Negative Input to Positive Output made SIMPLE

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ABSTRACT

There can be quite a few applications that require a conversion from a negative input voltage to a positive output voltage. This design space along with being limited is not well explored. There are a few ways to go about doing it. In this application note we will go over the use of an integrated boost regulator to convert a negative input voltage to a positive output voltage.

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1 Introduction

The LM2587 is part of the LM258x family of SIMPLE SWITCHER® boost regulators from Texas Instruments. The internal NPN is capable of handling a voltage of 65V and has a current limit of 6.5A. The maximum input voltage that the device can handle is 40V. Thus this device makes a good candidate for Wide V_{IN} solutions. The design shown here is created for a typical input of -12V and an output of +5V at 2A load current, with a common ground between input and output. But it can handle an input voltage range of -6V to -40V. The following sections will talk about the operation. The intent of this application note is to investigate the method used to level shift the output voltage without going into details about BOM calculations. For details of calculating the BOM for a buck-boost topology, see application note *Understanding Buck-Boost Power Stages in Switchmode Power Supplies*.

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2 Application Details

The basic operation of this circuit is that of a buck-boost topology. When the NPN is on, the current through the inductor ramps up and when the NPN switches off the inductor current now flows towards the load and the output capacitors. The voltage across the NPN is $–V_{IN}$ and $+V_{OUT}$. Therefore the device chosen has to be able to sustain a total voltage of $V_{IN}+V_{OUT}$ across it. Throughout this application note V_{IN} denotes the absolute value of the input voltage. Figure 1 shows the steady state waveform. Figure 2 shows the design schematic.

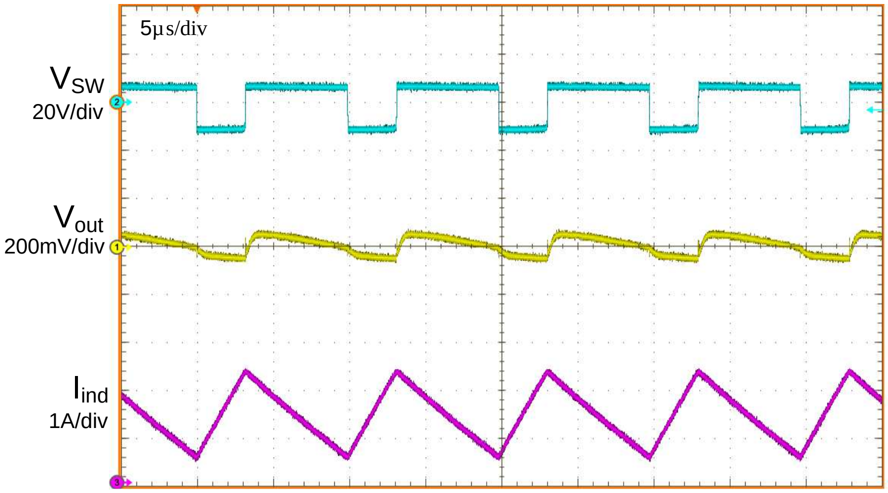

Figure 1. $-12V_{IN}$ $5V_{OUT}$ $1A$ I_{OUT}

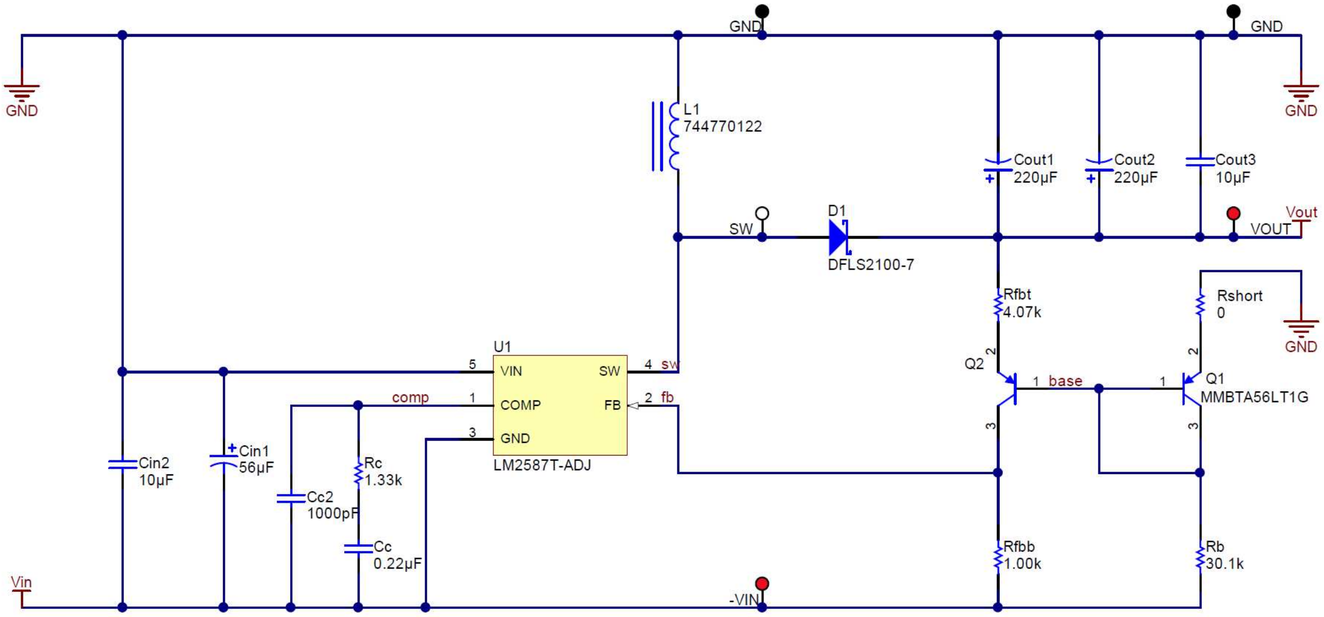

Figure 2. Design Schematic

In this design, the ground of the IC is referenced to the negative input voltage. To obtain a positive output, a level shifter is implemented using two PNP transistors. The advantage of using two transistors in this design is that the base-emitter diode voltage can be mostly nullified and the output can be more accurate. The base of the two transistors is pulled low to turn the transistors on. Since the emitter of Q1 is connected to ground, the base of both the transistors will be one diode drop below ground, i.e. $-V_{BE}$. Applying KCL at the FB node, we get:

$$I_1 = \frac{V_{OUT} + V_{BE1} - V_{BE2}}{R_{FBT}}$$

$$I_2 = \frac{V_{REF}}{R_{FBB}} \tag{1}$$

The reference voltage V_{REF} for the LM2587 is 1.2V. Setting R_{FBB} to be 1kΩ and equating I_1 and I_2, we can obtain the value for R_{FBT}. When two transistors are matched as closely as possible, their V_{BE}s will be alike and cancel out. That way the output voltage can be made accurate. It is even better to find a package with two transistors in it. That way due to any change in temperature the two V_{BE}s will be still close. While this method gives more accurate output voltage it is still not completely robust. It is known that the V_{BE} of the transistor will depend on the collector current (I_C) as shown:

$$V_{BE} = V_T \cdot \ln\left(\frac{I_C}{I_S}\right) \tag{2}$$

With change in the collector current the V_{BE} will change accordingly. The bottom feedback resistor R_{FBB} is set to 1kΩ which sets a current of 1.2mA in the collector of the transistor Q2. Resistor R_B sets the collector current of transistor Q1. Its value is set to give a matching current at max input voltage. Therefore:

$$R_B \cong \frac{V_{IN}}{0.0012} \tag{3}$$

At $36V_{IN}$, R_B is chosen to be 30kΩ. Now when the input voltage is reduced, because of the fixed resistor the collector current of Q1 reduces linearly. If Q2 collector current is twice as much as Q1 collector current then we can say the following:

$$V_{BE1} - V_{BE2} = \Delta V_{BE} = V_T \cdot \ln\left(\frac{2 \cdot I_C}{I_S} \cdot \frac{I_S}{I_C}\right) = V_T \cdot \ln(2) = 18\text{mV} \tag{4}$$

At room temperature V_T is 26mV. This means that ΔV_{BE} changes 18mV every time the collector current of Q1 is halved. This can be seen in Figure 3 which shows the line regulation.

3 Test Results

The following scope plots and efficiency data were taken on the custom PCB. The layout is shown in Figure 9 and Figure 10 and the BOM used is shown in Table 1.

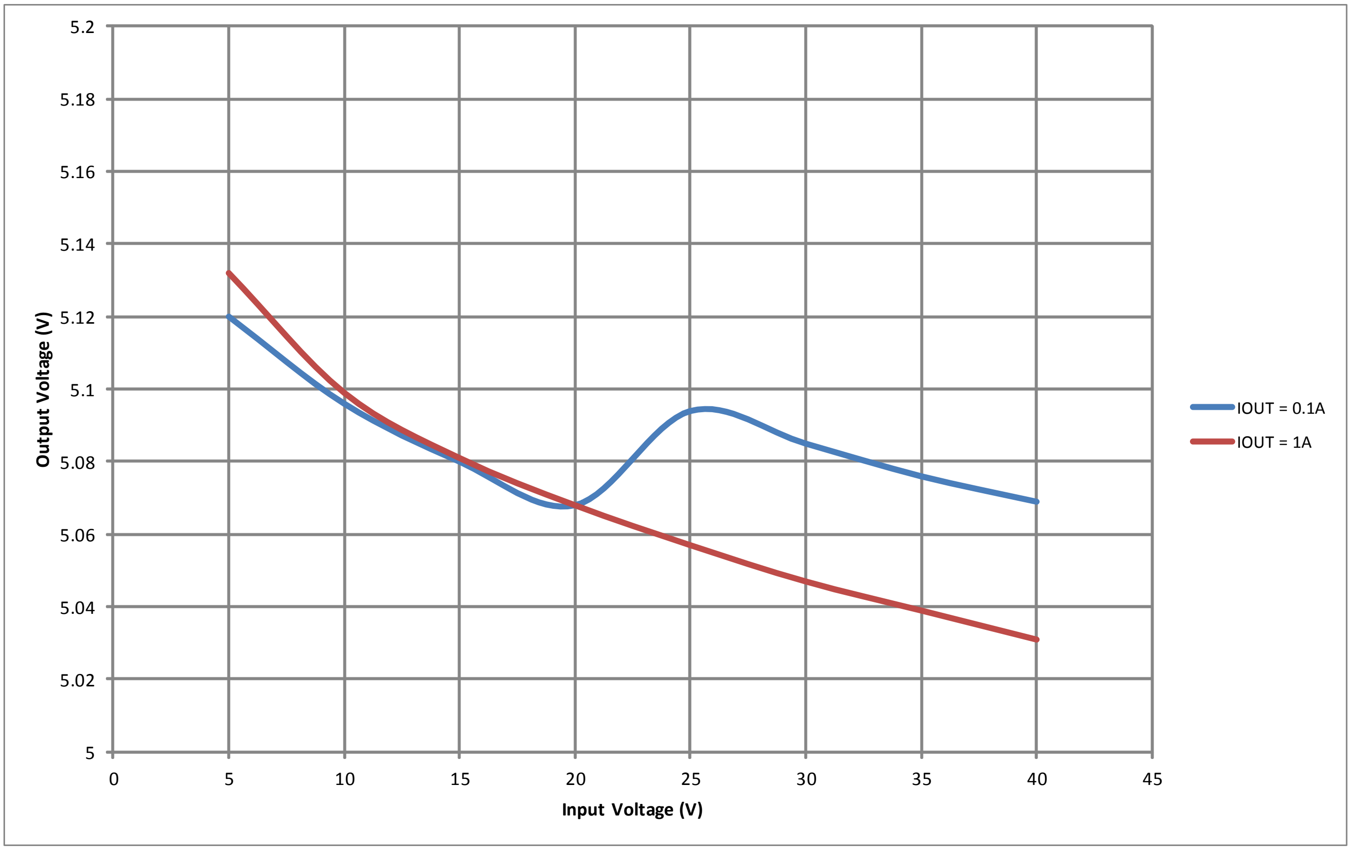

Figure 3. Line Regulation at I_{OUT} = 1A

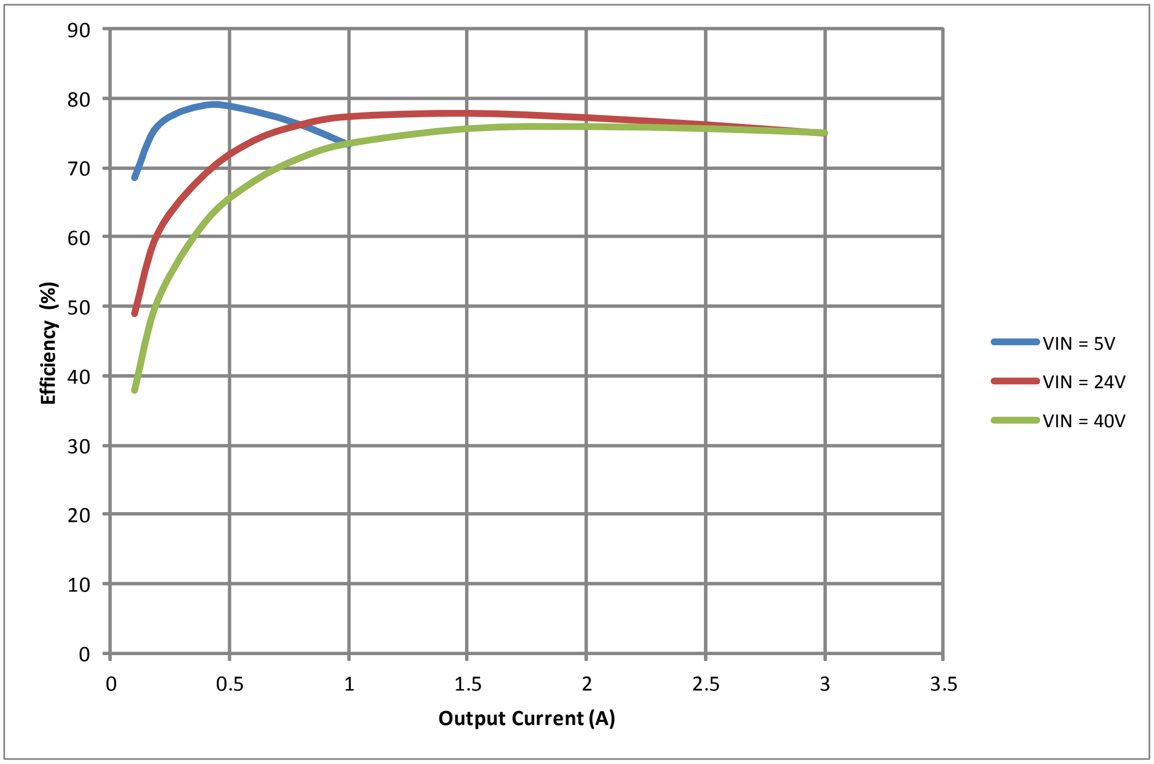

Figure 4. Efficiency Vs. I_{OUT}

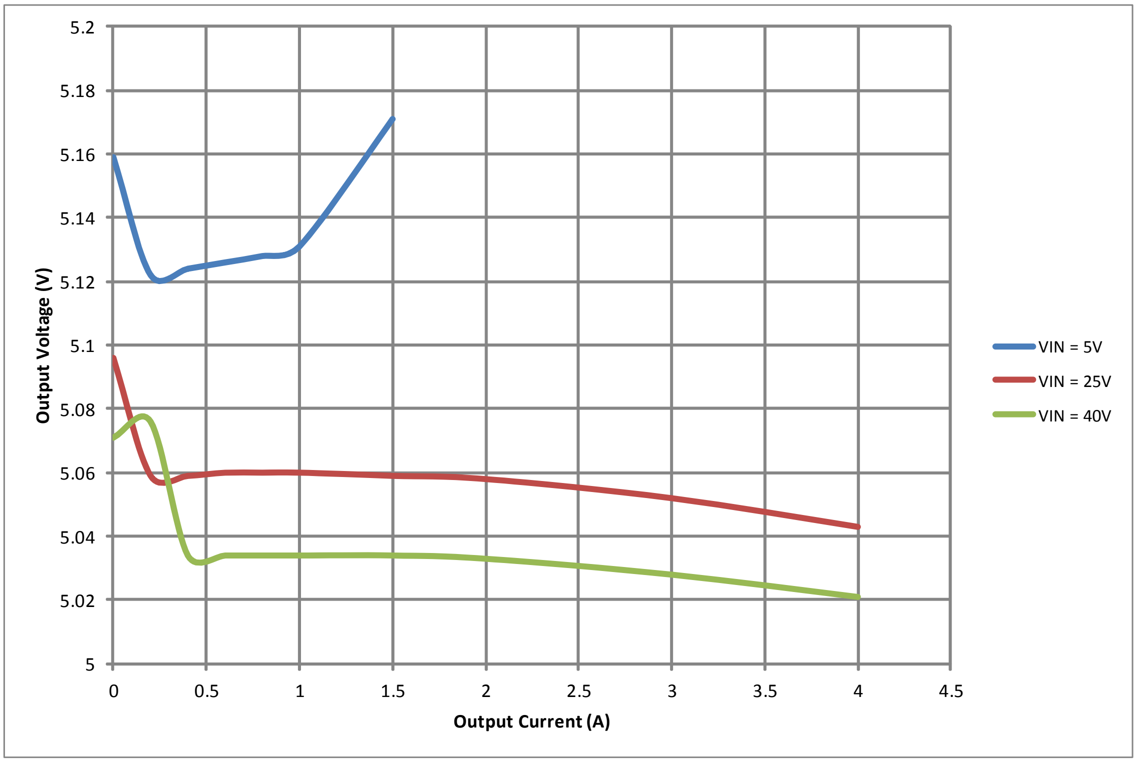

Figure 5. Load Regulation

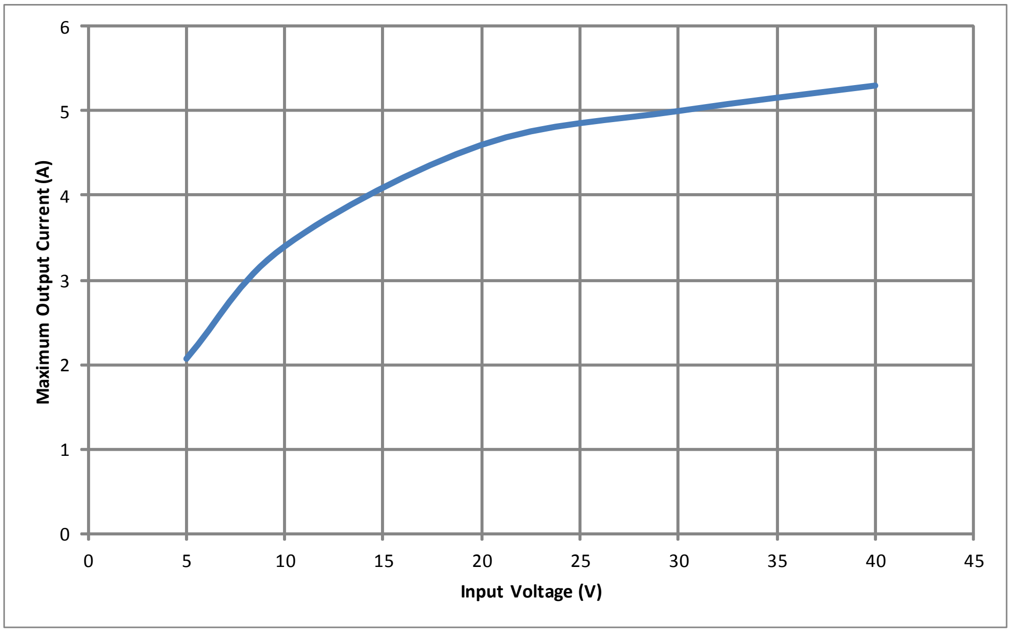

Figure 6. Maximum Output Current Vs. Input Voltage

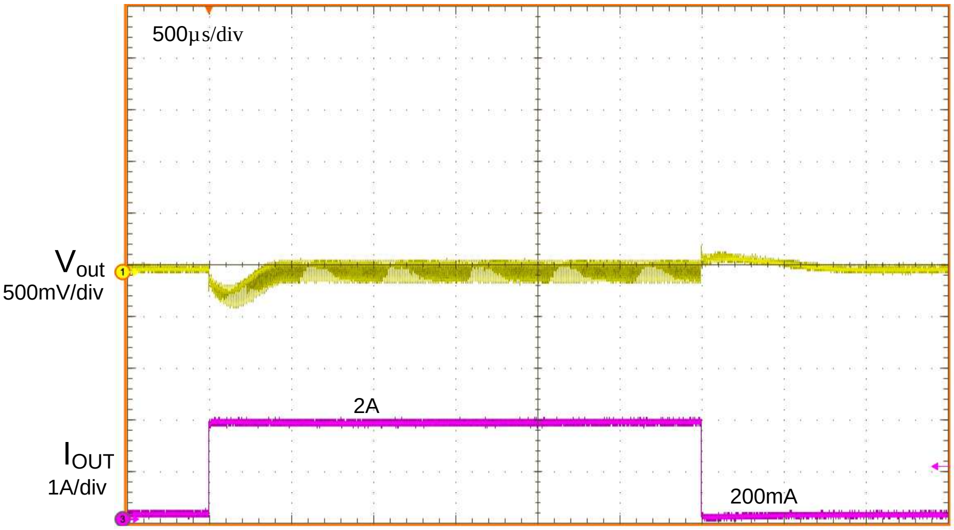

Figure 7. Load Transient V_{IN} = -12V, V_{OUT} = 5V, I_{OUT} = 200mA to 2A

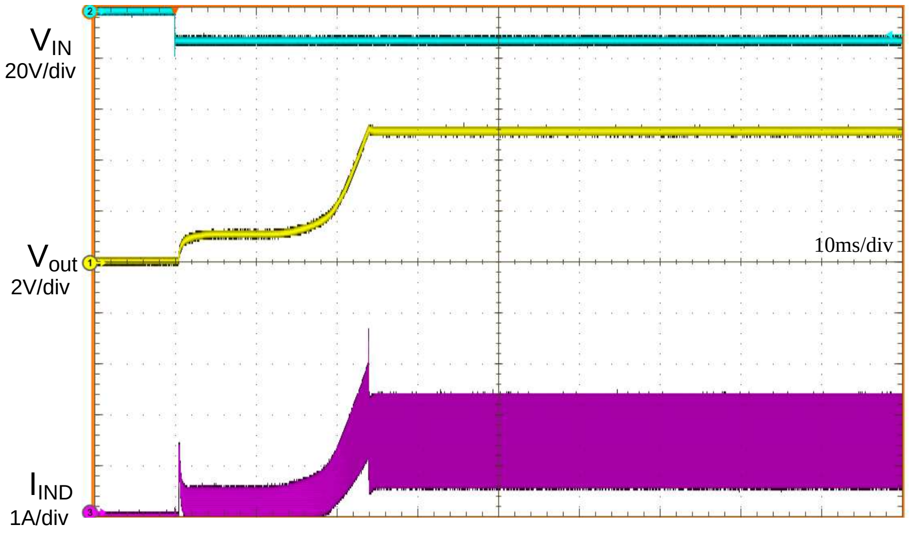

Figure 8. Startup V_{IN} = -12V, V_{OUT} = 5V, I_{OUT} = 1A

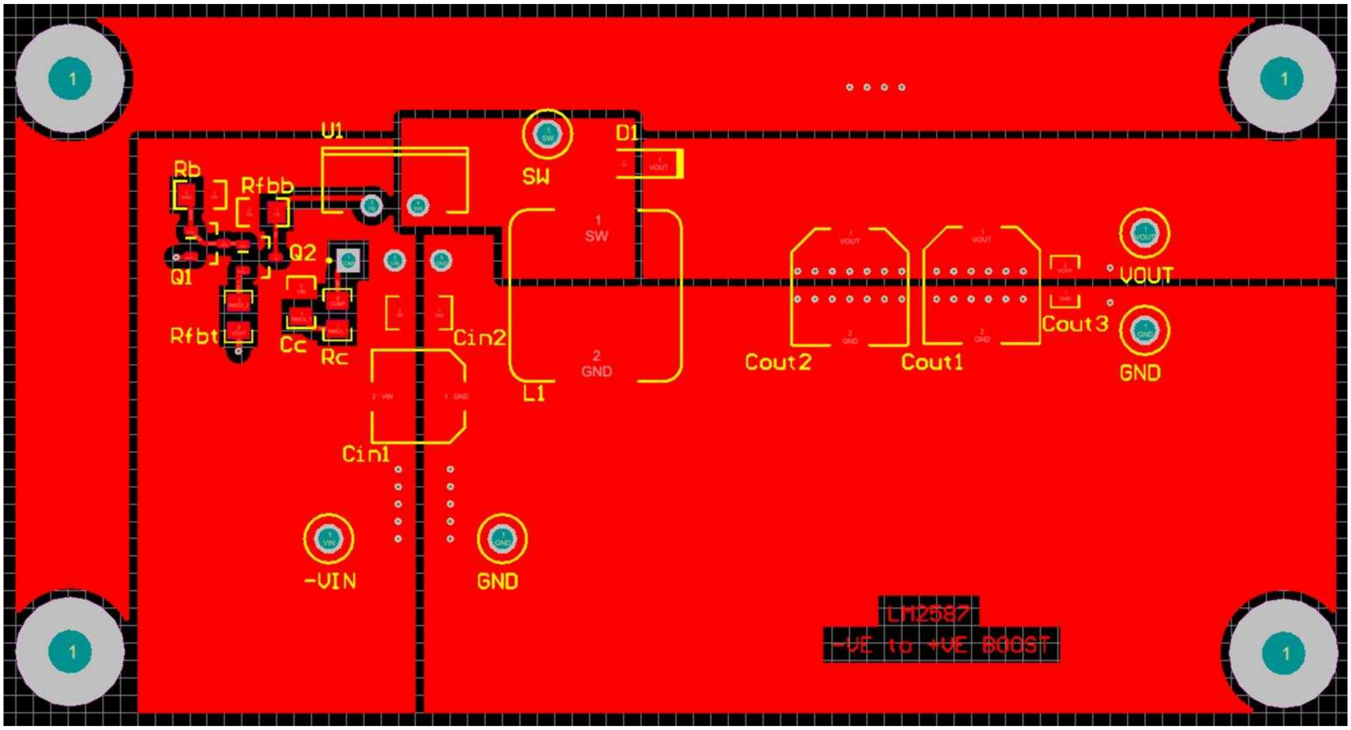

Figure 9. Top Layer

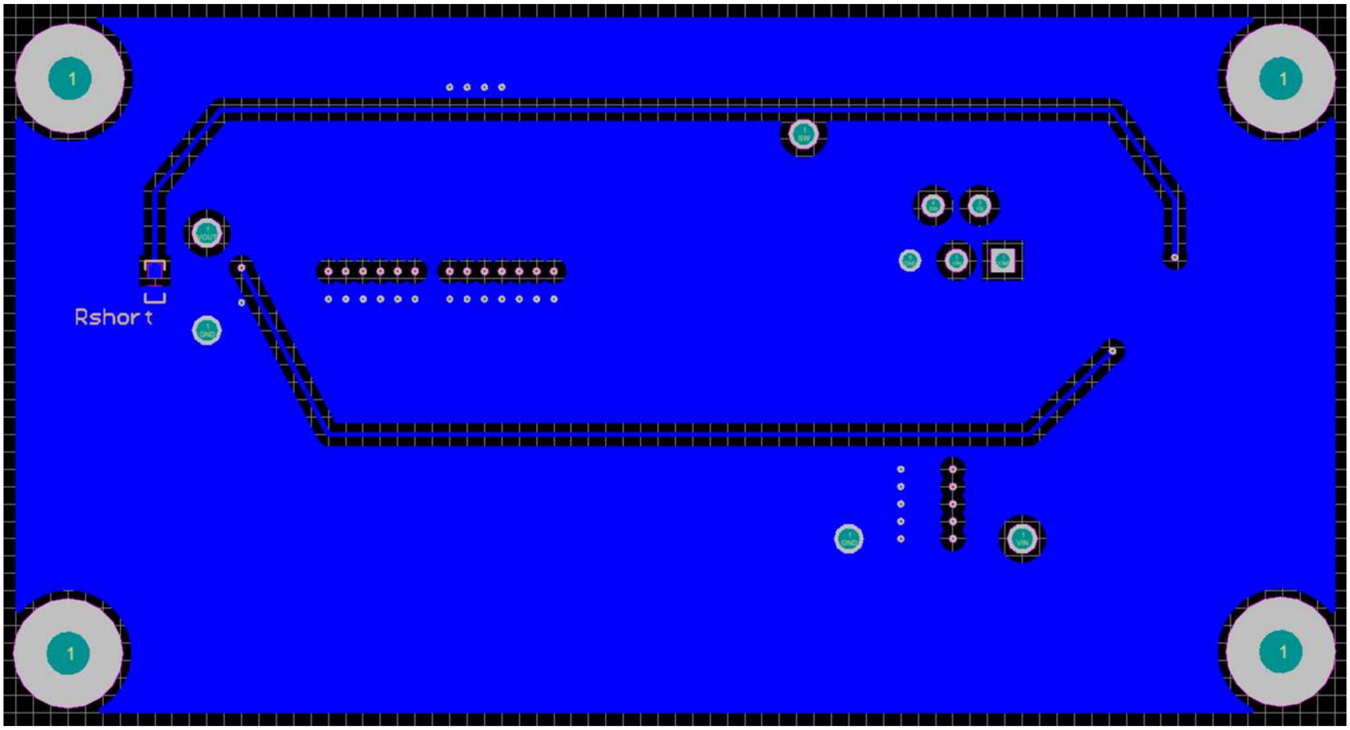

Figure 10. Bottom Layer (Flipped)

Table 1. Design BOM

DESIGNATOR	DESCRIPTION	PART NUMBER
Cc	CAP, CERM, 0.1 µF, 25 V, +/- 10%, X7R, 0805	08053C104KAT2A
Cin1	CAP, AL, 10 µF, 63 V, +/- 20%, ohm, SMD	EMVA630ADA100MF55G
Cin2	CAP, CERM, 1 µF, 100 V, +/- 20%, X7R, 1206	C3216X7R2A105M160AA
Cout1, Cout2	CAP, AL, 220 µF, 6.3 V, +/- 20%, 0.018 ohm, SMD	APXC6R3ARA221MH70G
Cout3	CAP, CERM, 1 µF, 16 V, +/- 10%, X5R, 0805	0805YD105KAT2A
D1	Diode, Schottky, 100 V, 2 A, PowerDI123	DFLS2100-7
L1	Inductor, Shielded Drum Core, Ferrite, 22 µH, 4.1 A, 0.033 ohm, SMD	744770122
Q1, Q2	Transistor, PNP, 80 V, 0.5 A, SOT-23	MMBTA56LT1G
Rb	RES, 30.1 k, 1%, 0.125 W, 0805	CRCW080530K1FKEA
Rc	RES, 1.33 k, 1%, 0.125 W, 0805	CRCW08051K33FKEA
Rfbb	RES, 1.00 k, 1%, 0.125 W, 0805	CRCW08051K00FKEA
Rfbt	RES, 4.07 k, 0.1%, 0.125 W, 0805	RT0805BRD074K07L

4 Conclusion

Thus we see that just by adding a couple of external components, a SIMPLE SWITCHER® boost regulator like the LM2587 could be used to create a positive output from a negative input using the buck-boost topology. The showcased design has good line regulation and load transient response.

5 References

1. *Understanding Buck-Boost Power Stages in Switch Mode Power Supplies*
2. *Converting Negative Input Voltages To Positive Output Voltages*

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