ATEE - 2004

SWITCHING POWER SUPPLY WITH MONOLITHIC SWITCHING REGULATOR SUBSYSTEMS AND DC-DC STEP-UP CONVERTER

PART B: Design Example, Pspice Simulation, Practical Considerations, Experimental Results

Adriana FLORESCU

"Politehnica" University of Bucharest
Electronics and Telecommunications Faculty,
Bd. Armata Poporului 1-3, Sect. 6, 77206 - Bucharest, Romania
adriana.florescu@home.ro

Abstract *– The paper presents switching power supplies with MC34063 and µA78S40 monolithic switching regulator subsystems and DC-DC step-up converter. General description of MC34063 and µA78S40 operation modes, mathematical design and PSpice under ORCAD simulation of the whole switching power supply, a numerical example and the practical implementation are included. Some practical considerations are also presented.*

1. SWITCHING POWER SUPPLIES WITH MC34063 OR µA78S40 AND DC-DC STEP-UP CONVERTER DESIGN EXAMPLE

Given are the following: V_{out} = 28V, I_{out} = 175 mA, f_{min}= 30kHz, $V_{in(min)}$ = 12V–25%· 12V =9V, $V_{ripple(p-p)}$ = 0.5% V_{out}=140 mV_{p-p}. Switching power supplies with MC34063 or µA78S40 for dc-dc step-up converters must be designed.

Design example goes as follows:

1. The ratio of switch conduction t_{on} versus diode conduction t_{off} time is determined using equation (4):

$$\frac{t_{on}}{t_{off}} = \frac{V_{out} + V_F - V_{in(\min)}}{V_{in(\min)} - V_{sat}} = \frac{28V + 0.8V - 9V}{9V - 0.8V} = 2.415 \qquad (13)$$

2. The cycle time of the LC network can be determined:

$$T_{(\max)} = t_{0n(\max)} + t_{off} = \frac{1}{f_{\min}} = \frac{1}{30\,kHz} = 33.3\mu s \qquad (14)$$

3. From equations (13) and (14) the switching times t_{on} and t_{off} are:

$$t_{off} = \frac{T_{\max}}{\frac{t_{on}}{t_{off}} + 1} = \frac{33.3us}{2.415 + 1} = 9.751\mu s \qquad (15)$$

$$t_{on} = T_{\max} - t_{off} = 33{,}3\mu s - 9.751\mu s = 23.58\mu s \qquad (16)$$

The ratio $t_{on}/(t_{on}+t_{off})$ is:

$$\frac{t_{on}}{T_{(\max)}} = \frac{9.751\mu s}{23.58\mu s} = 0.4135 < \frac{6}{7} = 0.857 \qquad (17)$$

Note that the ratio $t_{on}/(t_{on}+t_{off})$ does not exceed the maximum 6/7=0.857. This maximum is defined by the 6:1 ratio of charge-to-discharge current of timing capacitor C_T taken from the MC34063 or µA78S40 data sheet electrical characteristics table.

4. The MC34063 or µA78S40 timing capacitor C_T of the oscillator OSC is charged during t_{on} at the value $I_{chg(min)}$=20µA and the ripple voltage of C_T is ?v_{CT}=0.5V. The value for timing capacitor C_T is :

$$C_T = \frac{20\mu A}{0.5V} t_{on} = 4 \cdot 10^{-5} \cdot t_{on} = 4 \cdot 10^{-5} \cdot 23.588\mu s = 943.16\, pF \tag{18}$$

The standard value C_T=1500pF was used.

5. Equation (6) gives the peak switch current:

$$I_{pk(switch)} = 2 I_{out} \left(\frac{t_{on}}{t_{off}} + 1 \right) = 2 \cdot 175mA \cdot (2.415 + 1) = 1.195A \tag{19}$$

6. Equation (8) gives the minimum value of the inductance L in the boundary dc-dc step-up converter operation mode:

$$L_{\min} = \frac{9V - 0.8V}{1{,}195\ A} \cdot 23.58\,\mu s = 161.8\,\mu H \tag{20}$$

The value L=170µA>L_{min} was chosen in order to allow dc-dc step-up converter to work in the correct continuous mode.

7. A value for the current limit resistor R_{SC} can be determined by using the current level of $I_{pk(switch)}$ when V_{in}=12V:

$$I'_{pk(switch)} = \frac{V_{in} - V_{sat}}{L_{\min}} t_{on(\max)} = \frac{12V - 0.8V}{161.8\mu H} 23.58\mu s = 1.632A \tag{21}$$

The value for the limit resistor R_{SC} is:

$$R_{sc} = \frac{0.33}{I'_{pk(switch)}} = \frac{0.33}{1.632} = 0.2\Omega \tag{22}$$

where the voltage drop of 330mV on R_{SC} was calculated for V_{CC} =5V si I_{dischg} = 220µA using data sheet electrical characteristics table. The standard value R=0.22O was chosen.

8. From equation (10) filter capacitor value is:

$$C_0 = \frac{I_{out}}{V_{ripple(p-p)}} t_{on} = \frac{175mA}{140mV_{p-p}} \cdot 23.58\mu s = 294.75\mu F \tag{23}$$

Ideally this would satisfy the design goal, however, even a solid state capacitor of this value will have a typical ESR (Equivalent Resistance Series) of 0.3 O which will contribute 30mV of ripple. In satisfying the example shown, the standard value for the filter capacitor has been settled to C_0=330µF.

A tantalum capacitor with ESR of 1.1 O was chosen, but a suplementary LC output filter with L=1µH and C=100µF was introduced to keep the output voltage ripple $V_{riple(p-p)}$ to the given value.

9. The given nominal output voltage V_{out} is programmed by (R_1, R_2) resistor divider. The output voltage is:

$$V_{out} = V_{ref}\left[(R_2 / R_1) + 1\right] = 1.25V \cdot \left[(R_2 / R_1) + 1\right] \tag{24}$$

The divider current can go as low as 100µA without affecting system performance. In selecting a minimum current divider, $R_1$is equal to:

$$R_1 = 1{,}25V / 500\mu A = 2.2k\Omega \tag{25}$$

A standard value R_1=2.2 O was chosen.

From equations (24) and (25) yields the value for resistor R_2:

$$R_2 = R_1\left[\left(V_{out}/1.25V\right)-1\right] = 2.2k\Omega \cdot \left[\left(5V/1.25V\right)-1\right] = 47.08k\Omega \qquad (26)$$

The value R_2=47k O is a standard value, so it was kept.

10. Only for µA78S40 this step is necessary. In this example with V_{in}=12V the output drive transistor is driven into saturation with a forced gain ß=20. The required base drive is:

$$I_B = I_{pk(switch)} / \beta = 1.195A / 20 = 59.75mA \qquad (27)$$

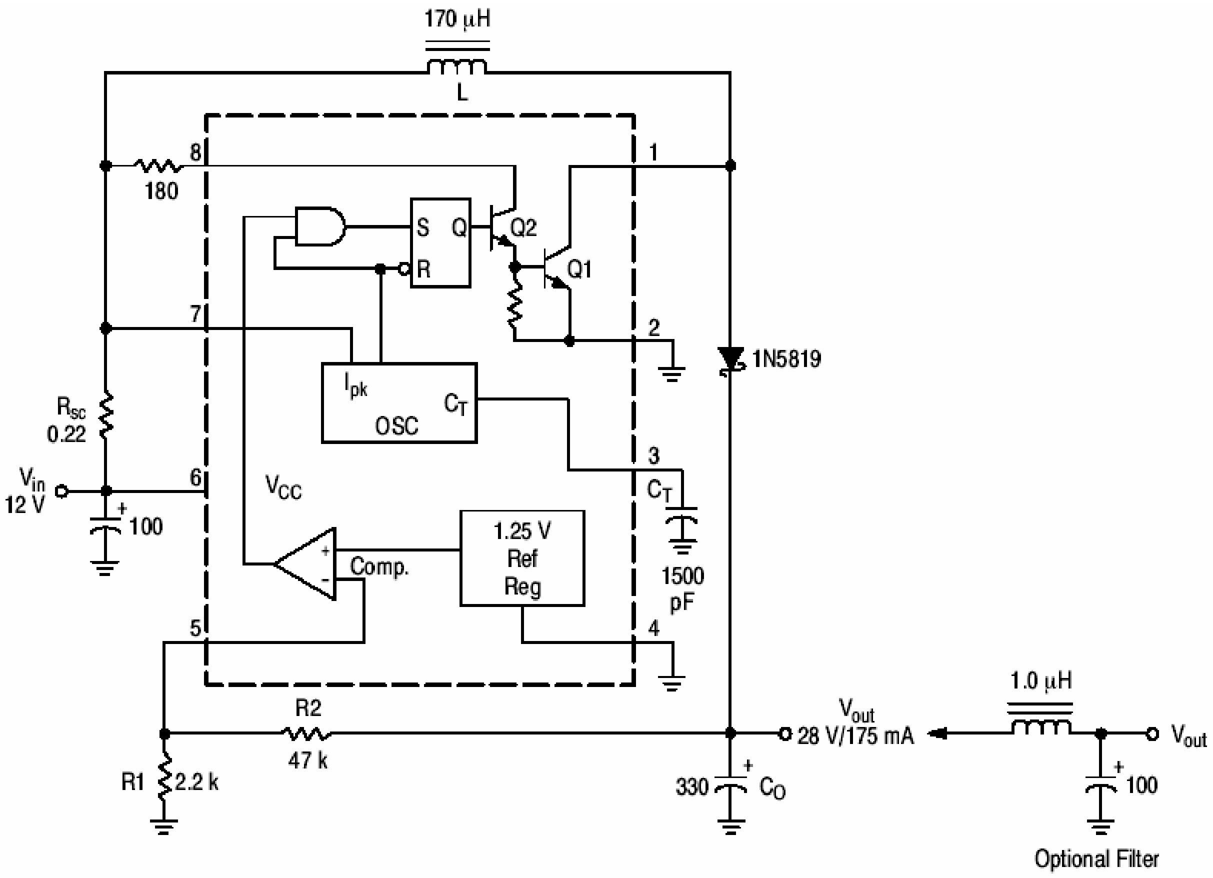


Fig.5. Switching power supply with MC34063 for dc-dc step-up converter

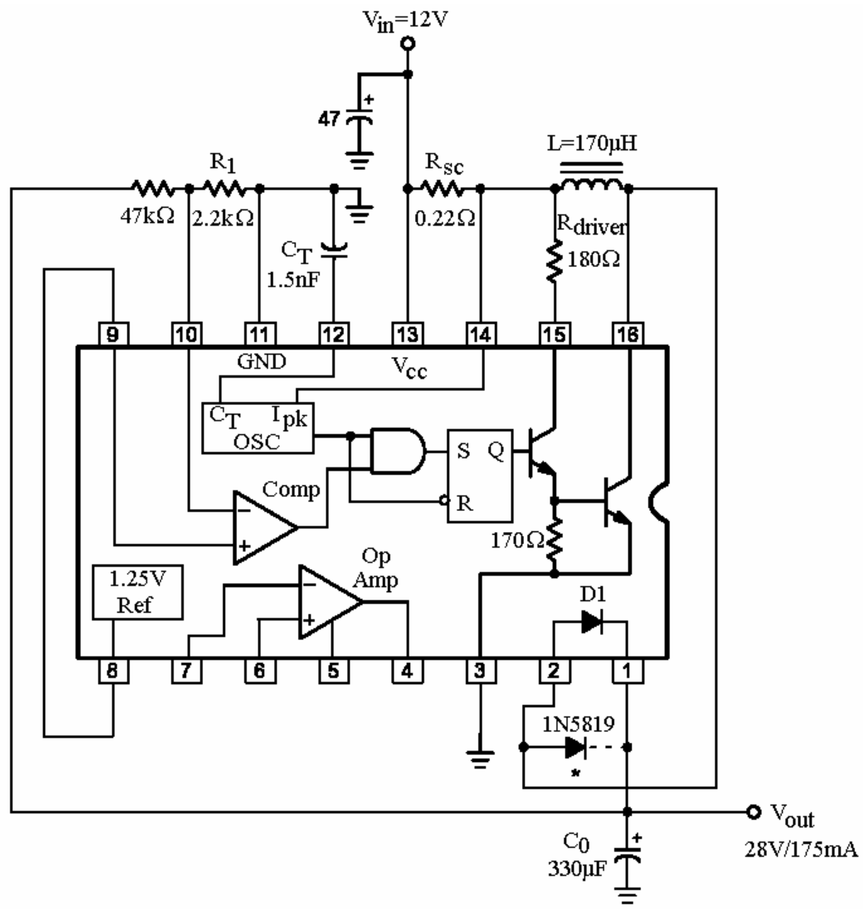


Fig.6. Switching power supply with µA78S40 for dc-dc step-up converter

Then the driver collector resistor is equal to:

$$R_{driver} = \frac{V_{in} - V_{sat(driver)} - V_{Rsc}}{I_B + V_{BE(switch)} / 170\Omega} = \frac{12V - 0.3V - 0.2V}{(59.75 + 4.1) \cdot 10^{-3} A} = 180{,}11\Omega \qquad (28)$$

The standard value of R_{driver}=180O was chosen.

The corresponding circuits for the switching power supplies with MC34063 and µA78S40 used to control dc-dc step-up converter are presented in fig.5 and fig.6. An input capacitor filter of 100µF for MC34063 and of 47µF for µA78S40 was introduced.

The two circuits are identical as operation mode because µA78S40 is the improved variant for more sophisticated applications of MC34063. It’s internal block diagram has in addition an operational amplifier and a power catch diode (fig.1 in Part A) and the reference regulator or 1.25V is not internaly connected to the comparator. The conclusion is that for this example it is sufficient to use MC34063 and further analysis focus only on it.

6. PSPICE SIMULATION FOR SWITCHING POWER SUPPY WITH MC34063

PSpice under ORCAD was used to software verify switching power supply with MC34063 for dc-dc step-up converter in fig.5. PSpice circuit model [2] for fig.5 is given in fig.7. Subcircuit for MC34063 was included. The most important simulation result is output voltage V_{out} waveform (fig.8) that proves the stability of witching power supply with MC34063 for dc-dc step-up converter the circuit in fig.5. The average value of V_{out} is of 28V as it was given in the example and it is reached in 2ms. The output voltage ripple $V_{ripple(p-p)}$ is arround 1V, three times bigger than the given design value 0,5%V_{out}=3V. This bigger value can be explained observing that fig.7 is not totaly identical to fig.5 because it doesn't include the optional suplementary filter that appears in fig.5.

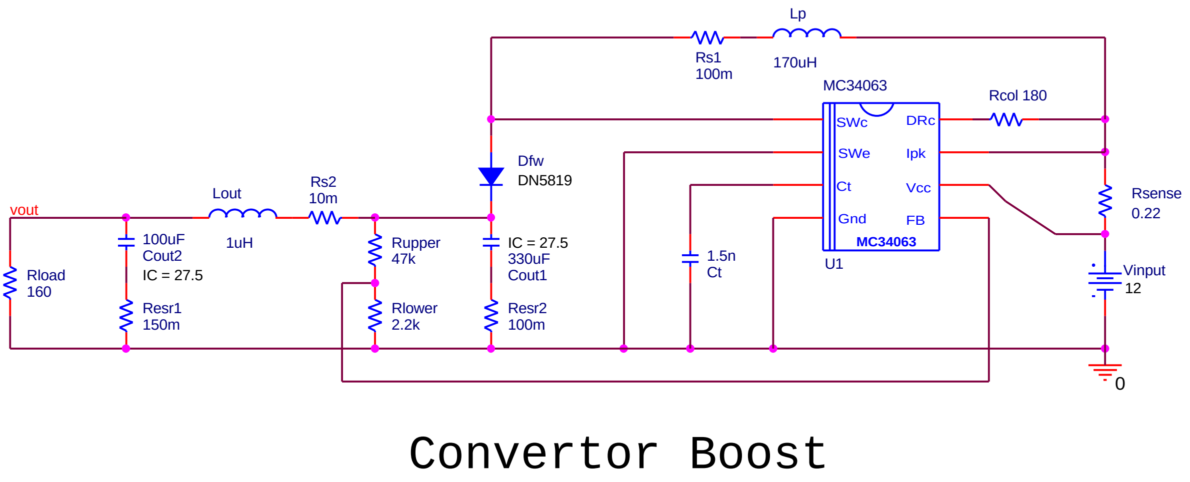


Fig.7. PSpice circuit model for fig.5

7. PRACTICAL CONSIDERATIONS AND EXPERIMENTAL RESULTS

The design equations for L_{min} were based upon the assumption that the switching regulator is operating on the onset of continuous conductions with a fixed input voltage, maximum output load current and a minimum charge-current oscillator. Typically the oscillator charge-current will be greater that the specific minimum of 20μA, thus t_{on} will be somewhat shorter and the actual LC operating frequency will be greater than predicted f_{min}.

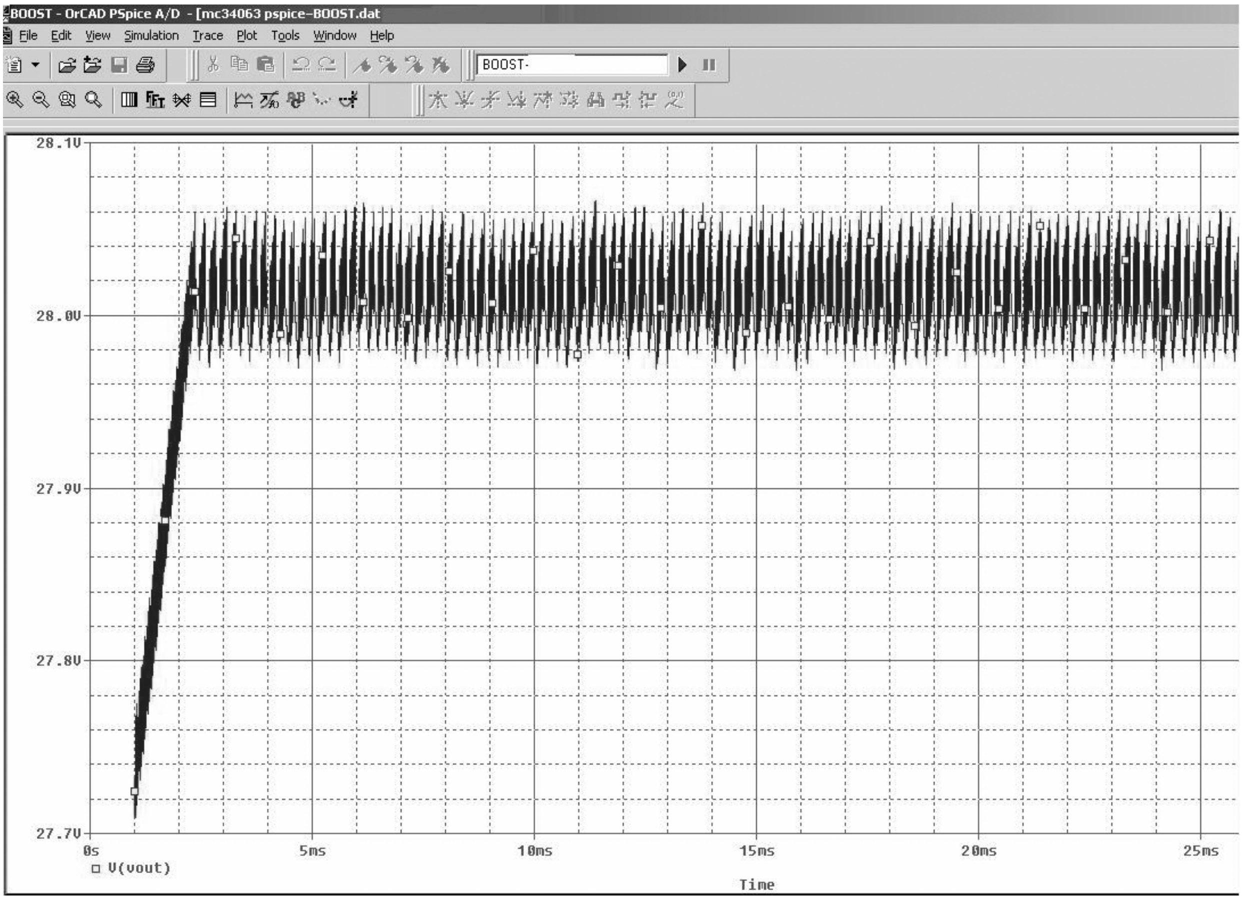
The voltage drop developed across the current-limit resistor R_{sc} was not accounted for in the ratio t_{on}/t_{off} and L_{min} formulas. This voltage drop must be considered when designing high current converters that operate with an input voltage of less than 5V.

High frequency circuit layout techniques are imperative with switching regulators. To minimize EMI, all high current loops should be kept as short as possible using heavy copper runs. The low current signal and high current switch and output grounds should return on separate paths back to the input filter capacitor. The R_1 and R_2 output voltage divider should be located as close to the integrated circuit as possible to eliminate any noise pick-up into the feedback loop. The circuit diagrams were purposely drawn in a manner to depick this.

All circuits used permalloy power toroid cores for the magnetics where only the inductance value is given.

Input voltage V_{in}=14V and output voltage V_{out} arround 28V waveforms on digital two-channels oscilloscope PSC64i are shown in fig.9. These waveforms are the most important for a switch power supply. Note that V_{in}=14V is bigger than the given 12V in the example and the circuit in fig.5 keeps the output voltage V_{out} to it's nominal voltage of 28V still stable. Output power is of 4.9W and conversion efficiency is of 87.7%.

Some other waveforms that confirm the theoretical ones in fig.4 are shown in fig.10 and fig.11.Values for t_{on}, t_{off}, T, and f can be practicaly verified.


BOOST - OrCAD PSpice A/D - [mc34063 pspice-BOOST.dat]
File Edit View Simulation Trace Plot Tools Window Help
BOOST-
28.1V
28.0V
27.9V
27.8V
27.7V
0s
5ms
10ms
15ms
20ms
25ms
V(vout)
Time

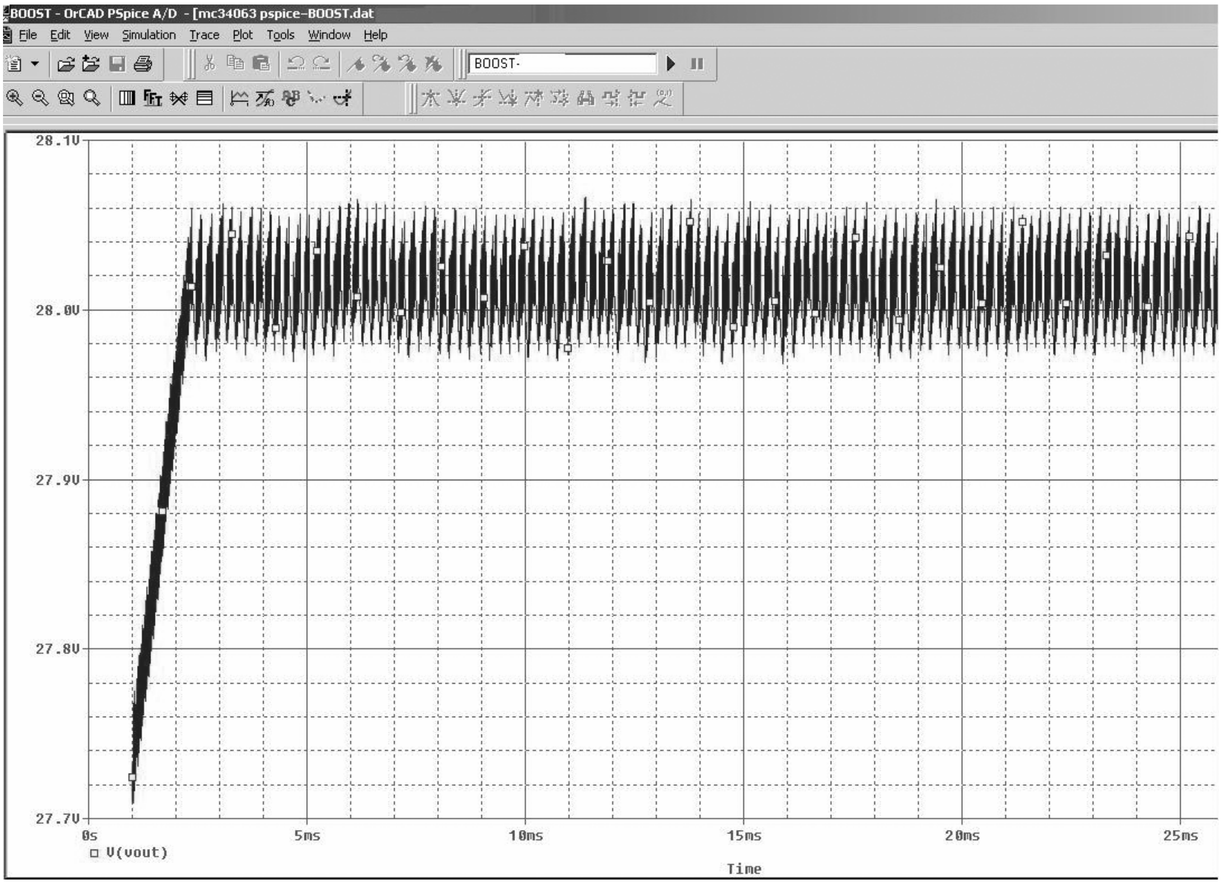


Fig.8. PSpice simulation waveform of the output voltage V_{out} on oscilloscope PSC64i

8. CONCLUSIONS

The goal of this paper was to obtain simple and complete switching power supplies with MC34063 and µA78S40 monolithic switching regulator subsystems used to control dc-dc step-up converter. The paper was split in Part A and Part B. Part A included brief introduction, general description and synthetical functional description of switching regulator subsystems and mathematical theory of the dc-dc step-up converter controlled by MC34063 and µS78S40. Part B included switching power supplies with MC34063 or µA78S40 and dc-dc step-up converter design example with it's PSpice under ORCAD modelling and simulation, practical considerations and experimental results.
For MC34063 numerical example, output voltage was of 4.9W and conversion efficiency of 87.7%. Mathematical theory fits with the simulation and experimental results.

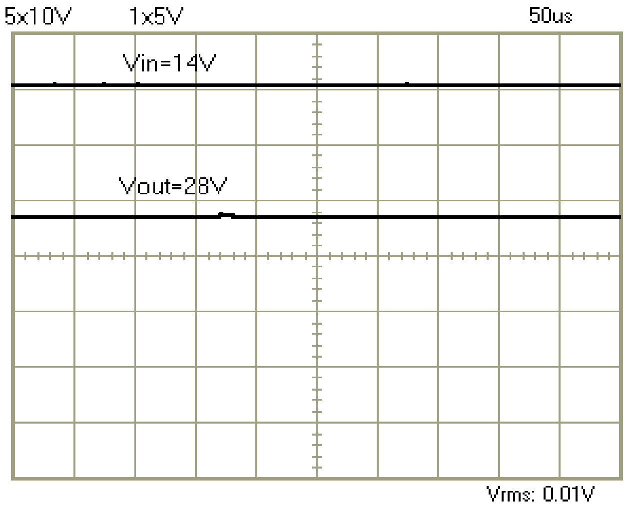


Fig.9. Input voltage V_{in} and output voltage V_{out} waveforms on oscilloscope PSC64i

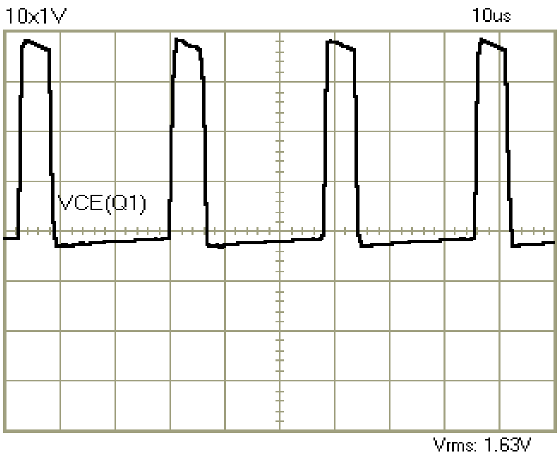


Fig.10. Voltage V_{CE} across switch Q1 waveform

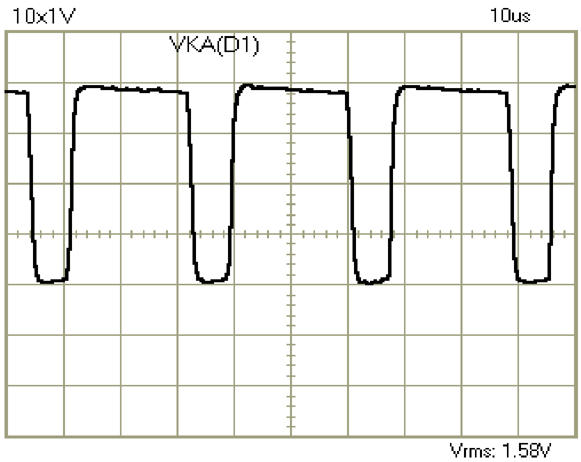


Fig.11. Voltage V_{KA} across diode D_1 waveform

REFERENCES

[1] Radoi, C., Drogoreanu, V., Grigore, V., Florescu, A., Lazarescu, V., Stoichescu, D., Stancescu, St. *Electronica si Informatica Industriala: Aplicatii practice. (Industrial Electronics and Informatics: Practical Applications),* Editura Tehnica, Bucuresti, 1997.

[2] Radoi C., Grigore V.,Drogoreanu V., *SPICE: Simularea si analiza circuitelor electronice. (SPICE: Electronic Circuits Simulation and Analysis)*, Amco Press, Bucuresti, 1994.

[3] Mohan, N., Undeland, T. M., Robbins, W. P., *Power Electronics: Converters, Applications and Design*, John Wiley & Sons, Inc., USA, 1995

[4] Rashid, M., H., *Power Electronics: Circuits, Devices and Applications*, Prentice-Hall, 1992

[5]***ON Semiconductor Components Catalogue, Aprilie 2002