Linearized Combiner Circuits for Power- and Low Noise - Amplifier Applications

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Abstract

Combiner circuits using two equal linear amplifiers, Fig.1, have been used for many years in order to efficiently produce higher output power levels than possible by a single amplifier and also in order to improve the reliability and availability of the amplifier system component. However, linearity of amplification of each individual amplifier is not improved and the noise figure of the combiner circuit is equal to the noise figure of the individual amplifiers.
On the other hand, amplifiers for very high linearity requirements in mobile communications successfully employ /1/ the feed forward linearization scheme which cancels the nonlinear intermodulation (IM) products of a high power primary amplifier by superposition of signals from a secondary amplifier. However, this concept suffers from a degradation of the efficiency of the amplifier which is due to the requirements on the secondary amplifier.
Another successful concept in linearization of power amplifiers is pre-distortion /1/, which can yield higher power efficiency, yet at lower cancellation ratios of unwanted products.
The presentation analyses the very recent amplifier concept /2/ of "cross cancellation" which combines the high efficiency of a power combiner of two equal power amplifiers with the linearization capabilities of the feed forward linearization scheme and the pre-distortion scheme:
In Fig.2, the basic circuit diagram of the new amplifier concept is shown. The two amplifiers are assumed to be identical with equal amplification v and unwanted distortion products s' under equal drive conditions. Signals are processed in such a way that the wanted-signal levels s at both amplifiers are the same and that the unwanted distortion products of both amplifiers cancel at the output power combiner, while the amplified wanted signal powers combine.
The concept deviates from the conventional power combining circuit of Fig.1 by the addition of a coupling- and feed back circuit and mixes the conventional linearization schemes in that the first loop is not a cancellation loop but rather a pre-distortion loop and the second loop (output) is a cancellation- and power combination loop, as known from feed forward linearization. The principal signal levels appearing in the circuit are indicated in Fig.3: Balancing of signal levels is only possible by employing a first power divider of 10 dB-ratio and also employing directional couplers with coupling ratio $k^2=2/v$. For the equalization of signal phase it is necessary to employ time delays in the signal paths of both amplifiers.
A demonstrator amplifier for 1 GHz operating frequency was designed using 1-W integrated circuit amplifiers and optimised at 6 dB backoff with respect to the single carrier 1 dB saturation level. Successful power combination was found together with improved linearity, which allowed reduction in back-off by about 3 dB for a 40 dB_c two-tone-IM suppression as compared to a single amplifier at identical drive conditions, Fig.4. However, it was found that IM suppression is not achievable at the same level as with the basic feed forward circuit concept. Inspection of the signal distribution within the combiner circuit, Fig.3, shows why: The coupler and power divider ratios are chosen such that the resulting signal amplitude s at the lower amplifier input is equal to the signal at the upper amplifier and that the unwanted products of the upper amplifier s' appear at the lower amplifier. Anti-phase of this signal is chosen in order to pre-distort the lower amplifier and signal amplitude ($s'vk^2=2s'$ at the output of the lower amplifier) is chosen such that it can cancel the upper amplifier's distortion

as well as the lower amplifier's distortion (both are assumed to produce identical unwanted signals). It is seen that the lower amplifier acts as a pre-distorted amplifier with the pre-distortion signal created by the upper amplifier, perfectly adaptive to the instantaneous operating conditions; thus, the term "cross cancellation". However, only the lower amplifier is pre-distorted, creating non-symmetric operating conditions of the amplifier pair and negating the assumption of perfectly identical operating conditions which is necessary for perfect cancellation, and the un-symmetry aggravating at high power levels. It is therefore advisable to use "pre-linearized" amplifiers with fixed pre-distortion circuits at each amplifier's input in order to reduce the degree of un-symmetry in the circuit. Also, in practical applications, the circuit needs to be controlled and tuned to follow changes of drive levels and signal formats and temperature change and aging. This can be done using electronically driven phase shifters and attenuators controlled by a processor unit as well known from feed forward linearizer circuits /1/.
An interesting application of the amplifier circuit should be the low-noise amplification (LNA) in receive front-ends. Such circuits employ small-signal amplifiers which are required to yield low noise figure and low intermodulation at the same time. Improvement of the IM-performance above the level that is attained by simple parallel combining obviously is possible by using the power combining linearizer circuit. With respect to added noise power, the pre-distortion signal will cancel the noise from the upper amplifier only, leaving two equal contributions of uncorrelated noise power to combine at the output combiner stage; thus, the noise figure of the power combining linearizer circuit is the same as that of each of the amplifiers (same as conventional parallel combining). Based on this, the dynamic range of the combiner circuit LNA is increased solely by improving the IM-ratio. However, compared to a simple paralleling of amplifiers, an improvement of 20 dB in dynamic range can be expected in practical circuits without extra power consumption. It should also be possible to create integrated circuits with single-chip pairs of amplifiers, providing high stability with respect to temperature drift and aging, thus needing no adaptive control and tuning of the circuit by attenuators and phase shifters as is necessary in high power applications.

Conclusion

The basic design and principle of operation of linearized power amplifiers using the novel concept of "cross cancellation" in amplifier combining circuits is presented. Results from an experimental power combiner linearizer circuit are presented and performance limitations are discussed and improvements proposed. A novel application as high dynamic range LNA-circuit is discussed.

Literature

/1/ P. B.Kenington, High-Linearity RF Amplifier Design, Artech House, Inc., 2000
/2/ L.T. Mucenieks, et al., United States Patent 6,111,462, Aug. 29, 2000

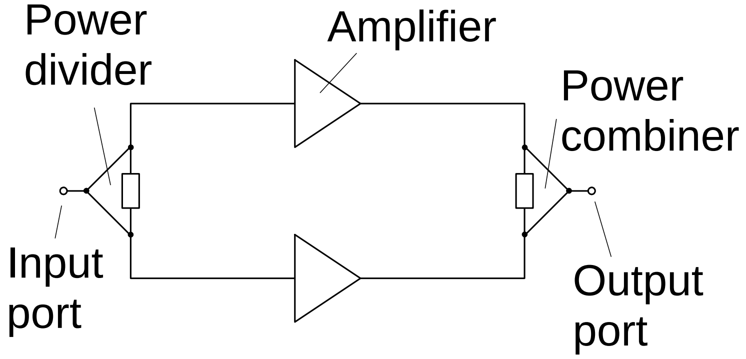

Fig.1 Conventional amplifier combiner using two equal amplifiers in parallel

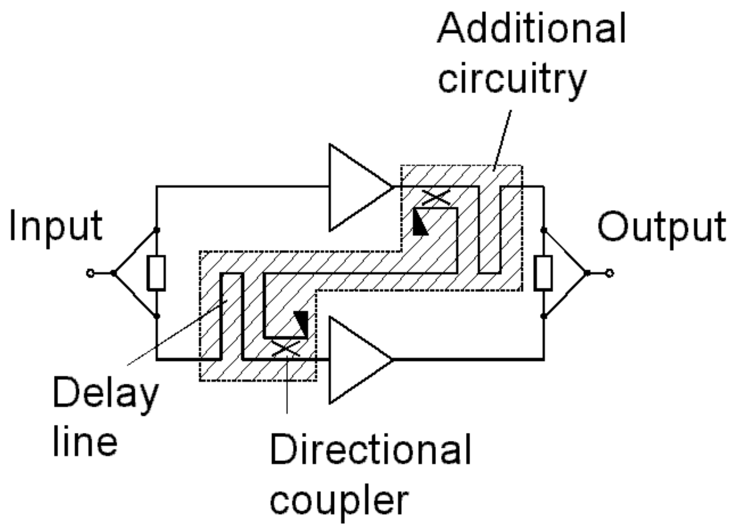

Fig.2 Concept of linearized amplifier combiner circuit

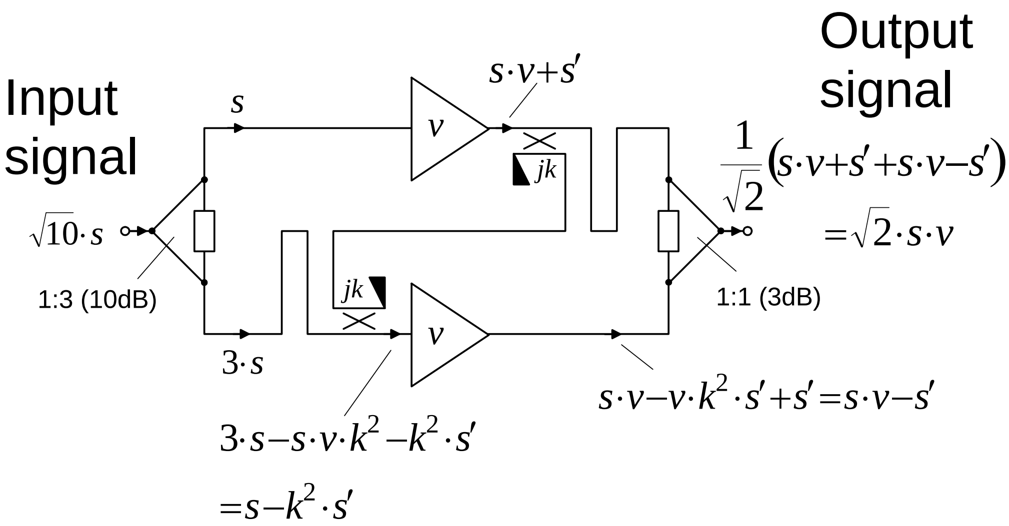

Fig.3 Linearized amplifier combiner circuit with signal levels indicated

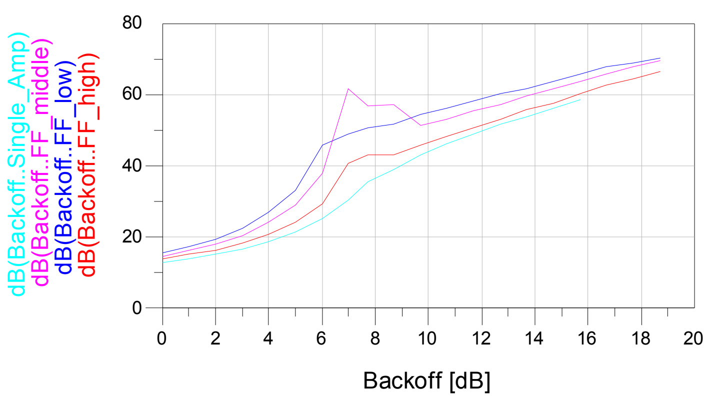

Fig.4 Back-off diagram comparing two-tone-IM suppression versus incident power level for a single amplifier and for the demonstrator circuit at three frequencies