AND9848/D

The Load Switch: Application Notes on Selection and Use of ecoSWITCH™ Products

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APPLICATION NOTE

Abstract

Load switches play an important part in the management of supply domains and the protection of the loads they supply. Loads switches are often used for power sequencing, standby load leakage reduction, and inrush current control. Integrated ecoSWITCH products deliver an area reducing solution, offering over current protection, load soft start, and extremely low on series resistances of sub − 20 mΩ. This article discusses the primary benefits of load switches, application considerations, and how ecoSWITCH differs from other types of integrated switch offerings. A generic cloud system application and USB power delivery example are presented to demonstrate how the addition of ecoSWITCH solves design challenges such as achieving low quiescent current, local load protection, and startup sequencing.

The Basic ecoSWITCH

Integrated load switches contain an integrated FET that allows power to be passed from VIN to VOUT when enabled. Figure 1 shows a general block diagram representing the primary functions of an ecoSWITCH.

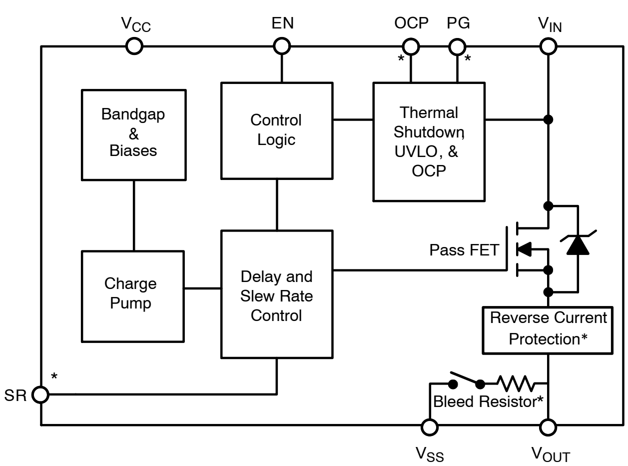

Figure 1. Basic ecoSWITCH Diagram

The integrated pass FET is the primary component of the ecoSWITCH. All other blocks shown in Figure 1 support the pass FET in its function of passing power from Vin (source) to Vout (load).

Charge Pump − The charge pump provides the voltage and current needed to charge the FET gate when turning the FET on, minimizing the on resistance of the FET.

Delay & Slew Rate Control − Turning on the FET too quickly can damage the load by allowing an in-rush current spike to pass to the load. The charging of an ecoSWITCH FET gate is controlled, thereby controlling the in-rush current and the rise time of the Vout voltage.

Control Logic − The control logic block dictates the timing and order of faults, turn on, and turn off events. The EN signal drives the control logic.

Fault Protection − Thermal protection, under-voltage lockout, and over current protection are offered on many ecoSWITCH products.

Bleed Resistor − The internal bleed resistor allows for quick dis-charge of the load and is controlled by the control logic.

Reverse Current Protection − Some ecoSWITCH products offer reverse current protection which prevents current from flowing from Vout to Vin.

All of these features play a part in the load switch trade space. Several ecoSWITCH families are offered to afford the designer with the optimal fit for their system application.

The Load Switch Trade Space

There are six key parameters that a system designer should consider when connecting and disconnecting a source from a load using an integrated FET based load switch.

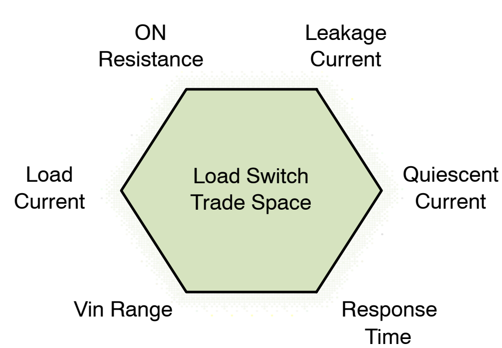

Figure 2. General Load Switch Trade Space

January, 2019 − Rev. 0

Publication Order Number:
AND9848/D

An ideal switch (connecting load to source) would be an open circuit when off, and a 0 Ω wire when on. Switching between an ideal open and an ideal short instantaneously can be damaging to a non-ideal source and load due to in-rush currents and transients. The load switch must intelligently deal with these transients and optimize these six parameters.

On Resistance

On resistance is directly in-line, source to load. MOSFET's have finite parasitic resistance. Electrons / holes in the inversion layer induced in a FET when its gate is charged have limited mobility. Both voltage drop from the system source to the load side of the load switch and power loss are directly proportional to the load switches ON resistance. Naturally, the lower on resistance the better. A reduction in this resistance results in direct power savings.

Max Load Current

Load switches are limited in the amount of current they can pass to a load. This is inherent due to the parasitic on resistance of the switch. Current through a resistance dissipates power through heat. Un-dissipated high levels of sustained heat damages the switch. Larger FETs are able to source more current to the load, however, a larger FET inherently has larger gate capacitance and requires more energy over time to turn on.

Response Time

Response time relates to turn ON / OFF timing, as well as fault protection timing. The size of the load switch FET is directly proportional to the energy and time it takes to turn it on. Power used to charge the gate of the FET ultimately eats into the power budget of the system. Most applications of a load switch benefit from a slower transition from OFF to ON.

Quiescent Current (Standby Current)

Quiescent current is defined by the amount of current the load switch uses when it is statically on, or off. This is in addition to any power dissipation by the load when the FET is on, and should be minimized.

Leakage Current

Current leaking from the source to the load when the load switch is OFF also eats into the system power budget. ecoSWITCH FETs are designed to maintain <1 μA leakage current.

Vin Range

The Vin Range of a load switch should exceed the application Vin supply range to provide margin. ecoSWITCH products offer minimum voltage of 1 V and lower, with maximum voltages to support 5 V, 12 V, and 24 V applications.

Benefits of ecoSWITCH

Controlled Power Up / Power Down

A load circuit is at the mercy of supply transients that can be unpredictable upon power up and power down. The diagram below shows a typical un-controlled power up / power down (in black) contrasted to the controlled current and voltage (in green) delivered to a load with an ecoSWITCH.

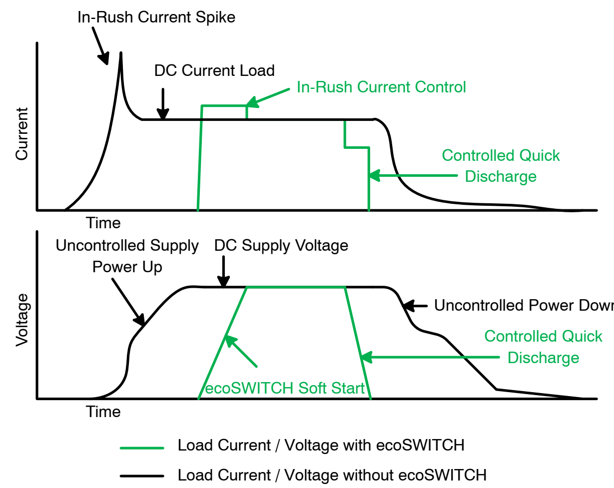

Figure 3. Load Switch Controlled Power Up / Power Down

ecoSWITCH prevents in-rush current spikes and ramps the supply voltage to the load in a controlled fashion. This is ideal for hot-swap applications where transients for power up and power down are unpredictable. On power up, ecoSWITCH provides a soft start, where the slew rate is controlled. ecoSWITCH products are available with programmable slew rate control.

Economic Cents

A discrete implementation providing base functionality uses a minimum of 9 components, adding cost to the build of materials and PCB real estate to the design. ecoSWITCH comes in package options from 2 × 2 mm to 4 × 4 mm.

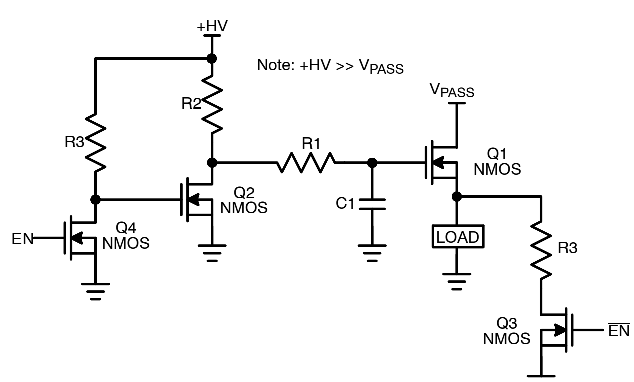

Figure 4. Typical ecoSWITCH Implementation

At a fraction of the cost an ecoSWITCH provides best in class performance with additional features not available via a 9 component discrete implementation.

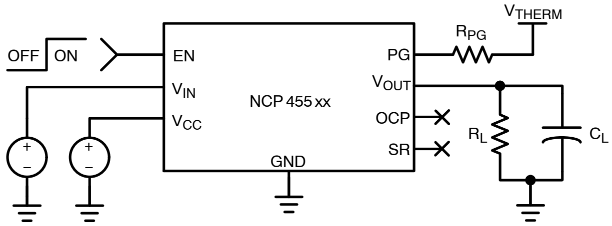

Figure 5. Typical ecoSWITCH Implementation

Reduced Leakage Current

Many designs have multiple power domains supplying sub-systems that are not needed 100% of the time. Non-critical sub-systems can be powered down using ecoSWITCH. This mitigates the leakage current from the powered down sub-systems. Load switches also allow for controlled sequencing of sub-systems.

Load Protection

Load switches can prevent damage to system loads and system supplies by disconnecting them in the event of an otherwise catastrophic failure. The ecoSWITCH offers the following load protection features:

- The over current protection (OCP) and short circuit protection features protect the part and system from sudden high-current events, such as Vout being shorted to ground or load malfunction.
- Under voltage lockout (UVLO) prevents a connection from the supply to the load when the supply voltage is too low.
- Over temperature lockout breaks the connection between the supply and the load if the temperature of the internal ecoSWITCH FET exceeds ~150°C to protect the load, switch, and supply in the event of an incorrect connection or over heating system.
- Reverse current protection is available on generation 4 ecoSWITCH products and prevents current from flowing back into the supply from the load. This is especially pertinent to USB Type C and Type C power delivery applications.

Figure 6 demonstrates OCP protection for different OCP settings on the NCP45630. By controlling the voltage on the OCP pin, the fault conditions can be catered to a specific application.

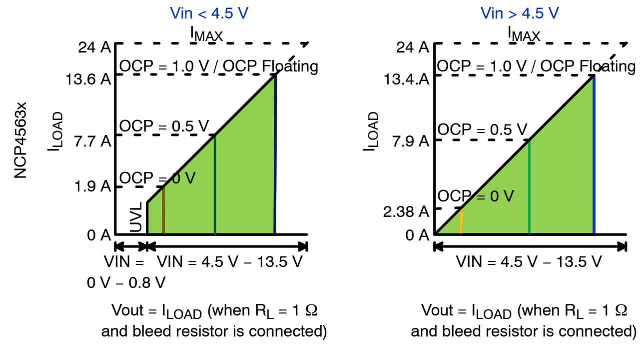

Figure 6. Safe Operating Area with Different OCP Settings

Design and Application Examples

Load switches can be used in a wide variety of applications. The feature rich ecoSWITCH family broadens the application spectrum. The following examples below show typical load switch applications. Further examples show a cloud system application, and a USB power delivery application. Load switches allow for controlled safe power supply multiplexing. Figure 7 shows one supply multiplexed to 3 loads. A controller would be used in this application to drive the EN pin to control which load gets power and when. The power for each load can be connected or disconnected to load level the system power and boost efficiency.

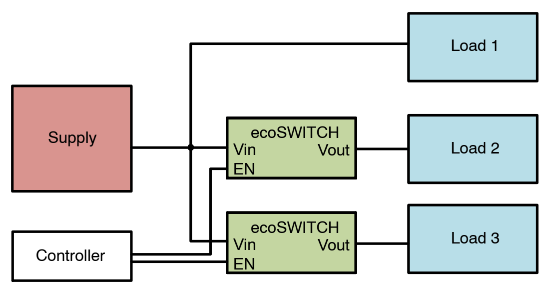

Figure 7. Basic Diagram Showing Supply Domain Management Using ecoSWITCH

Figure 8 shows a different application where one load is connected to multiple supplies through ecoSWITCH products. This application is perfect where a battery backup option exists or when the system can be powered by one of many sources.

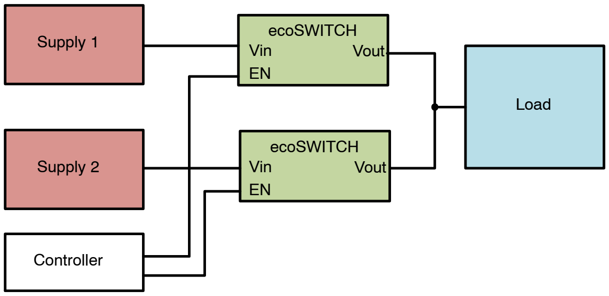

Figure 8. Power MUXing Example

Figure 9 shows yet another application where ecoSWITCH can be used to sequence the application of power to a number of loads without using a controller. Capacitance can be added to the PG outputs of each ecoSWITCH to delay the power up of the next load in the sequence.

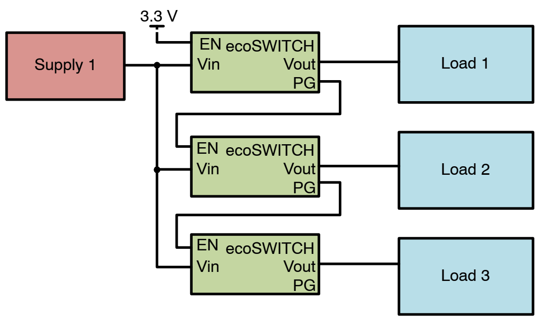

Figure 9. Power Sequencing Example without Controller

Figure 11 shows an example Cloud System application. In this application, the green boxes labeled "eS" represent ecoSWITCH products in the system. The load switches are placed after the DC/DC conversion of the primary supply, but before the internal loads, managing their connection to regulated power.

The soft start and quick power down features of ecoSWITCH products are conducive to USB applications. The diagram below shows how an ecoSWITCH with reverse current protection can be used for USB Type−C power delivery. The supply can be internal to the host, or provided from an external host, such as a device with an internal battery capable of powering other devices over USB, but can also be charged over USB.

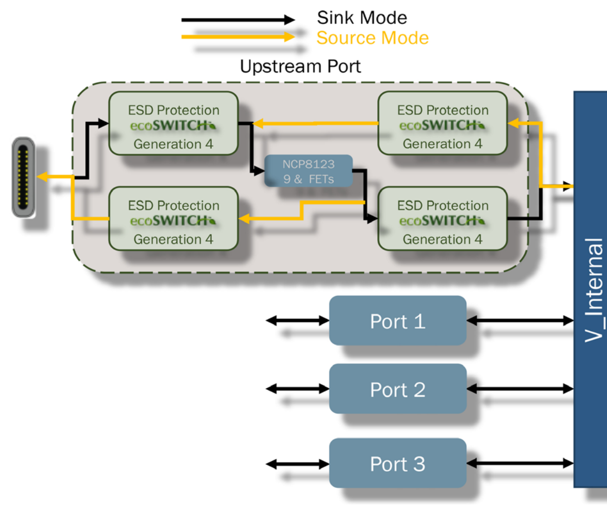

Figure 10. NCP457xx Supporting USB Type−C Power Delivery with Reverse Current Protection

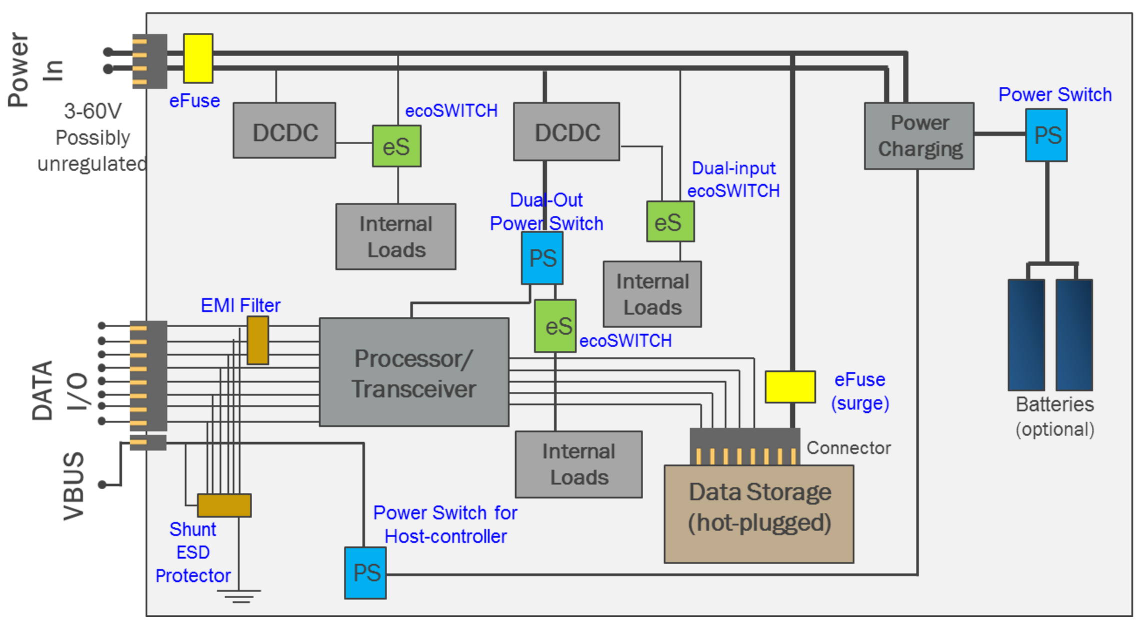

Figure 11. Generic Cloud System

Basic Load Switch Calculations

The following calculations can be used when determining the specifications required the load switch.

Voltage Drop

Voltage drop requirements from the supply to the load dictate the acceptable Ron specification. Use equation 1 to determine acceptable Ron maximum.

$$R_{ON,\,max} = \frac{V_{Drop}}{I_{LOAD}} \quad \text{(eq. 1)}$$

In-rush Current

The total load capacitance presented to the load switch determines the in-rush current where the initial current (I_O at time 0) is very large. ecoSWITCH has slew rate control (or soft start) to limit the initial current to a known acceptable value. Equation 2 below is uded to define the controlled in-rush current.

$$I_{in-rush} = \frac{dv}{dt} \cdot C_L \quad \text{(eq. 2)}$$

Where:

dv/dt is the slew rate setting, programmable on most ecoSWITCH products.
C_L is the total capacitive load

Power Dissipation

Equation 3 below is used to calculate the total power dissipation of the load when powered through the load switch.

$$P_D = V_{in} \cdot I_Q + I^2_{LOAD} \cdot R_{ON} \quad \text{(eq. 3)}$$

Where:
V_{in} is the input supply voltage
I_Q is the quiescent current
I_{LOAD} is the load current
R_{ON} is the on resistance of the load switch

When the load switch is disabled, is limited to the standby current, and is limited to any leakage from Vin to Vout through the disabled load switch, which is quickly bled down as any charge held by the total load capacitance is discharged through the ecoSWITCH internal bleed resistor.

ecoSWITCH Family Pedigree

The Table 1 below shows the full ecoSWITCH product line offering. Generally, there is a trade-off between features, cost and size. Many options are available to facilitate the optimization of this trade space for any given application.

Table 1. ecoSWITCH PRODUCT OFFERING (See individual datasheets for detailed specifications)

EcoSWITCH Part Number	Operating Input Voltage	Under Voltage Lockout	Thermal Shutdown	Short Circuit	Power Good	Variable Slew Rate	Reverse Current	Load Bleed	Over Current	RoHS Compliant	Production Availability
<5 mΩ											
NCP4545	1 V – 12 V					✓				✓	Production
NCP4545–L	1 V – 12 V					✓				✓	Production
NCP45560–H	1 V – 12 V	✓	✓	✓	✓	✓		✓		✓	Production
NCP45560–L	1 V – 12 V	✓	✓	✓	✓	✓		✓		✓	Production
<10 mΩ											
NCP45650	1 V – 12 V	✓	✓	✓	✓	✓		✓	✓	✓	Q2 '19
NCP45651	1 V – 12 V	✓	✓	✓	✓	✓			✓	✓	Q2 '19
NCP45520–H	1 V – 12 V	✓	✓	✓	✓			✓		✓	Production
NCP45520–L	1 V – 12 V	✓	✓	✓	✓			✓		✓	Production
NCP45521–H	1 V – 12 V	✓	✓	✓		✓		✓		✓	Production
NCP45521–L	1 V – 12 V	✓	✓	✓		✓		✓		✓	Production
NCP45540–H	1 V – 12 V	✓	✓	✓	✓	✓		✓		✓	Production
NCP45540–L	1 V – 12 V	✓	✓	✓	✓	✓		✓		✓	Production
NCP45541–H	1 V – 12 V				✓	✓		✓		✓	Production
NCP45541–L	1 V – 12 V				✓	✓		✓		✓	Production
NCP45630	1 V – 12 V	✓	✓	✓	✓	✓		✓	✓	✓	Q2 '19
NCP45631	1 V – 12 V	✓	✓	✓	✓	✓			✓	✓	Q2 '19
<20 mΩ											
NCP4543	1 V – 12 V						✓	✓		✓	Production
NCP45522–H	1 V – 12 V	✓	✓	✓	✓			✓		✓	Production
NCP45522–L	1 V – 12 V	✓	✓	✓	✓			✓		✓	Production
NCP45523–H	1 V – 12 V	✓	✓	✓		✓		✓		✓	Production
NCP45523–L	1 V – 12 V	✓	✓	✓		✓		✓		✓	Production
NCP45524–H	1 V – 12 V				✓			✓		✓	Production
NCP45524–L	1 V – 12 V				✓			✓		✓	Production
NCP45525–H	1 V – 12 V					✓		✓		✓	Production
NCP45525–L	1 V – 12 V					✓		✓		✓	Production
NCP45526–H	1 V – 12 V				✓			✓		✓	Production
NCP45610	1 V – 12 V	✓	✓	✓	✓	✓		✓	✓	✓	Q2 '19
1 V – 24 V <10 mΩ											

Other ON SEMICONDUCTOR Integrated Power Switch Offerings

ON Semiconductor offers other product families that further our solution diversification. ecoSWITCH products have focused on providing best in class ultra-low Ron resistance. IntellMax products focus on applications where low operational power and low cost are more important than low power dissipation in the series FET. eFuse products target high side switch applications where over-voltage protection is needed. Whatever the need, ON Semiconductor provides best in class solutions enabling customer success.

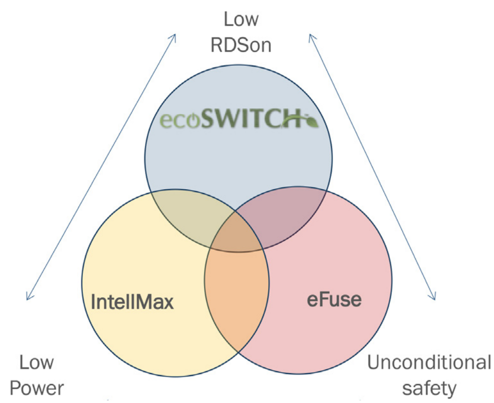

Figure 12.

Conclusion

Integrated ecoSWITCH load switches deliver an area reducing solution, offering over current protection, load soft start, and extremely low on series resistances of sub − 20 mΩ. Load switches are a critical component to achieving efficient low cost power distribution in complex systems.

PUBLICATION ORDERING INFORMATION

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