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Advanced Power Devices for Slimmer Slimline PSUs

TECHNICAL NOTE

Abstract

As power supplies for high-volume products such as televisions and computers are required to meet ever-tougher demands on form factor, efficiency and cost, power supply controllers must integrate more features helping to increase efficiency while minimizing component count, PCB size and complexity, and bill of materials costs.

Advanced power semiconductor processes enabling extra silicon integration and novel control capabilities enable next-generation devices such as ON Semiconductor's NCP1937 combined quasi-resonant converter and PFC controller to deliver improvements in all areas compared to conventional, less highly integrated alternatives.

Introduction: Pressures on Power Supply Design

The super-slim dimensions of today's flat-panel televisions, all-in-one PCs and notebook travel power adapters demands a smarter approach to AC/DC power supply design, to achieve a lower profile while also meeting tough targets for efficiency, overall power consumption and cost. To meet these requirements, the quasi-square-wave resonant (QR) power supply architecture has become popular. For designers bringing up a QR power supply, the selection of the controller IC can have a critical effect on power efficiency and also on component count, which in turn influences circuit complexity and PCB size.

Since the QR converter's switching frequency tends to increase as the output load decreases, conventional controllers use skip-cycle or frequency-foldback operation to increase light-load efficiency but are vulnerable to valley jumping, which produces audible noise, and require a low minimum switching frequency necessitating a larger transformer. ON Semiconductor's patented valley lockout technique featured on the NCP1937 converter/PFC controller helps avoid these drawbacks.

Although power-factor correction is mandatory in appliances over 70 W, it is not required at low loads and hence can be turned off to save energy losses. The ON Semiconductor NCP1937 has a built-in capability to turn the PFC circuitry off under light-load conditions and goes further than other controllers, both by allowing the designer to set the turn-on/turn-off thresholds and also by integrating the MOSFET switch needed to turn the PFC circuitry off.

The NCP1937, which is suitable for power supplies in the 90–120 W range, has several other differentiating features. Innovative X2 capacitor-discharge circuitry saves additional external components and their associated power dissipation, which are usually needed to meet safety agency standards. Also, a novel approach to controlling power-saving operation minimizes the current drawn in power-saving mode. In addition, the design of the latch-off circuit simplifies protection and reduces component count, and a soft over-voltage protection feature reduces acoustic noise generated by the power supply, while integrated short-circuit protection for the boost diode and a built-in brown-out resistor save further external components.

Maximizing the QR Efficiency Advantage

Quasi-Resonant operation of the flyback converter is currently popular in laptop power adapters and televisions, mainly through its use of Zero-Voltage Switching (ZVS), or valley switching. This improves switching efficiency and also generates lower electromagnetic interference (EMI) than a hard-switching architecture.

By nature, the QR converter's switching frequency varies according to input and output load conditions and tends to increase as the output load decreases. In a conventional QR converter the free-running frequency is typically clamped at 125 kHz, which is below the 150 kHz CISPR-22 EMI starting point. Hence at light loads the MOSFET cannot turn on as soon as a valley is detected but must wait for 8 μ s to expire, causing some valleys to be ignored. However, if the output power is at a level such that the off-time needed for cycle-by-cycle energy balance falls between adjacent valleys, two or three cycles of first valley switching may be followed by one cycle of second valley switching. This phenomenon, known as valley jumping, causes large variations in the switching frequency which are compensated by large changes in the peak current resulting in audible noise in the transformer.

Skip-cycle or frequency-foldback operation is often used to reduce the switching frequency as the frequency clamp is reached. This is effective in increasing light-load efficiency, but does not prevent valley jumping. Another drawback of this approach is the relatively low minimum switching

frequency required, typically around 30 kHz, necessitating a larger transformer.

ON Semiconductor’s patented Valley Lockout technique eliminates valley jumping by locking the converter in its selected valley until a significant change in output power is detected. In the NCP1937 this is achieved by using a gang of comparators to monitor the voltage on the feedback pin

and feed the information to a counter. The hysteresis on each comparator locks the operating valley. In addition to this, a frequency foldback circuit based on a VCO reduces the switching frequency as the output power decreases, delivering a further improvement in efficiency at light load. The schematic of Figure 1 illustrates the NCP1937’s integrated valley lockout detection circuitry.

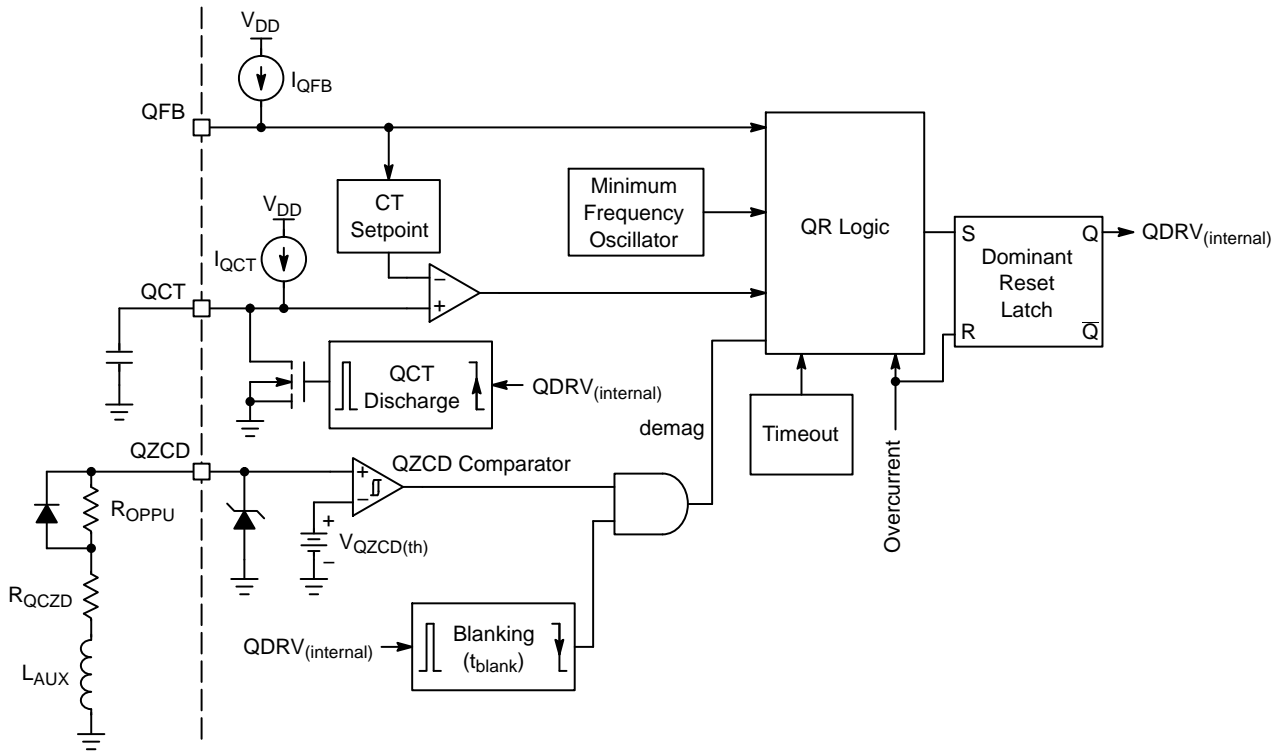


Figure 1. Valley Lockout Detection Circuitry

Enhancing PFC Control

Power-factor correction is mandatory in appliances over 70 W, and aims to minimize distortion of the mains AC waveform while also helping improve the energy efficiency of the appliance. However, since PFC is not required at low loads some controllers build in a function to turn the PFC circuitry off under these conditions to save energy losses.

Conventional QR/PFC converters typically take their reference for turning on and turning off of the PFC stage from the flyback frequency. One disadvantage of this approach is that an external feedback connection is usually required, with a MOSFET circuit to open or close the loop, which adds to complexity and bill-of-materials costs. The NXP Semiconductors TEA1752/3 is an example of a conventional combination controller that requires such external circuitry.

A novel feature of ON Semiconductor’s NCP1937 allows the user to program the PFC disable threshold based on the percentage of output power. Internal circuitry generates a current proportional to the output power, which is scaled and averaged using an external resistor and capacitor to produce a voltage proportional to output power. The IC uses this voltage in conjunction with an integrated PFC disable timer and a reference that varies with the line voltage to coordinate turning off and re-enabling the PFC. This allows the PFC stage to be disabled between 25% and 50% of the load at low line and between 50% and 75% at high line. The PFC stage is also disabled during power-up until the flyback soft-start time expires. Figure 2 illustrates the PFC on/off control circuitry.

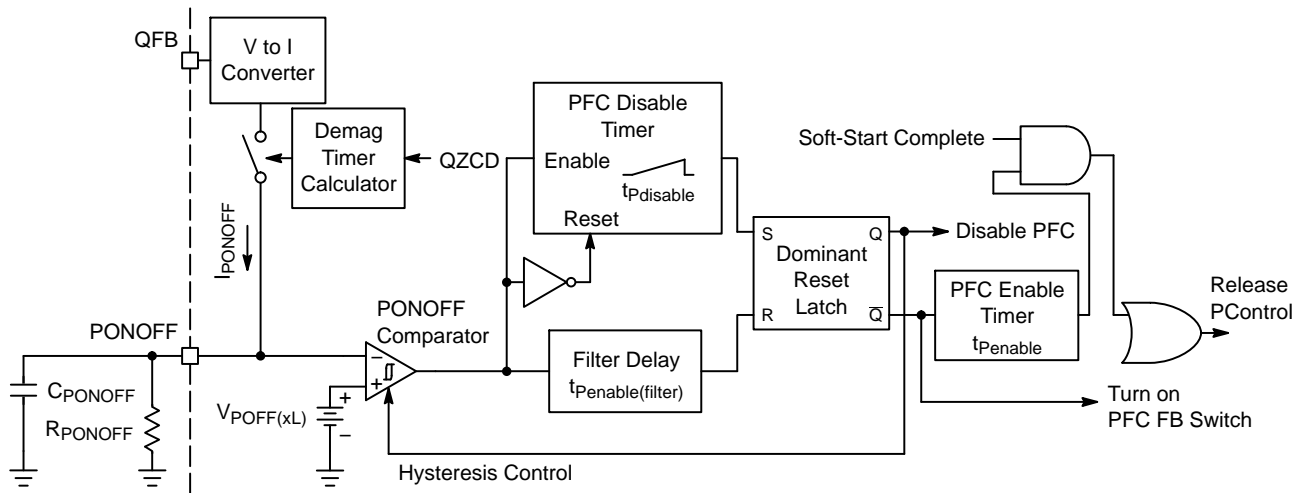


Figure 2. Integrated Circuitry for PFC On/Off Control

Improved X2 Capacitor Discharge

Safety agency standards for AC/DC power supplies require a means of discharging the X2 input filter capacitor when the AC line voltage is removed. In a conventional controller, such as the NXP TEA1752/3, the capacitor is typically discharged through an external resistor, hence not only adding to complexity, size and bill of materials but also incurring I^2R losses.

ON Semiconductor’s 700 V high-voltage process allows the NCP1937 to integrate most of the circuitry needed for discharging the X2 capacitor. This saves the PCB space and power consumed by the conventional external resistor network.

The NCP1937 controller has two high-voltage startup circuits, and a novel approach is used to reconfigure these to discharge the input filter capacitance upon removal of the AC line voltage.

One of the startup circuits, connected to the controller’s BO/X2 pin, is used to monitor the AC line voltage. Once it detects the absence of the AC line voltage, the controller is disabled and V_{CC} is discharged by a current source. As the voltage falls to a threshold level, $V_{CC(off)}$, the startup circuits source current from both high-voltage inputs to the V_{CC} pin so as to transfer charge from the input filter capacitor to the V_{CC} capacitor. This effectively discharges the input filter capacitor. The V_{CC} capacitor value is chosen to be large enough that the energy transferred is significantly lower than that needed to charge the V_{CC} capacitor from $V_{CC(off)}$ to $V_{CC(on)}$. The BO/X2 high-voltage circuit is also used for detecting brown-out faults. The brown-out detection resistor is also built into the device, reducing energy losses and component count. Figure 3 illustrates how X2 capacitor discharge occurs in three stages.



X2 Discharge at 265 VAC
 Ch. 1 (Yellow): BOX2 Voltage
 Ch. 2 (Blue): QR DRV
 Ch. 3 (Purple): V_{CC}

Figure 3. X2 Capacitor Discharge Waveforms

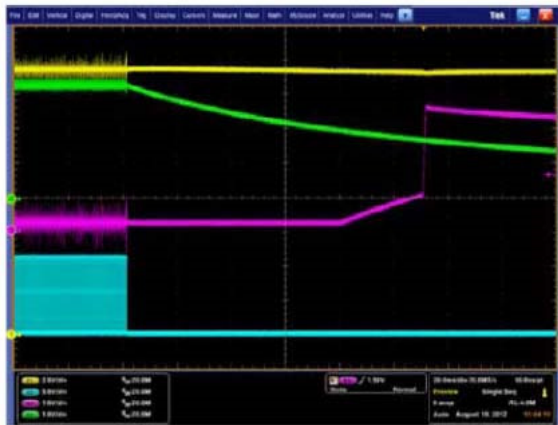
Power-saving Control of Power-save Mode

ON Semiconductor’s advanced process technology has also allowed a novel approach to the type of signalling required to hold the NCP1937 in Power-Saving Mode (PSM), which delivers a further saving in system power consumption.

The typical approach taken with conventional flyback control ICs uses an active-off signal to initiate the low-power mode, which requires an additional bias current to pull down the optocoupler on the secondary side and reduces the overall system efficiency. In contrast, the

NCP1937 has internal circuitry that eliminates the need for such a bias current, thereby improving system efficiency when no load is present. The circuitry comprises an internal current source that charges an external capacitor. When the secondary-side controller senses a load it pulls the optocoupler down which discharges the capacitor tied to the NCP1937. This keeps the voltage on the PSTimer pin ($V_{pstimer}$) below 3.5 V. When the secondary side controller senses there is no load it lets the optocoupler go high which then allows the capacitor tied to the NCP1937 to charge. This drives the $V_{pstimer}$ voltage above 3.5 V and puts the part into PSM mode.

Figure 4 shows how the NCP1937 enters PSM on detection of an active-on signal at the PSTimer pin. When operating in PSM, V_{CC} is regulated at $V_{CC(PS_ON)}$, typically 11 V, and the controller draws a current of only 70 μ A. Hence the NCP1937 allows an extremely low standby power consumption of less than 10 mW.



Entering PSM
 Ch. 1 (Yellow): V_{CC}
 Ch. 2 (Blue): QR FET DRV
 Ch. 3 (Purple): PSTimer Pin
 Ch. 4 (Green): V_{OFFDET}

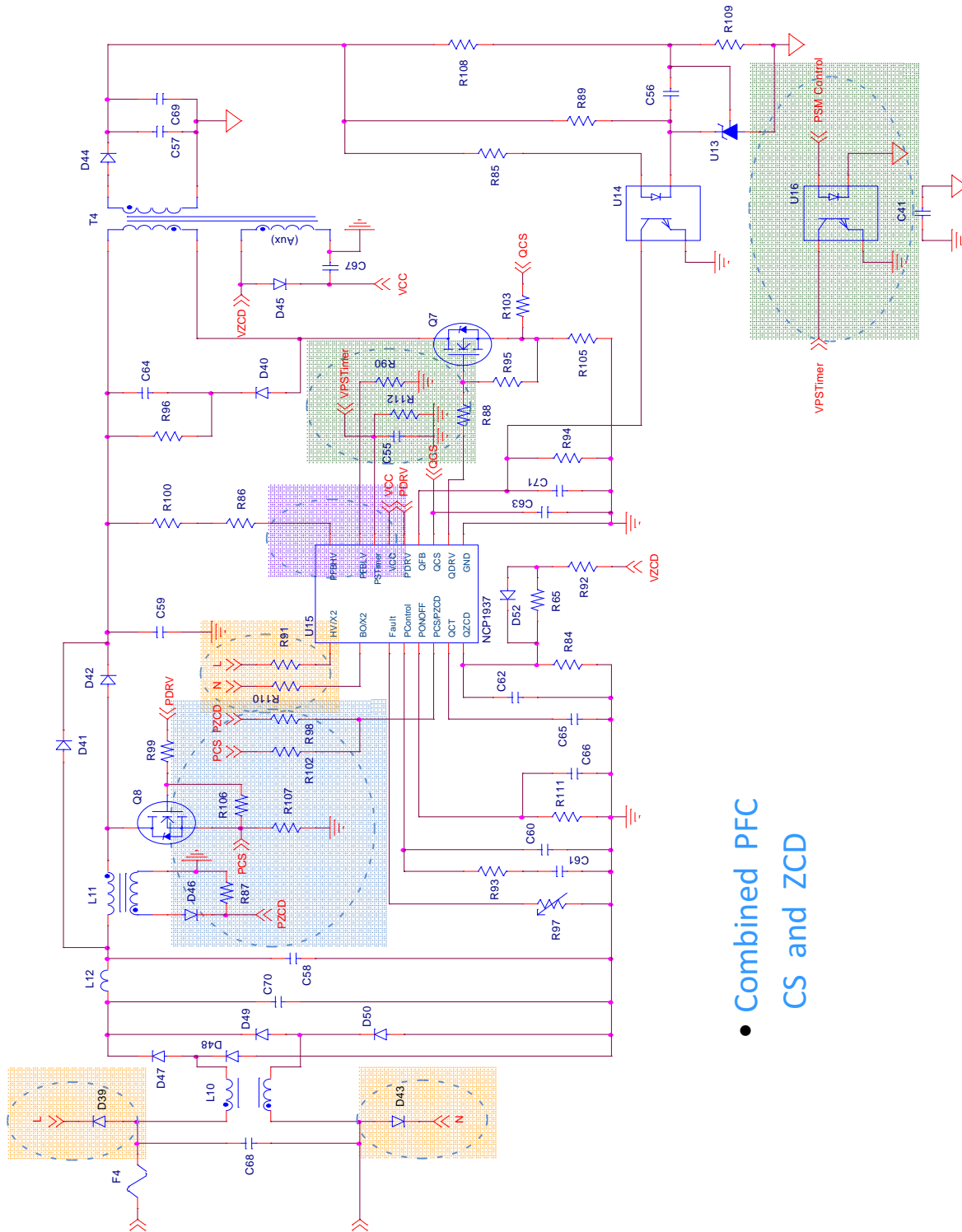
Figure 4. Voltage Waveforms on Entering Power-saving Mode

Increased digital integration, combined with the advanced 700 V high-voltage process, also allows more of the circuitry required for protection features, such as fault detection, current sensing and over-power compensation to be implemented on chip, reducing reliance on external components. Accordingly, the NCP1937 helps streamline AC/DC power supply design by providing a built-in brown-out resistor as well as soft Over-Over-Voltage Protection (OVP) for the PFC stage, leading to reduced acoustic noise and also allowing short-circuit protection for the integrated boost diode to be provided on-chip. This contributes to a robust design and can help shorten the debug cycle for new projects. This feature is not provided in controllers such as the TEA1752/3. As a consequence, designers using these devices must pay extra attention to thermal management in order to protect the PFC choke.

In addition, the NCP1937 features an innovative latch-off circuit design that allows the use of either an active-high or an active-low latching signal. This simplifies the design of OVP and Over-Temperature Protection (OTP) compared to other devices that require an active-low signal such as the TEA1752/3. In this case, if OVP is to be triggered by sensing the auxiliary winding voltage (V_{AUX}) directly, an external NPN transistor is needed to reverse the logical polarity of the V_{AUX} signal.

Savings Summary

Figure 5 shows a sample circuit diagram for a combined QR converter and PFC stage built using the NCP1937, highlighting key areas where the controller’s advanced features enable circuitry to be simplified.



- Combined PFC
CS and ZCD

Figure 5. Key Circuit Improvements Enabled by Increased Controller Integration

TND6049/D

Table 1 compares the key differences between implementations based on the NCP1937 and TEA1752, describing their effect on circuit design and efficiency.

Table 1. USING A HIGHLY INTEGRATED CONVERTER/PFC CONTROLLER SAVES COMPONENT COUNT AND BOOSTS EFFICIENCY

NCP1937	Conventional Controller such as TEA1752
Patented Valley-lockout Control	Vulnerable to Valley Jumping. Larger Transformer
Integrated X2 Capacitor Discharge	External Resistor Usually Required
Adjustable PFC On/Off Level	On/Off Control Based on Flyback Frequency
Integrated PF Feedback-circuit Switch	External MOSFET Needed
Active-on PSM Control	Current Needed to Hold Controller in Power-save
Soft OVP	Not Available
Boost Diode Short-circuit Protection	External Protection and Thermal Management
High/Low Latch-off Circuit Activation	NPN Transistor Needed if V_{AUX} Sensed Directly
Integrated Brown-out Resistor	External Brown-out Circuit Needed

Conclusion

The adoption of Quasi-Resonant flyback converters with active power-factor correction has enabled power supply designers to deliver competitively priced low-profile units for use in ultra-slim home electronics such as flat-panel televisions and all-in-one PCs. The latest advances in power

semiconductor technology are now taking a leading role enabling the next level of power-supply miniaturisation by permitting designers to further enhance efficiency and reduce component count, leading to savings in PCB size, circuit complexity and bill of materials.

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