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Efficiency Investigations of DC-DC Converter Supplying Power Amplifiers

Tihomir Brusev[1], Boyanka Nikolova[2], Georgi Kunov[3] and Stoyan Vuchev[4]

Abstract – **In the modern battery powered mobile communication devices output transmitted power is changed in wide range. Most of the energy in such electronic systems is consumed from power amplifier (PA). By increasing of power amplifier's efficiency significantly could be increased the overall efficiency of those portable devices. The widespread used method is modulation of collector voltage (V_{cc}) of PA. Using switching-mode dc-dc converter the operated voltage of power amplifier could be dynamically changed. In this paper are presented investigation results of dc-dc converter, which can be used for dynamically regulation of collector voltage of PA.**

Keywords – **dc-dc converter, efficiency, Cadence, CMOS technology.**

I. Introduction

The modern mobile communication electronic devices transfer data in the wide frequency range. One of the most critical parameter is their efficiency because of the limited battery resources [1]. Therefore power consumption of the system's building blocks has to be minimized. Most of the energy is consumed from power amplifier. Improving of transmitted power efficiency of this single component can help to increase the battery run time.

Power amplifiers (PAs) used in the portable communication devices have to be linear because the distortions have to be minimized. In order to fulfill this requirement class-A PAs are usually used. They are linear, but the maximum possible theoretical efficiency of those circuits is only 50 %. Their best efficiency can be achieved when the output signal of power amplifier swings from rail to rail [2]. Therefore results closed to 50 % could be reached if collector voltage (V_{cc}) is changed dynamically as a function of output signal's amplitude.

The regulations of power amplifier's collector voltage V_{cc} can be performed by high frequency voltage regulators. The optimal choice is switching-mode dc-dc converters because they are high efficient circuits. Collector voltage (V_{cc}) of power amplifier is smaller than battery voltage during most of the operation time of portable electronic devices. The focus of that paper is switching-mode buck dc-dc converter, suitable for dynamic output voltage regulation.

In Section II are presented the challenges and problems connected with efficiency improvement of power amplifiers used in the new mobile communication devices. Theory information about dc-dc converters is given also in the same section. Received investigation results of buck dc-dc converter, which can dynamically adjust V_{cc} voltage of PA, are presented in Section III. The whole switching-mode regulator system is designed for integrated circuits (IC) applications in CMOS technology.

II. Power Amplifier and DC-DC Converter in Mobile Electronic Devices

The new cellular technology is 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE). High data rate and high quality is ensured for mobile communications devices [3]. Therefore the increased customer requirements for more function of the portable electronic devices at low cost can be satisfied. For example nowadays online gaming, mobile television, multimedia streaming is available in the cellular phones.

LTE supports several channel bandwidths, which are: 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz, and 20MHz. Long Term Evolution maintain earlier 3GPP technology such as code division multiple access CDMA, wide-band code division multiple access/high-speed packet access WCDMA/HSPA, time division synchronous code division multiple access TD-SCDMA.

The most important parameters for modern generation mobile electronic devices are liner output power and high efficiency. Low energy consuming building blocks is challenge to the overall system design in order to be achieved longer battery run time [4].

A. Power Amplifier

Power amplifiers can work as a linear circuit with poor efficiency or as a circuit with better efficiency, but with distortion. Obviously trade-off between linearity and efficiency is needed when appropriate class of PA is selected from the designers [5]. Usually for RF power amplifiers in the new generation portable electronic devices is used class-A PA.

The easiest way is PA to be powered directly from battery. This is not efficient method because the mobile electronic devices work at different output powers level. The voltage

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regulators, which change their outputs according to the required signal being transmitted, are used. The efficiency of power amplifier is increased if collector voltage is adjusted.

The power added efficiency (PAE) is a parameter which describes the RF power amplifier efficiency:

$$PAE = \frac{P_{out} - P_{in}}{P_{DC}}, \tag{1}$$

where P_{out} is a output power of PA, P_{in} is a input power of PA and P_{DC} is a dc power which is delivered to PA. These parameters express how dc power is transformed to the RF power.

Different techniques are used for improving the efficiency and linearity of power amplifier [2]. The average power tracking and envelope tracking are different method used to adjust collector voltage V_{cc} as function of the transmitted output power. In the Fig. 1 are shown the principle of operation of those two techniques.

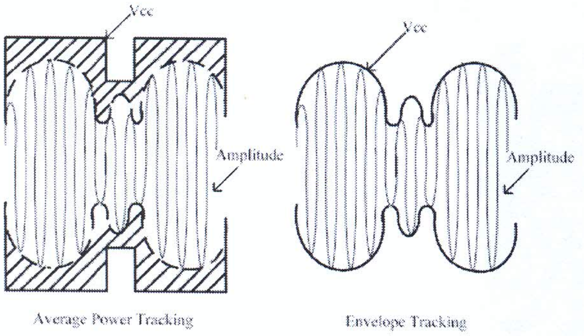

Fig. 1. Average power tracking and envelope tracking techniques.

Envelope tracking method is faster than average power tracking. The shaded area in average power tracking techniques is proportional to the power dissipation. As can be seen from the picture in Fig. 1 consumed energy in average power tracking is bigger compare to envelope tracking. Dissipated power is smaller if V_{cc} is closed to the output voltage amplitude. Envelope tracking mechanism is more efficient than average power tracking.

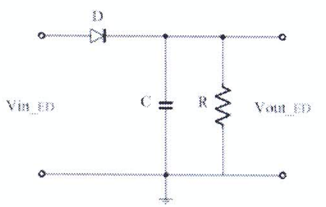

Fig. 2. Envelope detector.

For amplitude detection of the transmitted signal are used envelope detectors. The control system of dc-dc converter receives information from those circuit's blocks and adjust the output voltage of the regulator to the desired level [6]. One of the circuits, which can be used for the envelop detectors (ED), is shown in Fig. 2.

The circuit is simple and includes a diode and a *RC* (resistor-capacitor) filter. The designers have to choose values of *R* and *C* to satisfy the condition:

$$f_{signal} < \frac{1}{2\pi RC} \ll f_{carrier}, \tag{2}$$

where $f_{carrier}$ is a carrier frequency and f_{signal} is a base band signal frequency.

Linear voltage regulators have low efficiency when output voltage is not close to the input voltage. Because of the different powers of the transmitted signal, collector voltage V_{cc} of PA has to vary in order to be increase the efficiency. Therefore switching-mode dc-dc converter is better choice for voltage regulator's circuit.

B. DC-DC Converter

The efficiency of PA, which is the most energy consumed circuits in the modern portable electronic devices, can be increased by decreasing of power dissipation. Voltage regulator, which can control V_{cc}, is used.

High efficient voltage regulator is needed to improve the overall efficiency of the mobile devices. Linear regulators have simple structure and occupied small silicon area, but they have great energy dissipation, which is transformed in heat.

During most of the time collector voltage of power amplifier is less than battery voltage. Therefore switching-mode buck dc-dc converter is considered as a circuit, which can ensure dynamic regulation of collector voltage of power amplifier. Theoretically they have very high efficiency. The switching frequency f_s of the dc-dc converter should be much higher than base band signal frequency. In Fig. 3 is shown schematic of synchronous buck dc-dc converter.

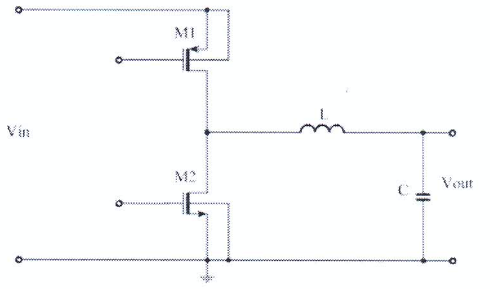

Fig. 3. Synchronous buck dc-dc converter.

Higher switching frequency f_s leads to increasing of switching power losses and decreasing of efficiency of the buck converter. The dc-dc converter efficiency is equal to:

$$\eta = \frac{P_{out}}{P_{in}}, \tag{3}$$

where P_{out} is a average output power of the regulator (output voltage of synchronous buck dc-dc converter in Fig. 3 is applied to collector of PA); P_{in} is a average input power of the regulator (input voltage of synchronous buck dc-dc converter in Fig. 3 is battery voltage of the mobile electronic devices).

The conducting losses in the MOS transistors are proportional to the switching frequency f_s and the rms-value of the current flowing through the device [7]. This relationship is given bellow:

$$P_{MOS} = k_1 i_{rms}^2 + k_2 f_s, \tag{4}$$

where k_1 and k_2 is are technology dependent coefficient, which are taking into account the size of the power MOS transistors, as well as the resistive and the capacitive losses associated with the MOS structure. Small inductor ripple current will result in smaller rms-value of the current through the MOS structure, and it will respectively lead to better efficiency.

III. Investigations Results of Designed Buck DC-DC Converter

Buck dc-dc converter is designed with Cadence on CMOS process for low voltage integrated circuits applications. The switching frequency f_s of the circuit should be much higher than 20 MHZ, which is larger base band supported from LTE. A Pulse-Width Modulation (PWM) control technique is used to regulate the two transistors in power stage of synchronous buck dc-dc converter. The schematic of designed switching-mode regulator is shown in Fig.4.

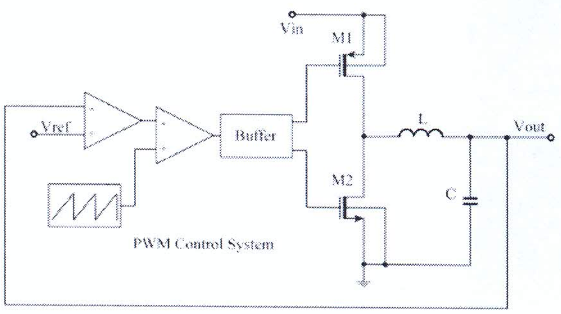

Fig. 4. Schematic of buck converter system designed on CMOS process.

The switching frequency f_s determined from ramp generator is equal to 76.2 MHz. Output voltage of the regulator has to be dynamically adjusted as function of transmitted signal from power amplifier.

The ability of designed buck converter to react at fast changes of reference voltage V_{ref} is examined. In Fig. 5 are presented received simulations results when voltage reference jumps from 0.5 V to 1.3 V. As can be seen from the picture output voltage of the buck converter is stabilized at the new desire level for approximately 1.5 µs.

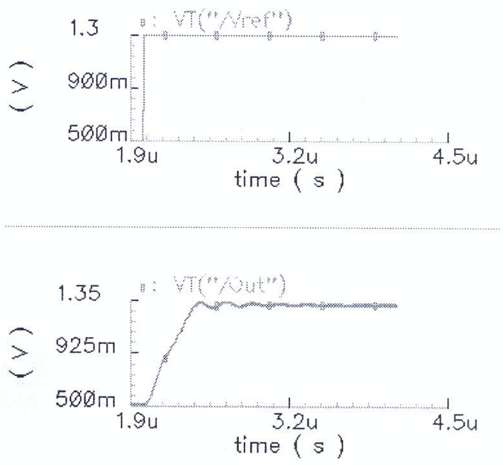

Fig. 5. Reaction of buck converter when voltage reference V_{ref} jumps from 0.5 V to 1.3 V.

In Fig. 6 are shown waveforms of ramp generator's signal and output voltage V_{out} of dc-dc converter, when V_{out} is stabilized. The reaction of the regulator when V_{ref} is changed from 1.3 V to 2.8 V is investigated. The received simulations results are presented in Fig. 7.

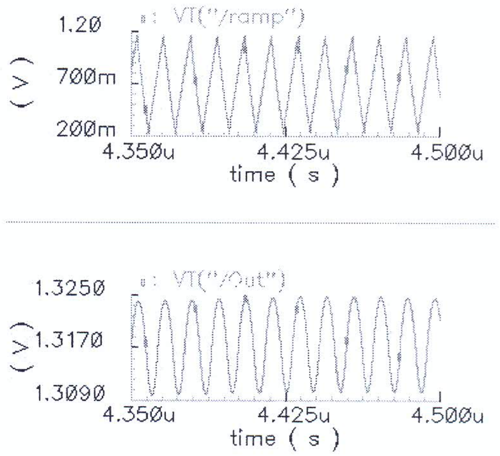

Fig. 6. Waveforms of V_{ramp} and V_{out} and when V_{ref} jumps from 0.5 V to 1.3 V.

As can be seen from the picture presented in Fig. 7 output voltage V_{out} is stabilized for approximately 1.5 µs.

High switching frequency f_s is key parameter for dc-dc converters, which have to change dynamically their output voltages according to the transmitted power level of mobile devices. On the other hand switching power losses of the voltage regulators are proportional to f_s. High switching frequency of buck converter can helps also for fully integration of whole regulator system together with other circuit's block of the mobile electronic devices.

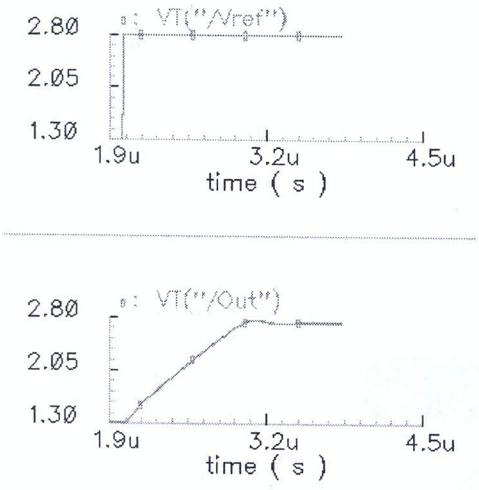

Fig. 7. Reaction of buck converter when voltage reference V_{ref} jumps from 1.3 V to 2.8 V.

The efficiency investigations of the designed buck converter system at different output voltages are performed. The received results are presented in Table 1.

TABLE I

EFFICIENCY RESULTS OF BUCK CONVERTER AT DIFFERENT OUTPUT VOLTAGES

Vout [V]	Efficiency [%]
0.5	52.4
1.3	77.2
2.8	85

As can be seen from the Table 1, the efficiency of the buck converter is equal to 77.2 %, when output voltage V_{out} is controlled to be 1.3 V. Decreasing of the transmitted power level, which required smaller collector voltage V_{cc} of PA, leads to decreasing of the overall efficiency of the dc-dc converter.

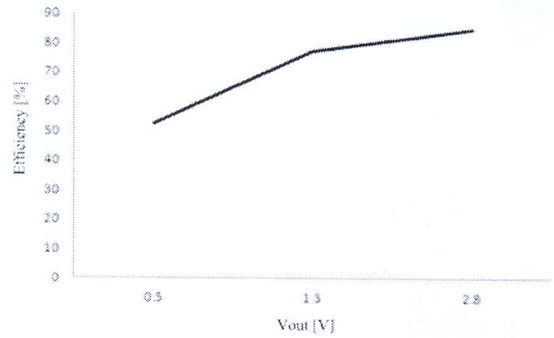

Fig. 8. Efficiency of buck converter as a function of output voltage V_{out}.

In Fig. 8 is presented graphically efficiency of the investigated circuit as a function of output voltage. When V_{out} of buck converter is controlled to be 0.5 V efficiency is 52. 4 %, as well as for V_{out} equal to 2.8 V efficiency is equal to 85 %.

IV. CONCLUSION

In this paper are presented investigations results of buck dc-dc converter, which can be used for dynamic regulation of power amplifier's collector voltage in mobile portable electronic devices. The problems connected with efficiency improvement of power amplifier are discussed. The reaction of regulator's output voltage as function of reference voltage of PWM control system is examined. The switching frequency f_s of the buck converter designed with Cadence on CMOS technology is equal to 76.2 MHz. The output voltage V_{out} of investigated circuit is stabilized for approximately 1.5 μs, when reference voltage jumps from 0.5 V to 1.3 V and from 1.3 V to 2.8 V. The efficiency of the buck converter varies from 52. 4 % to 85 %, when V_{out} is respectively 0.5 V and 2.8 V.

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