

AN APPLICATION OF ENVELOPE ELIMINATION AND RESTORATION TECHNIQUE FOR CLASS-E RF POWER AMPLIFIERS

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ABSTRACT

This paper presents an application of envelope elimination and restoration technique [1], [2] to improve the linearity of a highly efficient but nonlinear RF power amplifier. It comprises of an envelope detector, a limiter and a switching power supply.

I. INTRODUCTION

The rapid developments in voice and data transmission systems and the growing demand for mobile communication has introduced more emphasis on the design of faster, more efficient mobile communication systems. To make advanced communication systems faster, it is required to use modulation schemes that generate non-constant amplitude RF signals so as to increase spectral efficiency. However, these type of signals require linear RF power amplifiers (PAs) which are inherently less power efficient. Due to the low efficiency of the traditional class-A and class-AB power amplifiers, which ensure that sufficient linearity, more power is dissipated in the system and more complex heat management system is needed. Nonetheless, switched-mode power amplifiers can be highly efficient but will also be nonlinear and causes unacceptable distortion while amplifying non-constant envelope signals. So in these cases, the challenging block in designing faster and power efficient mobile communication systems is the RF power amplifier.

There are several implementations of using Kahn's EER technique have been reported. A medium-power HF transmitter employs a class-D RF PA and a class-S modulator achieves an efficiency of about 60% for virtually all input signals [3]. A3 low power UHF transmitter employs a class-E RF PA and a class-S modulator and also achieves an overall efficiency of 60% over most of its dynamic range [4]. Compared to the other linearization techniques, Kahn EER technique ensures sufficient linearity as well as an increase on the efficiency of the overall system.

In this paper an application of the EER technique for Class-E RF PAs working at 1.9 GHz is presented and some of the simulation results are shown. An amplitude modulated (AM) signal with 10 MHz bandwidth is used for the input of the system and this signal forced to pass two different paths simultaneously as seen from Figure-1.

II. ENVELOPE ELIMINATION AND RESTORATION TECHNIQUE

Figure-1 shows the block diagram of the EER linearization scheme as first proposed by Kahn [1]. In this scheme envelope of the AM input signal is first eliminated by a limiter to obtain a constant amplitude phase signal. At the same time, the magnitude information of the input signal is extracted by an envelope detector and driven into a switching power supply to generate the supply voltage (V_{DD}) for switched-mode RF PA. If we use a Class-E PA to recombine the magnitude and phase information, the output power will then be proportional to V_{DD}^2 and the output signal will have the phase information of the AM signal, so the output signal will then be an amplified replica of the input AM signal. Unfortunately, in practise the signals following two different paths will have different delay time and we need to add sufficient delay to the signal passing through the limiter before recombining it with the magnitude information by Class-E PA.

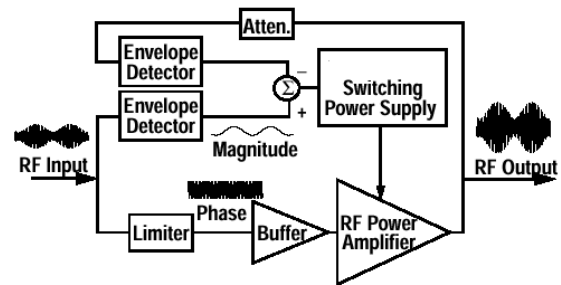


Figure 1. EER technique block diagram

III. ENVELOPE DETECTOR

The circuit of an envelope detector is shown in Figure-2. This system is capable of extracting 10 MHz envelope information from a 1.9 GHz AM signal. Due to the lack of an ideal diode that can operate at the RF frequencies in CMOS technology, transistor M_1 , C_1 and current source I_1 acts as a diode in this circuit. Transistor M_2 with current source I_2 are used to cancel the dc voltage and the distortion which comes from M_1 , [6].

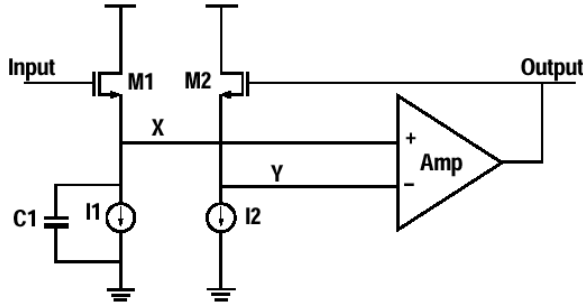


Figure-2. Envelope detector circuit

As shown in Figure-3 the output of the envelope detector changes with the envelope of the AM signal successfully. In other words output of the circuit follows the input correctly. The delay between these signals is around 5ns for this particular simulation. So we can use this magnitude information as an input signal for the switching power supply which is shown in Figure-1.

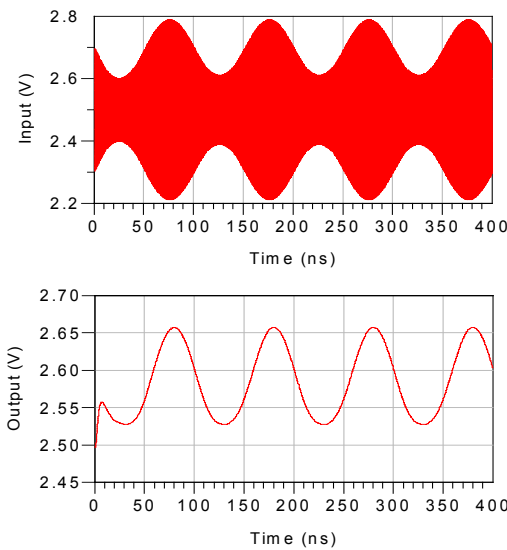


Figure 3. Envelope detector simulation results

IV. LIMITER

The block diagram of the limiter is shown in Figure-4. It consists of an envelope detector, a VGA (Variable Gain Amplifier), and an error amplifier. The limiting action is performed with a variable gain amplifier by changing its gain proportional to the magnitude at the output of the envelope detector. In this study we use the gain function of the VGA as ;

$$A_v = 8 - 8 V_{M1G} \quad (4.1)$$

As shown from (4.1) that when the envelope of the AM signal increases, the gain of the VGA decreases with $8 V_{M1G}$ so as to generate constant envelope phase signal.

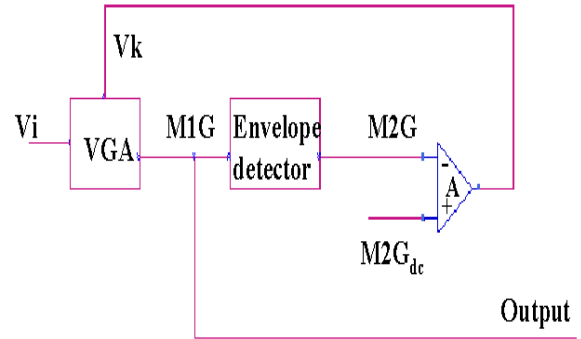


Figure 4. Limiter circuit

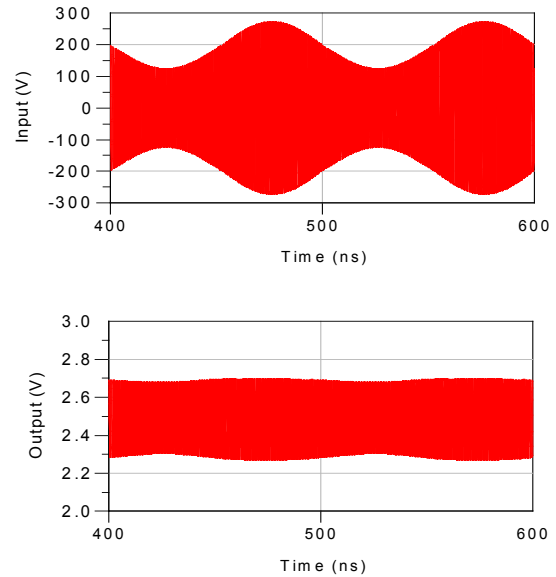


Figure-5. Limiter circuit simulation results

The simulation results are shown in Figure-5 for the limiter at 1.9 GHz carrier frequency with 10 MHz bandwidth input signal. It is clear that this circuit successfully removes the envelope variation of the AM signal and generates almost constant envelope output signal. The main source of the delay in this circuit is the envelope detector and we can take the delay of this circuit is 5 ns.

V. SWITCHING POWER SUPPLY

Figure-6 shows the block diagram of the switching power supply (SMPS) used in this study. It consists of a triangular wave generator (TWG), a pulse-width modulator and a class-S modulator. The input of the overall circuit comes from the envelope detector and defines the envelope variation of the AM signal. This envelope information is then compared with the triangular waves generated in system and pulse-width modulated (PWM) signals generated. Then, the PWM signals control the input of the Class-S modulator and a time varying voltage is generated at the output of the SMPS. This time varying signal in fact shows the envelope variation of the AM signal and used as V_{DD} voltage for the class-E PA.

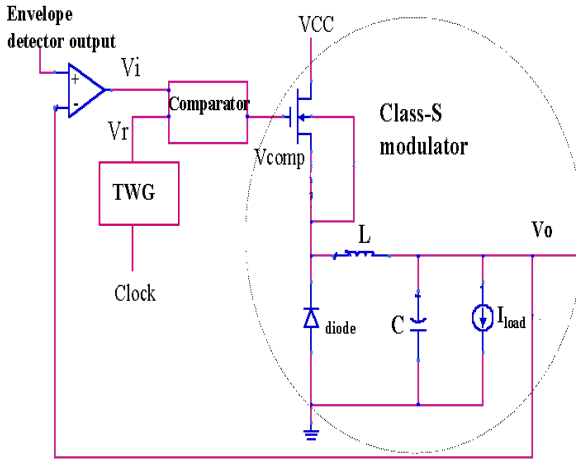


Figure 6. Switching power supply circuit

The maximum output power of this circuit is (5) ;

$$P_o \leq \frac{V_{CC}^2}{R} \quad (5.1)$$

The power dissipated in the system is

$$P_d = \frac{\theta_s^2}{4\pi} V_{CC} A \quad (5.2)$$

Where A is the average amount of output current , R is load impedance and θ_s is the transition time in radian for comparator circuit [5].

$$A = \frac{2V_{CC}}{\pi R} \quad (5.3)$$

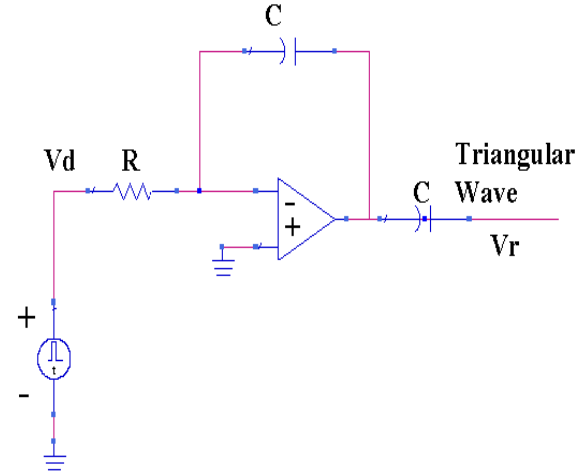


Figure 7. Triangular wave generator

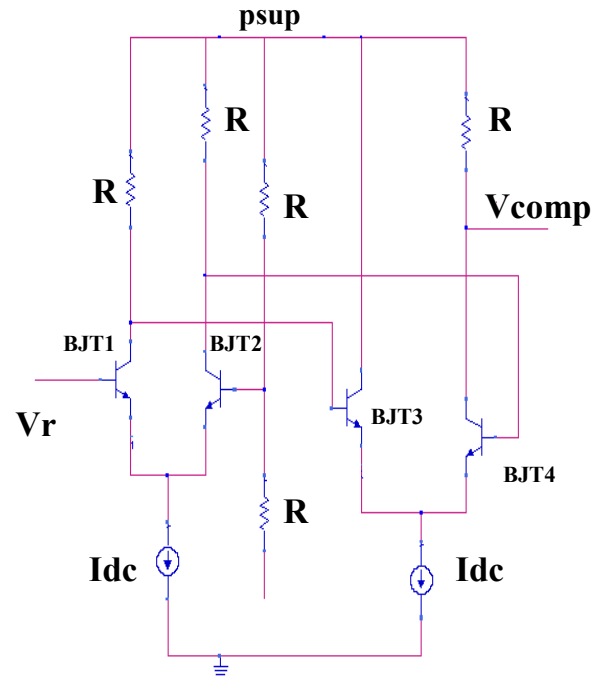


Figure-8. Comparator circuit

As shown in Figure-9 we obtain output voltage change between 0.140 V – 4.6 V with this circuit and this voltage is used to replace V_{DD} in a Class-E PA. We can also arrange the lower and upper limit of this voltage by changing the supply voltage (V_{CC}) and the value of the passive components of the SMPS so as to obtain sufficient power at the output of class-E RF PA. From the classical theory the optimum output power for class-E PAs is defined as ;

$$P_o = \frac{2}{1 + \pi^2/4} \frac{(V_{DD})^2}{R} \cong 0.577 \frac{(V_{DD})^2}{R} \quad (5.4)$$

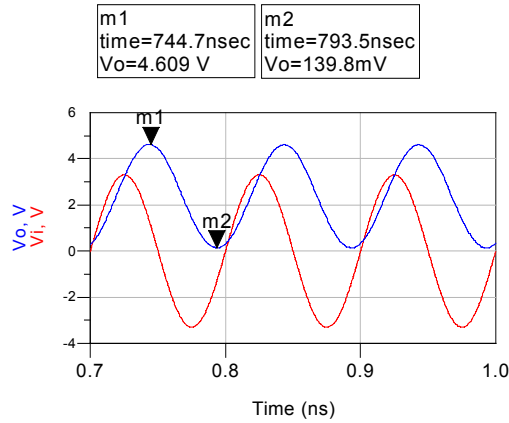


Figure 9. Switching power supply input-output signals

For different signal frequencies the delays of the SMPS will be different in time domain. In Figure-10 we can see these delays in radian are plotted for different input frequencies. In fact, this input frequencies equal to the bandwidth of the amplitude modulated signal and determines the speed of the SMPS. The biggest delay occurring in an EER system is always caused by SMPS and this is nearly equals a quarter of a signal period.

If sufficient amount of delay is not introduced upon the signal passing through the limiter circuit, there will be a phase shift between envelope and phase signals and the output signal will has a great distortion. Therefore, a proper delay equaliser should be included into the envelope signal path in order to avoid such a distortion.

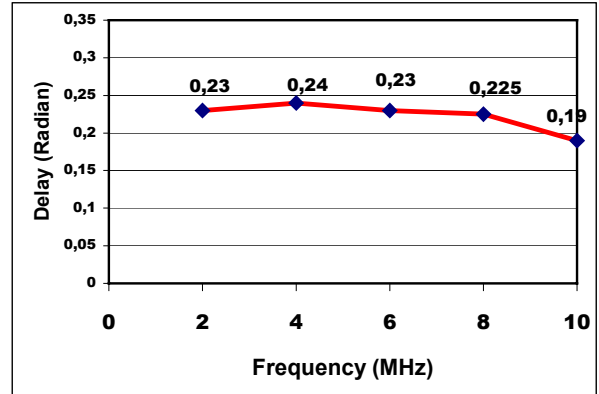


Figure 10. SMPS delay time for different frequencies

V. CONCLUSION

As shown with the simulation results first the envelope of the AM signal can be eliminated then it can successfully be restored on the phase modulated signal. If a Class-E PA is used as a combiner at the output operation of a power amplifier with a very high efficiency and an acceptable distortion can be obtained. Due to the efficiency benefit of this scheme (the theoretical efficiency of a class-E PA is 100%) compared to the other linearization schemes, EER technique might be dominate the next generation transmitter designs.

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