Integrated Linearizer/Block Upconverters

Allen Katz*, Robert Gray and Roger Dorval

Linearizer Technology, Inc., Hamilton, NJ, 08619 USA
*The College of New Jersey, Ewing, NJ, 08628 USA

Abstract — The trend in the design of linearizers has been to integrate more and more functions with the basic distortion correction element. This paper discusses the latest development in this trend: the combining of the linearizer with the block up converter (BUC) into a single functional LBUC module. This paper will discuss the advantages of combining a BUC with a linearizer and describe an LBUC developed for a Ka-band SATCOM application.

***Index Terms* — linearizer, linearization, predistortion, upconverter, high power amplifier, TWTA, SSPA.**

I. Introduction

Predistortion linearization has been successfully employed at microwave frequencies for many years to improve the linearity of TWTAs and SSPAs, particularly for SATCOM applications [1]. Since linearizers were first produced, the trend has been to integrate more and more functions with the basic linearizer. This paper presents the latest development in this trend, the combining of the linearizer and the block up converter (BUC) into a single integrated unit, referred to as an LBUC. It will focus on the design of a new Ka-band LBUC and document its performance. It will also discuss the advantages of combining a BUC with a linearizer, and the associated trades as whether to place the linearization elements and control components such as a wide range attenuator at the input or the output frequency band.

II. Linearizer/BUC System Concept

The components contained within a high power amplifier (HPA), typically include a BUC, solid state amplifier (SSA), linearizer, driver amplifier, power booster amplifier (solid state or traveling wave tube, TWT), power supply and control electronics as shown in Figure 1.

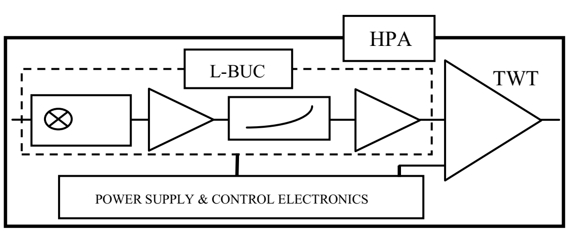

Fig. 1 – LBUC as part of an HPA.

The LBUC concept is depicted in Figure 1 by the dotted box and can incorporate the BUC (including internal/external reference and lock alarm), SSA, adjustable attenuator and gain blocks, linearization circuitry, versatile command interface, optional power detectors and mute function, and output driver amplifier (levels to > +27 dBm) into one compact package.

III. Advantages of a Combined BUC and Linearizer

Combining the BUC and the linearizer offers significant advantages. These include: a) reduction in size and weight (improved SWAP) due to the single assembly, b) reduced costs for materials and documentation associated with keeping track of multiple assemblies, and c) improved performance. The LBUC concept results in a flatter frequency response, since it can be tuned as a single assembly. Its gain ripple is also minimized since the separation between components and the number of interconnects can be minimized. The temperature compensation is improved by combining assemblies. In addition, since the BUC and the linearizer are nonlinear devices, they both produce unwanted spurious signals; emissions from the BUC when mixed with spectral components produced by the linearizer can produce new, unanticipated spectral terms when the two modules are combined. The integrated LBUC eliminates the possibility of such spectral surprises.

III. Intermediate Frequency/Baseband Correction

The use of an integrated LBUC also provides design flexibility resulting in superior performance over other configurations. For example, the linearization can be done at the frequency of the HPA, or at an intermediate frequency (IF), or even at baseband (BB). Most digital signal processing (DSP) based linearization is done at BB. The digitally predistorted signal is mixed up to the transmission or RF frequency using a balanced quadrature mixer (QM) as illustrated in Figure 2.

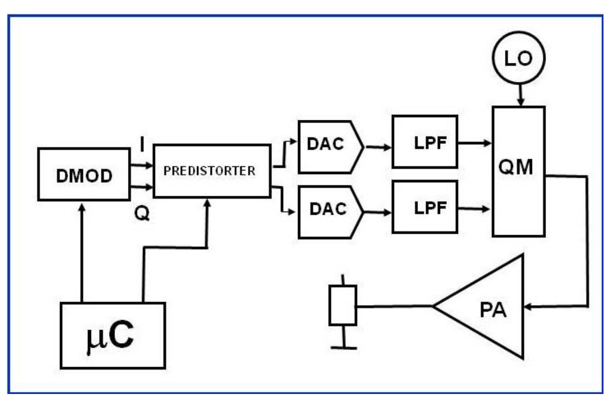

Fig. 2 – Baseband DSP linearization mixes up to RF with a QM.

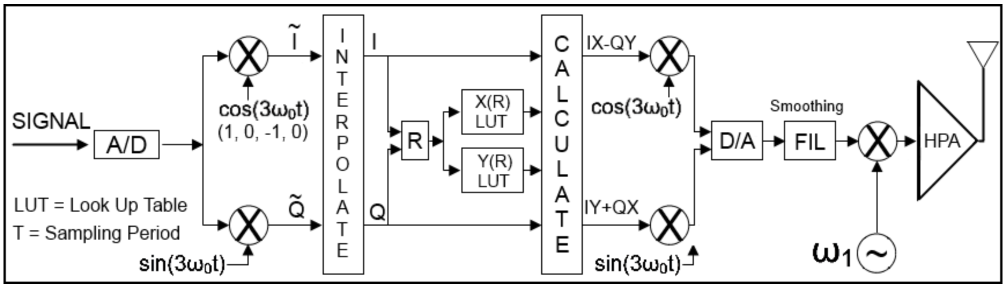

Fig. 3 – DDC may be used to remove the balance problems caused by the QM.

The balanced QM is used to attenuate the carrier and eliminate the need for a filter to reject the unwanted mixer products. It also allows the RF signal bandwidth to be twice the bandwidth of the BB signal. This can be important, as DSP linearization is limited in its ability to process high frequencies, and must process at 3 to 7 times the signal bandwidth (BWS), dependent on the desired improvement [2]. Thus it must process at a bandwidth (BWP) several times the BWS, typically:

$$\text{BWP} \geq 5\sim7 \text{ BWS} \qquad (1)$$

By using in-phase (I) and quadrature (Q) signals at BB, two DSPs (I and Q) can operate at the same time at BWP/2 or

$$\text{BWP} \geq 2.5\sim3.5 \text{ BWS} \qquad (2)$$

For BWS > 25, ~ 50 MHz, DSP can become quite costly, both economically and power wise, and analog predistortion linearization (PDL) often becomes the preferred method of linearization [3].

BB DSP is often not the preferred method because of the difficulty in maintaining sufficient balance by the QM. Direct digital conversion (DDC) is used to remove the problems caused by the QM, and the resulting IF signal is upconverted using a conventional mixer as illustrated in Figure 3. However, the use of DDC eliminates the DSP's bandwidth advantage in BB processing, (2) vs. (1).

Another complication with DSP PDL is that PA nonlinearity can change with frequency. For effective linearization over wide bandwidths, a PDL must change its nonlinear characteristics with frequency to match those of the HPA. Digital PDL cannot easily make these changes without going to very complex processing, which limits its capacity for wider bandwidth signals. For narrow band signals, it can partially compensate for this degradation by adaptively changing its correction characteristics. The ability of analog linearization to modify its characteristics over a multi-GHz frequency range has made it the preferred method of linearization for wideband applications.

If the HPA includes an attenuator for gain adjustment, the LBUC allows flexibility as to where this attenuator is located. (Note: It must always be located before the PDL.) The location of this attenuator affects both noise floor/noise figure and the level of spurious components. Generally, it is desirable to locate any high loss where the signal is at its highest possible level for noise considerations. Locating a wide range attenuator after the mixer, means that both signal and spurious will be attenuated. Locating it after the mixer also means the attenuator will be driven at its highest level and the mixer cannot be protected from overdrive by increasing the attenuation. Predistortion linearization should be done as close to the HPA as practical: The predistortor at any frequency must produce the opposite of the PA's transfer characteristics in magnitude and phase. The equations relating the input to the output are complex:

$$GL(P_{inL}) \;=\; GL_{ss} + GA_{ss} - GA(P_{inL} + GL(P_{inL})) \qquad (3)$$

$$\Phi L(P_{inL}) \;=\; \Phi L_{ss} + \Phi A_{ss} - \Phi A(P_{inL} + GL(P_{inL})) \qquad (4)$$

In the equations ss stands for *small signal* and inL stands for *into the linearizer*. When the desired PDL's transfer characteristics are expanded in a power series, higher than third order terms are required to obtain the required correction transfer curve – even if the HPA produced only third order nonlinearity as illustrated in Figure 4.

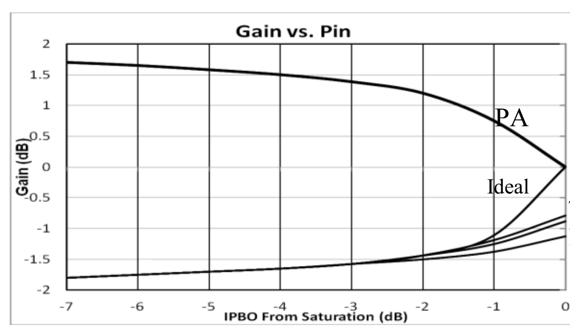

Fig. 4 – Gain vs. input power of a cubic (3rd order) HPA with 3rd, 5th, 7th, and infinite order PDL.

This result means that the linearizer must produce frequencies outside the correction bandwidth of the HPA. Any network (or filter) that limits these higher order terms will degrade the performance of the linearizer. This can be a major problem when predistorting before the BUC where sharp bandpass filters are required to attenuate unwanted spectral terms.

At each frequency, the transfer response of the PDL must compensate for the HPA's nonlinear response. The P_{outL} must correspond to the required power into the HPA. Any variation in ss gain between the PDL and the HPA, such as gain ripple due to mismatch, will throw off this relationship. Variation of ss gain must be equalized for best performance. For example a 2 dB gain ripple can degrade a 30 dB carrier-to-intermodulation ratio (C/I) by 3 dB [4]. Consequently, components between the PDL and the HPA that may affect flatness and increase ripple should be avoided. Components before the PDL may degrade overall system flatness, but do not degrade the linearizer's performance. Similar conclusions apply to temperature compensation. The effect of temperature on the gain relationship between the linearizer and the HPA must be compensated, but temperature related gain change in front of the PDL do not degrade linearizer performance. Thus when performing linearization at IF, the BUC must be carefully temperature compensated for the gain relationship between the PDL and the HPA, and not the overall system. (These same factors must be considered when performing digital BB PDL, but are normally mitigated by adaptively adjusting parameters to maintain the best linearity.) One factor working for the use of IF PDL is that percentage bandwidth increases at lower frequencies. The larger percentage bandwidth at IF, can make it easier to achieve a desired change in predistortor nonlinearity with frequency. This plus is usually out weighted by the other disadvantages.

IV Ka-band LBUC

A Ka-band LBUC is shown in Figure 5. It is 5.0" L x 3.5" W x 1.2" H and weighs less than 32 oz. It upconverts an L-band IF signal to an RF signal at 30 to 31 GHz and operates at a bus voltage of +12 V.

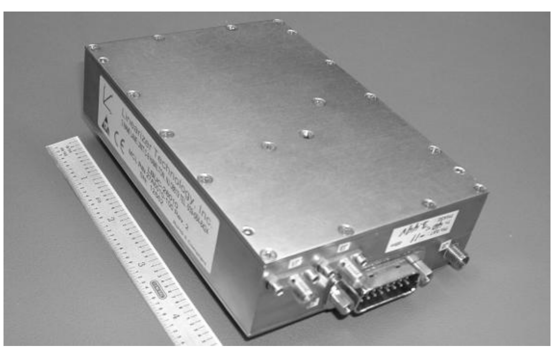

Fig. 5 – Photo of Ka LBUC (IF: L-band, RF: 30-31 GHz)

The LBUC provides a predistorted RF power of greater than 16 dBm and is temperature compensated from -40° C to 85° C. Spurious signals are less than -70 dBc; the image rejection and IF harmonic spurs are less than -60 dBc. LO leakage is < -65 dBm. Phase noise meets IESS 308/309 and MIL-STD-188-164. Figure 6 shows the improvement in transfer response that an LBUC can provide with a TWTA. The 1 dB compression point is 6 dB closer to saturation and the phase is reduced by > 40°.

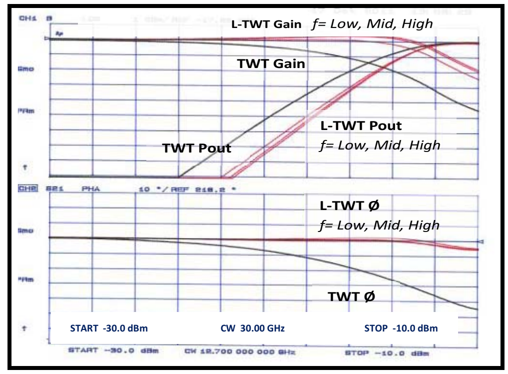

Fig. 6 – Transfer correction of Ka LBUC with a TWTA.

Figure 7 shows measured 2-tone C/I versus output power backoff (OPBO) for a Ka-band SSPA across a band from 30 to 31 GHz. The LBUC allows the SSPA to operate up to nearly a 2.5 dB OPBO and still maintain a 25 dB C/I. Similar results can be achieved with a TWTA. It enables an HPA to produce about 6 dB (4X) of additional output power.

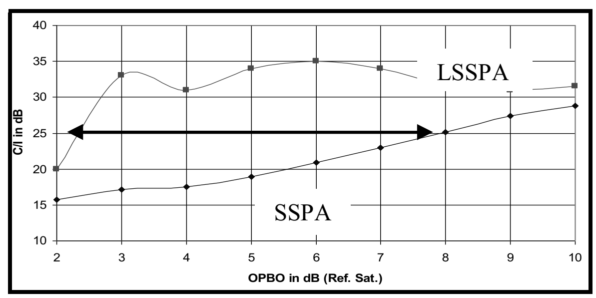

Fig. 7 – 2-tone C/I of Ka LBUC and SSPA vs. OPBO.

VI. Conclusion

A Ka-band LBUC has been presented. An LBUC can turn an HPA into a high performance mini-system that reduces the number of needed components and interconnects, and provides cost saving and improved performance over a separate BUC and linearizer.

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