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Power Amplifier Linearisation through Trans-conductance Synthesis

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Abstract:

This paper describes the application of derivative superposition to the design of power amplifiers using discrete power devices. The underlying theory of derivative superposition will be reviewed, followed by the application of this technique to a typical PA design. Measured performance suggests that this technique can offer control over the amplifier **nonlinear transfer function and improve amplifier performance.**

Introduction

Power amplifier distortion has been the subject of intense study since the early days of AM broadcasting. The simplest solution to achieving low waveform distortion is to back off the PA, but this leads to the inevitable loss of DC to RF conversion efficiency. In some applications this is acceptable, but in others, reliability concerns, cooling costs and space constraints necessitate looking at alternatives. Ultimately, the tradeoff between the PA efficiency and its linearity leads to difficult architectural challenges in linear amplifier design.

In general, odd order distortion and in particular the 3rd order, is of the greatest concern to PA designers. This component of the nonlinear transfer function is the one that leads to the generation of in-band interfering signals close to the parent tones, and are difficult to filter out. Requirements for intermodulation distortion at –60dBc or lower is common for many applications. Up until recently, a black box approach has been applied, where by means of additional circuitry, the PA distortion has been reduced to an acceptable level. Amongst these techniques , feedforward, feedback and predistortion and their variations are the most popular ones. Other elegant solutions such as Doherty pair and envelope elimination and restorations (EER) have also been proposed. In this paper, a design technique called derivative superposition [1] is reviewed, and the principle is applied to the design of a power amplifier using discrete components.

Derivative superposition

The concept of superposition is widely used in many aspects of engineering including waveform engineering and Fourier Series. Filter synthesis is another well-known example of superposition. Superposition in the context of power amplifier design can be described in the following way. The device nonlinear trans-conductance is given as:

$$i_d = g_1 v_{gs} + g_2 v_{gs}^2 + g_3 v_{gs}^3 + \ldots\ldots \qquad (1)$$

The 2nd and 3rd order small signal distortions are proportional to the g_2 and g_3 terms. It is obvious that in design of amplifiers, both these terms are undesirable, but the g_2 term is less problematic. However, in the design of mixers, although the 3rd order component is unwanted, the 2nd order term is the one, which performs the mixing and should be enhanced if possible. In derivative superposition approach, one can control these components by synthesizing the active device transfer function. The prospect to synthesize the amplifier transfer characteristics can be explained by considering a simplified version of Parker-Skellern model for a MES-FET [2].

$$V_g = V_{ST} \ln\left(\exp^{\left(\frac{V_{gs}-V_{TO}}{V_{ST}}\right)} + 1 \right), \quad \mathrm{I}_{ds} = \beta V_g^Q \qquad (2)$$

This representation allows a soft pinch-off of the device I-V characteristics. The interesting observation in this model is the 2nd and 3rd order derivatives. By plotting these terms versus the V_{gs}, it is clear that there are peaks in 3rd order term but more interestingly, there are areas where the 3rd order term exhibits a negative peak. The magnitude and the location of the peaks are the function of device gate-width and bias point. This in turn suggest that these two design variables can be utilized to adjust (synthesize) the transfer characteristics of a composite FET structure, where positive g_3 peaks of some devices can be controlled by the negative peaks of others.

Design Example

The following example outlines the results obtained by the design and test of an amplifier using derivative superposition. In this example, a balanced amplifier configuration was built at the 1800 MHz range using a pair of medium power MESFET transistors (Fujitsu FLL357). The amplifier pair was operated at class A and shallow AB modes, as a bench mark for both the linearity and efficiency. The same pair was then biased differently, when one device was operated at shallow AB and the other in deep AB (Class B) mode. A comparison of the performance is summarized in table 1, indicating improvements in efficiency and IMD. The full analysis, simulation and measurements will be presented in the workshop.

The balanced amplifier performance comparison with amplifiers in two different bias condition

I/P dBm,		O/P dBm		L-IMD3/dBc	U-IMD3/dBc	Amp A, I_d	Amp B, I_d	PAE%
F1=1.795 GHz	F2=1.805 GHz	F1=1.795 GHz	F2=1.805 GHz					
19.4	19.4	31.1	31.4	-25.2	-32.3	693	516	20.6
19.4	19.4	31.2	31.8	-27.2	34.4	506	265	36.8

Table 1

References:

1- Webster D R, et al, Low-Distortion MMIC Power Amplifier Using a New Form of Derivative Superposition, IEEE Trans. On MTT, Vol.49, No.2, February 2001.

2- Parker A E, Implementing Spice models with high-order continuity and rate dependence, IEE proceeding on circuits, Devices and Systems, Vol.141, No 4, August 1994, pp 251-257. Special Issue on Techniques for Nonlinear Circuit Simulation ed, P. Mole & H. Rokos.