Simplified RF Receive Frontend Architecture for Active Array Applications

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***Abstract*—A new concept for receive front end circuits is presented, which proposes the use of the low noise amplifier (LNA) in a second role as an amplifier of the local oscillator (LO) signal. Based on this concept, much of the complexity of the active array signal distribution networks (calibration and LO) can be reduced. It is shown that the danger of saturation, intermodulation and noise degradation can be overcome by using an unbalanced active mixer circuit which requires an LO-power level compatible with the limitations of modern LNAs.**

***Index Terms*—Active arrays, intermodulation distortion, mixers, noise, receivers.**

I. Introduction

THE complexity of receive frontend architecture is highly critical in active array applications where a high number of frontend circuits have to be realized, integrated into the system and supplied with receive (RF) signals, calibration signals (Cal) and local oscillator (LO) power. Applying conventional architecture to *superheterodyne* front ends [1], [2] requires separate networks for the distribution of calibration signals and LO-power because conventionally, the RF- and Cal-signals are fed into the front end antenna-port in order to travel through the LNA, while the LO-signal is fed separately into some extra LO-port of the mixer. Active array antenna systems thus pose complex 3-dim. integration requirements, as seen e.g. in [3].

A key to drastic reduction in complexity was found to be [4] the replacement of the usual balanced mixer with an unbalanced mixer and the amplification of LO-signal and Cal-signals through the LNA together with the received RF-signal, as shown in Fig. 1. However, this approach not only reduces the hardware effort and complexity of array systems but also bears the danger of degradation of the frontend noise characteristics and large-signal properties. The paper presents results from an experimental circuit and addresses the properties of the new front end architecture with respect to noise figure and intermodulation intercept point and discusses its unique application advantages.

II. Experimental Circuit

The architecture of Fig. 1 was realized at L-band using discrete components, Fig. 2. The circuit employs a proprietary bandfilter coupled LNA using a CFY19—field effect transistor and an active mixer built using a GAL4 (MiniCircuits) amplifier-block.

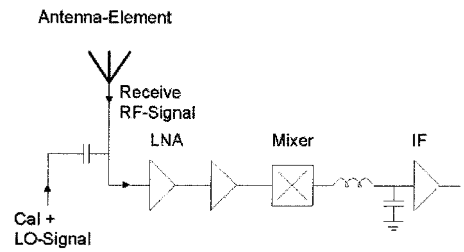

Fig. 1. Block diagram concept of new receive frontend architecture for active array systems.

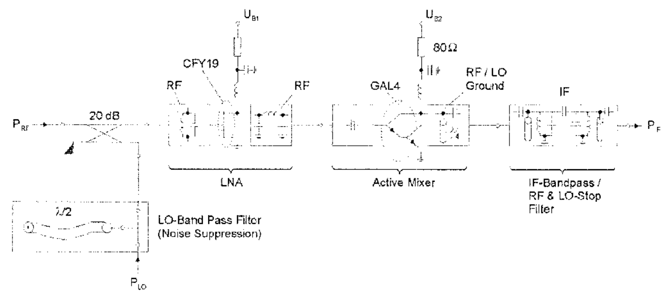

Fig. 2. Block diagram of experimental receive frontend using directional coupler to feed LO- and calibration signals into the LNA receive signal path and using an active mixer. Operating conditions: LNA at $I_{DS} = 10$ mA, mixer at $I_{CE} = 19$ mA, $U_{B2} = 6.5$ V.

The LO-signal is filtered and coupled through a directional coupler of 20 dB coupling into the LNA which is bandpass-coupled in order to suppress image frequencies and enhance the noise figure. The amplified signals are fed into the mixer which is realized as an active, unbalanced circuit exhibiting additive mixing (both RF-signal and LO-signal applied to the base of the bipolar transistor amplifier circuit). The mixer output incorporates the termination impedance required for optimum mixing operation.

From the circuit diagram of Fig. 2, it is obvious that common amplification of the RF-signal and the LO-signal by the band filter-LNA requires low IF in order not to suppress the LO-signal in passing through the RF-filter. It is also necessary to reject LO-noise sidebands from entering into the RF-signal path and being translated into the IF; this was realized by a narrow band filter for the LO-frequency inserted into the LO-signal feed line.

At the IF-end of the mixer, it is necessary to filter out the high-level LO-signal which is not suppressed due to the unbalanced mixer circuit.

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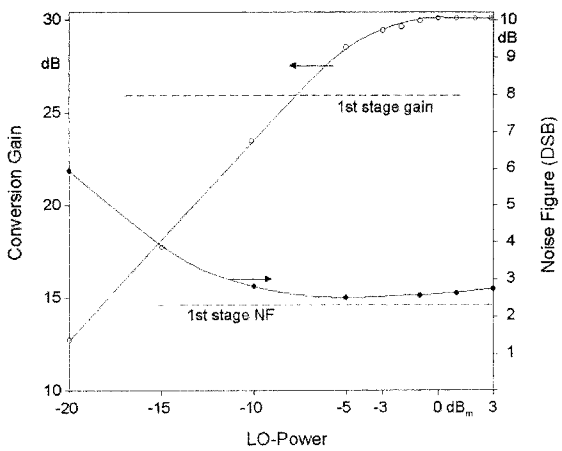

Fig. 3. Conversion gain and noise figure of the LNA-mixer chain versus LO-power at the input port of the coupler injecting into the LNA.

Questions concerning performance properties of the LNA-mixer chain can be discussed looking at Fig. 3.

In the figure, the conversion gain and the noise figure are plotted vs. the LO-power incident to the coupler. The measurement used an RF of 1295 MHz, LO-frequency of 1380 MHz and an IF of 85 MHz; with the given LNA bandwidth, the LO-frequency was placed at the band-filter upper -6 dB corner.

It can be seen that the noise figure of the first stage alone is only slightly degraded at LO-powers of -10 $\mathrm{dB_m}$ upward, which translates into about 0 $\mathrm{dB_m}$ of driving LO-level at the active mixer input. Higher LO-levels drive the mixer harder and provide mixing gain so that the total gain increases to 30 dB, which is about 4 dB above the first stage gain alone. At the same time, there is only a slight increase in noise figure with increasing LO-power, which can be attributed mainly to unsuppressed contributions from the LO synthezised source noise floor.

LO-drive power was chosen to be -3 $\mathrm{dB_m}$ for the measurement of the large-signal handling of the LNA-mixer chain. The output third-order intercept point (TOI) was measured at $+1$ $\mathrm{dB_m}$ which corresponds to -3 $\mathrm{dB_m}$ related to the mixer input and -29 $\mathrm{dB_m}$ related to the LNA-input. As was to be expected, the intermodulation properties are mainly governed by the mixer; since the LNA-output IP3 was measured at a high level of $+25$ dBm. In a separate measurement, the RF-gain compression of the LNA was measured. It was found that the gain degraded by only 0.1 dB at -3 dBm up to 0.2 dB at $+5$ dBm LO-power incident to the input coupler.

III. Discussion of Performance and Applications

From the above results, it can be concluded that the LNA was not degraded in its noise- and large-signal performance when employed in its second role as LO-preamplifier, as long as the produced LO-drive power was far below the amplifier's third-order intercept point, a condition that is easily satisfied using state of the art amplifiers and active mixer circuits. It can be stated thus that for the LNA-mixer chain the LNA fixes the noise figure while the mixer determines the large-signal handling capabilities. However, comparing the intercept points of conventional balanced mixers($+15$ to $+20$ dBm) to the present result for an active unbalanced mixer, it is obvious that the disadvantage of the proposed simplified RF receive frontend architecture lies in its inferior large-signal handling.

On the other hand, intermodulation requirements for individual modules in an active phased array can be drastically lowered by a factor equal to the number of elements in the array [5], so that the proposed architecture is viable for even medium-sized array applications. Apart from this, any other application that does not require superior large-signal handling, e.g. even small phased arrays for satellite navigation, can profit from a much reduced complexity of the array RF-circuitry [6].

References

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