A Low Cost, Low Parts-Count DC/DC Converter with Multiple Outputs

National Semiconductor
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I. INTRODUCTION

This application note describes a simple low cost, low parts-count multiple output DC/DC converter based on the LM2596 five terminal step-down switching regulator. The circuit described provides multiple output voltages (positive and negative) with good regulation using a step-down converter circuit with flyback windings. It uses only one switching regulator IC.

II. PERFORMANCE

The circuit has an input voltage range of 15V to 40V. It has 5 outputs: 3.3V at 1.5A; +12V and −12V at 50mA each; and +5V and −5V at 50mA each. The 3.3V, +5V and −5V output are regulated with ±5% accuracy over line and load variations. The +12V and −12V outputs are regulated with ±20% accuracy. A typical application of this circuit is where the 3.3V output provides the power to the main circuit which is 3.3V logic, the ±5V outputs power the 5V logic and ±12V outputs provide the bias supply of op-amps.

The efficiency of the circuit with full load at all outputs is 75%. The ripple voltage across the 3.3V output is less than 20mV and that across the ±12V outputs is less than 30mV. The ripple across the ±5V is less than 10mA

III. SCHEMATIC AND PARTS LIST

Figure 1 shows the schematic of the circuit. The parts list is shown in *Table 1.*

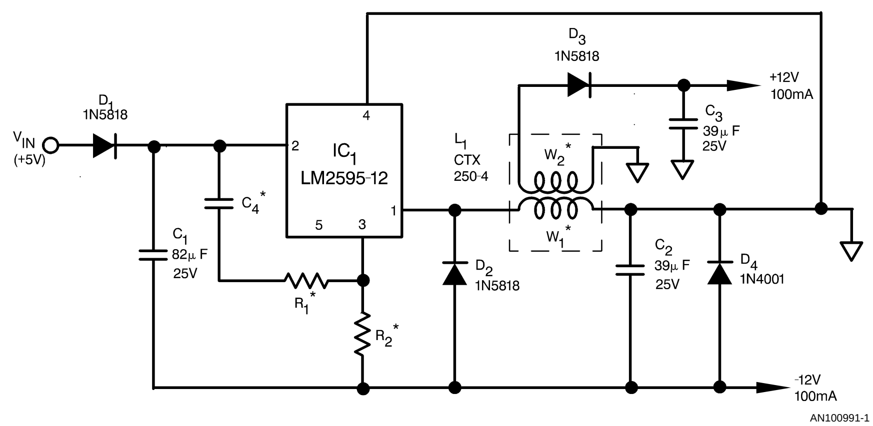


FIGURE 1. Circuit Schematic

TABLE 1. Parts List

Component	Component Information
C_{IN}	220µF, 50V, Nichicon UPL1H221MPH
C_1	270µF, 63V, Nichicon UPL1J271MPH
C_2	47µF, 35V, Nichicon UPL1V470MPH
D_1	MBR360
D_2	IN459
C_4, C_5	0.01µF
I_{C1}	LM2596-3.3 (SIMPLE SWITCHER® Step-Down Voltage Regulator)
I_{C2}, I_{C3}	LM78L05 and LM79L05.(3-Terminal Regulators)
L_1	Custom Inductor with three windings (W_1, W_2 and W_3) with the followiing specs:
	W1: 47µH; Peak Current: 2.6A, RMS Current ≅ 2.38A
	W2: Number of turns = 3.4 x Number of turns in W_1; RMS Current : 113mA
	W3: Same as W_2

IV. CIRCUIT OPERATION

The circuit operates as a standard step-down (buck) switching regulator, except for the flyback windings (W_2, W_3). The flyback windings conduct current during the on-period of D_1 and supply the 3-terminal regulators (IC_2 and IC_3). C_2 and C_3 should be of high enough value to smooth out the high ripple due to the flyback action of W_2 and W_3. The flyback windings supply the +12V and −12V output with ±20% accuracy. The 3-terminal regulators are used to provide +5V and −5V and ±5% accuracy. The LM2596 regulates the main output (3.3V) by standard step-down action.

V. DESIGN

Step 1: Design of Step-Down Regulator for the Main (3.3V) Output

This can be done using the *Switchers Made Simple®* software by National Semiconductor. The following values (underlined) are entered into the software:

V_{IN}(min)	15V
V_{IN}(max)	40V
V_{OUT}	3.3V
I_{OUT}	

$I_{OUT} = I_{O1} + N (I_{O2} + I_{O4} + I_{O5})$ 1.5 is the load for the 3.3V output. I_{O1}, I_{O2}, I_{O3}, I_{O4} and I_{O5} are the load currents of outputs V_{O1},V_{O2}, V_{O3}, V_{O4}, V and$_{O5}$ respectively. N is the turns ratio between W_2 and W_1 (also between W_3 and W_1). It is calculated using:

$$N = \frac{V_{O2} + V_{FD2}}{V_{O1} + V_{VD2}} = \frac{12 + 0.7}{3.3 + 0.4} = 3.4$$

In the equation V_{FD2} is the forward voltage drop of D_2 and V_{FD1} is the forward voltage drop of D_1. Using (1) , I_{OUT} = 1.5A + 3.4 (50mA + 50mA + 50mA + 50mA) = 2.18A

The peak current in W_3(I_{pkw3}) is

$$I_{pkw3} = \frac{I_{O4} + I_{O5}}{1 - \frac{V_{O1}}{V_{IN(min)}}} = \frac{0.05 + 0.05}{1 - \frac{3.3}{15}} = 128\text{mA}$$

(3)

The RMS current of W2 (I_{rmsw2}) is

$$I_{rmsw2} \approx \sqrt{I_{pkw2}^2 \left(1 - \frac{V_{O1}}{V_{IN(min)}}\right)}$$

$$= \sqrt{0.128^2 \left(1 - \frac{3.3}{15}\right.} = 113\text{mA}$$

(4)

The RMS current of W3 (I_{rmsw3}) is

I_{OUT} = 2.18A.

The software designs the step-down regulator and gives the following values:

IC_1	LM2596-3.3
C_{IN}	220µF, 50V, Nichicon UPL1H221MPH
C_1	270µF, 63V, Nichicon UPL1J271MRH
D_1	MBR360
L_1	47µH
IC Ipk	2.38A

CIN and C1 have been chosen primarily for ESR, not for voltage rating.

Step 2: Design of L_1 and Flyback Outputs

a. Design of L_1

The value of inductance due to W_1 is the same as the value of L_1 obtained in Step 1. The number of turns in windings W_2 (N_{w2}) and W_3 (N_{w3}) are

$N_{w2} = N_{w3}$ = N x Number of turns in W_1

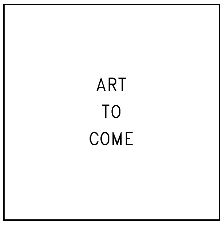
= 3.4 x Number of turns in W_1

(1)

The peak current in W_2(I_{pkw2}

$$I_{pkw2} = \frac{I_{O2} + I_{O3}}{1 - \frac{V_{O1}}{V_{IN(min)}}} = \frac{0.05 + 0.05}{1 - \frac{3.3}{15}} = 128\text{mA}$$

(2)



(5)

The peak current in W_1 (I_{pkw1}

$$I_{pkw2} = \frac{I_{O2} + I_{O3}}{1 - \frac{V_{O1}}{V_{IN(min)}}} = \frac{0.05 + 0.05}{1 - \frac{3.3}{15}} = 128mA$$

(6)

This value is below the ICL(min) specified in the LM2596 datasheet and thus is acceptable.

Since the current through W1 is continuous RMS current is approximately equal to IC IPK which is 2.38A.

b. Selection of C2 and C3

In this design, the selection of C2 and C3 is based on the ripple voltage requirements of the +12V and −12V outputs respectively. For example, if a ripple voltage (V_{RP}) of 100mV is desired on the +12V output, then C2 should be selected to have an ESR value of,

$$N_{w2} = N_{w3} = N \times \text{Number of turns in } W_1$$
$$= 3.4 \times \text{Number of turns in } W_1$$

c. Selection of D2 and D3

D2 and D3 should be selected to conduct the sum of the current through the two outputs each is connected to. In this application the value is 100mA. The DC blocking voltage rating of D2 (V_{RD2}) and D3 (V_{RD3}) are calculated using equations.

1N459 diodes which have a reverse voltage rating of 175V and rated at 500mA are used in this design.

Step 3: Design of 3-Terminal Regulators

The 3-terminal linear regulators are used to regulate the auxiliary outputs with ±5% accuracy. Their design is straightforward and can be done using the datasheets for the 3-terminal regulators.

VI. ADVANTAGES

This circuit can save both parts and cost by making use of only one step-down regulator IC, two inexpensive 3-terminal linear regulators, and a simple three-winding inductor to provide 5 outputs.

- The usual solution for this design with multiple (postive and negative) outputs is a flyback converter. The design described in this application note is better than using a flyback regulator with multiple outputs because:
- It uses a much smaller output capacitor for the 3.3V output (270µF against 2.4µF for flyback solution with a comparable output ripple voltage).
- It uses an inductor with only three windings whereas a flyback regulator solution requires a transformer with four windings.
- The overall peak current of the inductor in this design is less than that of a flyback transformer for the same application.
- Transformer construction is simplified because the leakage inductance does not result in power loss. Because of these reasons the magnetic structure of this design costs less than that in a flyback converter design.
- The peak switch current of this design is much less than that of a similar flyback design. The disadvantages of this design compared to the flyback converter are
- The 3.3V output should be loaded to keep the inductor in continuous conduction mode. Otherwise large peak currents result in the flyback windings. In worst cases (deep into discontinuous conduction mode), the auxiliary outputs (±12V and ±5V) will not be regulated.
- When the duty cycle of the main output gets large, large peak currents result in the flyback windings and may result in loss of regulation of the auxiliary outputs in worst cases. In most applications the advantages far outweigh the disadvantages, as can be inferred from the comparison above.

The ICs used in this circuit are all available in surface mount packages.

VII SUMMARY

In applications where multiple output DC/DC conversion is needed, the circuit presented in this application note is an attractive solution. It is low-cost, has a low-parts count, and provides the regulation needed with good efficiency. The detailed design procedure given in this application note makes this design easy and straightforward.

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