# LTC3351EUFF
# Hot Swappable Supercapacitor Charger, Backup Controller and System Monitor

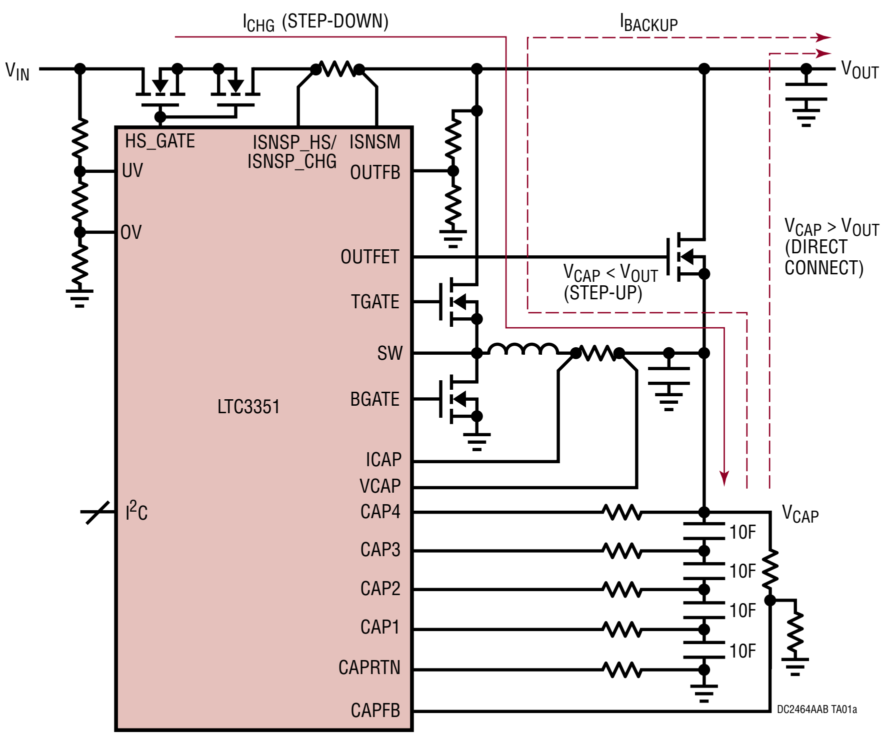
## DESCRIPTION

Demonstration circuit 2464A-A/2464A-B is a supercapacitor charger and backup controller with a hot swappable front end plus supercapacitor health and system monitoring; featuring the LTC®3351. The LTC3351 includes a buck supercapacitor charger and a backup boost controller. It has dual input hot swap FETs to control the inrush current when connected and to disconnect the input supply when an over current fault or input power loss occurs. An output ideal diode allows the supercapacitors to supply the output when $V_{CAP}$ is above the set backup voltage. As the capacitor stack voltage drops down to the set output voltage, the LTC3351 will operate as a boost regulator to supply the output until the energy in the supercapacitors is depleted.

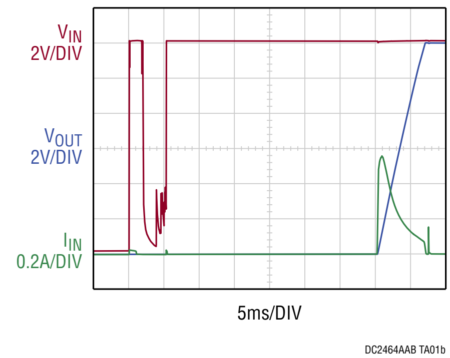
**Design files for this circuit board are available at http://www.linear.com/demo/DC2464A-A/A-B**



## TYPICAL APPLICATION




**Example Hot Swap from 12V**



## PERFORMANCE SUMMARY

**Specifications are at $T_A$ = 25°C**

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| Input Supply Range | DC2464A-A<br>DC2464A-B | 11<br>20 | 12<br>24 | 18<br>30 | V<br>V |
| Charger Input Current Limit | DC2464A-A<br>DC2464A-B | | 2.67<br>2 | | A<br>A |
| Hot Swap Input Current Limit | | | 4 | | A |
| $V_{OUT}$ Backup Operating Voltage, Boost Mode | DC2464A-A<br>DC2464A-B | | 6<br>18 | | V<br>V |
| $P_{OUT}$ Maximum Backup Power, Boost Mode | DC2464A-A<br>DC2464A-B | | 25<br>36 | | W<br>W |
| $V_{CAP}$ Float Voltage | Buck Mode | | 10 | | V |
| Max Charge Current | DC2464A-A<br>DC2464A-B | | 5.33<br>6.4 | | A<br>A |
| $t_{BACKUP}$ | $P_{BACKUP}$ = 25W, $I_{BOOST}$ = 9.67A, 3V ≤ $V_{CAP}$ ≤ 8.4V<br>$P_{BACKUP}$ = 36W, $I_{BOOST}$ = 11.6A, 3.7V ≤ $V_{CAP}$ ≤ 8.4V | | 2<br>1 | | s<br>s |

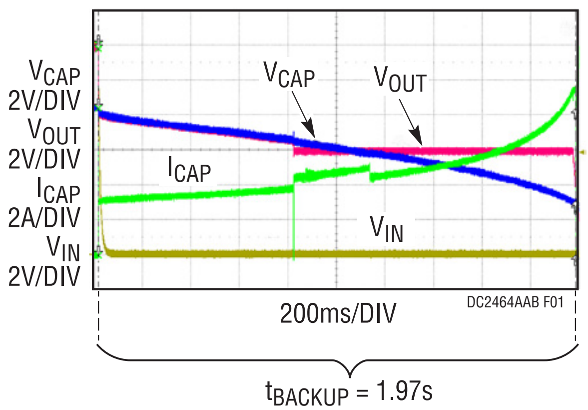



**Figure 1. DC2464A-A 25W Backup**

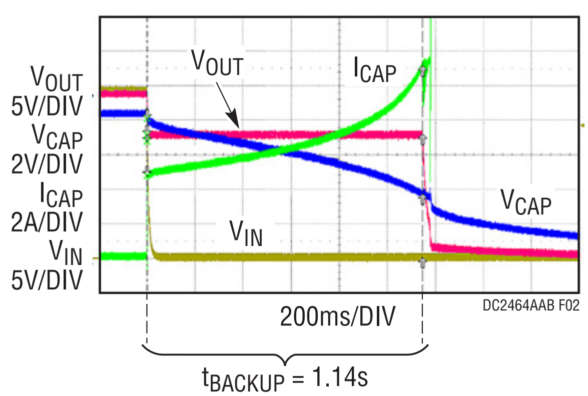



**Figure 2. DC2464A-B 36W Backup**

# BOARD PHOTO

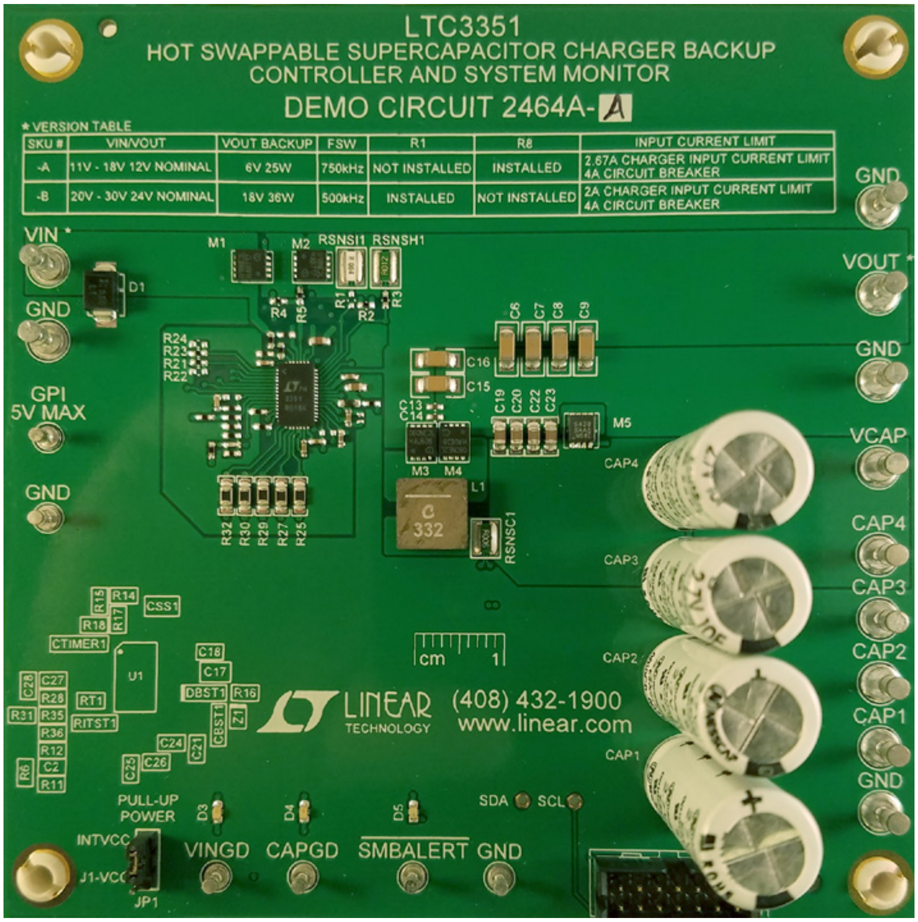



**Figure 3. DC2464A-A Board Photo**

## QUICK START PROCEDURE

Obtain and connect a DC2026C board to the DC2464A board. Use short twisted pair leads for the power connections and start with the LOAD and the power supply OFF. Refer to Figures 4 and 5 for the proper measurement and equipment setup and follow the procedure below.

1. Refer to the DC2026C Quick Start Guide for QuikEval™ setup and software installation details.
2. Make sure the USB cable is connected between the computer and the DC2026C controller board.
3. Connect a 14-pin ribbon cable from the DC2026C board to the DC2464A board.
4. Set jumper JP1 on the DC2464A board to the "$INTV_{CC}$" position.
5. Start the ADI QuikEval program. This program should automatically detect the presence of the LTC3351 demo board (DC2464A) and activate the appropriate GUI, as seen in Figure 9.
6. With power off, connect the appropriate supply, 0V to 20V (or 30V), 25W (or 36W) supply between the $V_{IN}$ and GND terminals for the DC2624A-A or DC2624A-B as shown in Figure 4.
7. Turn on and set the $V_{IN}$ input power supply to 12V for DC2624A-A or 24V for the DC2624A-B and observe the $V_{IN}$, $V_{OUT}$ and $V_{CAP}$ voltages and the input and charge currents on the GUI.

   NOTE. Make sure that the input voltage does not exceed 20V for the DC2624A-A or 33V for the DC2624A-B.
8. On the LTC3351 Control Window "Charger/Control" tab, as shown in Figure 9, click on the CAP SCALE button so it displays "SMALL". This will provide better time measurement resolution when measuring the capacitance.
9. On the LTC3351 Control Window "Cap/ESR Details" tab as shown in Figure 14, enter "2" seconds in the "cap_i_on_settling" text box. This allows the capacitor voltage time to reach the linear portion of the discharge voltage slope.
10. On the LTC3351 Control Window "Cap/ESR Details" tab as shown in Figure 14, enter "0.2" volts in the "cap_delta_v_setting" text box and then click on the Apply button on the bottom of the tab. This will provide a larger dV for more accuracy.
11. On the LTC3351 Control Window, click on the CAP and ESR Measurement START button. An "In Process" indicator displays while the measurement is in process.

    NOTE. Supercapacitors initially have large leakage currents which causes the capacitance measurement to be low. The capacitor measurements will be more accurate after the 10F capacitors have been continuously charged for more than 30 minutes.
12. Connect a constant power load box between $V_{OUT}$ and GND and set up to 25W for the DC2624A-A and 36W for the DC2624A-B.
13. Connect an oscilloscope probe to $V_{IN}$, $V_{OUT}$, $V_{CAP}$ and $\overline{PFO}$. Set the oscilloscope to trigger on the falling edge of $\overline{PFO}$.
14. Remove the input power by unplugging the $+V_{IN}$ supply cable and observe how the output drops to the regulation point and is maintained until the energy in the supercapacitors is exhausted.
15. Turn the load off and set the oscilloscope to trigger on the rising edge of $V_{IN}$.
16. Plugin the $+V_{IN}$ supply cable and observe how $V_{OUT}$ ramps up after the debounce time, showing the capacitors are charged up.
17. The LTC3351 has the ability to monitor and report on the supercapacitor and system voltages, currents, die temperature and capacitor health. See the software section and data sheet for more information.
18. The DC2464A can be modified to operate at different frequencies, operating voltages, input and boost currents. The "Hardware Config" tab allows the user to enter the appropriate changes so the GUI can report the correct measurements. See the software section for more details.

## QUICK START PROCEDURE

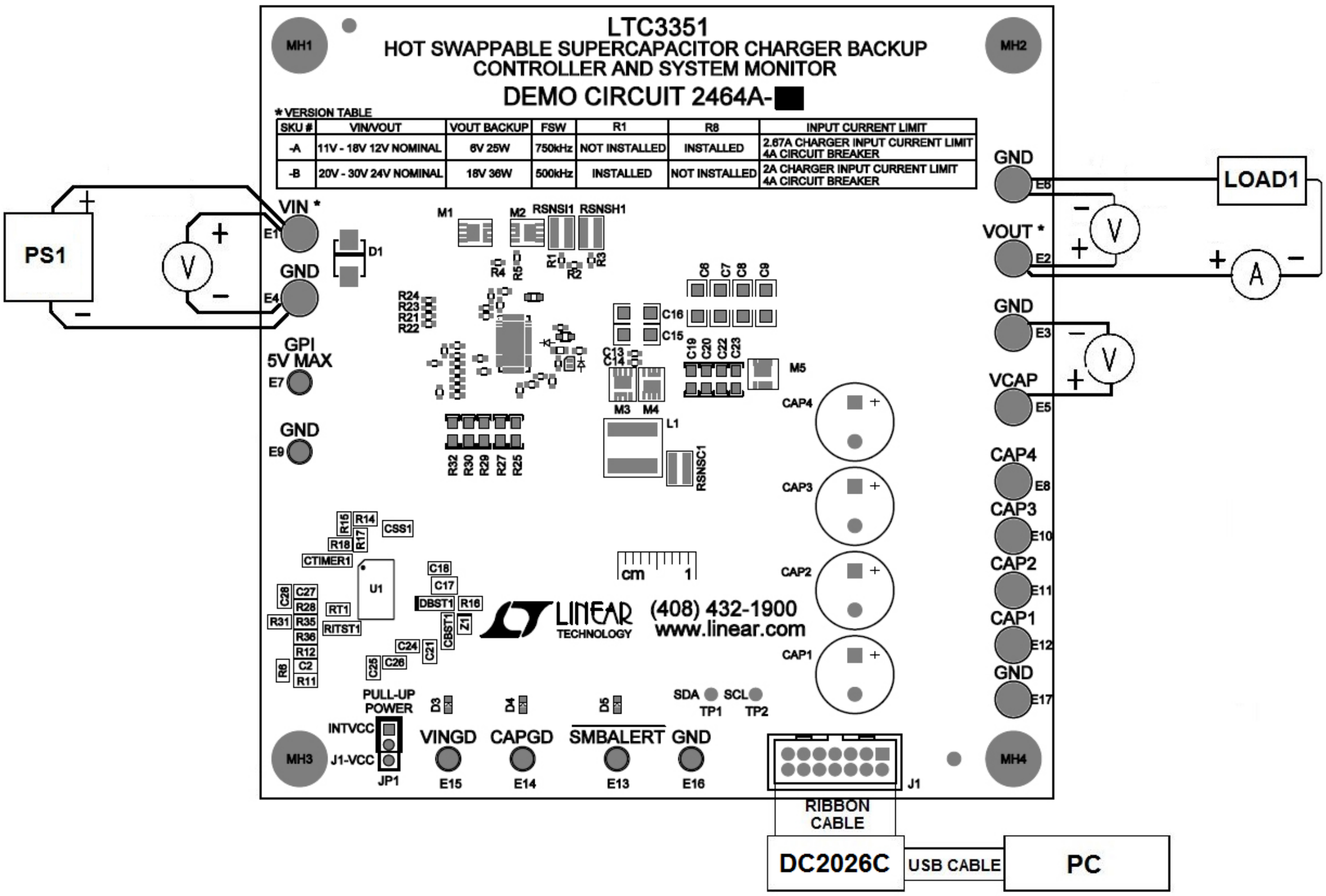



**Figure 4. Proper Measurement Equipment Setup**

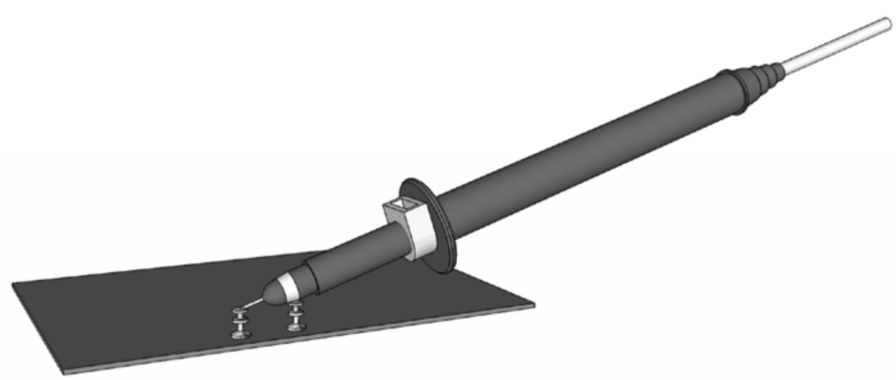


**Figure 5. Measuring Input or Output Ripple**

## APPLICATION INFORMATION

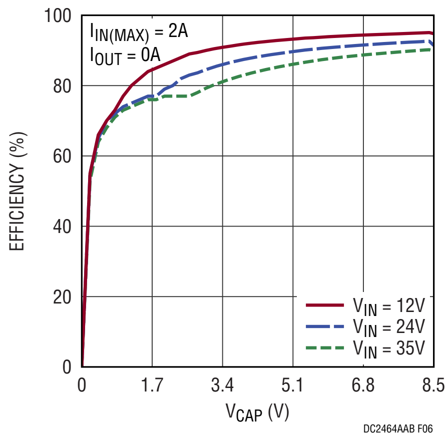



**Figure 6. Charger Efficiency**

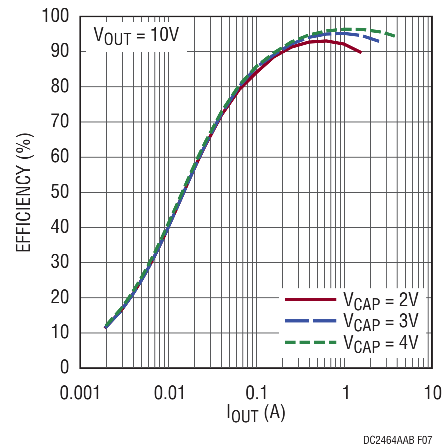



**Figure 7. Boost Efficiency**

The DC2464A was designed to safely connect to a powered system, charge up to four supercapacitors while supplying a load, and provide backup power when disconnected from the power system.

When first connected, the LTC3351, hot swap controller waits for the debounce period set by the CSS1 capacitor, about 26ms for this board. $V_{OUT}$ will then ramp up at a dV/dt set also set by CSS1. After the $V_{IN}$ is within the $V_{INGD}$ range then the charger will charge the capacitors to the set float voltage.

The capacitors are initially charged to about 84% of the full-scale, the default CAPFB setting. As the capacitors age decreasing their backup capability, the capacitor stack voltage can be increased the backup time as needed. This can increase the usage life of the capacitors.

When the power is disconnected, the LTC3351 quickly switches from charge mode to backup mode. If the set backup voltage is set below the $V_{CAP}$ voltage, the output power is initially powered from $V_{CAP}$ thru the output ideal diode as shown in Figure 8. As $V_{CAP}$ approaches the set $V_{OUT}$ backup voltage then the backup boost regulator starts to hold $V_{OUT}$ at the set voltage.

If the set $V_{OUT}$ backup voltage is set higher than $V_{OUT}$, the backup boost regulator starts immediately to pump up and maintain the $V_{OUT}$ to the set backup voltage.

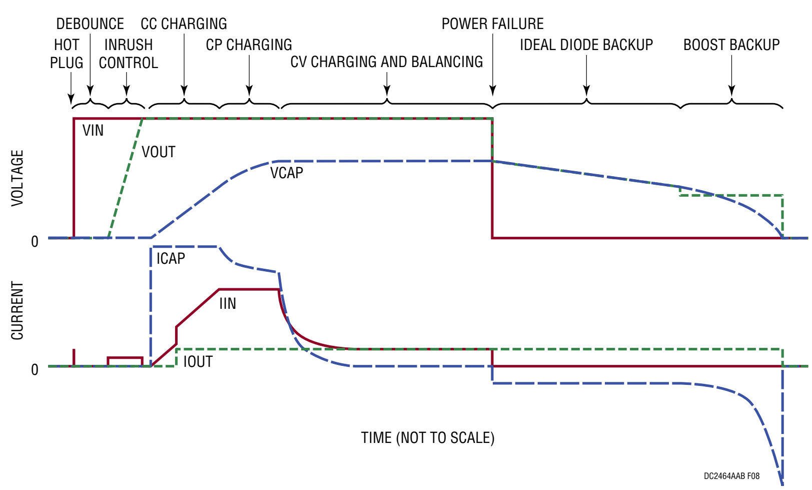



**Figure 8. Charge and Discharge Cycle**

## USING THE LTC3351 SOFTWARE

The LTC3351 program provides the ability to measure and monitor the system voltages and currents plus the health of the supercapacitors. It also allows the user to set up alarms to report on specific events such as power fail or CAP measurement done. Refer to Figure 9 for an illustration of the LTC3351 control window.

**VIEW LTC3351 PRODUCT PAGE** button opens an Internet browser and searches the ADI website for information on the LTC3351 when an Internet connection is available.

**CAP and ESR Measurement START** button starts a capacitor and ESR measurement. An indicator below the START button indicates the status of the CAP/ESR measurement. The different states are: In Process, Done, Pending or Failed.

**Number of Caps Selected** text box indicates the number of capacitors selected using the CAP_SLCTx pins.

**Hot Swap ENABLED** button sets the ctl_hotswap_disable in the ctl_reg. $V_{IN}$ is disconnected when this bit is set to simulate a power loss. This bit is automatically reset if the min_vout_hs_disable voltage has been reached.

**Clear SMBUS ALERT** button sends an SMBus alert response address to clear the SMBALERT. NOTE: the condition that caused the SMBALERT must be cleared before the SMBALERT signal can be cleared.

**CAP** text box indicates the latest measured capacitance in Farads for large capacitors and mF for smaller capacitors. This measurement is based on the CAP scale setting in the control register plus the current and oscillator resistor settings on the Hardware Config tab.

**ESR** text box indicates the latest measured ESR in mΩ.

**VCAP** text box indicates the latest $V_{CAP}$ voltage in volts when the VCAP ADC is enabled.

**ICHRG** text box indicates the latest measured charge/boost current in amps when the ICHRG ADC is enabled. This measurement is based on the RSNSC setting on the Hardware Config tab.

**VCAPx** text box indicates the latest measured capacitor voltage in volts for the corresponding VCAP when the VCAP ADC is enabled.

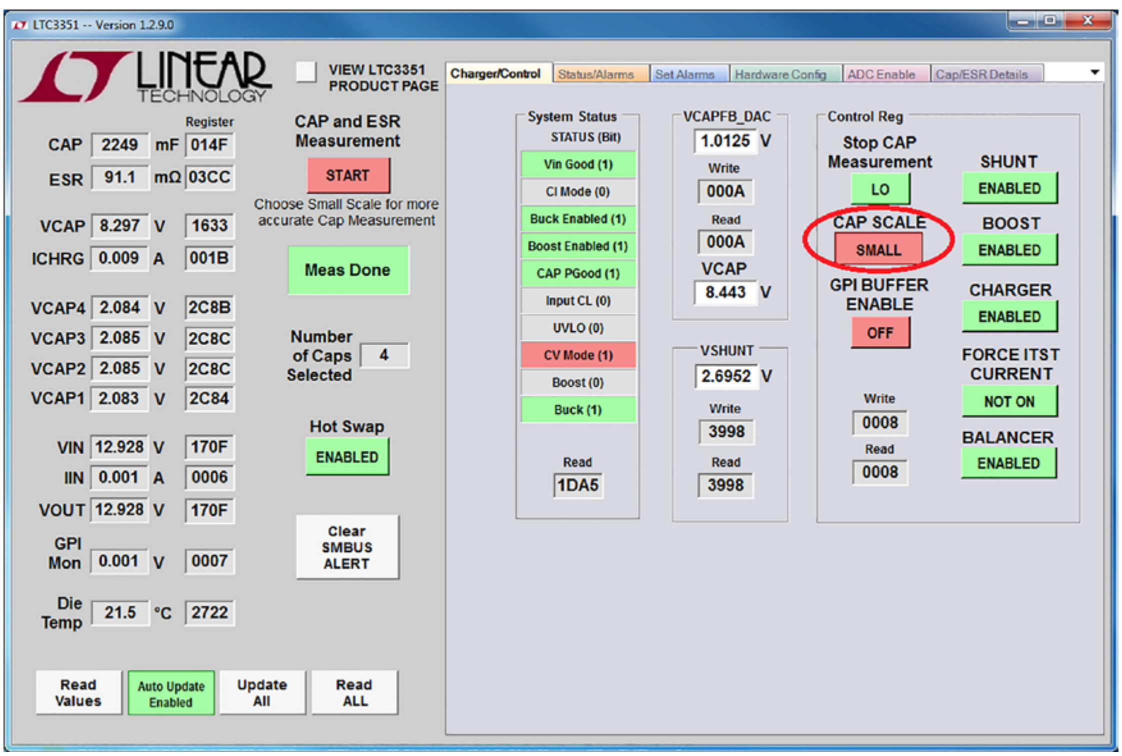



**Figure 9. LTC3351 Control Window**

## USING THE LTC3351 SOFTWARE

**VIN** text box indicates the latest measured input voltage in volts when the VIN ADC is enabled.

**IIN** text box indicates the latest measured input current in amps when the IIN ADC is enabled. This measurement is based on the RSNSI setting on the Hardware Config tab.

**VOUT** text box indicates the latest measured $V_{OUT}$ in volts when the VOUT text box is enabled.

**GPI Mon** text box indicates the latest measured GPI voltage in volts when the GPI Mon ADC is enabled. An internal buffer can be enabled for measuring high impedance inputs.

**Die Temp** text box displays the latest internally measured die temperature in °C when the Die Temp ADC is enabled.

**Register** text boxes displays the associated register values in hexadecimal format.

**Read Values** button causes the LTC3351 to read the ADC measured values. This is useful when the LTC3351 GUI "Auto Update" is disabled.

**Auto Update Enabled/Disabled** button causes the LTC3351 to read the LTC3351 registers periodically and writes to any register changed when enabled. The Read Values, Read All, or Update All buttons can be used instead to update the registers when in the disabled state.

**Read All** button causes the LTC3351 to read the LTC3351 registers. This is useful when the LTC3351 GUI Auto Update is disabled.

### Charger Control Tab

The Charger Control tab contains the indicators and controls for the capacitor charger and monitor plus the GPI buffer enable as shown in Figure 9.

**System Status STATUS (Bit)** indicates when the associated chrg_status register bits are set. See the data sheet for more information on these bits.

**System Status Read** text box displays the last read sys_status register value in hexadecimal format.

**VCAPFB_DAC** text box allows the user to set the CAPFB reference voltage from 0.6375V to 1.2V in 37.5mV increments. The value in the text box is rounded to the nearest mV. The VCAP text box is also updated with the calculated value of the CAPFB reverence voltage and the resistor network entered on the Hardware Config tab.

**VCAPFB_DAC Write** text box displays the value that will be or has been written to the vcapfb_dac register in hexadecimal format.

**VCAPFB_DAC Read** text box displays the last value read from the vcapfb_dac register in hexadecimal format.

**VCAP** text box allows the user to set the $V_{CAP}$ float voltage within the limits of the CAPFB reference voltage and the CAPFB resistor network on the Hardware Config tab. The value in the text box is rounded to the nearest mV. The VCAPFB_DAC text box is also updated with the calculated value using the CAPFB resistor network entered on the Hardware Config tab.

**VSHUNT** text box allows the user to set the shunt regulator voltage up to 5.5V. When set below 3.6V, the charger will limit current and the active shunts will shunt current to prevent this voltage from being exceeded. When programmed above 3.6V no current will be shunted, however, the charge current will be reduced as described. As a capacitor voltage nears this level, the charge current will be reduced. The shunt voltage will be reset to the default value of 2.6952 every time $INTV_{CC}$ is restored.

**VSHUNT Write** text box displays the value that will be or has been written to the VSHUNT register in hexadecimal format.

**VSHUNT Read** text box displays the last value read from the VSHUNT register in hexadecimal format.

**Stop CAP Measurement** sets the ctl_stop_cap_esr_meas bit in the ctl_reg register. This will cause any CAP/ESR measurement in process to stop. This bit will reset when the measurement has ceased.

**CAP SCALE** button sets the cap scale from large scale, default scale for larger capacitors, to small scale for smaller capacitors like used on the DC2464A. The resolution is increased by 100× in small scale.

**GPI BUFFER ENABLE** button sets the ctl_gpi_buffer_en bit when enabling the GPI input buffer. When the GPI BUFFER ENABLE is off then the GPI input is measured without the input buffer.

## USING THE LTC3351 SOFTWARE

**SHUNT ENABLED** button disables the shunt regulator when set. When not set, the shunt regulator will prevent the caps from charging over the set $V_{SHUNT}$ voltage.

**BOOST ENABLED** button disables the boost regulator when set. When not set, the boost regulator will operate as required in backup mode.

**CHARGER ENABLED** button disables the charger when set. When not set, charger will operate when possible.

**FORCE ITST CURRENT** button turns on the internal capacitor discharge current source. This can be used to discharge the capacitors or to manually measure the capacitors. NOTE: this does not disable the charger. Select the CHARGER ENABLED button to disable the charger.

**BALANCER ENABLED** button disables the capacitor balancers when set. When not set, the balancers will balance the capacitors about 10mV of each other.

**Control Reg Write** text box displays the value that will be or has been written to the ctl_reg register in hexadecimal format.

**Control Reg Read** text box displays the last value read from the ctl_reg register in hexadecimal format.

### Status/Alarms Tab

The Status/Alarms tab contains the indicators for the monitor_status_reg and alarm_reg bits plus control buttons for the Monitor Status Mask, Alarm Mask and Alarm Clear bits as shown in Figure 10.

**Monitor Status Status (Bit)** indicate when the associated monintor_status_reg bits are set. See the data sheet for more information on these bits.

**Monitor Status Read** text box displays the last read monitor_status_reg value in hexadecimal format.

**Mask Monitor Status** buttons will allow the rising edge of the associated monitor status bit to trigger the SMBALERT when the mask bit is set to 1.

**Mask Monitor Write** text box displays the value that will be or has been written to the monitor_status_mask_reg in hexadecimal format.

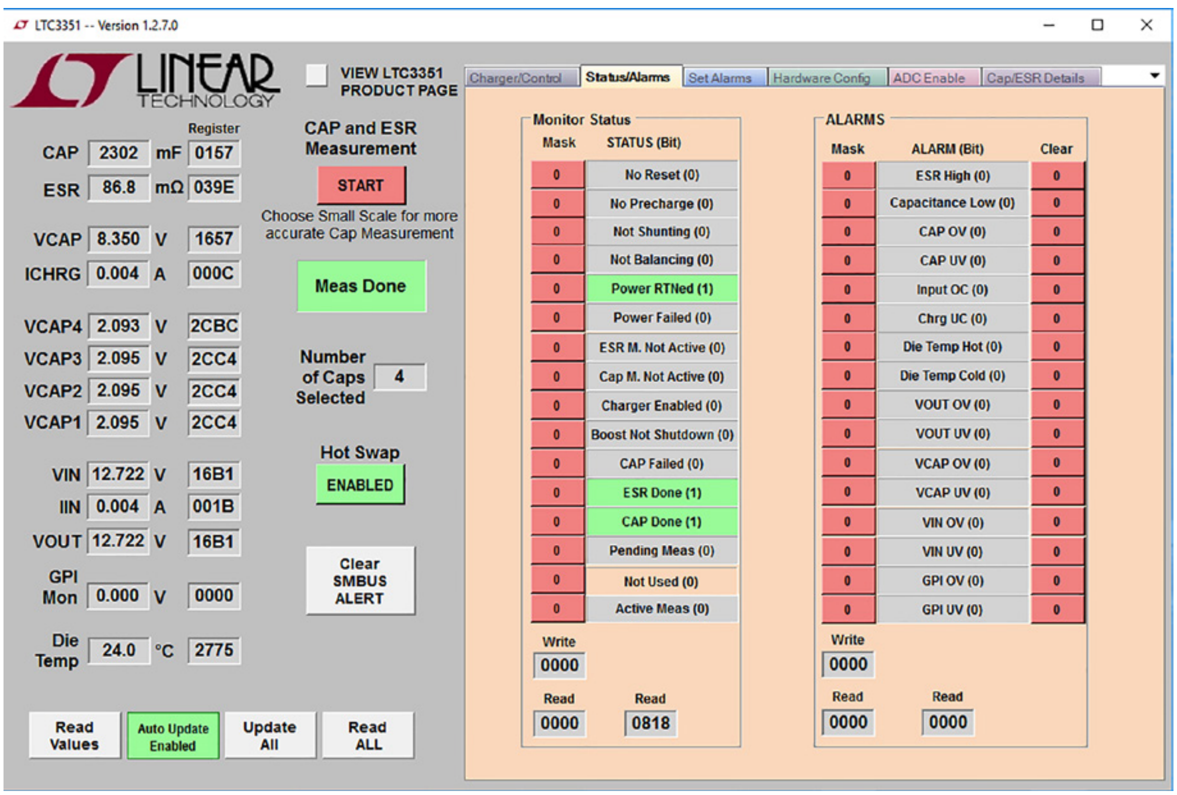



**Figure 10. Status/Alarms Tab**

## USING THE LTC3351 SOFTWARE

**Mask Monitor Read** text box displays the last read monitor_status_mask_reg value in hexadecimal format.

**ALARM (Bit)** indicate when the associated alarm_reg bits are set. See the data sheet for more information on these bits.

**Alarm Read** text box displays the last read alarm_reg value in hexadecimal format.

**Mask Alarm** buttons will allow the associated alarm bit to trigger the SMBALERT when the mask bit is set to 1.

**Mask Alarm Write** text box displays the value that will be or has been written to the alarm_mask_reg in hexadecimal format.

**Mask Alarm Read** text box displays the last alarm_mask_reg value in hexadecimal format.

**Clear Alarm** buttons will cause the associated alarm to clear when the alarm condition no longer exists by writing a "0" in the appropriate alarm_reg bit.

**Set Alarms Tab**

The Set Alarms tab contains text boxes to allow the user to set specific levels for each alarm register as shown in Figure 11. Each alarm has an associated Write text box to display the value that will be or has been written to the associated register in hexadecimal format. Each alarm also has an associated Read text box which displays the last read contents of the associated register in hexadecimal format.

**VIN/VOUT/VCAP/CAP/GPI UV Alarm** text boxes allow the user to enter a voltage that will trigger an alarm when the associated voltage drops below the entered voltage value and the associated alarm mask bit is set.

**VIN/VOUT/VCAP/CAP/GPI OV Alarm** text boxes allow the user to enter a voltage that will trigger an alarm when the associated voltage rises above the entered voltage value and the associated alarm mask bit is set.

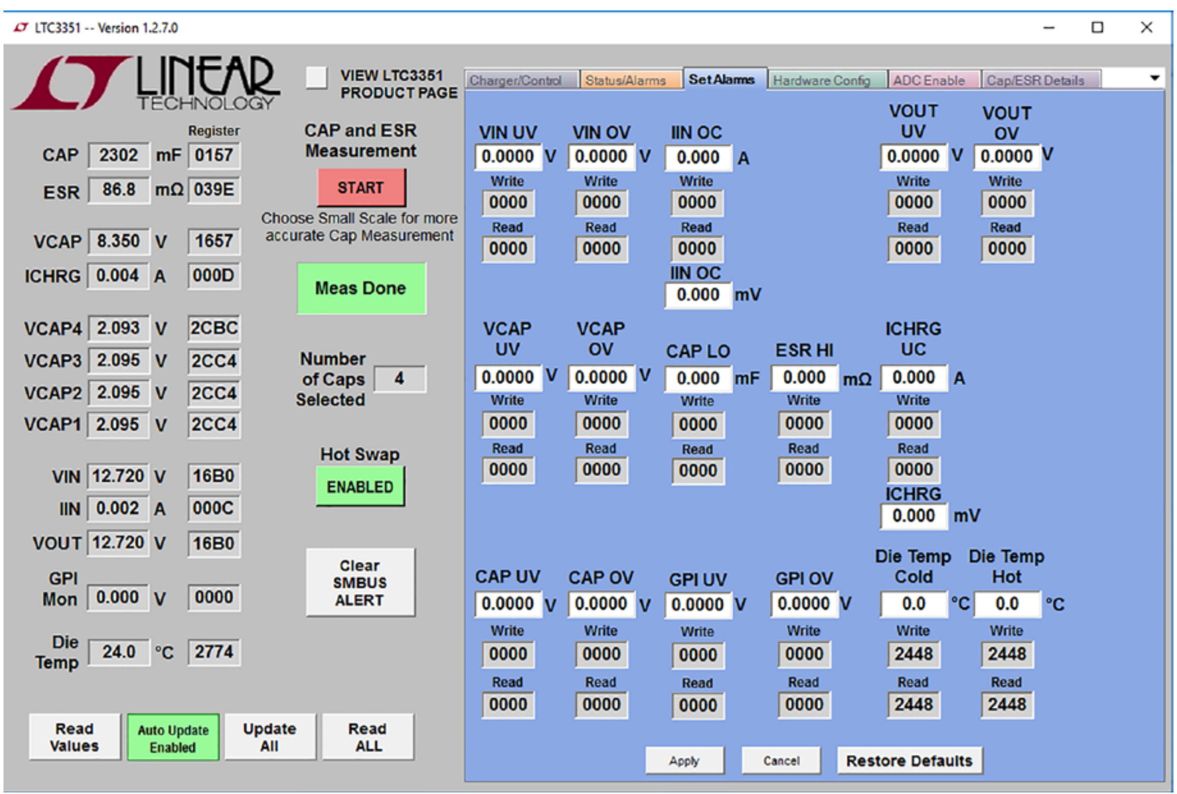



Figure 11. Set Alarms Tab

## USING THE LTC3351 SOFTWARE

**IIN OC** alarm text boxes allow the user to enter a current or the voltage across the sense resistor that will trigger an alarm when the input current increase above the entered value and the mask_alarm_iin_oc bit is set.

**CAP LO** alarm text box allows the user to enter a capacitance based on the current ctl_cap_scale setting in the ctl_reg. A CAP LO alarm will be triggered if the measured capacitance is lower than the entered value and the mask_alarm_cap_lo bit is set.

**ESR HI** alarm text box allows the user to enter an ESR value based on the RSNSC resistor value entered in the Hardware Config tab. An ESR HI alarm will be triggered if the measured ESR is higher than the entered value and the mask_alarm_esr_hi bit is set.

**ICHRG UC** alarm text boxes allow the user to enter a current or the voltage across the sense resistor that will trigger an alarm when the charge current decreases below the entered value and the mask_alarm_ichrg_uc bit is set.

**Die Temp Cold** alarm text box allows the user to enter a die temperature in °C that will trigger an alarm when the temperature decreases below the entered value and the mask_alarm_dtemp_cold bit is set.

**Die Temp Hot** alarm text box allows the user to enter a die temperature in °C that will trigger an alarm when the temperature increases above the entered value and the mask_alarm_dtemp_hot bit is set.

**Apply** button writes to the alarm registers and reads the values back from the LTC3351.

**Cancel** button changes all the entered values that have not yet been written to the LTC3351 back to their previous values.

**Restore Defaults** button changes the LTC3351 alarm registers back to the default values determined from the GUI. This does not set the alarm to the LTC3351's default settings of 0x0000.

### Hardware Config Tab

The Hardware Config tab, shown in Figure 12, contains text boxes to allow the user to enter the values to configure the necessary resistors to match the configuration of the demo board. These values are used by the GUI to calculate measured CAP and ESR values, display input/charge currents and max VCAP voltage for a given reference setting. These values are also used in the Set Alarm tab text boxes.

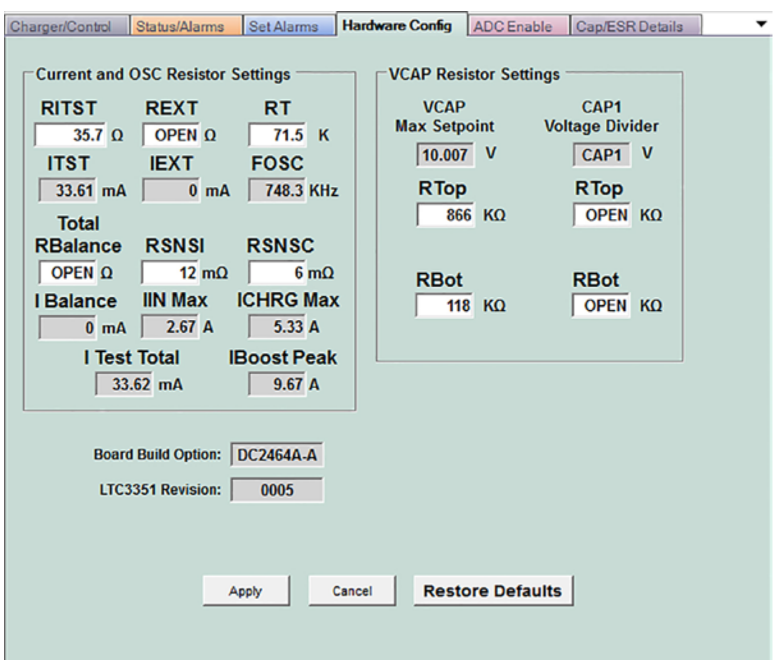



**Figure 12. Hardware Config Tab**

## USING THE LTC3351 SOFTWARE

**RITST** text box allows the user to enter the RITST resistor in Ω. The calculated test current setting is displayed in mA.

**REXT** text box allows the user to enter the external load resistance, R28 and R29, added in Ω if any. Enter 0 if there is not any external loading and OPEN will be displayed in the text box. See the Using Large Capacitor section for more details.

**RT** text box allows the user to enter the $R_T$ resistor in kΩ. The calculated oscillator setting is displayed in kHz.

**Total RBalance** text box allows the user to enter the equivalent total balance resistance in Ω if any for capacitance stacks or packs that have external balancing. Enter 0 if there is not any external balancing and OPEN will be displayed in the text box.

**RSNSI** text box allows the user to enter the RSNSI resistor in mΩ. The calculated input current limit setting is displayed in Amps. This is the total resistance sensed between the isnsp_chg and the ISNSM pin. If R8 is populated and R1 is not, then it should be the value of the RSNSH1 resistor. If R8 is not populated and R1 is, then it should be the total of the RSNSI1 and RSNSH1 resistors.

**RSNSC** text box allows the user to enter the RSNSC resistor in mΩ. The calculated maximum charge current setting is displayed in Amps.

**VCAP Resistor Settings** text boxes allow the user to enter the CAPFB resistor divider network in kΩ. The calculated maximum VCAP set point is displayed in volts.

**CAP1 Voltage Divider** text boxes allow the user to enter the CAP1 resistor divider network in kΩ if used. This could be used if a large capacitor stack or a capacitor pack with its own balancing was used. The displayed CAP1 voltage is calculated from the maximum VCAP voltage. Enter 0 in the CAP1 Voltage Divider RTop and RBot text boxes then OPEN will be displayed in both text boxes.

### ADC Enable Tab

The ADC Enable tab contains control buttons to enable the ADC measurements when charging and when operating on backup power. It also contains a text box to configure the delay for each ADC measurement, and configurable voltage thresholds which require specific ADC measurements to be enabled.

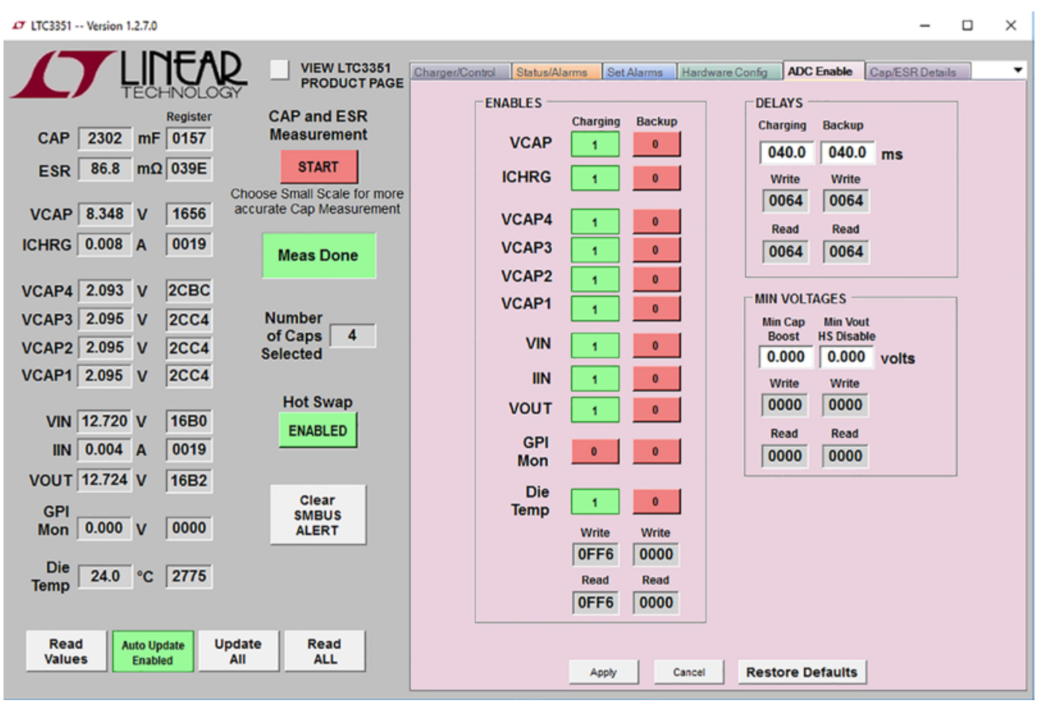



**Figure 13. ADC Enable Tab**

## USING THE LTC3351 SOFTWARE

Each control has an associated Write text box to display the value that will be or has been written to the associated register in hexadecimal format. Each control also has an associated Read text box which displays the last read contents of the associated register in hexadecimal format.

At the bottom of the tab are buttons to Apply, Cancel, and Restore Defaults for the settings on this tab.

**ENABLES.** These buttons enable and disable the ADC measurements in the LTC3351. Press the button to toggle the measurement between 1 (on) and 0 (off).

**DELAYS.** Set these text boxes to configure the wait time between ADC measurements in ms.

**MIN CAP BOOST VOLTAGE.** The Min Cap Boost setting requires the applicable VCAPx measurements to be enabled during backup. It controls the minimum capacitor cell voltage at which the LTC3351 will continue powering VOUT with the boost regulator.

**MIN VOUT HS DISABLE VOLTAGE.** The $V_{OUT}$ to match GUI Disable setting requires the $V_{OUT}$ measurement to be enabled in backup. It controls the minimum voltage at which the LTC3351 will disable Hot Swap and return to charging the capacitors when $V_{IN}$ power becomes available. The ctl_hotswap_disable bit is also cleared when this voltage is reached.

**APPLY/CANCEL/RESTORE DEFAULTS.** These buttons write and read the settings between the LTC3351 and the GUI. Apply will write the selected settings to the LTC3351, Cancel will restore the GUI to the settings in the LTC3351, and Restore Defaults will return both the GUI and the LTC3351 to the defaults for the IC.

### CAP/ESR Details Tab

The CAP/ESR Details tab contains text boxes to configure the measurements of the capacitance and ESR for each capacitor. When a CAP/ESR measurement is performed, intermediate calculations are reported in the registers displayed on this tab which can be used to evaluate the readings. The individual capacitance and ESR for each capacitor are calculated and reported at the bottom of the page.

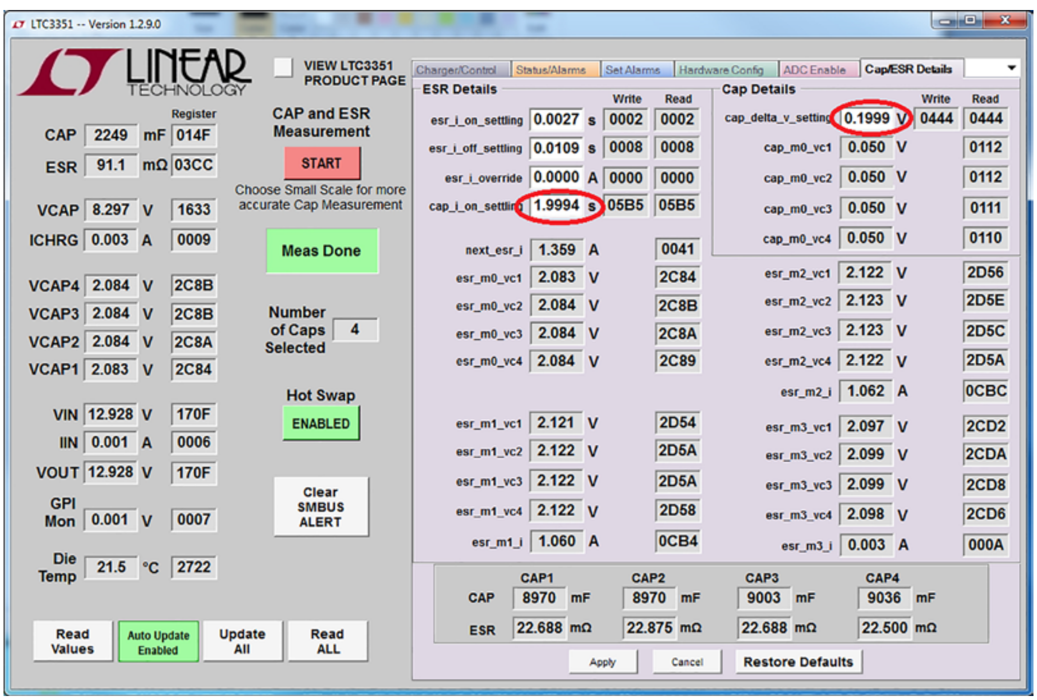



Figure 14. Cap/ESR Details Tab

## USING THE LTC3351 SOFTWARE

Each control has an associated Write text box to display the value that will be or has been written to the associated register in hexadecimal format. Each control also has an associated Read text box which displays the last read contents of the associated register in hexadecimal format.

**ESR DETAILS.** The text boxes at the top of this section contain the ESR and capacitor measurement settling times which can be adjusted for better measurement accuracy. The esr_i_override current is used to force a specific charge current to use when performing the ESR measurement. This is used if the next_esr_i current plus the load will cause the part to reach the input current limit and create an inaccurate ESR measurement. Refer to the ESR and Capacitor Measurement section of the LTC3351 data sheet for more information on the capacitor and ESR measurement.

When the ESR measurement is started and allowed to complete, the intermediate calculations performed for the final reported ESR value are displayed in this section.

**CAP DETAILS.** The cap_delta_v_setting text box at the top of this section contains the voltage difference used to perform the capacitance measurement. The voltage will be charged to 1.25* cap_delta_v_setting, turn on the discharge current source, wait for the cap_i_on_settling time and then measure the capacitor stack voltage. The LTC3351 then measures the time it takes to discharge the cap_delta_v_setting voltage. When the measurement has completed the charger turns on and maintains the float voltage.

When the capacitance measurement is started and allowed to complete, the voltage difference per capacitor is displayed in this section.

**CAP/ESR PER CAPACITOR**. The Capacitance and ESR for VCAP1/VCAP2/VCAP3/VCAP4 are reported at the bottom of the tab, using the reported details in the other sections.

**APPLY/CANCEL/RESTORE DEFAULTS.** These buttons write and read the settings between the LTC3351 and the GUI. Apply will write the selected settings to the LTC3351, Cancel will restore the GUI to the settings in the LTC3351, and Restore Defaults will return both the GUI and the LTC3351 to the defaults for the IC.

The DC2464A standard configuration is designed for supercapacitors of 200F or less. The standard configuration measures the time it takes to discharge the capacitor stack by 100mV at 33.6mA to calculate the capacitance. Larger supercapacitors have larger leakage currents, some over a milliamp, causing an inaccuracy in the capacitive measurement. To increase the measurement accuracy, the capacitor test current can be increased by loading the capacitor stack with external resistors, R50 and R51, during the measurement. The low threshold N-MOSFET, M6, is controlled by the ITST pin which turns on the load when needed.

# USING LARGE CAPACITORS

**Optional External Test Current**

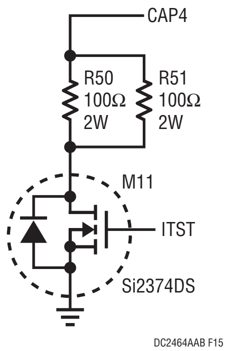



**Figure 15. External Test Current**

When using this circuit, the test current will be the original ITST circuit current plus an additional current due to the capacitor stack voltage across the resistor. This requires a modified equation for converting meas_cap to capacitance.

This equation for small scale is:

$$C = \frac{-56 \cdot 10^{-9} \cdot R_t \cdot meas\_cap}{R \cdot \ln\left[1 - \dfrac{\Delta V_{CAP}}{1.2V \cdot \dfrac{R}{R_{TST}} + V_{CAP}}\right]}$$

Larger capacitors also take longer to balance. If one capacitor is far enough off balance that it reaches the shunt voltage before the capacitor stack is fully charged. The charge current effectively is reduced to the shunt current until the capacitor stack is fully charged. The standard DC2464A board is set up for a 500mA maximum shunt current. This current can be increased by turning on external shunt resistors across each capacitor, R42 thru R49. The controlling FETs, M7 thru M10, are turned on from the voltage drop across the corresponding shunt resistor when the shunt regulator turns on. The 2.7Ω shunt resistors between the supercapacitor and the CAPx pin as shown in Figure 16 can be used to provide a larger shunt current.

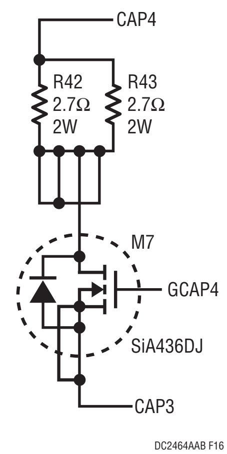



**Figure 16. High Current Shunting**

$$I_{SHUNT} = \frac{V_{SHUNT}}{2 \cdot R_{SHUNT}} + \frac{V_{SHUNT}}{R_{SHUNT(OPT)}}$$

# PARTS LIST – DC2464A-A

| ITEM | QTY | REFERENCE | PART DESCRIPTION | MANUFACTURER/PART NUMBER |
|---|---|---|---|---|
| **Required Circuit Components** | | | | |
| 1 | 1 | C1 | CAP., 1µF, X5R, 50V, 10%, 0603, AEC-Q200 | TDK, CGA3E3X5R1H105K080AB |
| 2 | 1 | C2 | CAP., 120pF, C0G, 50V, 5%, 0402 | MURATA, GRM1555C1H121JA01D |
| 3 | 6 | C6–C9, C15, C16 | CAP., 47µF, X5R, 25V, 20%, 1206 | TDK, C3216X5R1E476M160AC |
| 4 | 2 | C13, C14 | CAP., 2.2µF, X5R, 25V, 10%, 0402 | TDK, C1005X5R1E225K050BC |
| 5 | 1 | C17 | CAP., 4.7µF, X5R, 16V, 10%, 0603 | AVX, 0603YD475KAT2A |
| 6 | 4 | C18, C25, C26, CBST1 | CAP., 0.1µF, X7R, 16V, 10%, 0402 | AVX, 0402YC104KAT2A |
| 7 | 4 | C19, C20, C22, C23 | CAP., 22µF, X5R, 16V, 20%, 0805 | TDK, C2012X5R1C226M125AC |
| 8 | 1 | C21 | CAP., 1µF, X5R, 16V, 10%, 0402 | TAIYO YUDEN, EMK105BJ105KV-F |
| 9 | 1 | C28 | CAP., 0.01µF, X7R, 16V, 10%, 0402 | AVX, 0402YC103KAT2A |
| 10 | 4 | CAP1-CAP4 | CAP., 10F, ULTRA, 2.7V, –10/+20%, THT, RADIAL | NESSCAP, ESHSR-0010C0-002R7 |
| 11 | 1 | CSS1 | CAP. CER., 0.022µF, 100V, X7R, 0603 | TDK, C1608X7R2A223K080AA |
| 12 | 1 | CTIMER1 | CAP., 0.033µF, X5R, 16V, 10%, 0402, AEC-Q200 | TDK, CGA2B2X5R1C333K050BA |
| 13 | 1 | D1 | DIODE, TVS, 18V, 600W, SMB | DIODES INC., SMBJ18A-13-F |
| 14 | 1 | DBST1 | DIODE, GP SWITCHING, 80V, 125mA, SOD523, AEC-Q10X | DIODES INC., 1N4448HWT-7 |
| 15 | 1 | L1 | IND., 3.3µH, PWR., 20%, 10A, 21.45mΩ, SMD 7.5mm × 7.5mm, AEC-Q200 | COILCRAFT, XAL7030-332MEB |
| 16 | 2 | M1, M2 | XSTR., MOSFET, N-CH, 25V, 23A, TSDSON-8 | INFINEON, BSZ018NE2LSATMA1 |
| 17 | 2 | M3, M4 | XSTR., MOSFET, N-CH, 25V, 12A, TSDSON-8 | INFINEON, BSZ060NE2LSATMA1 |
| 18 | 1 | M5 | XSTR., MOSFET, N-CH, 20V, 16A, PowerPAK 1212-8 | VISHAY, SiS438DN-T1-GE3 |
| 19 | 2 | R4, R5 | RES., 10Ω, 5%, 1/16W, 0402 | VISHAY, CRCW040210R0JNED |
| 20 | 1 | R11 | RES., 649k, 1%, 1/16W, 0402 | NIC, NRC04F6493TRF |
| 21 | 1 | R12 | RES., 162k, 1%, 1/16W, 0402 | VISHAY, CRCW0402162KFKED |
| 22 | 1 | R14 | RES., 100Ω, 1%, 1/16W, 0402 | NIC, NRC04F1000TRF |
| 23 | 1 | R15 | RES., 665k, 1%, 1/16W, 0402 | NIC, NRC04F6653TRF |
| 24 | 1 | R17 | RES., 33.2k, 1%, 1/16W, 0402 | VISHAY, CRCW040233K2FKED |
| 25 | 1 | R18 | RES., AEC-Q200, 49.9k, 1%, 1/16W, 0402 | PANASONIC, ERJ2RKF4992X |
| 26 | 5 | R25, R27, R29, R30, R32 | RES., ANTI-SURGE, AEC-Q200, 2.7Ω, 5%, 1/2W, 0805 | PANASONIC, ERJ-P6WJ2R7V |
| 27 | 1 | R35 | RES., 866k, 1%, 1/16W, 0402 | NIC, NRC04F8663TRF |
| 28 | 1 | R36 | RES., 118k,1%, 1/16W, 0402 | NIC, NRC04F1183TRF |
| 29 | 1 | RITST1 | RES., AEC-Q200, 35.7Ω, 1%, 1/16W, 0402 | VISHAY, CRCW040235R7FKED |
| 30 | 1 | RSNSC1 | RES., SENSE, 0.006Ω, 1%, 1W, 1206 (0612) | SUSUMU |
| 31 | 1 | RSNSH1 | RES., SENSE, 0.012Ω, 1%, 1W, 1206 (0612) | SUSUMU, PRL1632-R012-F-T1 |
| 32 | 1 | RSNSI1 | RES., SENSE, AEC-Q200, 0.004Ω, 1%, 1.5W, 1206 (0612) | SUSUMU, KRL3216E-C-R004-F-T1 |
| 33 | 1 | RT1 | RES., 71.5k, 1%, 1/16W, 0402 | NIC, NRC04F7152TRF |
| 34 | 1 | U1 | IC, HOT SWAPPABLE SUPERCAPACITOR CHARGER BACKUP CONTROLLER AND SYSTEM MONITOR | ADI, LTC3351EUFF#PBF |

# PARTS LIST – DC2464A-A

| ITEM | QTY | REFERENCE | PART DESCRIPTION | MANUFACTURER/PART NUMBER |
|---|---|---|---|---|
| **Additional Demo Board Circuit Components** | | | | |
| 35 | 0 | C3, C4 | DNP | |
| 36 | 0 | C5, C12, C27 | DNP | |
| 37 | 0 | C10, C11 | DNP | |
| 38 | 0 | C24 | DNP | |
| 39 | 1 | C29 | CAP., 0.1µF, X7R, 16V, 10%, 0402 | AVX, 0402YC104KAT2A |
| 40 | 0 | D2 | DNP | |
| 41 | 2 | D3, D4 | LED, GREEN, MILKY WHITE DIFF., 0603 SMD, 565nm | LUMEX, SML-LX0603GW-TR |
| 42 | 1 | D5 | LED, SUPER RED, MILKY WHITE DIFF., 0603 SMD, 660nm | LUMEX, SML-LX0603SRW-TR |
| 43 | 2 | D6, D7 | DNP | |
| 44 | 0 | M5 | DNP | |
| 45 | 0 | M6 | DNP | |
| 46 | 0 | M7-M10 | DNP | |
| 47 | 0 | M11 | DNP | |
| 48 | 1 | Q1 | XSTR., MOSFET, DUAL N-CH, 20V, 1.3A, SOT-363 | VISHAY, Si1922EDH-T1-GE3 |
| 49 | 0 | R1 | DNP | |
| 50 | 2 | R2, R3 | RES., 1Ω,1%, 1/16W, 0402 | VISHAY, CRCW04021R00FKED |
| 51 | 2 | R6, R31 | RES., 20Ω,1%, 1/16W, 0402 | NIC, NRC04F20R0TRF |
| 52 | 0 | R7, R9, R22, R24 | DNP | |
| 53 | 0 | R8 | DNP | |
| 54 | 6 | R8, R10, R13, R16, R28, R52 | RES., 0Ω,1/16W, 0402 | ROHM, MCR01MZPJ000 |
| 55 | 2 | R19, R20 | RES., 5.1k, 5%, 1/16W, 0402 | NIC, NRC04J512TRF |
| 56 | 4 | R21, R23, R37, R38 | RES., 100k, 5%, 1/16W, 0402 | YAGEO, RC0402JR-07100KL |
| 57 | 3 | R26, R33, R34 | RES., 1MΩ, 5%, 1/16W, 0402 | YAGEO, RC0402JR-071ML |
| 58 | 3 | R39-R41 | RES., 1k, 5%, 1/16W, 0402 | NIC, NRC04J102TRF |
| 59 | 0 | R42-R51 | DNP | |
| 60 | 1 | U2 | IC, MEMORY, EEPROM, 2Kb (256 × 8), TSSOP-8, 400kHz | MICROCHIP, 24LC025-I/ST |
| 61 | 0 | Z1 | DNP | |
| **Hardware for Demo Board Only** | | | | |
| 62 | 11 | E1-E6, E8, E10-E12, E17 | TEST POINT, TURRET, 0.094", MTG. HOLE | MILL-MAX, 2501-2-00-80-00-00-07-0 |
| 63 | 6 | E7, E9, E13-E16 | TEST POINT, TURRET, 0.064", MTG. HOLE | MILL-MAX, 2308-2-00-80-00-00-07-0 |
| 64 | 1 | J1 | CONN., HDR., MALE, 2mm × 7mm, 2mm, THT, VERT, SHROUDED | MOLEX, 87831-1420 |
| 65 | 1 | JP1 | CONN., HDR, MALE, 1mm × 3mm, 2mm, THT, STR | WURTH ELEKTRONIK, 62000311121 |

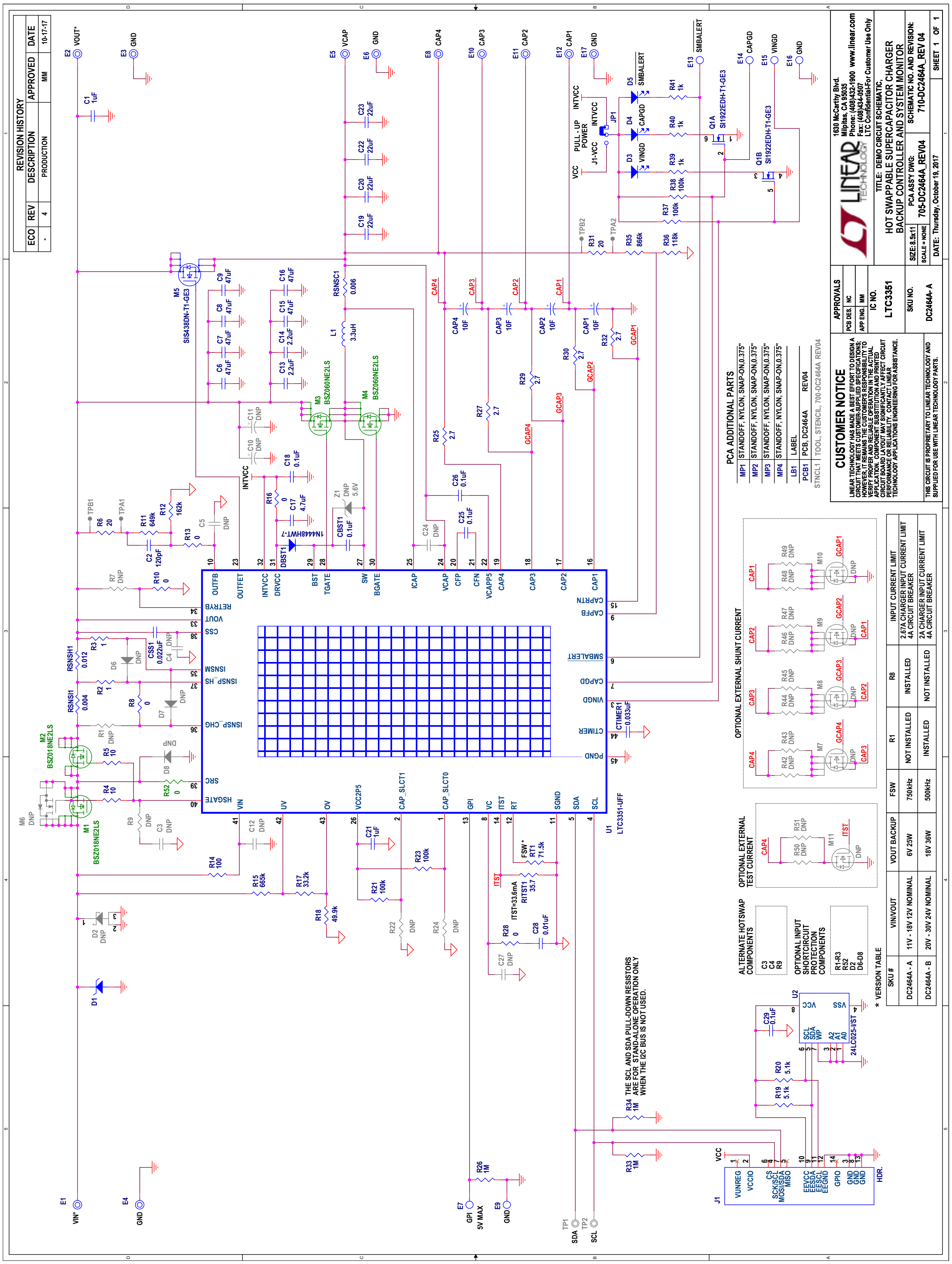
# PARTS LIST – DC2464A-B

| ITEM | QTY | REFERENCE | PART DESCRIPTION | MANUFACTURER/PART NUMBER |
|---|---|---|---|---|
| **Required Circuit Components** | | | | |
| 1 | 1 | C1 | CAP., 1µF, X5R, 50V, 10%, 0603, AEC-Q200 | TDK, CGA3E3X5R1H105K080AB |
| 2 | 1 | C2 | CAP., 120pF, C0G, 50V, 5%, 0402 | MURATA, GRM1555C1H121JA01D |
| 3 | 6 | C6-C9, C15, C16 | CAP., 10µF, X5R, 50V, 10%, 1206 | MURATA, GRM31CR61H106KA12L |
| 4 | 2 | C10, C11 | CAP., 33µF, ALUM., 50V, 20%, SMD 6.3mm × 7.7mm, AEC-Q200 | PANASONIC, EEHZA1H330XP |
| 5 | 2 | C13, C14 | CAP., 0.1µF, X7R, 50V, 10%, 0402 | MURATA, GRM155R71H104KE14D |
| 6 | 1 | C17 | CAP., 4.7µF, X5R, 16V, 10%, 0603 | AVX, 0603YD475KAT2A |
| 7 | 4 | C18, C25, C26, CBST1 | CAP., 0.1µF, X7R, 16V, 10%, 0402 | AVX, 0402YC104KAT2A |
| 8 | 4 | C19, C20, C22, C23 | CAP., 22µF, X5R, 16V, 20%, 0805 | TDK, C2012X5R1C226M125AC |
| 9 | 1 | C21 | CAP., 1µF, X5R, 16V, 10%, 0402 | TAIYO YUDEN, EMK105BJ105KV-F |
| 10 | 1 | C24 | CAP., 220pF, C0G, 50V, 5%, 0402 | AVX, 04025A221JAT2A |
| 11 | 1 | C28 | CAP., 1200pF, X7R, 50V, 10%, 0402 | AVX, 04025C122KAT2A |
| 12 | 4 | CAP1-CAP4 | CAP., 10F, ULTRA, 2.7V, –10/+20%, THT, RADIAL | NESSCAP, ESHSR-0010C0-002R7 |
| 13 | 1 | CSS1 | CAP. CER., 0.022µF, 100V, X7R, 0603 | TDK, C1608X7R2A223K080AA |
| 14 | 1 | CTIMER1 | CAP., 0.033µF, X5R, 16V, 10%, 0402, AEC-Q200 | TDK, CGA2B2X5R1C333K050BA |
| 15 | 1 | D1 | DIODE, TVS, UNI-DIR., 30V, 600W, SMB | LITTELFUSE, SMBJ30A |
| 16 | 1 | DBST1 | DIODE, GP SWITCHING, 80V, 125mA, SOD523, AEC-Q10X | DIODES INC., 1N4448HWT-7 |
| 17 | 1 | L1 | IND., 6.8µH, PWR, 20%, 9.2A, 19.62mΩ, SMD 7.2mm × 7.5mm, AEC-Q200 | COILCRAFT, XAL7070-682MEB |
| 18 | 4 | M1-M4 | XSTR., N-CH, 40V, 17.6A, PowerPAK 1212-8 | VISHAY, SIS434DN-T1-GE3 |
| 19 | 2 | R4, R5 | RES., 10Ω, 5%, 1/16W, 0402 | VISHAY, CRCW040210R0JNED |
| 20 | 1 | R11 | RES., 649k, 1%, 1/16W, 0402 | NIC, NRC04F6493TRF |
| 21 | 1 | R12 | RES., 46.4k, 1%, 1/16W, 0402 | VISHAY, CRCW040246K4FKED |
| 22 | 1 | R14 | RES., 100Ω, 1%, 1/16W, 0402 | NIC, NRC04F1000TRF |
| 23 | 1 | R15 | RES., 665k, 1%, 1/16W, 0402 | NIC, NRC04F6653TRF |
| 24 | 1 | R17 | RES., 14.3k, 1%, 1/16W, 0402 | VISHAY, CRCW040214K3FKED |
| 25 | 1 | R18 | RES., AEC-Q200, 28k, 1%, 1/16W, 0402 | VISHAY, CRCW040228K0FKED |
| 26 | 5 | R25, R27, R29, R30, R32 | RES., ANTI-SURGE, AEC-Q200, 2.7Ω, 5%, 1/2W, 0805 | PANASONIC, ERJ-P6WJ2R7V |
| 27 | 1 | R35 | RES., 866k, 1%, 1/16W, 0402 | NIC, NRC04F8663TRF |
| 28 | 1 | R36 | RES., 118k, 1%, 1/16W, 0402 | NIC, NRC04F1183TRF |
| 29 | 1 | RITST1 | RES., AEC-Q200, 35.7Ω, 1%, 1/16W, 0402 | VISHAY, CRCW040235R7FKED |
| 30 | 1 | RSNSC1 | RES., SENSE, 0.005Ω, 1%, 1W, 1206 (0612) | SUSUMU, PRL1632-R005-F-T1 |
| 31 | 1 | RSNSH1 | RES., SENSE, 0.012Ω, 1%, 1W, 1206 (0612) | SUSUMU, PRL1632-R012-F-T1 |
| 32 | 1 | RSNSI1 | RES., SENSE, AEC-Q200, 0.004Ω, 1%, 1.5W, 1206 (0612) | SUSUMU, KRL3216E-C-R004-F-T1 |
| 33 | 1 | RT1 | RES., 107k, 1%, 1/16W, 0402 | VISHAY, CRCW0402107KFKED |
| 34 | 1 | U1 | IC, HOT SWAPPABLE SUPERCAPACITOR CHARGER BACKUP CONTROLLER AND SYSTEM MONITOR | ADI, LTC3351EUFF#PBF |

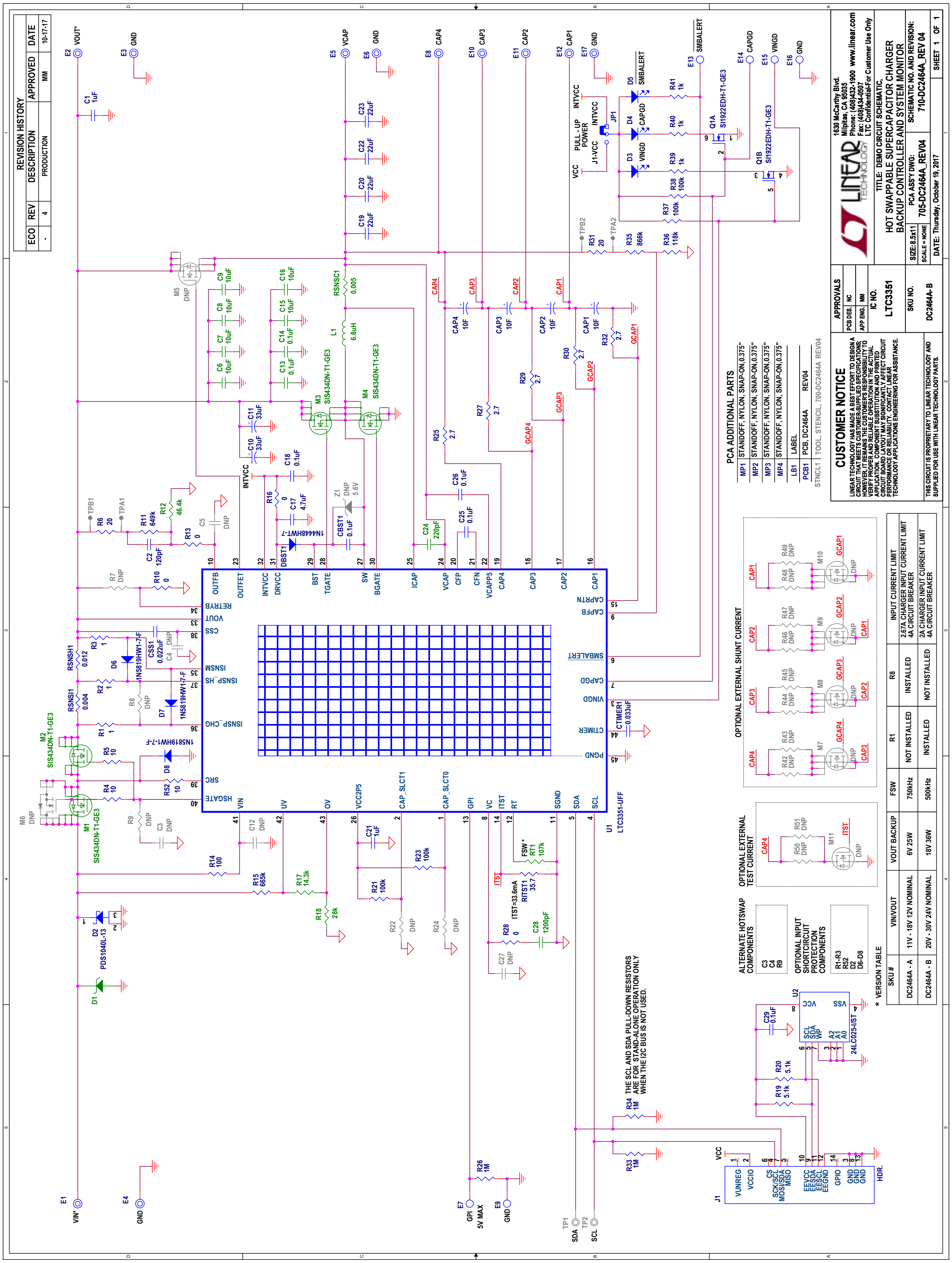
## PARTS LIST – DC2464A-B

| ITEM | QTY | REFERENCE | PART DESCRIPTION | MANUFACTURER/PART NUMBER |
|---|---|---|---|---|
| **Additional Demo Board Circuit Components** | | | | |
| 35 | 0 | C3, C4 | DNP | |
| 36 | 0 | C5,C12,C27 | DNP | |
| 37 | 1 | C29 | CAP., 0.1µF, X7R, 16V, 10%, 0402 | AVX, 0402YC104KAT2A |
| 38 | 1 | D2 | DIODE, SCHOTTKY, 40V, 10A, PowerDI5 | DIODES INC., PDS1040L-13 |
| 39 | 2 | D3, D4 | LED, GREEN, MILKY WHITE DIFF., 0603 SMD, 565nm | LUMEX, SML-LX0603GW-TR |
| 40 | 1 | D5 | LED, SUPER RED, MILKY WHITE DIFF., 0603 SMD, 660nm | LUMEX, SML-LX0603SRW-TR |
| 41 | 3 | D6-D8 | DIODE, SBR, 40V, 1A, SOD123F | DIODES INC., 1N5819HW1-7-F |
| 42 | 0 | M5 | DNP | |
| 43 | 0 | M6 | DNP | |
| 44 | 0 | M7-M10 | DNP | |
| 45 | 0 | M11 | DNP | |
| 46 | 1 | Q1 | XSTR., MOSFET, DUAL N-CH, 20V, 1.3A, SOT-363 | VISHAY, Si1922EDH-T1-GE3 |
| 47 | 3 | R1-R3 | RES., 1Ω, 1%, 1/16W, 0402 | VISHAY, CRCW04021R00FKED |
| 48 | 2 | R6, R31 | RES., 20Ω, 1%, 1/16W, 0402 | NIC, NRC04F20R0TRF |
| 49 | 0 | R7, R9, R22, R24 | DNP | |
| 50 | 0 | R8 | DNP | |
| 51 | 4 | R10, R13, R16, R28 | RES., 0Ω, 1/16W, 0402 | ROHM, MCR01MZPJ000 |
| 52 | 2 | R19, R20 | RES., 5.1k, 5%, 1/16W, 0402 | NIC, NRC04J512TRF |
| 53 | 4 | R21, R23, R37, R38 | RES., 100k, 5%, 1/16W, 0402 | YAGEO, RC0402JR-07100KL |
| 54 | 3 | R26, R33, R34 | RES., 1MΩ, 5%, 1/16W, 0402 | YAGEO, RC0402JR-071ML |
| 55 | 3 | R39-R41 | RES., 1k, 5%, 1/16W, 0402 | NIC, NRC04J102TRF |
| 56 | 0 | R42-R51 | DNP | |
| 57 | 1 | R52 | RES., 10Ω, 5%, 1/16W, 0402 | VISHAY, CRCW040210R0JNED |
| 58 | 1 | U2 | IC, MEMORY, EEPROM, 2KB (256 × 8), TSSOP-8, 400kHz | MICROCHIP, 24LC025-I/ST |
| **Hardware-For Demo Board Only** | | | | |
| 59 | 11 | E1-E6, E8, E10-E12, E17 | TEST POINT, TURRET, 0.094", MTG. HOLE | MILL-MAX, 2501-2-00-80-00-00-07-0 |
| 60 | 6 | E7, E9, E13-E16 | TEST POINT, TURRET, 0.064", MTG. HOLE | MILL-MAX, 2308-2-00-80-00-00-07-0 |
| 61 | 1 | J1 | CONN., HDR., MALE, 2 × 7, 2mm, THT, VERT, SHROUDED | MOLEX, 87831-1420 |
| 62 | 1 | JP1 | CONN., HDR, MALE, 1 × 3, 2mm, THT, STR | WURTH ELEKTRONIK, 62000311121 |

# SCHEMATIC DIAGRAM – DC2464A-A



# SCHEMATIC DIAGRAM – DC2464A-B



**ESD Caution**

**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

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