5V and 3.3V Hot Swap Controller

July 2009 **Reference Design RD1057**

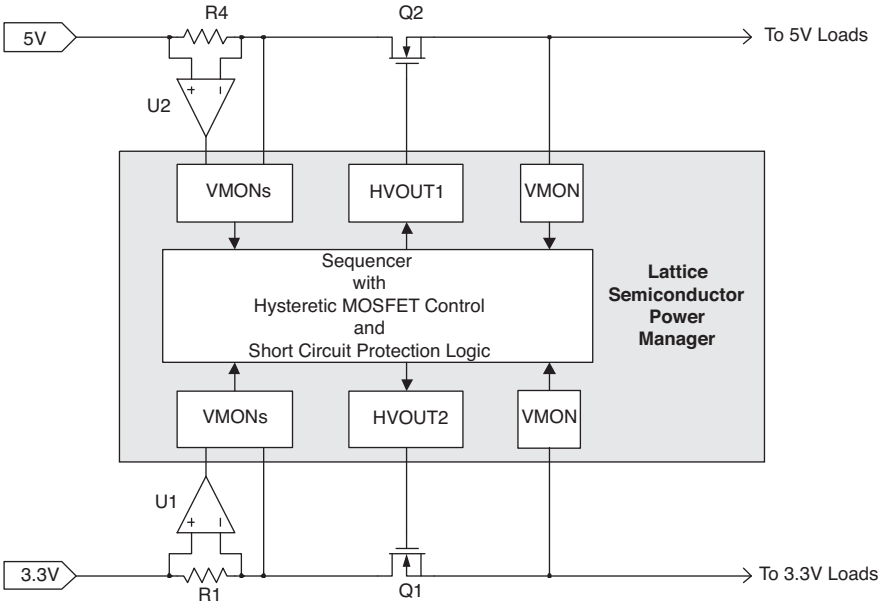
Introduction

This reference design describes the **POWR1014A-2-HS-Controller.PAC** design that is located in the Examples folder of the PAC-Designer® installation. This design can be opened in PAC-Designer by using the menu **File->Design Examples…** and browsing to the design file. This design manages both a 5V and 3.3V supply to limit inrush current to a user-defined level. It also initiates a shut-down if either supply exhibits a short-circuit. By sensing the voltage across the MOSFET and limiting the inrush current, the design operates the transistors in the Safe Operation Area (SOA).

Features

- 5V and 3.3V hot-swap controller
  - Operate MOSFETs in Safe Operation Area (SOA)
  - Short circuit protection
  - Protection against over current faults during operation
- Programmable SOA and over current levels for both 5V and 3.3V
- Customize the design to suit most MOSFETs
- Initial contact de-bounce period programmable from 32us to 2 seconds

Figure 1. Hot Swap 3.3V and 5V Top-Level Block Diagram



Functional Description

Both the 3.3V and 5V supply lines have a small series resistor (current shunts R1 & R4) to monitor the current and N-channel MOSFETs (Q1 & Q2) to switch the voltage to the loads. The voltage across the current shunt is amplified so that the VMON input can sense the value. This is accomplished using the Zetex ZXCT1010 high side current sense amplifier (U1 & U2). The supplies are sensed both before and after the MOSFET with additional VMONs. The PLD contains the sequence that enables the hot-swap. The PLD also implements the logic for hyster-

etic and SOA control of the MOSFETs and short-circuit detection. When the voltage drop across the MOSFET is large (initial turn on) then they are controlled using the SOA mode of operation. When the voltage drop across the MOSFET is relatively small then they are no longer under SOA control and are turned on fully.

Design Description

The circuits and logic for the 3.3V and 5V supplies are similar and almost independent of each other so we will discuss the control in generic detail and mention the 3.3V or 5V specifics where it is appropriate. For this design the LogiBuilder source is distributed across the three different interfaces; sequencer, exceptions, and supervisory logic as shown in Listings 1-3.

The main sequence is responsible for startup and shutdown by monitoring the VMONs and timers. The Input and Board VMONs use the Window Mode to provide an OK signal when the voltage is between the lower and upper trip points (see Figures 2 and 3). Timer 1 is used to define the contact bounce period and is set in this design for 1ms but, could be changed based on system needs. Timer 2 is used to provide a maximum short-circuit duration and is set in this design for 2ms but, could be modified based on actual MOSFET specifications. The main sequence does not control the outputs directly; rather it enables or disables two control node macrocells: Start_HotSwap_With_SOA and Turn_MOSFET_On_Fully. The following pseudo-sequence describes the logic flow that is detailed in Listing 1.

Main Sequence

- Turn MOSFETs off
- Wait for 5V and 3.3V input rails to stabilize after contact bounce using Timer 1
- Enable hot-swap operation, operate MOSFETs in SOA
- Wait for 5V and 3.3V output from the MOSFET to reach acceptable levels within short circuit timeout period using Timer 2
- If short circuit timer expires then jump to shutdown sequence
- If 5V and 3.3V reach acceptable levels then turn MOSFETs on fully
- Halt

Shutdown Sequence

- Shut the MOSFETs Off

Listing 2 shows the exception that will force the main sequence to the shutdown sequence if either the 5V or the 3.3V current sense circuits detect an over-current condition. This exception is only enabled in steps 6, 7, and 8 of Listing 1 so it is only in effect after the MOSFETs have been turned on. The VMONs that are used for current sense do not use the Window Mode rather the two comparators provide two levels of current sense; SOA limit and over current limit (see Figures 2 and 3).

Listing 3 shows the four Supervisory Logic equations that control the HVOUTs which in turn control the MOSFETs. These equations are also detailed in Figures 2 and 3. The MOSFET is turned on when the main sequence enables Start_HotSwap_With_SOA and the Over_SOA_Limit is not exceeded. This both limits in-rush current and operates the MOSFET in the SOA. When the Over_SOA_Limit is exceeded the MOSFET is turned off. This provides the hysteretic control that keeps the MOSFET in the SOA. The MOSFET is also turned on when the main sequencer enables Turn_MOSFET_On_Fully. If either the 3.3V or 5V Over_Current signals become true then the MOSFETs are turned off immediately from the asynchronous reset equations (EQ 1 and 3).

Listing 1. Main Sequence (State Machine 0)

```
Step 0    // ispPAC-POWR1014A reset
          Begin Startup Sequence
Step 1    Wait for  AGOOD
Step 2    // Do not start the Hot-swap until the supplies are stable
          Turn_MOSFET_On_Fully = 0, Start_HotSwap_With_SOA = 0,
Step 3    // Start the Debounce Timer (Set timer1 to required period)
          Start timer 1 (1.02ms)
Step 4    If  Inp_3V3_OK AND Inp_5V_OK Then Goto 4
            Else If Timer 1 Then Goto 5
            Else Goto 1
Step 5    // 5V and 3.3V Supplies are Stable for Debounce period, So start HotSwap
          Start_HotSwap_With_SOA = 1,
Step 6    // Ensure 3.3V and 5V turn on within specified time period, else shut off
          Wait for  Brd_3V3_OK AND Brd_5V_OK or 2.05ms using timer 2; on timeout Goto 9
Step 7    // Backplane voltage is stable;
          // turn the MOSFETs on Fully and Monitor for Over Current
          Turn_MOSFET_On_Fully = 1,
Step 8    // Hotswap operation Complete. Wait for the board to operate Normally
          Halt
Step 9    Begin Shutdown Sequence
Step 10   // There may be a short circuit, disconnect backplane
          Turn_MOSFET_On_Fully = 0, Start_HotSwap_With_SOA = 0,
Step 11   Halt (end-of-program)
```

Listing 2. Sequencer Exception

```
E 0: If  I_3V3_Over_Current OR I_5V_Over_Current, Starts at step 9, Outputs: <no outputs
specified>
```

Listing 3. Supervisory Logic Equations

```
EQ 0:    // Hot swap in SOA or Turn the MOSFET on Fully
         HS_3V3_MOSFET_Drive.D  = ( NOT I_3V3_Over_SOA_Limit AND Start_HotSwap_With_SOA )
                                  OR Turn_MOSFET_On_Fully
EQ 1:    // Hot swap 5V supply or fully turn on
         HS_5V_MOSFET_Drive.D   = ( NOT I_5V_Over_SOA_Limit AND Start_HotSwap_With_SOA )
                                  OR Turn_MOSFET_On_Fully
EQ 2:    // Trip Both MOSFETs if Any Current Exceeds Over Current Limit
         HS_3V3_MOSFET_Drive.ar = I_3V3_Over_Current OR I_5V_Over_Current
EQ 3:    // Trip Both MOSFETs if Any Current Exceeds Over Current Limit
         HS_5V_MOSFET_Drive.ar  = I_3V3_Over_Current OR I_5V_Over_Current
```

The actual current limit values are a function of the shunt resistors (R1 and R4) the gain of the current sense amplifier and the output resistors (R2 and R5). The gain of the ZXCT1010 is 10,000 uA/V. The following equations can be used to calculate either the VMON trip point or the current limit where I_{Trip} is the current limit and VMON is the trip point voltage. The equations can work with either the 3.3V or the 5V current sensing circuits. However, be mindful of the ZXCT1010 limitations such as input and output voltage and output current. Table 1 lists current limits for some common resistor values and VMON trip points that will work with the ZXCT1010. When sensing large currents (such as 10A) make sure the resistor can handle the power dissipation ($W = I^2 \times R$).

$$I_{Trip} = VMON / (R1 \times 10^{-2} \times R2)$$

$$VMON = I_{Trip} \times R1 \times 10^{-2} \times R2$$

Figure 2. Hot Swap 3.3V Block Diagram

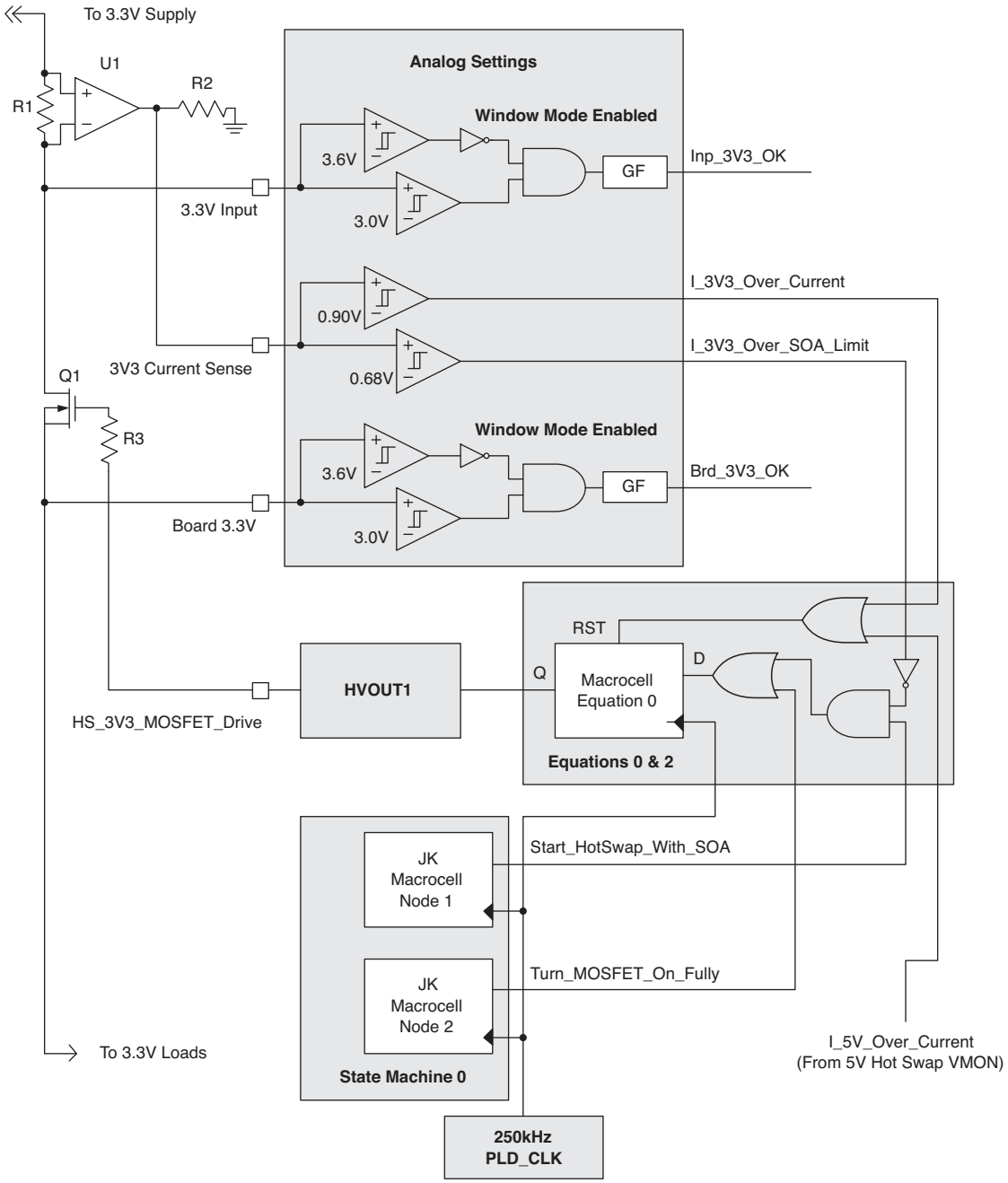
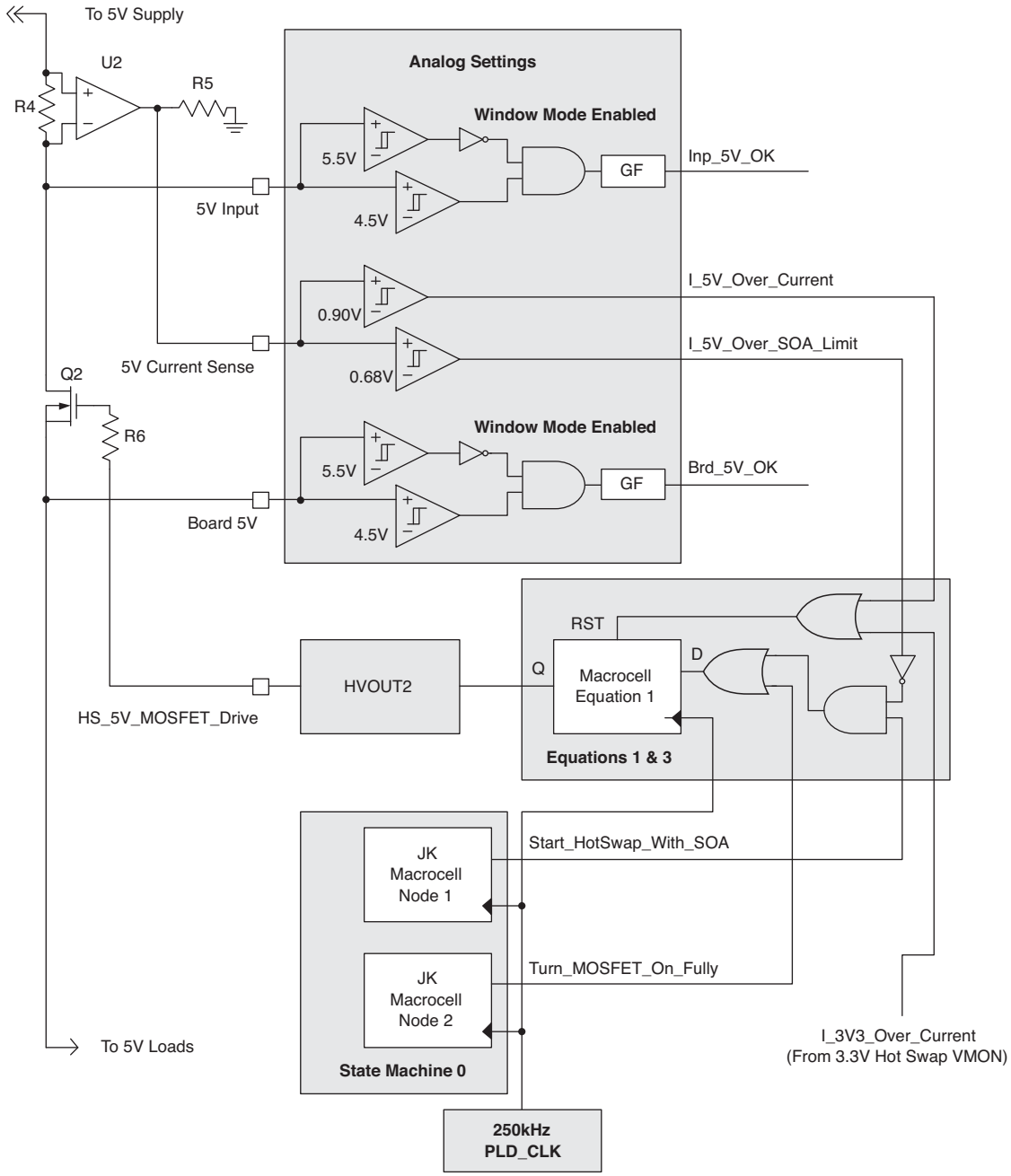


Table 1. Current Limits for Common Resistors and Trip Points

Shunt R1, R4 (ohms)	R-Out R2, R5 (ohms)	VMON Trip Point (V)	Current Limit (A)
0.040	1500	0.680	1.133
0.040	1500	0.900	1.500
0.020	1500	0.680	2.266
0.020	1500	0.900	3.000
0.010	1500	0.680	4.533
0.010	1500	1.500	10.00

Figure 3. Hot Swap 5V Block Diagram

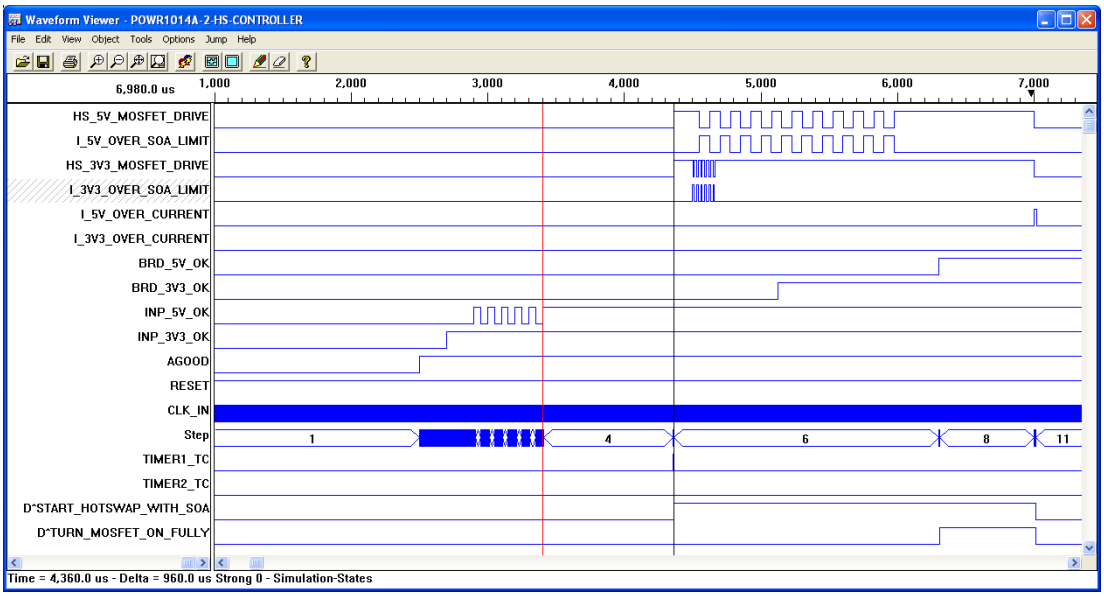


Simulation and Verification

The simulation results are shown in Figure 4. After AGOOD is true the sequencer cycles through Steps 1, 2, 3, 4 and repeats until both 3.3V and 5V are both OK (around 3400us). Note there is simulated contact bounce on the 5V supply from 2900us to 3400us. After Timer 1 times out the sequence moves to Step 5 to activate the internal node Start_HotSwap_With_SOA which results in both MOSFET drive signals to become active (around 4350us). At 4500us the 3.3V MOSFET is started to turn on and the inrush current is simulated to exceed the SOA limit. The MOSFET drive is shutdown and the current drops. This cycle is repeated until the load capacitors are simulated to be fully charged and the SOA current limit is not exceeded any more (around 4670us). This is simulated by the BRD_3V3_OK signal becoming active at 5125us. The same scenario is simulated for the 5V MOSFET drive but,

with a wider cycle delay and the BRD_5V_OK signal is simulated to go high at 6300us. At which point the sequencer moves to Step 7 to enable the node Turn_MOSFET_On_Fully and halts at Step 8 waiting for an over current exception. The 5V rail is simulated to have an over current condition at 7000us which forces the sequencer to Steps 9, 10, and 11 for a safe shut down.

Figure 4. Simulation with Short Circuit on 5V at 7000us



Implementation

Table 2. Performance and Resource Utilization[1]

Device	Macrocells	Product Terms	VMONs	I/Os	Timers
ispPAC-POWR1014A	13	56	6	2	2

1. Resource utilization characteristics are generated using PAC-Designer 5.1 software. When using this design in a different device, utilization characteristics may vary.

References

- ispPAC-POWR1014/A Data Sheet
- Zetex ZXCT1010 Data Sheet

Technical Support Assistance

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Revision History

Date	Version	Change Summary
July 2009	01.0	Initial release.