Application Note

Generate Negative Power Supply from Positive Power Supply

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ABSTRACT

Negative power supply is required and widely used in medical imaging systems and other electronic systems, although positive power supply is dominant in all electronic systems. Unlike positive power supply, designs for negative power supply often are a challenge for junior engineers and not straightforward. Engineers also have less options for best negative power supply designs in the market compared to the positive power supply. This application note introduces several methods to convert a positive power supply to a negative power supply to meet miscellaneous requirements from engineers under complexity, performance, and package constraints.

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1 Introduction

Negative power supply is widely used together with a positive power supply in electronic systems in history for bias transistors circuits. Negative power supply in electronic systems are reduced greatly compared to past systems. But there still are lots of electronic systems that require a negative power supply. For example, in ultrasound imaging systems, the transmitter requires three negative power supply for bias and generate symmetry waveform to excite the transducer. In an MRI system, an engineer can generate a negative power supply from positive power supply to bias a RF switch. In fiber communication and optical systems, an engineer requires a negative power supply to bias photo diodes. In communication systems, a -48V power supply is system bus voltage. In some high precise electronic systems, amplifiers require a dual power supply.

Before switch mode power supply is widely used in designs in modern electronic systems, generating a negative power supply in the past often used a transformer to transfer high alternating voltage to low alternating voltage and then rectify this low alternating voltage to direct voltage. The direct voltage then is regulated and a stable negative voltage power supply is obtained to power electronic systems. See Figure 1-1.

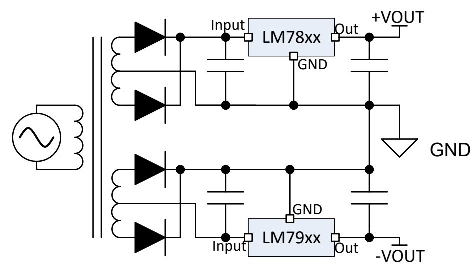

Figure 1-1. Legacy Methods to Generate a Negative Power Supply

This legacy design is still used in cost sensitive electronic systems. The drawback is the bulk volume of the transformer and low efficiency.

Modern electronic engineers often must design a compact negative power supply for a specific application under constraint of cost, efficiency, and volume. In the following sections of this application note, several designs to generate a negative power supply from positive power supply are discussed to meet miscellaneous requirements from real-world applications.

2 Methods to Design a Negative Power Supply from Positive Voltage

In theory, any isolated power supply can be treated as a negative power supply by wiring the high level output voltage terminal to ground of system and makes the low level voltage output terminal as the negative output power supply. This method sometimes means high cost, a little complex technology, and large volume. The designer has special skills associated with switch mode power supply. This application note discusses small output power, compact size, and low cost methods to obtain a negative power supply from a positive power supply.

2.1 Generate Negative Power Supply by Using a Charger Pump

The first method to generate a negative power supply from positive power supply is to use a charger pump. The principle of negative power supply charge pump is shown in Figure 2-1 . The voltage inverter portion of the charger pump contains four large CMOS switches which are switched in sequence to invert the input supply voltage. Energy transfer and storage are provided by external capacitor C1. In the first time internal, the switches S2 and S4 are open, as Figure 2-1 shows. S1 and S3 is closed. Then input energy is transferred to external capacitor C1. In the second time interval, S1 and S3 are open. At the same time, S2 and S4 are closed, and C1 is charging COUT. After a number of cycles, the voltage across COUT is pumped into VIN. Because the anode of COUT is connected to ground, the output at the cathode of COUT equals –(V_{IN}) when there is no load current. When a load is added the output voltage drop is determined by the parasitic resistance (R_{DS_ON} of the MOSFET switches and the equivalent series resistance (ESR) of the capacitors) and the charge transfer loss between the capacitors. In this way, the charger pump converter applies a positive input voltage to negative output voltage. Obviously, the amplitude of output voltage is equal input voltage if there is no load.

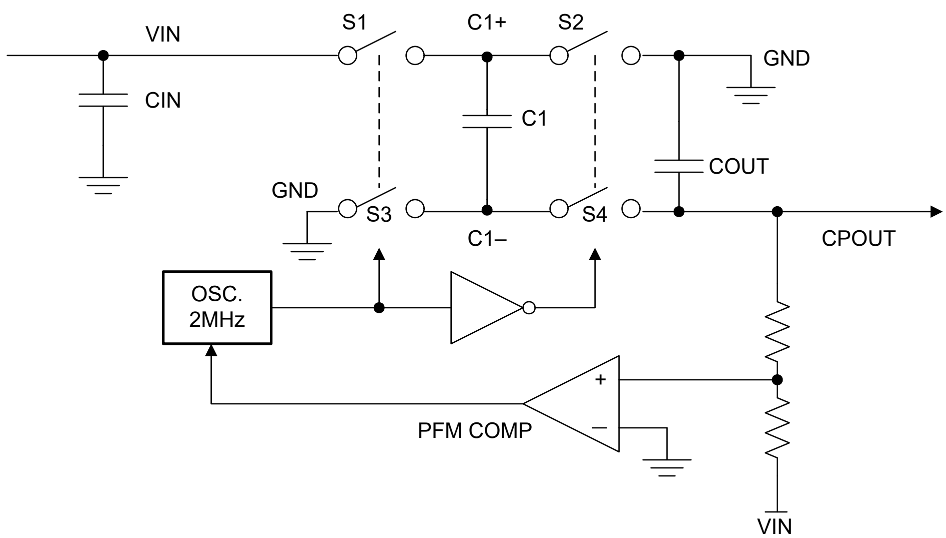

Figure 2-1. Principles of Positive Voltage Input and Negative Output Charger Pump

The output characteristic of the charger pump can be approximated by a voltage source in series with resistance. The voltage source equals –(V_{IN}). The output resistance R_{OUT} is a function of the ON resistance of the internal MOSFET switches, the oscillator frequency, the capacitance, and the ESR of C1 and COUT. Because the switching current charging and discharging C1 is approximately twice as the output current, the effect of the ESR of the pumping capacitor C1 is multiplied by four in the output resistance. The charge-pump output capacitor COUT is charging and discharging at a current approximately equal to the output current; therefore, the ESR only counts once in the output resistance. A good approximation of charge-pump R_{OUT} is shown in Equation 1:

$$R_{out} = 2R_{SW} + \frac{1}{f_{SW} \times C_1} + 4ESR_{C1} + ESR_{COUT} \quad (1)$$

where R_{SW} is the sum of the ON resistance of the internal MOSFET switches. High capacitance and low-ESR ceramic capacitors reduce the output resistance. With this function, designer can estimate the maximum output voltage under specific output current and input voltage.

TI has lots of negative output charger pump can meet specific application requirements. The LM27761 has not only integrated a negative charger pump but also integrates an LDO for better power supply performance and noise removal. See Figure 2-2. Figure 2-3 shows the typical application diagram. The advantages of the LM27761 are better performance, simple design, low cost and compact size. Equation 2 shows the output voltage.

$$V_{output} = -\left(1+\frac{R_1}{R_2}\right)\times V_{REF} = -1.22\times\left(1+\frac{R_1}{R_2}\right) \quad (2)$$

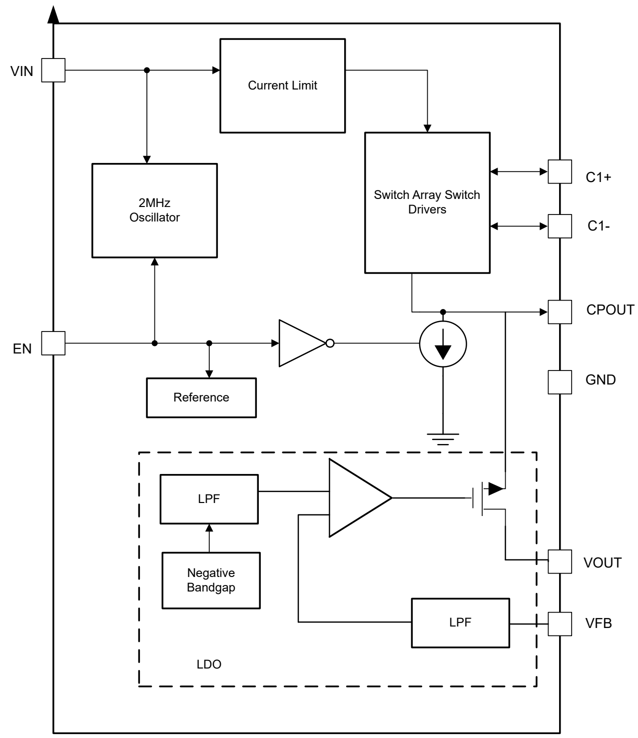

Figure 2-2. LM27761 Block Diagram

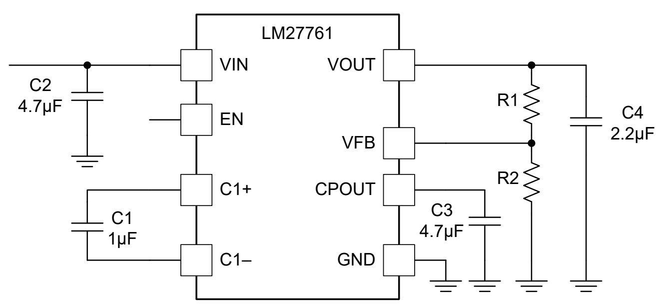

Figure 2-3. Typical Application Circuit of LM27761

The maximum output current for a charger pump in the market generally is less than 300mA. The maximum output current for LM27761 is 250mA and this can meet many applications. The second constraint for the charger pump is the amplitude of output voltage must not be larger than the input voltage and must keep a little margin. For example, a designer cannot obtain -5V output voltage from a 5V input voltage. To obtain a -5V output voltage under 250mA output current, the input voltage must be larger than 5.5V for LM27761 according to the data sheet.

2.2 Generate Negative Power Supply Using An Inverter Regulator

The second way to generate a negative output voltage from a positive power supply is to use an inverter regulator. The topology of the inverter is shown in Figure 2-4. In the first-time interval, Q1 switches on and Q2 switches off, and the current of the inductor increases under input voltage stimulation. The load is powered by output capacitor C. In the second time interval, Q1 switches off and Q2 switches on, the inductor inverse charge output capacitor C by Q2 switches. The output voltage has a negative power supply.

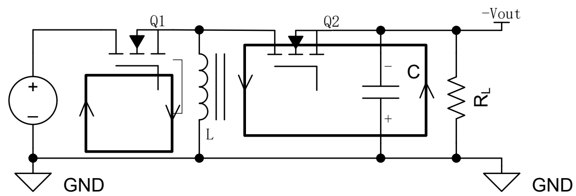

Figure 2-4. Topology of Inverter Converter

When Q1 switches on, the average current of inductor L is equal average input current. When Q2 switches on, the average current of the inductor equals the output current. Assume the efficiency of circuit is η, the output voltage amplitude is Vo and input voltages are Vin, then the average current of inductor is shown in Equation 3

$$I_{L\_avg} = I_{input\_avg} + I_O = \frac{|V_O| \times I_O}{V_{input} \times \eta} + I_O = I_O\left(1 + \frac{|V_O|}{V_{input} \times \eta}\right) \quad (3)$$

The maximum voltage for Q1 and Q2 is V_{in}-Vo. Remember that Vout in here is negative voltage. Then the customer can configure peak current of inductor to 1.2 times of average current. The values of inductor is shown in Equation 4

$$L = \frac{V_{input} \times D \times T}{\Delta I_L} = \frac{V_{input} \times D}{0.4 \times f \times I_{L\_avg}} \quad (4)$$

Here, f is switching frequency, D is duty cycle and shown in Equation 5

$$D \approx \frac{|V_O|}{V_{input} + |V_O|} \quad (5)$$

With all previously mentioned equations, designer can design an inverter converter to meet specific application requirements.

TI has several inverter regulators with 300mA-1A output current capacity and various input voltage range can meet customer most actual applications. Among these inverter regulators, TPS63700 is a 2.7- 5.5V input voltage and -1.213-15 output adjustable negative power supply with maximum 360mA output current. 3mm × 3mm package and 1.4MHz switching frequency makes TPS63700 is a compact design to generate a negative power supply from positive power supply and can meet most application requirements. The typical application as Figure 2-5 shows.

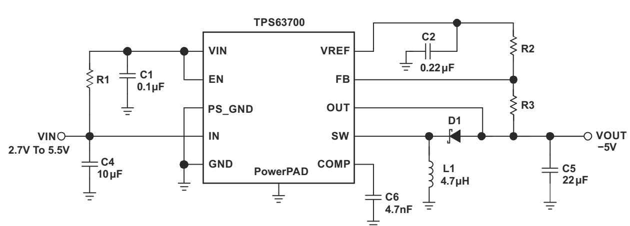

Figure 2-5. Typical Application Circuit of TPS63700

The output voltage of TPS63700 can be configured by using Equation 6

$$V_O = -\frac{R_3}{R_2} \times V_{REF} = -1.213 \times \frac{R_3}{R_2} \quad (6)$$

The input current and output current of the converter is discontinued. As a result, the inverter converter generally has a larger ripple and requires a good filter in input and output. The second issue is there are less inverters to meet miscellaneous customer applications.

2.3 Generate Negative Power Supply Using A Buck Regulator

There are fewer inverter converters compared to buck regulators in the market. This potentially means that the designer cannot find a good inverter converter to meet miscellaneous specific requirements for example, large input voltage or more output current. In this condition, a designer can build an inverter regulator by reconfiguring an ordinary buck regulator. Figure 2-6 shows a buck topology and inverter topology. A designer can see the topology between buck regulator and inverter is exactly the same except one terminal of inductor was grounded and low side MOSFET is the output. This means that a buck regulator potential can be configured to an inverter converter by reconfiguration. Figure 2-7 shows how to build an inverter converter with a traditional LMR33640 buck regulator.

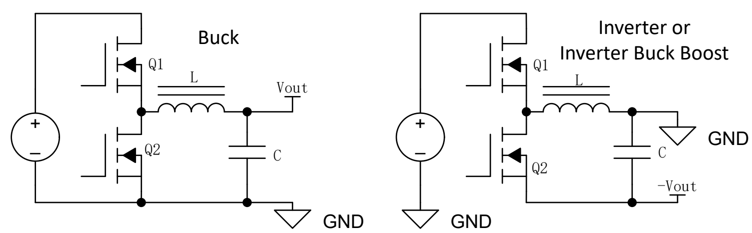

Figure 2-6. Buck Converter Topology and Inverter Buck-Boost Topology

The connection changes are shown in the following list:

1. Reassign buck positive output as system ground.
2. Reassign buck regulator ground nodes as the negative output voltage node.
3. Positive input stays the same.
4. Feedback input always referred to GND of regulator chips.

Designers can use any buck regulator to build an inverter converter to meet the specific application by following the four rules that were mentioned previously.

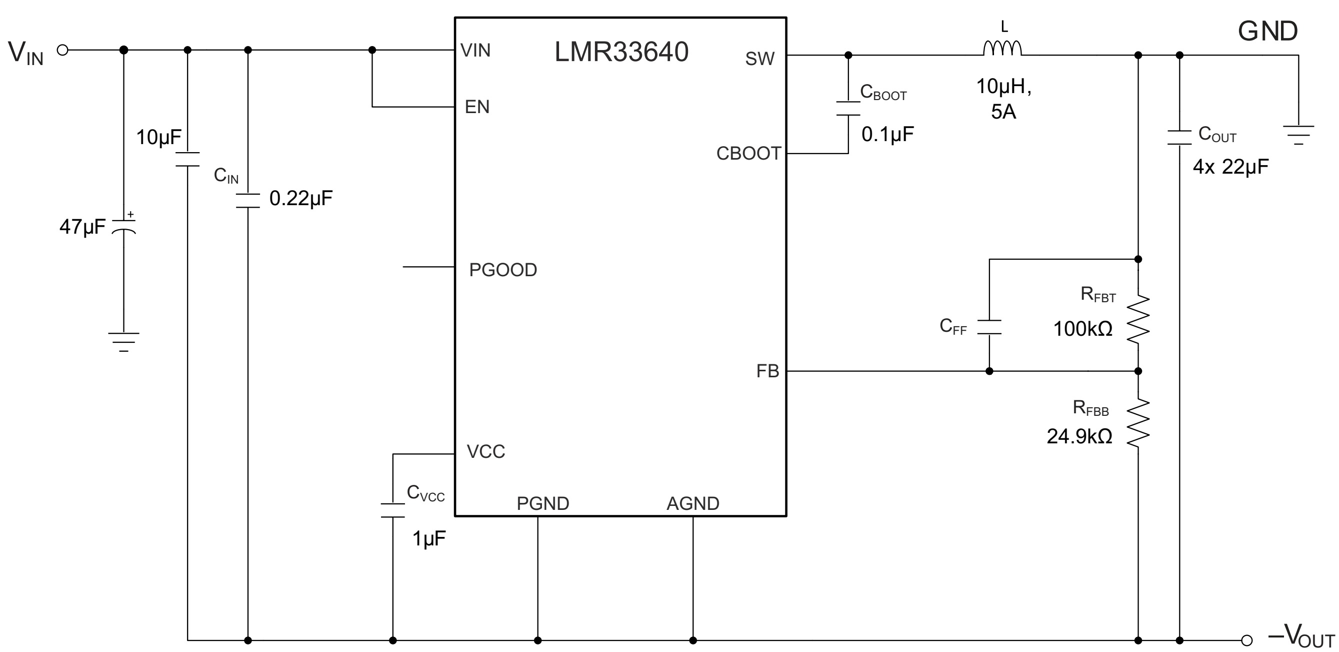

Figure 2-7. Inverter Buck Boost Converter Based LMR33640

Designers must also check the following list during actual design course.

1. The maximum endure voltage of MOSFET in buck regulator now is need big than V_{in}-$V_{output.}$
2. The saturation current of inductor needs big than $1.2I_o(1+V_o/(V_{in} \times \eta))$
3. The setup output voltage as a buck regulator but note that the reference voltage always refers to the GND of chips. The output voltage is shown in Equation 7

$$V_{output} = -\left(1 + \frac{R_{FBT}}{R_{FBB}}\right) \times V_{REF} \tag{7}$$

2.4 Generate Negative Power Supply Using A Cuk Regulator

A Cuk regulator also can generate a negative power supply from a positive input voltage power supply. The topology of the Cuk regulator is shown in Figure 2-8 .

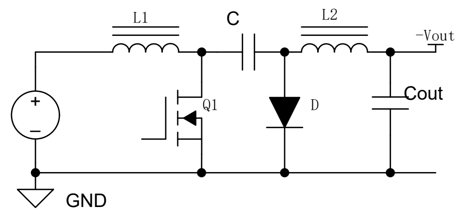

Figure 2-8. Cuk Converter Topology

In the first stage, switch Q1 is switched on, diode D is switched off. Current of inductor L1 increases linearity, couple capacitor C discharges to output capacitor C_{out} and loaded by inductor L2. The current of inductor L2 increases linearity since C is large enough. In the second stage, switch Q1 switches off and diode D is switched on. Couple capacitor C is charged by inductor L1 and input power supply. The voltage of couple capacitor C increases. Inductor L2 charges output capacitor Cout and load by diode D. Equation 8 shows the duty and stress voltage of Q1 and diode (D) for Cuk converter. Customers can select MOSFET and diode according to Equation 8, Equation 9, Equation 10, Equation 11, and Equation 12 .

$$D = \frac{|V_{output}| + V_F}{|V_{output}| + V_{input} + V_F} \tag{8}$$

$$V_{Q1} = V_{input} + |V_{output}| + V_f + \frac{V_{C\_ripple}}{2} \tag{9}$$

$$V_D = V_{input} + |V_{output}| + V_f + \frac{V_{C\_ripple}}{2} \tag{10}$$

$$I_{L1\_avg} = \frac{|V_{output}| \times I_{output}}{V_{input} \times \eta} \tag{11}$$

$$I_{L2\_avg} = I_{output} \tag{12}$$

LM2611 is a current mode Cuk regulator that can operate from 2.7V-14V with 1.4MHz switching frequency Customers can use a previously mentioned equation to estimate the minimum output voltage under a specific input voltage. The output voltage can be configured by Equation 13

$$V_{output} = -\left(1 + \frac{R_T}{R_B}\right) \times V_{REF} = -1.23 \times \left(1 + \frac{R_T}{R_B}\right) \tag{13}$$

Customera also can use a boost regulator to build a Cuk converter since there are less Cuk converters in the market to meet miscellaneous applications from customers. However, designers must add an external inverter amplifier to converter the negative output to positive feedback voltage since the feedback of most boost converter requires a positive input feedback voltage. As an example, designers can use LM5158 and TLV171 to build an Cuk converter, as Figure 2-9. The output voltage is shown in Equation 14

$$V_{output} = -\frac{R_f}{R_1} \times V_{REF} \tag{14}$$

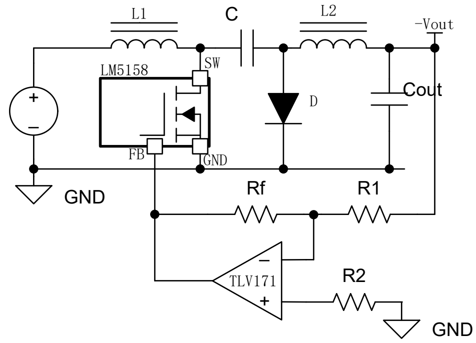

Figure 2-9. Use Boost Converter to Build a Cuk Converter

2.5 Generate Negative Power Supply With A Fly-Back Converter

In theory, any isolated power supply can be used as a negative power supply just by tying the high level terminal to system ground and treating the low level terminal as a negative power supply. However, isolated power supply generally has complex topology and requires specific skills associated with power electronics. Among this topology, primary-side regulated (PSR) flyback converter is a simple isolated topology that is fitted to be a negative power supply. Unlike traditional flyback topology, PSR flyback does not require an opto-coupler to transfer feedback signals. The feedback directly goes in the primary side coils during switch off stage and as a result there is a simple circuit with low cost and low size.

The TI LM25184 is a primary-side regulated (PSR) flyback converter with high efficiency over a wide input voltage range of 4.5V to 42V. The LM25184 is a high-density, cost-effective design for industrial systems requiring less than 10W of isolated DC/DC power supply. LM25184 integrated a 65V, 2.5A N-channel power MOSFET. During the MOSFET on-time, the transformer primary current increases from zero with a slope of V_{IN} / L_{MAG} (where L_{MAG} is the transformer primary-referred magnetizing inductance) while the output capacitor supplies the load current. When the MOSFET is turned off by the control logic, the switch (SW) voltage VSW swings up to approximately V_{IN} + (N_{PS} × V_{OUT}), where N_{PS} = N_P/N_S is the primary-to-secondary turns ratio of the transformer. The magnetizing current flows in the secondary side through the flyback diode, charging the output capacitor and supplying current to the load. To minimize output voltage regulation error, the LM25184 senses the reflected secondary voltage when the secondary current reaches zero. During MOSFET switch off, the output voltage is reflected to the primary side by turns ratio between primary side and secondary side N_{PS} (V_{out} +V_D). This voltage is attenuated by the ratio of the resistor between FB pin and SW pin to the resistor at the RSET pin and sets the output voltage. The output voltage can be configure according Equation 15.

$$R_{FB} = \left(|V_{output}| + V_f\right) \times N_{PS} \times \frac{R_{SET}}{V_{REF}} \quad (15)$$

Figure 2-10 shows the typical application circuit. See the LM25184 data sheet for more information.

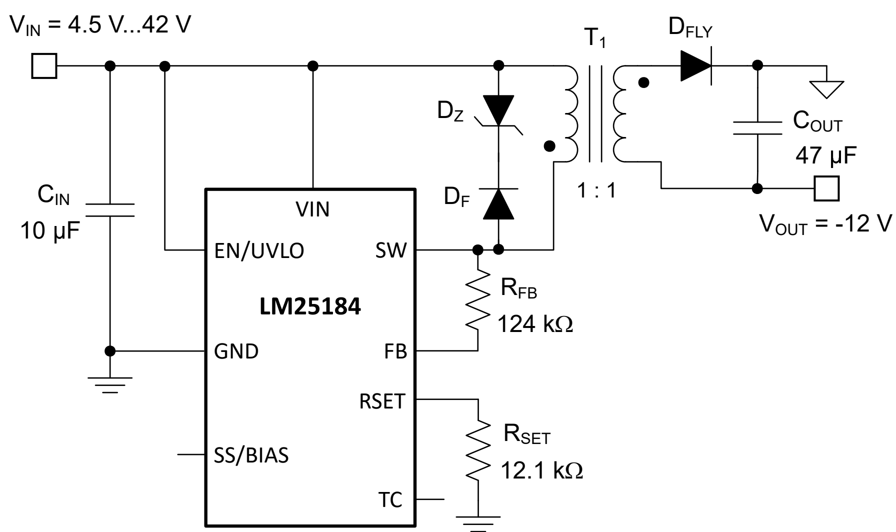

Figure 2-10. Generate Negative Power Supply by a Primary Side Feedback Fly-Back Converter

The drawback for PSR flyback converter is designer must design or purchase a customer flyback transformer. This is not convenient for most engineers. The second drawback is the output voltage is not very precise since the diode has a forward voltage drop.

3 Summary

This article introduced several ways to generate a negative power supply from a positive input power supply. A charger pump has a very simple circuit. The drawback is the output voltage in most cases cannot be adjustable and less than 300mA maximum output current. An inverter converter can output large current and only requires one inductor. The circuit is simple but the drawback is the input and the output must have good filters to obtain good performance. There are less options in the market to obtain an inverter converter. The inverter buck-boost converter is exactly same with the inverter converter in topology and the designer has more options. However, the inverter buck-boost converter is not straightforward and needs good input and output filter if the designer expects good performance. Cuk topology has good input and output performance but requires two inductors. The second shortage is there are less Cuk inverters in the market. Designer can use a boost converter to build a Cuk converter and must add an inverter amplifier in the feedback loop. The drawback of PSR flyback is that designers require a design for a specific transformer. In the actual design, the designer can select a design to meet the specific application for the circuit size, and so on.

4 References

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2. Texas Instruments, *Inverting Buck-Boost Application for the LM63615-Q1*, application note.
3. Texas Instruments, *LM27761 Low-Noise, Regulated, Switched-Capacitor Voltage Inverter*, data sheet.
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5. Texas Instruments, *LM2611 1.4-MHz Cuk Converter*, data sheet.
6. Texas Instruments, *LMR33640 Simple Switcher 3.8-V to 36-V, 4-A Synchronous Step-Down Converter*, data sheet.
7. Texas Instruments, *LM25184 42-VIN PSR Flyback DC/DC Converter with 65-V, 4.1-A Power MOSFET*, data sheet.
8. Texas Instruments, *LM5158x 2.2-MHz Wide VIN 85V Output Boost/SEPIC/Flyback Converter with Dual Random Spread Spectrum*, data sheet.
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