*Application Report*

# *High-Precision Negative-Voltage APD Power Supply Design with TPS61391*

*Helen Chen*

**ABSTRACT**

Avalanche Photodiodes (APDs) were widely used in the LIDAR and fiber optic communication systems. However, some APDs require a high reverse voltage bias of -20 V to -150 V or even lower. Current negative power supply options are bulky while with low precision. This application note delivers a low cost, high-precision and small-sized power supply design for the negative-voltage-biased APD application with TPS61391.

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# 1 Introduction

The TPS61391 is a fully integrated boost converter with an 85-V FET to convert a low input voltage to a higher voltage for biasing the APD. The TPS61391 supports an input voltage ranging from 2.5 V to 5.5 V, the maximum output voltage can reach 85 V. In some applications, for example, mechanically scanning LIDAR, robot LIDAR, or laser distance meters, negative voltage biased APD were also used, the voltage range is from -20 V to -150 V or even lower. Those negative supply voltage need to be of high precision, low ripple, and small solution size.

This application note delivers a low cost, high-precision and small-sized power supply design for the negative-voltage-biased APD application with TPS61391. The output voltage is tightly regulated at a certain value regardless of the line voltage or load current change. This design can cooperate with trans-impedance amplifier, similar to LMH32401 for light detection and ranging (LIDAR) applications, or laser distance measurement systems.

# 2 Design Process

## 2.1 Schematic Design

Figure 2-1 shows the schematic of this application note. To achieve -90 V output, two negative charge-pump cells were used. The maximum output voltage of TPS61391 can reach 85 V, so if the required negative voltage is within 0 to -80 V, only one charge pump cell needed; if the required negative voltage is within -80 to -160 V, two charge pump cells should be adopted.

To convert the negative output voltage to a positive feedback voltage, a level shift circuit is implemented. It uses a current mirror circuit built with two inexpensive PNP transistors, and one NPN transistor to regulate the output voltage. For best performance and tighter regulation accuracy, a matched pair can be used, so that the two $V_{BE}$ can be canceled out.

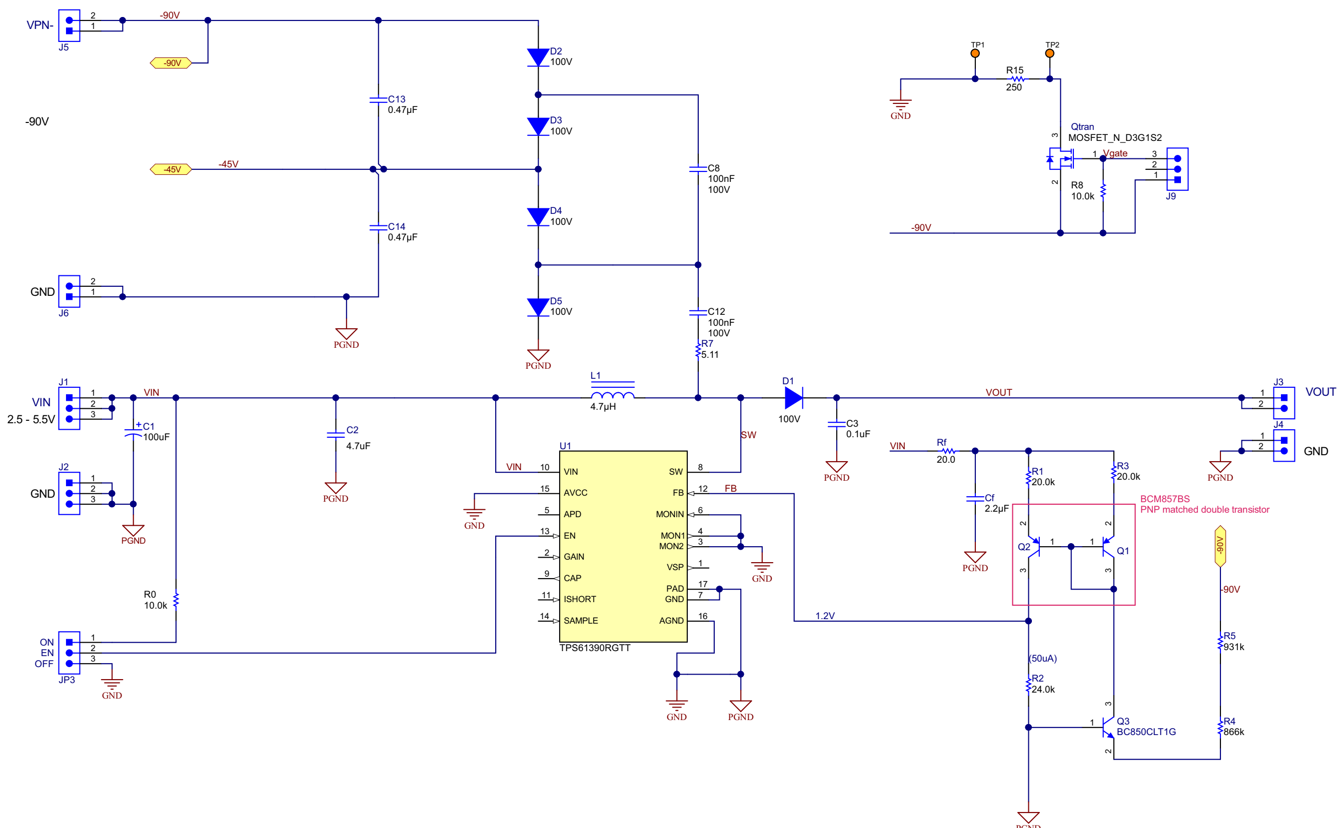


**Figure 2-1. 3.3 V Input -90 V Output Conversion with TPS61391**

## 2.2 Parameter Calculation

During normal working, the current $I_{FB}$ flowing through R2 and Q2 equals to Vref/R2. The current flowing through Q1 is effected by the $V_{BE}$ mismatch of Q1 and Q2, but the $V_{BE}$ mismatch can be reduced to a minimum level by using matched double transistors in the design. For the PNP matched double transistors, the $V_{BE}$ mismatch is lower than 2mV, neglect this mismatch, $I_{Q1}$ can be derived from the below equation:

$$I_{Q1} = \frac{V_{REF}}{R2} \tag{1}$$

The output voltage equals to:

$$V_{OUT} = -\frac{V_{REF}}{R2} \times \left(R_4 + R_5\right) - V_{BE} \tag{2}$$

The precision of the output voltage is mainly determined by the tolerance of the output voltage dividing network R2, R4 and R5, the tolerance of the reference voltage $V_{ref}$ and $V_{BE}$. Set $I_{FB}$ = 50uA, then R2 = 24k ohm based on 1.2 V reference voltage. The value of R1 and R3 is limited by the minimum input voltage, therefore a 20k ohm resistor is chosen in this application note. The total value of R4 and R5 can be calculated by below equation:

$$R_4 + R_5 = -\frac{V_O + V_{BE}}{V_{REF}} \times R_2 = -\frac{-90\text{ V} + 0.5\text{ V}}{1.2\text{ V}} \times 24\text{ k} = 1790\Omega \tag{3}$$

In this application note, the total value of R4 and R5 is set at 1797k ohm, which is quite close to the calculated value.

The output voltage drift caused by the $V_{BE}$ mismatch of the PNP matched double transistors Q1 and Q2 can be calculated by the below equations:

$$V_{OUT} = -\left(\frac{V_{REF}}{R_2} \mp \frac{\Delta V_{BE}}{R_3}\right) \times \left(R_4 + R_5\right) - V_{BE} \tag{4}$$

The output voltage variation caused by the $V_{BE}$mismatch is:

$$\Delta V_{OUT\_BE} = \pm \frac{\Delta V_{BE}}{R_3} \times \left(R_4 + R_5\right) = \pm \frac{2\text{ mV}}{20\text{ k}} \times 1797\text{ k} = \pm 179.7\text{ mV} \tag{5}$$

In this application note, BCM857BS is chosen for its <2m V small $V_{BE}$ mismatch.

## 3 Test Result

Figure 3-1 shows the 3.3 V input voltage startup waveform of SLVAEZ7. The output voltage decreases monotonically from 0 V to -90 V.

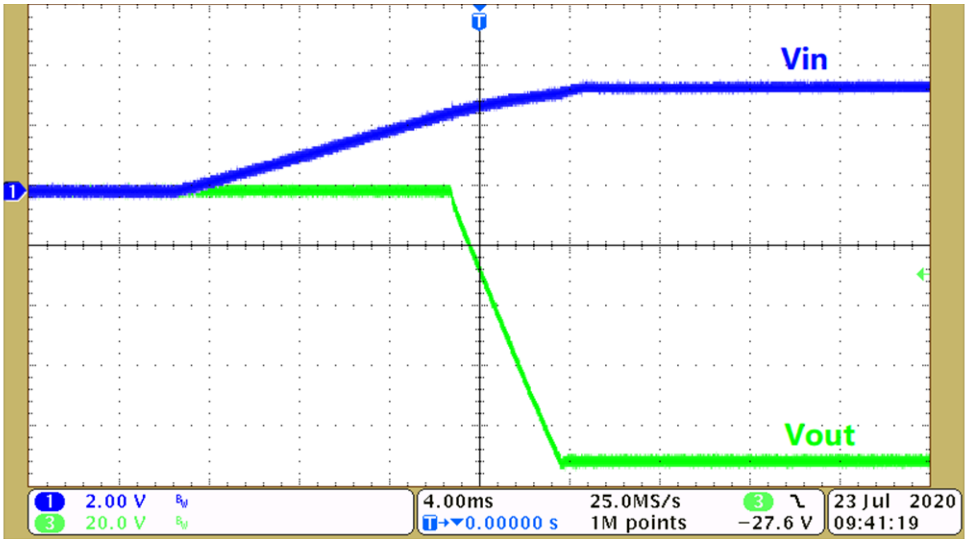


**Figure 3-1. Input Voltage Start-up Waveform (Vin=3.3 V, Vout=-90 V)**

Figure 3-2 shows the enable startup waveform of SLVAEZ7. The output voltage decreases monotonically from 0 V to -90 V.

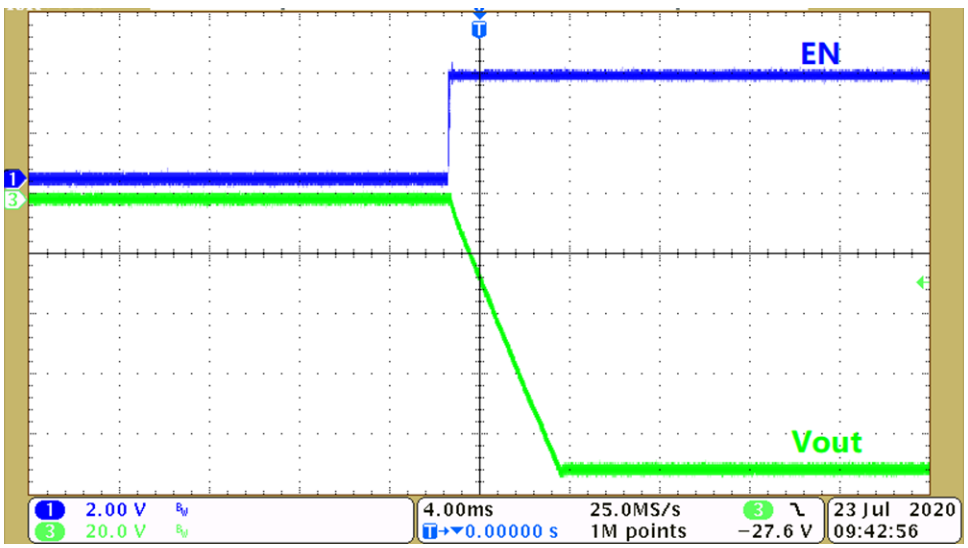


**Figure 3-2. Enable Start-up Waveform (Vin=3.3 V, Vout=-90 V)**

Figure 3-3 and Figure 3-4 show the output voltage ripple at 1mA and 2mA load current respectively. The output voltage ripple is around 20mV at 2mA load current based on schematic show in Figure 2-1.

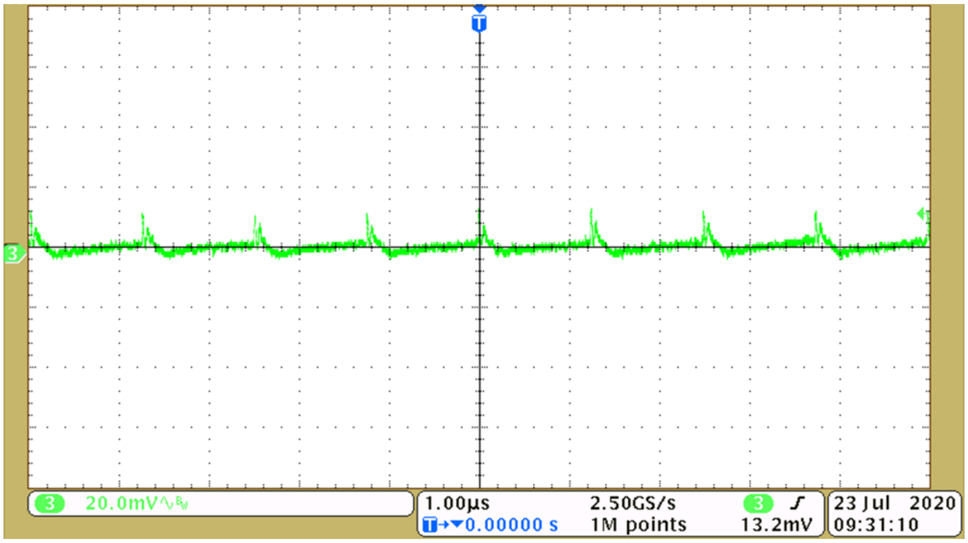


**Figure 3-3. Output Voltage Ripple at 1mA load Current (Vin=3.3 V, Vout=-90 V)**

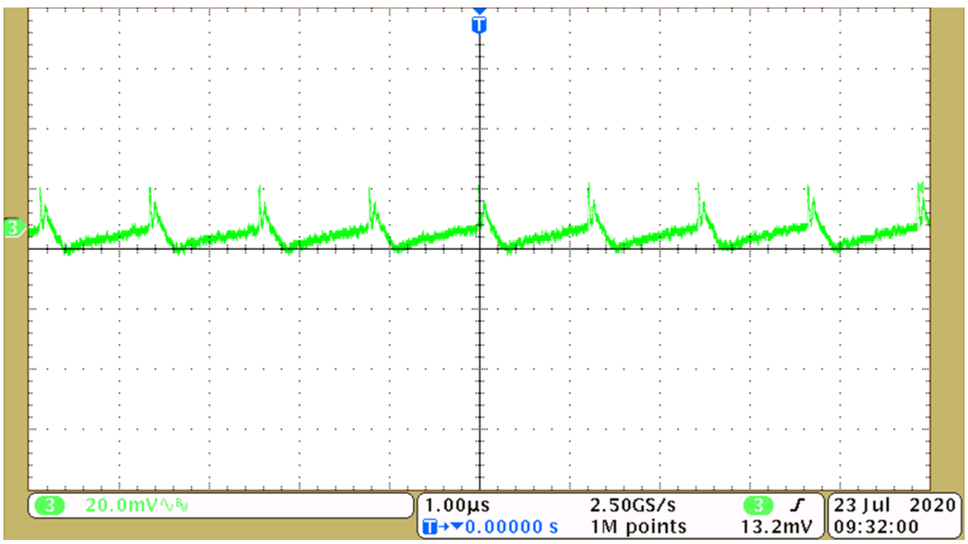


**Figure 3-4. Output Voltage Ripple at 2mA load Current (Vin=3.3 V, Vout=-90 V)**

Figure 3-5 shows the load dynamic performance. When Vgate high, there's a current flowing through R15. We control the Vgate high-low level to generate a dynamic load current. The voltage drop on the -90 V output is less than 500mV with a 2mA load step.

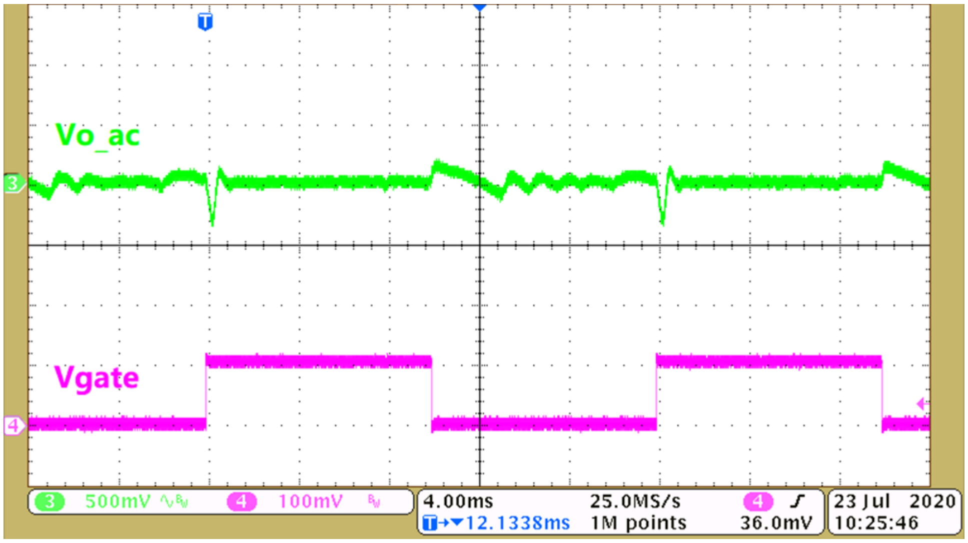


**Figure 3-5. Load Dynamic Performance at 2mA Load Step (Vin=3.3 V, Vout=-90 V)**

Table 3-1 shows the line and load regulation performance. The output voltage doesn't changes with the load, but slightly changes with the input voltage.

**Table 3-1. Line Load Regulation**

| Vin(V) | Vout(V) | | |
|---|---|---|---|
| | Io=0mA | Io=1mA | Io=2mA |
| 3.3 | -90.1 | -90.1 | -90.1 |
| 4 | -90.0 | -90.0 | -90.0 |
| 5 | -89.9 | -89.9 | -89.9 |

# 4 Summary

This application note delivers a low cost, high-precision and small-sized power supply design for the negative-voltage-biased APD application with TPS61391. The output voltage is tightly regulated at -90 V regardless of the line load change. It is of small ripple and good dynamic performance. This circuit can cooperate with the trans-impedance amplifier LMH32401 to form a detection circuit for light detection and ranging (LIDAR) applications, laser distance measurement applications or various robot LIDAR applications.

# 5 References

1. Texas Instruments, 85-VOUT Boost Converter with Current Mirror data sheet
2. Texas Instruments, TPS61391 85-VOUT Boost Converter with Current Mirror Integrated
3. Texas Instruments, LMH32401 450-MHz, Programmable Gain, Differential Output Transimpedance Amplifier data sheet