Application Report
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Multi-rails supply regulated outputs to power TFT screen from car battery

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ABSTRACT

Battery voltage cranking in automotive system imposes extra precaution and circuit optimization. Circuit may work correctly in steady state but surprises can appear during cranking. Selecting the right external parts during design phase is a key objective for reliability, time saving and money saving. See Figure 2 and 3.

Objective

Thin film Transistor (TFT) requires 3 regulated supply voltages from a single 2.7V to 5V supply. The 3 output voltages are higher than the input. Boost converter is necessary. The 3 outputs are boost V_O1, positive charge pump V_O3 and negative charge pump V_O2. See Figure1.

The negative charge pump, one of the regulated outputs, is the main focus in this paper. Negative charge pump can induce a negative voltage on its feedback pin FB2 and Reference voltage REF during cranking. The induced negative voltage may cause a device shutdown and results in a TFT (LCD) to display a white screen if the problem occurs. A reliable fix is introduced in this paper.

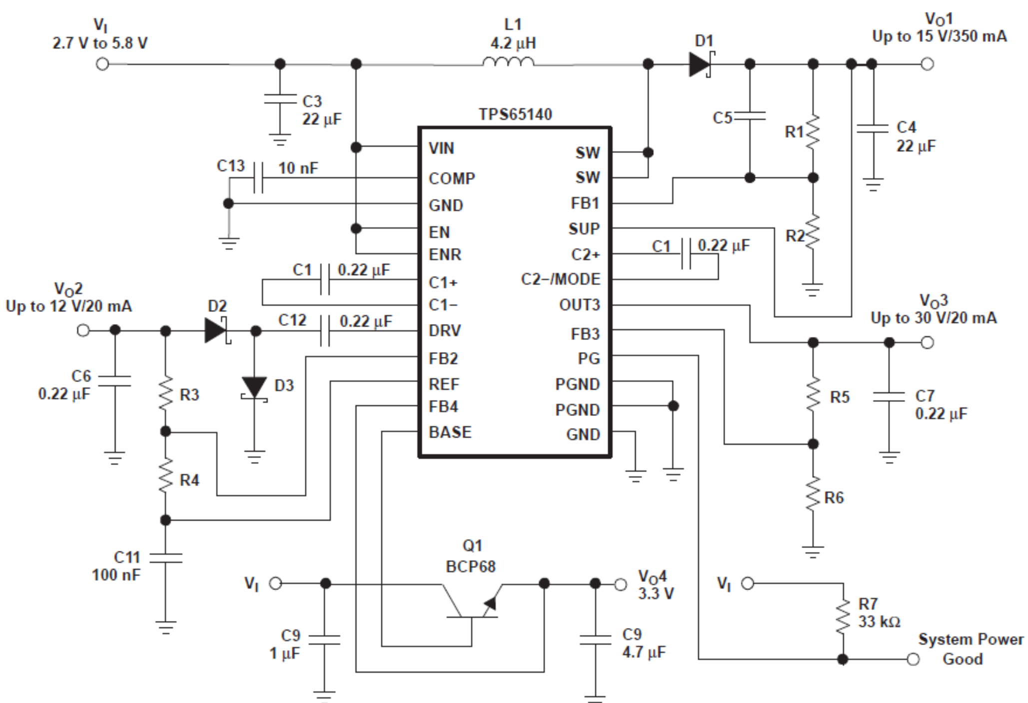

Figure 1. Typical circuit for TFT supply

Description

The TPS65100, 140, 145-Q1 offers a compact and small power supply solution to provide all three voltages required by thin film transistor (TFT) LCD displays. The main output V_O1 is a 1.6MHz fixed frequency PWM boost converter providing the source drive voltage for a LCD display. An externally adjustable negative charge pump V_O2 provides the negative gate drive voltage. A fully integrated adjustable positive charge pump V_O3 Doubler/Tripler provides the positive LCD gate drive voltage. Due to the high 1.6MHz switching frequency of the charge pumps, inexpensive and small 220nF capacitors can be used. The device also has a linear regulator using an external transistor to provide regulated 3.3V output for digital circuits. The TPS65100-Q1 has an integrated VCOM buffer to power the LCD backplane while the TPS65140, 145-Q1 has a system power good output to indicate when all supply rails are acceptable. See Figure 2.

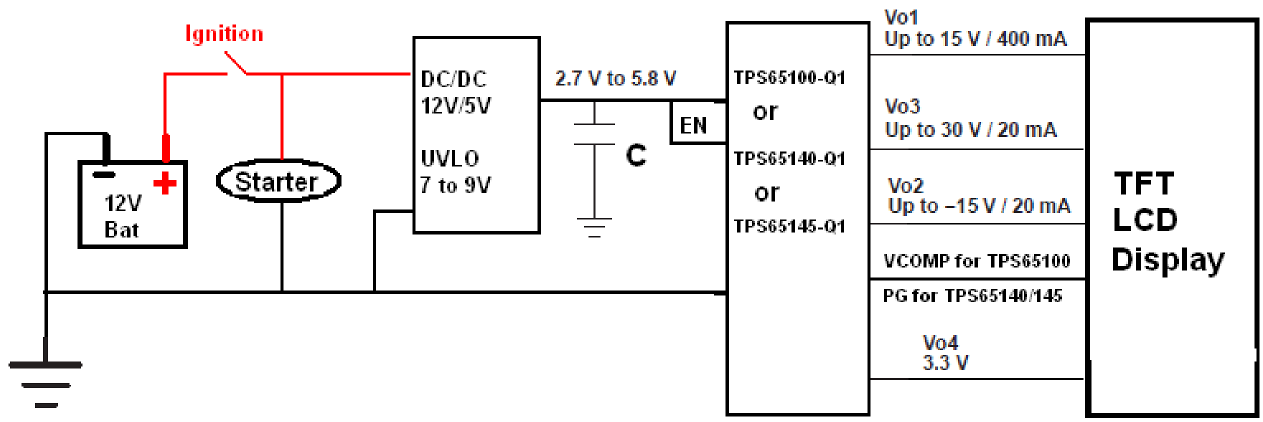

Figure 2. Automotive application diagram

What can happen during cranking?

During normal operation, battery voltage is at nominal value and the TPS6510, 140, 145 is enabled and supplying the TFT screen. During cranking the battery drops and causes the DCDC front end buck converter to turn off which results in a drop of the intermediate voltage VIN (the DCDC output and input of TPS65100, 140, 145-Q1). See Figure 3. This brownout condition might cause abnormal shutdown of display supplies and may not recover. This results in white screen.

More detailed explanation of this issue and potential work around is given in the following sections.

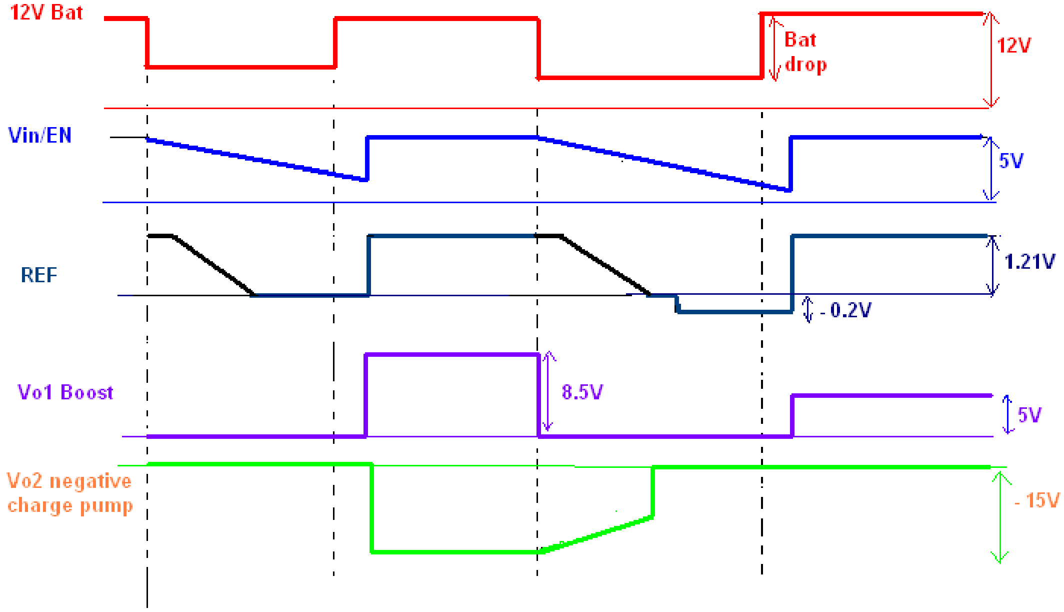

Figure 3. Waveform illustration at ignition

Figure 3 shows the following signals:

- Battery voltage during cranking
- TPS65100, 140, 145 input voltage VIN
- Reference voltage REF
- Boost output Vo1
- Negative charge pump output Vo2

When VIN is below UVLO the device shuts down. The negative charge pump capacitor holds the charge for a while and forward bias the ESD cell on feedback pin FB2. The ESD cell forward voltage Vd is around 500mV. This induces a negative voltage of 500mV on FB2 pin and causes REF pin voltage pulled below ground.

Power up sequences and safety features

TPS65100, 140, 145-Q1 incorporates all necessary power up sequences and safety (Figure 4) required by the TFT. It has an internal band-gap reference (Vref) of 1.213V. The reference voltage is used to regulate all three output voltages (boost converter, positive charge pump and negative charge pump).

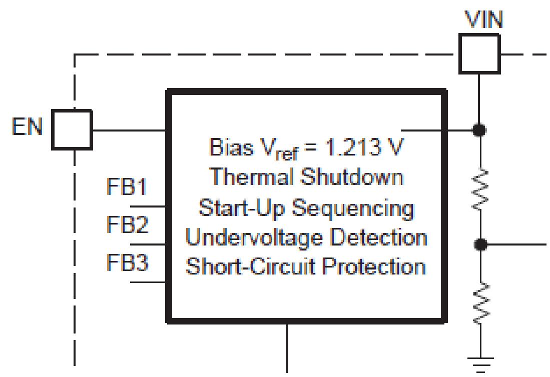

Figure 4. Fault protection diagram

For maximum safety, the entire device goes into shutdown as soon as any of these conditions is true:

- Bias Vref is 10% out of regulation
- One of the outputs is out of regulation
- One of the output is under short circuit
- Thermal Shutdown

Designer should take these safety conditions into consideration during their first design stage to assure the device is working properly in any circumstances.

Negative charge pump configuration

Negative charge pump standard configuration is shown in Figure 5. Detailed explanation is given in the appendix at the end.

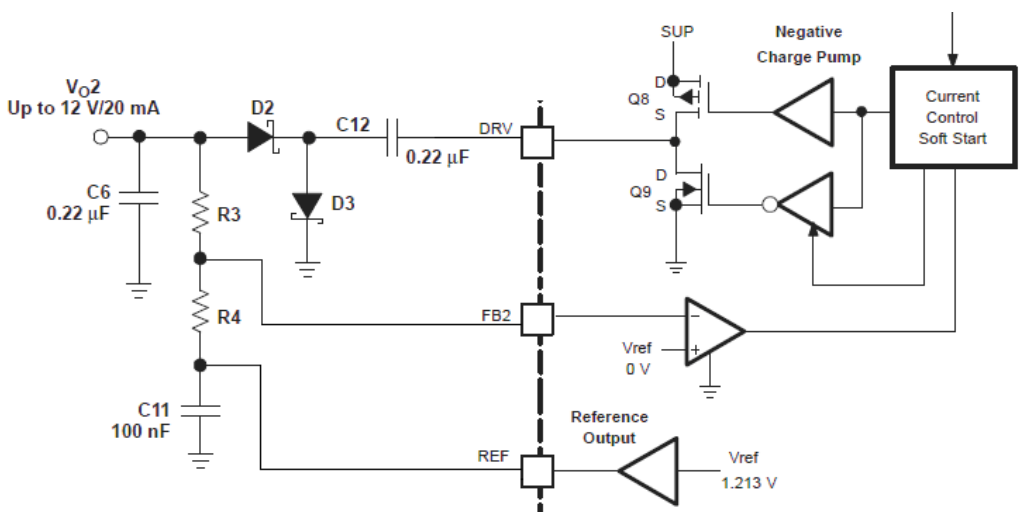

Figure 5. Standard negative charge pump configuration

During brownout (Figure 6); the negative charge pump output capacitor, connected between V_O2 and ground, holds the charge for a while. The output capacitor is discharged through FB2 ESD cell and forward biases it. This causes a negative voltage being preset at FB2 pin equal to the ESD diode forward voltage Vd, which is around 500mV. REF pin may go below ground if the voltage drop across R4 is lower than Vd according to this equation: Vref = -Vd + R4 x Iref, where Iref is REF pin sourcing current and R4 is one of the feedback resistors between REF and FB2 pins.

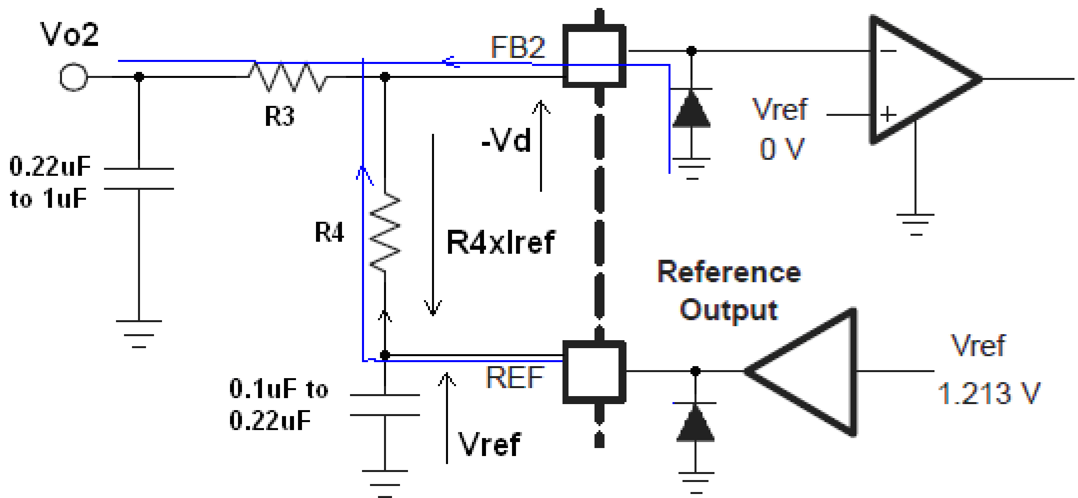

Figure 6 Negative charge pump current circulation when device turned off

Pulling REF below ground adds additional time to reach its nominal value of 1.21V when VIN is recovering from cranking. VIN reaches UVLO at time T. REF voltage has to reach its nominal value at time T; otherwise, the device triggers a flag and prevents it from starting up. See Figure 7.

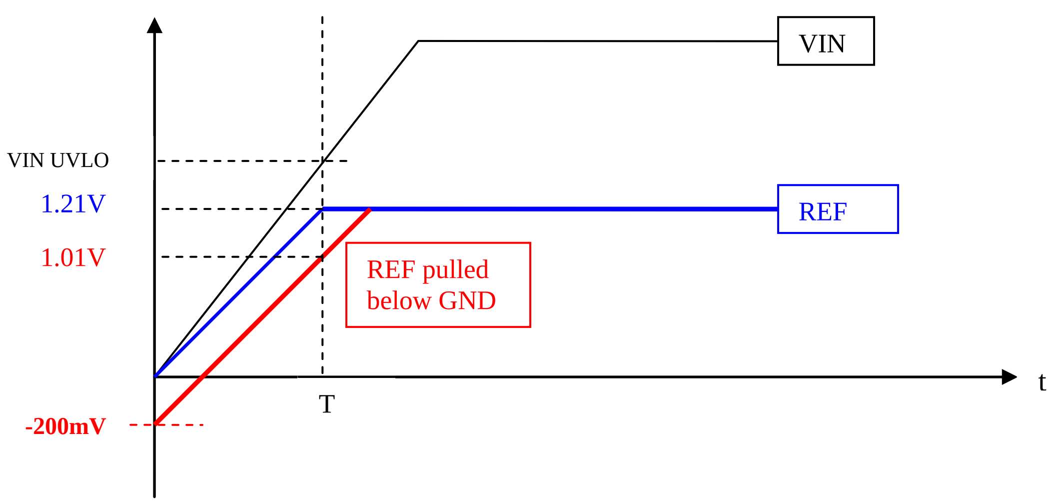

Figure 7. Shows REF level at time T if pulled 200mV below GND

The negative charge pump can also be configured as Doubler by rectifying the SW signal through one additional capacitor and 2 Schottky diodes. See Figure 8.

If used as voltage Doubler, the output voltage V_O2 is more negative. This would require higher current from REF pin during brownout and worsen the situation.

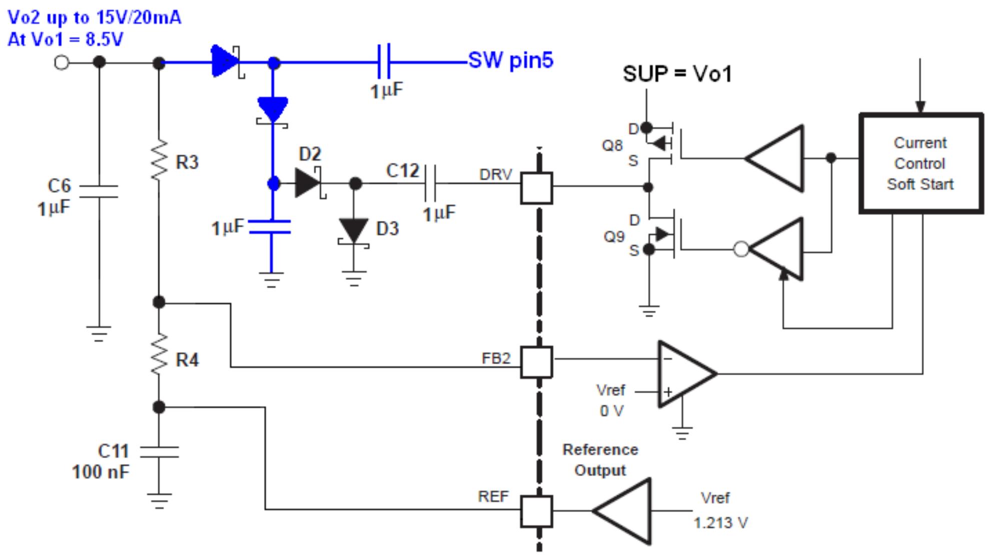

Figure 8 Double Charge Pump

How to prevent white screen?

The REF current sourcing during brownout worse case is above 5µA. There are 2 solutions for circuit optimization:

1- Increase the resistor between REF and FB2 value. Vref = R4 x Iref – Vd. REF should not drop more than 120mV below GND.

$$\text{R4 x Iref} = \text{Vd} - \text{Vref so R4} = \frac{(\text{Vd} - \text{Vref})}{\text{Iref}} = \frac{(500\text{mV} - 120\text{mV})}{5\ \text{A}} = 76\text{K}\ .$$

2- Add Schottky diode from FB2 pin to GND. In this case, the negative voltage at FB2 pin during brownout is only 300mV max. Resistor R4 can be lowered to (300m -120mV)/5µA = 36K. See Figure 9.

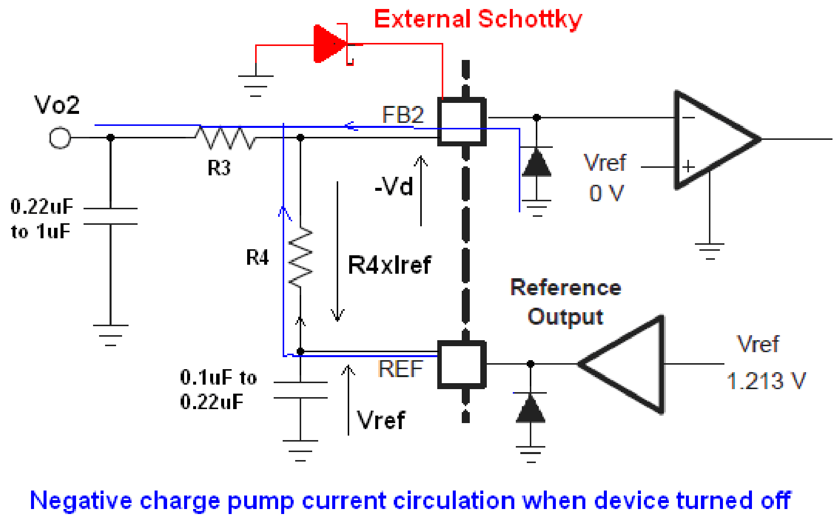

Figure 9. Adding external Schottky diode

Lab measurements

The system behavior at cranking was proved in the lab with following setup:

- Boost voltage V_O1 regulated at 8.5V
- Negative charge pump V_O2 is Doubler configuration and regulated at -15V
- Positive charge pump V_O3 is Doubler configuration and regulated at +15V

Battery voltage and input voltage VIN are not shown in the scope picture. It clearly shows the negative charge pump feedback pin FB2 voltage is -500mV. It is caused by ESD cell turning on during brownout and device in off state.

Figure 10. REF pin drops 270mV below GND and device does not startup properly

CH1 (yellow) negative charge pump feedback pin 500mV/Div

CH2 (light blue) is REF signal 500mV/Div

CH3 (purple) is negative charge pump signal 2V/Div

CH4 (green) is BOOST switch node signal 10V/Div

The REF current sourcing is limited. If R4 x Iref < 500mV, REF drops below GND. In Figure 9, the feedback resistors value R4 = 45.3k and R3 = 560k are marginal. Also, the REF sourcing current is low at about 5uA during off time. The voltage drop across R4 is 45.3 x 5 = 226mV.

Resulting in Vref = R4 x Iref – Vd = 226 – 500 = -273mV.

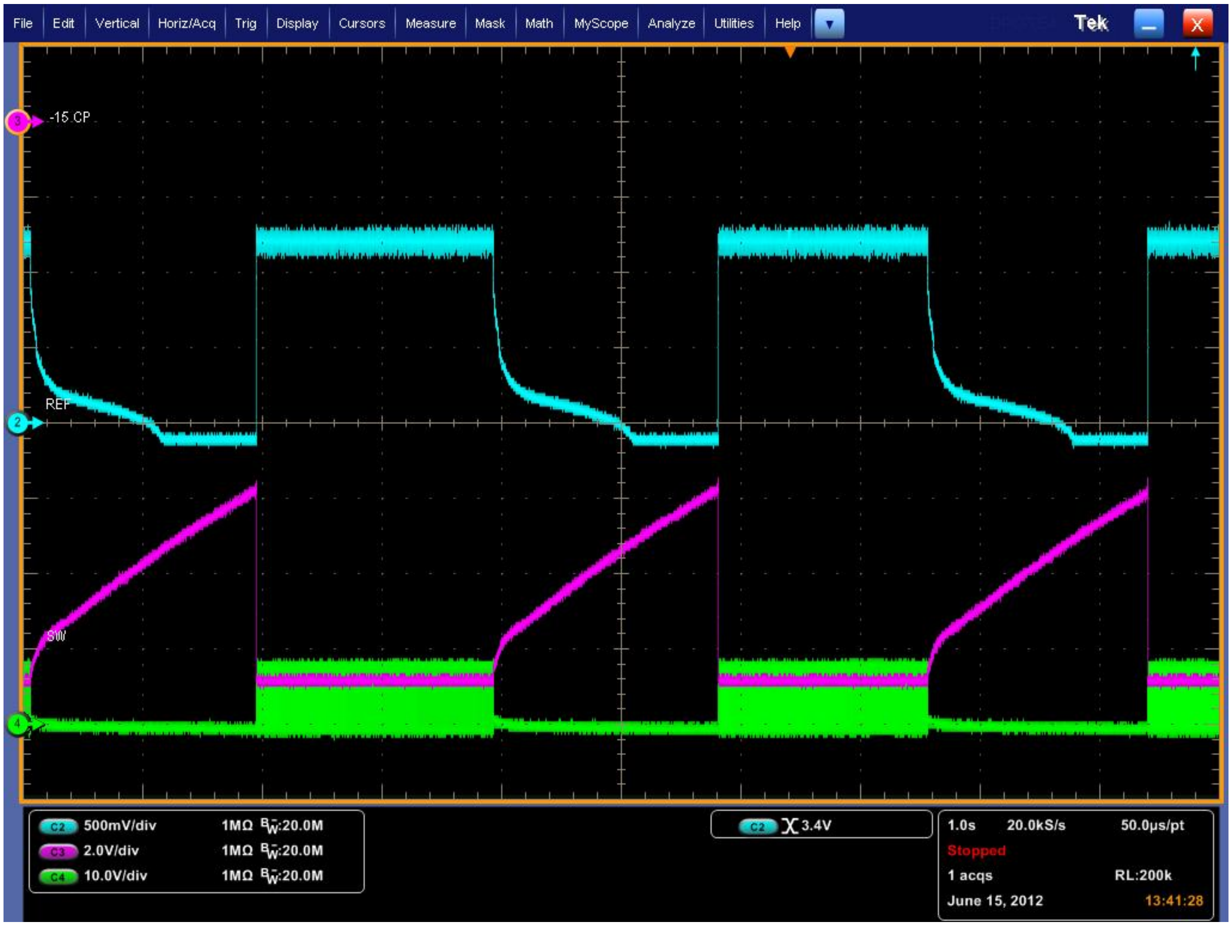

Figure 11. REF pin drops only 150mV below GND and device is on

CH2 (light blue) is REF signal 500mV/Div

CH3 (purple) is negative charge pump signal 2V/Div

CH4 (green) is BOOST switch node signal 10V/Div

In order to limit the REF pin voltage drop below GND, R3 and R4 were increased. Thereby, the current pulled from the device is reduced. In Figure 10, the feedback resistors value R4 = 70k and R3 = 865k. The voltage drop across R4 is 70 x 5 = 350mV.

Resulting in Vref = R4 x Iref – Vd = 350 – 500 = -150mV.

Conclusion

TPS56100, 140, 145-Q1 is a perfect solution to power your TFT screen. Negative charge pump total feedback resistors lower limit of 500K works great when the device stands alone. Extra precaution has to be taken in a complex system. REF voltage must not be 120mV below ground when the device is starting up. If the REF voltage drops more than 120mV below ground it may result in improper startup, which causes a TFT white screen during ignition if not reset.

Appendix

Negative Charge Pump

The negative charge pump provides a regulated output voltage by inverting the main output voltage, Vo1. The negative charge pump output voltage is set with external feedback resistors.

The maximum load current of the negative charge pump depends on the voltage drop across the external Schotty diodes, the internal on resistance of the charge pump MOSFETS Q8 and Q9, and the impedance of the flying capacitor, C12. When the voltage drop across the components is larger than the voltage difference from V_O1 to V_O2, the charge pump is in drop out, providing the maximum possible output current. Therefore, the higher the voltage difference between V_O1 and V_O2, the higher the possible load current. See the possible output current versus boost converter voltage Vo1 and the calculations below.

$$Vout_{min} = -(V_O1 - 2\,V_D - Io\,(2 \times r_{DS(on)Q8} + 2r_{DS(on)Q9} \times X_{cfly}))$$

Setting the output voltage:

$$V_{out} = -\,V_{REF} \times \left[1 + \frac{R3}{R4}\right] + V_{REF} = -\,1.213\text{ V} \times \left[1 + \frac{R3}{R4}\right] + 1.213\text{V}$$

$$R3 = R4 \times \left[\frac{\left|V_{out}\right| + V_{REF}}{V_{REF}} - 1\right] = R4 \times \left[\frac{\left|V_{out}\right| + 1.213}{1.213} - 1\right]$$

The lower Feedback resistor value, R4, should be in a range between 40kΩ to 120 kΩ or the overall feedback resistance should be within 500 kΩ to 1 MΩ. Smaller values load the reference too heavy and larger values may cause stability problems. The negative charge pump requires two external Schotty diodes. The peak current rating of the Schotty diode has to be twice the load current of the output. For a 20-mA output current, the dual Schotty diode BAT54 or similar is a good choice.