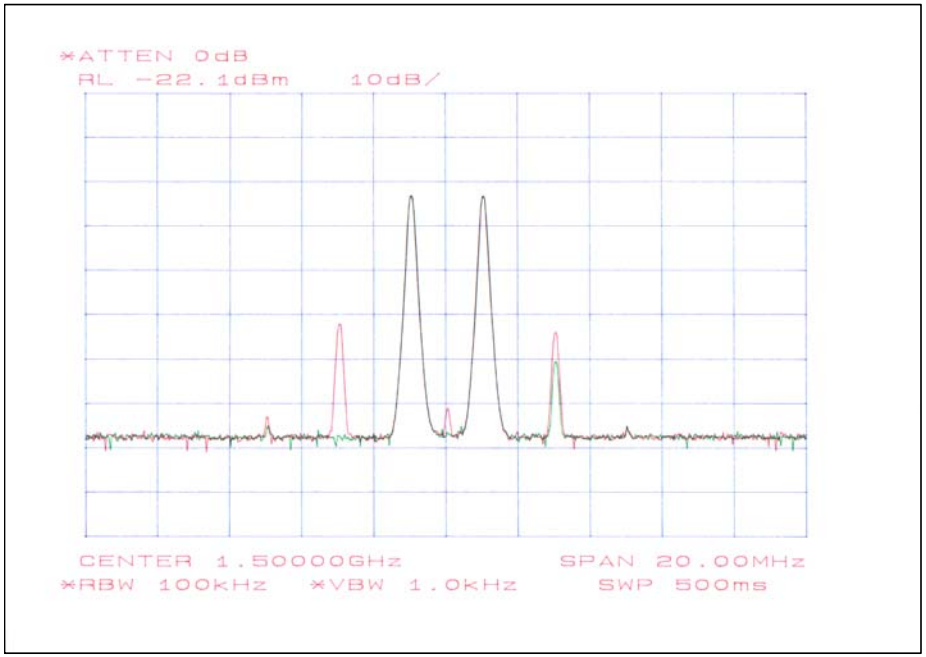


Asymmetry of 3rd order intermodulation distortion products due to memory effects

Problems due to memory effects

- The intermodulation distortion can increase due to the contribution of the envelope and second harmonic
- The intermodulation distortion can be asymmetrical
- The reduction of the intermodulation distortion with a predistortion linearizer is difficult when the distortion sidebands are asymmetrical

Predistortion of asymmetrical signals

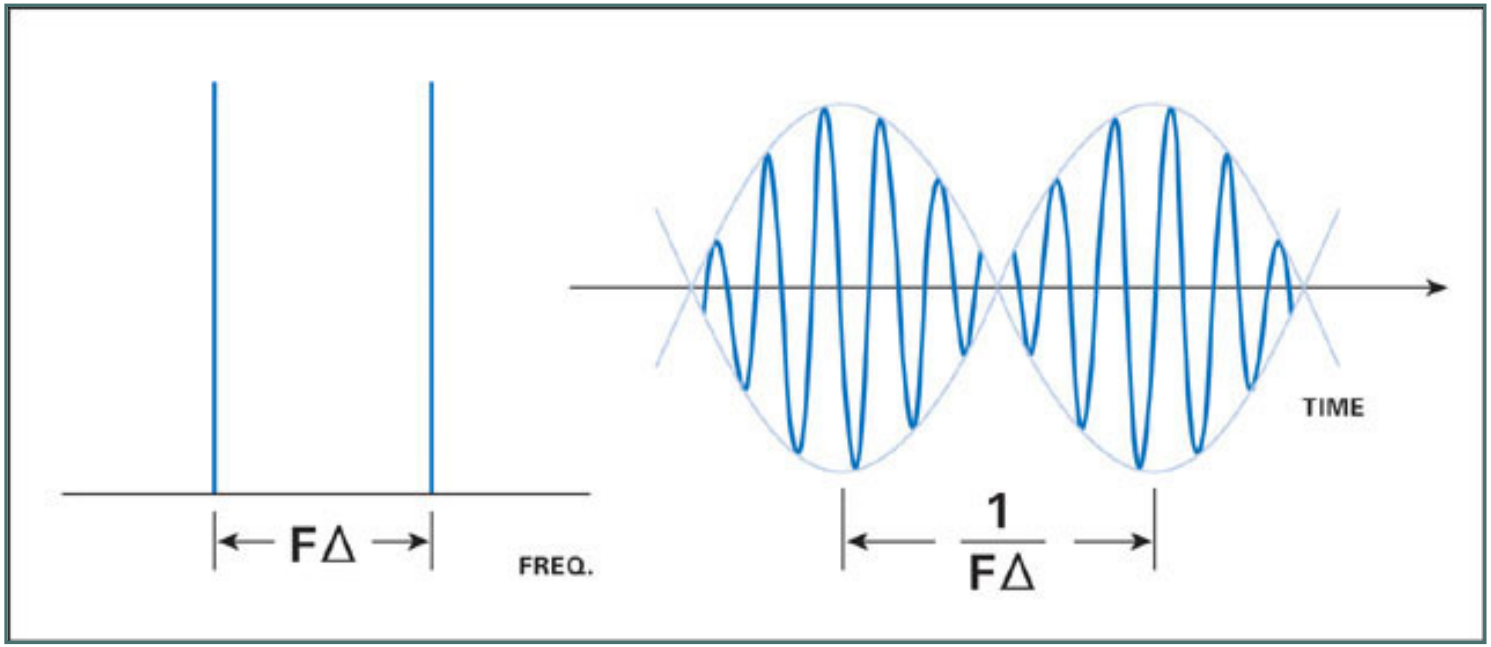


A memoryless predistortion linearizer cannot completely cancel asymmetric intermodulation distortion

Problems due to memory effects

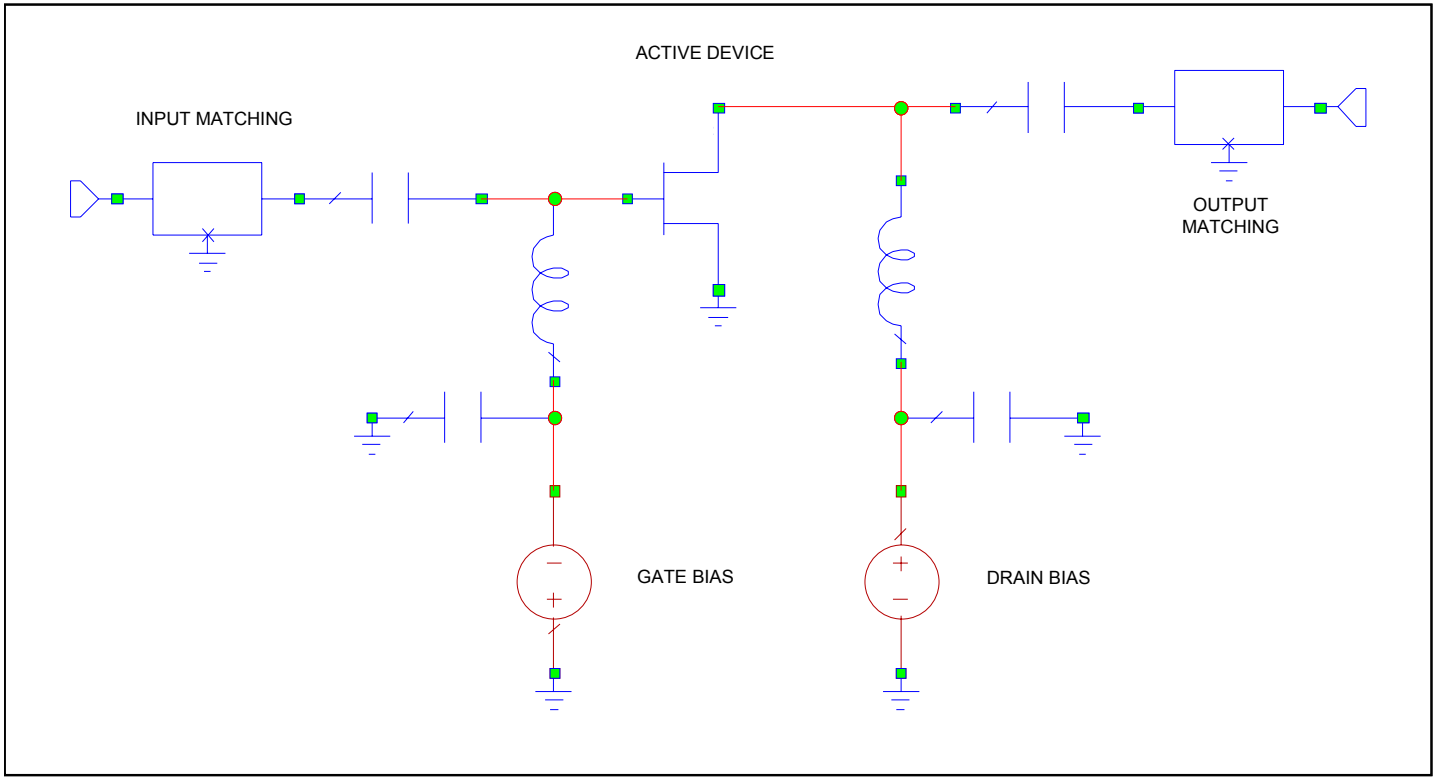
- The intermodulation distortion can increase due to the contribution of the envelope and second harmonic
- The intermodulation distortion can be asymmetrical
- The reduction of the intermodulation distortion with a predistortion linearizer is difficult due to the asymmetry of the distortion sidebands
- The observed distortion can be exclusively due to memory effects and not to a nonlinear effect!

Two tone signal

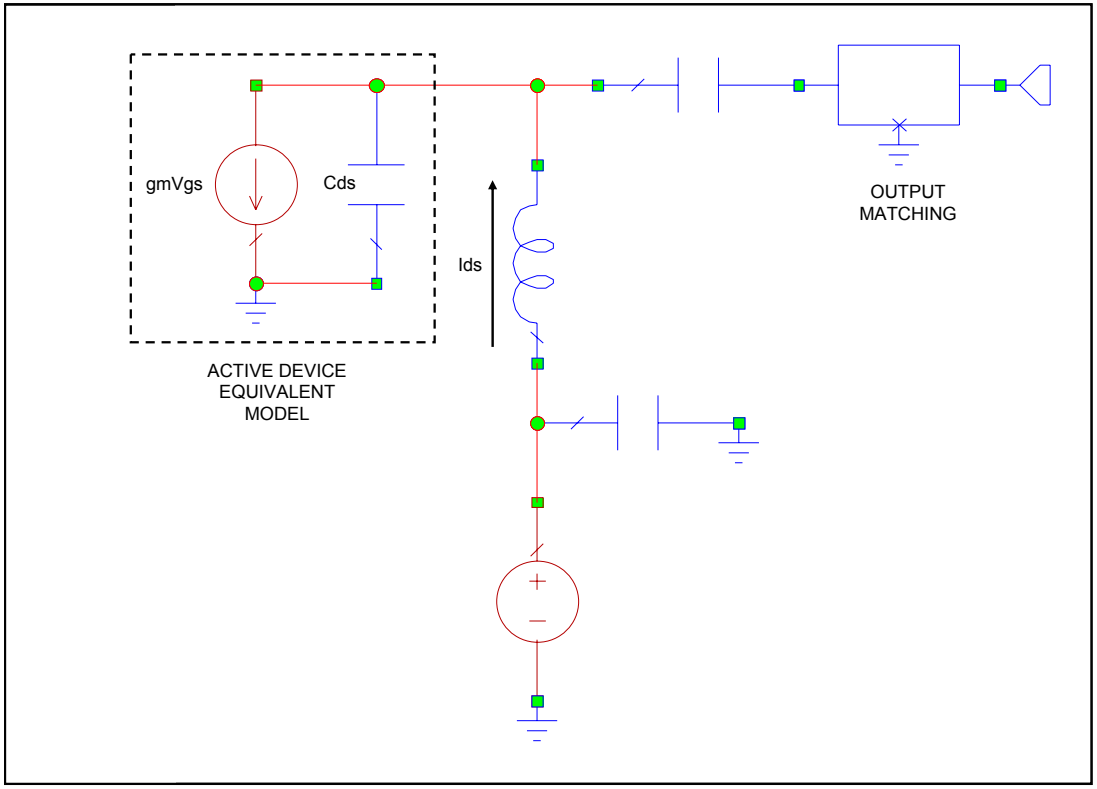


Representation of a two tone signal in the frequency and time domains

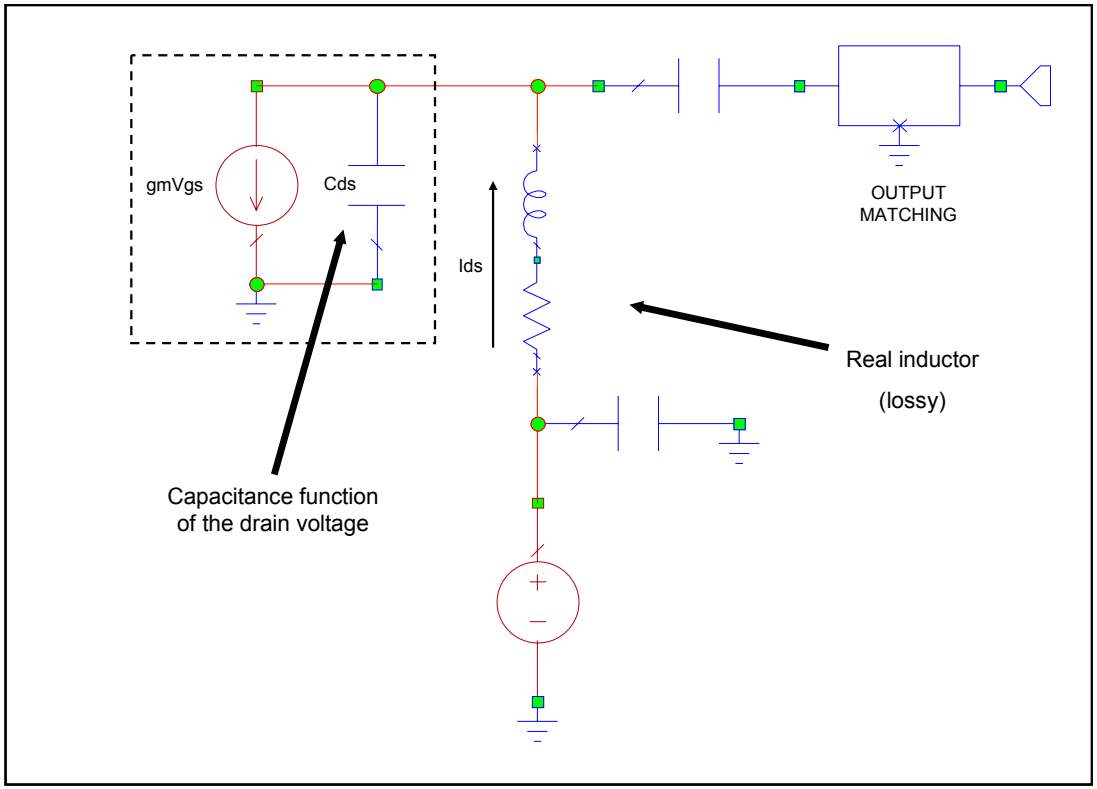
Typical RF power amplifier



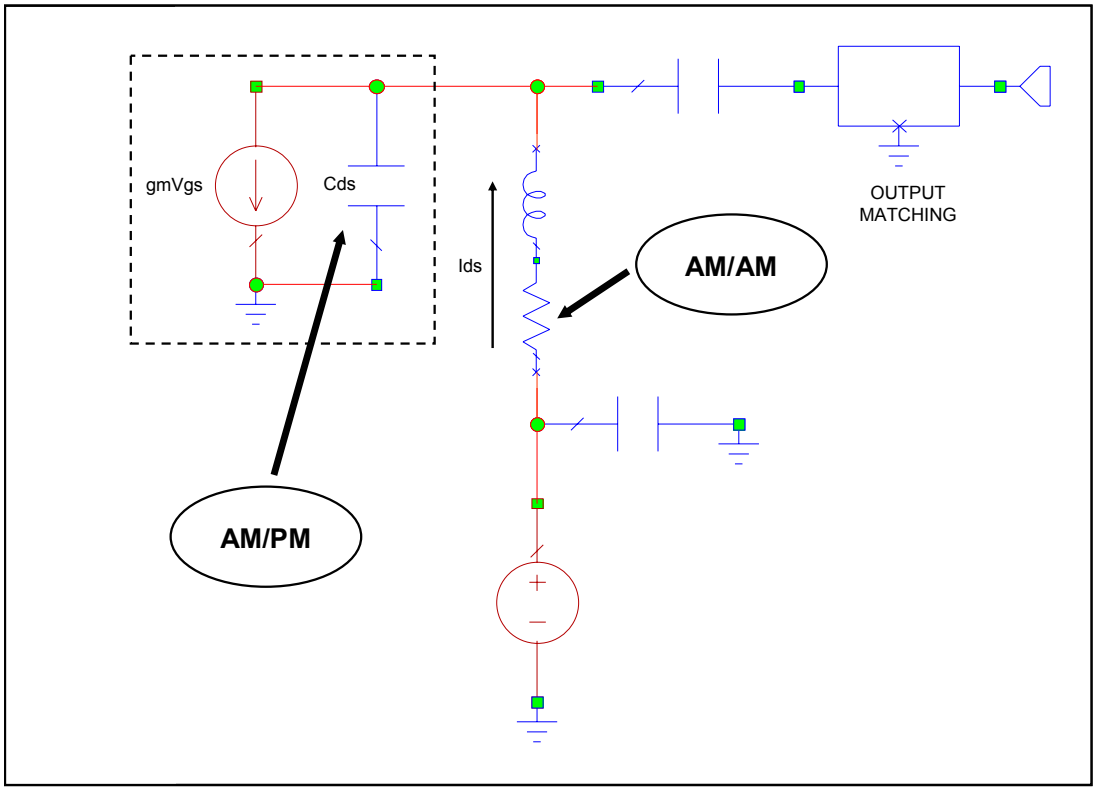
Typical RF power amplifier - Output circuit



Typical RF power amplifier - Output circuit



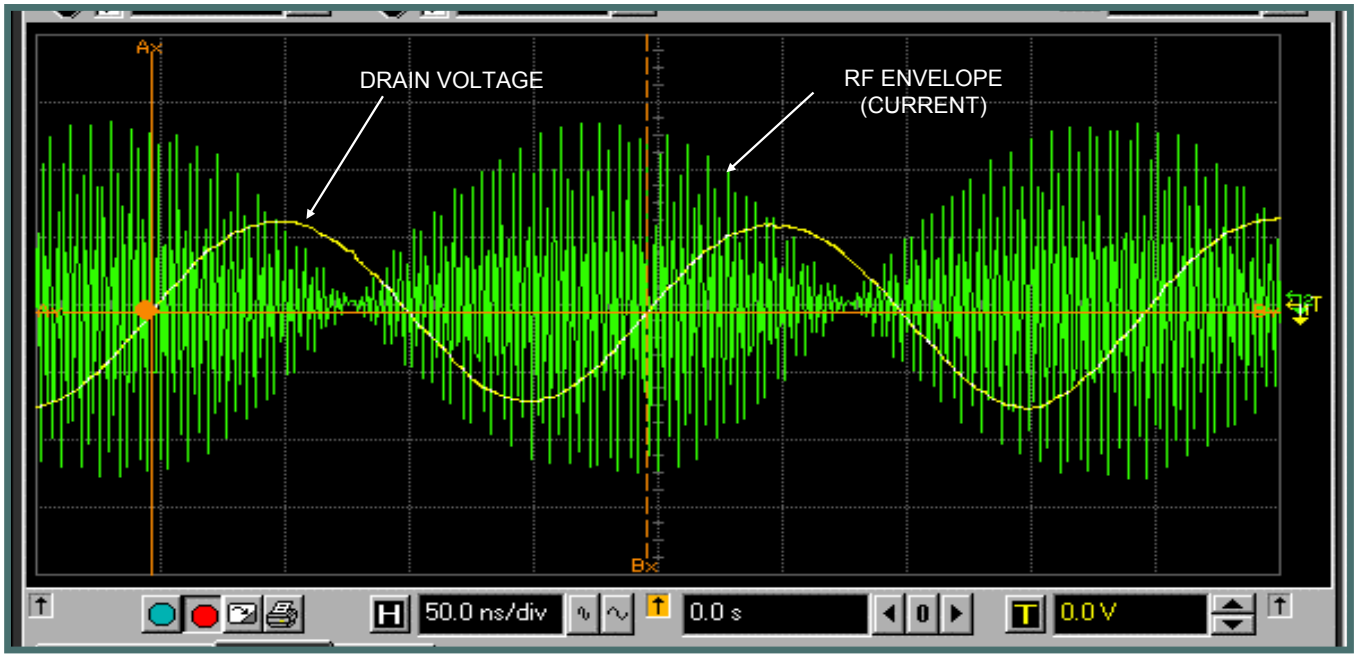
Typical RF power amplifier - AM/AM and AM/PM bias modulation



AM/AM and AM/PM generated by bias modulation

- AM/AM is generated mainly by the voltage drop across the loss resistance of the drain inductor
- AM/PM is mainly generated by the variations of the drain-source capacitance as a function of drain voltage
- The sidebands due to the bias modulation have the same frequency as the intermodulation distortion products

Two tone drain signal waveform



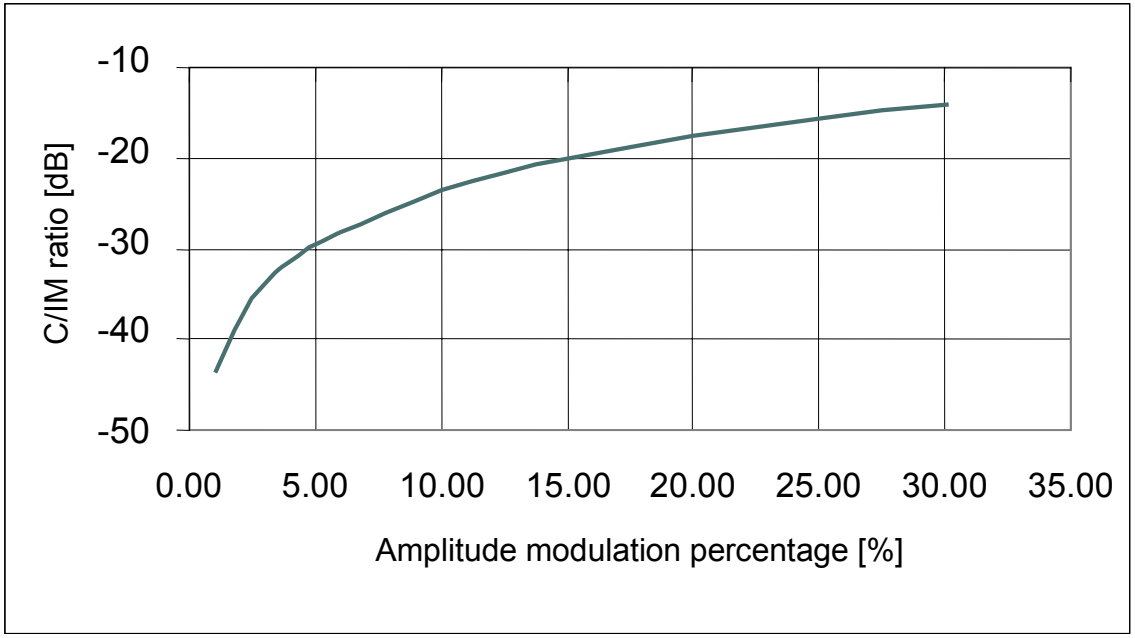
Drain voltage and current are out of phase due to the reactance in the biasing network

Asymmetry in the bias induced modulation

- Simultaneous amplitude and phase modulation does not generate asymmetric sidebands

- Simultaneous amplitude and *delayed* phase modulation does generate asymmetric sidebands

Drain bias modulation sensitivity

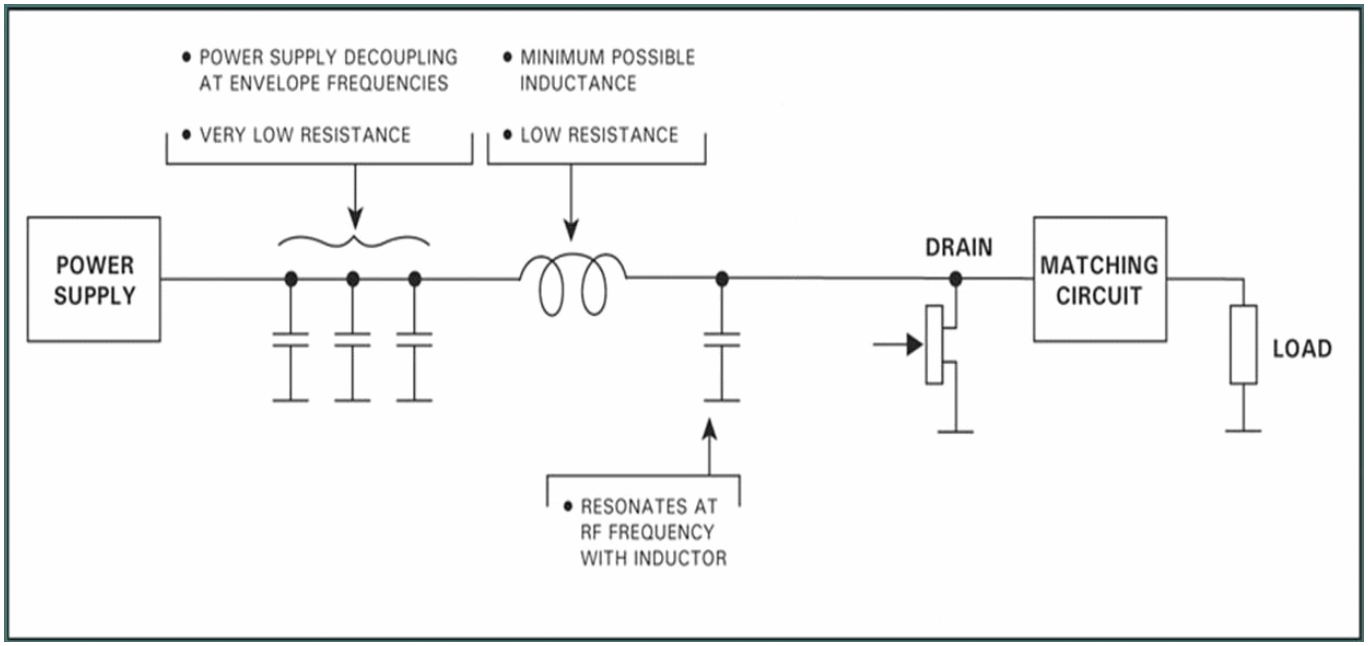


Carrier to intermodulation ratio (C/IM) as a function of drain amplitude modulation at constant output power

Minimization of bias-induced memory effects

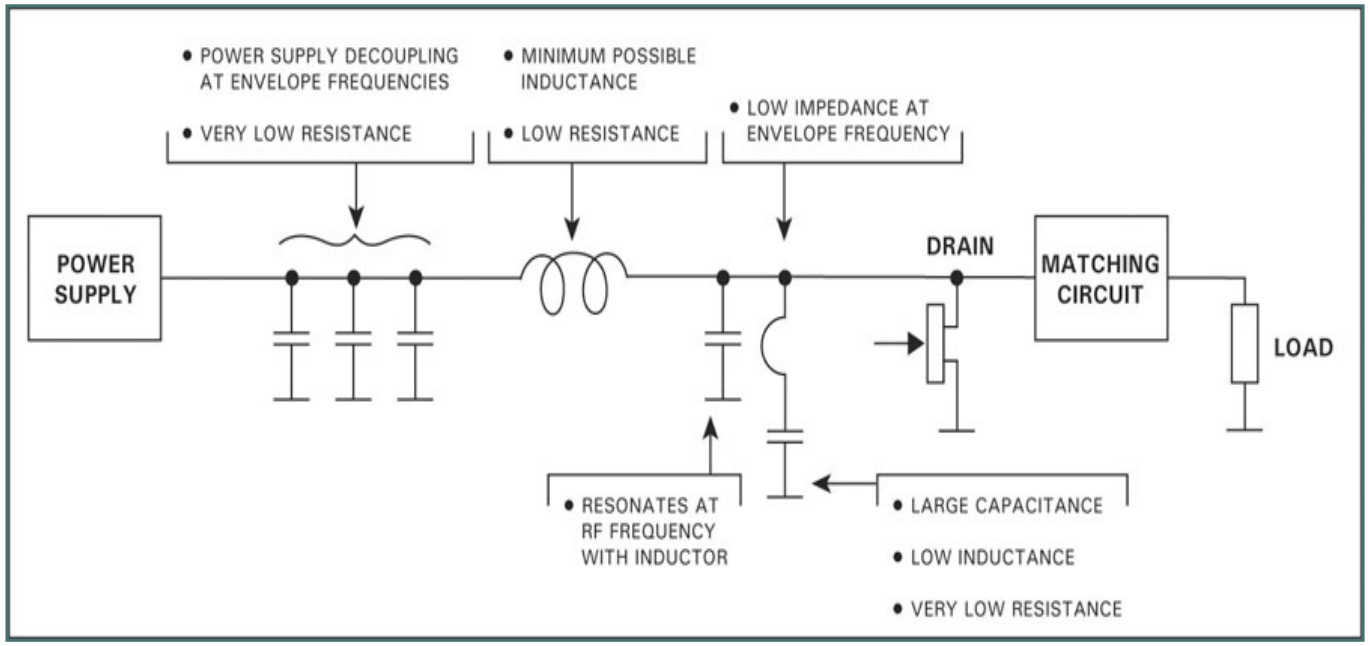
- Bias modulation effects can be reduced by terminating the active device in a very low impedance at the envelope frequency
- Both drain and gate bias circuits can generate bias modulation
- Thermal memory effects depend on the physical properties of the active device

Minimization of memory effects - Typical drain bias network



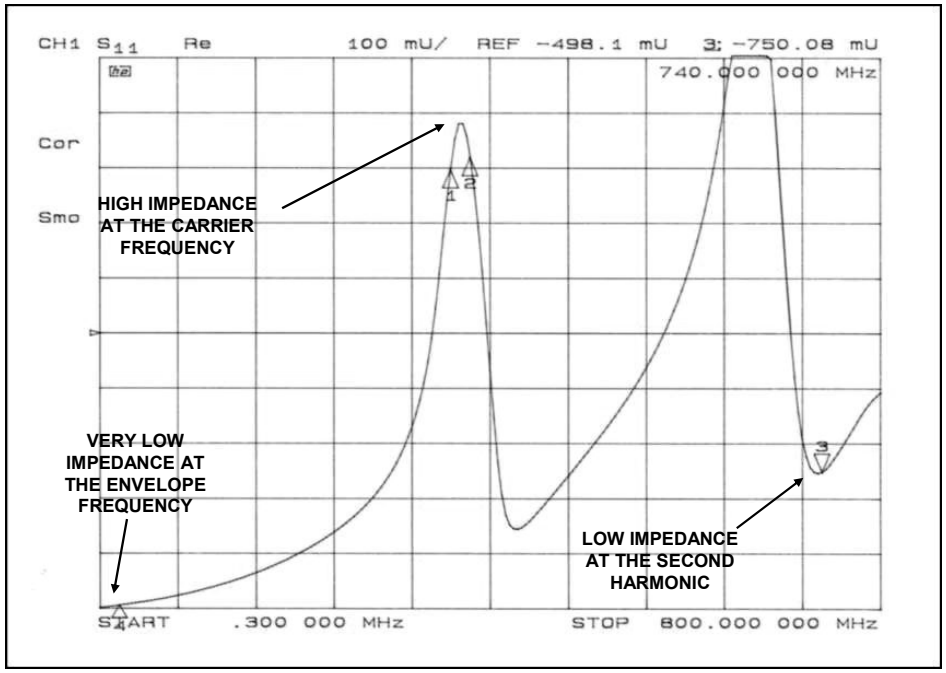
Typical drain biasing network in which the inductance has been reduced to minimize memory effects

Minimization of memory effects - Improved drain bias network



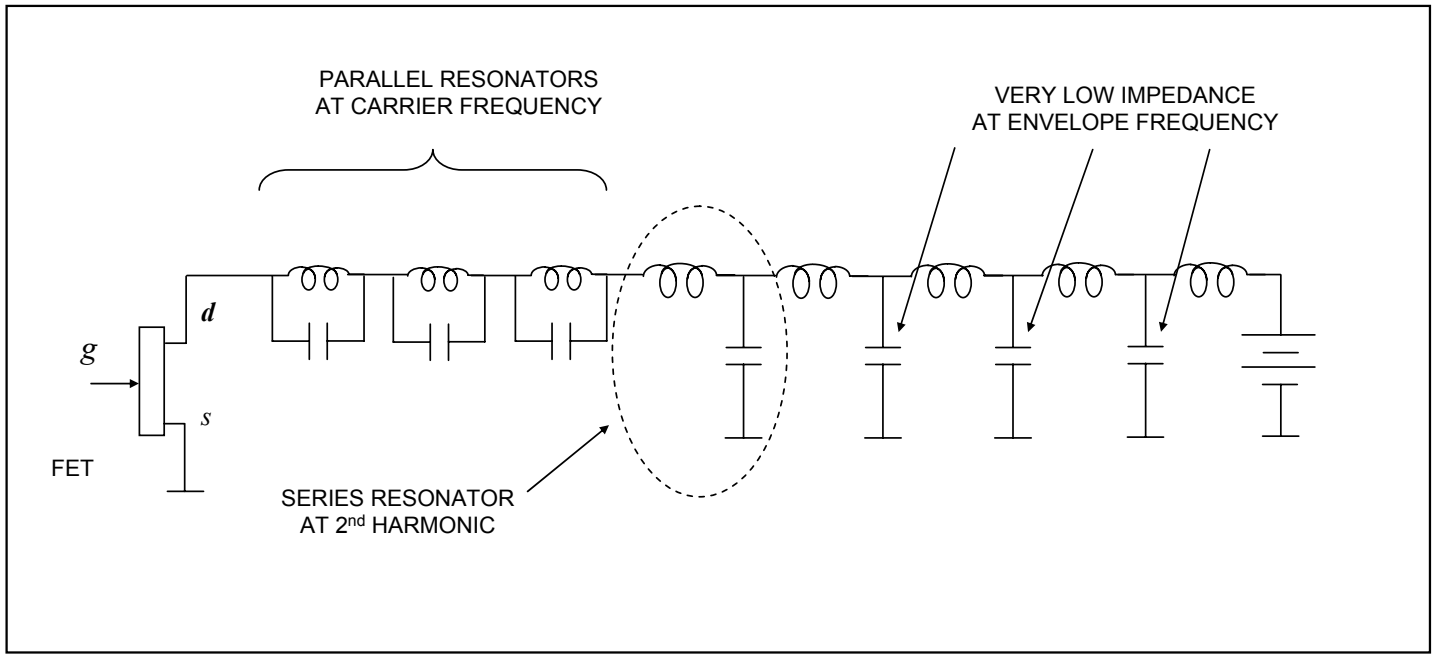
Improved drain biasing network in which the inductance has been reduced to minimize memory effects, and the envelope is terminated in a short circuit

Minimization of memory effects - Improved drain bias network



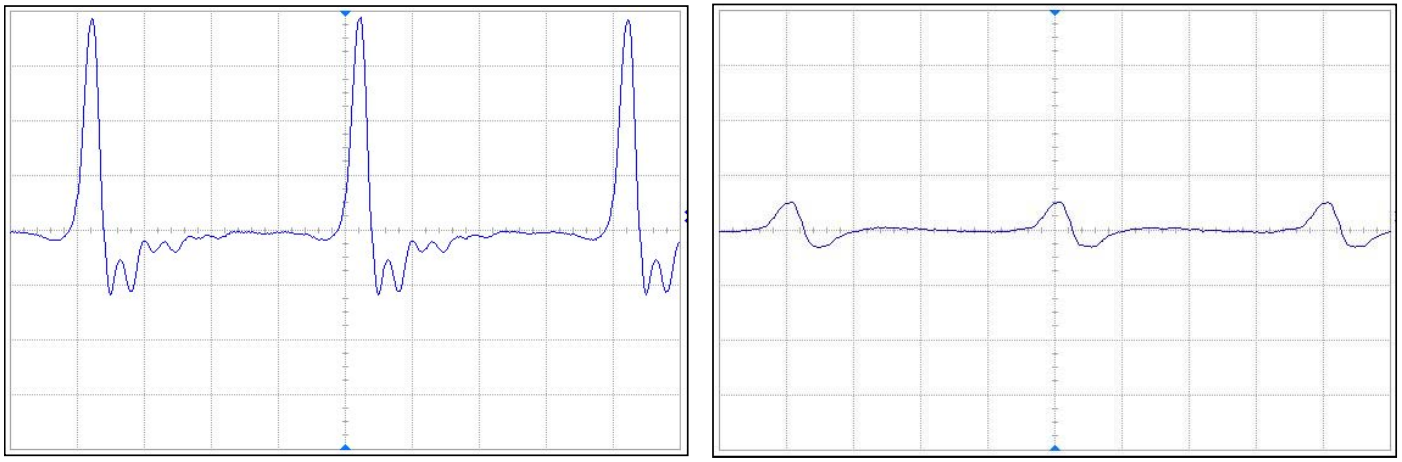
Frequency response of a bias network that minimizes memory effects and maximizes the efficiency by short-circuiting the second harmonic

Minimization of memory effects - Improved drain bias network



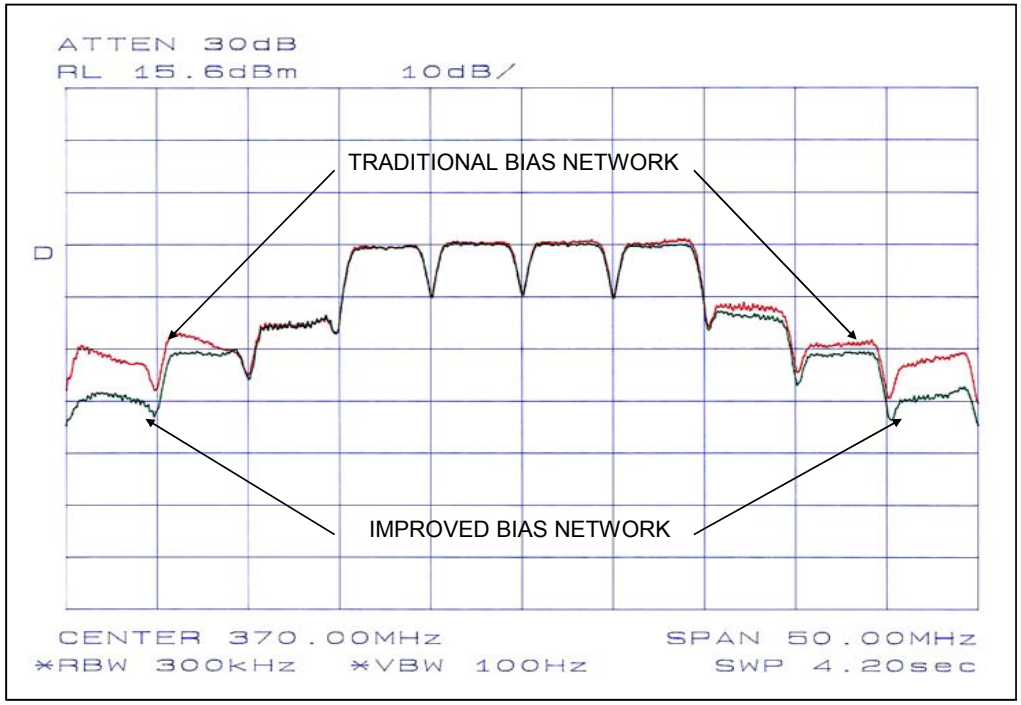
Implementation of the improved drain bias network in a UHF power amplifier

Minimization of memory effects - Improved drain bias network



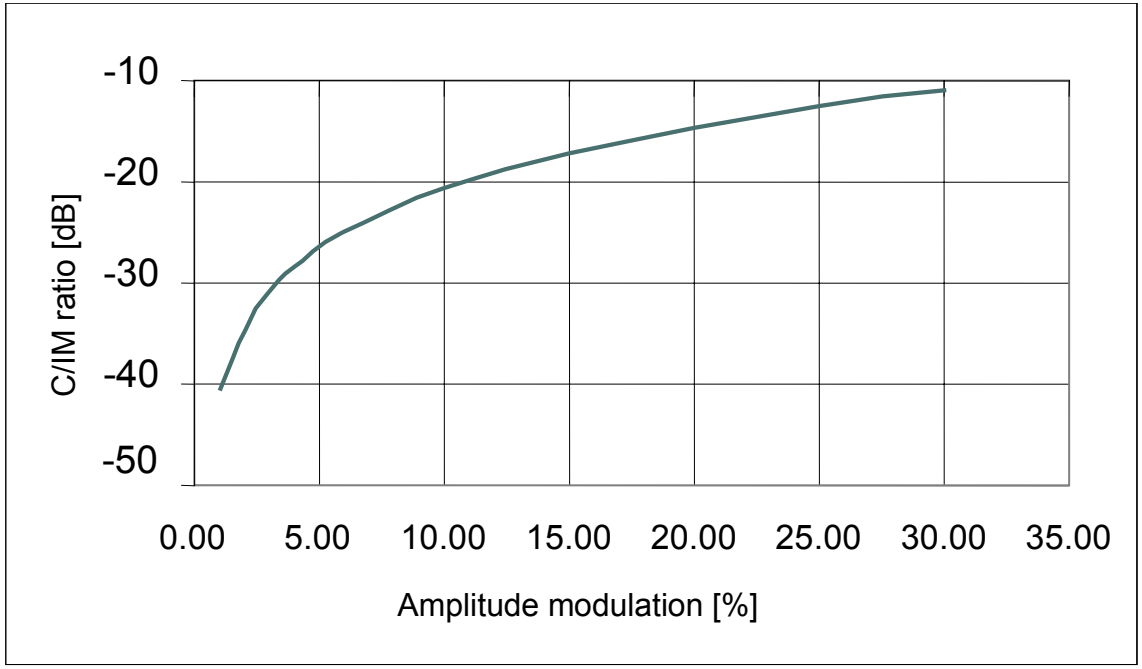
Measured ac component at the drain of the FET
with a 5 MHz two-tone signal at 1 dB output back-off
LEFT: Traditional bias network
RIGHT: Improved bias network
(20 mV/div, 50 nsec/div, 30 MHz low pass filter)

Minimization of memory effects - Improved drain bias network



Spectrum of 4 WCDMA carriers with both drain bias networks

Gate modulation sensitivity



Carrier to intermodulation ratio (C/IM) as a function of gate amplitude modulation

Conclusion

- Memory effects in RF power amplifiers are variations of the nonlinear gain due to the frequency of the signal, the frequency of the envelope of the signal, or temperature
- Memory effects generate asymmetry in the distortion sidebands – this effect can reduce or increase them
- It is desirable to minimize memory effects during the design of the RF power amplifier

Conclusion

- Bias modulation of the amplifier is generated by terminating the active device on an impedance greater than zero at the signal envelope frequency
- Bias modulation can be minimized by using biasing networks with minimum reactance at the envelope frequency
- A worst case scenario will occur for high power, low drain voltage amplifiers, operating at low frequencies with very wide signal bandwidth (high envelope frequency)