Quick Convert : Theory of Operation

Overview of the "Quick Convert" a
DC / DC Converter for Embedded Systems.

Custom magnetics available from:
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Introduction

Have you ever designed a small embedded system and found the power supply costs more the the remaining components? Despite the availability of components that simplify power supply design, many engineers treat power supply design like the Bubonic Plague and follow the advice of always purchasing commercial supplies. While there are good reasons to "Buy" and not "Build" power supplies, there are some good reasons to roll your own. The purpose of this article is to show what can be done to simplify the powering of an embedded system. The design of a small DC / DC converter and many of the design tradeoffs are discussed.

Overall Architecture

One of the very good reasons not to build a supply is to avoid dealing with line circuits and potential liabilities. Given my choice of input power sources I would pick a wall transformer any day of the week. WhileI will agree that these wall warts tend to clog the receptacles on a power distribution strip, they are also available with input cords and standard plugs. Wall transformers also provide a degree of "Internationalization" in that various input voltages and receptacle styles are available.

If you have an application that requires less than 15 watts at a single, unregulated voltage then a wall transformer is a no brainier. Unfortunately many embedded applications require several voltages with some level of regulation. A DC / DC converter with multiple output voltages is an ideal candidate for turning your everyday wall transformer into a great small system power supply.

At this point we start to form an architecture for our power system. If we limit our power requirement to less than 20 watts then a DC converter with multiple regulated outputs would be ideal. Power from an external wall transformer (AC input, unregulated DC output.) feeds an inexpensive DC converter circuit built on the application PCB. But, as we grab a data book (or hit the web) we quickly realize that in order to design a converter we need to deal with magnetic components.

Magnetic design is not all that difficult but it is not a task where many engineers have lots of experience. Of all the electronic components to work with, transformers are one of the most difficult to acquire as "off the shelf" components. Even if an engineer designs a transformer and builds a prototype, where does he go to purchase a few hundred? The answer better be off shore. Small high frequency transformers are very labor intensive. Domestic labor rates make building these units very expensive. What is required is a DC converter reference design with a source for the magnetic components. The remaining portion of this article provides that reference design, a supply of low cost magnetic components, and a discussion of the tradeoffs made during the design phase. With this knowledge any engineer can easily adjust the basic design to a specific application.

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Switching converters come in a variety of configurations with each configuration having its own advantages. In this application we are looking for less than 20 watts, low cost, and multiple regulated outputs. We want all the components to be PCB mounted using a minimal amount of PCB space. The 20 watt limit with multiple outputs suggests a flyback converter. Flyback converters tend to be noisy but this is a low power supply so filtering should not be a problem. We will address the noise later. Current mode PWM controllers are available from many sources. One advantage of current mode PWMs is they limit primary currents during fault conditions. We chose a LT1170 single chip 100Khz converter.

While we use the LT1170 component in this design, a lower cost design can be constructed using a PWM converter and an external MOSFET switch. Using a strip of PCB trace as a current sense resistor can also help trim costs. Physical design constraints were to keep the circuit small and inexpensive. Keeping the parts at a low height also helps make the design easy to adapt. The big problem with controlling component height was capacitor selection. Keeping capacitors to less than 1/2 inch and still getting low ESR is difficult. In addition to detachable 0.200 inch spaced terminal blocks a 2.1mm power jack is provided for direct connection of a wall transformer.

Winding Design

A key advantage of flyback converters is their ability to provide multiple regulated outputs. Using a feedback loop to regulate a single output allows additional output winding to generate regulated outputs. Various output voltages are easily generated by controlling the turns ratios between output windings. While flyback regulation is very good with respect to input variations, load changes do introduce output variations. Winding design in the flyback magnetics makes a significant impact on cross regulation. Output windings close to the primary can be expected to pickup “Extra” output energy from primary leakage flux. Likewise, any one winding which is heavily loaded will also affect near by windings. For the “Quick Convert” output windings were selected at +5, +3.3, +13 and -13 volt outputs. Targeting 13 volts allows linear regulation for precision control of 12 volts for flash memory or other voltage critical applications. Simple op amp and other linear circuits work fine without post regulation.

Applications which require additional voltages can rearrange secondary winding to increase output voltages. Connecting a 13 volt winding in series with the +5 winding provides +18 volts, great for VEE supplies for many LCD displays. If you need 1/2 amp on the 13 volt supply you can connect the two 13 volt windings in parallel. Another trick is to pull a little energy during the conduction phase of the PWM switch. This operates the transformer in a forward converter mode.

With a 12 volt input transformer the turns ratio provides 24 volts on the 13 volt windings and -9 volts on the +5 volt winding. These additional voltages are not regulated as they track the input voltage. Using a regulated wall adapter will result in regulated outputs. When using this technique keep the filter capacitors to low values and use small series resistors with the rectifier. Operation as a forward converter results in the load impedance

being reflected directly to the PWM switch. Large capacitive loads can trigger PWM current limits and reduces available load power. Using all these trick can provide +5, +3.3, +13, -13, -9, +24 and -24 volts.

In addition to all these voltages you get another supply voltage, the feed from the wall transformer. LCD backlight supplies typically operate from a wide input voltage range and they regulate lamp current for a constant lamp output. This allows a backlight to operate directly from the wall transformer output saving regulator capacity and adding another 4 to 8 watts to the power budget. Since the supplies for digital logic tend to be the most critical, a single taped winding was used for both +5 and +3.3 windings. Direct regulation of the +5 (or optionally the +3.3) output provides good regulation on the other digital output voltage. A taped winding is difficult to construct but the quality of the regulation is very good.

The 13 volt outputs can be expected to increase if they are lightly loaded and the digital outputs are heavily loaded. Increasing the 13 volt load current will compensate. A voltage adjustment control is provided which can be used to adjust the overall placement of all outputs. A difficult task in designing the windings is producing the number of required turns with the proper amount of copper cross section. You want to keep windings designed such that a single traversal of the bobbin provides a completed winding. Tricks include using 2 or more strands of a smaller wire size to adjust a winding width to the bobbin width.

Noise Control

Control of switching transients is provided with a RC network (3.9 ohm and 4700pf) across the primary winding. This “AC Dummy Load” reduces dv/dt on the primary switch at the expense of some efficiency. Cost was controlled by using electrolytic capacitors as both input and output filters. The ESR rating of these capacitors is important, be sure that low ESR units are used. The Panasonic units listed in the parts list have an ESR of 0.12 ohms each. A better capacitor would reduce input and output ripple but the real EMI offender is usually higher frequency common mode currents. Smaller, but more expensive tantalum capacitors can be used with a significant saving in board real estate. Be sure to use the low ESR versions. D sized tantalum capacitors of 300uf at 6.3 volts are available but the number of suppliers is limited.

While an electrostatic shield between primary and secondary circuits would reduce common mode currents, this design uses common mode chokes on both input and outputs. When placing this circuit with an application on a PCB it is unlikely that both chokes would be required. Conducted EMI is controlled with the input choke, the output choke is useful only if you have significant cable runs from the converter to a PCB. In either case be careful that the output common is not connected to the input power negative terminal. Connecting these will result in choke bias currents which saturates choke magnetics and reduce the effectiveness of the common mode chokes.

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When porting this circuit to an application pay attention to the PCB artwork in the design package. Several nodes are connected using section of copper pours. These are areas with very high di/dt currents. Ignore these nodes and you will introduce high frequency noise. When moving components on a new PCB try to maintain spacing between the main flyback transformer and common mode chokes. Stray magnetic flux can appear as output voltages on the chokes.

Control Circuits

A couple of additional control circuits are required to make the power supply a little more robust and easy to use. A zener diode and P Channel JFET form a voltage sensitive circuit that shuts down operation if the input voltage falls below a minimum operating level. A big problem with many small DC converter circuits is they draw excessive currents at low input voltages. Adding a low voltage cutoff limits current in switch and magnetic circuits and reduces transient loads on the power source. Remote shutdown is supported using a transistor switch. Shorting the control voltage through this transistor operates very much like the the JFET shutdown circuit. Shorting the LT1170 “Control” pin to GND shuts down converter operation.

Operating voltage range is controlled by adjusting the zener voltage. While the basic design operates down to the 5 volt point, input currents become significant at low voltages. The LT1170 contains a current limit, but without a heat sink the LT1170 will get very hot at low input voltages. The suggested minimum operating point is about 8 volts at 10 watts. If the zener is adjusted to allow operation with less than 8 volts transformer and LT1170 temperature should be monitored and ambient temperatures controlled. On the high side the input capacitors and JFET / zener bias current limit input voltages.

A set of dummy resistors is provided with one dummy load resistor connected to each output line. These are very important. The rectifier diodes and output capacitors make a very good energy capture and storage circuit. Leakage inductance within the flyback transformer causes a small amount of energy to be transferred on every switching cycle. Without the dummy load resistor a capacitor voltage would increase until either the capacitor or diode fails. Dummy resistors must be sized to provide the minimum safe load at all operating levels. Typically the worst case is with fully loaded digital (+5 and +3.3) outputs with no load on the +13 or -13 outputs. Once the circuit is integrated with an application the dummy loads can be removed. If an output is not used the rectifier diode for that circuit can be removed.

Design Package

A design package is available for web download at no cost. Included in this package are the schematic, bill of material, PCB gerber files and printouts of artwork layers. The magnetic components are available from Index Designs at www.indexdesigns.com. Completed circuit circuit boards are also available. Readers are invited to email questions to sales@indexdesigns.com. When requesting design packages please include

your name, address, e-mail address and telephone numbers. Design packages can not be sent without this information. The package will be sent via e-mail to the supplied e-mail address.

Contained in the design package is:

- *README.TXT Overview of files*
- *QCManual.PDF This manual*
- *QCSchen.PDF Schematic Diagram*
- *QCPCB.PDF Viewable Gerber Files*
- *QCGerber.ZIP Zipped Gerber Files*
- *QCBOM.PDF Bill of Material Information*

Author Info.

Robert Kondner has over 20 years experience designing custom products and embedded systems. Many applications have used ARM processors with LCD graphic panels in portable or vehicle environments. A number of the techniques described in this article are the result of designing the Battery Boss product line. This series of specialized DC converters and miniature UPS systems can be seen at http://www.indexdesigns.com.