TECHNICAL ARTICLE

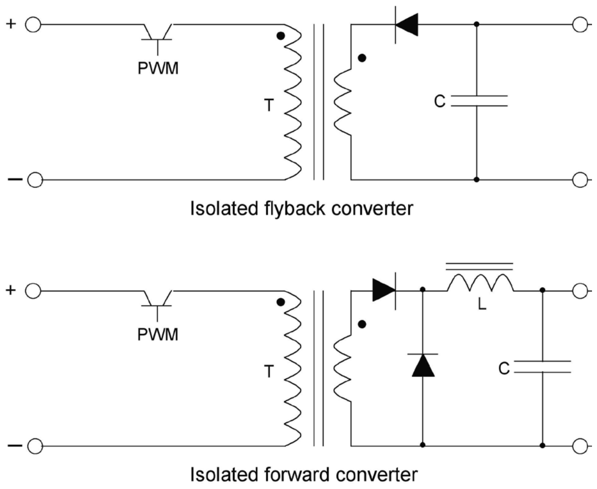
THE EVER SHRINKING POWER SUPPLY

Changes in power supply design are rarely revolutionary. Rather, they are evolutionary and dependent upon a host of component and manufacturing technologies that, for the most part, develop at a modest pace. Moore's law simply doesn't apply to power supply design; if it did, a 200 W switcher the size of a thumbnail would have arrived some time ago. However, even marginally improved versions of some critical components can have a dramatic affect on power supply size. In this article we take a look at the technologies that impact the design of 50 W to 200 W AC/DC switchers and the contribution each makes to the overall size of the end product. In doing so, I aim to give some guidance to engineers who design power supplies in-house but also to help engineers who specify power supplies from external sources to better understand the solutions they are offered and the potential specification trade-offs that they may face.

AC-DC basic topologies

Broadly speaking, switchers up to 150 Watts tend to use flyback topologies in which the energy is only transferred to the load during the off-time of the switching element. Above this rating, typically forward converters are adopted. In a flyback, the converter can operate in two states: continuous, where the input inductor current does not start at zero at the beginning of the cycle, and discontinuous, where the inductor current starts at zero at the beginning of each cycle. Both topologies use a transformer to provide isolation. In the case of the flyback converter there is only one main energy storage magnetic device, the transformer. In the forward converter there are two, the main transformer and output inductor. Figure 1 shows isolated flyback and forward converter topologies. The largest individual components in such power supplies will be the energy storage capacitors and magnetic components.

Figure 1



Switching frequency

Higher switching frequencies enable smaller inductors and capacitors to be used. At relatively high frequencies, less energy per cycle needs to be stored in inductors and capacitors, resulting in lower inductance and lower capacitance values. The trade-off is that switching losses increase with frequency, leading to decreased efficiency. So the practical limit for flyback converters, where energy is stored in the primary of the transformer every cycle, is 100 kHz. In forward converters energy is not stored in the main transformer but in the output inductor and practical switching frequencies are up to 200 kHz. Of course, low voltage DC/DC converters often operate at 2-4 times these frequencies simply because the relatively close turns ratio of transformers means smaller windings, lower leakage and lower losses, so it’s easier to achieve efficient power conversion.

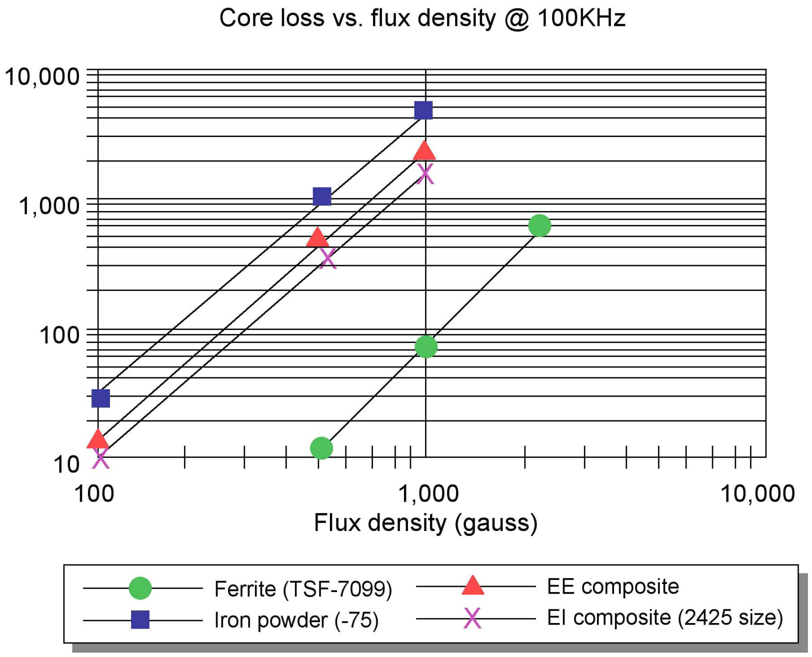
Magnetic components show future promise

In the last few years most improvements in power density have been achieved through advances in semiconductor and capacitor technologies. Looking forward, the most promising developments that will impact power supply design in the near term are in the composition of magnetic cores.

From a power supply transformer perspective, the objective is to find a low-cost core material with enough inductance to store energy, one that does its job with acceptable temperature rise and does not create excessive electromagnetic interference. Powdered iron cores offer the best flux density and magnetic coupling, but are relatively lossy due to the inherent distributed air gaps. Ferrites are efficient, but they are usually too easily saturated to be useful where high energy levels are involved. Gapping the core, with either EI or EE construction, reduces the saturation problem to some degree.

Recent developments in composite cores can help to overcome the disadvantages of both traditional types. For example, in a standard 2425-size core, when one half of the magnetic path length of an iron powder core set is replaced with soft ferrite, losses can be reduced by around 50%. By replacing even more of the iron, reductions of over 60% are possible. Figure 2 shows the core loss vs. flux density for such a core using iron powder, soft ferrite, and a composite material. Clearly, composites can deliver low losses and high flux density and, by varying their composition, the optimum performance characteristics for a given application can be attained.

Figure 2



Developments in composite magnetic materials will have significant impact on power supply design over the next few years, their take-up being limited only by availability and price. As with most new technologies, availability of composite cores is restricted at present to relatively few suppliers.

Semiconductor on-resistance continues to fall

The on-resistance (Rdson) of MOSFETs has fallen by over 75% in the last 5 years, and this is a continuing trend. Rdson is a critical parameter in determining the efficiency of the switching circuit, and hence of the power supply as a whole, but even modest reductions often carry a substantial price penalty, particularly if the devices are relatively new and not yet produced in high volume. For example, an IRF 840 with 0.85 Ohm Rdson today costs around $0.50 while an SPPP20N60 equivalent with 0.19 Ohm Rdson is nearer $1.30. However, using the SPPP20N60 in a 500 Watt power supply improves efficiency by 2% - a very worthwhile gain. In general, the cost of MOSFETs has fallen rapidly in recent times, so this does mitigate the problem to some degree. For power supplies with low voltage outputs, 5 V and below, synchronous rectification is increasingly utilized. This technique, in which switched MOSFETs replace output rectifier diodes, is now found in power supplies rated as low as 130 W. It results in improved efficiency because, as diode losses depend on I x VFD (where VFD is the diode forward volt drop), paralleling diodes does not reduce dissipation; therefore large diodes are needed at high currents. Conversely, MOSFET losses depend on I2 x Rdson (where Rdson is drain-source ON resistance), so splitting current between two MOSFETs reduces each current by 2 and the dissipation in each device by 22, i.e. to a quarter, halving the total dissipation and boosting efficiency. As Rdson has fallen it has become less necessary to parallel transistors to reduce the resistance. Using fewer, lower resistance MOSFETs saves board space, but the cost vs. space trade-off needs to be considered for each individual design.

Capacitors improve incrementally and new technologies offer promise for low-voltage circuits

The two primary applications of capacitors within power supplies are high voltage energy storage at the input and low voltage filtering at the output. The input capacitor – an aluminium electrolytic capacitor – is usually the second largest component on the board after the main transformer. The use of active power factor correction (PFC) - now common on most everything above 200 W – reduces the required capacitance 4-fold due to the 375 VDC bus voltage. 100 µF is the typical value found in a 150 W power supply and the active power factor correction circuit takes up little space compared with having to utilize a larger capacitor. The PFC circuit typically takes up the same real-estate as the extra bulk capacitor, but makes the design of the main transformer easier, and reduces its size.

While aluminium electrolytic is really the only practical capacitor technology for the input circuit – nothing else offers the combination of high voltage and high capacitance within a given size - designers are not restricted to this technology for output filtering. Here, a number options are available, but with some limitations on maximum capacitance or working voltage. These include multilayer ceramic capacitors, tantalum capacitors and, most recently, polymer cathode capacitors. Polymer cathode capacitors replace the wet electrolyte in aluminium electrolytics, or the MnO2 cathodes of tantalum capacitors, with conductive polymers. They offer low equivalent series resistance (ESR) and will typically operate at up to 105 °C without derating, but the available capacitance values and voltage ratings are still restricted compared with those of conventional electrolytics and there is, of course, a price premium for these newer technologies. However, overall costs have to be considered when single polymer capacitor may replace several aluminium electrolytics because of the low ESR.

The capacitance per unit volume of aluminium electrolytic capacitors has improved steadily in recent years, mainly due to improved etching techniques used on the aluminium foil. Better etching delivers a higher effective surface area and hence higher capacitance for a given component case size. But there have been no dramatic changes.

For both input and output capacitors, the key challenge in minimizing power supply size, while not adversely affecting reliability, is finding components with high enough temperature ratings. Capacitors rated at above 105 °C are relatively uncommon, and expensive. Yet most other components within a power supply will operate at up to 125 °C or more. Hence capacitors can often be the components that limit the power rating of an AC/DC switcher. Heatsinks for capacitors are available, but they add cost, manufacturing complexity and size to the overall unit, so are not a popular choice.

Surface mount technology: a major driver

Only 5 years ago relatively few components were available in SMD format, now most are available except larger inductors and capacitors. The widespread introduction of surface mount components and assembly techniques has been one of the most important drivers in reducing the size of power supplies. It has also enabled added functionality without increases in size by placing control components on the previously unused underside of the board.

Of course, adding complexity and increasing the component count adds cost, but there is increasing demand for control and monitoring signals in power supplies that power critical systems. The additional costs are relatively modest, so most AC/DC power supplies now have integrated DC-OK, remote sensing, and over-current, over-voltage and over-temperature protection as standard. Even though many customers may not use these functions, their cost does not usually lead power supply manufacturers to create multiple product variants with or without such functions. It’s not economically viable, so they are offered as standard.

Hand-in-hand with the adoption of surface mount technology has been the use of multilayer PCBs to provide greater interconnect density for a given board area. Using multilayer boards again adds cost, but the falling cost of other components, particularly power semiconductors, has meant that the cost-per-watt of AC/DC power supplies has decreased steadily in recent years.

Advances in thermal management

As reliability is directly related to temperature, effective thermal management has always been a critical consideration in power supplies. Wherever possible, the use of fans needs to be avoided to minimize cost, size and noise. The increasing availability of thermally clad materials is helping. The PCB itself can be used to conduct heat; heat is removed from both power semiconductors and surface mount devices in this way. However, utilizing insulated heatsinks offers the greatest potential space savings. Multiple devices, at different potentials, can be attached to a heatsink. For example, the power factor correction circuit, power MOSFETs and output rectifiers can all be mounted on a common heatsink. The price is higher than a traditional heatsink but there are savings in manufacturing and the space taken by the single heatsink can be some 30% less than using a number of smaller versions.

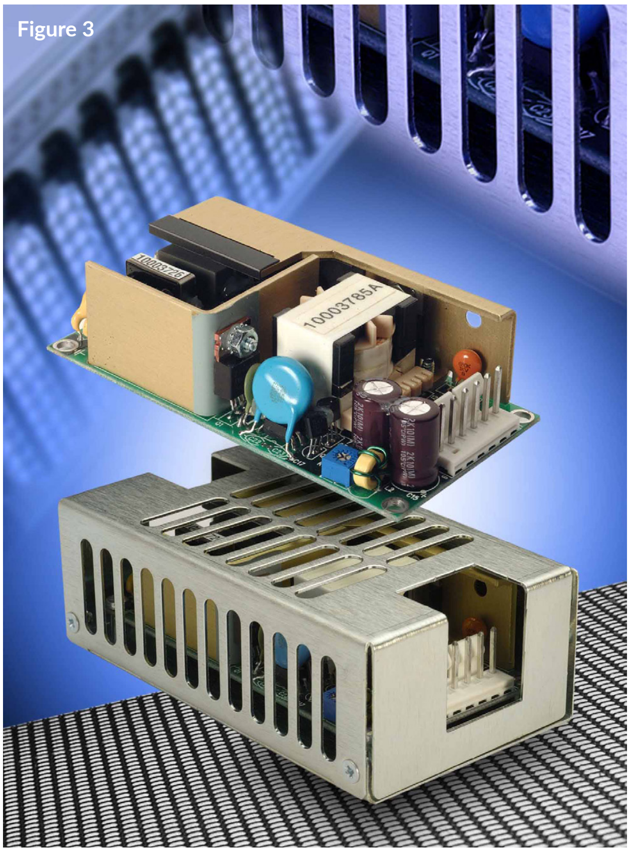
A recent example of shrinking power supply size

A recent new power supply from XP, the ECM60 illustrates the benefits of concentrating design efforts on the critical components within a power supply to minimize size. This flyback converter measures 2” x 4” (50. 8mm x 101. 6mm) and 1.2” (30.48 mm) high - some 47% smaller than the previous model (Figure 3).

Virtually all of this space saving is achieved by reducing the size of the main transformer and replacing through hole with SMD components on back of board. Use of a smaller transformer is made possible through combining discontinuous and continuous mode operation.

Discontinuous mode is the more stable from a loop stability standpoint but, since the energy stored is a function of Ipk2, allowing the current to increase so that the transformer goes into continuous mode allows more energy to transfer. Providing the core does not saturate, this technique works well and avoids the need for the larger transformer that would be required for purely discontinuous operation.

Figure 3

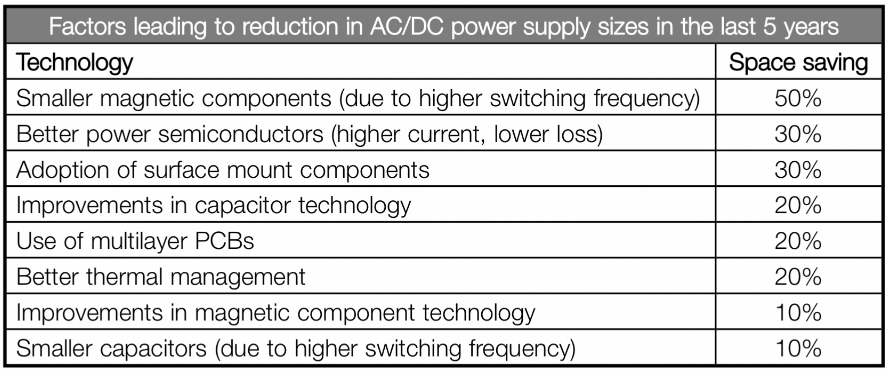


The ECM60 is designed to eliminate the potential loop instability and saturation problems normally associated with continuous operation. A single MOSFET and standard output rectifier provides the power conversion and two on-board heatsinks are used for cooling. The power supply delivers full power between –10 °C and +50 °C and will operate at up to +80 °C with derating and only 5CFM of cooling. The key factor limiting power to 60 W is the temperature rating of aluminium electrolytic capacitors. These components are so-called ‘long-life’ capacitors, rated for operation at up to 105 °C, but if 125 °C rated components were available at reasonable cost, the same power supply could be rated at 80 W output – a further 33% improvement in power density.

Conclusions

Table 1 shows the approximate savings in space that various technologies have enabled in the last 5 years. The savings shown add up to more than 100%, but in reality it is never possible to utilize every size-reduction technique in a single power supply – there are too many trade-offs in terms of cost, manufacturing complexity, and thermal management issues. EMC constraints have to be taken into account too.

Table 1



Factors leading to reduction in AC/DC power supply sizes in the last 5 years	
Technology	Space saving
Smaller magnetic components (due to higher switching frequency)	50%
Better power semiconductors (higher current, lower loss)	30%
Adoption of surface mount components	30%
Improvements in capacitor technology	20%
Use of multilayer PCBs	20%
Better thermal management	20%
Improvements in magnetic component technology	10%
Smaller capacitors (due to higher switching frequency)	10%

Improved manufacturing techniques and falling power semiconductor prices have enabled the cost-per-watt of AC/DC switchers to fall steadily, even while other component prices have risen, and overall complexity and functionality of power supplies has grown. However, the most important thing for power supply designers to remember is that even incremental improvements in the critical components - input transformers, capacitors, and power transistors – can, with creative design, deliver dramatic improvements in power density. It’s always worth keeping track of developments in these components.