Ultra Linear/Feedforward Amplifier Design

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ABSTRACT: The proliferation of cellular and personal communication networks burdens an already overcrowded frequency spectrum. These systems require modern RF power amplifiers to maintain high levels of spectral efficiency for minimized adjacent channel interference. Amplifiers must maintain ultra linear transfer functions to achieve spectrally efficient operation. Several amplifier architectures (including feed-forward) capable of ultra linear operation are illustrated, compared and analyzed.

There are three general classes of RF power amplifiers: linear, enhanced linear and ultra linear. Classes of linearity can be distinguished by the intermodulation distortion performance and/or third order intercept point. There are several amplifier architectures that are applicable to each class of linearity, however technical and economic considerations determine which architectures are most suitable. The amplifier classes will be quantitatively defined, and methods of achieving that particular class will be discussed.

An amplifier's linearity can be classified in variety of ways. One of the most common methods is intermodulation distortion or IMD. IM distortion products are generated when two or more sinusoidal signals are propagated through a non-linear medium. The level of distortion is then quantified by referencing the amplitude of the distortion response products to the level of the carrier amplitudes. These terms are characterized in -dBc or dB below the carrier.

Basic linear class amplifiers have an IMD response of anywhere from -15 to -35 dBc. Enhanced linear class amplifiers yield IMD responses of -35 to -55 dBc, while ultra linear class amplifier architectures are capable of -55 dBc to -85 dBc of operation.

Class 'A' amplifiers form the core method for linear class amplification. Typically, transistors biased into class 'A' operation easily produce IMD spectrums lower than -25 dBc to -30 dBc. There are several advantages to this architecture including: 1) broadband operation, 2) repeatable performance from unit to unit, 3) relatively temperature independent response.

In fact, knowing the third order IMD products reduce 2 dB for every 1 dB reduction in carrier level leads into a combined, derated output class 'A' amplifier (Fig. 1). For example, if a given amplifier could only achieve -20 dBc of IMD and -30 was the spec, the response could be improved to -32 dB by combining four identical amplifiers, reducing the required output level of each amplifier by 6 dB and the overall IMD level by 12 dB. This approach could be taken further by combining greater amounts of modules, however, the network becomes too costly and inefficient. Enhanced linear performance is accomplished by the use of

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

a predistortion network. The basic concept of predistortion is simple: given an amplifier with a compressed transfer function, it is cascaded with a driver amplifier that has a complimentary expanding transfer characteristic. The aggregate response of the two networks yields an overall quasi linear performance (Fig. 2). This technique provides a cost effective approach to achieving enhanced linear performance. Difficulties may arise when trying to achieve broadband or wide dynamic range responses.

To enter into the ultra linear class of amplification, the network architecture must change dramatically. Figure #3 displays a basic feedforward system. It primarily consist of two loops: 1) signal cancellation loop 2) distortion cancellation loop. The operation is basic in concept: a signal of two or more carriers is split by a signal divider. One portion is sent to the main amplifier which increases the power of the signal and generates distortion products. The other portion is sent through a delay line which delays the distortion free signal. A sample of the spectrum from the main amplifier is coupled to a hybrid combiner which combines the (signal & distortion) spectrum of the amplifier with the (pure signal) spectrum of the delay line. Phase, amplitude and time characteristics of each spectrum are carefully controlled such that all are precisely equal in magnitude, with only the phase out by 180 degrees. The hybrid combiner in theory, yields a distortion (error) spectrum, free of signal. The same process is repeated except the distortion spectrum is amplified to a higher level by the error amplifier and injected into the main amplifiers output via a directional coupler, canceling the distortion products.

A properly designed feedforward network can easily give ultra linear performance, however, the basic system itself is relatively narrowband and to achieve high levels of cancellation may require unrealistic levels of circuit tolerance.

To counter this problem different techniques of linearization can be integrated together. Figure #4 shows the integration of a predistortion network nested into a feedforward system. The predistorted main amplifier will have better IMD response, easing the demand on the distortion canceling network of the feedforward system.

Another problem with feedforward networks is their sensitivity to temperature. Component value deviation inevitably causes overall system performance degradation. While analog control loops are useful in circumventing this problem, digitally controlled networks are providing consistently better performance.

The network shown in Figure #5 is a pilot-tone feedforward system. The operation is similar in principle to a conventional feedforward system. The most significant difference is the injection of a pilot tone into the distortion spectrum. Since the tone is in the distortion spectrum, any effort to cancel it will by default cancel the distortion. The output of the main amplifier is coupled down in amplitude, mixed down in frequency, detected and digitized. The digitized signal is then monitored by a microprocessor which continuously adjusts the phase shifter and attenuator in the error cancellation loop so as to minimize the pilot-tone distortion spectrum. The salient feature of this approach is that it is closed loop, any variation of the analog networks can be digitally compensated for.

Three classes of linear amplification have been characterized. Several amplification architectures were considered. The last of which is indicative of future trends in RF/Microwave amplifier engineering. To achieve higher levels of performance, amplifier networks will become increasingly dependent upon digital circuitry.

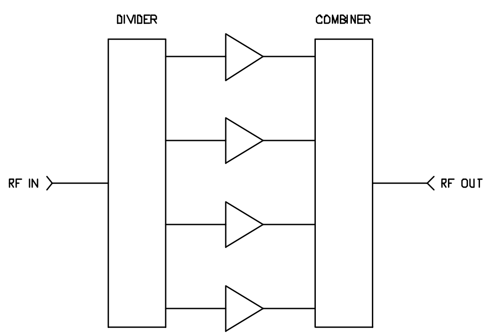

FIGURE 1

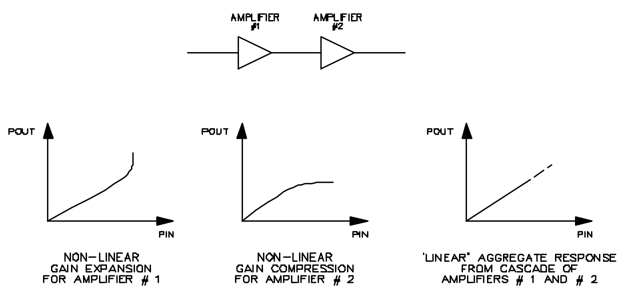

FIGURE 2

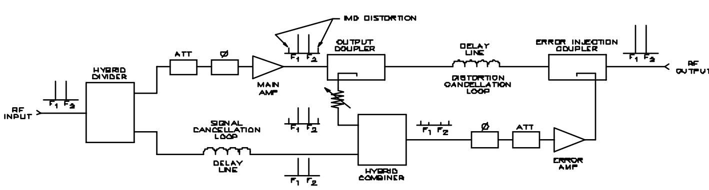

FIGURE 3

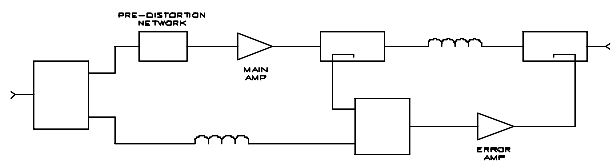

FIGURE 4

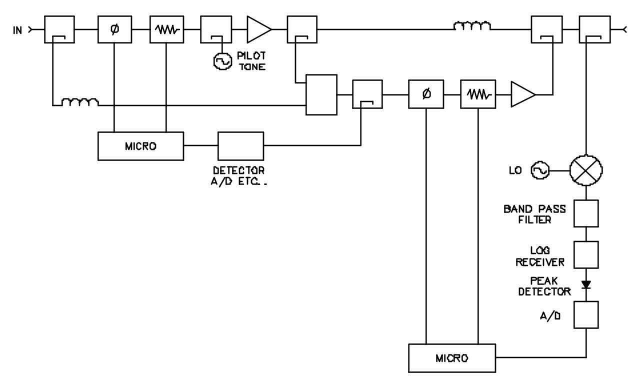

FIGURE 5