Application Report
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# Conserving Battery Life when Connecting TPS65090 to an Unpowered AC Adapter

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## ABSTRACT

The TPS65090 is front-end power management unit consisting of a charger, three step-down converters, and seven load switches for multi-cell battery applications. When connected to an unpowered AC adapter, special attention is required to support the higher-than-recommended input capacitance. This document details two application solutions which allow the TPS65090 to support excess input capacitance while conserving battery life.

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## 1 TPS65090 Overview

The TPS65090 is an advanced portable power management integrated circuit (PMIC/PMU), designed to interface power between a multi-cell battery and the sub-system PMU powering the processor and modules of a tablet or ultra-portable laptop device. The TPS65090 incorporates a multi-cell Lithium-Ion/Polymer battery charger and power-path management circuit which support charging from an AC adapter and other charging sources. The TPS65090 also contains three step-down switching converters, two always-on low-dropout regulators (LDOs), seven load switches and an ADC for monitoring current and voltage.

## 2 TPS65090 AC Adapter Input Capacitance

The TPS65090 is designed to support an input capacitance in the range of a two micro-Farads on the AC adapter input. This is sufficient if connecting to a powered AC adapter. However, when the input capacitance is higher than recommended, if the charger was enabled and the AC adapter was unplugged from the wall but still plugged in to the device, for example, the current consumption of the TPS65090 would be slightly higher than if the AC adapter was unplugged from the device. If this condition were present for a long period of time (overnight) the result would be a drained battery. Implement one of the following circuits to prevent higher quiescent current when plugged in to an un-powered AC adapter.

## 3 Explanation of Behavior

Under normal operation, the TPS65090 uses an internal discharge circuit which periodically checks for a valid adapter voltage. This circuit performs the check when a battery is present and the current from the AC adapter is less than approximately ten percent of the maximum value set by the sense resistor, R1 of Figure 1. The circuit first turns off the AC FETs, then sinks a small discharge current from the AC input, and determines from change in voltage if the source is powered or if the voltage is remaining charge on the input capacitance. When this input capacitance is higher than the recommended value of two microfarads, the discharge circuit does not discharge the capacitance below UVLO and the TPS65090 misrecognizes the large capacitance as a weak source. The screen shots in Figure 2 demonstrate how VAC voltage drops to VBAT voltage and does not continue to discharge as expected. These scope plots were captured when a VAC of 12V was removed and a 7.5V battery remained connected. The charger was enabled and charging at 1A and the converters were unloaded.

Excess current consumption occurs because the TPS65090 does not detect the absence of an AC adapter and therefore does not put the charger into a low power sleep state. When the AC adapter is removed from the wall, the output of the adapter (and input to the TPS65090), V_AC, slowly discharges to near the battery voltage and the charger's duty cycle nears one-hundred percent mode operation. Since the charger architecture has a bootstrap capacitor for the high-side gate drive, the low-side switch needs to turn on to charge this bootstrap capacitor pulling current from the battery through the inductor. When the low-side switch turns off, the excess energy in the inductor goes to the system rail, boosting the voltage higher than the battery voltage, and preventing the charger from entering sleep mode. This operation is due to a tradeoff in the design that opted for lower power consumption over a high current sink capability at the AC input. A schematic diagram of the TPS65090 power path is visible in Figure 1, where Q1 and Q2 are the AC FETs and V_AC is the AC adapter connection.

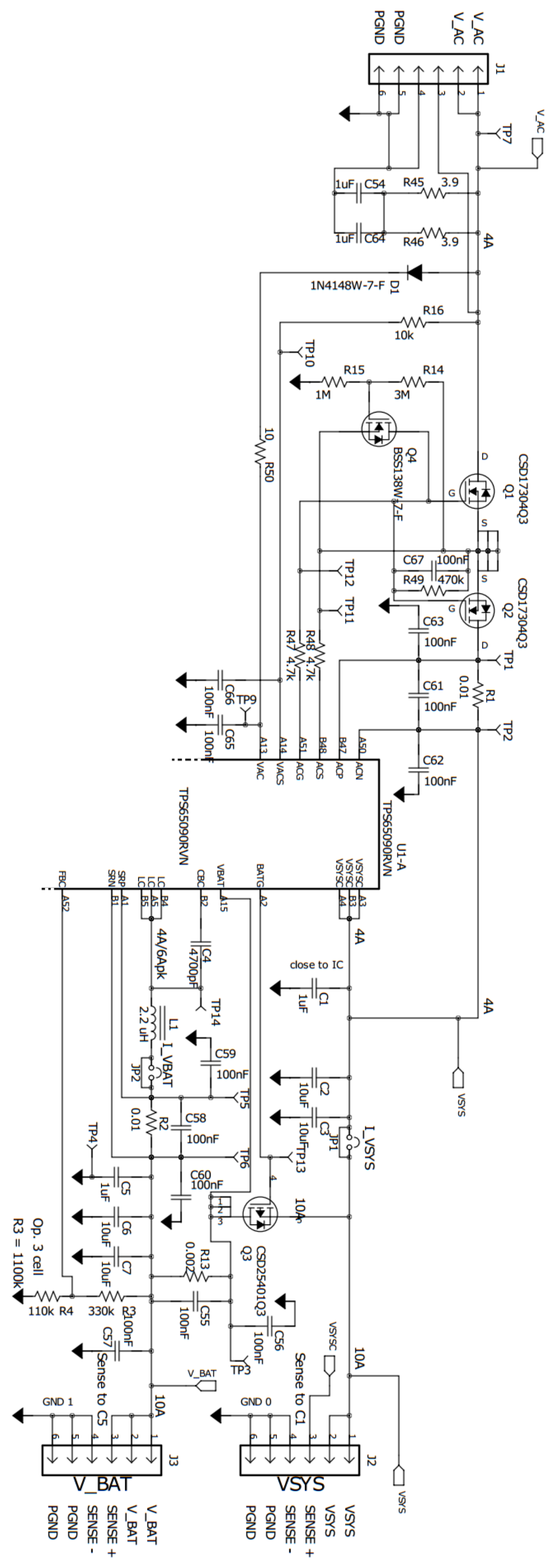
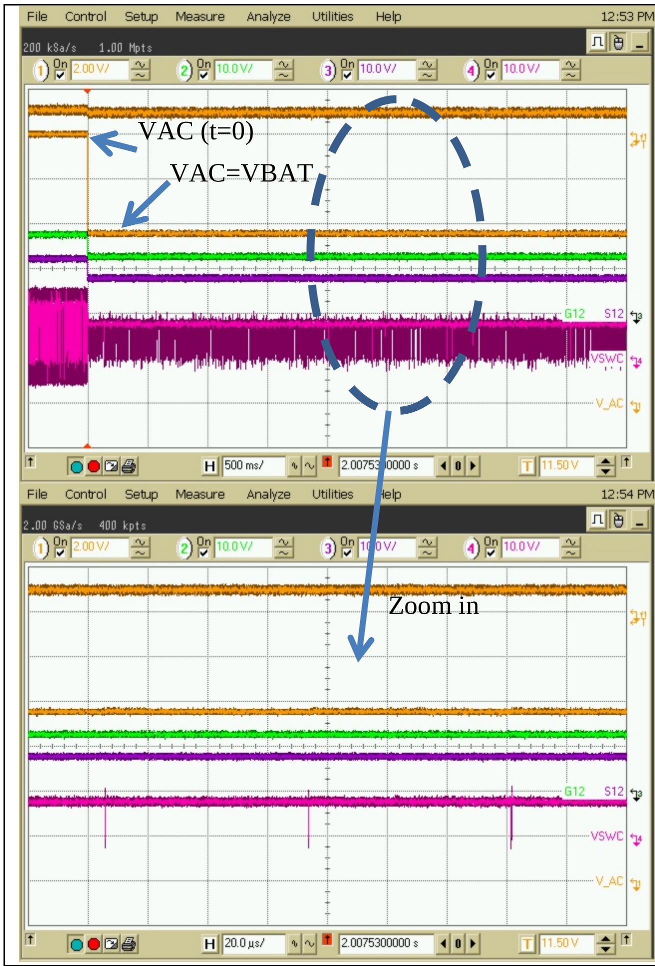


**Figure 1. TPS65090 EVM Power Path Schematic**




| | |
|---|---|
| F1 | G12-S12=AC FET on |
| Ch1 | VAC |
| Ch2 | G12 (gate at AC FETs, Q1 and Q2) |
| Ch3 | S12 (source at AC FETs Q1 and Q2) |
| Ch4 | VSWC (charger switching node) |

**Figure 2. Oscilloscope Plot of Undesired Behavior**

## 4 Solutions

One solution is immune to the amount of input capacitance and allows for smaller components and the second solution supports up to 750 µF at the AC pin and discharges the input capacitance to five-volts before the capacitor is left to discharge through leakage paths. A tradeoff to consider is that the first circuit can support any input capacitance but leaves more charge on the capacitance to discharge through leakage paths than the second solution.

In addition, for both solutions, the charger enable (ENC) should be connected to the AC voltage good comparator output (VACG) and through a resistor to a pull-up source, to only enable the charger when a good AC adapter source is present and indicated by the TPS65090 VACG open drain output. Also, the external capacitor from gate to source for the AC switches has been reduced from 100 nF to 10 nF (C67) in regard to the original TPS65090 EVM configuration. This capacitor reduction is recommended to reduce the existing load on the gate drive, ACG, from the TPS65090 since this source will later be driving the discharge circuit associated with both solutions.

## 4.1 Solution 1: Forcing Disconnection of High Input Capacitance

The first solution is a circuit to disconnect the high input capacitance from the system. This circuit discharges the VACS input of the TPS65090 so that the AC FETs are forced off by the TPS65090 logic. The VACS pin is the AC adapter input voltage sense of the TPS65090. The voltage on this pin is what dictates the behavior of the AC FETs. Pulling this pin low disconnects the AC adapter voltage from the system rail by turning off the AC FETs, Q1 and Q2, as designated in Figure 1. The hysteretic comparator at this pin prevents the AC FETs from turning back on until VACS is above the system voltage. The circuit is presented in Figure 3 and the test results are displayed in Figure 5.

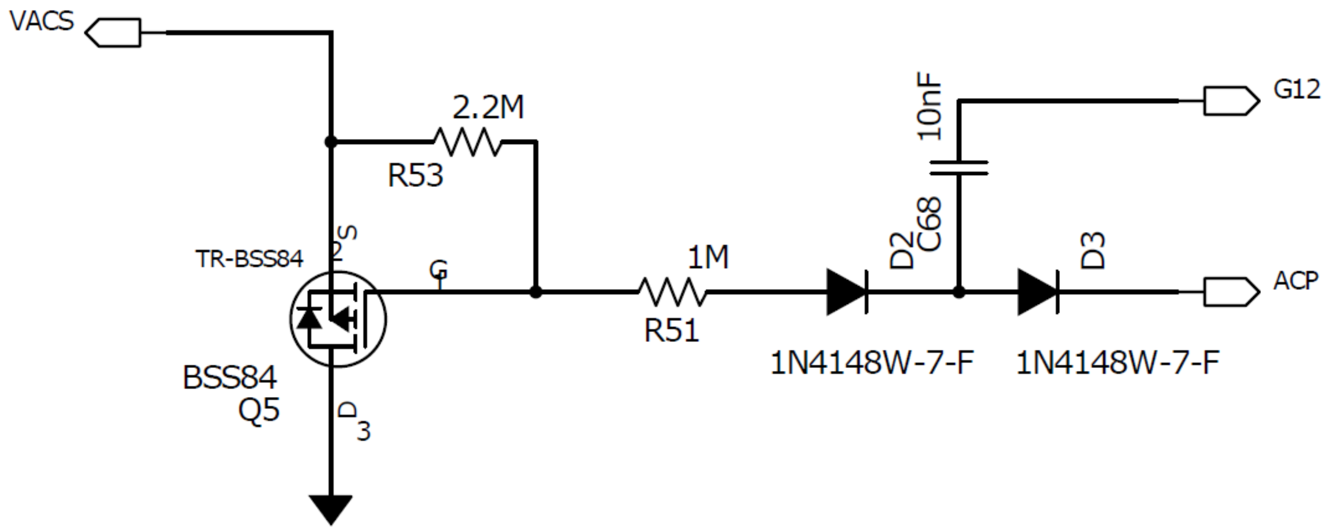



**Figure 3. AC Adapter Sense (VACS) Discharge Circuit**

This external discharge circuit is triggered by signals labeled G12 and ACP, taking advantage of the existence of the internal discharge protocol. Signal G12 is the electrical connection at the gate of the AC FETs. When the AC FETs are on, ACP remains at V_AC potential while G12 is pumped $\Delta V \approx 5$ V higher than that voltage. Capacitor C68 is then charged with $\Delta V - V_F(D3) \approx 4$ V. If the AC FETs are now turned-off, ACP = G12 = V_AC, and the connection of C68 to the diodes will be ≈ –4 V from GND. That potential pulls charge from $C_{GS}$ (Q5), turning it on and discharging the VACS capacitance. The resistor R51 limits the current drawn by the charge pump on terminals ACG and ACP of the TPS65090. Once the AC FETs are turned on, Q6 gate must have a voltage higher than V_AC by two times the forward voltage of the diodes, $V_F$ (D2, D3), which prevents Q5 from triggering. Transistor Q5 (BSS84) is a cheap option for the discharge transistor though $Rds_{ON}$ is loosely specified. The required materials are listed in **Table 1**.

**Table 1. Required Materials for Adapter Sense (VACS) Discharge Circuit**

| Type of Component | Reference Designator | Value | Description |
|---|---|---|---|
| P-Channel MOSFET | Q5 | BSS84* | |
| Capacitor | C68 | 10 nF* | 0402 10-V X5R Ceramic |
| Diode | D2 | LL4148** | |
| Diode | D3 | LL4148 | |

| | | | |
|---|---|---|---|
| Resistor | R51 | 1 MΩ* | 0402 |
| Resistor | R53 | 2.2 MΩ* | 0402 |

* Size the package to the application need.

** Any other small signal diode can be substituted, including arrangements of two diodes in series (for example, MMBD4148SE).

The VACS discharge circuit should be connected to the VACS and ACP pins and to the gate of the AC FETs as indicated in Figure 4.

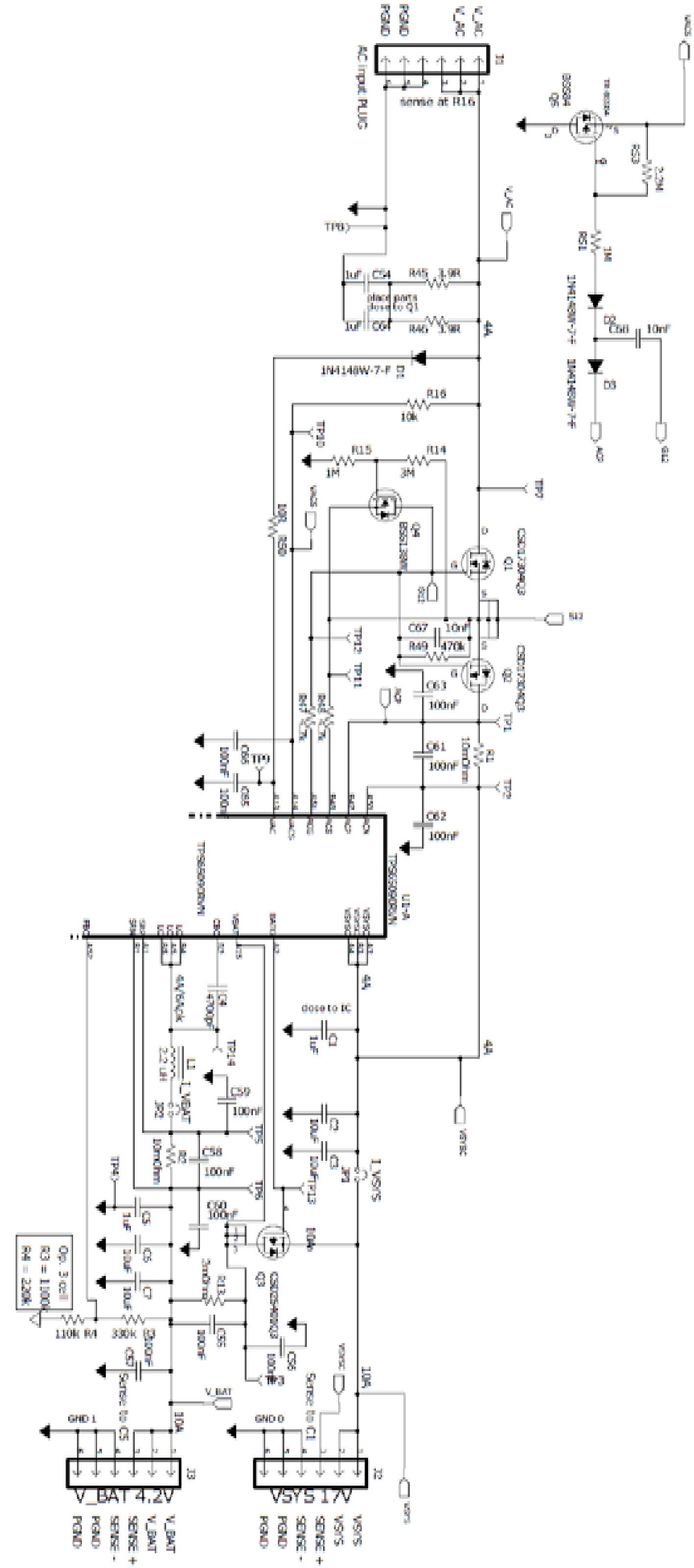


**Figure 4. TPS65090 Power Path Schematic with AC Adapter Sense Discharge Circuit**


| | |
|---|---|
| Ch1 | VAC |
| Ch2 | VACG |
| Ch3 | ACG |
| Ch4 | IBAT |

**Figure 5. Oscilloscope Plot of VACS Discharge**

## 4.2 Solution 2: High Input Capacitance Discharge Circuit

The second solution is an external discharge circuit to unload any bulk capacitance at V_AC. As in the other solution, in order to not always sink current through this circuit, the AC FET gate drive, G12, is connected to an additional FET; in this case, Q5, which connects and disconnects the discharge circuit at the appropriate times. This operation is visible Figure 6.

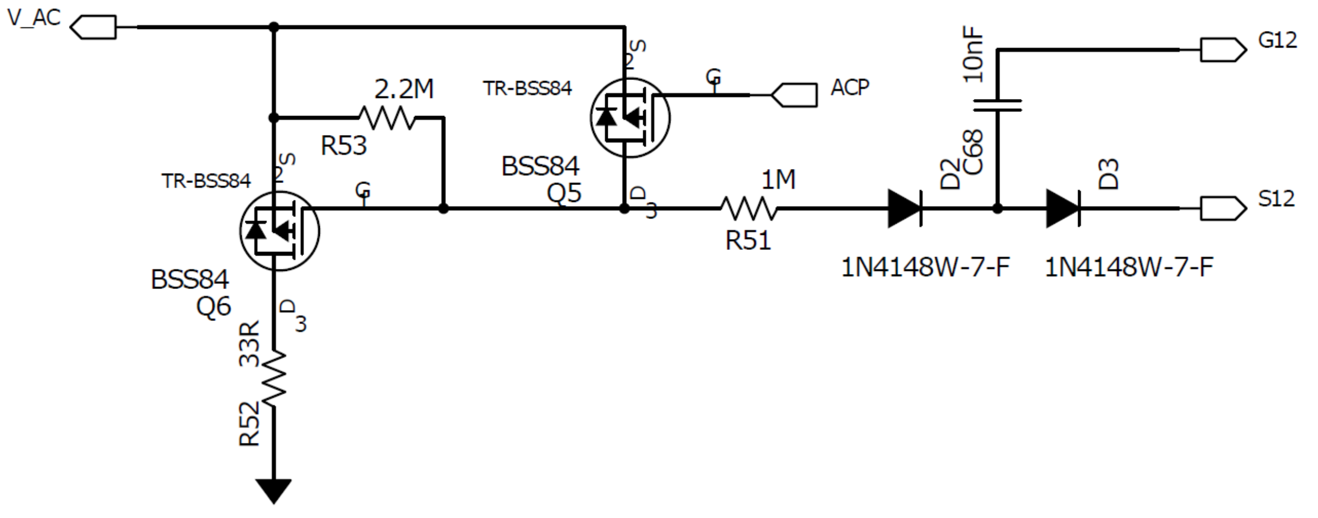



**Figure 6. AC Adapter (V_AC) Capacitor Discharge Circuit**

Similar to the first solution, this external discharge circuit is triggered by signals G12 and S12. Signals G12 and S12 are the electrical connections at the AC FETs gate and source respectively. The additional elements are used to prevent the V_AC capacitor from discharging when the adaptor is plugged back in to the wall outlet. The connection ACP is the electrical point which connects V_AC to VSYS; it is connected after the AC FETs and before a 10-mΩ shunt resistor in the power path. If ACP is lower than V_AC, it means that the battery voltage is lower than the AC voltage and Q5 should tie Q6 gate potential to its source potential (V_AC), preventing Q6 from being triggered and then avoiding the discharge of the adaptor output capacitor. Once the AC FETs are turned-on, ACP is at V_AC potential, releasing Q5, but then also Q6 gate must have a voltage higher than V_AC by 2 times $V_F$ (D2, D3), preventing Q6 from triggering. The discharging AC voltage takes place in R52 which dissipates the input capacitor energy. Since transistor Q6 has an unpredictable $Rds_{ON}$ (in the range of 10Ω according to datasheet) in series with R52, scaling the input capacitance size to twice its value leads to less than half the discharge resistance (R52). Due to this, successful experimental results are required to ensure that the proposed discharge circuit will work for a given input capacitance. The required materials are listed in Table 2.

**Table 2. AC Adapter (V_AC) Discharge Circuit Required Materials**

| Type of Component | Reference Designator | Value | Description |
|---|---|---|---|
| P-Channel MOSFET | Q5 | BSS84 | |
| P-Channel MOSFET | Q6 | BSS84 | |
| Capacitor | C68 | 10 nF* | 0402 10-V X5R Ceramic |
| Diode | D2 | LL4148** | |
| Diode | D3 | LL4148 | |
| Resistor | R51 | 1 MΩ* | 0402 |
| Resistor | R52 | 33 Ω *** | 1206 |
| Resistor | R53 | 2.2 MΩ* | 0402 |

* Size the package to the application need

** Any other small signal diode can be substituted, including arrangements of two diodes in series (for example, MMBD4148SE).

*** Scale this value to the input capacitance, proportional to 1/C. 33 Ohm has been tested for 750-µF, 63-V input capacitor. The resistor must sink $1/2CV^2$ during on-time for discharge MOSFET (Q6). On time roughly defined by RC network of R53 and GS capacitance of Q6. Package size 1206 or larger is recommended.

The input capacitor discharge circuit is shown connected to the TPS65090 EVM power path in Figure 7.

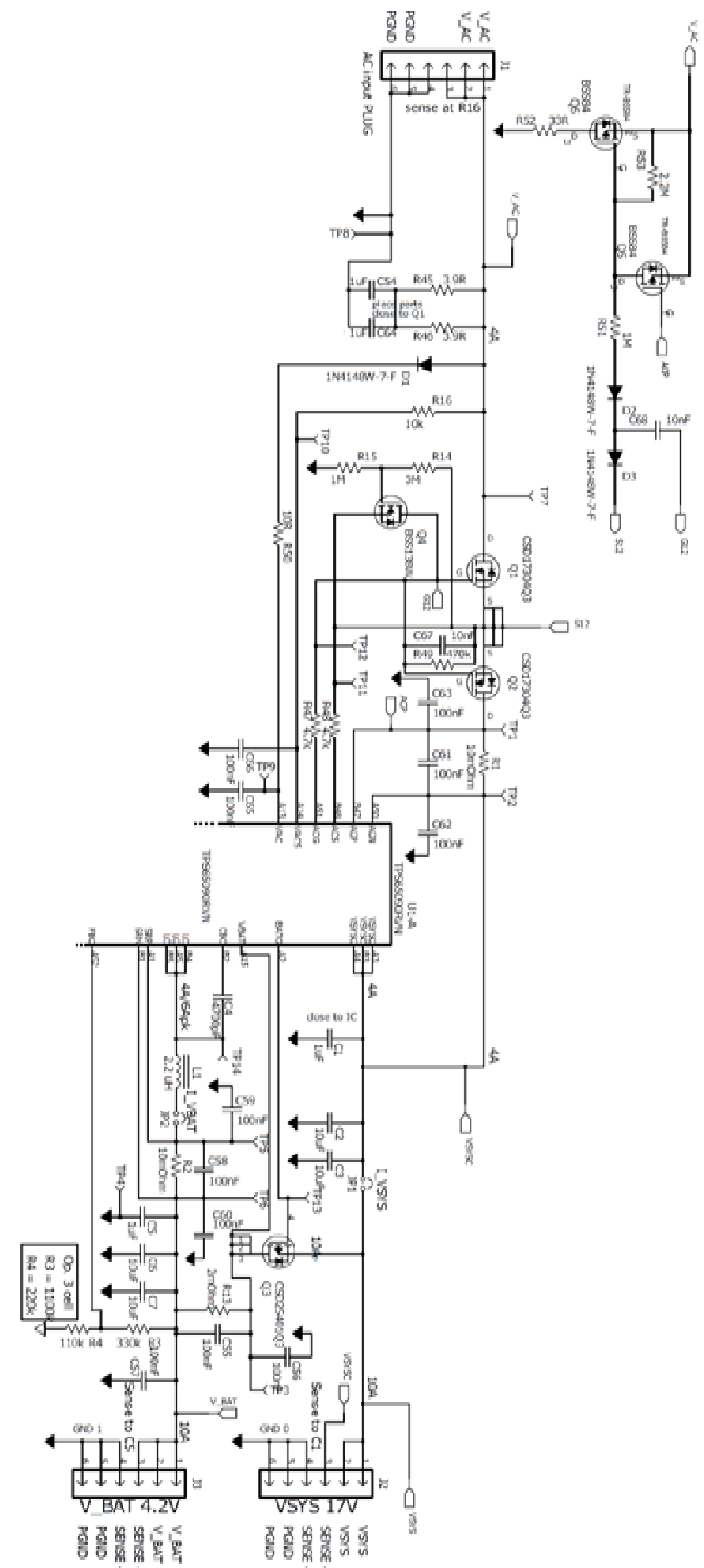


**Figure 7. TPS65090 Power Path Schematic with AC Adapter Capacitor Discharge Circuit**

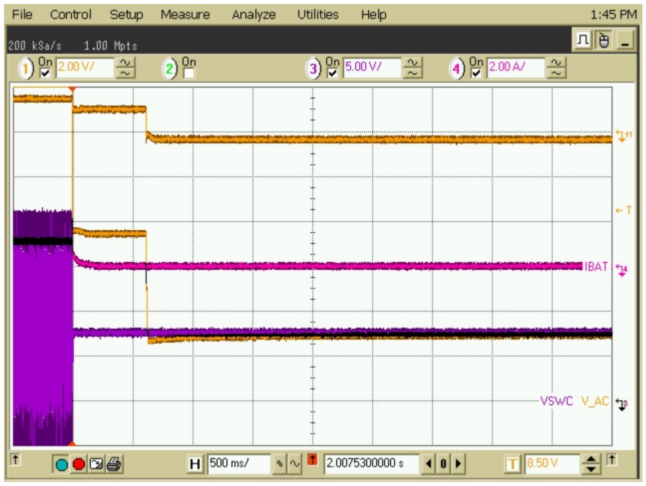
| | | |
|---|---|---|
|  | Ch1 | VAC |
| | Ch2 | G12 (gate at AC FETs, Q1 and Q2) |
| | Ch3 | VSWC (charger switching node) |
| | Ch4 | IBAT |

**Figure 8. Oscilloscope Plot of V_AC Discharge**

## 5 Conclusion

In order to avoid extra drain on the battery when an AC adapter is plugged in but unpowered, implement one of the previously mentioned circuits. The first circuit forces the TPS65090 to disconnect the AC adapter from the system voltage by turning off the AC FETs. The second circuit discharges the input capacitance to a level where the AC FETs are disabled by the TPS65090. The first solution, turning off the AC FETs, is preferred since it discharges less energy and therefore requires smaller components; however, the user should evaluate and select the best fit for their application.

## 6 References

1. *TPS65090A Datasheet* (SLVSBO6).
2. *TPS65090EVM User's Guide* (SLVU778A).
3. *TPS65090 Evaluation Module* (TPS65090EVM).

For more information on how Texas Instruments can solve your power management needs across the board, visit www.ti.com/power