# A CMOS Hybrid Switching Amplitude Modulator for Class-E2 EDGE Polar Transmitters

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**Abstract** - *A hybrid switching amplitude modulator for class-E2 EDGE polar transmitters is proposed. To achieve both high-efficiency and high-speed, it consists of a wideband buffered linear amplifier as a voltage source and a hysteresis-controlled switching amplifier as a dependent current source. The novel linear amplifier has a high current driving capability of approximately 160mA with a bandwidth wider than 7MHz. It can also operate on two quadrants with very low output impedance of about 300mΩ around the switching frequency attenuating the output ripple voltage. The output voltage of the hybrid modulator ranges from 0.3V to 3V for a 3.3V supply. It can drive an RF power amplifier with an equivalent impedance of 7Ω up to a maximum output power of 1.1W with a maximum efficiency of about 85%. The chip is fabricated using thick-oxide devices in a 0.13um CMOS process and occupies an area of 3.9mm$^2$.*

**Keywords:** Polar transmitter, EDGE, switching amplifier, output impedance, buffer.

## 1 Introduction

Polar transmitters shown in Fig. 1 are good candidates for high data rate systems using amplitude as well as phase modulation because it is easy to obtain high efficiency by using efficient switched-mode RF power amplifiers in addition to multi-mode function and unnecessariness of filters. In particular, recently, power consumption has been further reduced by replacing LDO linear modulators in the amplitude path with switching modulators. Nevertheless, LDO modulators are still used in most polar transmitters because of the limited bandwidths of switching modulators. Essentially, in the course of splitting a complex signal into its amplitude and phase components, the bandwidth of each component becomes wider than that of the original signal [1]. Moreover, it is difficult for a switching modulator to follow a high-frequency magnitude signal efficiently since high switching frequencies are required and switching loss increases with switching frequency. Therefore, switching modulators have either been used in envelope tracking applications or have been implemented with external components or expensive high-speed processes such as GaAs or SiGe. A CMOS amplitude modulator based on the concept of interleaving delta modulation was suggested for polar transmitters in [2]. However, it consumes a lot of power and requires many external components, especially, binary-weighted inductors. In this paper, the hybrid switching amplitude modulator is designed to meet Class-E2 EDGE requirements using only a few external components.

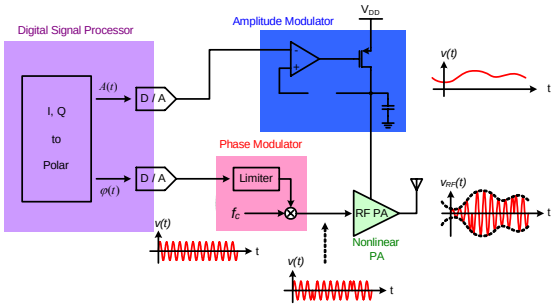


Fig. 1 Block diagram of polar transmitter

## 2 Hybrid switching amplifier based on the hysteretic control

As shown in Fig. 2, the proposed amplitude modulator has a hybrid structure consisting of a wideband linear amplifier as a voltage source and a hysteresis-controlled switching amplifier as a current-controlled current source to obtain both high-speed and high-efficiency. Although this concept has been suggested for audio [3, 4] and envelope-tracking applications, it has not been used for a polar transmitter in a CMOS process because it was too difficult to design a linear amplifier with a wide bandwidth, a low output impedance and a high current driving capability.

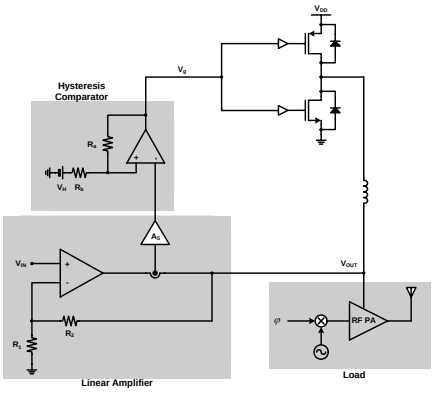

Fig. 2 Block diagram of hybrid switching amplifier

The bandwidth of linear amplifier should be higher than 2MHz because that of the switching amplifier is too narrow to meet the EDGE spectral requirement [1]. Low output impedance at the switching frequency and its harmonics is also an essential characteristic to prevent the output ripple voltage from violating the spectral requirement of -60dBc.

## 3 Linear amplifier with very low output impedance

Several CMOS output stages have used common-source (CS) or source-follower (SF) configurations. However, a CS output stage has inherently high output impedance, and a SF output stage has a limited output swing unsuitable for rail-to-rail operation. Thus, the novel class-AB output buffer shown in Fig. 3 is proposed. SF transistors ($M_{NSF}$ and $M_{PSF}$) as voltage sources and CS transistors ($M_{PCS}$) as a current-controlled current source constitute two local loops in the middle range of the output voltage, respectively. During positive output swings, $M_{NSF}$ is turned off by SW1, and one loop ($M_{PSF}$-$M_{N1}$-$M_{PCS}$) source the output ripple current. During negative output swings, $M_{PSF}$ is turned off by SW2, and the other loop ($M_{NSF}$-$M_{P1}$-$M_{PCS}$) performs the same function. By turning off SW1 or SW2 near each supply rail just before the output is clipped, rail-to-rail control is possible. The linear amplifier has an $f_T$ of about 7MHz, the output impedance of about 0.3Ω around the switching frequency and a current driving capability of approximately 160mA.

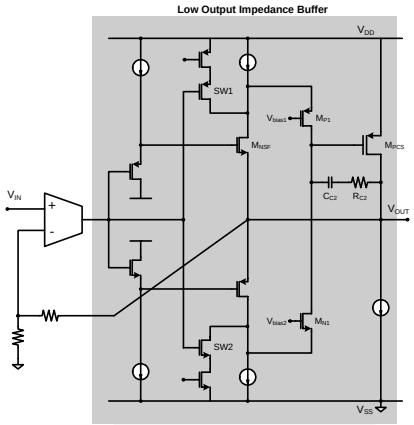


Fig. 3 Two-quadrant low output impedance amplifier

## 4 Experimental results

This chip is fabricated using thick-oxide devices in 0.13μm CMOS process with an area of 3.9mm$^2$. Fig. 4 shows a micrograph of the chip. Waveforms for a 50kHz sinusoidal and square-wave signal with a 7Ω load are given in Fig. 5(a) and 5(b), respectively. The hybrid switching modulator can supply a maximum 1.1W to a 7Ω load with about 85% efficiency.

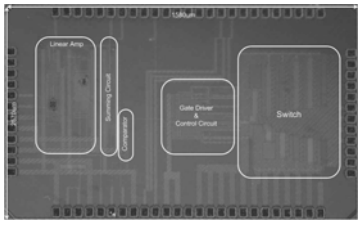


Fig. 4 Chip micrograph

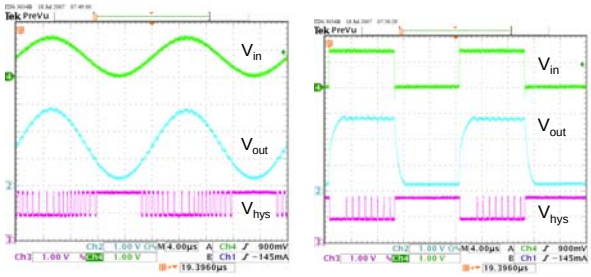


Fig. 5 (a) sinusoidal and (b) step response at a 7Ω load

## 5 Conclusions

A CMOS hybrid switching amplitude modulator based on a hysteretic control is proposed to achieve both high-efficiency and high-speed for class-E2 EDGE polar transmitters. We also propose a novel buffer amplifier with a wide bandwidth, low output impedance, two-quadrant operation, and a high current driving capability. In conclusion, the hybrid switching amplitude modulator satisfies the requirements of the output power, the error vector magnitude and the spectral mask margin.

*Acknowledgment :*

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## References

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