Duty-Cycle Linearization Technique for Microwave and RF Transmitters

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Abstract — **The exponential growth of the mobile and wireless applications is continuing unabated so that more and more demands are being placed on the available spectrum. This has stimulated the utilization of complex modulation techniques such as QAM, as well as spread spectrum system. Preserving the required severe linearity constraints using the conventional methods, however, deteriorates the overall power efficiency [1].**

Reconciliation of the power-added efficiency and the spectral bandwidth efficiency has been addressed by using the Duty-Cycle principle with a high efficient Switching amplifier. In this paper, it will be discussed the Duty-Cycle modulation technique as a new transmitter configuration for broadband communication systems and non-constant envelope RF signals.

The configuration developed comprises a comparator, a class S amplifier and two linear elements. The primary linear element is considered to be the required class S amplifier's matching network although the auxiliary filter is supposed to regulate the system's resonation frequency. The simulation results emphasis the broadband linearization and power-efficiency features of the "Duty-Cycle Modulation" technique.

Keywords— **SAFE; ProRISC; Duty-Cycle principle; transmitter; Class-S amplifier; efficiency; complex modulations; QAM; linearity; broadband system;**

I. INTRODUCTION

Unprecedented demands for higher bandwidth efficiency in RF transmission systems have led to the employment of sophisticated modulation techniques, as for example QAM. Use of these modulation techniques requires transceivers having very linear transmission properties in order to process the signal correctly and to suppress interference with adjacent transmission channels.

Simultaneously maintaining linearity and efficiency over a wide dynamic range is basic issue for the microwave and RF transmitters, in particular Power Amplifiers (PAs). Such modulated signals, however, contain a non-constant envelope, which results in a relatively large envelope peak-to-average ratio. Accordingly, conventional linear-mode power amplifiers, for example class A, AB, or B, have to operate in a region well below the 1-dB compression point, resulting in a poor power efficiency performance.

A new transmitter configuration with a high efficient Switching amplifier and based on the Duty-Cycle principle (see [2], [3] and [4]) has been investigated.

II. DUTY-CYCLE PRINCIPLE

A Duty-Cycle Modulator is a self-oscillating circuit consisting of a non-linear element and a linear element which are operating in a negative feedback loop (see Figure 1). The Duty-Cycle system may contain only a discreet set of limit cycle amplitudes and frequencies.

The non-linear (or relay) device converts an input signal into a discrete-level output signal, for example a two level (1 bit) signal using a switching device. Errors introduced by the relay device are shaped in the frequency domain.

This configuration has been referred in the literature as *asynchronous sigma-delta modulator* due to its pulse width modulation characteristic (see [2] and [4]), and it consists in an Integrator with a Loop-Gain block as the linear component and a two-level quantizer with hysteresis as the non-linear component (see Figure 1). The pulse width modulation property allows the implementation of switching type devices (e.g. a high efficiency Class S power amplifier, see [1]).

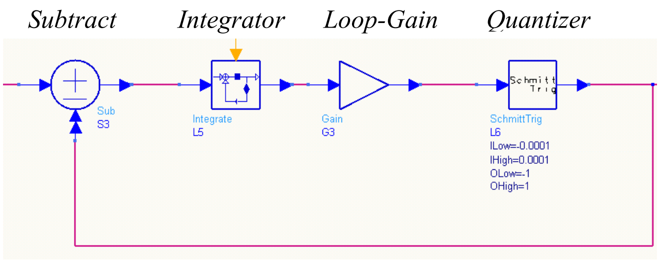

Figure 1. The basic configuration of the Duty-Cycle principle.

In the absence of the input signal, the undamped oscillation frequency (the natural stability condition) of the limit Duty-Cycle can be derived from the following equations,

$$\begin{aligned} &1+N(A,\omega)L(j\omega)=0\\ &\Re(N(A,\omega))\Re(L(j\omega))-\Im(N(A,\omega))\Im(L(j\omega))=-1\\ &\Re(N(A,\omega))\Im(L(j\omega))+\Re(N(A,\omega))\Im(L(j\omega))=0 \end{aligned}$$

$N(A,\omega)$ and $L(j\omega)$ are respectively the describing function of the nonlinear component and frequency response function of the linear component. From the above equations can be concluded that when the nonlinear component does not possess hysteresis property, the resonation frequency of the limit cycle modulator will be determined only by the phase-shift introduced by the linear component.

Due to the self-oscillating properties of the Duty-Cycle modulator, the RF input signal is modulated in such a manner that non-linear products, created by the relay device, are frequency modulated. The interference rate between the non-linear frequency modulation products and the desired frequency is on the one hand a function of the offset between the desired and the resonation frequency and on the other hand the signal's power level. This interference rate can be inclined by shifting the system's resonation frequency towards the higher frequency range which in return complicates the operational condition and deteriorates the performance of semiconductor devices.

Furthermore, improving the overall power efficiency imposes the reduction of the power consumption of the system's resonation frequency which can be achieved either by the increasing the impedance level at the resonation frequency or by the suppressing the system's resonation frequency.

III. TRANSMITTER ARCHITECTURE BASED ON THE DUTY-CYCLE PRINCIPLE

The wideband linearization feature of the "Limit Duty-Cycle Modulation" technique, in conjunction with the applicability of the switching type amplifier (see [1]) enables the realization of a new kind of transmitter architecture that facilitates the optimization of linearity and power-efficiency. Figure 2 presents a Duty-Cycle modulator which comprises a comparator, a switching type amplifier and two linear elements. The primary linear element is considered to be the required Class S matching network although the auxiliary filter is supposed to regulate the system's resonation frequency. In the absence of the auxiliary filter the primary linear element has to:

- determine the resonation frequency,
- act as the output termination,
- suppress the magnitude of the oscillating frequency.

The imposed restrictions on the characteristic of the primary linear component complicate the design process of the filter. An additional degree of freedom can be introduced by an auxiliary filter in the feedback path. In this way, the primary filter can regulate the output termination and simultaneously restrict the power dissipation of the resonation frequency, though the auxiliary filter adjusts the resonation frequency.

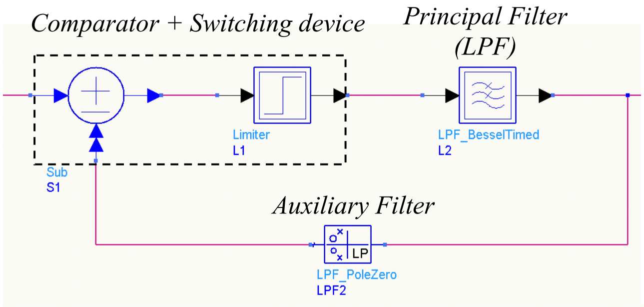

Figure 2. The Duty-Cycle configuration suitable for broadband communication applications.

IV. SIMULATION RESULTS

For the illustrative purposes, the primary filter is assumed to be a Bessel type filter and the resonation frequency of the system is normalized to one. Figure 3 presents the signal to distortion ratio, SDR, as a function of the input power level, in the case of a two-tone input signal. The desired signal is allocated at the 1/5±1/100 of the resonation frequency and the SDR is measured in a bandwidth of 3/5 of the resonation frequency. Figure 4 shows the output spectrum for the input signal power corresponding to the maximum SDR.

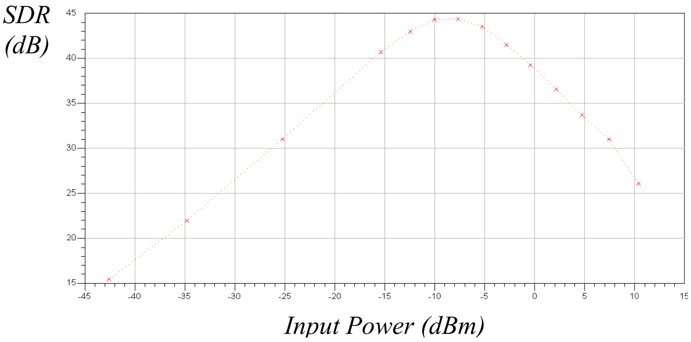

Figure 3. The SDR measurement vs. Power of the two-tones input signal (f_{in} = 1/5±1/100).

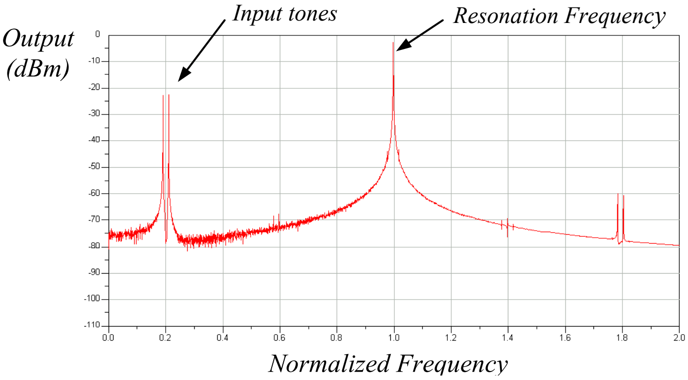

Figure 4. The Output spectrum for the maximum SDR.

Figure 5 presents the response of the system to a 16-QAM which has a bandwidth of 1/8 of the resonation frequency and is allocated at the 1/10 of the resonation frequency.

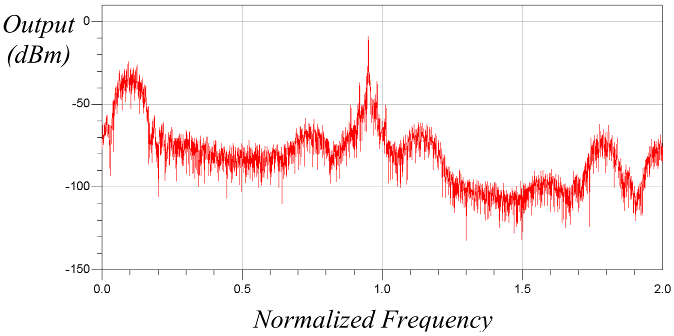

Figure 5. The Response of the Duty-Cycle Transmitter configuration to a 16-QAM.

V. CONCLUSIONS

A concept of achieving high-efficiency linear amplification of non-constant envelope RF signals has been presented.

The wideband linearization feature of the "Limit Duty Cycle Modulation" technique, in conjunction with the applicability of the Class S power amplifier, enables the realization of a new kind of transmitter architecture that facilitates the optimization of linearity and power-efficiency over a large operating-range of output power level and frequency bandwidth.

Distinguished characteristics of the presented configuration enable the achievement of an optimal linearization amplifier in terms of linearity, efficiency, bandwidth and dynamic range.

VI. REFERENCES

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